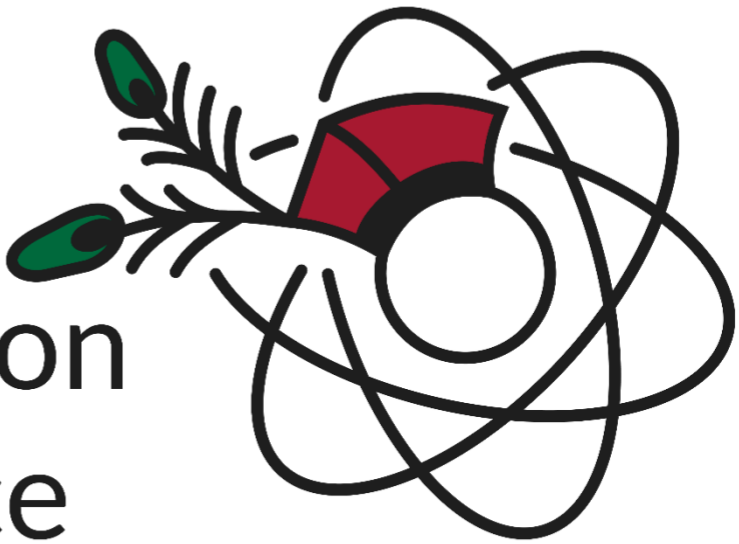
25th Radiocarbon Conference



Book of Abstracts

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Version 1.2

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AGH UNIVERSITY OF KRAKOW

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PROGRAM OVERVIEW

SUNDAY, 29th June	MONDAY, 30th June		TUESDAY, 1st July			
	plenary session		Room A		Room B	
	topic		topic		topic	
	9:00	Conference opening	9:00	A01	9:00	A05
	9:20	Invited talk	9:20	A01	9:20	A05
	9:40		9:40	A01	9:40	A05
	10:00	M1	10:00	A01	10:00	A05
	10:20	M1	10:20	A01	10:20	A05
	10:40	Coffee break	10:40	Coffee break	10:40	Coffee break
	11:10	M1	11:10	A02	11:10	A05
	11:30	M1	11:30	A02	11:30	A05
	11:50	M1	11:50	A02	11:50	A05
	12:10	M1	12:10	A02	12:10	A05
	12:30	M2	12:30	A02	12:30	A05
	12:50	Lunch break	12:50	Lunch break	12:50	Lunch break
	14:20	M2	14:20	A02	14:20	A05
	14:40	M2	14:40	A02	14:40	A05
	15:00	M2	15:00	A02	15:00	A05
	15:20	M2	15:20	A02	15:20	A05
	15:40	M2	15:40	A02	15:40	A05
	16:00	Coffee break	16:00	Coffee break	16:00	Coffee break
	16:20	M2	16:20	A02	16:20	A05
	16:40	M2	16:40	A02	16:40	A05
	17:00	M2	17:00	A02	17:00	A05
	17:20	Invited talk	17:20	A02	17:20	A05
	17:40		17:40	A02	17:40	A05
18:00 Conference reception @AGH/A0	18:00	Poster session and coffee	18:00	Poster session and coffee		
	20:00	End of the day	20:00	End of the day	20:00	End of the day

M1	Methods	Developments in measurement techniques
M2	Methods	Developments in sample pretreatment
M03	Methods	Compound specific radiocarbon analysis
M04	Methods	New and updated facilities, status reports
M05	Methods	Laboratory management and organization
M06	Methods	Calibration and calibration records
M07	Methods	Statistical analysis and modelling
A01	Applications	Hydrology, limnology, oceanography, reservoir effects
A02	Applications	Terrestrial environment, sedimentology, plant, landscape, etc.
A03	Applications	Climate studies
A04	Applications	Soil dynamics
A05	Applications	Archaeology
A06	Applications	Dendrochronology and single-year analysis
A07	Applications	Towards Better Management of Artefacts Collections: Preservation, Ethics, and Future Directions
A08	Applications	Diet studies
A09	Applications	Anthropogenic impacts
A10	Applications	Forensics application of radiocarbon
A11	Applications	Bio-medical
A12	Applications	Other radiocarbon applications
O01	Other	Other cosmogenic nuclides

WEDNESDAY, 2nd July

	Room A topic	Room B topic
9:00	A06	A03
9:20	A06	A03
9:40	A06	A03
10:00	A06	A03
10:20	A06	A03
10:40	Coffee break	Coffee break
11:10	A06	A07
11:30	A06	A07
11:50	A06	A07
12:10	A06	A04
12:30	A06	A04
12:50	Lunch break	Lunch break
14:20	A06	A04
14:40	A06	
15:00	City walk	

THURSDAY, 3rd July

	Room A topic	Room B topic
9:00	M07	A09
9:20	M07	A09
9:40	M07	A09
10:00	M07	A09
10:20	M07	A09
10:40	Coffee break	Coffee break
11:10	A12	A09
11:30	A12	A09
11:50	M04	A10
12:10	M04	A10
12:30	M03	A10
12:50	Lunch break	Lunch break
14:20	M03	A10
14:40		
15:00	Poster session and coffee	
17:00		

19:00 Conference dinner @AGH/BGH

FRIDAY, 4th July

plenary session

	topic
9:00	Invited talk
9:20	
9:40	M06
10:00	M06
10:20	M06
10:40	Coffee break
11:10	M06
11:30	M06
11:50	M06
12:10	M06
12:30	Announcements
12:50	Conference closing
14:20	Lunch

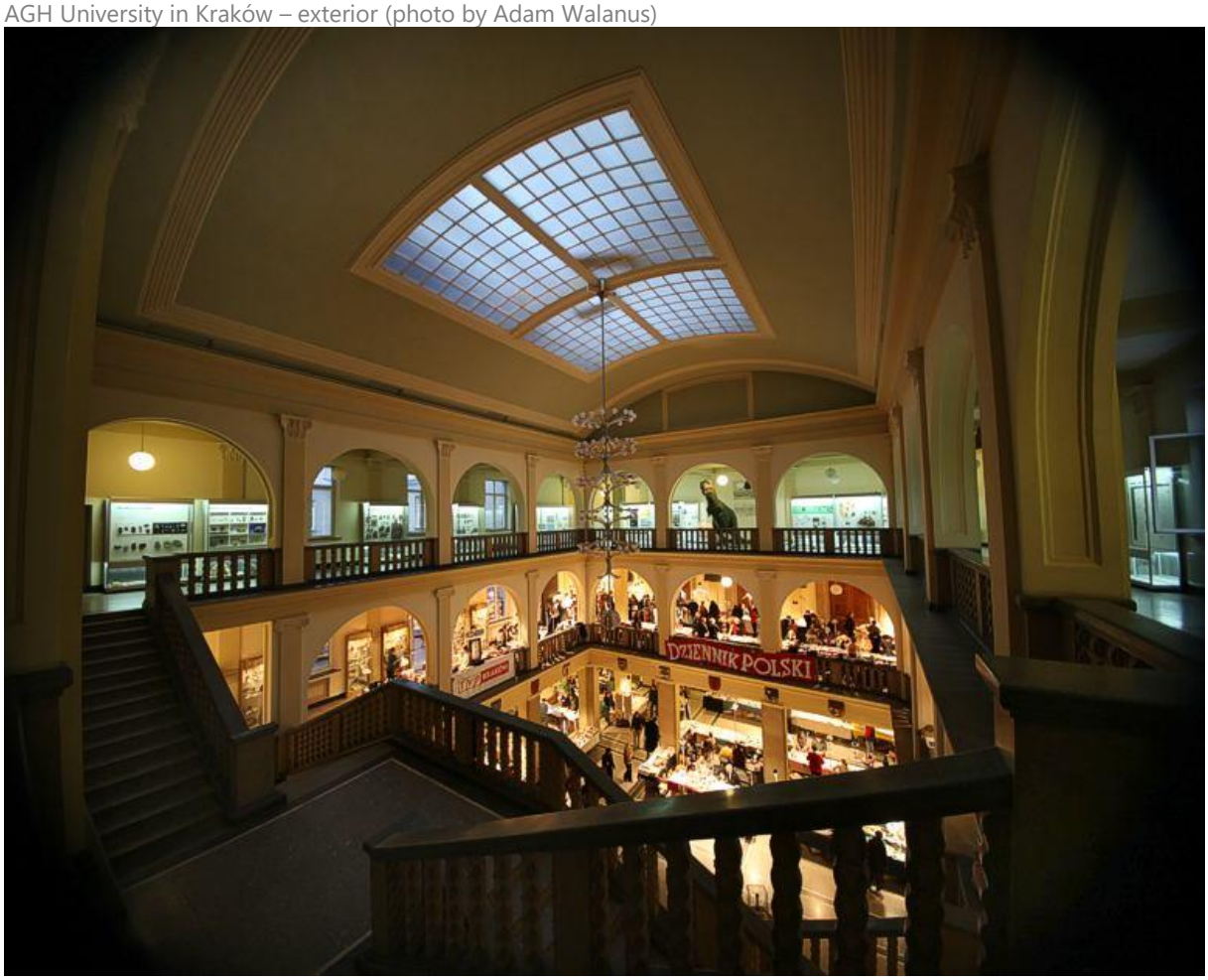
M1	Methods	Developments in measurement techniques
M2	Methods	Developments in sample pretreatment
M03	Methods	Compound specific radiocarbon analysis
M04	Methods	New and updated facilities, status reports
M05	Methods	Laboratory management and organization
M06	Methods	Calibration and calibration records
M07	Methods	Statistical analysis and modelling
A01	Applications	Hydrology, limnology, oceanography, reservoir effects
A02	Applications	Terrestrial environment, sedimentology, plant, landscape, etc.
A03	Applications	Climate studies
A04	Applications	Soil dynamics
A05	Applications	Archaeology
A06	Applications	Dendrochronology and single-year analysis
A07	Applications	Towards Better Management of Artefacts Collections: Preservation, Ethics, and Future Directions
A08	Applications	Diet studies
A09	Applications	Anthropogenic impacts
A10	Applications	Forensics application of radiocarbon
A11	Applications	Bio-medical
A12	Applications	Other radiocarbon applications
O01	Other	Other cosmogenic nuclides

DETAILED PROGRAM

SUNDAY, 29TH JUNE

18:00 Conference reception

AGH University in Kraków – exterior (photo by Adam Walanus)



AGH University in Kraków – main hall (photo by Adam Walanus)

MONDAY, 30TH JUNE

9:00-9:20 **Conference opening**
9:20-10:00 **Invited talk**: Radiocarbon and AMS, a lasting friendship
Session M1
10:00-10:20 QuadCore PIMS instrument commissioning
10:20-10:40 Radiocarbon measurements using PIMS and SSAMS at the Atmosphere and Ocean Research Institute, the University of Tokyo for the study of Climate, Environment and Biological Sciences
10:40-11:10 **Coffee break**
11:10-11:30 µGRAPHILINE: Recent updates and performance of an automated combustion and graphitization system
11:30-11:50 The new compact ^{14}C AMS system at CEDAD for biomedical and pharmaceutical research: acceptance, performances and future applications
11:50-12:10 Recent technical developments and an overview of the current product portfolio at Ionplus AG, Switzerland
12:10-12:30 Thoughts on the calculation of radiocarbon results using a MICADAS AMS system
Session M2
12:30-12:50 Integrated sample processing via stepped combustion, EA, and IRMS
12:50-14:20 **Lunch break**
14:20-14:40 Advances in biocarbon ^{14}C analyses of liquid and gas fuels at HEKAL Laboratory
14:40-15:00 Conservation of wood and its effect on ^{14}C ages
15:00-15:20 Effective strategies to cope with the many challenges of radiocarbon dating of mortars
15:20-15:40 Non-destructive radiocarbon dating of bone
15:40-16:00 Pyrolysis-GC-MS & Metabolomics – Developing an Integrated Approach for the Analysis of Archaeological Bones and Implications for Radiocarbon Dating
16:00-16:20 Radiocarbon dating of tooth enamel from the Holocene
16:20-16:40 **Coffee break**
16:40-17:00 Accurate dating of contaminated bone collagen after purification of amino acids using a strong cation exchange resin
17:00-17:20 A sampling and preservation test of radiocarbon free ground water for dissolved inorganic carbon C-14 measurement
17:20-17:40 **Invited talk**: Radiocarbon and forensics
17:40-18:00 **Intermission**
18:00-20:00 **Poster session and coffee**

TUESDAY, 1ST JULY

Room A

Session A01

9:00-9:10 Timeless: the last 800 years of New Zealand settlement

9:10-9:20 Abroupt shifts in paleoenvironmental record of landslide depressions – climat event or reactivation of landslide? A case study of jeziora landslide zone

9:20-10:00 High-precision radiocarbon dating and carbon reservoir effect of a Maar lake in south China

10:00-10:20 Marine radiocarbon reservoir age simulations for the past 50000 years revisited

10:20-10:40 Carbon deposition in deep oceanic peridotite: radiocarbon constraints from a 1.3 km borehole

10:40-11:10 **Coffee break**

Session A02

11:10-11:30 Vegetation and hydrological changes recorded in the Kotoń fen deposits (the Outer Western Carpathians, S Poland) during ca. 14,600–13,500 calBP and their extraregional context

11:30-11:50 Ecosystem engineers of the Karoo: how Bush Karoo rats shape soil properties and carbon storage

11:50-12:10 Radiocarbon dating of the Xiawangdu neolithic site in the lower Yangtze region and its implications for human-environment interaction

12:10-12:30 Correlating transported and sequestered organic carbon provenance and age in aotearoa new zealand using geochemical and radiocarbon methods

12:30-12:50 What is Switzerland's (radio)carbon footprint?

12:50-14:20 **Lunch break**

Room B

Session A05

9:00-9:10 Dating very old carbonate samples with on-line leaching: example of Littorina shell beads from the Chatelperronian site of Saint-Cesaire (France)

9:10-9:20 Climate and human responses in northern Fennoscandia during the Holocene: a paleoenvironmental and archaeological perspective

9:20-10:00 Re-dating the thera eruption

10:00-10:20 Toward a comprehensive framework for radiocarbon dating maya bone: karsts, coasts, corn, chronology

10:20-10:40 **Intermission**

Session A05

11:10-11:30 Radiocarbon dating reveals relations between cathedral, people and environment in medieval Stavanger, Norway

11:30-11:50 The Pacific archaeology radiocarbon database

11:50-12:10 Bronze Age fishing in Denmark: radiocarbon dates and reservoir effects

12:10-12:30 Chronological modelling of the ancient Egyptian Old Kingdom

12:30-12:50 Wiggle matching people

TUESDAY, 1ST JULY

Room A

Session A02

14:20-14:40 Presenting the radiocarbon inventories of Switzerland database: connecting atmosphere, land and water on a national scale

14:40-15:00 Pyrogenic carbon dynamics in tropical savannah soils: radiocarbon evidence from a frequently burned landscape in Lopé National Park, Gabon

Session A02

15:00-15:20 The Middle-Late Pleistocene history of the brown bear Ursus arctos Linnaeus, 1758 in Poland

15:20-15:40 Radiocarbon age of supraglacial organomineral formations from Antarctica to Arctica

15:40-16:00 Dated speleothems and deposits of the gravity induced caves and their relation to hydrological changes during the late glacial and Holocene; Polish flysch Carpathians case study

16:00-16:20 **Coffee break**

Session A02

16:20-16:40 Dynamics of cave sediment formation processes during the last glacial cycle using the example of Barová cave, Moravian karst

16:40-17:00 Tracing honey carbon sources with radiocarbon analysis

17:00-17:20 Determination of the origin of the peat bogs of the Śnieżnik massif (SW Poland, N Czech Republic) and the beginning of their development based on radiocarbon age determinations

17:20-18:00 Expanding the internal error with non-poisson statistics and the 12c current noise

17:40-18:00 **Intermission**

Room B

Session A05

14:20-14:40 Modelling culture and genetics: a critical evaluating of the Mesolithic - Neolithic transition in southern Scandinavia

14:40-15:00 Using annual calibration curves for highly resolved dating

Session A05

15:00-15:20 Radiocarbon dating of iron reinforcements of Notre-Dame de Paris cathedral: an original contribution to the chronology of the construction and restoration phases

15:20-15:40 A revised chronology of the portel-ouest cave sequence (ariège, france): implications for late neanderthal occupations in the pyrenees region

15:40-16:00 Dating methods on earth architecture in Central Germany

Session A05

16:20-16:40 Archaeometry (radiometric dating, metallography) for two early Iron-Age axes from Northern Europe and Central Asia

16:40-17:00 New technological studies and radiocarbon dating of the open-air site of Piekary III (Kraków, Poland)

17:00-17:20 The boomerang's return: revisiting the Early Upper Paleolithic chronology of Obłazowa cave (Poland), with high-resolution ^{14}C dating

17:20-17:40 Radiocarbon dating of lead corrosion products in funerary contexts: examples from the cemetery of Grandmont abbey and the coffin of Notre-Dame de Paris cathedral

17:40-18:00 Radiocarbon dating the foundations of Inca Cusco

18:00-20:00 **Poster session and coffee**

WEDNESDAY, 2ND JULY

Room A

Session A05

9:00-9:20 Interdisciplinary investigation and radiocarbon dating of the Romanesque wall Paintings of Santa Maria Assunta in Sorengo (Lugano, CH)

9:20-9:40 Radiocarbon insights into the inca expansion at Cordillera Vilcabamba

Session A06

9:40-10:00 Exploring extreme solar events through annual ^{14}C data in tree rings

10:00-10:20 Current understanding of Miyake events in light of the Edinburgh meeting

10:20-10:40 Reconstructing long-term solar activity from a multi-centennial radiocarbon dataset

10:40-11:10 **Coffee break**

Session A06

11:10-11:30 How the chronological challenges presented by the Hallstatt plateau may be overcome

11:30-11:50 High-precission ^{14}C determinations from Fitzroya Cuppresoides tree-rings between 3,200-1,500 cal yrs BP in southern Chile (~41.5 °s)

11:50-12:10 Annual atmospheric δ14C variation in eastern China from 1850 to 1933

12:10-12:30 Radiocarbon age validation in support of herb-chronology of belowground woody organs in species of the Brazilian savanna

12:30-12:50 The radical project: tracing fossil fuels with ^{14}c — a scalable approach to biomonitoring and bioremediation

12:50-14:20 **Lunch break**

Room B

Session A03

9:00-9:20 Maya cultural decline recorded in a speleothem dead-carbon decrease, Yucatan, Mexico

9:20-9:40 Monitoring and modelling of atmospheric 14CO2 over Switzerland

9:40-10:00 A new dynamic model of atmospheric radiocarbon transport in application to extreme solar particle events

10:00-10:20 Comparing simulated marine reservoir ages of the non-polar surface ocean between different models under consideration of abrupt changes in the AMOC during the last 55 kyr

10:20-10:40 Age and process of river pattern transformation from macromeanders to small meanders – case study from river valleys in Holy Cross Mts. Region

Session A07

11:10-11:30 Users' laboratories and ^{14}C dating objects of cultural heritage

11:30-11:50 Investigating the use of IR spectroscopy to identify wood cellulose for radiocarbon dating

11:50-12:10 Radiocarbon sample archives and the Native American Graves Protection and Repatriation Act (NAGPRA): what we're doing at the Center for Applied Isotope Studies, University of Georgia

Session A04

12:10-12:30 Rock organic carbon sustains heterotrophic bacteria in early stages of soil development after glacial retreat

12:30-12:50 Investigating soil carbon storage in vineyards: δ13C and δ14C as indicators of carbon dynamics under cover crops and tillage

WEDNESDAY, 2ND JULY

Room A

Session A06 🟡

14:20-14:40 Dating the mt. Mazama eruption to a calendar year using single year tree-ring ^{14}C

14:40-15:00 Refinement of the ^{14}C-based age determination of the Alpine glacier mummy Ötzi

15:00 **City walk/Lab visit**

Room B

Session A04 🟢

14:20-14:40 Evaluating the persistence and stability of temperate soil carbon via ramped oxidation and radiocarbon analysis

14:40-14:50 Production rate calibration of in situ ^{14}C in quartz in Antarctica

Kraków – Main Market Square (photo by Adam Walanus)

Kraków – skyline (photo by Adam Walanus)

THURSDAY, 3RD JULY

Room A

Session M07

9:00-9:20 Simple and complex methods to additively expand quoted errors to account for long-term effects

9:20-9:40 Cross referencing – a simple yet powerful tool for integrating an increasing range of information in bayesian chronological models

9:40-10:00 A new approach to radiocarbon summarisation: rigorous identification of variations/changepoints in the occurrence rate of radiocarbon samples using a Poisson process

10:00-10:20 Oxcal and the IntChron data integration tool

Session M03

10:20-10:40 Quantifying HPLC column backgrounds for routine bone hydroxyproline dating

10:40-11:10 **Coffee break**

Session M03

11:10-11:30 Chronology of mobile pastoralists settlements and dairy exploitation in Neolithic iran through compound-specific radiocarbon analyses of archaeological pottery

Session M04

11:30-11:50 History and status report of the Gliwice ^{14}C and mass spectrometry laboratory

11:50-12:10 Status report on the accelerator mass spectrometry at the CETA Accelerator Laboratory in Bratislava

Session M06

12:10-12:30 Single year ^{14}C from tree-rings, improving calibration and anchoring timelines 2500-1100 BCE

12:30-12:50 Sub-annual variation in tree cellulose radiocarbon in AD 993/994 and AD 1054/1055

12:50-14:20 **Lunch break**

15:00-17:00 **Poster session**

19:00 **Conference dinner**

Room B

Session A09

9:00-9:20 Evolution of the Nida river valley during the holocene based on radiocarbon data

9:20-9:40 Time-integrated air sampling for 14CO2 in Irvine, California, USA from 2009 to 2025 and its implications for evaluating urban fossil fuel CO2 sources

9:40-10:00 Carbon-14 in the marine environment of the Swedish west coast

10:00-10:20 Partitioning of atmospheric CO_2 load using radiocarbon and stable carbon isotopes: a case study from Krakow (Poland)

10:20-10:40 Tracing the urban carbon emission peaks and synergizing reductions of carbon emissions and air pollutants through tree-ring ^{14}C

Session A09

11:10-11:30 Tracing seasonal urban greenhouse gas patterns with carbon isotopes in Debrecen, Hungary

11:30-11:50 Turnover rates in human hip bones: the continuation of a story

11:50-12:10 Intracortical radiocarbon (F14C) and stable isotope variation in human femora

Session A10

12:10-12:30 Utilizing radiocarbon to date unidentified human remains

Session A12

12:30-12:50 Pushing the boundaries of mortar dating: applying ramped pyrolysis on Bronze Age samples

FRIDAY, 4TH JULY

9:00-9:40 **Invited talk**: Radiocarbon: a useful dating tool for the recent past
Session M06
9:40-10:00 Preparing for the next IntCal
10:00-10:20 Clues from ^{10}Be data for improving the ^{14}C calibration curve
10:20-10:40 Radiocarbon Calibration Potential of Varved Sediments in the Maya Lowlands
10:40-11:10 **Coffee break**
11:10-11:30 Mid-latitude intra-year ^{14}C offsets in the Northern Hemisphere 412–325 BCE
11:30-11:50 Annually resolved ^{14}C record from southern South America (970–1084 AD): tracking atmospheric ^{14}C variability
11:50-12:10 Variation in bomb radiocarbon in trees along a N-S transect in Norway
12:10-12:30 The 1950s bomb-^{14}C peak
12:30-12:50 **Announcements**
12:50-14:20 **Conference closing**
14:20 **Lunch**

ABSTRACTS FOR THE ORAL SESSION

INVITED TALK

RADIOCARBON AND AMS, A LASTING FRIENDSHIP

Walter Kutschera

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Abstract

Radiocarbon dating was invented about 80 years ago by Willard Libby and collaborators at the University of Chicago. For many years, ^{14}C was measured solely by the feeble beta-decay signals until, in 1977, a paradigm shift in radioisotope dating happened by introducing "counting atoms rather than decays" with an accelerator (Muller 1977). Thus, the method of accelerator mass spectrometry (AMS) was born and increased the sensitivity of detecting ^{14}C by many orders of magnitude. The construction of dedicated AMS systems (Purser et al. 1980) started a development of tandem-based systems with ever smaller terminal voltages, eventually leading to the widely used MICADAS (Mini CArbon DAting System), essentially a table-top-like system (Synal et al., 2007). Although many different long-lived radioisotopes across the nuclear chart are measured with AMS, ^{14}C is by far the most used one (Hajdas et al. 2021). This presentation will try to convey the joy and excitement of AMS measurements of radiocarbon, with seemingly unlimited applications.

References

Hajdas I, Ascough P, Garnett MH, Fallon SJ, Pearson CL, Quarta G, Spalding KL, Yamaguchi H and Yoneda M (2021), Radiocarbon dating, Nat. Rev. Methods Primers 1, 1–26.

Muller RA (1977), Radioisotope dating with a cyclotron: The sensitivity of radioisotope dating is improved by counting atoms rather than decays, Science 196, 489–494.

Purser KH, Liebert RB and Russo CJ (1980), MACS: an accelerator-based radioisotope measuring system, Radiocarbon 22/3, 794-807.

Synal H-A, Stocker M and Suter M (2007), MICADAS: A New Compact Radiocarbon AMS System, Nucl. Instr. Meth. Phys. Res. B 259, 7-13.

INVITED TALK

RADIOCARBON AND FORENSICS

Gianluca Quarta[1]

[1] CEDAD (Centre of Applied Physics, Dating and Diagnostics), Department of Mathematics and Physics "Ennio de Giorgi"-University of Salento, Lecce, Italy

INVITED TALK

RADIOCARBON: A USEFUL DATING TOOL FOR THE RECENT PAST

Quan Hua

M1 SESSION

QUADCORE PIMS INSTRUMENT COMMISSIONING

Stewart Freeman[1], Cameron McIntyre[1], Richard Shanks[1], Andrew Tait[1], Richard Kitchen[2], Leanne Verster[3]

[1] SUERC, East Kilbride, UK
[2] National Electrostatics Corp. (NEC), Middleton, WI, USA
[3] Thermo Fisher Scientific (TFS), Bremen, Germany

Abstract

Radiocarbon positive ion mass spectrometry (PIMS) is ^{14}C mass spectrometry without the sputter ion source and particle accelerator of traditional accelerator mass spectrometry, and concomitant limitations. Featuring a convenient plasma ion source of positive ions and subsequent chemical reaction cell at ground electrical potential to remove measurement interferences, the technology inherently lends itself to automation and other-systems integration; PIMS was invented at SUERC and is being developed with commercial partners.

The SUERC prototype PIMS instrument is rearranged into the so-called QuadCore configuration of twin mass spectrometers and matching gas sample handling. Sample introduction is via a selection of interfaces including a new TFS Isolink CN elemental analyser. This delivers CO_2 in He carrier to both a NEC Gas Sample Hub, for impedance matching gaseous samples to the PIMS spectrometer, and a TFS ConFlo IV supplying a DeltaQ isotope ratio mass spectrometer. The whole is commanded by the TFS Qtegra control system that can process two gaseous samples simultaneously and asynchronously for efficient analysis. The DeltaQ provides complementary $\delta^{13}C$ values.

The presentation addresses SUERC instrument commissioning specifically and PIMS instrument establishment more generally at a time of commercial instrument deployment elsewhere too. A goal is deeper & more varied future systems integration afforded by Qtegra.

M1 SESSION

RADIOCARBON MEASUREMENTS USING PIMS AND SSAMS AT THE ATMOSPHERE AND OCEAN RESEARCH INSTITUTE, THE UNIVERSITY OF TOKYO FOR THE STUDY OF CLIMATE, ENVIRONMENT AND BIOLOGICAL SCIENCES

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Abstract

A single-stage accelerator mass spectrometer (National Electrostatic Corporation, YS-AMS) at the Atmosphere and Ocean Research Institute (AORI), University of Tokyo, has been operating smoothly since 2013 (Yokoyama et al., 2019). The stable operational performance of YS-AMS allows us to routinely perform small-scale radiocarbon measurements, also thanks to the updated graphitization system. Applications for earth and environmental sciences have expanded, including compound specific radiocarbon measurements on marine and lacustrine measurements to understand the timing of past environmental events (eg., Yamane et al., 2019; Prothro et al., 2020; Johnson et al., 2021). This also leads to efficient measurements of pollen radiocarbon dating using flow cytometry (Ota et al., 2024). In March 2025, the first commercial positive ion mass spectrometer (National Electrostatic Corporation, PIMS) outside of Europe was installed and reliable datasets using the IAEA standard were produced.

In this talk we will present recent developments in our YS-AMS related studies, in particular small-scale radiocarbon dating, as well as initial performance of the PIMS installed at AORI.

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M1 SESSION

µGRAPHILINE: RECENT UPDATES AND PERFORMANCE OF AN AUTOMATED COMBUSTION AND GRAPHITIZATION SYSTEM

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Abstract

µGRAPHILINE is a fully automated, modular system for combustion and graphitization, developed to prepare graphite targets from a wide range of sample types for radiocarbon analysis with Accelerator Mass Spectrometry (AMS). Apart from traditional setups, µGRAPHILINE eliminates the need for technical gases and liquid nitrogen, employing a controlled dual-zone combustion process and an iron–zinc reduction.

This presentation outlines system performance evaluated using IAEA reference materials, analyzed on two independent AMS systems, and illustrates recent system upgrades. The results demonstrate µGRAPHILINE's efficiency, background level, ion currents, small sample graphitization and operational reliability. Presented results support its application in routine high-precision radiocarbon measurements.

M1 SESSION

THE NEW COMPACT ^{14}C AMS SYSTEM AT CEDAD FOR BIOMEDICAL AND PHARMACEUTICAL RESEARCH: ACCEPTANCE, PERFORMANCES AND FUTURE APPLICATIONS

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Abstract

As part of the PRP (Pathogen Readiness Platform) project, funded under Italy's National Recovery and Resilience Plan (PNRR), a new compact Accelerator Mass Spectrometry (AMS) system has been installed at CEDAD (Centre of Applied Physics, Dating, and Diagnostics) within the Department of Mathematics and Physics "Ennio de Giorgi" at the University of Salento.

This state-of-the-art system will play a crucial role in pharmaceutical research by utilizing Biomedical Accelerator Mass Spectrometry (BAMS), an advanced bioanalytical technique applied in pharmacology and toxicology. Specifically, it will support traditional Drug Metabolism and Pharmacokinetics (DMPK) studies, where carbon-14 serves as a tracer to analyze the distribution and binding properties of new drug candidates, enabling the use of ultra-low drug doses. The application of microdosing and microtracing techniques will streamline drug development, making it more efficient in terms of cost and time.

The new setup is based on a ^{14}C-dedicated AMS system, the HVEE 4102Bo model manufactured by High Voltage Engineering Europa, operating at a terminal voltage of 210 kV. It incorporates an S-110C hybrid multi-cathode ion source, capable of processing both solid and gaseous samples via a dedicated gas interface. The tandem accelerator is powered by a vacuum-insulated power supply integrated within the vacuum vessel.

The system is equipped with permanent magnets to minimize power consumption (approximately 2.5 kW) and features an automated tuning and data analysis system. Thanks to its compact dimensions (around 3 x 2.8 meters), the new AMS system has been installed in the same hall currently housing the Tandetron accelerator (HVEE Mod. 4130HC).

This presentation will provide an overview of the system's technical specifications and results obtained in the first months of operation. In particular the acceptance tests demonstrated reliable operations of the system and precision levels on $^{14}C/^{12}C$ determinations below 0.3 % in standard, routine conditions while high precision measurements < 0.2 % have been also shown. Accuracy of the results was assessed by analyzing IAEA reference and SIRI samples while machine background levels in the 10-16 range are achieved on unprocessed graphite.

M1 SESSION

RECENT TECHNICAL DEVELOPMENTS AND AN OVERVIEW OF THE CURRENT PRODUCT PORTFOLIO AT IONPLUS AG, SWITZERLAND

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Abstract

We present a brief overview of Ionplus' current product range, showcasing both established products and latest developments. In the first part of the talk, we cover the current state of well-established products such as MICADAS, the high precision radiocarbon AMS system, GIS, the CO2 gas interface, and MILEA, the multi-isotope system, along with various peripheral devices.

A particular focus will be placed on the latest additions to the Ionplus product portfolio: the even more compact radiocarbon AMS, LEA, and the High Throughput gas Interface (HTI), which enable highly automated CO2 gas measurements on a small footprint, occupying less than 4 x 2 m2. Moreover, the optional magazine storage robot, AMC, can increase the number of available measurement cathodes from 39 in a standard MICADAS magazine to up to around 400 during more extensive and largely unsupervised measurement campaigns.

In the second part of the talk, we provide an update on our ongoing development efforts to further integrate AMS into the biomedical and materials industry. In 2023, Ionplus was awarded the Swiss Innosuisse grant, which supports these developments over a 2.5 year funding period. We outline the various work packages comprising AMS system and peripheral design, software development, and regulatory (GxP) integration efforts. This is followed by an update on the current project status and an outlook on further development.

We conclude with a brief outlook on future projects, including the integration of peripherals (e.g. GIS) into a new software platform.

M1 SESSION

THOUGHTS ON THE CALCULATION OF RADIOCARBON RESULTS USING A MICADAS AMS SYSTEM

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Abstract

Accelerator Mass Spectrometry (AMS) has gone through many stages of evolution since its beginning in 1977 (Bennet et al 1977, Nelson et al 1977). A significant evolution in the field has been the development of AMS at lower energies, notably the MICADAS system (Synal et al 2007). Numerous laboratories (more than 30 worldwide, Kutchera 2023) use this system routinely, obtaining great radiocarbon results. Since then, two new low energy AMS systems have been developed by IonPlus AG with the same principle: The LEA used exclusively for ^{14}C measurements and the MILEA (and its light version) which can measure several isotopes.

Many of the facilities operating AMS systems made by IonPlus AG use the same software, BATS (Wacker et al 2010), for the calculation of results from raw measurements to final isotope ratios. While BATS is user friendly and produces good results, there have been issues concerning small samples (Thil et al. 2024). Similarly, many facilities based on AMS systems from IonPlus AG use the quasi-automatic system optimization protocol provided by IonPlus AG, which is easy to use and should provide consistent settings for the instrument.

The MICADAS of the Radiocarbon and Mass Spectrometry Laboratory in Gliwice, Poland, was installed in 2022 (Ustrzycka et al 2025). It has been used for routine measurements since then and is usually optimized using the quasi-automatic tuning protocol. The results are calculated using BATS 4.0.

We present a re-analysis of the raw results of the Gliwice MICADAS using different calculation methods. These include different normalization groupings, either at the cycle (block*), pass (run*), or magazine (wheel*) level; different machine and process blank corrections; and different selection of the raw results (e.g. rejection of the first measurements or of measurements when the ion current diminishes). We also investigate the effects of machine isotopic fractionation and the best way to account for it in the calculation of the results. We will compare these findings to the results obtained in Trondheim, Norway, with a 1 MV HVE AMS system (Nadeau et al 2015) that has produced reliable results for the past 10 years.

Additionally, we will present an analysis of how we could normalise the data across several magazines or wheels for both systems. This leads to an assessment of the stability of the quasi-automated optimization protocol of the MICADAS through an evaluation of the variations in the system parameters and the influence of these variations on the isotopic ratios.

*Indicates the terminology used by AMS systems other than from IonPlus AG.

M1 SESSION

INTEGRATED SAMPLE PROCESSING VIA STEPPED COMBUSTION, EA, AND IRMS

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Abstract

Integrated and efficient sample preparation workflows are essential for high-precision radiocarbon and stable isotope analyses, particularly in the context of small or heterogeneous samples. This work presents a novel configuration that combines stepped combustion in the µGRAPHILINE automated graphitization line (developed by miDose Solutions) with elemental analysis and isotope ratio mass spectrometry (EA/IRMS) systems by Thermo Fisher Scientific Inc. The aim was to streamline ^{14}C and $\delta^{13}C$ measurement workflows.

We connected the µGRAPHILINE system's gas outlet to a Thermo EA and IRMS setup. Pure and mixed reference materials were combusted in µGRAPHILINE using controlled stepped-temperature protocols. The obtained CO_2 was collected and a precise portion of the gas was transferred to the EA system; 0.4 mL gas aliquots at 3900 mbar were injected under standard analytical conditions. $\delta^{13}C$ values were obtained with high reproducibility, demonstrating compatibility between stepped combustion gas products and downstream IRMS analysis.

The connection of a continuous CO_2 stream (36 µl/min) to the plasma ion source (Pantechnik), which produces a stable C^+ beam for the PIMS spectrometer (NEC), was also tested

This approach provides a flexible platform for dual-purpose sample processing, combining quantitative ^{14}C graphitization with $\delta^{13}C$ measurement from the same CO_2 source.

M2 SESSION

ADVANCES IN BIOCARBON ^{14}C ANALYSES OF LIQUID AND GAS FUELS AT HEKAL LABORATORY

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Abstract

The increasing amount and demand of used biobased liquid fuel components require reliable and independent measurement techniques of the biocontent ratio determinations in blends. It is difficult to distinguish the fossil (petroleum based) and biogenic (recent) component of the mixed fuel samples using classical analytical techniques, such as chromatography methods, because the physical and chemical properties of these materials are quite similar. Determination of the biological component ratio by the radiocarbon (^{14}C) method has been standardized (ASTM D6866 2020), but different laboratories use different preparation methods and AMS instruments made by different manufacturers for the measurement (Varga et al., 2023).

In this study, we applied an automatized EA-AGE system combination (IonPlus AG) to combust and graphitize the liquid fuel samples and then a LEA/MICADAS type AMS (IonPlus AG) for their ^{14}C analyses. The analytical performance of the elegant and automated preparation method (EA-AGE) was compared to our "manual" way (sealed tube combustion) of biocontent AMS ^{14}C analyses. In case of the EA-AGE system, 7 samples for one run were weighed and closed into Sn capsules. Then an elemental analyser (EA) was applied for combustion in a programmed order and the outlet gas was cleaned and passed to the Automated Graphitization Equipment (AGE, Ionplus AG) to make AMS graphites.

The manual (sealed tube combustion) way of sample preparation meant that fuel samples were weighed into a borosilicate combustion tube already containing MnO2 powder as oxidation reagent. In case of gas samples we have used a syringe injection method into the evacuated combustion tube. The fuel samples in sealed tubes were combusted off-line at 550°C, 24 hr in a muffle furnace. The produced CO2 was cryogenically (and manually) recovered one-by-one from the combustion tubes and transferred to graphitization ampules in a gas handling line. Sealed tube graphitization method was used to convert the purified CO2 to graphite by Zn reduction method for AMS ^{14}C analyses. This "manual" method was already tested in an international intercomparision exercise between CEDAD (Italy) and ETHZ (Zürich) (Varga et al., 2023).

We have split the liquid fuel samples and run them both ways: manually and the automated (AGE) way too. In this study we present and compare the results of process blanks, carbon recovery, ^{14}C analyses repeatability between the two tested methods, in our Laboratory.

Acknowledgments
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M2 SESSION

CONSERVATION OF WOOD AND ITS EFFECT ON ^{14}C AGES

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Abstract

Recent developments in radiocarbon dating have made this technique increasingly attractive for dating cultural heritage artefacts. However, one of the biggest challenges that still exists in the radiocarbon dating of cultural heritage is the presence of exogenous carbon introduced during burial, conservation, restoration, or storage. The study of various types of wood conservation and their impact on radiocarbon dating was completed in 2016 as part of a Bachelor of Arts (BA) in archaeology. Existing protocols were applied to the pre-treatment of samples and compared to well-established archaeological ages.

Well-dated Swiss archaeological sites are rich in waterlogged wood, often dated by dendrochronology (Leuzinger et al. 2017). Seven wood samples were selected from the archaeological archives of well-dated wood, which was preserved using Arigal C, PEG, Sugar, Alcohol-Ether, dried in air, and freeze-dried. The age of the wood ranges from Roman times to the 4th millennium BCE.

We have tested six different treatment protocols, which combined solvents, ABA, and cellulose separation. The radiocarbon age of untreated samples was compared to the ^{14}C ages obtained after the various preparation procedures. The effectiveness of the protocols is illustrated by the offset between the expected (dendro) age and the ^{14}C ages of samples obtained for the used preparation methods. Additionally, the archived sample material was analyzed using Fourier Transform Infrared Spectroscopy (FTIR), which enabled verification of the presence of the conservation material (Hajdas et al., 2024).

Our results illustrate the need for extensive research focusing on the documentation, detection and removal of conservation that impacts the ^{14}C signal of studied cultural heritage.

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M2 SESSION

EFFECTIVE STRATEGIES TO COPE WITH THE MANY CHALLENGES OF RADIOCARBON DATING OF MORTARS

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Abstract

Radiocarbon dating of mortars is still a topic highly discussed in the international community. Mortars are in fact so heterogeneous in their compositions that the application of such dating method introduces lots of challenges: the complete isolation of an aerial binder with respect to the several aggregates, the possible paths that are responsible to reach the full carbonation, the possible sources of the different carbonates components, the possible processes that may affect the material after setting. Characterizing the mortar prior to dating is thus essential to identify the most effective procedure for identifying the good material to be isolated for the measurement.

This presentation discusses the experience of the collaboration between INFN, ISPC-CNR and the Department of Earth Science, University of Florence, highlighting the key issues of our experimental procedure developed to characterize, isolate, prepare and date mortars. Our procedure follows four steps: first accurate architectural and historical analysis to sample; general mineralogical, petrographic and chemical characterization to evaluate the feasibility of applying radiocarbon; non-destructive multi-analytical characterization (XRD, FTIR-ATR, micro Raman) of binder-rich portions and/or lumps that have been preliminary selected, final preparation and measurement by AMS of those samples that have passed the previous step. Different case studies will be presented: samples from Florentine area (they show a weak hydraulic behaviour), pozzolanic mortars, materials just datable exploiting their organic aggregates.

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M2 SESSION

NON-DESTRUCTIVE RADIOCARBON DATING OF BONE

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Abstract

Bone is commonly used in the radiocarbon dating of archaeological sites. This is a destructive process, involving drilling or sawing of the bone prior to subsequent pretreatment and ^{14}C measurement. Could radiocarbon dating bone ever be done non-destructively? Other methods such as ancient DNA and palaeoproteomics, have developed non-destructive strategies for bone/teeth, but this has not yet been done for radiocarbon dating.

In this presentation we will outline experimental work on a non-destructive, water-based extraction method for dating whole bone that avoids any destructive cutting or drilling of samples. We took samples of whole bone and submerged them in ultrapure (MilliQ) hot water for several hours. We tested bone of known age, as well as archaeological bone samples of unknown age, and succeeded in extracting collagenous material, based on its appearance, that was comparable to collagen obtained through the traditional destructive approaches. We obtained amino acid profiles, stable isotope data and atomic C/N ratios that were indicative of collagen. The extracted collagen was subsequently further purified using ultrafiltration or XAD-2 resin and then AMS radiocarbon dated. The radiocarbon determinations obtained through the non-destructive extraction were statistically identical to radiocarbon ages obtained through the traditional destructive method. There were no macroscopic changes to the bone surface visible.

This experimental method opens up many new opportunities for research on samples and worked bone objects (e.g., carved or with osteological landmarks) that would ordinarily be too small or precious to be subjected to the traditional, destructive approach of radiocarbon dating bone.

M2 SESSION

PYROLYSIS-GC-MS & METABOLOMICS – DEVELOPING AN INTEGRATED APPROACH FOR THE ANALYSIS OF ARCHAEOLOGICAL BONES AND IMPLICATIONS FOR RADIOCARBON DATING

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Abstract

Archaeological bone remains are widely analysed for chronological and dietary reconstructions. However, the data produced can be compromised by contamination from burial environments or conservation treatments. To improve the reliability of such analyses, this study explored Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GC-MS) as a molecular screening tool for archaeological bones coupled with a metabolomic approach. The workflow allows for the detection of exogenous compounds in bones and supports the selection of optimal chemical pretreatment strategies for radiocarbon dating. It also enables assessment of the chemical quality and purity of extracted collagen before its dating by Accelerator Mass Spectrometry, offering a critical validation step in the dating workflow. Metabolomics, as an advanced data processing approach in analytical chemistry, facilitates the interpretation of the complex Py-GC-MS data.

In this study, we applied this Py-GC-MS-based–metabolomics approach to over 100 bone and collagen samples from Eurasian archaeological sites, ranging from the Pleistocene to the medieval period. The method proved highly efficient in detecting substances, such as conservation materials, that were not necessarily documented in the curatorial history of the artefacts (Devièse et al., 2019; Devièse et al., 2021). When applied to collagen post-standard pretreatment, the workflow enabled the identification of samples requiring targeted re-purification steps. By delivering a rapid and comprehensive molecular profiling that goes beyond conventional C/N measurement, this approach supports tailored sample processing strategies and enhances the reliability of the dating.

In conclusion, this research demonstrates that the use of such an integrated Py-GC-MS-based metabolomics workflow provides a powerful methodology to validate radiocarbon dating. By improving the detection of contamination, it provides a useful criterion to ensure accurate dating and contributes to more robust archaeological interpretations. Furthermore, this approach offers a comprehensive view of the organic molecular composition of archaeological samples, enhancing our understanding of the preservation and degradation processes. In the future, this method should ideally be applied a priori, to select the most suitable samples and pretreatments, rather than a posteriori, to discard unreliable results after measurement. Such preliminary screening using Py-GC-MS could help avoid wasting time and resources on poorly preserved and contaminated samples. Ultimately, this approach could lead to more accurate reconstructions of past interactions between humans, fauna, and environments, offering deeper insights into ecological and cultural dynamics.

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M2 SESSION

RADIOCARBON DATING OF TOOTH ENAMEL FROM THE HOLOCENE

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Abstract

Radiocarbon dating bone that is more than a few thousand years old in tropical and arid regions is hampered by the rapid degradation of the protein normally targeted for dating. This can result in low quality chronologies, where the only samples available for radiocarbon dating are poorly associated with the event of interest, such as charcoal from burial contexts. The carbonate ion within tooth enamel may provide an alternative for radiocarbon dating. Dates are rarely accurate: typically at least 15 % of the carbonate in enamel is a contaminant, and this cannot be removed with routine pretreatment. This abstract will explore the success of a method to grind tooth enamel finely prior to acid leaching to remove carbonate contamination within pores between crystallites on teeth from the Holocene. Using a range of data from archaeological sites in South East Asia and Oman, we show that whilst measurements from the tropics appear to frequently underestimate the age of teeth by around 200 years, samples from more arid regions appear to produce accurate age estimate. We suggest that a range of preparation methods are used to assess the degree of contamination within a sample, and to establish whether an age estimate is likely to be accurate. This presentation will review how chronological questions can be framed to best realise the potential of the material, and appreciate the uncertainties that remain.

Acknowledgments
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M2 SESSION

ACCURATE DATING OF CONTAMINATED BONE COLLAGEN AFTER PURIFICATION OF AMINO ACIDS USING A STRONG CATION EXCHANGE RESIN

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Abstract

The removal of exogenous carbon from samples is critical for obtaining reliable and accurate radiocarbon dates. This is particularly challenging for bone and dentine collagen, as soil-derived carbon is often thought to form covalent bonds with the collagen matrix. Two main approaches have been developed to isolate collagen carbon from such contaminants: (1) the use of XAD resin to purify hydrolysed collagen amino acids, and (2) the use of preparative high-performance liquid chromatography (HPLC) to isolate hydroxyproline.

Hydroxyproline dating is often regarded as the 'gold standard' for radiocarbon dating of contaminated bone due to its specificity, but it is time-consuming, costly, and may potentially suffer from issues such as HPLC column bleed. While XAD resin purification has seen some adoption amongst the community, concerns persist about its effectiveness in removing all exogenous carbon—particularly polar compounds and condensation products formed during acid hydrolysis in the presence of contaminants.

XAD resin is a non-ionic, non-polar polymeric resin that removes non-polar compounds (including many humic substances) via hydrophobic interactions. However, other more polar, non-amino acid contaminants may pass through and inadvertently contribute to the determined age.

In contrast, strong cation exchange resins such as Dowex 50W-X8 selectively bind amino acids by their protonated amino groups. This allows for the elution and removal of non-amino acid compounds, followed by deprotonation and recovery of purified amino acids. To our knowledge, strong cation exchange resins have not been used in the pretreatment of samples for radiocarbon analysis without subsequent chromatographic isolation of amino acids.

Here, we describe the development and validation of the Dowex purification method and compare its performance with both the XAD resin and hydroxyproline isolation methods. Dowex-purified and non-purified amino acid fractions from a highly contaminated tooth dentine sample were assessed for purity using high-field NMR spectroscopy amongst other techniques.

M2 SESSION

A SAMPLING AND PRESERVATION TEST OF RADIOCARBON FREE GROUND WATER FOR DISSOLVED INORGANIC CARBON C-14 MEASUREMENT

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Abstract

We performed tests to determine the sensitivity of sampling protocols for the radiocarbon analysis of dissolved inorganic carbon (DIC). $F^{14}C$-free ground water was collected from an artesian well in North Carolina in 2022 and 2024. Samples were collected in 120 mL glass bottles with 20 mm openings, crimp tops with heavy duty stoppers, and preserved with mercuric chloride. Two factors, the head space in the bottles and the time between filling and capping were examined. We found that head space volume up to 17% did not change the $F^{14}C$-DIC results. Additionally, up to 10 minutes could pass between filling and capping without compromising the samples. There was no change of $F^{14}C$-DIC after room temperature storage in these bottles for 29 months.

A01 SESSION

TIMELESS: THE LAST 800 YEARS OF NEW ZEALAND SETTLEMENT

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Abstract

After more than 150 years of archaeological enquiry and 74 years since the first radiocarbon lab opened, we are still unable to precisely date significant events that influenced the lives of Polynesians who settled Aotearoa/New Zealand. Our archaeologically constructed timeline of Māori history is divided into three broad periods labelled – Archaic, Early or 'Moa Hunter', Middle or Transitional, and Late or Classic periods. Within these, we cannot precisely date regional variation in artefact styles and subsistence practices or the timing of the loss of connection with central East Polynesia. The Bayesian radiocarbon revolution did not pass us by. However, a heavy reliance on shell radiocarbon ages calibrated out of necessity with a regionally corrected global marine calibration curve, combined with poorly constrained site stratigraphy, have not lent themselves to precise constructs.

Recent insights from South Pacific coral and archaeological radiocarbon datasets indicate that there are temporal changes not included in the global calibration curve. These changes suggest that the response of the marine reservoir to major environmental events is different to that of the atmospheric reservoir. However, rather than being a problem, these differences may be the answer to improving our understanding of the initial settlement of New Zealand by providing tie points, or markers, for refining chronologies. Over the last 3 years, a team of researchers have been undertaking an intensive dating program using high-precision AMS to revisit, refine, and rethink the orthodox chronology using paired charcoal/shell dates from Archaic and Transitional period sites and over 4000 legacy dates in order to improve our understanding of the regional marine reservoir and early Polynesian settlement.

A01 SESSION

ABROUPT SHIFTS IN PALEOENVIRONMENTAL RECORD OF LANDSLIDE DEPRESSIONS – CLIMAT EVENT OR REACTIVATION OF LANDSLIDE? A CASE STUDY OF JEZIORA LANDSLIDE ZONE (POLISH OUTER CARPATHIANS)

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Abstract

The distinct permeability contrasts and the presence of dense fissure networks contribute to the overall complexity and uniqueness of landslide hydrogeology (Guglielmi et al. 2000). In the Flysch Carpathians, landslides are commonly successional forms, repeatedly rejuvenated by successive generations of mass movements. Subsequent episodes of landslide activity alter the rock structure and transform slope morphology, leading to modifications in hydrogeological conditions. A specific feature of landslide relief is the presence of numerous fens and lakes formed in landslide depressions. The sediments in these reservoirs constitute a valuable archive of paleoenvironmental changes (Margielewski, 2018). Consequently, it was impossible to determine whether the observed sediment variability represents a climatic event, the terrestrialization of the reservoir, or alterations in the hydrogeological conditions of the landslide due to its reactivation. Determining the influence of landslide reactivation on the past slope hydrogeological conditions may be possible in the extensive, multi-stage landslide zone (the Jeziora landslide zone) in the Gorce Mountains (Polish Carpathians), where two landslide depressions have been studied. In these landslide depressions, situated just 100 meters apart, two temporary landslide lakes currently occur: Lake Zawadowskie (upper reservoir) (Buczek, 2019), and Lake Iwankowskie (lower reservoir) (Bucała et al., 2014). Present inundation episodes of landslide depressions, lasting from several to dozen weeks, are restricted to thaws or intense rainfall events. In our research, we examined sediment sequences from both landslide depressions using a multiproxy approach, including lithological, pollen, and NPPs analyses, plant macrofossils, Cladocera and diatom analyses, as well as chronologies based on radiocarbon dating. According to the age-depth model, the formation of Zawadowskie Lake occurred significantly earlier (approximately 8 ka cal BP) than Iwankowskie Lake (approximately 2.7 ka cal BP). The results revealed that the formation of the younger depression coincided with an abrupt shift recorded in the paleoenvironmental data of the older Zawadowskie Lake (around 2.8 ka cal BP). The abundant

presence of aquatic plant pollen (e.g., Nuphar, Nymphaea), Pediastrum algae, as well as Cladocera and diatoms in the sediment sequence of Zawadowskie Lake from 5.5 to 2.8 ka cal BP, indicates that, prior to the reactivation of the landslide zone, the reservoir was characterized by stable hydrological conditions and functioned as a permanent lake. The disappearance of aquatic vegetation around 2.8 ka cal BP, along with the decreasing abundance and diversity of Cladocera and diatoms, marked the deterioration of water conditions in the reservoir and its transformation into a temporary lake. The mass movements that led to the formation of Lake Iwankowskie possibly altered the water circulation in the landslide zone, reducing the surface and groundwater catchment area of older reservoir (Lake Zawadowskie). Another factor that may have contributed in water regime change of Zawadowskie Lake was the propagation of extensional fissures within the landslide body that currently separates the two reservoirs. The development of preferential flow paths could have caused the partial drainage of Lake Zawadowskie, the infiltration of water into the landslide masses, and subsequently groundwater flow toward Lake Iwankowskie and/or the springs located at the foot of the landslide.

Acknowledgments

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A01 SESSION

HIGH-PRECISION RADIOCARBON DATING AND CARBON RESERVOIR EFFECT OF A MAAR LAKE IN SOUTH CHINA

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Abstract

High-resolution maar lake records with robust age control provide an ideal foundation for investigating paleoclimate change. However, in tropical-subtropical South China, the carbon reservoir effect of lake sediments is poorly understood, resulting in a lack of high precision records, hindering the comprehensive understanding of regional climate change and its forcing mechanism. In this study, based on a newly drilled core from the Tianyang (TY) maar lake located in South China, we conducted detailed radiocarbon dating of various materials to assess the reservoir effect and establish a reliable high-resolution chronology of the maar lake. Comparing radiocarbon ages of different grainsize and different fractions, the ages of bulk samples were closest to those of plant remains or charcoals which we consider as the reliable dating materials. Pairs of bulk samples and plant remain or charcoal ages indicate a limited but variable reservoir effect in TY maar lake. The reservoir effect is negligible from the surface to 623 cm (0-30.95 ka) and then gradually increased from negligible to approximately 700 years between the depth of 623-747 cm (30.95-37.15 ka). We hypothesize that the reservoir effect in the deeper part of the lake results from a combination of longer mean residence time due to lower sedimentation rates and increased groundwater level, which is linked to higher sea levels during the marine isotope stage 3 (MIS3). After reservoir correction, Bayesian age-depth modelling was performed based on 53 reliable radiocarbon ages, achieving a high-resolution chronology of TY maar lake covering the past ~37 ka period with a mean age model uncertainty of 357 years, providing a reliable dating framework for paleoclimate reconstruction.

Acknowledgments

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A01 SESSION

MARINE RADIOCARBON RESERVOIR AGE SIMULATIONS FOR THE PAST 50000 YEARS REVISITED

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Abstract

Prior to about 14 ka BP, the IntCal20 radiocarbon (^{14}C) calibration curve is based on a combination of terrestrial and marine ^{14}C archives. To gain insight into the spatio-temporal evolution of the involved marine ^{14}C records and their systematic ^{14}C concentration differences from the atmosphere, IntCal20 has considered marine ^{14}C reservoir age (MRA) simulations of the LSG ocean general circulation model. The LSG model was not fully coupled to the atmosphere and did not include a prognostic sea ice component. Instead, it applied various stadial and interstadial climate boundary conditions to assess upper and lower bounds of past climate variations and the associated effects on past MRAs. Here, we present results of new long-term MRA simulations which overcome these limitations. We apply the Earth system model of intermediate complexity CLIMBER-X which we have equipped with $\Delta^{14}C$ and inert gas tracers. CLIMBER-X is forced with reconstructed insolation, greenhouse gas concentrations, and continental ice sheet thicknesses and bedrock topography. Atmospheric $\Delta^{14}C$ is either prescribed according to IntCal20 and SHCal20 or alternatively calculated from cosmogenic ^{14}C production data. While the new IntCal20 / SHCal20-driven simulations confirm some of the LSG model results at the global scale, there are considerable regional differences. For example, we find a weaker inhibition of marine $^{14}CO_2$ uptake in the presence of sea ice and hence lower polar MRAs than the LSG model. Furthermore, we find that meltwater discharge from continental ice sheets considerably affects the MRA history during the last deglaciation and that the model results strongly depend on the chosen ice sheet reconstruction. According to our results, at least one of these reconstructions can be questioned. Our ^{14}C-production-driven simulations help to disentangle the effects of climate and production onto the evolution of past MRAs and indicate that during the first phase of the last deglaciation and around the Laschamps excursion, the MRA development was dominated by ^{14}C production variations. In addition, our results suggest that around the Laschamps excursion the interhemispheric gradient of atmospheric $\Delta^{14}C$ could have been twice as high as previously assumed.

Acknowledgments

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A01 SESSION

CARBON DEPOSITION IN DEEP OCEANIC PERIDOTITE: RADIOCARBON CONSTRAINTS FROM A 1.3 KM BOREHOLE

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Abstract

The mineral carbonation of mantle peridotite acts as a sink of CO_2 over geologic time and is now being explored as an engineered solution for long-term carbon storage. Radiocarbon (^{14}C) dating of carbonate deposited in peridotites has provided critical constraints on the rates of natural mineral carbonation and dissolution, the timing of deposition events, and carbon fluxes over short term and geologic timescales. A 1268-m-deep borehole (International Ocean Discovery Program Hole U1601C) was drilled in 2023 on the Atlantis Massif (30°N, 42°N) into serpentinized peridotite and altered gabbro (Lissenberg et al., 2024). The recovered samples provide the first direct data on the carbon abundances and radiocarbon content of oceanic peridotite beyond depths of (near-)seafloor weathering, previously available only for samples shallower than 200 mbsf. Total carbon abundances match predictions well, but our radiocarbon data reveal some unexpected results: carbonates deposited at depths from 650 – 1100 mbsf have younger radiocarbon ages than those from 30 – 650 mbsf. While counterintuitive, these data are consistent with the understanding that hydrothermal focused flow occurs 1 – 3 km below the seafloor, and would introduce a continuous flux of downwelling seawater carrying modern carbon. A major change in lithology occurs at 640 mbsf that could facilitate increased fluid flow below this depth. These findings underscore the effectiveness of ^{14}C in tracking carbon mass transfer beneath the seafloor.

Expedition 399 Science Party: Andrew M. McCaig, Susan Q. Lang, Peter Blum, Natsue Abe, William J. Brazelton, Rémi Coltat , Jeremy R. Deans, Kristin L. Dickerson, Marguerite Godard, Barbara E. John, Frieder Klein, Rebecca Kuehn, Kuan-Yu Lin, C. Johan Lissenberg, Haiyang Liu, Ethan L. Lopes, Toshio Nozaka, Andrew J. Parsons, Vamdev Pathak, Mark K. Reagan, Jordyn A. Robare, Ivan P. Savov, Esther M. Schwarzenbach, Olivier J. Sissmann, Gordon Southam, Fengping Wang, C. Geoffrey Wheat

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A02 SESSION

VEGETATION AND HYDROLOGICAL CHANGES RECORDED IN THE KOTOŃ FEN DEPOSITS (THE OUTER WESTERN CARPATHIANS, S POLAND) DURING CA. 14,600–13,500 CAL BP AND THEIR EXTRAREGIONAL CONTEXT

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Abstract

In this paper we present a new multi-proxy results obtained from the Kotoń landslide fen deposits (the Beskid Makowski Mountains, the Outer Western Carpathians, S Poland), including plant macrofossil analysis, radiocarbon dating and loss on ignition analysis. The aim of the study was to reconstruct past local vegetation, palaeohydrological and palaeoclimatic changes during the climatic oscillations of the Bølling, Older Dryas and the beginning of Allerød (500–300 cm depth interval of the current Kotoń sediment profile). Furthermore, a reliable absolute chronology enabled us to compare the local palaeoecological stages of the Kotoń fen development with the Greenland ice cores event stratigraphy (Rasmussen et al. 2014), especially during the short GI-1d climate cooling occurring 13,904–14,025 yr BP, corresponding to the Older Dryas.

Results showed that four palaeoecological stages of development can be distinguished for the Kotoń sediment sequence in a period ca. 14,600–13,500 cal BP. Stage KT-1 (from ca. 14,240 ± 103 to > ca. 14,070 ± 72 cal BP, > ca. 170 years; corresponding to the GI-1e/Bølling and possibly the GS-2/Oldest Dryas) was characterized by the development of a poor-in-vegetation waterbody surrounded by the open-space landscape which presumably resulted from the local landslide conditions and/or cold climate. Stage KT-2 (from ca. 14,070 ± 72 to ca. 13,900 ± 56 cal BP, >ca. 170 years, corresponding to the GI-1d/ Older Dryas) was represented by a gyttja-like deposits of a shallow waterbody in which aquatic organisms succession progressed. Aquatic vegetation of the KT-2 stage was dominated by Characeae meadows, *Sarmentypnum trichophyllum* and sedges, whereas in the vicinity the arctic/alpine flora developed suggesting steppe-tundra conditions. Moreover, a presence of mosses species *Hygrohypnum ochraceum* and *Hygrohypnum molle* s. lat. implies the stony stream inflow to the KT-2 waterbody. Stage KT-3 (from ca. 13,900 ± 56 to ca. 13,820 ± 68 cal BP, ca. 80 years; the transition from the GI-1d/Older Dryas to GI-1c/Allerød) documented further waterbody overgrowing as a result of natural autogenic succession and a transition into (calcareous) extremely rich fen (Hájek et al. 2006) inhabited by calciphilous Bryopsida species. Moss composition is dominated by *Calliergon giganteum* (up to 90% of the total Bryopsida abundance) which at some depths of the sequence withdrew at the expense of the other calciphilous species: *Philonotis calcarea* and *Palustriella decipiens*. Stage KT-4 (from ca. 13,820 ± 68 to ca. 13,500 ± 115, ca. 320 years; corresponding to GI-1c/ Allerød) documented the birch-pine boreal forest development in the Kotoń fen surrounding caused by climate warming. Locally within the fen, *Calliergon giganteum* becomes replaced by acidophilus *Sarmentypnum exanullatum* (up to 100% of Bryopsida abundance), which presence may suggest the transition of the Kotoń mire towards the moderately rich fen. This change could result from the natural autogenic succession and increasing

thickness of the moss fen peat deposits which, in turn, could block access to the calcium-rich groundwater.

Palaeoecological stages of development determined for the Kotoń landslide fen deposits between ca. 14,600–13,500 cal BP are in agreement with the earlier pollen-based chronozones of the Kotoń deposits (Margielewski et al. 2003) and with the extraregional chronology of the Greenland ice cores. Despite the fact that influence of GI-1d (the Older Dryas) climate cooling on the regional vegetation was recognized (steppe-tundra) for the Kotoń KT-2 deposits, in case of local vegetation and palaeohydrological changes more detail multi-proxy research is necessary to clarify whether the process of the waterbody shallowing is affected only the local autogenic vegetation succession or partly also by climate change. Nevertheless, based on the Kotoń absolute chronology correlation with NGRIP, Kotoń landslide fen can be considered as a unique and rare locality with the GI-1d (the Older Dryas) deposits not only in a scale of the Carpathians and Poland but also in the scale of Europe, contributing to the better understanding of the short climatic oscillations occurring throughout the late glacial period.

Acknowledgments

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A02 SESSION

ECOSYSTEM ENGINEERS OF THE KAROO: HOW BUSH KAROO RATS SHAPE SOIL PROPERTIES AND CARBON STORAGE

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Abstract

As part of the SMEEB and COBESOLI projects [1] aiming to deepen our understanding of ecosystem functioning in the Succulent Karoo biodiversity hotspot in South Africa, we investigated the impact of Bush Karoo rats (*Otomys unisulcatus*) on soil health and functioning. These small mammals build extensive stick lodges up to 70cm high and 2.5m wide, by collecting plant material and animal dung in their surroundings. These lodges are built inside shrubs of different species and can be several decades old. By foraging, Bush Karoo rats reduce the abundance of dominant plant species around their extensive stick lodges, creating space for other species to thrive and thus promoting plant biodiversity. While this ecological role is well documented, their influence in soil properties remains poorly understood.

To explore how Busk Karoo rat lodges affect soil characteristics, we collected paired soil cores under (abandoned and occupied) lodges as well as under controls shrubs without lodges, for different shrub species. Additionally, we collected sample as reference cores from unvegetated areas. The Succulent Karoo Research Station [2], which monitored the field site for 24 years, provided data on lodge occupancy and abandonment. We present initial findings on soil physical properties (texture, grain size distribution, colour, odour, bulk density) and geochemical signatures (C, N content and $\delta^{13}C$, $\delta^{15}N$, ^{14}C).

Our preliminary results suggest a potential increase in soil carbon stock linked to lodge presence. We aim to determine the underlying mechanisms – whether through enhanced organic matter input, greater organic molecules recalcitrance, and / or improved soil organic carbon preservation. Additionally, we seek to rank key factors (soil physical characteristics, vegetation type, lodge occupation duration) influencing the extent of this effect.

This study sheds new light on the role of small mammal ecosystem engineers in semi-arid environments and their contribution to soil carbon dynamics in a plant biodiversity hotspot threatened by overgrazing, erosion leading to soil degradation, biodiversity loss and global climatic change.

Acknowledgments

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[2] https://www.stripedmouse.com/

A02 SESSION

RADIOCARBON DATING OF THE XIAWANGDU NEOLITHIC SITE IN THE LOWER YANGTZE REGION AND ITS IMPLICATIONS FOR HUMAN-ENVIRONMENT INTERACTION

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Abstract

The lower Yangtze region in China, with varied coastal environments and a flourishing Neolithic culture, was one of the major rice domestication centers in Asia. Sedentary societies occupied the Lower Yangtze in the eastern coastal regions of China at the beginning of the Holocene. In present day China, the region is highly developed, densely populated, and is commonly referred to as "the land of fish and rice." Environmental changes, such as climate, vegetation, and sea-level rise, play major roles in supporting sustainable development. A detailed radiocarbon dating of the Neolithic sites is critical to understand the relationship between the process of domestication and climate variability and sea-level rise. And, furthermore, help to accurate predict future climate change impacts, including recent global warming and on-going sea-level rise, thereby benefitting societies and their economies. Here we present the results of 36 radiocarbon datings (including TOC, pollen concentration, seeds and wood) and 24 grain-size analyses from Xiawangdu neolithic site in the Ningshao Plain, southern part of the lower Yangtze which including both Hemudu and Liangzhu cultural stages. The results show that Xiawangdu site was occupied 6300 cal. yr BP before and the Liangzhu culture began at about 5200 cal. yr BP. Radiocarbon dating of TOC and pollen concentration are usually older than the actual stratigraphic age because of participation of organic matter from source areas. The rise and fall of cultures are closely linked to changes in sea level and the processes of land-sea interaction under the context of global climate change.

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A02 SESSION

CORRELATING TRANSPORTED AND SEQUESTERED ORGANIC CARBON PROVENANCE AND AGE IN AOTEAROA NEW ZEALAND USING GEOCHEMICAL AND RADIOCARBON METHODS

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Abstract

In coastal marine sediments, lateral transport and burial of organic matter are critical components to controlling release or sequestration of carbon in the environment. Principal sources of carbon sequestered in coastal marine sediments include primary productivity in the water column, lateral transport of resuspended matter, and eroded terrestrial organic matter. As a result of earthquake-driven landslides, heavy rainfall, gullying, and mass wasting processes, land-derived material composed of a mixture of modern plant debris, soil mixtures of composite ages, and ancient rock sediment is a significant source of carbon transported and sequestered in the coastal waters of New Zealand. Characterisation of organic carbon under different depositional conditions allows us to gain insight into the processes that drive transport and sequestration of carbon into the sediment.

We have applied combinations of ramped pyrolysis oxidation radiocarbon (RPO-AMS), lipid biomarker, pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS), and compound specific radiocarbon (CSRA) analysis methods to develop a chemical composition fingerprint to track carbon transport and burial in coastal New Zealand environments. Biomarkers and CSRA isolate individual compounds to inform the age, provenance, and chemical composition of the sequestered carbon, providing specific, detailed information about a few compounds in the sediment matrix. RPO-AMS and Py-GC-MS complement this by partitioning carbon thermochemically, determining the age profile and stability of all pyrolysable compound classes present in the sediment, giving a more holistic representation of the sequestered carbon.

These techniques have been utilised to characterise two distinct transport and sequestration regimes in New Zealand. First, we have investigated the sedimentary response to a natural hazard event via the Kaikōura Canyon-Hikurangi Margin submarine canyon-channel system. Specifically, we have traced the 2016 Kaikōura earthquake canyon flushing event that mobilised and sequestered substantial terrestrial carbon >1300 km offshore. Second, we have applied these techniques to understand conventional transport and sequestration occurring in the steep, friable geologic structure of the New Zealand fjords, specifically Tamatea/Dusky Sound, Patea/Doubtful Sound, and Isthmus Sound within Rakituma/Preservation Inlet, which generate high sedimentation rates and resultant high carbon burial rates. Characterisation of these two sedimentation regimes, which account for a significant amount of transported and sequestered terrestrial carbon, can be used to refine the New Zealand carbon budget.

A02 SESSION

WHAT IS SWITZERLAND'S (RADIO)CARBON FOOTPRINT?

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Abstract

Improved constraints on carbon exchange between atmospheric, terrestrial and aquatic systems are needed to reduce uncertainty in predicting future perturbations to the global carbon cycle and associated climate change. Radiocarbon is a powerful tool for studying the carbon cycle due to its ~5700-year half-life that sheds light on processes occurring on centennial to millenial timescales, as well as the ^{14}C "bomb spike" resulting from above-ground nuclear weapons testing in the mid-20th Century that serves as a tracer of carbon flow among more rapidly cycling pools. The "Radiocarbon Inventories of Switzerland" ("RICH") project is a collaborative initiative that involves a first-of-its-kind, national-scale ^{14}C survey spanning all major carbon pools and encompassing the major river drainage basins and the five different Swiss ecoregions. The goal of the project was to acquire a comprehensive "snapshot" of ^{14}C measurements for carbon species in the atmosphere, soils and the hydrophere (e.g., ^{14}C in atmospheric and soil-derived gas samples, ^{14}C in bulk samples and different sub-fractions of soil, water and sediment samples), and to develop historical context through ^{14}C analysis of natural archives and of archived samples spanning the pre-bomb era to the present. The extensive suite of ^{14}C data (> 4000 new measurements) are used to study various carbon cycle processes, including turnover rates of different soil carbon fractions, transit times among carbon reservoirs, budgets of riverine carbon, and anthropogenic emissions of CO_2 and CH_4. This presentation will outline the objectives of the RICH project and will provide illustrations of key insights that have emerged from this collaborative undertaking. We highlight how the interplay between geomorphic properties, climate and land use influences carbon cycling within watersheds and among ecoregions. We show that carbon storage and turnover in soils plays a pivotal role in modulating carbon cycling on broader scales. In particular, we find that mineral association has a pervasive influence on organic matter stability and sequestration throughout the terrestrial-aquatic continuum. We focus on the role of different reservoirs and ecosystems as carbon sources or sinks, and on the extent to which radiocarbon measurements can be used to identify vulnerable carbon pools in the context of environmental change. The project structure is envisioned to serve as template that can be adapted in carbon cycle studies on regional to global scales.

A02 SESSION

PRESENTING THE RADIOCARBON INVENTORIES OF SWITZERLAND DATABASE: CONNECTING ATMOSPHERE, LAND AND WATER ON A NATIONAL SCALE

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Abstract

Radiocarbon (^{14}C) analysis is a powerful tool for tracking carbon fluxes and storage in natural ecosystems over decadal to millennial timescales. However, ^{14}C studies in environmental sciences often focus on specific carbon reservoirs or processes and their data are hosted on fragmented or field-specific databases, limiting insights into cross-ecosystem interactions. To address this gap and in light of an emerging focus on land–water–atmosphere connections, we present RICH-db (Radiocarbon Inventories of Switzerland Database), the first comprehensive national ^{14}C database. RICH-db integrates monitoring data across Switzerland's diverse climates and land uses, encompassing major carbon reservoirs and fluxes: from the atmosphere (CO_2, CH_4) and terrestrial ecosystems (leaves, wood, roots, soil density fractions, soil respiration) to aquatic systems (groundwater, rivers, lakes, sediments), as well as anthropogenic sources (urban and industrial CO_2 emissions, ^{14}C emissions from nuclear power plants). The dataset comprises over 4,000 ^{14}C measurements alongside extensive data on stable carbon isotopes ($\delta^{13}C$), carbon-to-nitrogen ratios (C/N), dissolved ions and other key parameters. A Python-based interface enables seamless integration into modeling and analytical workflows. By providing a comprehensive, unified and accessible national-level database, we aim to promote cross-disciplinary applications of ^{14}C in environmental sciences and advance research on carbon cycle dynamics spanning different reservoirs of the Earth system.

Acknowledgments

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A02 SESSION

PYROGENIC CARBON DYNAMICS IN TROPICAL SAVANNAH SOILS: RADIOCARBON EVIDENCE FROM A FREQUENTLY BURNED LANDSCAPE IN LOPÉ NATIONAL PARK, GABON

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Abstract

Pyrogenic carbon (PyC) is formed during the incomplete combustion of biomass, resulting in a polyaromatic structure, and increased chemical resistance, compared to the starting biomass. PyC is one of the most persistent forms of organic carbon, with estimated turnover times of up to several thousand years (e.g. Preston and Schmidt, 2006; Bowring et al., 2022). PyC clearly plays a key role in carbon biogeochemical cycling, but its formation, turnover, and persistence remain poorly constrained in several important areas. Among these are tropical grasslands, which represent the largest annually burned area worldwide, due to both wildfires and the use of fire as an important land management tool, aiming to protect and promote biodiversity. With the bulk of all fires occurring on the African continent, the majority of which are in tropical grasslands, it is remarkable how little is known about soil C pools, including PyC stocks, and turnover in these ecosystems.

Radiocarbon is a critical tool for understanding the dynamics of PyC within landscapes, particularly regarding its persistence and transport times, including vertical and lateral movement. Radiocarbon also provides a means to distinguish between PyC derived from recent burning events and legacy carbon from past fires over much longer timescales. However, applying ^{14}C to study PyC dynamics also presents several important challenges, including reliably isolating PyC from bulk soil samples, and accurately interpreting measurements representing a weighted average of multiple individual burning events.

Here we present results from work conducted as part of the SPECTRAL (Stabilisation of pyrogenic carbon in tropical grasslands) project led by the University of Stirling. The project was designed to investigate PyC dynamics in the tropical savannah soils of Lopé National Park, Gabon. This region has been subject to managed burning for several decades (Jeffery et al, 2014), affording an excellent opportunity to investigate the role of fire frequency, slope position, depth, and starting material (C3 versus C4 plants) upon PyC abundance and age. Seven sites were sampled using a split-plot, nested design incorporating burn frequency (high vs. low), two slope positions, and depth intervals down to 75 cm. Hydropyrolysis (HyPy) was used to isolate and quantify PyC from soils at the sampling sites, followed by radiocarbon dating of the PyC itself. The findings highlight the complex interactions between fire regime, topography, soil processes, and legacy PyC in tropical savannah soils. We also consider the advantages and limitations of applying ^{14}C to questions of PyC stability in soil systems and suggest potential ways forward in this area.

Acknowledgments

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A02 SESSION

THE MIDDLE-LATE PLEISTOCENE HISTORY OF THE BROWN BEAR *URSUS ARCTOS* LINNAEUS, 1758 IN POLAND

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Abstract

During the Late Pleistocene (MIS 5e-2), the brown bear Ursus arctos was widespread in Poland. From this time interval, the species was recorded in 337 localities, including 42 open-air and 295 cave sites. A total of 88 radiocarbon dates obtained from the material showed the presence of the species in this territory 46–12.6 kya ago during the Late Pleistocene. Most of the dates are concentrated between 45.7 and 29.3 kya, with 12 dates confirmed the presence of U. arctos just before and during the LGM. Even during the coolest part of the GS-2.1b interval (about 20.9–19.0 kya), the species was recorded in the territory of Poland. A large, broad-toothed, highly carnivorous Ursus arctos taubachensis adapted to live in open grasslands occurred during the Late Pleistocene, while Ursus arctos arctos was rarely recorded from that period. The post-LGM time (17.5–14.7 kya) was characterised by increasing numbers of brown bear dates on the territory of Poland. It was also a period of progressive afforestation and the disappearance of Ursus arctos taubachensis. The latest occurrence of this ecomorph in the territory of the Poland was represented by a robust specimen from the Solna Jama Cave, dated at 15.4–14.9 kya.

Keywords: occurrence; Late Pleistocene; Poland; radiocarbon; ecomorph

A02 SESSION

RADIOCARBON AGE OF SUPRAGLACIAL ORGANOMINERAL FORMATIONS FROM ANTARCTICA TO ARCTICA

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Abstract

In the 21st century, glaciers are perceived as a distinct biome that has taken on special significance in modern climate change and widespread glacial retreat (Mergelov et al., 2023). Supraglacial organomineral formations during glacier melting are involved in the process of soil formation and have a significant impact on the periglacial zone

During more than 10 years of work on different glaciers from Antarctica to the Arctic, unique material of organomineral formations has been collected and analyzed. Investigating the ^{14}C age and properties of organic matter has been one of the most important tasks of our research. As part of our research, we considered supraglacial organo-mineral formations as objects of soil science, with special attention to the formation of soils and soil-like bodies in the supraglacial zone of glaciers. The biogeochemical processes occurring in them have a great influence on the glacial biome and surrounding landscapes, which determines the relevance of such studies. The main object for radiocarbon dating in our research was the cryoconites, which are the most important product of organomineral interactions on the glacier (Rozwalak et all., 2022).

Various supraglacial organomineral formations may contain from a few to tens of percent (or more) of organic C of different genesis. We obtained more than 200 ^{14}C dates, as well as organic matter (OM) characteristics for supraglacial systems in the High Latitudes (East Antarctica, Svalbard Archipelago, Franz Josef Land) and for mountain glaciers of the Caucasus, Altai, Polar Urals and Kamchatka. The radiocarbon ages for different types of supraglacial formations vary from modern to 10,000 ^{14}C year BP and more. Despite the presence of a large number of primary producers in the supraglacial zone, radiocarbon ages determined from total organic C are often found to be ancient. An attempt is made to identify the sources of "old carbon" on the surface of the studied glaciers: it can be aerosols formed during fuel combustion or ancient sedimentary and metamorphic rocks and/or aerially introduced soil material of Holocene or more age. ^{14}C ages are not the same in different fractions of supraglacial material. Separation of cryoconite OM by densitometric fractions showed that the oldest OM was contained in the fractions associated with the organo-mineral complex and absorbed on the mineral matrix. Thus, with a variety of sources and compositions of OM, the interpretation of the measured radiocarbon age of supraglacial material is complicated. Moreover, in supraglacial systems, as in other nonequilibrium systems, organic C pools have different turnover rates. The radiocarbon age and OM properties of supraglacial systems allow us to use this data for a fundamental understanding of the evolution of the Earth's ecosystems, including under changing climate conditions.

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A02 SESSION

DATED SPELEOTHEMS AND DEPOSITS OF THE GRAVITY INDUCED CAVES AND THEIR RELATION TO HYDROLOGICAL CHANGES DURING THE LATE GLACIAL AND HOLOCENE; POLISH FLYSCH CARPATHIANS CASE STUDY

Włodzimierz Margielewski[1], Jan Urban[1], Valentina Zernitskaya[2], Karel Žák[3], Marzena Schejbal-Chwastek[4], Katarzyna Korzeń[5], Artur Górecki[6]

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Abstract

In the Polish Flysch Carpathians, built of flysch rocks, over than 1500 gravity induced (non karst) caves have been recorded up till now (see: Margielewski, Urban, 2017). Since these caves are usually the initial forms of mass movements, it is important to determine the time of their formation and transformations. Among the secondary mineralogical formations (speleothems) occurring in some of these caves, calcite and organic speleothems were formed due to the dissolution of the carbonate sandstone cement in which the caves developed. Dating of these speleothems using the ^{14}C method (both: LSC and AMS) allows us to determine the time of formation of the caves (Margielewski, Urban, 2017). Some of the carbonate speleothems are also characterized by lamination: laminas (from several tens of a milimetre to a few millimetres thick) are built of crystalline calcite of a columnar structure (Urban et al., 2015). In some speleothems, particular section of laminas show a change in the direction of growth: from concentric to eccentric. This is caused by the change in water flow due to the rotation and gravitational displacement of the blocks that form the rock structure hosting the cave. So far, the authors have carried out 34 radiocarbon dates determining the beginning of the formation of speleothems and the time of changes in the growth of laminae in these speleothems from concentric to eccentric (Urban, Margielewski, 2015; Margielewski, Urban, 2017). Another source of data determining the time of cave formation are sediments in several caves, whose formation was related to the intensive flow of water through the caves. In the Jaskinia Miecharska Cave (Beskid Śląski Mts.), the alluvial deposits (mainly sandy silts) were dated using the radiocarbon method and a full palynological profile of this sediments with a thickness of 0.75 m was analysed, which indicated that the sediments was formed approx. 1000 years ago. The pollen record does not differ from the record in surface sediments, as found in the nearby peat bog. Consequently, in order to determine the pollen source and circulation in the underground depositional environment (and atmosphere), we have observed "palynology" (palynological composition) of fluid (glycerine) in the special pollen catchers installed in the Jaskinia Miecharska Cave. Analysis of pollen fall carried out in the cave over the last 5 years (every year material from two catchers were analysed) has shown an aeolian origin of the pollen, delivered from the surface through numerous rock openings (crevices). This is interesting because plant pollen has also been found in cave speleothems, both in organic dripstones from the Beskid Śląski Mts. and in carbonate dripstones

from the Beskid Niski Mts. The palynological analysis of the pollen record in individual segments of laminated carbonate speleothems allowed for determining the time of their formation stages and for verifying absolute dating. It was helpful in the assessment of so-called reservoir effect – estimated by us at ca. 1350 years – whose value is important for determining the proper time of carbonate speleothem formation (Urban et al., 2015; Margielewski, Urban, 2017). Numerous U/Th datings of speleothems were carried out, which turned out to be incorrect (they were usually much older than the ^{14}C datings of the same parts of speleothems), which was caused by the low uranium content and the significant content of detrital thorium in the samples as well as calcite recrystallisation (Urban et al., 2015).

Dating of the speleothems shows that the gravity induced caves are forms that have formed at different stages of development (disintegration) of rock massifs and could have developed for a very long time. The oldest of the dated speleothems were formed in the Late Glacial (Margielewski, Urban, 2017). The probability density curve of the dates of the beginning of speleothem formation shows the relationship between the development of these forms and the following phases of climate humidity growth during the Late Glacial and the Holocene: Allerød Interstadial, Preboreal Phase, Boreal/Atlantic transition, during the Holocene climatic optimum (Atlantic), beginning of Subboreal, and at the Subboreal/Subatlantic transition, as well as in the Little Ice Epoch (Margielewski, Urban, 2017). Similarly, the transition of laminas growth in speleothems from concentric to eccentric are well correlated with the phases of climate humidity growth in the Holocene. Also, the onset of alluvial formation was associated with the climate moisture during the Little Ice Eppoch (Margielewski, Urban, 2017).

The dating the beginning of speleothems formation, the time of transition of speleothem lamination from concentric to eccentric, or the time of caves' alluvial deposit formation using the ^{14}C method significantly complements the database of dated mass movements and enables a more complete reconstruction of the phases of mass movement intensification, previously distinguished in the Carpathians based on radiocarbon dates (Starkel et al., 2013; Pánek et al., 2013).

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A02 SESSION

DYNAMICS OF CAVE SEDIMENT FORMATION PROCESSES DURING THE LAST GLACIAL CYCLE USING THE EXAMPLE OF BAROVÁ CAVE, MORAVIAN KARST

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Abstract

The last climatic cycle is studied in the terrestrial environment usually from loess and in the context of palaeoenvironments or palaeolithic settlements. Formation processes are most commonly dated using optically stimulated luminescence (OSL) or ^{14}C dating. The karst environments usually have an absence of loess. On the contrary, however, cave entrances may serve as sedimentary traps. OLS is not effective in the distal parts of the caves where illumination during the formation process is absent. The chronology of such situations has to be solved mainly due to sedimentary analysis or up to the limit of radiocarbon dating. Radiometric dating ^{14}C and U-Th coupled with analysis of the formation processes of the sedimentary record indicates that the intensive clearing of Barová Cave took place at least at the end of the last interglacial, in MIS4 and early MIS3. During the period ca. 55-36 kyr BP, i.e. during the primary period of MIS3, relatively slow sedimentation occurred into the open space in the cave, which was created over the underlying sediments by the previous clearance. The sedimentary record consists almost exclusively of osteological material that shows signs of corrosion, including collagen depletion. This layer of osteological material is overlain by relatively thick clayey sediments, again with a number of animal bones dated consistently to MIS3, representing a rapid erosional phase. This erosional phase can probably be related to the transition between MIS3 - MIS2. MIS2 itself, or the transition between the LGM and the Holocene, is represented in the cave record by redeposited loess with signs of freezing. The beginning of the Holocene is represented by a continuous layer of sinter. The combination of ^{14}C, U-Th, and sedimentological and micromorphological analysis has proven to be an effective approach for interpreting the formation record of the site and its relationship to climatic changes during the last climatic cycle.

A02 SESSION

TRACING HONEY CARBON SOURCES WITH RADIOCARBON ANALYSIS

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Abstract

Research on honey has been ongoing at the Hungarian Nuclear Research Institute for more than 5 years. In addition to elemental composition measurements, the AMS ^{14}C technique is utilised for the purpose of detecting carbon sources in contemporary honeys. The initial studies focused on the most prevalent Hungarian honey species, namely acacia honey (Varga et al., 2020), with subsequent research extending to rapeseed, sunflower, and forest honeys (Sajtos et al., 2022). In contrast to acacia honey radiocarbon results, significant offsets from expected atmospheric radiocarbon values were found in the other honey types. Significant difference was observed, that means more than 1-2 years, even more than 10-years offset compared to the expected values. In order to investigate this phenomenon in more depth, US honeys from a larger area were obtained, where similar results, radiocarbon ages were documented (Varga et al., 2024). In this US honey study, we also found the contribution of aged carbon sources to honeys throughout the east coast of the USA. We extended our research with targeted nectar sampling, collecting individual samples from linden, acacia, apple, sunflower and rapeseed flowers, whose $^{14}C/^{12}C$ AMS measurements further confirmed the results of our previous studies, as nectar samples also showed a significantly older age than expected. Our research shows that a significant amount of old carbon can contribute to fresh honey, presumably from the stored non-structural carbon of trees and also from the carbon content of the soil. The presented results demonstrate the diverse role of plant liquids, particularly nectar or honey as a bee product, in the complex biogeochemical cycle. They also highlight how easily soil-related organic materials or aged plant liquids can enter the food chain unnoticed.

Acknowledgments

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A02 SESSION

DETERMINATION OF THE ORIGIN OF THE PEAT BOGS OF THE ŚNIEŻNIK MASSIF (SW POLAND, N CZECH REPUBLIC) AND THE BEGINNING OF THEIR DEVELOPMENT BASED ON RADIOCARBON AGE DETERMINATIONS

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Abstract

The Śnieżnik Massif is an area of several mountain peat bogs located at various altitudes, from about 1320 m above sea level (soligenic peat bog under Mały Śnieżnik) to about 820-810 m above sea level (Biała Woda peat bog). Most of them lie on the ridges or in the sub-peak areas of the Śnieżnik Massif. All of them are very valuable ecosystems and deserve protection. In 2023, the Sadzonki peat bog was placed under reserve protection, including it in the Śnieżnik Kłodzki reserve. In 2022-2023, an international team undertook preliminary interdisciplinary geological, geobotanical and chronostratigraphic studies aimed at reconstructing the development of raised and transitional peat bogs in the Śnieżnik Massif. These peat bogs have been studied to varying degrees in the past. One of the best studied is the Sadzonki peat bog. The others were only recognized botanically, and only a few were paleobotanically. In all the studied peat bogs, peat cores were taken and preliminary georadar studies were performed.

Samples were taken from the examined cores and sent for radiocarbon dating at three radiocarbon

laboratories: the Poznań Radiocarbon Laboratory, the ^{14}C and Mass Spectrometry Laboratory of the Silesian University of Technology and the Laboratory of Absolute Dating in Kraków. We obtained the following dates from the floor of the examined peat bogs: Nad chatou Ludmilou 4597 ± 33 (GdA-7305.3.1); Mokrý Hřbet 4462 ± 166 (CU-468); Stříbrnická saddle 2635 ± 30 (Poz-22135); Sadzonki 3 2470 ± 90 (QU-484); Sadzonki 2 1745 ± 30 BP (Poz-163144); Sadzonki 1 1710 ± 90 (MKL-4054); Under Little Śnieżnik MS1 2066 ± 26 (GdA-7302.2.1); Soligenic under Little Śnieżnik SMS 1787 ± 28 (GdA-7304.1.2.); Under Little Śnieżnik MS2A 1295 ± 25 (GdA-7303.3.1); Under Sušinou 1069 ± 29 (GdA- 7306.2.1).

The obtained results were compared with all previously published dating results of peat bogs in the Sudetes. The results of our studies clearly indicate a relatively younger age of the peat bogs in the Śnieżnik Massif in comparison with other peat bogs in the Sudetes (Dumanowski et al. 1962; Pazdur et al. 1985; Wicik 1986; Hűttemann, & Bortenschlager 1987; Kuszell, 1988; Marek, 1988; Chmal & Traczyk, 1997; Malkiewicz et al. 2016; Kuneš & Jankovská 2000; Speranza et al. 2000; Svobodová 2002, 2004; Baranowska-Kącka 2003; Brej 2004; Madeyska, 2005; Skrzypek et al. 2005; Traczyk et al. 2008; Dudová et al. 2010, 2012; 2014; Novák et al. 2010; Dudová 2016; Glina et al. 2017; Fiałkiewicz-Kozieł et al. 2022). The oldest come from the Atlantic and are no more than 5,000 years old. The next few dates associated with the Sadzonki peat bog cover the period from 2635 to 1710 BP (Subboreal/Subatlantyk). A similar period is represented by the Pod Małym Śnieżnikiem MS1 peat bog. The age of the youngest ones is from 1787-1069 BP (Subatlantyk). We suggest that their development was related to the improvement of thermal conditions in Central Europe (Torbenson et al. 2023).

The analyses performed show a statistically significant relationship indicating that younger peat bogs dominate at higher altitudes. It is likely that in the ridge zones, the covers of older peats were destroyed during periods of greater intensity of denudation processes - related either to a greater frequency of heavy rainfall or to a greater intensity of nival processes. In some cases, e.g. on the Równia pod Śnieżką (profiles S1 and S2), exploitation of peat bogs was possible.

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EXPANDING THE INTERNAL ERROR WITH NON-POISSON STATISTICS AND THE ^{12}C CURRENT NOISE

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Abstract

The Poisson distribution has been a fundamental principle for estimating the relative standard error of the ^{14}C count rates as $1/\sqrt{N_T}$ (internal error), which provides a straightforward formula for quickly estimating the uncertainty of the sample. It is also used to calculate the quoted error after propagating other uncertainties from the standards and the $\delta^{13}C$. In this work, we have re-evalauted a 2.5-year-long data record to quantify non-Poisson results by fitting models to the ^{12}C and ^{14}C data. The non-Poisson internal error of the count rates was calculated as $D/\sqrt{N_T}$, where $D \geq 1$ is an overdispersion parameter derived from a non-Poisson model. Additionally, the ^{12}C relative standard error was calculated from the signal noise to ascertain if the magnitude was significant. The novelty of this work lies in the incorporation of a non-Poisson perspective into the counting statistics and the ^{12}C noise, with the aim of obtaining a more accurate internal error.

From replicated measurements (Scott et al. 2007), it is established that the traditionally quoted errors are often underestimations due to unknown uncertainties. The aim of this work is to quantify the number of non-Poisson results in our data to conceptually demonstrate that, because the non-Poisson internal error is greater than the traditional method, a portion of the unknown uncertainties can be attributed to non-Poisson counting.

The non-Poisson method involved fitting a cubic spline to the ^{12}C current data from the first pass and then proportionately scaling the ^{12}C model into the ^{14}C count rate data. The fitting was optimised by adjusting the smoothness parameter of the spline to minimise the log-likelihood of the Akaike Information Criterion. This process was repeated for each pass, with each pass having its own model. The quasi-Poisson overdispersion, denoted as φ_{qp}, was calculated from the Pearson χ^2 of the ^{14}C count rate data and model. The quasi-Poisson dispersion D was equivalent to $\sqrt{\varphi_{qp}}$. The same Pearson χ^2 was employed to transform the expected ^{14}C count rate non-stationarity into stationary data. Non-stationarity occurs when the expected rate is not constant across the passes but behaves like a moving average. The negative binomial, another non-Poisson model, was applied to the stationary data to infer the parameter φ_{NB}, with its dispersion D defined as $\sqrt{(1+\varphi_{NB})}$. While these methods are not novel within the field of statistics, they are computationally demanding. Computer simulations were conducted to emulate the AMS machine counting process, beginning with an arbitrary function for the ^{12}C signal that mirrors the empirical behaviour. These simulations were essential for elucidating some empirical findings.

The empirical results and simulations demonstrated that the ^{12}C standard error was significantly lower compared to the Poisson and non-Poisson counting errors. Thus, there was no need to propagate the ^{12}C noise to the counting error. The simulations of D input–D output plots assisted us in determining whether a particular dispersion D fell into a category of slightly non-Poisson or strongly non-Poisson results by inferring the uncertainty of measuring D (σ_D=0.05) from those plots. Poisson results were identified in the range of D between 1 and 1.05 (1 to $1+\sigma_D$), as theoretically D=1 represents pure Poisson behaviour. Slightly and strongly non-Poisson results were classified within the ranges of 1.05-1.2 ($1+\sigma_D$ to $1+4\sigma_D$) and greater than 1.2 ($>1+4\sigma_D$), respectively. The analysis of over two years of empirical data from samples and reference materials (n=7985) revealed that the majority of the results (63 %) exhibited

Poisson characteristics, 34.2 % were slightly non-Poisson, and only 2.8 % demonstrated strongly non-Poisson characteristics. The ^{12}C uncertainty varied between 0 % and 0.15 %, which was insufficient to influence the external error of most ^{14}C samples.

Our method for checking the accuracy of the non-Poisson internal error was to compare it with the external error from a χ^2 distribution perspective. The external error was calculated with the $\delta^{13}C$-corrected ratios The squared quotient of the external to internal errors gives the ratio Q and the distribution of Q values should conform to a reduced χ^2 distribution where most of the data ought to exhibit a Q close to 1 (indicating that internal and external errors are similar). However, there remains a proportion of the data with Q ratios significantly different from 1 within the chi-squared confidence intervals, where counting statistics still apply. We found that the Q distribution for the non-Poisson internal error was somewhat better than the Q distribution calculated with Poisson internal errors.

In conclusion, we observed a significant number of non-Poisson results in our operations, which challenges the traditional assumption that radiocarbon AMS counting statistics follow a Poisson distribution. Given the small magnitude of ^{12}C noise, it is unnecessary to propagate it with the ^{14}C counting statistics. As the counting statistics are usually used to calculate the quoted error and the quoted error is used to calculate expansion parameters to account for unknown uncertainties affecting replication, intercomparison and long-term studies, and even radiocarbon calibration curves then, conceptually, the usage of non-Poisson internal errors should reduce the magnitude of the expansion parameters helping to close the gap of the unknown components.

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A05 SESSION

DATING VERY OLD CARBONATE SAMPLES WITH ON-LINE LEACHING: EXAMPLE OF LITTORINA SHELL BEADS FROM THE CHATELPERRONIAN SITE OF SAINT-CESAIRE (FRANCE)

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Abstract

Dating carbonate shells near the limit of the radiocarbon range is notoriously challenging, primarily due to contamination and diagenesis processes. In this study, we attempted to date shell beads associated with Châtelperronian artifacts recovered from recent excavations at the site of La-Roche-à-Pierrot in Saint-Césaire (France; Bachellerie, Gravina, Rigaud et al., submitted). We employed a dedicated protocol involving sequential leaching to eliminate surface contaminants (Bard et al. 2015). Shells were first cleaned with a scalpel, ultrasonicated in Milli-Q water and then fragmented into pieces to enable detailed examination under a binocular microscope. Quantitative XRD analyses (Sepulcre et al. 2009) revealed that the fossil shells are composed of both calcite (ostracum) and aragonite (hypostracum) in proportions comparable to those found in modern *Littorina obtusata* shells. This compositional similarity indicates that the most complete fossil shells have not undergone recrystallization.

Selected fragments of the fossil shells were processed using a carbonate handling system coupled with the automated graphitization equipment (CHS-2 & AGE-3). Hydrochloric acid leaching was performed in up to four successive steps on the *Littorina* shells and on blank carbonate standards of similar size. All leachates and residues were then analyzed for ^{14}C on AixMicadas. The data revealed a significant reduction in contamination —consistent with previous leaching experiments (Bard et al. 2015, Fagault et al. 2019). In line with expectations, ^{14}C levels in the leachates decreased progressively over the sequential leaching experiments of ten samples.

The final residue, corresponding to the last 30% of the compact calcitic ostracum, constitutes the most pristine part of each shell. Four ^{14}C measurements obtained on the residues of three complete shells yielded ages ranging from 53.5 to 58.9 ky ^{14}C BP, all consistent within analytical errors. The weighted mean ^{14}C age of the shell residues is 55.3 ± 1.3 ky ^{14}C BP. In the absence of a site-specific *Littorina* blank from Saint-Césaire, the blank correction was based on the IAEA-C1 marble standard, which may underestimate the true level of residual contamination in these samples. As a result, the finite age of 55.3 ± 1.3 ky ^{14}C BP, corresponding to a very low ^{14}C level ($F^{14}C \approx 0.001$) slightly above the background, likely represents a minimum estimate of the shells' true ^{14}C age.

Radiocarbon ages for marine shells are consistently older than those of contemporaneous terrestrial material derived from the atmosphere and must be corrected for the reservoir age of the surface ocean layer. This marine reservoir age correction varies through time and space, but can reach up to 2 kyr (Bard 1988, Tisnerat-Laborde et al. 2010, Heaton et al. 2020, 2023). Regardless of the correction applied, the mean ^{14}C age of these pristine shells lies beyond the range of the current calibration whatever the

assumption made on the reservoir correction (Heaton et al. 2020, 2023a,b). Overall, these *Littorina* shells are certainly older than 55 ky in calendar years BP given that ^{14}C ages are systematically younger than true ages in the oldest portion of the calibration (Heaton et al. 2021).

These *Littorina* shell beads are thus significantly older than the currently accepted chronology for the Châtelperronian and much older than the radiocarbon ages obtained on bones from the same archaeological context (Bachellerie, Gravina, Rigaud et al., submitted). One plausible explanation for this conundrum could be that the shells were collected by humans as already fossilized specimens (e.g. Rick et al. 2005), possibly from exposed Upper Pleistocene deposits along the Atlantic coast which were accessible during glacial periods when sea level was lower than during the Last Interglacial.

Acknowledgments

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A05 SESSION

CLIMATE AND HUMAN RESPONSES IN NORTHERN FENNOSCANDIA DURING THE HOLOCENE: A PALEOENVIRONMENTAL AND ARCHAEOLOGICAL PERSPECTIVE

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Abstract

This study examines the relationship between climate and human habitation in northern Fennoscandia during the Holocene. We hypothesize that climate has played a crucial role in human survival through its impact on resource availability, particularly in farming communities, where crop failures were historically devastating. Similarly, we assume that cold and dry periods also affected hunter-gatherer subsistence strategies by limiting key resources such as seals, moose, and reindeer, which were essential for survival in northern environments.

A central assumption is that the strength of the archaeological signal correlates with population density and resource availability. Our primary archaeological dataset consists of radiocarbon dates from archaeological contexts, recognizing both the strengths and limitations of this approach. Paleoenvironmental data are derived from tree-ring records from Lapland, while archaeological data encompass radiocarbon-dated contexts from northern Fennoscandia, specifically Finnmark and Troms in Norway, the Kola Peninsula, Sweden, and Finland.

By comparing datasets from different regions, we aim to assess the resilience of human settlements to climatic fluctuations. The study area is divided into three ecological zones: the Arctic coastal region (Norwegian and Kola coasts of the Barents Sea), the Arctic inland region (north of the Arctic Circle in Sweden, Norway, Finland, and the Kola Peninsula), and the northern Baltic region (Finland and Sweden at similar latitudes).

While numerous studies have explored the relationship between climate and past human populations, further research is needed to refine chronological comparisons and incorporate additional archaeological indicators beyond radiocarbon dates. Expanding paleoenvironmental and zooarchaeological datasets will be essential for improving our understanding of how key animal populations fluctuated in response to climatic changes and how this impacted hunter-gatherer resilience across the region.

Acknowledgments

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A05 SESSION

RE-DATING THE THERA ERUPTION

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Abstract

The volcanic eruption of Thera (Santorini) in the Aegean Sea had a drastic influence on the civilizations of the surrounding region. The precise date of the 2nd millennium BCE ("Minoan") eruption of Thera (Santorini) is also important because the tephra layer acts as a distinctive time-horizon of Late Bronze Age contexts across the Eastern Mediterranean. However, discrepancies between radiocarbon and archaeo-historically based eruption date have long been a long-term source of controversy, limiting understanding of societal and environmental dynamics in the Bronze Age.

Here, we report on a series of new high-precision radiocarbon measurements on a branch from an olive tree buried alive in tephra on Santorini (Friedrich et al. 2006) and on an olive shrub carbonized by the same eruption deposits on neighbouring Therasia (Pearson et al. 2023). While these specimens were previously measured for radiocarbon, the new results are at a significantly higher resolution. These high-resolution measurements allow us to take advantage of the fine structure in the radiocarbon calibration curve for accurate radiocarbon wiggle matching without relying on questionable growth band counts in these two olive samples.

The results from the samples retrieved from the Minoan eruption deposits in different locations around the Santorini archipelago are mutually supportive as they show similar fine structure. Based upon these results, we date the eruption to the 16th century BCE, more recent than most previous (lower-resolution) radiocarbon dates have suggested. The new results will be presented and a possible link to ice-core records given.

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A05 SESSION

AN UPDATED CHRONOLOGY FOR THE MIDDLE TO LATER STONE AGE SEQUENCE AT TAFORALT, MOROCCO

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Abstract

We present an updated chronology for the stratigraphic sequence in Sector 2 at the cave site of Grotte des Pigeons, Taforalt, Morocco. Taforalt has provided one of the longest continuous records of Late Pleistocene sediments with human occupation in North West Africa. Multiple dating strategies have been used at the site, including radiocarbon, luminescence, U-Series, bio-stratigraphic correlation, and tephrochronological methods (Barton et al. 2015). Here, we present an updated synthesis of these approaches, with a chronological focus on layers relating to the Middle Stone Age and overlying "intermediate" industry (Barton et al. 2016). The updated chronology is based on a new series of radiocarbon dates on charcoal and seeds from Sector 2 at Taforalt. Radiocarbon determinations are calibrated and further constrained by Bayesian modelling. Using the updated chronology and estimates for the emergence and duration of these Palaeolithic industries, we compare the timing of behavioural changes at Taforalt to other North African archaeological sequences, along with palaeoenvironmental reconstructions for this region and period. Finally, we consider the influence of palaeoenvironmental change on human populations during Marine Isotope Stage (MIS) 4, MIS 3, and the beginning of MIS 2.

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A05 SESSION

TOWARD A COMPREHENSIVE FRAMEWORK FOR RADIOCARBON DATING MAYA BONE: KARSTS, COASTS, CORN, CHRONOLOGY

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Abstract

The last decade of Maya archaeology has seen a widespread application of direct radiocarbon dating and isotopic analysis of newly excavated burials and legacy collections of archaeological human bone. This direct approach to archaeological chronology building lies within a broader culture-historical chronological edifice supported hieroglyphic records of the Maya calendar system – with potential resolution to an exact day – and local to regional ceramic seriations that are thought to be diagnostic to phases of typically 25 or 50 years. Given more than a century of such "high-precision" no-cost chronometry, and the variability of the atmospheric calibration curve during the Classic Period (~AD 250 to AD 900) that leaves even the lowest sigma ^{14}C ages spanning 200-250 calibrated years, researchers can be forgiven for doubting the usefulness of directly ^{14}C dating human burials in the region. That said, several recent studies take the approach of treating the existing seriations and cultural chronologies as hypotheses to be tested, and testing them by directly dating, e.g., human bone associated in burial contexts with formally diagnostic ceramics, dedicatory dates, other burial goods, or distinct burial postures. At a broader regional level, the direct dating of commoner burials – regardless of any necessary typologically distinctive burial goods – allows for demographic patterns to be explored, particularly focussing on the timing of political collapses of regional polities versus the demographic collapse or depopulation of a given area, timing of conflict between polities, and movements of population in response to, e.g., the Great Maya Drought. Implied in the latter is also a desire for high-precision dating of Maya bone to bring calibrated ^{14}C uncertainties down to the same scale of resolution as climate records (mainly isotope records in speleothems or lake cores) that have been developed since the 1990s and more recently in the 2000s. Hence, the factors that could affect the radiocarbon content of human collagen in the Maya world need to be characterized: 1) as to their existence at all; 2) to their magnitude so that they can be accounted for and corrected where possible; or 3) if correction is not possible the uncertainties can be realistically estimated and acknowledged during chronology building.

The aim of this review is to frame the potential factors at play, partly from first principles of carbon cycling and geochemistry and partly from experimental observation of archaeological and geological data. The focus here is primarily on processes affecting in vivo radiocarbon content rather than diagenetic alteration of collagen – though the role of bioapatite carbon isotope analysis in elucidating or obfuscating diet must be treated. The main concerns to address and that indicate fruitful directions for research include: the presence and magnitude of freshwater reservoir effects given the largely karstic geology of the Maya lowlands and presence some freshwater animal remains in middens and burials; for coastal populations or inland groups trading for marine foods the marine proportion of the diet and the appropriate ΔR to use for corrections; to address either of the preceding issues dietary reconstruction from zooarchaeological remains or collagen and other isotopes is required, but the C4 staple of maize dominating the diet may confound the creation of a realistic δ13C and δ15N diet space; and, further the karstic geology also has peculiar strontium and sulfur geochemistries that constrain their application to marine/terrestrial interpretations, the cenote rings that mark the impact of Chicxulub in the Yucatan being an obvious signal of the complications for interpreting δ34S, for example. Putting these main factors into context and proper proportion should form a basis for targeted investigations to resolve these outstanding issues and better articulate the culture historical, environmental and human

chronologies of the Maya world.

A05 SESSION

RADIOCARBON DATING REVEALS RELATIONS BETWEEN CATHEDRAL, PEOPLE AND ENVIRONMENT IN MEDIEVAL STAVANGER, NORWAY

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Abstract

The town of Stavanger in southwest Norway celebrates its 900-year anniversary in 2025. Stavanger cathedral is Norway's best-preserved medieval cathedral and has been in continuous use during the past 900 years. Its construction history and development, however, remain shrouded in mystery, due to the scarcity of written sources. The same applies to the foundation and development of the town itself. Thus, archaeological and scientific methods have the potential to greatly increase our understanding of the medieval period – from individual life-histories to the beginning of the urbanisation process in Scandinavia.

Recently, two research projects have been producing new radiocarbon dates for medieval Stavanger, in addition to a wealth of biomolecular data. The project "FuturePast (Future preservation of past life: A multidisciplinary investigation into preservation of ancient biological remains from medieval cemeteries)" focuses on biomolecular analyses of human skeletons. It combines systematic analyses of previously excavated skeletons with new excavations and in-situ measurements of preservation conditions. Additionally, a sediment core was sampled from the lake Breiavatnet, just next to the cathedral, for macrofossil and pollen analyses, as well as radiocarbon dating of terrestrial macrofossils. The project "STICKING STONES: Rediscovering medieval wood tar adhesives for stone conservation" focuses on ancient techniques of stone construction and repair using natural adhesives (Ebert 2024). As part of this process, samples of mortar, wood tar adhesives and wood remains from scaffolding in the cathedral were dated to provide a chronology for construction and repairs of the cathedral (Barrett et al. 2025, Ebert et al. (in review)).

This study combines results from both projects to improve the chronology of Stavanger. Stable isotope analyses and excavation stratigraphy are used to improve the accuracy and precision of the radiocarbon dates on human bones. The cemetary chronologies are then compared to the environmental reconstruction from the lake sediment core, and to the cathedral's history of constructions and repairs. Thanks to the absolute radiocarbon dates, we are able to link the development of the cathedral to the town, its inhabitants and environment. This allows us to challenge popular perceptions about the age of the cathedral and surrounding town.

Acknowledgments

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Radiocarbon dating of samples from the Cathedral construction was financed by a grant from the Oseberg foundation and the Sticking Stones research project (project number 344868), funded by the Research Council of Norway for the period 2024-2028.

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Ebert, B., Bjelland, T., & Philippsen, B. (in review) Medieval wooden scaffolding provides new insights into the dating and construction of Stavanger Cathedral in Norway. International Journal of Wood Culture

A05 SESSION

THE PACIFIC ARCHAEOLOGY RADIOCARBON DATABASE

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Abstract

Many online regional radiocarbon databases have been developed worldwide, motivated by specific research and community-driven objectives. The most ambitious coverage of the globe includes projects like XRONOS (xronos.ch), which incorporates multiple datasets with over 350,000 dates (as of January 2025). However, these databases leave much of Asia and the Pacific underrepresented, and most of the islands of Oceania are missing entirely. This lack of centralised management of archaeological ^{14}C data across the Pacific Islands is problematic because of the region's importance in the migration story of humans across the globe, evidence of increasing genetic complexity and linkages to environmental drivers.

This paper introduces the Pacific Archaeology Radiocarbon Database (PARD), which expands on the original Aotearoa/New Zealand Radiocarbon Database (Bickler & Petchey, 2024; Petchey et al., 2022; over 4600 dates). The PARD now has over 12,000 dates from across the Pacific islands extracted from academic papers, books and unpublished reports by research and consulting archaeologists. This ^{14}C database uses ArcGIS Online, a geospatial system with searchable fields and locational navigation. Our work enables researchers to access details of more than 11,000 radiocarbon dates from archaeological sites across the region and opens up new avenues for chronometric research.

A05 SESSION

BRONZE AGE FISHING IN DENMARK: RADIOCARBON DATES AND RESERVOIR EFFECTS

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Abstract

Fishing has played an important role in the economy of prehistoric Northern Europe. In Denmark, this is evidenced by numerous wooden structures built for passive coastal fishing dating back to the Stone Age. These structures were in use during the Mesolithic (c. 8900-4000 cal. BC) and their use intensified during the Neolithic (c. 4000-1800 cal. BC). However, it is generally believed that fishing practices changed during the Bronze Age (c. 1800-500 cal. BC): frequent discoveries of larger gadid bones (cod and haddock) suggest deep-sea fishing with hooks and lines, interpreted as evidence of elite prestige or spiritual activities (Enghoff 2016). This interpretation aligns with ship and fish symbols found in rock art and metal artifacts, as well as the rise of long-distance maritime trade.

Estimating the role of fish in the human diet during the Bronze Age has been challenging due to the limited number of well-preserved and thoroughly analysed fish bone assemblages. Results from the large-scale rescue excavations of the Femern project (2012-2022) on the island of Lolland, Denmark, indicate a more complex scenario than a singular focus on deep-sea cod fishing. Passive wooden structures - fish weirs and traps - continued to be used from the Mesolithic to the Bronze Age (Koivisto et al., 2024). Analyses of fish bones from Bronze Age pits reveal a diversity of species utilized (Koivisto et al., submitted).

In this study, we present radiocarbon dates obtained during the Femern project and new dates from the research project SylFish (https://museumlollandfalster.dk/projekter/sylfish/), focusing on the Bronze Age. Dates on stationary fishing structures indicate the continuous tradition of this fishing strategy. Paired dates on fish bones and terrestrial samples are used to estimate the reservoir effect of the fish, aiding in the correction of dates on fish bones without associated terrestrial samples. Additionally, reservoir ages and stable isotope values of the fish bones are used to reconstruct the environment from which these fish were harvested, such as coastal eelgrass meadows versus the open sea.

Acknowledgments

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Age Fisheries in Southern Scandinavia: The Role of Coastal Fishing and the Use of Aquatic Resources in Bronze Age Denmark

Koivisto, S., Robson, H. K., Philippsen, B., Stafseth, T., Brinch, M., SchmöLcke, U., Astrup, P. M., Casati, C., Henriksen, M. B., Uldum, O., Lundbye, M., Maring, R., Kanstrup, M., Måge, B. T., & Groß, D. (2024). Fishing with Stationary Wooden Structures in Stone Age Denmark: New Evidence from Syltholm Fjord, Southern Lolland. *Proceedings of the Prehistoric Society*, 90, 147-176. https://doi.org/10.1017/ppr.2024.15

A05 SESSION

CHRONOLOGICAL MODELLING OF THE ANCIENT EGYPTIAN OLD KINGDOM

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Abstract

The MERYT project aims to establish an accurate, high-resolution, multi-technique chronological model of the Egyptian Old Kingdom (~2900-2200 BCE), reigns by reigns, by building a statistical model based on Bayesian inferences, that reconciles Egyptological and analytical data.

Through a historical approach, textual sources preserving chronological evidence have been re-evaluated in order to establish the most accurate estimates of the lengths of each king's reign, given our state of knowledge. Using an archaeometrical approach, series of more than 100 radiocarbon dates have been carried out at the Ifao laboratory on samples collected directly from several ongoing archaeological excavations in Egypt, the discovery contexts of which were clearly associated with a particular historical reign (from the 1st to the end of the 6th dynasty). Particular developments have been made on the analyses protocols of textile and bone samples, in order to ensure their dating and to accurately model their results. The possibility of a specific regional shift in the ^{14}C content of the atmosphere due to a seasonal effect on the Egyptian territory has also been considered and studied through the analysis of botanical samples from the Herbarium of the Muséeum National d'Histoire Naturelle in Paris. The whole data is finally confronted in a Bayesian statistical model whose formalism is developed for this project.

The MERYT model will suggest the first absolute holistic chronology of the Old Kingdom gathering Egyptologists and archaeometrical investigations. The impact will go beyond Egyptology alone and will potentially affect the chronological knowledge of civilizations of the Eastern Mediterranean in the 3rd millennium, highlighting the contribution of analytical and modelling approaches to archaeological research.

This talk will present the results of the Meryt model and be completed by open perspectives, bringing new insights on the start of the Egyptian state.

Acknowledgments

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A05 SESSION

WIGGLE MATCHING PEOPLE: APPROACHES AND POTENTIALS

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Abstract

It has long been recognised that plants and animals produce tissues over their lifespans, with the resultant material formed of materials of different radiocarbon ages. Indeed, it was the different radiocarbon ages identified in the tissues of the ice mummy 'Ötzi' that led to the development of the earliest version of the OxCal program (Bayliss and Bronk Ramsey 2004). Development of 'wiggle matching' approaches in the radiocarbon measurements of preserved timbers with annual growth cycles has allowed both the construction of the radiocarbon calibration dataset and age estimate applications where neither radiocarbon nor dendrochronological measurements on their own were not sufficient to resolve the archaeological research questions. However, the application of wiggle matching techniques to animals has received less attention. This is in part because animal tissues laid down sequentially (e.g. skin and hairs) are not often preserved in the archaeological record. Skeletal tissues by contrast *are* routinely preserved on many archaeological sites and represent an archive of materials of different calendar and radiocarbon ages. The time of formation of these skeletal tissues has a much greater variability dependent on the element, the age and sex of the individual, and other aspects impacting on their metabolic state.

This paper presents some recent applications that exploit the inherent differences in the radiocarbon ages of different skeletal elements to 'wiggle match' people. We present approaches that make use of the different rates of formation of different tissues in the lifecycle of an individual and the known ages at which they form. We also present case studies where historically attested events or archaeological stratigraphic information can also be utilised as highly informative prior information in the analysis of wiggle matching people.

Acknowledgments

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A05 SESSION

MODELLING CULTURE AND GENETICS: A CRITICAL EVALUATING OF THE MESOLITHIC-NEOLITHIC TRANSITION IN SOUTHERN SCANDINAVIA

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Abstract

The Mesolithic-Neolithic transition in Southern Scandinavia has received immense archaeological attention over the past c.175 years, traditionally interpreting the introduction of agriculture as either a result of Neolithic farmers moving into regions previously inhabited by fisher-hunter-gatherer (FHG) population (demic diffusion), or as indigenous FHGs adopting farming practices through contact with Neolithic farmers (cultural diffusion). A recent genetic ancestry study suggests a direct link between the introduction of agriculture and in-migration of Central European farmers with a mix of Anatolian Neolithic ancestry around 4000 BC, which is interpreted as robust evidence for demic diffusion. Critics have however refuted such 'simplified migration narratives' and there is growing archaeological evidence that the transition was a multistranded and extended process with cultural and economic negotiations between the last FHGs and the first Neolithic farmers.

Further interdisciplinary dialogue and integration of archaeological and genetic data are required to better explore prehistoric migration and processes of change, and this paper aims to do just that. We present preliminary results from a study modelling cultural and genetic evidence with relation to the Mesolithic-Neolithic transition in Southern Scandinavia, exploring the archaeological and genetic transitions as separate phenomena, possibly separated in time and space. We draw on extensive legacy data from archaeology, ^{14}C data, dietary isotopes ($\delta^{13}C$, $\delta^{15}N$), strontium isotopes ($^{87}Sr/^{86}Sr$), ancient DNA and osteology, which are modelled within a Bayesian framework.

The adoption of agriculture is one of the most fundamental changes in human prehistory and this innovative and interdisciplinary methodological approach will integrate large-scale data on population movement with small-scale data on local case studies to critically evaluate the introduction of agriculture in Southern Scandinavia and contribute to the ongoing debate about Stone age migration and mobility.

A05 SESSION

USING ANNUAL CALIBRATION CURVES FOR HIGHLY RESOLVED DATING

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Abstract

Radiocarbon dating is a cornerstone method for determining the age of organic material. The method relies on measurements of radiocarbon content calibrated against a reference curve. The accuracy of this method is fundamentally tied to the structure and resolution of the calibration curve. Recent advancements have significantly refined portions of the curve through the high-resolution analysis of radiocarbon concentrations in individual annual tree rings. These advancements have revealed finer-scale structures, such as signals from 11-year solar cycles and solar energetic proton events (Miyake et al., 2012; Brehm, et al., 2021, 2022, 2025). So far multiple studies showed how the signal of a solar proton event can be used to achieve an annual date date (Philippsen et al., 2022; Maczkowski, et al., 2024). However no annual date could be achieved by only using the signature of the 11-year solar cycle. Here we show the potential for highly resolved calibrated dates using newly measured short tree ring sequences together with a new annual radiocarbon calibration curve. Our findings underscore the transformative possibilities for precision dating in radiocarbon research.

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A05 SESSION

RADIOCARBON DATING OF IRON REINFORCEMENTS OF NOTRE-DAME DE PARIS CATHEDRAL: AN ORIGINAL CONTRIBUTION TO THE CHRONOLOGY OF THE CONSTRUCTION AND RESTORATION PHASES

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Abstract

Iron reinforcements of Notre-Dame de Paris cathedral are a source of data for the interpretation of gothic architecture. The radiocarbon dating of these metal structures can provide information on the chronology of the different construction periods of the building as well as revealing potential recycling during restoration phases. In addition, this method coupled with archaeometallurgical and chemical analyses can illuminate the roles played by iron in the strategy of the monument erection.

Among iron artefacts in the cathedral Notre-Dame de Paris are found staples in the masonry of the tribunes, nave, aisles and upper walls. The restoration works also reveal various tie-rods, dowels, ridge caps and framing irons such as nails, bolted rods or keyed dowels. M. L'Héritier et al. [1] performed the radiocarbon dating of six staples: two of which were retrieved from the tribunes and four from the upper walls. These initial findings revealed that the staples from the tribunes are older than those from the upper walls, and it coincides with the cathedral's construction phases (middle of the 12th century and beginning of the 13th century). According to the experimental procedure developed by S. Leroy et al. [2] for Bourges and Beauvais cathedrals' iron reinforcements, 26 additional iron armatures were dated. This approach was adopted to ensure the consistency and reliability of the results between the two previously described corpuses and the parts of the cathedral recently dated. According to the first data obtained for the new artefacts, it can be confirmed that these reinforcements are primarily from the medieval construction phase of Notre-Dame de Paris, thereby confirming the metallographic observation. Two of these artefacts appear to be more recent and could be examples of later restoration work of the monument.

Radiocarbon analyses, coupled with metallographic and archaeometric studies, provide a deeper understanding of this gothic monument and more precisely of the buildings techniques through the use of iron reinforcements.

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A05 SESSION

A REVISED CHRONOLOGY OF THE PORTEL-OUEST CAVE SEQUENCE (ARIÈGE, FRANCE): IMPLICATIONS FOR LATE NEANDERTHAL OCCUPATIONS IN THE PYRENEES REGION

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Abstract

The Middle to Upper Palaeolithic transition in Europe is a highly debated topic, and growing evidence highlights regional variations in its chronological framework [1,2]. This period is marked by the disappearance of Neanderthal, generally associated with the Mousterian industry, and the expansion of Homo sapiens. The diversity of the first Upper Palaeolithic industries across Europe further underscores the complexity of that period, particularly given the ongoing debate over the attribution of certain industries, such as the Châtelperronian [3,4]. Establishing robust chronologies based on well-preserved archaeological sequences across Europe is essential for understanding this biological and cultural transition, as well as potential interactions between human groups. The Pyrenean region is of particular importance in this context, as it contains numerous Mousterian and Upper Palaeolithic sites.

The Portel-Ouest cave (Ariège, France) is an ideal site for radiocarbon dating. Extensive excavations (Vézian: 1949–1987; Becam: since 2019) have revealed a rich and well-preserved Mousterian sequence, directly overlain by an Upper Palaeolithic complex with Châtelperronian tools [5]. In addition, the site has yielded 33 Neanderthal remains [6] - the largest assemblage on the northern slope of the Pyrenees - firmly establishing the Mousterian-Neanderthal association in the region. Multidisciplinary studies, including sedimentology, palynology, (micro-)faunal analyses, and ESR-U/Th dating [7], have provided a preliminary chronological framework.

This study aims to reassess the chronology of human occupations at the Portel-Ouest cave through radiocarbon dating and Bayesian modelling. We present 29 new Accelerator Mass Spectrometry (AMS) ^{14}C dates obtained from the collagen of faunal bones with anthropogenic modifications at the AixMICADAS facility (CEREGE, Aix-en-Provence) [8,9] and modelled using Chronomodel software [10]. Additionally, a technological and typological analysis of the lithic material from the Upper Palaeolithic complex was conducted to clarify its cultural context and stratigraphic integrity.

This study refines previous ESR-U/Th dating and confirms an extended Neanderthal occupation at the cave. It spans from at least 55 ka cal BP, reaching the limit of radiocarbon dating, to an estimated end phase between ca. 46–39 ka modelled BP (95% confidence interval) or ca. 45–42 ka modelled BP (68%

confidence interval). The Neanderthal occupation at Portel-Ouest aligns with published ages from Gatzarria and Le Noisetier caves on the northern slope of the Pyrenees [11,12]. The end of Neanderthal occupations at Portel-Ouest partially overlaps with estimates for Abri Romani and Arbreda on the southern slope but is likely slightly earlier [13,14]. Furthermore, lithic analysis of the Upper Palaeolithic complex confirms the presence of Gravettian, Aurignacian, and a few Châtelperronian diagnostic tools, mixed with numerous Mousterian elements. While Gravettian and Aurignacian ages are well-represented, no Châtelperronian-specific ages were identified in our radiocarbon dataset. These results suggest that the Châtelperronian at Portel-Ouest represents a brief episode rather than a predominant phase, as previously proposed [5].

Our study underscores the necessity of high-quality radiocarbon dating and Bayesian modelling, alongside archaeological and stratigraphic analyses, for a clearer understanding of the Middle to Upper Palaeolithic transition. It establishes one of the most refined chronological frameworks for a Mousterian site on the northern slopes of the Pyrenees, and provides a significant contribution to the chronostratigraphic study of key Pyrenean sites.

Acknowledgments

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A05 SESSION

DATING METHODS ON EARTH ARCHITECTURE IN CENTRAL GERMANY

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Abstract

The dating of edifice in building research, especially in rural, traditional construction, is conventionally carried out using dendrochronology on timber. Dendrochronology allows very accurate dating and, ideally, even the exact year in which the tree was felled. However, in the case of solid adobe buildings that do not contain any load-bearing timbers, only a minimum age can often be determined using the overlying wooden roof truss or ceiling beams, which had to be replaced often. However, this is inadequate for building research and monument conservation, as the date of the first appearance of this type of construction method in central Germany can still only be roughly estimated.

As part of a project from the BMBF-funded GOLEHM alliance, adobe walls themselves are now being dated for the first time using various scientific methods. The focus is on the radiocarbon method (^{14}C dating) and the method of optically stimulated luminescence method (OSL).

The radiocarbon method generally allows very precise dating with low uncertainty, provided that organic material is present in the clay. Weller clay is particularly suitable for dating because of its high straw content. However, for the period between the 16th century AD and the present, there are limitations in the evaluation of the ^{14}C data due to strong natural, but also anthropogenic fluctuations in the atmospheric ^{14}C levels over long periods. This means that often only several possible periods can be given as the time of origin, with inaccuracies of a few years or decades. However, a combination with OSL dating can solve these problems. OSL dating determines the time of production of the clay mixture as the mineral grains it contains are bleached by light. Incomplete bleaching is possible, which increases the error beyond the 10% normally associated with OSL dating. Nevertheless, this method allows direct dating of the clay wall and is optimally complemented by the ^{14}C method, which determines the time of growth of the organic lean. By combining the two methods, it is possible to determine a very precise period for the construction of a building.

The first results on the dating of corrugated earth buildings from central Germany from the 16th to the 20th century will be presented and discussed together with dendrochronological data and dating-relevant information from pictorial and written sources.

A05 SESSION

ARCHAEOMETRY (RADIOMETRIC DATING, METALLOGRAPHY) FOR TWO EARLY IRON-AGE AXES FROM NORTHERN EUROPE AND CENTRAL ASIA

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Abstract

The possibility to date archaeological iron using iron-bound carbon by ^{14}C was proposed and performed more than 50 years ago (Van der Merwe 1965, 1969; Van der Merwe and Stuiver 1968) and adopted by many researchers afterwards (a.o. Chresswell 1992, Nakamura et al. 1995, Cook et al. 2001, Hüls et al. 2004, Scharf et al. 2004, Oinonen et al. 2009). Concerns such as contamination during sample preparation or during the iron production itself have been raised and discussed by Craddock et al. (2002), Scharf et al. (2004), Hüls et al. (2011). To validate ^{14}C dates for iron objects, additional metallurgic investigations have been proposed.

We demonstrate ^{14}C dating and additional metallurgy for two arbitrarily selected archaeological iron axes from the early iron age in Kazakhstan and Northern Germany.

The Kazakhstan Axe was excavated within the Kyzylzhartas burial ground in the Karaganda region of the Republic of Kazakhstan (Karaganda Axe; Beisenov et al 2023, 2024). The German Axe was excavated at an Iron Age settlement located close to the city of Bad Segeberg near Högersdorf in N-Germany.

^{14}C ages were measured on thermally (about 950°C – 1000°C) extracted carbon from shredded iron pieces by AMS. The Karaganda Axe gave a ^{14}C age of 2180(20) BP, calibrated to 357BCE-164BCE (2σP), and the the Högersdorf Axe a ^{14}C age of 2310(35) BP, calibrated to 480BCE-211BCE (2σP).

The Karaganda Axe was found inside a grave complex of the Tasmola culture (8^{th}-5^{th} century BCE; Beisenov 2024), which also revealed luting in the past. The axe corresponds in shape to a Pickel-Axe with two blades perpendicular to each other. Microstructure inspection indicate an advanced production technique by careful selection of different carburized iron for different purposes, e.g. steely iron for the blades and softer, carbon free metal around the hole for the wooden handle (Beisenov et al 2023). The main blade is composed of fine Pearlite (Troostite), indicating heat treatment. Hardness varied between 165 HV_{10} to 376 HV_{10}. SEM-EDX analyses of slag inclusions (SI) within the metal matrix give a low Fe content, indicating an efficient iron ore smelting, seen in Europe much later, e.g. during the Medieval.

The Högersdorf Axe belong to a Hoard find of 4 axes at an assumed Iron-Age settlement. The traditionally formed axe with one blade consists of a poorly carburized, phosphoric-rich ferritic iron. Microstructure inspection reveal an arrangement of phosphor-rich and phosphor-poor ferritic iron layers. Elongated SI indicate mechanical force when different iron layers are forged. Measured hardness varied between 170 HV_{10} and 238 HV10 with no obvious gradient and is considerably softer than the Kazakhstan counterpart. Elemental composition of SI by SEM-EDX analysis show a comparably high Fe

concentration and indicate a lower iron-ore reduction efficiency during smelting as compared to the Karaganda axe which is also more in-line with archaeological iron finds in Northern Europe (Buchwald 2005) from the Iron Age up to the Medieval.

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A05 SESSION

NEW TECHNOLOGICAL STUDIES AND RADIOCARBON DATING OF THE OPEN-AIR SITE OF PIEKARY III (KRAKOW, POLAND)

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Abstract

During the Late Pleistocene, human settlement in Central Europe was strongly influenced by climate change and environmental shifts, with dispersals into areas above 45°N occurring only during periods of climatic improvement (Picin, 2025). Southern Poland was affected by these fluctuations and can be interpreted as a satellite area within the settlement system of prehistoric hunter-gatherers, visited cyclically for the exploitation of seasonal resources (Picin et al., 2020; Picin et al., 2023; Talamo et al., 2021b). Expanding the high-resolution chronometric dataset for the Pleistocene archaeological record will aid in understanding the timescale of these movements and the patterns of Neanderthal and Homo sapiens occupations in Polish territories.

Since the late 19th century, the area of present-day Krakow has been intensively investigated for archaeological research, leading to the discovery of several Middle and Upper Paleolithic sites (Chmielewski et al., 1977; Sachse-Kozłowska and Kozłowski, 2004; Sawicki, 1957; Sitlivy et al. 2008, 2009). Among these, the Piekary complex, located on the left bank of the Vistula River valley at the narrow eastern section of the Krakow Gate, approximately 12 km upstream from Krakow, is particularly significant. The area has been subject to extensive archaeological investigations, revealing multiple open-air sites with Middle and Upper Paleolithic occupations, including Piekary I (Jama Cave), Piekary II and IIa, Piekary III, Piekary IV (Na Gołąbcu Cave), and Piekary V (Sachse-Kozłowska and Kozłowski, 2004).

Of particular importance is the open-air site of Piekary III, first tested in two trenches by Krukowski (1939) in 1927 and subsequently excavated in 1936 over an area of approximately 360 m^2 (Tomaszewski, 2004). The stratigraphic sequence comprises nine archaeological layers, with the sterile layer (Layer 9) resting directly on Jurassic limestone. A few Micoquian artifacts were recovered from Layer 8, while Layer 7 yielded the richest lithic assemblage, followed by Layers 6 and 5, where the number of archaeological finds decreases sharply. Very little information is available for the remaining layers up to Layer 2, where a few Neolithic pottery sherds were discovered (Tomaszewski, 2004). However, this stratigraphic distinction should be approached with caution, as the association of artifacts with specific layers remains uncertain due to limited documentation on their precise locations.

This study presents a technological reassessment of the lithic industry of Piekary III alongside new radiocarbon dates from eight bone samples. The lithic assemblage was analyzed as a whole to better understand its technological composition and evaluate potential mixing of artifacts. The study focused on all cores and asymmetrical bifacial knives, as well as a sample of flakes and stone tools. The technological analysis revealed that a significant portion of the assemblage is characteristic of the Central Eastern European Micoquian (CEEM), including Keilmesser, bifacial and Quina scrapers, groszak, and Mousterian points. The core assemblage further supports this attribution, consistent with other CEEM sites in Central Europe, with a predominance of hierarchized and simple unidirectional cores,

whereas Levallois and discoid technologies are few.

In addition to the Micoquian materials, several cores and artifacts typical of the Upper Paleolithic were also identified. The presence of massive blade cores and carinated end-scrapers, resembling those found at the nearby site of Kraków-Zwierzyniec 1, suggests an Aurignacian occupation. Conversely, other blade and bladelet cores are more likely associated with the Epigravettian.

To establish a chronological framework for the site's occupation, eight bone samples underwent collagen extraction using advanced ultrafiltration protocols at the Bologna Radiocarbon Laboratory (BRAVHO) (Talamo et al., 2021a) and were dated at the Klaus-Tschira-AMS facility of the Curt-Engelhorn Centre in Mannheim (Germany). The results indicate that the stratigraphic sequence spans from 45–44 ka BP in layer 7 to 42–41 ka BP in layer 5. Two outliers were identified in layer 6: one sample dated to 42 ka BP, which most likely originates from layer 5, and another yielding an age of 26–25 ka BP, likely associated with an Epigravettian occupation.

The technological reassessment of the Piekary III lithic assemblage, combined with new radiocarbon dates, provides key insights into the site's occupational history. The Neanderthal occupation of Piekary III took place during MIS 3 whereas the presence of Aurignacian and Epigravettian are consistent with the archaeological record of nearby sites such as Piekary II, IIa, Kraków-Księcia Józefa Street, and Kraków-Zwierzyniec 1, where ephemeral Upper Paleolithic occupations have also been documented. The results highlight Piekary III as another key locality for understanding the shifting settlement dynamics of Neanderthals and Homo sapiens in southern Poland, emphasizing the cyclical and discontinuous nature of human presence in the region.

Acknowledgments

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A05 SESSION

THE BOOMERANG'S RETURN: REVISITING THE EARLY UPPER PALEOLITHIC CHRONOLOGY OF OBŁAZOWA CAVE (POLAND), WITH HIGH-RESOLUTION ^{14}C DATING

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Abstract

The Early Upper Paleolithic period marks a crucial phase in the cultural and technological evolution of *Homo sapiens*, characterized by increasing symbolic behaviors, artistic expressions, and technological innovations. This period, spanning from approximately 45,000 to 30,000 years ago, saw the widespread expansion of modern humans across Europe and the development of distinctive archaeological cultures, including the Aurignacian and Gravettian traditions (Picin, et al., 2023). Among the hallmarks of this era are the production of sophisticated bone and ivory tools, intricate personal ornaments, and the earliest known artistic representations (Talamo, et al., 2021a). The cognitive advancements of these early populations are reflected in their ability to adapt to diverse environments, exploit a wide range of resources, and develop complex social structures.

One of the most remarkable finds associated with this period is a mammoth tusk boomerang from Layer VIII of Obłazowa Cave, Poland, discovered in association with a human phalanx (Valde-Nowak, Nadachowski and Wolsan, 1987). This artifact, carved from a single piece of ivory, represents one of the earliest known examples of aerodynamic tool-making, challenging previous assumptions that boomerangs were exclusively associated with later hunter-gatherer societies, such as those in Australia. Understanding the precise chronology of this site and the context of these discoveries is essential for reconstructing the behavioral and technological repertoire of early *Homo sapiens* in Central Europe.

This study seeks to enhance the chronological framework of Layer VIII at Obłazowa Cave by applying

high-resolution radiocarbon dating to faunal remains and the associated human fossil, providing a more precise temporal context for human occupation and cultural activities. We conducted Accelerator Mass Spectrometry (AMS) radiocarbon dating on 13 animal bone samples and one human phalanx. The samples underwent collagen extraction using advanced ultrafiltration protocols at the Bologna Radiocarbon Laboratory (BRAVHO) (Talamo, et al., 2021b) and were measured at the Laboratory of Ion Beam Physics, ETH Zürich. To ensure robust chronological assessments, we employed Bayesian modeling using OxCal 4.4, to refine the temporal placement of the occupation phase.

Our results indicate that the primary human occupation at Obłazowa Cave occurred between 42,640–34,970 cal BP, encompassing three distinct habitation phases linked to climatic fluctuations (GS-10, GI-9, and GS-8). The mammoth ivory boomerang, previously dated to an anomalously young age due to conservation treatments, is now indirectly estimated to date between 41,780–37,220 cal BP (68.3% probability), making it one of the earliest known examples of this tool type in Europe. The human phalanx yielded a direct radiocarbon age of 31,210 ± 155 ^{14}C BP, suggesting a minimum age due to possible contamination. Stable isotope analysis (δ^{13}C, δ^{15}N, and δ^{34}S) suggests a terrestrial diet with possible freshwater fish consumption. DNA analysis confirmed the human remains as belonging to *Homo sapiens*.

These findings contribute to a refined understanding of technological and symbolic developments during the Early Upper Paleolithic. The study underscores the significance of integrating radiocarbon dating, Bayesian chronological modeling, and multidisciplinary analytical approaches to reconstruct the cultural and environmental dynamics of early human groups in Central Europe. Our work provides a critical chronological anchor for evaluating the emergence of complex behaviors and material culture in the region.

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A05 SESSION

RADIOCARBON DATING OF LEAD CORROSION PRODUCTS IN FUNERARY CONTEXTS: EXAMPLES FROM THE CEMETERY OF GRANDMONT ABBEY AND THE COFFIN OF NOTRE-DAME DE PARIS CATHEDRAL

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Abstract: How to date a grave without bones?

In 2016, M. van Strydonck and co-workers presented the first radiocarbon dating of the corrosion products of a lead coffin. In the following years, other based-lead carbonates materials were successfully dated in different contexts: ancient cosmetics, lead white pigments and paints, mural paintings (Beck et al., 2018, 2020; Hendriks et al., 2019; Messager et al., 2021)

Absolute dating of lead white by the radiocarbon method have been developed quite recently. ^{14}C dating was made possible by the lead white synthesis process, based on the corrosion of lead in the presence of vinegar and horse manure (Gonzalez et al., 2019). Manure fermentation releases CO_2 which reacts with lead to form lead carbonates. By reproducing this process in the laboratory, it has been demonstrated that the produced cerussite ($PbCO_3$) and hydrocerussite ($2PbCO_3.Pb(OH)_2$ contain carbon of organic origin, allowing the absolute dating of lead white by the radiocarbon method (Messager et al., 2022, Beck et al., 2024).

In this study, a similar approach is proposed to date lead carbonates formed by *in situ* corrosion of lead-based materials in funeral context. Two case studies are presented.

The first deals with lead bottles found in burials in the cemetery of the Grandmont Abbey (France). Since 2013, a multidisciplinary team from the University of Picardie has been carrying out research on the site of the Grandmont Order's motherhouse. Lead was used extensively in the architecture of the abbey church, thanks in particular to the patronage of Henry II Plantagenet in the second half of the 12th century, who supplied large quantities of lead from England. When the monastery was founded around 1124, lead was chosen to make eulogy bottles, which were placed in contact with the bodies of the monks at their funerals. During the archaeological excavations, 45 bottles covered with corrosion products were found in the graves. Lead carbonates were taken during the restoration of 15 bottles for radiocarbon dating.

The second example comes from the recent ground excavation of the cathedral of Notre-Dame de Paris, carried out by INRAP. After the fire and during the restoration, two human-shaped lead coffins were

discovered beneath the ground, at the transept crossing. The coffins contained bones and lead corrosion products identified as cerusite by X-Ray Diffraction. Four samples of lead carbonates were taken from inside one of the sarcophagi for radiocarbon dating.

Samples were prepared by thermal decomposition (Beck et al., 2019) and measured using the AMS ARTEMIS/LMC14 in Saclay. The consistency of the dates obtained on both lead carbonates and bones (when available and preserved) confirms that lead carbonates are the result of the corrosion of the metal by organic substances, linked to the decomposition of the bodies. Successful results were obtained for the two sites, with different archaeological contexts (acidic soil in Grandmont and under the pavement the cathedral in Paris) and times (12th and 15th-16th centuries).

Thus, ^{14}C dating of lead carbonates gives access to the date of burial, and opens up new perspectives for dating graves even when bones are no longer present or poorly preserved.

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A05 SESSION

RADIOCARBON DATING THE FOUNDATIONS OF INCA CUSCO

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Abstract

Like many ancient capitals, Inca Cusco's origins are intertwined with myth and legend. While these narratives reflect historical events, they primarily served to legitimize the existence and expansion of the Inca state. By integrating these accounts with archaeological and historical records, scholars have developed a relative chronology of Cusco's foundation and growth. However, establishing absolute dates for key transformations remains a challenge.

Recent excavations at Sacsayhuaman, a monumental complex located within the urban center of Inca Cusco, provide a critical dataset for addressing this issue. A stratified sequence of radiocarbon samples, ranging from pre-Inca occupations to the colonial period, has been systematically collected. These samples, obtained from well-documented and securely dated contexts, enable the application of Bayesian modeling to refine the construction chronology of Sacsayhuaman.

This study combines radiocarbon dating with stratigraphic and architectural analyses to create a clearer timeline of the construction phases for this significant site. The findings will enhance the broader dialogue regarding the absolute dating of Cusco's foundation, offering new insights into the timeline of Inca state formation. Furthermore, details about the Sacsayhuaman foundation will be framed within the context of the Inca conquest in the Cordillera Vilcabamba, providing perspective on the reign of Inca Pachacuti Yupanqui during the height of the Inca Empire. By employing Bayesian modeling and precise calibration, a highly accurate sequence of events has been established. This research not only deepens our understanding of Inca urban development but also functions as a methodological model for dating extensive archaeological features within intricate stratigraphic contexts settings.

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A05 SESSION

MORTAR PETROGRAPHY AS A TOOL FOR ASSESSING CHALLENGES IN DETERMINING THE TRUE AGE OF THEIR PRODUCTION: IMPLICATIONS OF DEAD CARBON AND RECRYSTALLIZATION

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Abstract

The composition of mortars is crucial when it comes to the possibility of dating the age of a given structure. Usually, the composition of mortars is related to the local geological structure, as well as the chosen preparation technique and the purpose of the mortar itself. Knowledge of the local geological structure and its comparison with the petrographic composition of mortars greatly facilitates the interpretation of components carrying the so-called "dead carbon" (Caroselli at al., 2023; Hayen et al., 2016; Michalska et al., 2017; Nawrocka et al., 2005). Mortar composition is also often used to determine relative chronology if we have a long-standing history of a structure at a given site. The mortars components, especially carbonates, including magnesium and those that impart hydraulic properties to mortars, are of great importance in the preparation and dating of mortars. This article will show the different compositions of mortars and indicate their influence on the result of ^{14}C measurement (aging or rejuvenating age).

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A05 SESSION

RADIOCARBON INSIGHTS INTO THE INCA EXPANSION AT CORDILLERA VILCABAMBA

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Abstract

This study examines the urbanization processes that led to the construction of Machu Picchu, emphasizing the Inca conquest and the historical and environmental factors that shaped this development. A central research question concerns how the Incas reached and integrated the Machu Picchu region before transforming it into a significant urban and ceremonial center. The site's strategic location at the gateway to the Cordillera Vilcabamba- encompassing the Huayabamba and Vilcanota valleys- made it a crucial nexus in the Inca expansion into the eastern Andes.

To reconstruct this process, radiocarbon dating was applied to archaeological sites across the Vilcanota and Huayabamba valleys, revealing distinct phases of occupation and interaction among different groups. The analysis identifies a long sequence of human activity, with the colonial period representing the most recent transformation of the region. The results contribute to refining the chronology of Machu Picchu and its surrounding settlements, shedding light on the timeline and nature of the region's integration into the Inca state.

This research builds upon data from the Cusichaca Project and a decade of Polish-Peruvian archaeological investigations conducted in the National Archaeological Park of Machu Picchu. By synthesizing radiocarbon evidence with historical and archaeological data, this study offers new insights into the urban and political history of Machu Picchu, enhancing our understanding of its role in the broader Inca landscape.

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A05 SESSION

INTERDISCIPLINARY INVESTIGATION AND RADIOCARBON DATING OF THE ROMANESQUE WALL PAINTINGS OF SANTA MARIA ASSUNTA IN SORENGO (LUGANO, CH)

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Abstract

The church of Santa Maria Assunta in Sorengo, a small town near Lugano in the canton of Ticino (Switzerland), owes its present appearance to significant changes during its long history. In the 16th century, Franciscan monks built a convent and enlarged the church, transforming it from a modest structure into a larger monastic building with new cross vaults. Despite these Renaissance modifications, the interior of the building still preserves important elements of its original phase, dating back to the early 11th century. In fact, in the nave and in the attic, there are still large sections of Romanesque frescoes, precious evidence of the first construction. These frescoes were rediscovered in 1938 during the restoration work carried out by Emilio Ferrazzini. Later, in 1979, archaeological excavations carried out by the Canton of Ticino's Department of Cultural Heritage made it possible to reconstruct the main phases of the church's development.

Thanks to a recent collaboration between the Beate and Hans Peter Autenrieth Foundation and the Conservation and Restoration Unit of SUPSI (University of Applied Sciences of Southern Switzerland), the original Romanesque appearance of the church has been further studied. Students from the Conservation and Restoration course carried out a field study to analyse the techniques used to produce the Romanesque paintings. Archival research, stratigraphic analysis of the masonry and scientific analyses of the materials have enabled a more detailed reconstruction of the early appearance of the church. Radiocarbon dating applied for the first time provided scientific data that confirmed and refined the previously hypothesized chronology, which had been based solely on stylistic and iconographic analysis.

An interdisciplinary approach proved essential: architectural studies led to the discovery of two original wooden corbels from the Romanesque period, as well as the remains of the original bell tower, whose existence had been forgotten. The church was originally built in masonry so called “a pietra rasa”, then plastered and white painted. Petrographic analysis of plaster and mortar samples revealed the use of magnesian lime and local sand, materials typical of the region.

The Romanesque paintings can be divided into two phases. The first cycle of high artistic quality despite the use of simple materials, depicts the Annunciation and saints and shows clear Byzantine and Eastern influences. The second cycle, visible only in the attic, represents the Last Supper and was executed with a less refined technique, using a very thin layer of paint applied directly to the plaster.

Finally, radiocarbon dating of the mortar and wooden corbels confirmed the Romanesque origin of the church, helping to clarify the sequence of architectural changes and challenging some previous historical

and artistic interpretations.

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A06 SESSION

EXPLORING EXTREME SOLAR EVENTS THROUGH ANNUAL ^{14}C DATA IN TREE RINGS

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Abstract

Solar eruptions, such as solar flares and coronal mass ejections (CMEs), are the most energetic phenomena in the solar system. The disturbances that occur near Earth because of such solar activity are collectively referred to as space weather phenomena. These events can cause malfunctions in artificial satellites, increased radiation exposure at aviation altitudes, and even large-scale power outages and communication disruptions on the ground. In today's society, where dependence on electronic devices and space-based infrastructure continues to grow, the threat posed by space weather is becoming increasingly significant.

Meanwhile, evidence of extreme solar eruptions far exceeding those observed in recorded history has been found through analyses of cosmogenic radionuclides, such as carbon-14 (^{14}C) in tree rings, and beryllium-10 (^{10}Be) and chlorine-36 (^{36}Cl) in ice cores. These traces are characterized by sharp increases—spikes—in cosmogenic nuclide concentrations and may represent serious threats to modern civilization. Therefore, understanding the occurrence and characteristics of such extreme solar eruptions is of critical importance. To date, the search for such events has primarily been conducted using ^{14}C data from tree rings, and several cosmogenic nuclide spikes have been found e.g., in 774 CE, 993 CE, 664 BCE, and 7176 BCE, via analyses of ^{14}C in tree rings and of ^{10}Be and ^{36}Cl in ice cores.

We are currently conducting a long-term exploration of extreme solar events by analyzing ^{14}C concentrations in tree rings from Russia, Finland, and Japan, covering the period from the 5th to the 2nd millennium BCE. Such continuous measurements contribute to a more accurate understanding of the occurrence frequency of extreme solar events. In this presentation, we report the latest updates regarding our solar event exploration.

Acknowledgments

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A06 SESSION

CURRENT UNDERSTANDING OF MIYAKE EVENTS IN LIGHT OF THE EDINBURGH MEETING

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Abstract

Rapid increases in radiocarbon concentration in the atmosphere, or so-called Miyake Events, have sparked a revolution in radiocarbon dating and understanding of extreme space weather phenomena. To address ongoing challenges around the causal mechanism(s) and occurrence frequency of such events, as well as their utility for radiocarbon dating, a two-day Royal Society Theo Murphy meeting was organised in Edinburgh in May 2025. The meeting brought together solar and isotope physicists, chronologists and historians in a rare interdisciplinary effort to reach a consensus on the current state-of-affairs on this topic. In this presentation, I would like to summarise the key findings of the meeting. This will entail a summary of what can and cannot yet be said about Miyake Events, a discussion of some of the latest isotope and accompanying data, some observations about best practices for the use of these events for chronology, and an overview of the direction in which this field of research is now heading.

Acknowledgments

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A06 SESSION

RECONSTRUCTING LONG-TERM SOLAR ACTIVITY FROM A MULTI-CENTENNIAL RADIOCARBON DATASET

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Abstract

Annual-resolution radiocarbon (^{14}C) chronologies have recently garnered attention as potential proxies for reconstructing solar variability patterns, and their geophysical linkages across historical periods. This study analyses multi-centennial ^{14}C datasets from annual tree rings in the first millennium CE measured by Curt-Engelhorn-Center for Archaeometry (CEZA) as part of the HISCAR project. A comparative analysis with the IntCal20 calibration curve shows that the dataset remains within the 2σ uncertainty interval throughout the study period, except for short periods of minor deviation. Using the open-source carbon box modelling program, ticktack[1], and non-stationary signal analysis tools, we quantitatively reconstructed ^{14}C production rates and identified three key findings: (1) A persistent 11-year Schwabe cycle dominates the solar signal. (2) A possible grand solar minimum (GSM) occurred between 200 CE and 260 CE. (3) Analysis with further data from the first millennium BCE suggests some long term trends in the 22-year Hale cycle. Future work within the HISCAR project will expand this dataset and include the computation of solar modulation parameters. These findings, along with future developments, will contribute to a deeper understanding of long-term solar activity.

Acknowledgments
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A06 SESSION

HOW THE CHRONOLOGICAL CHALLENGES PRESENTED BY THE HALLSTATT PLATEAU MAY BE OVERCOME

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Abstract

The mid-first millennium BCE was a significant period worldwide. For instance, in large parts of Europe it corresponds to the last phase of prehistory (Iron Age), in China to The Spring and Autumn Period and it is one of the most eventful periods in the Bible. However, the Hallstatt Plateau creates a major dating uncertainty in ^{14}C dating for this time period, making it hard to determine exactly when important events or transitions happened by using this dating method.

This presentation discusses ideas to obtain nevertheless high-resolution dates from this period, focusing on wood samples with multiple growth rings which are not suitable for dendrochronological dating. One method involves the Miyake Event in the 660s, by using it as an anchor point to wiggle match series of ^{14}C dates from tree ring samples to the exact calendar year. A new dataset of ^{14}C analyses of known-age wood over the 660s Miyake Event that was carried out at the Centre for Isotope Research, University of Groningen, will be presented. Another method that can be used in conjunction involves developing oxygen isotope chronologies for wood from 8th to 5th century BCE. The oxygen isotope signal in alpha cellulose of tree-rings is influenced by water sources and humidity. Long sequences of tree-ring $\delta^{18}O$ values have been effectively used to date archaeological timbers. By unifying these chronometric approaches, we believe that the dating obstacles presented by the Hallstatt Plateau may be overcome.

Acknowledgments

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HIGH-PRECISSION ^{14}C DETERMINATIONS FROM *FITZROYA CUPPRESOIDES* TREE-RINGS BETWEEN 3,200-1,500 CAL YRS BP IN SOUTHERN CHILE (~41.5 °S)

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Abstract

Calibration is a key component of radiocarbon dating. However, the current Southern Hemisphere (SH) calibration curve, SHCal20, is still based on limited raw data (Hogg et al., 2020). Here we present 209 new ^{14}C age determinations from two dendrochrologically dated Fitzroya cupressoides (Alerce) tree.ring series from the Lenca site in southern Chile (41°33'S, 72°35'W), for which a robust tree-ring chronology has been established (Lara et al., 2020). Tree-ring holocellullose has been dated at quinquennial or decadal resolution between 3,200-1,500 cal yrs BP, extending the SH atmospheric ^{14}C record by ~1,000 years. In addition, single-year tree-ring were analyzed between 2,620–2,600 cal yrs BP, providing the first SH record for the ~2,610 cal yrs BP Miyake event. In total, 30 replicates were analyzed, for which 27 are statistically indistinguishable at the 95 % confidence interval.

In the time span covered by the Alerce dataset, two other dendrochronologically dated tree records have been ^{14}C-dated in the SH (Hogg et. al., 2011; Zimmermann et al., 2010). Between 1,595-1,505 cal yrs BP, these records fall within 1σ or 2σ of the Alerce ^{14}C ages. However, between 2,145 and 1,595 cal yrs BP, a direct comparison is not possible, as the decadal Alerce series represent different years. For this interval, over 95% of the decadal Alerce determinations are within the 1σ envelope of SHCal20, with an average offset from the mean of ~4 yrs. Furthermore, between 3,200-2,145 —where the curve was constructed without any SH raw data— the Alerce ^{14}C ages remain within the 1σ envelope, but values are generally closer to its older limit, with a mean offset of ~20 yrs. This suggests that while the SHCal20 model is well-constructed, there is still potential for improving its precision.

Single-year tree-ring ^{14}C determinations between 2,620 and 2,600 cal yrs BP, caracterizing the Miyake event, display Δ14C peak values comparable to those observed in the Northen Hemispehre (NH; e.g., Park et al., 2017), although with a different Δ14C peak structure. This difference may arise from dendrochronologies uncertainties, trees biology, site conditions, or to interhemispheric differences related to the event's origin.

The good reproducibility of de data, along with consistency between the Alerce series and previous SH and NH datasets, highlights the robustness of this dataset and its potential to contribuite to the extension and refinement of the SHCal calibration curve.

Acknowledgments

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A06 SESSION

ANNUAL ATMOSPHERIC $\delta^{14}C$ VARIATION IN EASTERN CHINA FROM 1850 TO 1933

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Abstract

The ^{14}C content preserved in tree-rings serves as a valuable proxy for inferring past solar activity, natural carbon cycle variations, and anthropogenic impacts. However, existing pre-bomb tree-ring ^{14}C records are primarily limited in high-latitude regions, hindering our understanding of temporal evolution of ^{14}C concentration from a global perspective.

We have collected tree-ring samples in Eastern China, a region located in NH zone 3 of worldwide atmospheric $\Delta^{14}C$ distribution (Hua et al. 2021) and where $\Delta^{14}C$ levels was assumed to be significantly influenced by maritime air masses. The samples are dendrochronologically dated and sliced into annual rings for AD 1850-1933. Then the samples are pretreated to obtain holocellulose and measured $\Delta^{14}C$ values in the Laboratory of AMS Dating and the Environment of Nanjing University, China (Lin et al. 2024; Zhang et al. 2024).

Annual tree-ring $\Delta^{14}C$ datasets of the same period from other high-latitude regions and calibration curves IntCal20 (Reimer et al. 2020) are compared with ours. We found no significant regional offset compared to the IntCal20 data. However, our record exhibits a weaker solar activity signal compared to those from high-latitude regions. These findings enhance our understanding of the global distribution of ^{14}C.

Acknowledgments

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A06 SESSION

RADIOCARBON AGE VALIDATION IN SUPPORT OF HERB-CHRONOLOGY OF BELOWGROUND WOODY ORGANS IN SPECIES OF THE BRAZILIAN SAVANNA

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Abstract

The Brazilian savanna, or Cerrado, exhibits a diverse array of woody species. In the case of some small plants, the presence of belowground organs ensures the persistence of those native species in areas where fires, frost, or large herbivores can recurrently suppress the aboveground biomass (Pausas et al., 2018; Pilon et al., 2021). In the absence of an aboveground component to help on estimating the ages of those lineages, herbchronology using the ring-like patterns of the belowground woody growth have been used (Hiebert-Giesbrecht et al., 2018). In this study, we used the species Campomanesia adamantium (Cambess.) O.Berg (Myrtaceae) as a model to analyse whether the growth rings of the woody belowground organs were formed annually, and if the age estimations (based on annual growth increments) were also correct. The aboveground portion of this species grows no taller than 1.5 meters on average, while its belowground may have multiple branched roots which is believed can aid in vegetative propagation. The belowground organs of C. adamantium was classified as xylopodium (Chiminazzo et al., 2023).

Two short shrub-like plants of C. adamantium were entirely uprooted during July/2024 field campaign at a savanna reserve in southeastern Brazil (22°48'59"S, 49°14'12"W). The first one contained a single belowground wood organ of about 1 m x Ø6 cm, while the second one showed six belowground wood organs of about 50 cm x Ø3-10 cm each. The samples were sectioned into disks slightly below the root collar, polished using sandpapers to enhance the visibility of growth layers, which were subsequently counted to determine the age (Stokes and Smiley, 1996). The radiocarbon (^{14}C) analyses followed the methods of Santos et al. (2023). In the case of the single root sample, we isolated the strategic rings for the years 1974 (pith), 1976, 1977, and 1978 based on preliminary dating to determine the annual variation in the years with the greatest change in F14C relative to the plant's age. For the plant with multiple roots, we dated for each root both the pith portion and the outermost ring, near the bark.

Herbchronology analysis of the single root plant determined that it could be as old as 49 years (i.e., 1974-2023). However, ^{14}C results suggested an offset of about 5 years (i.e., 1979-2023). Regarding the plant with multiple roots, by classical dendrochronological dating, we assigned the date of the outermost ring to the year 2023, considering that the growing season begins in October of the current year and ends in April of the following year (Schulman, 1956). Through ^{14}C dating of the pith and outermost ring

of six cross-sections from the belowground wood organs of the second C. adamantium plant, we discovered that some roots have ceased growth for up to a decade. This finding was possible thanks to the combination of the two dating techniques. Studies on xylopodium growing in the Cerrado have shown that when a root cannot overcome obstacles in the soil, it suspends its growth and is replaced by a lateral root (Rizzini, 1965). In other studies, evidence has shown that xylopodium can remain dormant for decades until favorable growth conditions are reestablished (Faleiro et al., 2022). Additionally, the formation of new roots can be influenced by chemical signals in the plant and soil, such as hormones and the presence or absence of essential nutrients (Beeckman and Eshel, 2024). Our study highlights the need to expand research on savanna species age distribution and age-related patterns for a better understanding of their survivorship curves in the current state of the Cerrado ecosystem.

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THE RADICAL PROJECT: TRACING FOSSIL FUELS WITH ^{14}C — A SCALABLE APPROACH TO BIOMONITORING AND BIOREMEDIATION

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Abstract

Aquatic environments, whether coastal, estuarine, or freshwater, are often located near densely populated and industrialized areas, making them particularly susceptible to pollution. The impacts of such contamination can lead to long-term environmental degradation, public health risks, and significant economic and social consequences. In Brazil, for example, the metropolitan region of Rio de Janeiro is renowned for its striking contrast of urban development and natural beauty. One of its most prominent water bodies, Guanabara Bay, is a tropical estuary affected by multiple sources of pollution, including untreated domestic sewage, industrial discharges from pharmaceutical facilities, heavy ship traffic, refineries, and oil and gas terminals. Both direct anthropogenic inputs and indirect sources, such as those transported by rivers, play a critical role in introducing and retaining not only nutrients but also harmful substances like hydrocarbons and heavy metals.

Despite decades of scientific research and environmental monitoring, effective remediation strategies remain insufficient. In this context, biological materials in aquatic environments offer dual advantages: they can act as bioindicators of contamination and, in some cases, actively contribute to the physical and chemical removal of pollutants. Therefore, understanding how oil pollution affects algal communities across different sites using a variety of analytical proxies is essential for advancing both biomonitoring and bioremediation strategies. This work aims to share with the radiocarbon community results from The RADICAL Project, which applies radiocarbon accelerator mass spectrometry (^{14}C-AMS) for biogenic fraction determination in algae exposed to fossil-derived contamination.

The project was carried out through a partnership between the Radiocarbon Laboratory (LAC-UFF) and the innovation-driven company Infinito Mare, beginning with controlled indoor experiments using radiocarbon and n-alkane analyses to evaluate fossil fuel contamination in algal samples (Silva et al., 2021; Tremmel et al., 2025a, 2025b). In the second phase, outdoor tests were conducted using a low-cost prototype based on Algal Turf Scrubber (ATS) systems to assess the biomonitoring potential of algae across three urban coastal environments: a shellfish farming area, a recreational beach, and a central ferry terminal. Fossil contamination was detected at all locations, with the highest levels observed near the ferry terminal (biogenic carbon fraction ~50%). The elemental study of the algae also revealed a significant spectrum of accumulated metals that indicated a positive correlation with the fossil source, such as cadmium, copper, vanadium, manganese, and iron, suggesting that these may originate from similar sources. These findings confirm that algae can serve as effective biomonitors and represent a promising nature-based solution for the bioremediation of metal and oil-contaminated waters.

Preliminary results from the third phase of the project, developed in collaboration with São Paulo State University (UNESP), will also be presented, highlighting possible conversion of harvested biomass into bioproducts through Green-RDF (Refuse-Derived Fuel) technology, contributing to circular economy practices and the development of clean, renewable energy sources.

Acknowledgments
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A06 SESSION

DATING THE MT. MAZAMA ERUPTION TO A CALENDAR YEAR USING SINGLE YEAR TREE-RING ^{14}C

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Abstract

The caldera-forming eruption of Mount Mazama which formed Crater Lake, Oregon, was one of the largest volcanic events of the Holocene. It has a calculated magnitude of 7.1 and an eruption volume of over 60 km3 Dense Rock Equivalent. Volcanic ash from the eruption spread to the northeast, across a wide region of the western USA and Canada as a visible fall deposit, with cryptotephra found in Newfoundland and Greenland. These deposits provide an invaluable temporal marker for a wide range of environmental and archaeological studies in the wider region as well as connecting with a specific volcanic sulfate layer in the Greenland ice cores. Obtaining an absolute, calendar secured date for this eruption therefore is important for a wide range of studies. Recent ice-core age estimates for the event place it around 7572-7562 BP and large radiocarbon modeling studies based on a wide range of charcoal samples and palaeosols associated with the Mazama ash place it c. 7682–7584 cal BP (95.4%). Carbonized wood samples with an intact bark edge were obtained directly from primary pyroclastic flow deposits from the eruption. The tree-rings were matched together using patterns of growth derived from regional climate forcing but could not be calendar dated by this standard dendrochronological approach. Using the ice-core date range associated with the Mazama ash as a guide to target the approximately correct time range, we dissected single years of calendar dated bristlecone pine and produced a single year ^{14}C reference curve. We then dissected single years of the carbonized wood. All samples were run at very high precision at ETH Zurich. The datasets matched with good agreement allowing us to date the eruption to an exact calendar year.

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A06 SESSION

REFINEMENT OF THE ^{14}C-BASED AGE DETERMINATION OF THE ALPINE GLACIER MUMMY ÖTZI

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Abstract

The Neolithic glacier mummy named Ötzi was found in 1991 along with his equipment at the Alpine pass Tisenjoch in Italy at the border with Austria at about 3200 m asl. He is one of the oldest mummies worldwide and is used as a reference for archaeological as well as environmental and climate studies. Ötzi's age determination is based on a series of ^{14}C dates carried out on the mummy's own bones and tissue, but also on samples of his equipment. However, even highly precise radiocarbon age determinations yield large calibrated age ranges due to a pronounced plateau in the calibration curve, i.e., Ötzi has been dated to 3368-3108 BCE so far (Kutschera and Müller, 2003).

Here, we aim to refine the age of Ötzi by combining computer tomography documentation, tree-ring analyses and new radiocarbon dates, as well as using a new series of ^{14}C ages obtained on single-year tree-ring samples, covering the period from 3450 to 3050 BCE. The tree-ring analyses focused on the unfinished bow as part of Ötzi's equipment and allowed the establishment of a tree-ring width series comprising more than 70 values. Three wood samples for radiocarbon analyses were taken from the bow, with a fixed reference to the tree-ring series. This, together with a new ^{14}C date from Ötzi's tissue, enabled the application of the wiggle-matching approach. Combining this with the use of the improved calibration curve and the assumption that he died a few years after the end of the tree-ring series, Ötzi's death can be dated to around the second half of the 32nd century BCE.

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A03 SESSION

AGE AND PROCESS OF RIVER PATTERN TRANSFORMATION FROM MACROMEANDERS TO SMALL MEANDERS – CASE STUDY FROM RIVER VALLEYS IN HOLY CROSS MTS. REGION

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Abstract

Large meander (macromeanders) of very large width and radius are described from very numerous European Valley as a transitional stage between braided rivers, typical of the Younger Pleniglacial and meander rivers, typical of the Holocene. In most valleys, they functioned in the Late Glacial, locally with a break in the Younger Dryas, and in the Preboreal they were replaced by meander channels with parameters several times smaller (Kalicki 2006 there literature). Although the age of this change is relatively well recognized, the transformation process has not been described so far. Studies of the Holy Cross Mts. region (Świętokrzyskie) valleys allowed the formulationof a hypothesis how this transformation.

Large meander has been recognized so far in several Świętokrzyskie valleys, e.g. Czarna Nida (Kalicki et al. 2012), Czarna Staszowska (Kalicki et al. 2016), Czarna Konecka (Kalicki, Kusztal 2021). OSL, radiocarbon and palynological Datong of their plastic-organic fill and sandy point bar indicate that they functioned in the Late Glacial, perhaps from the end of the Younger Pleniglacial (Czarna Konecka: cut off 14 100±120 BP), and their activity ended at the beginning of the Holocene. In most valleys, the cut off large meanders occurred as a results of neck cut off, the traces of which have been preserved in the relief. However, in the Czarna Nida valley near Ostrów (Krupa 2015) and Czarna Konecka near Małachów – in the relief within the macromeanders, winding systems of small palaeomeanders are visible, indicating the use of this floodplain area by rivers in the Holocene. Initialy, it seemed to be a secondary incursion of streams, but the results of detailed studies in the Czarna Konecka valley indicate a different mechanism.

Between Wąsosz and Małachów, compact fragments of terrace II are preserved with circular undercuts of terrace III, indicating the meandering pattern of the river. In the Małachów area, three large palaeomeanders up to approx. 100 m wide are visible in the relief, radii-curvatures of 100-200 m. These palaeochannels are accompanied by 1-2 m higher point bar zones (Czarna 31: OSL 12.8±1,9 ka and 11.8±1,8 ka) with clearly visible inter-bar depressions and point bars, indicating lateral migration of the river. Within the large radius palaeochannels, the are four systems of small palaeomeanders consisting of several (4-9) bends. Their parameters are many times smaller, the average width of the channels is 8 m (4.75-10.4 m), and the radius is 22.2 m (18.2-26.3 m).

In the western part of study area, within the macromeander palaeochannel, tere are several cut and fill created Turing the functioning of small meanders. The peat bottom (215 cm) from the fill of the deepest

of these small meanders (Trumna) was dated to 8900±90 (MKL-6328) cal. 8280-7747 BC. In the eastern part, the A system of small meanders was abandoned before 6670±70 BP (MKL-5890) cal. 5712-5480 BC, and in peat fill there is an inserted of sandy colluvia poured after 2160±60 BP (MKL-5891) cal. 371-50 BC.

The results of the research indicate that the large meanders were not cut off, but along with the hydrological and climatic changes at the beginning of the Holocene, the channel narrowed and deepened. Within the wide and shallow beds of the macromeanders, narrow and deeper meandering channels with small parameters began to function. Their lateral migration in the Eo- and Mesoholocene (up to middle Atlantic) transformed these Late Glacial beds: creating the Holocene cut and fill within them, caused undercutting point bar of macromeanders. There is clearly visible in contemporary relief. The river withdrew from this part of the floodplain in the late Atlantic, and the area became peat bogs. Presented scheme shows a new way of transformation of the fluvial system, changes in channel pattern and floodplain relief in the Holocene.

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A03 SESSION

MAYA CULTURAL DECLINE RECORDED IN A SPELEOTHEM DEAD-CARBON DECREASE, YUCATAN, MEXICO

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Abstract

The dead-carbon fraction (DCF) in speleothems reflects the relative contributions of modern versus aged soil-derived $^{14}CO_2$ to the $^{14}CO_3^{2-}$ content of karst waters during limestone dissolution. In a theoretical closed-system scenario, DCF values are expected to reach approximately 50% depletion relative to atmospheric ^{14}C. However, aged soil CO_2 can lower the DCF further, while increased system openness—via exchange with atmospheric or soil CO_2 during dissolution—can reduce DCF to only a few percent. Therefore, DCF serves as a sensitive proxy for the degree of system openness and soil-CO_2 dynamics, which are in turn influenced by vegetation cover and soil thickness.

Here, we present high-resolution ^{14}C data from a speleothem collected in northeastern Yucatán (Áaktun Kóopo Cave), that extend across the Terminal Classic Period (TCP) of the Maya civilization. Two analytical methods were employed: (1) conventional AMS measurements on graphite targets, and (2) gas-source ^{14}C analysis on micro-drilled carbonate samples. Both techniques yielded consistent results, with gas-source measurements enabling the detection of rapid, decadal- to centennial-scale changes in DCF.

DCF values varied between 24.8 ± 0.3% and 8.6 ± 0.3%, while $\delta^{13}C$ values ranged from −6.3‰ (828 CE) to −12.2‰ (1192 CE). Measurement uncertainties were approximately 0.3% for conventional AMS and 0.7% for gas-source data, supporting the robustness of observed trends. Notably, both DCF and $\delta^{13}C$ declined markedly during the TCP, indicating concurrent shifts in soil CO_2 production and karst system openness. These changes, though lacking direct evidence of ancient agriculture above the cave, may reflect a cessation of agricultural activity that coincided with the regrowth of natural vegetation during the decline of Maya civilization.

A03 SESSION

MONITORING AND MODELLING OF ATMOSPHERIC $^{14}CO_2$ OVER SWITZERLAND

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Abstract

Anthropogenically-induced climate change is inextricably linked with perturbations to the carbon cycle brought on by emissions of greenhouse gases, particularly carbon dioxide (CO_2), derived predominantly from fossil fuel utilization. ^{14}C serves as a quantitative tool for the distinction of carbon-containing material from fossil compared to modern sources. With this, a few ppm of fossil CO_2 can be detected and quantified within the current ambient CO_2 concentration of ~420 ppm so that local and regional emissions of fossil CO_2 may be monitored. We determined the fraction of biogenic and fossil CO_2 emissions using ^{14}C at different locations in Switzerland within the SNSF project *Radiocarbon Inventories of Switzerland (RICH)*. The overarching goal of this project was to use ^{14}C to derive novel constraints on carbon exchange between terrestrial and aquatic reservoirs and the atmosphere at regional scales. We present here the outcome of the study of atmospheric $^{14}CO_2$ within the carbon cycle of Switzerland.

Over 2021-2023, we measured atmospheric CO_2 concentrations as well as their respective ^{14}C content at four rural sites and one urban site of the Swiss Plateau (*i.e.*, the flatlands from Lake Geneva to Lake Constance) and at the high-elevation alpine background site Jungfraujoch. Sampling of dried air into PE-Al-PE bags for an hour was performed biweekly. At Jungfraujoch, integrated sample collection over two weeks was performed only sampling around nighttime each day. For this, the self-developed Jungfraujoch Air Sampling System (JASS) was installed. In total, more than 400 air samples were collected, the CO_2 was extracted and measured for $\Delta^{14}C$ at the Laboratory for Ion Beam Physics (LIP) at ETH Zurich and the Laboratory for the Analysis of Radiocarbon with AMS (LARA) at the University of Bern. Measurements were compared to atmospheric simulations using the Lagrangian transport model FLEXPART-COSMO and based on Swiss and European CO_2 anthropogenic emission inventories, simulated biosphere-atmosphere exchange of CO_2., and sector-specific ^{14}C signatures.

The measurements of CO_2 and $\Delta^{14}CO_2$ revealed a statistically significant fossil CO_2 contribution for both, the rural and the urban sites, compared to the background at Jungfraujoch. As expected, the fossil CO_2 excess was higher at the urban compared to the rural sites on the one hand and larger in winter than in summer at all sites on the other hand. The comparison of the CO_2 and $\Delta^{14}CO_2$ measurements with atmospheric simulations showed an excellent agreement in winter, whereas an underestimation of biogenic CO_2 concentrations was observed during early summer. This deviation was attributed to an insufficient representation of biospheric fluxes within the model, which requires further improvement.

Acknowledgments

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A03 SESSION

DEVELOPMENT OF A VERSATILE α-CELLULOSE-CAPABLE AUTOMATED PRETREATMENT SYSTEM FOR RADIOCARBON AND STABLE ISOTOPE ANALYSIS

John du Plessis[1*], Jian Wang[1*], Sybren Couwenberg[1], Dipayan Paul[1,2], Marcel de Vries[1], Michael Dee[1]

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Abstract

α-cellulose has proven to be a reliable and widely used constituent of wood for recording tree ring isotope signatures. The extraction of α-cellulose from tree rings is crucial to reconstructing past atmospheric radiocarbon concentrations and allows for a number of other isotopic analyses. High precision accelerator mass spectrometry (AMS) radiocarbon dates of tree-ring α-cellulose facilitate refinements to the radiocarbon calibration curve as well as the study of single-year anomalies and other processes influencing the atmospheric radiocarbon record. Despite advances in pretreatment, α-cellulose extraction remains a labour-intensive process, typically involving a number of reagent washes and many rinses with demineralised water[1]. These steps have a large impact on the speed, cost and throughput of tree ring isotope analyses, and would thus benefit greatly from automation. We present a prototype of an automated pretreatment system capable of performing α-cellulose extraction with enhanced functionality, including reactions with up to four different reagents at controlled temperatures and ultrasonication under a controlled atmosphere. This automated system represents a significant advancement in α-cellulose extraction, reducing the labour investment and increasing sample throughput. By ensuring consistent and efficient sample preparation, this system has the potential to enhance the accuracy and reproducibility of radiocarbon and stable isotope analyses of tree rings.

Acknowledgments

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A03 SESSION

A NEW DYNAMIC MODEL OF ATMOSPHERIC RADIOCARBON TRANSPORT IN APPLICATION TO EXTREME SOLAR PARTICLE EVENTS

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Abstract

Extreme solar particle events (ESPEs) are rare but impactful phenomena capable of producing significant enhancements in cosmogenic radiocarbon ^{14}C concentrations in the Earth's atmosphere. Their signatures, aka Miyake events, can be identified in annually resolved natural archives, most notably tree rings, providing critical insights into the history of solar activity and forming clear tie points in the chronology. At present, nine such ESPEs are identified, mostly during the Holocene, but one was ca. 14300 BP. The latter is identified as the strongest presently known ESPE. Modelling and full analysis of such events is challenging as the standardly used quasi-static carbon-cycle box model is not well suited for fast events, especially beyond the Holocene conditions.

We present a brand new fully dynamical chemistry-climate model, SOCOL:^{14}C-Ex based on SOCOL-AERv2 (Uusitalo et al., 2024; Golubenko et al., 2025), to model the radiocarbon atmospheric transport. It explicitly simulates ^{14}C production by either solar energetic particles (SEPs) or galactic cosmic rays, full dynamical transport in the atmosphere, and a simplified sink to surface water and biosphere at any location around the globe.

The model utilizes the Gaussian transform horizontal grid with the T42 triangular truncation (64 latitudes and 128 longitudes), splitting the model space into grid cells of about 2.8° ×2.8° in size. The model's vertical-direction grid consists of 39 levels in the hybrid sigma-pressure coordinate system, covering altitudes ranging from the ground surface to about 80 km (0.01 hPa). The real orography is smoothed over the model grid cells (Stenke et al., 2013). The model consists of the general circulation module MA-ECHAM5 (Hommel et al., 2011) and the atmospheric chemistry module MEZON (Egorova et al., 2003), which exchange information every two modelling hours. The model includes advective and diffusive transport as well as dry and wet deposition of ^{14}C.

The model reproduces the temporal and spatial evolution of atmospheric ^{14}C concentration on short timescales (up to 7—10 years), enabling robust estimation of the strength and timing of an ESPE, for various climatic and geomagnetic conditions. The model was applied to analyse the strongest ESPEs of 14300 BP (Late Glacial) and 1175 BP (775 AD, Holocene). It was shown that the radiocarbon response, $\Delta^{14}C$ to an ESPE is defined mostly by the ESPE strength, geomagnetic dipole intensity, and the ambient CO2 content in air. The regional variability of the $\Delta^{14}C$ response is within 1 ‰. This model allows to analyse ESPEs also beyond the Holocene, for the first time. A full analysis of the 14300 BP event revealed that the ESPE was 18±11% stronger than the 775 AD one and likely occurred between Jan—Apr 14300 BP. This event is the only ESPE known beyond the Holocene and currently the strongest detected, forming a new benchmark for extreme solar activity.

The new model enables systematic modelling and analysis of past ESPEs, also beyond the stable Holocene climate conditions. The model can be applied to any specific time (provided independently

assessed geomagnetic field and paleoclimate parameters) and location. This establishes a new way to reconstruct the parameters of the parent extreme solar events (strength and occurrence time) over millennia.

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A03 SESSION

COMPARING SIMULATED MARINE RESERVOIR AGES OF THE NON-POLAR SURFACE OCEAN BETWEEN DIFFERENT MODELS UNDER CONSIDERATION OF ABRUPT CHANGES IN THE ATLANTIC MERIDIONAL OVERTURNING CIRCULATION DURING THE LAST 55 KYR

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Abstract

The marine reservoir age (MRA) of the non-polar surface ocean is an important information used for the establishment of age models for marine sediment cores and/or artifacts found in latitudes <50°. This MRA is dependent on the underlying radiocarbon calibration curve. For the most recent one, IntCal20, this MRA (Marine20) was directly calculated from the atmospheric $\Delta^{14}C$ record using a carbon cycle box model, that considered observed changes in the carbon cycle, but neglected changes in the strength of the Atlantic meridional overturning circulation (AMOC) related to Dansgaard/Oeschger and Heinrich events. A recent study (Köhler et al., 2024) suggested that abrupt AMOC changes would lead to changes in MRA of less than 100 ^{14}C yrs in the non-polar surface ocean. Although this is within the uncertainty range of Marine20, the effects of abrupt AMOC changes have not been considered during the calculation of the uncertainties in Marine20, which might add additional uncertainties to the calculated MRA. Abrupt AMOC changes might thus be considered in the next iteration of IntCal. To better constrain the impact of AMOC changes on MRA we here compared these previous box model results with the output from three Earth System Models of Intermediate Complexity (EMICs) over the last 55 kyr. The applied models are LOVECLIM, Bern3D, ClimberX. The setups of the models are not identical, but all models are forced by atmospheric CO_2 and $\Delta^{14}C$ to have the surface ocean carbon cycle as close as possible to reconstructions. We find that the size of the abrupt AMOC changes in the EMICs is also in the order of less than ±100 ^{14}C yrs with Bern3D simulating changes up to ±200 ^{14}C yrs. While the models tend to agree that a reduced AMOC leads to smaller MRA in the non-polar surface ocean, under some conditions the opposite is found (e. g. simulations with LOVECLIM across the Heinrich 1 event). Thus, the amplitude of the AMOC-related changes in the non-polar surface ocean MRA are indeed to a certain degree model-dependent and one needs to discuss how these findings are implemented in the next iteration of IntCal. For a better evaluation model results are also compared with data for the surface and deep Atlantic Ocean, since this is the area most important for AMOC changes, and best covered by data.

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A07 SESSION

USERS' LABORATORIES AND ^{14}C DATING OBJECTS OF CULTURAL HERITAGE

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Abstract

Radiocarbon dating is a great tool for dating objects of cultural heritage. Many laboratories provide the analysis to the non-public or commercial sector, such as the antiquities market, art research laboratories, art collectors, and private persons. More than a decade ago, the Society of Africanist Archaeologists (SAfA) sent a message to the radiocarbon community about the effect of commercial analysis on the looting of heritage sites (Huysecom et al., 2017). The petition issued during the 21st International Congress of SAfA in Toronto, 2012 reads: „In order to preserve the African cultural heritage and prevent its looting, SAfA urges C-14 dating laboratories to stop dating African artefacts. In particular, for ethical reasons, C-14 dating laboratories should not provide any dating of samples from archaeological or ethnographic items commissioned by dealers, auction houses or individuals". In response to this petition, guidelines have been established by the radiocarbon community (Hajdas et al., 2019). The current geopolitical situation shows that the call must be extended to the whole world. To prevent misuse of radiocarbon analysis, radiocarbon laboratories must follow the guidelines and stop accepting undocumented samples.

In this paper, I will share my experience that I had with users who attempt to date samples that are poorly documented. Moreover, I will address the issue of extending the due diligence documentation check to paintings and other precious objects. Finally, I will address the challenges of dating precious art objects and show a few examples of radiocarbon results questioned by disappointed customers.

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INVESTIGATING THE USE OF IR SPECTROSCOPY TO IDENTIFY WOOD CELLULOSE FOR RADIOCARBON DATING

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Abstract

Trees are fundamental to human survival and progress, serving as essential resources throughout history. From early societies to modern civilizations, they have provided materials for shelter, tools, transportation, and fuel. The development of ancient societies was often closely tied to forests, which supplied wood for construction, shipbuilding, and daily implements (Milks et al., 2023; Yonenobu and Tsuchikawa, 2003; Florindi et al., 2024). Beyond their practical uses, trees hold profound symbolic and spiritual significance in many cultures, representing life, wisdom, and resilience (Ferrara et al., 2024). Moreover, their preserved remains continue to shape historical and environmental research, offering invaluable insights into ancient timelines, climatic shifts, and human activity. Tree rings serve as natural archives of past environmental conditions, while their organic material provides a crucial foundation for radiocarbon dating, one of the most reliable methods for establishing absolute chronologies in archaeology (Reimer et al., 2020; Talamo et al., 2023a; 2023b). By analyzing the carbon isotopes in ancient wood, scientists can precisely date artifacts, settlements, and cultural transitions, refining our understanding of human history and the broader prehistoric world. A major challenge, however, is that radiocarbon dating is a destructive method, requiring the removal and chemical pre-treatment of a portion of the wood sample necessary for the ^{14}C age determination (Cercatillo et al., 2021). This process permanently alters or consumes the analyzed material, posing a significant dilemma for archaeologists, especially when working with rare or culturally significant wooden artifacts.

Therefore, sampling must be minimized as much as possible while still ensuring accurate ^{14}C measurement. To address this issue, this study explores the potential of infrared (IR) spectroscopy as a non-invasive diagnostic tool for assessing cellulose preservation in archaeological wood specimens before radiocarbon dating.

This study builds upon the recent research by Malegori et al. (2023), which employed near infrared hyperspectral imaging (NIR-HIS) to assess collagen preservation in prehistoric bones for radiocarbon dating. While their work focused on the creation of collagen mapping in bone samples, this current study extends the use of infrared spectroscopy to focus on archaeological wooden artifacts. Infrared spectroscopy (IRS), including Fourier Transform Infrared (FTIR) and Near-Infrared (NIR) techniques, was applied to a set of well-characterized archaeological wood samples with varying degrees of cellulose preservation. Secondarily, qualitative spectral analysis was integrated with chemometric analyses, including Principal Component Analysis (PCA), to enhance spectral interpretation.

Additional research is focused on the creation of predictive models for cellulose quantification and mapping cellulose distribution within artifacts to enhance conservation efforts and ^{14}C dating accuracy.

Finally, this study aims to highlight the potential of NIR spectroscopy as a rapid and non-destructive technique for evaluating the suitability of wooden artifacts to radiocarbon analysis. Through the combination of IR spectroscopy with advanced analytical techniques, the ultimate goal of this research is to establish a reliable screening method and sampling strategy, reducing material loss while ensuring precise and accurate ^{14}C measurements, particularly for rare and valuable wooden artifacts.

Acknowledgments

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A07 SESSION

RADIOCARBON SAMPLE ARCHIVES AND THE NATIVE AMERICAN GRAVES PROTECTION AND REPATRIATION ACT (NAGPRA): WHAT WE'RE DOING AT THE CENTER FOR APPLIED ISOTOPE STUDIES, UNIVERSITY OF GEORGIA

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Abstract

NAGPRA is a United States federal law, passed in 1990, which requires the return of human remains, funerary objects, sacred objects, and objects of cultural patrimony held by federally-funded institutions in the United States to federally-recognized Native American tribes, Native Hawaiian organizations, and lineal descendants. Scientific sample collections, including radiocarbon sample archives, are included under this law (Bader et al. 2023), which means that radiocarbon laboratories in the United States have a legal obligation to follow NAGPRA in both letter and spirit. The Center for Applied Isotope Studies at the University of Georgia maintains a large archive of radiocarbon sample remnants, dating back to CAIS's inception in 1968. Between 2022-2024, CAIS undertook a rehabilitation of this collection. During this process, samples consisting of NAGPRA-covered materials were identified, and a procedure for respectfully and efficiently identifying those samples and initiating the repatriation process was developed in collaboration with the University of Georgia's NAGPRA office. To date, we completed approximately 59 transfers, transferring a total of over 1200 samples consisting of definite and possible NAGPRA-covered materials out of the sample archive collection, and have identified at least another 200 which will require transfer. This process has been labor intensive, with an estimated input of over 7,000 person hours from CAIS alone. In addition to the transfer and repatriation of samples, this process has resulted in policy changes regarding sample submission, retention, and legal status at CAIS. While NAGPRA is a US-based law, we argue that it is relevant to the international radiocarbon community for two reasons: 1- As more US-based labs work toward NAGPRA compliance, clients and researchers who want to analyze NAGPRA-covered materials may seek options outside of the United States. 2- The practices required under NAGPRA, specifically the explicit requirement that any research done on NAGPRA-covered materials must be granted the free, prior, and informed consent of relevant federally-recognized Native American groups, are relevant to international and disciplinary discussions surrounding the best practices, professional standards, and complicated ethics of destructive testing on human remains and other cultural heritage objects.

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A04 SESSION

ROCK ORGANIC CARBON SUSTAINS HETEROTROPHIC BACTERIA IN EARLY STAGES OF SOIL DEVELOPMENT AFTER GLACIAL RETREAT

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Abstract

Rock-derived ^{14}C-dead organic carbon (ROC) is considered a recalcitrant carbon source in soils. However, recent studies have demonstrated that microorganisms can assimilate ROC, challenging its presumed recalcitrance and raising questions about deep soil carbon sequestration[1,2]. Here, we analyzed the ^{14}C-content of soil organic carbon (SOC), water-extractable organic carbon (WEOC), and compound specific bacterial phospholipid fatty acids (PLFAs) in soils developed on ROC-rich shale and ROC-poor granite bedrocks along two alpine glacial forelands, covering soil ages of 50–70, 100–160, and more than 5000 years. Using ^{14}C-analysis, we determined whether increasing plant carbon allocation to soils affects the proportion of microbial ROC assimilation during different stages of soil development.

Plant biomass, SOC and WEOC increased similarly with soil age in both glacial forelands. However, SOC from granitic soils was always higher in ^{14}C compared to SOC from shale soils, highlighting the importance of ROC in reducing the SOC ^{14}C-content of shale soils, even in the surface layer of well-developed soils. In granitic soils, PLFA ^{14}C-contents were consistent with atmospheric $^{14}CO_2$ levels of the sampling year, indicating that recently fixed carbon was the primary microbial carbon source. Interestingly, in shale soils, the PLFA ^{14}C-contents varied widely among PLFA-based phylogenetic groups and soil ages, indicating the use of different carbon sources by soil microbes that shifted over time. In particular, br15:0 PLFAs, indicative of Gram-positive bacteria, were strongly ^{14}C-depleted in subsoils of the youngest age group, indicating the importance of ROC for heterotrophic bacteria during early stages of soil succession. As the ecosystem develops and plant carbon inputs increase, all PLFAs become ^{14}C-enriched, with br15:0 PLFAs from the oldest subsoils reaching the highest proportion of bomb ^{14}C, corresponding to the atmospheric $^{14}CO_2$ of 1980. DNA-based microbial community profiling revealed that *Pseudarthrobacter sp*ecies dominated the bacterial communities in all shale soils. As well-described producers of large amounts of brC15:0 PLFAs and degraders of aromatic hydrocarbons, which are highly abundant in shale-derived organic matter, *Pseudarthrobacter species* are likely to be key players in ROC assimilation during early stages of soil development. Overall, our data shows that ROC is an important microbial carbon source in young shale soils, while organic carbon from recent CO_2-fixation remains the main driver of soil carbon dynamics in granitic soils.

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A04 SESSION

INVESTIGATING SOIL CARBON STORAGE IN VINEYARDS: $\delta^{13}C$ AND $\delta^{14}C$ AS INDICATORS OF CARBON DYNAMICS UNDER COVER CROPS AND TILLAGE

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Abstract

Soil organic carbon (SOC) plays a critical role in both climate regulation and agricultural sustainability. Increasing SOC stocks is recognized as a key strategy for mitigating climate change and contributing to soil fertility and overall ecosystem resilience. Perennial cropping systems, such as vineyards, have received increasing attention for their potential to sequester SOC. Compared to annual crops, vines may contribute to SOC accumulation through their permanent root systems, extensive biomass production, and long-term organic matter inputs to the soil. Vineyard soils, however, are subject to diverse management practices that can either promote or deplete SOC stocks. At either end of the spectrum, we have, for example, permanent plant cover between the rows and ploughing to eliminate all grass, considered a competitor for access to water. However, the effect of these practices on SOC turnover and stabilization remains poorly understood. This study aims to assess the influence of cover cropping and tillage on soil carbon storage using $\delta^{13}C$ and $\Delta^{14}C$ isotopic analysis.

Soil samples were collected from two vineyard sites in the Toro region, Spain, located very close to each other. One site has been managed with soil covered with spontaneous vegetation for 13 years, while the other has undergone tillage. The samples were collected to a depth of 90 cm, with 5 cm interval down to 20 cm, and then 10 cm intervals thereafter. The content of C and N content, as well as $\delta^{13}C$ were analyzed to trace carbon sources, while $\Delta^{14}C$ is used to access carbon dynamics and stabilization. These measurements help determine how different management practices influence SOC accumulation and persistence over time.

The study will provide novel insights into the role of vineyard management practices in soil carbon storage. By comparing $\delta^{13}C$ and $\Delta^{14}C$ profiles under different practices, we aim to improve our understanding of soil carbon dynamics and inform sustainable practices. These findings will contribute to broader discussions on enhancing soil health, adapting land management strategies to climate change and mitigating climate change by limiting soil carbon loss, even increasing its storage and sequestration.

Keywords: Soil carbon storage, vineyard soil management, $\delta^{13}C$, $\Delta^{14}C$, plant cover, tillage

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A04 SESSION

EVALUATING THE PERSISTENCE AND STABILITY OF TEMPERATE SOIL CARBON VIA RAMPED OXIDATION AND RADIOCARBON ANALYSIS

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Abstract

Understanding the stability and turnover of soil organic carbon (SOC) is crucial for determining where terrestrial carbon is stored, how ecosystems respond to climate change, and which strategies may effectively enhance carbon sequestration. However, our ability to link SOC persistence to specific properties of soils or ecosystems faces important limitations. For example, current global models underestimate SOC residence time compared with empirical data (e.g. Shi et al., 2020). Radiocarbon (^{14}C) holds great promise for resolving these issues by adding a time dimension to investigations.

Standard approaches for investigating SOC residence time typically involve fractionating soil on a physical and/or chemical basis into operationally defined components (e.g., Haddix et al., 2020) for ^{14}C analysis. While this allows for comparison of ^{14}C values among different functional pools, such as SOC in mineral-associated organic matter, these pools themselves are a weighted average of many different chemical components. An alternative approach for partitioning SOC for ^{14}C analysis involves sequential thermal analysis either by ramped oxidation (ROx) or ramped pyrolysis-oxidation (RPO), depending on instrumentation (e.g., Hanke et al., 2023). These methods use thermal separation to isolate components based on their activation energy and have been applied to offer valuable insights into how mineral interactions influence SOC persistence in both bulk soils and sub-fractions (Stoner et al., 2023).

This presentation investigates whether ROx, combined with ^{14}C analysis can reveal additional useful information on the age structure of soil organic carbon (SOC), offering new insight into the mechanisms controlling SOC persistence and turnover. We apply this approach to both bulk soils and physical sub-fractions from the Mycorrhizal Drivers project (Joly et al., 2025), which examined how converting temperate grassland to coniferous forest influences below-ground carbon dynamics in Scotland, UK. By comparing ^{14}C results from traditional fractionation with those from thermal fractions, we assess the added value of ROx in revealing the age structure and persistence of SOC. We also consider how these insights could usefully add to our understanding of the effects of land-use change on soil carbon storage.

Acknowledgments
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A04 SESSION

PRODUCTION RATE CALIBRATION OF IN SITU ^{14}C IN QUARTZ IN ANTARCTICA

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Abstract

We present a revised Antarctic in situ ^{14}C production rate calibrated using over a decade of published measurements of the saturated CRONUS-A laboratory intercomparison material from eight in situ radiocarbon labs.

In situ cosmogenic nuclide (e.g., ^{14}C, ^{26}Al, ^{10}Be) exposure ages are used to study the rate and timing of deglaciation (thinning or retreat) prior to the observational record (Balco, 2011). Most studies rely on in situ ^{10}Be because of its well-constrained production pathway and low background abundance in Earth surface materials. However, due to its relatively long half-life, ^{10}Be can be incorporated from multiple periods of exposure, a phenomenon known as inheritance, often making it challenging to constrain the timing of glacier or ice sheet change following the Last Glacial Maximum (LGM, ~20 ka). Throughout the last 15 years, the measurement of in situ ^{14}C, with a short half-life of 5700 +/-30 yr, has allowed us to resolve ambiguous datasets of exposure ages influenced by inheritance (Hippe, 2017; Nichols, 2022).

The production rate of a cosmogenic nuclide, defined as the number of atoms produced by cosmic rays in a gram of sample per year, relates the cosmic ray flux at the Earth's surface to the concentration of cosmogenic nuclides in a rock or sediment sample (Koester and Lifton, 2023). The production rate varies with geomagnetic latitude and atmospheric thickness (elevation), and as such, can be determined by measuring nuclide concentrations at calibration sites and adjusting the calculated value from the calibration site to the sampling site using cosmogenic nuclide scaling methods (Lifton et al., 2014). Inaccurate production rates determined at calibration sites have the potential to offset the estimated exposure age from the true exposure age by up to thousands of years. Therefore, an accurate calibration site production rate is critical for converting a measured nuclide concentration to a surface exposure age used to make inferences about Earth surface processes.

Here, we use a compilation of over 100 measurements of the CRONUS-A intercomparison material made by eight labs to calibrate the Antarctic in situ ^{14}C production rate. CRONUS-A was collected from the Dry Valleys in Antarctica as part of the CRONUS-Earth project (Jull et al., 2015) and is saturated with respect to in situ ^{14}C, allowing it to be easily used as a production rate calibration site. The current production rate that many studies use, in part because it is incorporated into a widely used online exposure age calculator (https://hess.ess.washington.edu, Balco, et al., 2008), is based on measurements of CRONUS-A only from a single laboratory with a lower average measured concentration than other laboratories, which results in a lower production rate estimate (Lifton et al., 2023). A lower production rate (relative to that derived from measurements of CRONUS-A from other laboratories) yields older exposure ages compared to when a higher production rate is used. To produce a robust production rate calibration dataset, we compiled all published in situ ^{14}C measurements of CRONUS-A and use the compilation average and maximum likelihood values to calibrate the production rate for in situ ^{14}C in Antarctica using two commonly applied scaling methods.

We calculate the maximum likelihood concentration of in situ ^{14}C for CRONUS-A as $6.90 \pm 0.53 * 10^5$ ^{14}C atoms g^{-1}. This value corresponds to a ^{14}C production rate of 14.7 atoms g^{-1} $year^{-1}$ for Antarctica measured in quartz using the LSDn scaling method. Previously applied production rates in Antarctica using a subset of our complete compilation have been close to 13 atoms g^{-1} $year^{-1}$ (e.g., Goehring et al., 2019) or used an alternate calibration dataset and a production rate of 12.2 atoms g^{-1} $year^{-1}$ (e.g., Balco et al., 2016). These estimates are 11.5% and 17% lower than our estimated production rate; however, our production rate agrees better with the theoretical production rate of 15.8 atoms g^{-1} $year^{-1}$ (Koester and Lifton, 2023) than previous estimates. Our updated in-situ ^{14}C production rate will yield more precise and accurate i) glacier chronologies and ii) quantifications of other surface processes (such as erosion rates) in Antarctica. An updated production rate estimate necessitates the reinterpretation of published Antarctic deglacial ages. Therefore, we present a preliminary analysis of the impact of our work on the deglacial timing at some key study sites in Antarctica.

Acknowledgments

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M07 SESSION

SIMPLE AND COMPLEX METHODS TO ADDITIVELY EXPAND QUOTED ERRORS TO ACCOUNT FOR LONG-TERM EFFECTS

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Abstract

In radiocarbon, the quoted error (*QE*) typically corresponds to the $F^{14}C$ uncertainty which consists of a propagation of the isotopes measurement uncertainties of the blanks and standards. These uncertainties arise from instrument instability, target inhomogeneity and the inherent detection uncertainty corresponding to the short measurement time (couple of days). In the long-term (several months), there are other unknown sources of uncertainty that affect the variability (*LT*) of the measured $F^{14}C$ of replicates that are not accounted inside the quoted error. The error multiplier (Scott et al. 2007) has been usually used to capture these unknown components for replicates of sample treatments within intercomparisons (Scott et al. 2018), Calibration curve construction (Heaton et al. 2020) and long-term studies. In this work, we propose a simple and a sophisticated method to additively expand the quoted error using an excess error in order to make it comparable, in average, with the long-term variability; show a defined and confined range of possible excess error values as the robustness of the complex method and the results of the complex and simple method are quite similar.

The simple method was based on the 7-year data length of Salazar et al. 2021 for the University of Bern where the average QE was obtained for several secondary standards. LT was estimated as the standard deviation of each secondary standard long-term control chart. The quadrature difference between LT and QE is defined as the excess uncertainty (ε) which magnitude depends linearly on the $F^{14}C$ consensus value, thus ε is characterized by a slope and intercept (ε_0, ε_{slope}). The complex method is original to this work and carries out a more robust statistical analysis to infer ε_0 and ε_{slope}. The complex method systematically variates the initial values of ε_0 and ε_{slope} to minimize the global reduced χ^2 calculated as the variability of measured $F^{14}C$ of a certain standard relative to the additively expanded QE with ε. The global χ^2_{red} is the average of the χ^2_{red} of all the secondary standards. The χ^2_{red} is minimized using algorithms from the ***R*** program. The initial values of ε_0 and ε_{slope} were selected near and centred to the values obtained from the simple method but with a strong wide distribution and then minimizing the global χ^2_{red} repeating the process many times in a Monte Carlo fashion. A second analysis was done randomly initializing the ε_0 and ε_{slope} but using a fraction of the whole data each time in a bootstrapping fashion. The fraction of the data was also random. The distributions of the optimum ε_0 and ε_{slope} values were our main interest.

We obtained for the simple method for a 2-year data from the Andre Lalonde facility the values of ε_0 of 6.0 and 4.6 ($x10^{-4}$ $F^{14}C$) for the years 2022-2023 and 2023-2024 respectively. The ε_{slope} was 9.4 and 10.6 ($x10^{-4}$). The complex method showed ε_0 of $(6.3\pm1.3)x10^{-4}$ $F^{14}C$ for 2022-2023 and $(4.6\pm0.6)x10^{-4}$ $F^{14}C$ for 2023-2024. ε_{slope} was $(9.7\pm2.6)x10^{-4}$ for 2022-2023 and $(10.5\pm3.0)x10^{-4}$ for 2023-2024. The distribution were close to Gaussian distributions.

The slope for the simple and complex methods in average are quite close, within 9.4-10.6 ($x10^{-4}$) independently of the year range and the statistical method. The intercepts for the year 2022-2023 range are quite close for the simple and average of the complex method, within 6.0-6.3 ($x10^{-4}$ $F^{14}C$). The same happens for the year 2023-2024 range for both methods are similar, 4.6 $x10^{-4}$. This means that the results of the simple and complex method are quite compatible. However, between year ranges, both methods

show that there is a difference in the intercept. This means that for the year range 2023-2024, the long-term variability close to the radiocarbon blank is lower than the long-term variability of the blank for 2022-2023. This improvement was due to a change of policy within our laboratory and it was decided to clean the ion source with higher frequency since the start of 2023.

We demonstrated that because the simple and complex method output very similar results then future users do not need to carry out the complex method, saving time and efforts. Furthermore, the user can be confident that the results of the simple method will be quite similar to a more robust statistical method. We have demonstrated statistically that by changing the ion source cleaning frequency, we have improved our quality controls.

Acknowledgments

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M07 SESSION

CROSS REFERENCING – A SIMPLE YET POWERFUL TOOL FOR INTEGRATING AN INCREASING RANGE OF INFORMATION IN BAYESIAN CHRONOLOGICAL MODELS

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Abstract

Scientific analyses of archaeological material, e.g. genetic ancestry of human bone and teeth, today form an integral part of many larger projects. Their main aim is not chronology, yet they may still contain relevant temporal information, and it would be beneficial to incorporate this information into our formal Bayesian chronological models. This however introduces the predicament that a single radiocarbon age may be associated with multiple, independent events in a Bayesian chronological model but using it more than once violates the underlying independence assumption. We recognise that for the posteriors to be accurate and precise, they should be consistent between sequences and incorporate any relevant prior information. We therefor propose a solution that requires stepping away from the more intuitive sequential model construction and instead construct more parallel models linked by cross-referencing key parameters. The cross referencing function in OxCal is a simple yet powerful tool that explicitly allows a single likelihood to be used in parallel models incorporating separate sources of prior information, e.g. a genealogy and the evolution of artefact typology. Extensive use of cross-referencing does however remain computationally challenging. We envision the use of cross referencing to become increasingly important with endeavours to contextualise dating evidence from the new generation of Big Data in archaeology. We will illustrate the usefulness and challenges of large-scale applications of the cross reference function based on published studies and our own experience correlating multiple lines of evidence from archaeology and genetic ancestry.

M07 SESSION

A NEW APPROACH TO RADIOCARBON SUMMARISATION: RIGOROUS IDENTIFICATION OF VARIATIONS/ CHANGEPOINTS IN THE OCCURRENCE RATE OF RADIOCARBON SAMPLES USING A POISSON PROCESS

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Abstract

A commonly-used paradigm to estimate changes in the frequency of past events or the size of populations is to consider the occurrence rate of archaeological/environmental samples found at a site over time. The reliability of such a "*dates-as-data*" approach is highly dependent upon how the occurrence rates are estimated from the underlying samples, particularly when calendar age information for the samples is obtained from radiocarbon (^{14}C).

The most frequently used "*^{14}C-dates-as-data*" approach of creating Summed Probability Distributions (SPDs) is not statistically valid, or coherent, and can provide highly misleading inference. In this talk, we provide an alternative method with a rigorous statistical underpinning that also provides valuable additional information on potential changepoints in the rate of events. Furthermore, unlike current SPD alternatives, our summarisation approach does not restrict users to pre-specified, rigid, summary formats (e.g., exponential or logistic growth) but instead flexibly adapts to the dates themselves.

Our methodology ensures more reliable "*^{14}C-dates-as-data*" analyses, allowing us to better assess and identify potential signals present. We model the occurrence of events, each assumed to leave a radiocarbon sample in the archaeological/environmental record, as an inhomogeneous Poisson process. The varying rate of samples over time is then estimated within a fully-Bayesian framework using reversible-jump Markov Chain Monte Carlo (RJ-MCMC). Given a set of radiocarbon samples, we reconstruct how their occurrence rate varies over calendar time and identify if that rate contains statistically-significant changes, i.e., specific times at which the rate of events abruptly changes, which might suggest key times corresponding to changes in important external environmental factors. Users can implement the approach using the *carbondate* R library available on CRAN and on Github at https://tjheaton.github.io/carbondate/.

We illustrate our method with both a simulation study and a practical example concerning the expansion of humans, and the parallel disappearance of megafauna, in the Yukon and Alaska in the late Pleistocene and early Holocene: investigating both the timings of such migrations in comparison with the climatic changes known to have occurred during this period, and the potential interactions between humans and the various species in the region.

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M07 SESSION

OXCAL AND THE INTCHRON DATA INTEGRATION TOOL

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Abstract

OxCal (Bronk Ramsey 2009) is an analysis package for radiocarbon calibration and Bayesian chronological analysis. The IntChron integration tool originally designed for integration of different timescales and online data sharing (Bronk Ramsey et al. 2019), has developed into a data management package suitable for project data storage and archiving, used for example for the IntCal datasets (Bronk Ramsey et al. 2023).

There is now close integration between these two packages enabling the IntChron integration tool to be used as a data management and analysis tool for chronological information. This combination allows for automated calibration of radiocarbon dates and for the handling of Bayesian models. In particular Bayesian models can be generated and run from within IntChron with the posterior estimates being read back and integrated with the data. For age-depth models, proxy data can be displayed and put onto different time scales. There is also a special component enabling data to be visualised either in maps or in other 2D plots.

This paper covers how this integration works in practice and considers how IntChron and OxCal can be used together to support projects involving chronological data without having to develop specific project databases. Within IntChron projects can be shared with other users and archived in publications or repositories. The import and export of data and integration with other software tools such as Excel, R and Python will also be discussed.

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M03 SESSION

QUANTIFYING HPLC COLUMN BACKGROUNDS FOR ROUTINE BONE HYDROXYPROLINE DATING

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Abstract

The last two decades have seen significant advances in the isolation of hydroxyproline from archaeological bone. Hydroxyproline is an amino acid rarely found outside mammalian collagen which, when dated directly, can help overcome the challenges of bone contamination and/or poor preservation.

However, the method remains challenging. In addition to the need to avoid organic solvents in the mobile phase, the stationary phase of the SIELC Primesep A has also recently proven problematic, with column bleed contaminating samples and resulting in high backgrounds. Continued tests and pretreatment improvements at the Oxford Radiocarbon Accelerator Unit (ORAU) have led to a significant decrease in contamination for subsequent samples, with backgrounds settling at a level consistent with those seen previously.

We report c. 30 new AMS dates from hydroxyproline isolated from both background and modern bone using the same column and use these to quantify the procedural background per injection as 3.6 ± 3.7 µgC with an age of approximately 12.1 kBP. This confirms that the Primesep A column remains suitable for the isolation of hydroxyproline for radiocarbon dating. We also provide an update on the migration of the method to a new LC system.

M03 SESSION

CHRONOLOGY OF MOBILE PASTORALISTS SETTLEMENTS AND DAIRY EXPLOITATION IN NEOLITHIC IRAN THROUGH COMPOUND-SPECIFIC RADIOCARBON ANALYSES OF ARCHAEOLOGICAL POTTERY

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Abstract

Agropastoralism developed in southwest Asia in the 9th millennium BC. The Zagros mountains in Iran are one of the centres of goat domestication. The management of caprine herds and the climatic constraints of this region led to the development of pastoralism with seasonal mobility. The temporary campsites of mobile pastoral groups, which were probably occupied on several occasions, generally include ceramic and lithic materials that are not very distinctive. The dearth of organic materials conventionally used for ^{14}C dating provides challenges in establishing the chronology of the settlements. Therefore, the development of CSRA of lipids in ceramic vessels provides a unique alternative to resolve the chronology of such campsites.

We study first the lipid preservation in about 400 ceramics from Neolithic permanent settlements, open-air campsites, and cave campsites of pastoral groups. It showed a reliance on both carcasses and dairy products of their caprine herds. The overall low lipid preservation led to performing ^{14}C measurements on less than 100 µg of C of lipids in ceramic, which diverged from the routine method with sample sizes over 200 µg of C. We therefore employed the EA-GIS interface linked to ECHoMICADAS to do gas measurements on single lipid.

Despite the relatively low precision obtained on the measurements, we were able to:

(1) provide chronological context to prospection surveys in the Zagros;

(2) show a reuse of three open-air and cave campsites across several centuries or millennia;

(3) demonstrate dairy exploitation in the ceramic vessels by pastoral groups in the Zagros mountains was already established during the 7th millennium BC.

Key words: compound-specific radiocarbon analyses, ceramic, pastoralist, dairy, mobility

M04 SESSION

HISTORY AND STATUS REPORT OF THE GLIWICE ^{14}C AND MASS SPECTROMETRY LABORATORY

Natalia Piotrowska[1], Danuta J. Michczyńska[1], Alicja Ustrzycka[1], Christine Hatté[1,2], Marzena Kłusek[1], Marie-Josée Nadeau[1,3], Adam Michczyński[1], Fatima Pawełczyk[1], Sławomira Pawełczyk[1], Konrad Tudyka[1], Komal Aziz Gill[1,4], Jean Baptiste Baranyika[1], Mukkaram Ejaz[1], Maksymilian Jędrzejowski[1], Agnieszka Bolik-Głuszek[1], Anna Kamińska[1], Mateusz Wolniewicz[1]

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Abstract

The Radiocarbon and Mass Spectrometry Laboratory is traditionally known as Gliwice Radiocarbon Laboratory, will celebrate its 58th anniversary in 2025. It was the first such Laboratory in Poland and among the earliest worldwide. It was founded by Prof. Włodzimierz Mościcki (1911-1977), a European pioneer of research in radiocarbon measurements using the gas proportional counters (GPC; Mościcki 1953). The Laboratory was moved from Gdańsk to the Institute of Physics at the Silesian University of Technology in Gliwice in 1971. Prof. Mościcki built a team whose researching traditions continues to this day. The devices constructed by Prof. Mościcki and his successors (Pazdur et al. 2000, 2003) were used until 2010 when they were, unfortunately, irreparably destroyed by flooding.

Since the beginning, the Laboratory has specialized in physical isotopic methods applied to Earth sciences, environmental sciences, and humanities. In the 1990s, the liquid scintillation technique was brought to the Laboratory, as a Quantulus 1220 spectrometer was acquired with support from IAEA (Pawlyta et al. 1998). A graphite preparation laboratory for ^{14}C AMS measurements was launched in 1999 (Czernik and Goslar, 2001) and further developed (Piotrowska 2013). As more scientific challenges appeared, the development of other dating methods: luminescence (TL and OSL), ^{210}Pb, ^{137}Cs was undertaken. In 2003, capabilities were expanded to stable isotopes analysis (H, C, N, O) with the acquisition of an Isoprime isotope ratio mass spectrometer.

Significant upgrades followed the move to new premises in 2014, including the installation of an AGE-3 graphitization system (Wacker et al. 2010), and most notably, the installation of a Mini Carbon Dating System (MICADAS - Synal et al. 2007). As of September 2022, all routine AMS ^{14}C analyses are performed at the Gliwice Laboratory, and its excellent performance was proved by Ustrzycka et al. (2024). New sample preparation methods are also being developed, such as for highly degraded wood (Jędrzejowski et al. 2024), bone re-treatment with ultrafiltration (Pawełczyk et al. 2024), "perfect bulk" of soil carbon organic matter (Ejaz et al. 2025). Biocarbon content determination has been investigated for both liquid fuels (Baranyika et al. 2022) and solid materials (Aziz et al. 2022). Research continues on LSC optimization, including the removal of ^{222}Rn (Tudyka et al. 2021) and overcounting estimation methods (Jędrzejowski et al. 2023).

This presentation will highlight the laboratory's facilities, instrumentation, and current analytical capabilities.

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M04 SESSION

STATUS REPORT ON THE ACCELERATOR MASS SPECTROMETRY AT THE CENTA ACCELERATOR LABORATORY IN BRATISLAVA

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Abstract

The Centre for Nuclear and Accelerator Technologies (CENTA) has been established at the Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava, Slovakia in 2013 as an IBA (Ion Beam Analysis) and AMS (Accelerator Mass Spectrometry) laboratory with a 3 MV Pelletron tandem accelerator (Povinec et al., 2015). In the first stage, the system was equipped with two ion sources, low-energy injection system, accelerator and post-acceleration IBA beamline. Recently, the second stage of this project has been completed - this accelerator system has been upgraded with a fast bouncing system and a dedicated AMS beamline with high-resolution analysing magnet, multi Faraday cup chamber and two 45° electrostatic analysers, terminated in a multi-anode ionization chamber for ion detection and isobar suppression.

Our research connected to accelerator mass spectrometry is focused mainly on radiocarbon analysis of both archaeological (wood, charcoal, bones, mortar/plaster, wine, etc.) and environmental samples (atmospheric CO_2 and carbohydrates, carbonaceous aerosol, tree rings, ground- and seawater, etc.). Additional long-lived radionuclides, such as ^{10}Be, ^{26}Al,^{129}I, uranium and plutonium isotopes, belong to our research interests as well.

Development of new sample preparation methods for radiocarbon analysis and the optimization of already existing methodologies was performed during both phases of the development of our laboratory. The experiences and findings mainly regarding the combustion and graphitization processes will be presented

Performance tests of radiocarbon measurement were carried out on this system together with first tests of ^{10}Be, ^{26}Al and ^{129}I measurement. The parameters, initial operation and performance of the AMS system will be reported.

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M06 SESSION

SINGLE YEAR ^{14}C FROM TREE-RINGS, IMPROVING CALIBRATION AND ANCHORING TIMELINES 2500-1100 BCE

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Abstract

A sequence of single year ^{14}C was generated from calendar dated tree-rings between 2500 and 1100 BCE (4450-3050 BP) with the primary goal of testing the possible contribution of these high-resolution data for improving the International Radiocarbon Calibration Curve (IntCal20). The main impetus was to explore points within this temporal sequence where radiocarbon and archaeo-historical dating discrepancies have hindered progress on the synchronization of timelines from the ancient East Mediterranean, Levant and Egypt. In this talk we will review the potential impact of the most significant changes to calibration curve shape suggested by the single year data for this period and how these may impact some key archaeological debates. We also demonstrate the use of single lab, single year ^{14}C tree-ring sequences for anchoring floating tree-ring sequences in time.

Acknowledgments

This work was funded by the Malcolm H. Wiener Foundation, ICCP (PI Pearson – 2015-2022), ETH Zürich and Historic England.

M06 SESSION

SUB-ANNUAL VARIATION IN TREE CELLULOSE RADIOCARBON IN AD 993/994 AND AD 1054/1055

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Abstract

The radiocarbon production spike in AD 993/994 (Miyake et al. 2013) is thought to be caused by a solar particle event and is observed globally. Data combined from several sites has suggested that this event happened in the the boreal spring of 993 (Büntgen et al. 2018), whereas samples from the earlywood and latewood of tree rings from Poland date the event to September of AD 993 (Rakowski et al. 2022). However, datasets from both hemispheres suggest variations in the timing and intensity of the spike, likely influenced by atmospheric transport effects and latitude (Miyake et al. 2022).

A possible excursion of uncertain magnitude, origin and duration has been reported around AD 1054/1055 (Terrasi et al. 2020), but data has not been conclusive (Menjo et al. 2005; Brehm et al. 2021; Scifo et al. 2024).

We present sub-annual tree ring measurements on the cellulose of seven Scots pines from Norway for the years 990-998 and 1052-1057. Our aim is to investigate the structure of the AD 993 spike and the proposed event in AD 1054/55 as seen in Norwegian trees at 3-7 increments per year. The sub-annual resolution should help eliminate uncertainties in modelling yearly averaged data. The results offer insights into production variations and help refine our understanding of radiocarbon anomalies and enhance the temporal resolution for climate and solar activity studies.

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M06 SESSION

PREPARING FOR THE NEXT INTCAL

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Abstract

The last updates to the IntCal family of calibration curves were finalised in 2020 (Reimer 2020). Since then there have been significant publications of new data, and there is even more data already generated by researchers due to be published within the next year. The IntCal group is therefore preparing a new update for release in 2026.

This presentation will cover the stages involved in the generation of a new curve. There will be a particular focus on what types of data are needed for the new update, and on what researchers should do if they have data which they think might be suitable for inclusion. In addition to the data itself there are specific requirements for supporting information, depending on the type of record. As in previous updates, the data included will normally be separately published and the timing for this will need to be considered to ensure the relevant references are available in time for curve publication.

The group has already started the process of importing new data into a database for preparation of the new curves. This follows the model of the database archive generated for IntCal20 (Bronk Ramsey et al 2023) and researchers can use this database as a model for future submissions. The aim will be for a new archive with all the data, metadata and publications to be released with the updated curves.

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M06 SESSION

CLUES FROM ^{10}BE DATA FOR IMPROVING THE ^{14}C CALIBRATION CURVE

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Abstract

The ^{14}C calibration curve is not only the key for obtaining robust calendar age estimates from ^{14}C measurements but it also provides important information about past changes in solar activity, geomagnetic shielding and the carbon cycle. However, in the light of recent discoveries about rapid short-term ^{14}C increases, the ^{14}C calibration curve still lacks the required high-resolution data to resolve the fine structure for the complete Holocene period. Furthermore, well-dated and high-quality tree ring ^{14}C data is limited to the last about 14000 yrs. Here, I will provide a few examples where high-resolution ^{10}Be & ^{36}Cl data can help us to identify periods where the ^{14}C calibration curve might miss structures and benefit from additional ^{14}C measurements or where the present calibration curve might underestimate the real uncertainties.

M06 SESSION

RADIOCARBON CALIBRATION POTENTIAL OF VARVED SEDIMENTS IN THE MAYA LOWLANDS

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Abstract

This study explores the potential of annually laminated (varved) lake sediments from two Mesoamerican sites—Lake Petexbatún (Guatemala) and Lake San Claudio (Mexico)—as new archives for radiocarbon calibration. Both lakes are located in the southern Maya Lowlands, a region of high archaeological interest.

We present new AMS radiocarbon measurements of terrestrial macrofossils from well-preserved varved sequences covering at least 600 years. The annual laminations in both lakes are exceptionally well preserved, allowing precise varve counting based on conventional varve analysis techniques. The clarity and continuity of the sequences enabled the construction of high-resolution chronologies, which in turn made it possible to apply robust wiggle-matching to the IntCal20 calibration curve using Bayesian modelling.

The resulting chronologies show excellent internal consistency, with estimated ^{14}C ages determined to be within approximately ±5 years at Lake Petexbatún. Notably, both sites exhibited a systematic offset of around 50 years relative to IntCal20 throughout the entire period examined. The consistency of this offset across two independent lake records—one in Guatemala and one in Mexico—strongly suggests the presence of a region-specific deviation in atmospheric ^{14}C levels in the tropical Americas. This pattern is further supported by preliminary radiocarbon measurements of modern terrestrial plants and lake waters from the same regions, which also show comparable depletion relative to global expectations. One possible explanation involves persistent easterly trade winds transporting marine air masses, depleted in ^{14}C due to elevated sea surface temperatures and outgassing of old CO_2, onto the Yucatán Peninsula.

These Mesoamerican varved sediments offer a promising new archive for high-resolution radiocarbon calibration in the tropics, with particular relevance for archaeological and palaeoenvironmental research in the region.

M06 SESSION

MID-LATITUDE INTRA-YEAR ^{14}C OFFSETS IN THE NORTHERN HEMISPHERE 412-325 BCE

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Abstract

The analysis of a limited number of atmospheric and modern tree-ring samples through the 'bomb' period indicates latitudinal/regional zones for contemporary (same calendar year) ^{14}C values within the two hemispheres (e.g. Hua et al. 2022). In general, the division between the Northern Hemisphere (NH) Zone 1 to Zone 2 regions is placed around latitude 40˚N, but there are some variations: for example NH Zone 1 is indicated in the most recent assessment as varying up and then dipping down into lower latitudes in western North America (Hua et al. 2022: Figure 1), revising the previously straight line in an earlier version (e.g. Hua and Barbetti 2004: Figure 3), as based on available but relatively limited data. Other work has indicated some evidence for both small latitudinal differences in contemporary (same year) mid-latitudes atmospheric ^{14}C ages (e.g. Braziunas et al. 1995; Büntgen et al. 2018) and/or for intra-annual growing-season differences (partly latitude, partly elevation, partly specific environmental context) (e.g. Manning et al. 2020). Often suggestions for such differences are complicated because they are small, combine data not run under the same conditions at the same laboratory, or are not replicated – and thus are effectively discounted (e.g. Bayliss et al. 2020). In this paper we present analyses of known calendar age single-year samples from a subfossil oak (*Quercus* sp.) timber from the Elbe River in Germany (provided by the dendro archive of Curt-Engelhorn-Zentrum Archäometrie, CEZA, Mannheim) (Dee et al. 2025), and of single-year samples from a sequoia (*Sequoiadendron giganteum*) timber from Mountain Home State Forest in California (Manning et al. 2024) to investigate whether there are measurable intra-annual differences in ^{14}C ages in the period 412-325 BCE. The samples were prepared for α-cellulose extraction and ^{14}C measurements were run on a number samples at the Centre for Isotope Research, University of Groningen (GrM) and the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer at the University of California Irvine (UCIAMS). In all 217 ^{14}C measurements were run on this material, including a number of replicates on the same years. Where measurements were made on the same calendar year samples the data from the two laboratories could thus be directrly compared, and, critically, same-year samples of both the oak and sequoia were run at GrM allowing a parallel same laboratory comparison in addition. The comparisons of same calendar year oak versus sequoia, whether between the two laboratories, or from the same laboratory, yield similar differences, and both point to larger than expected differences at the 3-4‰ level: 33.1±6.3 ^{14}C years GrM sequoia versus GrM oak (19 pairs of data) and 26.7±4.3 ^{14}C years for UCIAMS sequoia versus GrM oak (16 pairs of data). The overall data from these 217 oak and sequoia measurements can also be compared with other recent first millennium CE ^{14}C data on single-year known age samples (Brehm et al. 2025) as part of considerations towards appropriate future calibration of ^{14}C data from different regions.

Acknowledgments

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M06 SESSION

ANNUALLY RESOLVED ^{14}C RECORD FROM SOUTHERN SOUTH AMERICA (970-1084 AD): TRACKING ATMOSPHERIC ^{14}C VARIABILITY

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Abstract

We present the first annually-resolved radiocarbon dataset for southern South America (Patagonia, Argentina), spanning 970 -1084 AD. This unique record was specifically designed to cover the late 10th and 11th centuries, a timeframe during which sharp radiocarbon anomalies, such as the Miyake event, have been previously identified in the Northern Hemisphere.

Here, we illustrate how this new dataset integrates with existing records and we highlight atmospheric ^{14}C variability both within the Southern hemisphere and between hemispheres. This variability reflects the combined effect of location of ^{14}C production, tree phenology, and the redistribution of ^{14}C among the different carbon reservoirs.

Acknowledgments

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M06 SESSION

VARIATION IN BOMB RADIOCARBON IN TREES ALONG A N-S TRANSECT IN NORWAY

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Abstract

To better utilize tree-rings as an archive of atmospheric CO_2 composition, we must try to disentangle the influence of different factors like growing season, altitude, and latitude. We have previously measured the ^{14}C content of incremental slices of tree-rings in three Scots pine (*Pinus sylvestris* L.) trees in Norway (presented at the Radiocarbon conference in Zürich in 2022 and Svarva et al. 2019), showing that we do observe differences in the bomb spike ^{14}C content of trees at different latitudes and elevations in Norway. We have measured two additional Scots pines from the north of Norway and compare sub-annual bomb radiocarbon from 1950-1965 in wood cellulose from the five trees growing along the Norwegian coast in a latitudinal transect between 63°N and 69°N.

All trees have lower $\Delta^{14}C$ than the local atmosphere (Nydal & Løvseth 1996) in the period 1962-1965. They are lower than the NHZ1 bomb calibration curve in 1963, and close to NHZ1 values in the other years. We observe latitudinal differences in ^{14}C concentration between the trees, and that the latitudinal variation changes over time. These differences could also be interpreted as a delay of the incorporation of carbon in the cellulose.

A delayed incorporation of carbon into cellulose is suggested in ^{13}C-spike experiments of Kagawa et al (2005). The apparent delay could also be caused by stored photosynthates in the tree as suggested by Kromer et al. (2024). It could also reflect the contribution of by biospheric decay CO_2 (Svarva et al. in press), or a mixture of both.

We will discuss the potential effects of geographic distribution of detonation yields, growing season differences, physiological effects in the tree, such as storage and delayed carbon incorporation into cellulose, and stored photosynthates.

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M06 SESSION

THE 1950S BOMB-^{14}C PEAK

Pieter M. Grootes[1,2], Helene Svarva[1], Martin Seiler[1], Marie-Josée Nadeau[1,3] Bente Philippsen[1]

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Abstract

The increase in atmospheric $^{14}CO_2$ concentration as a result of atmospheric nuclear testing has been well documented by atmospheric measurements starting around 1960. Before this, our information is largely based on measurements of tree rings or plant material with annual resolution. Svarva et al. (this conference) report a close relation between sub-annual bomb ^{14}C concentrations in Scots pine and the $\Delta^{14}C$ of the local atmosphere in 1962-1965 (Nydal & Løvseth 1996). The Norwegian sub-annual Scots Pine data set can thus provide insights into details of the atmospheric ^{14}C concentrations during the growing seasons 1950-1960 with a monthly to bi-weekly resolution.

We will discuss the significance of these new atmospheric ^{14}C concentration data for calibration purposes and for understanding atmospheric mixing. While the trees show very similar, constant ^{14}C concentrations around -26 ‰ in 1950, values are more variable in 1951. From 1952 onward, we start to see an increase in the ^{14}C concentration during the growing season of the trees. The rate of this ^{14}C concentration increase rises gradually from ca. 0.5 ‰ per week in 1952 to ca. 5.6 ‰ per week in 1958. This is coeval with the atmospheric bomb test yields recorded by the Stockholm International Peace Research Institute (SIPRI) (Bergkvist and Ferm, 2000). The Norwegian data document a 1950s bomb peak with a sharp increase in the growing seasons of 1958 and 1959 followed by lower and approximately constant values in the 1960 and 1961 seasons during the testing moratorium.

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A09 SESSION

EVOLUTION OF THE NIDA RIVER VALLEY DURING THE HOLOCENE BASED ON RADIOCARBON DATA

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Abstract

The subject of this interdisciplinary work is the evolution of the Nida River valley floor during the Holocene. The aim of this study is to capture the most important regularities and phases of the evolution, and to determine the significance and influence of natural factors and human activities (both in the Prehistoric and historical times) on the environment changes that resulted in the transformation of fluvial processes shaping the relief and sediments of the flood plain. The study focused on the importance of various factors of valley morphogenesis at the local scale, establishing the architecture of the valley bottom, the amount, structure and age of cut and fills, identifying changes in channel pattern, determining phases of erosion and accumulation, as well as periods of an increased fluvial activity.

The location of the Nida catchment in a loess area of Polish Uplands and, at the same time, outside the area of the Old Polish Industrial District, made it possible to capture the impact of the Neolithic and, at the same time, to eliminate the effect of the Prehistoric and historical mining and metallurgical activities on the transformation of the catchment environment and the riverbed itself (e.g. the construction of an anthropogenic small water retention system). The estuarial section of the Nida River to the Vistula enabled the tracing of interactions in valley bottom formation between rivers differing considerably (10 times) in size.

It is based on a query of geological, paleogeographic, archaeological (Archaeological Map of Poland) and historical sources, as well as on field research - geomorphological and geological mapping of the Quaternary covers and laboratory analyses of sediments. Seven sections of the valley bottom from Żerniki/Brzegi downstream to the mouth of the Vistula (65 km long) have been studied in detail. It was found that geological, lithological and tectonic conditions, as well as the Quaternary evolution, are different in individual sections. They created the main features of the relief and had a very large impact on the development of the valley in the Late Glacial and Holocene. The work shows the distinctiveness of the Nida valley not only regionally, but also supra-regionally on a Polish and even Central European scale.

The floodplain began to be formed, similarly to other valleys, after the Late Pleistocene incision. Changes in the Nida River's development in the last 15,000 years have proceeded differently from the Falkowski model (1982) with supplements by Kalicki (1991) and Krupa (2013). The Late Glacial macromeanders have been not observed, and the river has been anastomosing (anabrached type) for almost the entire Holocene, creating cut and fill of various ages. In last centuries, the Nida has become a single-channel, meandering stream, not a braided stream as in the above-mentioned model.

The structure of the Nida valley floor is very complicated. Tectonic forms (horsts) and inversion karst forms (polja) have been incorporated into its area. The floor has been locally built up by alluvial fans of tributaries, which reflect the deforestation phases in the Neolithic, Roman period and Middle Ages. In

the mouth section of the Vistula, the alluvium of the Nida is "closed" inside its valley. This prevented the alluvial fan accumulation through the Nida into the Sandomierz Basin during the Holocene.

An increase of fluvial activity in the entire Nida catchment occurred in the middle Atlantic (6700-6000 BP), the Roman period and the Little Ice Age, which is consistent with the phases distinguished for Central European rivers (Kalicki 2006). However, it seems that some changes recorded in the oxbow lakes of the anastomoses at Stawy were caused by single catastrophic events, e.g. in the early Middle Ages.

Human impact in the catchment area has been increasing since the Neolithic in several phases, especially in the right-bank, loess part of the Nida drainage basin. Its record is, for example, the Mozgawka alluvial fans (Neolithic, Roman period, Middle Ages), torential fans at the mouth of dry valleys drained by periodical streams (Middle Ages) and proluvial fans (Gorysławice/Żydowiec – Mierzanowice and Trzciniec cultures), deluvial covers (Neolithic, Middle Ages). In the valleys of the Nida tributaries, there is a diachronic of the accumulation of overbank sediments. However, the anthropogenic transformation of the environment did not cause the formation of Holocene mineral-organic and overlying mineral deposits in the lower Nida valley bottom, which are characteristic of other upland valleys on loess areas, e.g. Nidzica (Michno 2004)

Direct human interference in the Nida fluvial system has been noted since the Middle Ages in the mouth section, e.g. the artificial canal to the W of the castle at Nowy Korczyn. However, it was only the embankment of the mouth section of the Nida River in the 1930s and 1940s that caused the backwater phenomenon to appear.

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A09 SESSION

TIME-INTEGRATED AIR SAMPLING FOR $^{14}CO_2$ IN IRVINE, CALIFORNIA, USA FROM 2009 TO 2025 AND ITS IMPLICATIONS FOR EVALUATING URBAN FOSSIL FUEL CO_2 SOURCES

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Abstract

$^{14}CO_2$ is a unique tool for evaluating fossil fuel-derived CO_2 input in the atmosphere. A month-long time-integrated sampling method, via capillary tubing linked to 32 L canisters, has been used to collect air for ^{14}C and ^{13}C analyses in Irvine, California (33.67°N, 117.82°W) from March 2009 to February 2025. The City of Irvine is a highly urbanized area, located 6 km from the coast within the Los Angeles basin and metropolitan area.

The $^{14}CO_2$ time series shows a distinct seasonal cycle, with a maximum during the summer (May-Jul) and minimum during the winter (Nov-Jan). The amplitude varies interannually, with an average peak-to-valley range of 52.0±9.2‰ (1σ SD, n=15). This pattern corresponds to an average fossil fuel-derived CO_2 contribution of 2.6±1 ppm in summer and 25.4±2.1 ppm in winter during the past fifteen years. The seasonal pattern of $^{14}CO_2$ in Irvine is likely the result of coastal clean air intrusion associated with a persistent marine layer during May and June, higher energy usage, and lower boundary layer height during the winter. This interpretation is supported by the anti-correlation between $^{14}CO_2$ and the CO mixing ratio measured at a nearby air quality monitoring station (Costa Mesa, CA). The $\delta^{13}C$ seasonal cycle is similar to that of the $^{14}CO_2$ cycle, which is consistent with fossil fuel CO_2 addition, air transport, and general inventory patterns in Irvine.

The time series also reveals long-term trends in atmospheric $^{14}CO_2$. From 2010 to 2018, the summer peak of $^{14}CO_2$ (a local baseline) decreased at a rate of 5.3‰ yr^{-1}, slightly faster than at the NH background site of Pt. Barrow, AK (4.3±0.5‰ yr^{-1}). After 2018, the $^{14}CO_2$ summer peak declined significantly more slowly at a rate of 2.4 ‰ yr^{-1}. Moreover, there was no change in summer peak $^{14}CO_2$ between 2019 and 2020, which likely resulted from reduced fossil fuel CO_2 emissions during the global lockdown imposed by the COVID-19 pandemic.

This study demonstrates the advantage of using time-integrated sampling methods for obtaining long-term $^{14}CO_2$ trends in an urban environment where fossil fuel CO_2 emission fluctuate rapidly due to changes in many point sources.

A09 SESSION

CARBON-14 IN THE MARINE ENVIRONMENT OF THE SWEDISH WEST COAST

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Abstract

Today, the expansion of nuclear energy production is promoted as a climate-friendly alternative to meet the demands of increased production of electricity. One aspect that needs to be considered prior to extending nuclear power is operational releases of long-lived radionuclides that disperse globally and remain in the environment for hundreds and thousands of years. Here, ^{14}C is a key radionuclide (UNCEAR, 2016). In Sweden, ^{14}C often dominates the estimated committed effective dose to the public from operational releases from nuclear power plants (NPPs) (Aquilonius and Hallberg, 2005). To be able to evaluate the future radiological impact of nuclear power it is essential to understand the behaviour of ^{14}C, locally as well as globally.

We have assessed ^{14}C levels in the marine environment of the Swedish west coast by analysis of ^{14}C in three sample sets. The first set consists of brown algae (*Fucus* spp.) that have been regularly collected in shallow waters at Särdal (56.76N, 12.63E) since 1967 (Mattsson et al, 2022). Present levels have been assessed not only through ^{14}C measurements of *Fucus* spp. at various sites on the Swedish west coast in 2020-2024 (Eriksson Stenström and Mattsson, 2022; Eriksson Stenström et al, 2025), but also through a one-year study of ^{14}C in various marine organisms close to Ringhals nuclear power plant (57.26N, 12.11E). The ^{14}C-measurements were done by accelerator mass spectrometry.

The Särdal site is located ~65 km south of the operational Ringhals NPP and ~130 km north of Barsebäck NPP. The latter is currently under deconstruction (reactors closed in 1999 and 2005). A rough estimation using the Särdal data from around 1980 yields that $F^{14}C$ in the shallow waters of Särdal is to ~80% represented by the atmospheric data and to ~20% by the modelled value for oceanic water to a depth of 75 m (Reimer et al, 2009). This is expected since the habitat of *Fucus* spp. is close to the water surface where CO_2 from the atmosphere enters the ocean water as dissolved inorganic carbon (DIC) which is absorbed by the algae. However, after about 1990 the Särdal ^{14}C values start exceeding the atmospheric CO_2 curve. Furthermore, a pronounced increase can be seen in 1998 and another one in the mid-2010s. This is mainly believed to be due to ^{14}C transported by ocean currents from the spent nuclear fuel reprocessing plants La Hague (France) and Sellafield (UK) to the Swedish west coast (Eriksson Stenström and Mattsson, 2022; Mattsson et al, 2022). This assumption is strongly supported by the observation that the temporal pattern of the Särdal $F^{14}C$ data correlates with reported liquid discharge rates from these reprocessing facilities (Eriksson Stenström and Mattsson, 2022; Mattsson et al, 2022). We estimate that since the end of the 1990s, the liquid discharges from La Hague and Sellafield have resulted in an excess $F^{14}C$ in *Fucus* spp. from Särdal of 0.030-0.063, with an average of ~0.047.

The spatial and temporal variations in $F^{14}C$ in *Fucus* spp. collected between 2020 and 2024 along the Swedish west coast and at two reference stations in the Baltic Sea showed that (Eriksson et al, 2025): 1) $F^{14}C$ gradually increases towards the north of the west coast due to increased influence from the La

Hague and Sellafield discharges; 2) the northernmost sites at the west coast have up to ~10% higher $F^{14}C$ than in the Baltic Sea. The data has been used to obtain a hypothetical reference value for the site of Ringhals NPP (a linear relation with $F^{14}C \approx 1.060$ in January 2020 and 1.041 in Januari 2024).

The one-year study (2023-2024) at Ringhals NPP, presently hosting two pressurized water reactors of the light-water type, covered the coastal area from up to ~9 km north to ~8 km south of the NPP´s cooling water outlet. The general order of $F^{14}C$ seen in different marine species was: *Fucus vesiculosus* (brown algae) ≤ *Magallana gigas* (Pacific oyster) < *Mytlius edulis* (blue mussel) < *Symphodus melops* (corkwing wrasse). *Cancer pagurus* (crab) appeared to have somewhat higher $F^{14}C$ than *F. vesiculosus* collected at the same site. The highest concentrations of ^{14}C were found close to the cooling water outlet of the NPP. There, biofouling plates had $F^{14}C$ up to 8.250±0.023, *S. melops* up to 5.058±0.017, *M. edulis* up to 2.812±0.010 and *F. vesiculosus* up to 2.070±0.007. The organic fraction of sediment had up to $F^{14}C$ = 2.128±0.008. The spatial variability in marine ^{14}C at Ringhals NPP was consistent with the expected dispersion patterns due the direction of the liquid discharges (to the south) and due to the Baltic current twisting the dispersed cooling water plume towards the north.

The results of the study demonstrate that even though the liquid ^{14}C discharges from Ringhals NPP are believed to be small compared to the total ^{14}C operational releases, the resulting ^{14}C signal in marine biota can be substantially higher than in terrestrial biota. We believe that liquid discharges of water-soluble organic compounds (less diluted in seawater than DIC) from the pressurized water reactors at Ringhals NPP play a significant role in the observed excess of ^{14}C in *S. melops* and *M. edulis*. The results of ^{14}C analysis of particulate carbon, which also shows significantly elevated ^{14}C content, support this hypothesis. Today, ^{14}C is monitored through stack air measurements at Swedish NPPs. Source monitoring of liquid ^{14}C discharges is not performed, neither is environmental monitoring of ^{14}C in the terrestrial or the marine environment. We recommend that such monitoring is made mandatory.

Acknowledgments

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A09 SESSION

PARTITIONING OF ATMOSPHERIC CO_2 LOAD USING RADIOCARBON AND STABLE CARBON ISOTOPES: A CASE STUDY FROM KRAKOW (POLAND)

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Abstract

The partitioning of atmospheric carbon dioxide (CO_2) in Krakow, a site representing a typical urban background, was investigated through combined measurements of CO_2 mixing ratios and isotopic composition ($^{14}CO_2/^{12}CO_2$ and $^{13}CO_2/^{12}CO_2$). Measurements were conducted during 12 months from 2021 to 2022. The Kasprowy Wierch station, located on the main ridge of the Tatra Mountains at the Polish-Slovak border, was selected as a regional reference site due to its minimal anthropogenic influence.

CO_2 concentrations were determined using a Picarro G2311-f gas analyzer, with air samples collected every four hours via a flask autosampler from the rooftop of the D10 AGH University of Krakow building. To ensure data quality, Picarro G2311-f measurements were cross-validated against LiCor LI-7500DS data, obtained at a 30-minute resolution. Further isotopic analysis was performed on collected gas samples, with radiocarbon ($^{14}CO_2/^{12}CO_2$) measured using Accelerator Mass Spectrometry (AMS) and stable carbon isotopes ($^{13}CO_2/^{12}CO_2$) analyzed via Isotope-Ratio Mass Spectrometry (IRMS).

During the campaign, CO_2 concentrations ranged from approximately 403 ppm to 525 ppm, $\delta^{13}CO_2$ values varied between -13.85 ‰ (heating season) and -8.56 ‰ (vegetation season), while $\Delta^{14}CO_2$ ranged from -132.1 ‰ to 3.4 ‰, respectively.

The contributions of biogenic and anthropogenic CO_2 sources were quantified using an isotope mass-balance approach. The results indicate that during the vegetation season, biogenic sources were the dominant contributor to atmospheric CO_2, whereas in the heating season, anthropogenic emissions played a predominant role.

Acknowledgments

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A09 SESSION

TRACING THE URBAN CARBON EMISSION PEAKS AND SYNERGIZING REDUCTIONS OF CARBON EMISSIONS AND AIR POLLUTANTS THROUGH TREE-RING ^{14}C

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Abstract

Carbon peak is the premise of carbon neutrality, which is crucial for establishing a roadmap for achieving carbon neutrality goal in China. Thus, it is important to identify whether and when the carbon emissions is peak or not. We present a study identifying peak carbon emissions from two Chinese cities using urban tree-ring $\Delta^{14}C$ time series during 2000–2019. After subtracting background atmospheric $\Delta^{14}C$ from urban tree-ring $\Delta^{14}C$, we find a minimum of local $\Delta^{14}C$ ($\Delta^{14}C_{local}$) in 2010 in Beijing and that in 2013 in Xi'an. These levels correspond with the urban carbon emission peaks in 2010 and in 2013 in the two cities. Additionally, we observed the synchronous changing trends of urban yearly CO_{2ff} and $PM_{2.5}$, and the decrease in yearly $PM_{2.5}/CO_{2ff}$ ratios and $\Delta CO/CO_{2ff}$ indicate the effectiveness of air pollution control actions and the improvement of combustion efficiency in China, which provide an observation support for the synergizing reductions of carbon emissions and air pollutants in China.

Acknowledgments

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A09 SESSION

TRACING SEASONAL URBAN GREENHOUSE GAS PATTERNS WITH CARBON ISOTOPES IN DEBRECEN, HUNGARY

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Abstract

Industrial and transport-related emissions from urban areas play an important role in shaping greenhouse gas trends in the atmosphere. To monitor these emissions, the Integrated Carbon Observation System (ICOS) was established in Europe, launched the ICOS Cities program. The programme performs coordinated, high-quality greenhouse gas monitoring alongside regional background measurements and sampling, strengthening the scientific basis for cities' climate protection efforts.

Similarly, to investigate urban emissions, atmospheric ambient air samples were collected in three different seasons (winter, spring and summer) at the HUN-REN ATOMKI in Debrecen. Sampling was designed to represent the differences between weekdays, weekends and morning and afternoon periods. The analysis of the samples was carried out in the context of an international collaboration. The stable isotope compositions of carbon dioxide and methane were determined at the IMAU laboratory at Utrecht University. In parallel, the concentration and radiocarbon ratio of the samples were analysed at ATOMKI. This novel measurement combination allows characterisation and source analysis of atmospheric greenhouse gases.

The isotopic composition of carbon dioxide ($\delta^{13}C$ and $\Delta^{14}C$) revealed distinct seasonal signatures. Stronger fossil fuel signals under inversion dominated winter, spring showed mixed influences with increasing biogenic contribution, while biogenic sources characterized summer. The analysis of methane concentrations and stable isotope composition indicates increased winter biogenic emissions, with a potential source in the urban wastewater network. These patterns reflect a complex interaction between photosynthetic activity, human activity intensity and planetary boundary layer dynamics.

Acknowledgments

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Keywords: global warming, carbon dioxide, methane, radiocarbon, stable isotope

A09 SESSION

TURNOVER RATES IN HUMAN HIP BONES: THE CONTINUATION OF A STORY

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Abstract

Bone and tissue fractions, obtained in 2017 following hip replacement surgery on a healthy Caucasian male, born in 1944, reflect in their ^{14}C concentrations the integrated effect of the life-time metabolic uptake and replacement of atmospheric bomb ^{14}C at different tissue-specific turnover rates (Nadeau & Grootes, *in press*). A simple bone growth and regeneration model used in combination with the NH atmospheric ^{14}C concentrations (Hua et al. 2021) indicates remodelling rates around 9 % per year in the healthy bone and a doubling to tripling in the damaged area depending on the model chosen. The results also showed regeneration of cartilage with a much-increased rate near the damaged part of the femur head. These results, however, were derived form only one joint.

We obtained a second hip joint (femur head, femur interior, acetabulum) from the same individual and a hip joint from a Caucasian female, also born in 1944, who has the same diet and lifestyle, both in fall 2022. The radiocarbon content of the bio-apatite and collagen fractions of the femur interior and acetabulum shavings as well as several bone sections of the femur head from damaged and healthy areas from these new acquisitions were measured. We also sampled different part of the cartilage covering the femur head, from the damaged area, where the cartilage was completely eroded to healthy areas. The comparison between two hip bones removed 5 years apart from the same individual as well as the difference between male and female having the same diet allows distinctions which were not possible with a single hip joint.

We present the results of these new measurements and the regeneration models now refined by the new results.

Acknowledgments

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A09 SESSION

INTRACORTICAL RADIOCARBON (F14C) AND STABLE ISOTOPE VARIATION IN HUMAN FEMORA

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Abstract

Human bone, commonly used in archaeology and forensics for radiocarbon dating (^{14}C) and stable isotope analysis, has differential intra-skeletal turnover rates. Diet in adults is conventionally investigated using a single bone collagen measurement, resulting in a low temporal resolution averaging of the biochemical data, interpreted as a long-term 'adult' diet. Single-measurement bulk samples thus inevitably mask potential isotopic shifts and important dietary variation that may have occurred over time in life.

The aim of this study is to define relative differences in human cortical bone turnover rates, based on 25 femoral bone collagen $F^{14}C$ (fraction modern) dates and associated carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope measurements. The data came from five modern donors who lived through the ^{14}C 'bomb spike' caused by nuclear testing in the mid-20th century, enabling precise bomb curve calibration of the ^{14}C measurements.

Our results demonstrate a sequential variation in biochemical composition of the collagen in femoral cortex, with the radiocarbon age of the bone cross-section decreasing gradually from the endosteal to the periosteal bone. From the $F^{14}C$ variation in modern femora, we infer a novel sampling approach for isotope analysis. In archaeology and forensics this will allow the recreation of chronological dietary and mobility history in adult life at an unprecedented resolution and will improve ^{14}C dating precision in forensic contexts.

A10 SESSION

UTILIZING RADIOCARBON TO DATE UNIDENTIFIED HUMAN REMAINS

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Abstract

Over the past five years, the lab has been collaborating with Australian Coronial Services and police to determine the Year of Death (YOD) for human remains. Currently, there are over 800 sets of unidentified remains in Australia. Before conducting the time-consuming and costly DNA analysis, radiocarbon dating is utilized to ascertain whether the remains are less than 100 years old and, therefore, of coronial significance. We will present the current results on approximately 70 different sets of remains and highlight a recent case where we dated teeth, hair, and nails to determine YOD and Year of Birth. This individual was subsequently identified through DNA, but the case remains under investigation.

A12 SESSION

PUSHING THE BOUNDARIES OF MORTAR DATING: APPLYING RAMPED PYROLYSIS ON BRONZE AGE SAMPLES

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Abstract

Mortar, a building material used throughout human history, potentially holds valuable chronological information that can be accessed through radiocarbon dating. Due to complications such as contamination from older carbon of geological origin and younger carbon through recrystallization, the application of mortar dating has been met with scepticism. However, a steady stream of research on the application of ramped pyrolysis on mortar dating has recently shown significant promise in obtaining precise and accurate results on historical mortar (Barrett et al. 2020, 2025). Yet, its successful application to mortar predating classical antiquity remains unconfirmed.

This study assesses the feasibility of ramped pyrolysis method for dating Bronze Age mortar samples from Tel Lachish. Four mortar samples from secure archaeological contexts were analysed. Our investigation involved Fourier Transform Infrared Spectroscopy (FTIR) for characterization, followed by ramped pyrolysis to isolate and extract the correct CO_2 fraction, which was then radiocarbon dated.

Our findings are very promising and suggest that mortar dating might be successfully applied to Bronze Age samples. This study explores the potential for systematically correcting radiocarbon dates affected by contamination from older carbon sources. We will discuss the steps toward establishing a robust protocol for ancient samples. With further refinement, this method could become a valuable chronological tool for archaeological sites where organic material is scarce.

Acknowledgments

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^{14}C OFFSETS IN MARINE LIMPETS: OBSERVATIONS ON UPPER-SHORE MOLLUSCS AND IMPLICATIONS FOR THEIR USE IN RADIOCARBON DATING

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Abstract

The use of shells for radiocarbon dating purposes has generally been avoided due to the uncertainties involved with marine reservoir corrections and the possibility, particularly in some species, of old carbon being incorporated into the shell from carbonate substrates (Dye 1994; England et al 2013). A previous study investigated the possibility of ^{14}C offsets from grazing limpets on Irish limestone coasts. Results from *Patella vulgata* collected live on limestone and volcanic substrates on the coasts of Ireland indicated that the shells were formed in equilibrium with the seawater, with no significant ^{14}C offsets (Allen et al 2019). However, there are reported results of older dates from at least one rocky intertidal species (*Patella rustica*) collected live from rocky shores in Gibraltar (Ferguson et al 2011). It is conceivable then, that molluscs from this location are affected by the limestone geology of this region or there could be another explanation. The question is whether these offsets are related to species or habitat.

To investigate this, the authors obtained radiocarbon measurements on a range of grazing molluscs collected from Gibraltar limestone locations with additional filter-feeding species as controls as well as more individuals of one of the species, *Patella rustica* from Sardinia, a location with varied substrates. In addition, we hope that stable isotope analysis of both shell and flesh can provide more information about the formation of the shell, including environmental and metabolic inputs, which could possibly provide an indication of the origin of the offset. Initial results imply that shells from upper shore species will have a very large uncertainty in their reservoir age and, therefore, are not suitable for radiocarbon dating, especially if they have come from an area of carbonate geology. Indications are that grazing species from lower shore habitats, which experience daily immersion, may be suitable for dating from any substrate.

Acknowledgments

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RADIOCARBON REVEALS GROUNDWATER DYNAMICS ON A SMALL CARBONATE ISLAND AND SUBMARINE GROUNDWATER DISCHARGES

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Abstract

Groundwater faces significant challenges in the 21st century due to overexploitation and depletion of aquifers. Small island aquifers are particularly valuable resources , and thus, a scientific understanding of their dynamics is key to sustaining these resources. A study using radiocarbon combined with stable oxygen isotopes, stable hydrogen isotopes and hardness analysis ($\Delta^{14}C$, $\delta^{18}O$, δD, Ca, Mg) of groundwater was conducted on Kikai Island, a southern island in the Amami Archipelago, Japan (Tsujino et al., 2024). The geological characteristics and small size of the island make it an ideal location for the evaluation of groundwater recharge and discharge relationships. Groundwater dynamics were investigated using samples collected seasonally from 15 sites around the island (wells, springs, and an underground dam). C-14 results indicated that despite considerable differences in precipitation, spatial variations are more prominent than seasonal variations, suggesting the presence of a large groundwater reservoir. Stable isotopes and hardness values, commonly used to assess groundwater dynamics, did not provide clear evidence of this trend for the study site, a low-lying small island. However, the combination of deuterium excess (d-excess) values with radiocarbon analysis has the potential to provide a better understanding of groundwater flow. Taking into account geomorphological and geological features, groundwater on Kikai Island was classified into five groups, providing insights into spatial groundwater flow. In addition, seawater collected from coastal sites around the island indicated significant contributions from groundwater discharges. Comparison with nearby corals suggested that the influence of groundwater is significant for samples living at the shore, such as bivalves and gastropods, indicating the importance of sample selection for reconstructing the local marine reservoir ages.

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REMINERALIZATION OF ORGANIC MATTER IN MARINE SEDIMENTS FROM SVALBARD FJORDS ALONG A GRADIENT OF ATLANTIFICATION

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Abstract

Atlantification refers to the inflow of Atlantic water masses into the Arctic Ocean, which has been observed to increase over the past decades (Tesi et al. 2021). The North Atlantic Current transports warmer, nutrient-rich water to the west of Svalbard (Winkelmann and Knies 2005). Its inflow has strong effects on local productivity and ecology. There is also a potential impact of Atlantification on remineralization of sedimentary organic matter via two separate mechanisms: Organic matter input to fjord sediments derives from primary production as well as from land brought into the marine realm from land, e.g., via fjords supplying eroded and finely ground bedrock materials, both of which can be stimulated by increasing temperatures. Second, the breakdown of organic carbon into its inorganic forms is dependent on factors such as temperature, and biotic activities (Chen et al. 2022). It has recently been found that microbial utilisation of organic matter in sediments might, however, also include fossil carbon, making it another potential source of fossil greenhouse gases (Ruben et al. 2023). The amount of this fossil organic matter efflux from sediments, however, remains to be quantifies.

We analysed carbon isotopic ($\delta^{13}C$ and $\Delta^{14}C$) signatures of fjord sediments and porewater dissolved inorganic carbon (DIC) samples from three fjords around Svalbard in order to understand the remineralization of organic matter from the sediment and the impact of Atlantification in Arctic fjords on remineralization. In each fjord, two cores were taken, respectively, at its mouth and in the fjord's interior close to glacier fronts. Radiocarbon analysis of DIC in porewater reveals that in the western-facing Van Mijenfjorden at the interior site fossil carbon was utilized by sedimentary microbial communities and contributed to DIC efflux from the sediment while DIC porewater profiles of the core taken at the fjord mouth suggests the utilisation of mostly modern material. The northward-facing Wijdefjorden is characterized by the remineralization of modern organic matter at both sampling stations. Total organic matter content in the sediment is higher in Van Mijenfjorden than in Wijdefjorden, suggesting that the input of organic matter is lower in the latter and thus, less readily degradable organic carbon is available for remineralization. Both fjords receive petrogenic material from sources which differ in their carbon content (Kim et al. 2022). Furthermore, Atlantic water influences are expected to be greatest at the western margin of Svalbard (Athanase et al. 2021), bringing more nutrients and changing primary production patterns (Tesi et al. 2021; Winkelmann and Knies 2005). This study shows that fossil carbon can be utilised and effects of Atlantification can be observed in western Svalbard fjords.

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RADIOCARBON IN THE CARIBBEAN: SYNCHRONIZING RECORDS USING A DAMPED OSCILLATOR APPROACH.

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Abstract

Radiocarbon in the Caribbean Ocean is of great interest because it is used for both radiometric dating of marine organisms as well as studies of ocean circulation pathways and gas exchange. The Caribbean as the source region of the Gulf Stream plays a central role in northern hemisphere heat transport and the carbon cycle. Several ^{14}C records on tropical corals exist in this ocean basin spanning the past 100 years revealing anthropogenic CO_2 and nuclear bomb-^{14}C uptake, regional upwelling variations, and subtropical gyre recirculation strength.

Here, we present a new annually-resolved centennial $\Delta^{14}C$ record from Puerto Rico, spanning the periods 1885–1909 and 1935–1990. Pre-bomb $\Delta^{14}C$ values (prior to 1950) average -37‰, with associated 2σ uncertainties of 3–4‰, and show a significant Suess effect of (-0.053 ± 0.015) ‰/yr as expected. The bomb-peak maximum is observed in 1974, characterized by an increase of (189 ± 6) ‰.

To achieve comparability among various coral records, we estimate the bomb-peak response to atmospheric ^{14}C changes using the boundary case of an aperiodic harmonic oscillator. In this approach, the abrupt atmospheric ^{14}C increase due to nuclear bomb testing was treated as an impulse event, triggering a rapid initial response followed by an exponential decay in oceanic Δ14C, characteristic of a damped oscillatory system without full oscillation cycles. Synchronization of datasets was achieved by aligning them according to the onset of the steep rise in $\Delta^{14}C$ values, explicitly excluding early, gradual-rise data points. The determined onset date for the steep $\Delta^{14}C$ increase was (1959.7 ± 0.7) AD. Notably, deviations from the model fits provided no evidence for upwelling events previously described by Paterne et al. (2023).

Our newly presented coral core exhibits a damping constant of (72.2 ± 1.3) $\times 10^{-3}$ yr^{-1} that translates to a reservoir residence time of (11.9 ± 0.4) years. By contrast, a nearby sediment core (<10 km) analyzed by Kilbourne et al. (2007), located further offshore and more exposed to open-ocean conditions, reflects a substantially greater influence of older water masses, characterized by a significantly lower pre-bomb $\Delta^{14}C$ baseline (~-52 ‰), a reduced damping constant of (58.6 ± 1.2)$\times 10^{-3}$ yr^{-1}, and an extended reservoir residence time of (17.1 ± 0.4) years. A weaker atmospheric influence at that site is further supported by the absence of a significant Suess effect.

Our new data now enables a combined analysis of the gas-exchange-dependent damping constants and distinct pre-bomb baseline levels, allowing for the separation and evaluation of advective versus convective components of water mass transport following the approach initially put forward by Kilbourne et al. (2007).

Acknowledgments

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EVALUATING RADIOCARBON AND STABLE ISOTOPE SIGNALS IN CALCITE AND ARAGONITE LAYERS OF ABALONE SHELLS

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Abstract

Abalones (gastropods of the genus *Haliotis*) are culturally and ecologically important marine mollusks, with over 70% of commercially harvested species now classified as threatened. In northeastern Japan, the cold-water species *Haliotis discus hannai* (Ezo abalone) faces rising mortality and declining populations, possibly linked to climate-driven shifts in the Kuroshio and Oyashio currents. Understanding these changes is not only scientifically important but also vital for conservation and sustainable aquaculture management.

Radiocarbon analysis of abalone shells offers promising potential for paleoceanographic reconstruction in high-latitude regions where corals are absent. Fossilized shells may offer insights into past human–nature relationships, but modern shells are needed to address methodological uncertainties. While a previous study demonstrated that *Haliotis discus hannai* shells can reflect past seawater radiocarbon variations, it did not consider differences in biomineralization between aragonite and calcite layers. A key question is whether radiocarbon signals in ambient seawater are better captured in the outer prismatic layer of calcite, the inner nacreous layer of aragonite, or through bulk analysis combining both.

To address this, we compare radiocarbon ($\Delta^{14}C$) and stable isotope ($\delta^{18}O$, $\delta^{13}C$) values in calcite and aragonite portions of modern abalone shells collected with corresponding seawater from Otsuchi Bay, Northeastern Japan. By analyzing multiple geochemical parameters within abalone shells, we aim to explore how sampling strategies may influence the interpretation of environmental signals, and to assess the effectiveness of calcite versus aragonite layers in preserving those signals.

ANTHROPOCENE NORTH WESTERN PACIFIC SEA-SURFACE RADIOCARBON VARIABILITY RECORDED IN CORAL SKELETON FROM OKINOERABU ISLAND, JAPAN

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Abstract

The Ryukyu Current branches off the Kuroshio, a western boundary current of the North Pacific, near Taiwan and flows north along the eastern side of the Ryukyu Islands. These currents play a critical role in climate variability in East Asia. Understanding their variability using instrumental data at different observation sites is key to providing insight into the oceanography and climatology of the region, although long-term time series data with high temporal resolution are still needed. One of the proxies used to reconstruct ocean circulation is radiocarbon (^{14}C) recorded in coral skeletons. Corals incorporate dissolved inorganic carbon containing ^{14}C into their calcium carbonate skeletons as they grow. Therefore, the ^{14}C concentration ($\Delta^{14}C$) in coral skeletons can be used as a long-term indicator of water mass distribution. In particular, radioactive nuclide fallout from atmospheric nuclear testing in the central tropical Pacific in the 1950s produced a distinctive signature in oceanic $\Delta^{14}C$, known as early $\Delta^{14}C$ spikes (Andrews et al., 2016; Hirabayashi et al., 2017). The timing and magnitude of $\Delta^{14}C$ spikes vary with the distance from the source of test sites along the Kuroshio (Yokoyama et al., 2022), making them a characteristic indicator of water mass movement and mixing.

Here, we measure high-resolution $\Delta^{14}C$ of a coral from Okinoerabu Island (27.3°N), located between Ishigaki (24.3°N) (Hirabayashi et al., 2017) and Kikai (28.3°N) (Zeng et al., 2024) Islands, Japan, to reconstruct oceanic transport variability in the Kuroshio region with higher precision. Oxygen isotope ratios ($\delta^{18}O$) and carbon isotope ratios ($\delta^{13}C$) are also measured to understand long-term variability of seawater temperature, salinity and $\delta^{13}C$ of dissolved inorganic carbon. The presentation will discuss the oceanography of the Northwest Pacific during the mid-20th century using coral $\Delta^{14}C$ together with $\delta^{18}O$ and $\delta^{13}C$.

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RADIOCARBON DATING OF SEDIMENTS FROM LAKE ŻARNOWIECKIE

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Abstract

The study aimed to establish the chronology of bottom sediment deposition in Lake Żarnowieckie, a glacial-origin lake located in the coastal zone of the Baltic Sea in northern Poland, through radiocarbon dating. An 8-meter-long sediment core of mainly homogenous gyttja of varying colors and sand at the bottom layers was extracted from the lake's bottom. 21 samples of bulk sediment, as well as plant remains were selected from the layers of visible lithological borders. After selecting the most suitable material for dating, some samples were sieved through a 90 µm mesh to isolate organic remains. The samples underwent ABA chemical preparation and were subsequently processed into graphite for analysis using the MICADAS accelerator mass spectrometer at the ^{14}C and Mass Spectrometry Laboratory in Gliwice.
A total of 20 dating results, ranging from 2,300 BP to near the limit of the radiocarbon method, were obtained, calibrated, and compared with lithological and preliminary palynological analyses. A significant reservoir effect, leading to considerable age discrepancies, was observed in many cases. The reservoir effect in Lake Żarnowieckie was estimated at several hundred to 2,000 years, consistent with findings from other Polish lakes. Two samples showed particularly large age discrepancies compared to the age-depth model suggesting possible redeposition of older material and sedimentation disturbances, such as landslides or increased erosion. Additionally, two samples, with ages approaching the radiocarbon method's limit, originated from deep, sandy layers that were likely deposited by glacial processes before lake formation.
The construction of the sediment chronology will be refined with future research to verify the current interpretation and address observed discrepancies.

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MARINE RESERVOIR EFFECTS ON *TEREBRALIA PALUSTRIS* SHELLS IN THE UNITED ARAB EMIRATES

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Abstract

This presentation gives an overview over various radiocarbon measurements of *Terebralia palustris* shells that had been recovered from archaeological sites along the coasts of the United Arab Emirates. We compare the data from the coast of the Arabian/Persian Gulf, especially the site Shimal in the Emirate Ras al-Khamiah, and of the coast along the Gulf of Oman, mainly Kalba, Emirate Shajah. Over time, the marine reservoir effect (MRE) varies significantly. In comparison with other paleoclimate data such as stalagmites, sea-level to name but a few, it is easier to understand these variations in the context of changing environmental conditions.

RADIOCARBON MARINE RESERVOIR EFFECTS AROUND THE SURUGA BAY, PACIFIC COAST OF CENTRAL JAPAN

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Abstract

The radiocarbon (^{14}C) age of surface seawater prior to nuclear testing was 200 to 1,000 years older than terrestrial samples in the marine areas around Japan (Marine reservoir database; Reimer & Reimer 2001). This age difference is known as the marine reservoir effect, which varies by region. When calibrating the ^{14}C age of marine-derived samples to calendar years, it is necessary to take the reservoir effect into account. To determine the marine reservoir effect along the Suruga Bay coast, we investigated Holocene sediments from the Shimizu Plain, Ukishimagahara, and Kikugawa Lowland. We compared the ^{14}C ages of shell fossils and terrestrial plant fragments from the same stratigraphic horizons at multiple depths to examine the spatial and temporal variations of the marine reservoir effect in this region.

We collected 30 plant fragments and 22 shell fossils from five borehole core samples, each with a drilling length of 70.5 m, obtained at the mouth of the Tomoe River in Shizuoka City (Kitamura & Kobayashi 2014). The ^{14}C ages of these samples were measured at the Korea Institute of Geoscience and Mineral Resources (KIGAM). We also utilized the dates of 47 existing samples to examine the presence or absence of redeposition. From the 85 samples not affected by redeposition, we selected 12 pairs of plant fragments and shell fossils from the same horizons and examined the age differences. During the period of 11,000–2,300 cal BP, marine reservoir effects of 130 ± 40 to 590 ± 40 years were obtained for species inhabiting inner bays, such as *Dentalium aprinum*, *Nassarius livescens*, *Veremolpa micra*, *Macoma incongrua*, *Umbonium costatum*, *Batillaria multiformis*, *Batillaria zonalis*, *Cerithium coralium*, and *Pirenella nipponic*a (Nakanishi et al. 2025a).

We also analyzed a borehole core sample (drilling length: 30 m) collected from a reclaimed area of Ukishimagahara, the innnermost part of Suruga Bay (Ishiyama et al. 2019). This sample contained 13 plant fragments and 6 shell fossils whose ^{14}C ages were measured at KIGAM. From the six horizons not affected by redeposition, we analyzed the age differences between shell fossils and plant fragments. For the period of 7,900–6,800 cal BP, marine reservoir effects of 150 ± 70 to 470 ± 60 years were identified in estuarine to inner bay sediments inhabited by species such as *Dosiniella angulosa*, *Veremolpa micra*, and *Ringicula doliaris* (Nakanishi et al. 2025b).

We collected a borehole core sample (drilling length: 23.3 m) from the mouth of the Kikugawa River, outside Suruga Bay (Hori et al. 2022). The ^{14}C ages of 16 plant fragments and 16 shell fossils from this core were measured at the Institute for Space-Earth Environmental Research, Nagoya University. From the 28 horizons unaffected by redeposition, we selected seven pairs of plant fragments and shell fossils from the same horizons and compared their ^{14}C age differences. For the period of 9,400–7,600 cal BP,

marine reservoir effects of 30 ± 60 to 510 ± 70 years were estimated for species inhabiting estuarine to delta front environments, including *Ruditapes philippinarum*, *Solidicorbula erythrodon*, *Anomia chinensis*, and *Solecurtus divaricatus*.

Combining these 25 pairs, the average marine reservoir effect around Suruga Bay was calculated to be 310 ± 130 years. Estimating these reservoir effects is useful for obtaining accurate calendar ages of Holocene marine-derived samples along the Suruga Bay coast.

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VERTICAL PROFILES OF GROUNDWATER AGE IN THE KAMIKITA COASTAL PLAIN, NORTHEASTERN JAPAN

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Abstract

For intermediate depth disposal of radioactive waste, it is necessary to evaluate the regional groundwater flow including a potential repository site. We have previously developed a conceptual model of groundwater flow in the Kamikita coastal plain, northeastern Japan, based on groundwater chemistry and a series of isotopic data obtained for existing wells (Tosaki et al., 2023). To verify the shallow part of the model, we conducted borehole drilling surveys (~200 m depth) at four locations in the plain, from recharge to discharge areas of the regional groundwater flow system. Here we report on the vertical profiles of groundwater ^{14}C age from the four boreholes, together with chemical and stable isotopic data.

The Kamikita Plain is a relatively low-lying coastal plain with marine terraces widely distributed throughout the region. It includes a large brackish coastal lagoon, Lake Ogawara, in the northeastern part. The geology is generally flat in the main part of the plain; the Pleistocene Misawa Formation and the Pliocene Katchi Formation constitute the main confined aquifers.

Drilling surveys were conducted at four locations (boreholes KMK-1 to 4) to obtain detailed geologic columns, groundwater chemistry, isotopes, and hydraulic data. Groundwater pumped during the pumping tests at each depth was collected for analyses. The $\delta^{13}C$ values and DIC concentrations were measured using a continuous-flow isotope ratio mass spectrometer coupled with gas chromatography. The ^{14}C concentrations in dissolved inorganic carbon were analyzed by accelerator mass spectrometry at Paleo Labo Co., Ltd., Japan. The calibrated ^{14}C ages were obtained using the IntCal20 calibration curve and are treated here as apparent ages that do not take groundwater mixing into account.

In the recharge area (borehole KMK-4), the ^{14}C ages of the pumped groundwater samples are modern with detectable tritium concentrations, except for a sample (depth: 115.0-120.0 m) just above the flexure structure (~2,000 yr). In the downstream lowlands (borehole KMK-1), the apparent ^{14}C ages correspond to 10,000 to 17,000 yr ($\delta^{13}C$ values range from -19.9‰ to -17.1‰). The ^{14}C ages in deeper layers tend to be older, except at 39.8-45.0 m where the age is ~16,000 yr. The apparent ^{14}C ages at depths of 163.0-169.2 and 187.0-190.0 m in borehole KMK-3 (further downstream; west shore of Lake Ogawara) are approximately 17,000 and 19,000 yr, respectively ($\delta^{13}C$ values -19.3‰ and -20.3‰, respectively), close to the Last Glacial Maximum. At the coastal hill to the east of Lake Ogawara (borehole KMK-2), tritium was detected in shallow samples (1.7-2.4 TU), suggesting that groundwater is being recharged by young water from the surface. On the other hand, deeper samples (95.8-101.4, 118.0-128.4 and 157.3-163.3 m) show ^{14}C ages ranging from 4,000 yr to ~12,000 yr ($\delta^{13}C$ values range from -16.7‰ to -15.1‰).

It is considered that the borehole surveys have revealed a more detailed groundwater age distribution that was not captured in existing wells with wider screen widths. In the presentation, we will discuss the detailed distribution of dating tracers, isotopes and groundwater chemistry, and the characteristics of the groundwater flow system in the area. Our case study demonstrates that ^{14}C age profiles from drilling

surveys play an important role in verifying or developing conceptual models of groundwater flow.

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THE IMPLICATION OF DUAL CARBON ISOTOPE SIGNATURES IN COLD-SEEP MACROFAUNA FROM THE SOUTH CHINA SEA

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Abstract

The cold-seep ecosystem, known as the "oasis" due to its abnormally high biomass, is an essential part of the ocean carbon cycle and plays a significant role in regulating climate change. The carbon of sea-surface and deep-sea macrofauna is mainly derived from the product of photosynthesis, while the carbon of macrofauna in cold seeps mainly comes from the chemosynthesis. The understanding of the contribution of cold seep ecosystem to global carbon cycle is limited, mainly due to the lack of quantitative research. We analysed the ^{14}C and ^{13}C isotope signature of the organic tissues and inorganic shells of macrofauna in the cold-seep ecosystem at Site F in the South China Sea, to quantitively tracing the carbon sources of organisms of difference species. For organic tissues, Δ ranges from -896.9 ‰ to -449.2 ‰, and δ13C ranges from -70.6 ‰ to -47.7 ‰. The results show that the carbon sources of the organic tissues of macrofauna at Site F all exhibit a significant two-end-member mixture. Through isotope mass balance, the contribution of methanotrophic substances can be quantitatively calculated. And the mussel shows the highest proportion of contribution from substances of methanotrophic sources. For Inorganic shells, Δ ranges from -288.7 ‰ to -227.7 ‰, and $\delta^{13}C$ ranges from -13.4 ‰ to 0.3 ‰. The carbon sources of the inorganic shells show that mussels and gastropods have a similar source of the dissolved inorganic carbon in ambient seawater for their shells which are mainly composed of carbonates, and the inorganic composition of the chitin shell of squat lobsters and alvinocaridid shrimp have a mixture sources. This study demonstrates that dual carbon isotopes can play a robust role in tracing and quantifying the carbon cycle of macroorganisms in extreme ecosystems such as cold seeps. This would helps to accurately assess the role of cold seep ecosystems in the global carbon cycle.

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ESTABLISHING THE MARINE RESERVOIR EFFECT ON THE COAST OF ENGLAND AND WALES

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Abstract

This study established a modern baseline for variability in the marine radiocarbon reservoir effect (ΔR) along the East, South, and Welsh coasts of Britain. Until now, only a single datapoint has been available for the cost of England, and data in Wales is limited to three shells, meaning that values from northern France, the Netherlands and Denmark have been used to estimate a local ΔR. Whilst marine shells are rarely dated within archaeological and paleoenvironmental contexts in the UK given the good preservation of organic remains, the reservoir effect is relevant as marine protein provides a significant dietary contribution particularly in coastal communities.

This project involved radiocarbon dating filter feeding marine bivalve mollusc shells of known age and location from museum collections. We produced forty-one ΔR values from twenty-three coastal locations, revealing that British coastal waters are generally more ^{14}C depleted than the global ocean average. Regional analysis showed no significant variation in mean ΔR estimates among most UK coastal regions, although data from the West Coast region was most variable. This study significantly increases the number of ΔR measurements for the southern part of Britain and provides the only estimates from the east coast. These are broadly in agreement with previous measurements for the North Atlantic and North Sea. The findings emphasize the importance of using ΔR values representative of the marine carbon contribution and raise a question about the appropriate number of samples to establish a thorough baseline.

Acknowledgments

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RADIOCARBON EVIDENCE FOR THE SOURCE OF THE BOTTOM WATER IN THE SOUTHERN PHILIPPINE BASIN

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Abstract

One of the most distinct features of inter-ocean connections in global circulation is the northward spread of the bottom water from the Antarctic. Under increasing global warming, changes in surface water temperature would be transferred to deep layers. Many physical oceanographic observations, including deep Argo and repeated moorings, have detected noticeable warming in the abyssal zones in the northwestern Pacific attributed to the source from the Southern Ocean. However, few attempts using geochemical tracers have been made to characterize the water masses migration that would be associated with the observed deep water warming, hence limiting our understanding of the mixing processes in the abyssal ocean. Here we report radiocarbon (^{14}C) in dissolved inorganic carbon (DIC) of seawater samples collected at 10 CTD stations in the Southern Philippines Basin (SPB) and Caroline Basins (CBs) during the NORC2022-09 Expedition in 2023. The $\Delta^{14}C$ range in the whole water column is 10.0 ‰ to -230.2 ‰. By comparing with the historical data obtained in 1996 from the GLODAP v2.2023 database, we observe the transfer of bomb-^{14}C from the upper layer to the intermediate ocean. We focus on the origin of the bottom water (>4000 m) in the SPB, which has long been a subject of wide interest. The North Philippines Basin (NPB) in the north and the CBs in the south are two potential source areas of the SPB bottom water. Our data show that the $\Delta^{14}C$ in the deep layer of the SPB is lower than -217.3 ‰, similar to that in the NPB where we previously identified the Lower Circumpolar Deep Water (LCDW) originating in the Southern Ocean as one of the major sources. The fact that the $\Delta^{14}C$ of the deep water to the north and south of the Central Basin Fault (CBF) does not change significantly indicates that the bottom water in the NPB can cross the CBF into the SPB. We therefore suggest that the apparent absence of the LCDW in the SPB is more likely induced by mixing with upper water before the water mass reaches the CBF rather than being blocked by it. The $\Delta^{14}C$ in the CBs shows clear stratification with contrasting values ranging between -209.3 ‰ and -227.4 ‰. Its deep layer displays the characteristics of the UCDW, which has traditionally been considered as a major source for the bottom water of the SPB. We argue that the $\Delta^{14}C$ of the bottom water in the SPB is influenced by both the UCDW from the CBs and the mixed water masses from the NPB. In addition, we find that the $\Delta^{14}C$ of the bottom water in the SPB in 2023 was lower than that measured in 1996. We interpret this as reflecting the reduction in the contribution of the LCDW to the bottom water in the SPB, which is consistent with the observed warming phenomenon in the past decade resulting from the slower input of cold dense water entering the deep Philippine Sea.

RADIOCARBON DATING OF BONE MATERIAL FROM THE CAVE CONTEXT

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Abstract

The subject of the research described in the study involved eight samples of animal bones from the Jaskinia z Kominkiem Cave (also known as Graniczna Cave), located in the Kraków-Częstochowa Upland in the Krzeszowice municipality, southern Poland.

The site is considered unique due to the diversity of well-preserved faunal remains, offering valuable insights into regional paleoecology.

The analysed bones, representing various species of Pleistocene fauna, were examined at the ^{14}C and Mass Spectrometry Laboratory using the radiocarbon dating method.

To supplement the results, an additional sample was collected for dating using the optically stimulated luminescence (OSL) method, which was analysed at the Gliwice Luminescence Laboratory. The application of this method enabled the determination of the age of mineral sediments, which in turn allowed for a better understanding of the processes of deposition and preservation of the remains in the studied cave.

The study emphasizes the importance of interdisciplinary collaboration in modern scientific research. By employing different dating techniques and conducting a detailed analysis, valuable data were obtained that can serve as a reference point for further research in the region. The obtained results are crucial for understanding the chronology of osteological materials that were extracted from cave sediments during uncontrolled unblocking of the chimney which made these sources contextless. Thus, the results provide not only valuable data on Pleistocene faunal deposits in karst environments, but also the chronology of the karst chimney filling.

Due to the risk of collapse, exploration work has been suspended, however, continued research remains possible in parts of the cave that are still accessible.

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HOLOCENE JANUARY AIR PALAEOTEMPERATURE AT THE ANADYR SITE ON THE EASTERN COAST OF CHUCKHI PENINSULA, BASED ON STABLE ISOTOPE COMPOSITION OF AMS ^{14}C DATED SYNGENETIC ICE WEDGES

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Abstract

Key words: ice wedge, peatland, Chuckhi Peninsula, radiocarbon age, Holocene, stable isotopes, palaeotemperature

In the outcrop of syngenetic Holocene strata of the first marine terrace along the coast of Onemen Bay near Anadyr town (Chuckhi Peninsula, easternmost region of the Russian permafrost zone), ice wedges were exposed in sandy loams overlaid by peat and in the peatland 2-2.5 m thick. Peat from upper part of marine terrace was dated to 9.2 cal ka BP, organic matter from ice wedge was dated to 5.4 cal ka BP. A series of ^{14}C dates from 12.4 to 1.1 cal ka BP was obtained from the peatland. Soil-peat veins in the peatland were dated to 4.7 and 2.4 cal ka BP. Organic matter from ice wedges exposed in the peatland were dated from 10.7 to 7.1 cal ka BP. According to ^{14}C dates peatland accumulation began in early Greenlandian stage of Holocene (about 12 cal ka BP), about 9 cal ka BP peat began to accumulate on the surface of the marine terrace. During the Northgrippian stage (7-4.7 cal ka BP) peatland accumulation most likely was interrupted due to flooding and erosion. Ice wedge growth was mainly syngenetic, in the peatland they formed 10.7-7.1 cal ka BP, in the marine terrace they grow about 5.4 cal ka BP.

The reconstruction of mean January air temperature is based on the correlation of δ^{18}O in modern ice veinlet and the mean January air temperature at nearest weather station, obtained by Yu.Vasilchuk (1989) for different regions of Russian permafrost. The ratio $T_{mean\ January} = 1.5\delta^{18}O_{ice\ veinlet}$ (± 3°C) was used to calculate Holocene mean January air temperature. This ratio is suitable for the study site as modern ice veinlets near Anadyr are characterized by δ^{18}O values from –15.8 to –16.9‰, and during the most severe winters, when ice wedges mainly grow, the average values of the mean January temperature range from –23 to –26°C. δ^{2}H-δ^{18}O ratio in the ice wedges allows to evaluate the processes of fractionation altering the primary isotopic composition of snowmelt before entering the frost crack or during its freezing. The slope of the δ^{2}H-δ^{18}O ratio line in the studied Holocene ice wedges is 7.8 (R^2=0.8), which is close to that of the global meteoric water line and indicates an insignificant influence of secondary processes on the original isotope signal of winter precipitation during ice wedge formation. δ^{18}O values in ice wedges varied from –16.6 to –19.4 ‰. According to the calculation, the mean January air temperature during the first half of the Holocene at the Anadyr site ranged from –29 to –25°C, indicating generally more severe winter conditions compared to modern ones.

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RADIOCARBON DATING OF ORGANIC MATTERS IN PERMAFROST SEDIMENTS ON THE SEVUOKUK MOUNTAIN, ST. LAWRENCE ISLAND, ALASKA

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Abstract

St. Lawrence Island, located on the shallow Bering Shelf, is a critical component of Beringia vital for understanding Quaternary climate (Brigham-Grette et al., 2001). Permafrost, particularly in unglaciated or partially glaciated parts of Beringia like St. Lawrence Island, serve as valuable archives preserving a wealth of information about past climates, ecosystems, and landscapes (Schirrmeister et al., 2013). Sevuokuk Mountain, a prominent upland adjacent to Gambell village on the Northwest Cape, is underlain by a resistant Cretaceous granitic pluton (Patton et al., 2011). Its elevation and composition made the mountain summit area a relatively stable feature throughout the Quaternary. However, recent warming climate induced permafrost degradation and thermokarst development in the island (Liu et al., 2024).

Our study aims to understand the history of permafrost development and initial paleoenvironmental conditions preserved within these valuable frozen archives. As a first step presented here, we focus on establishing the chronology and characterizing the basic physical properties of collected permafrost cores to reconstruct the depositional processes and permafrost development history at specific sampling sites.

Fieldwork was conducted in May 2023 near Gambell, St. Lawrence Island. We collected permafrost cores at three sites (G1, G2, G3) on the mountain summit flat, reaching depths up to 4.07 m. Initial analyses include radiocarbon dating of organic materials and detailed logging of sediment lithology and ground ice characteristics.

Radiocarbon dating indicates that the surficial peat layer at these sites began accumulating from approximately 1,170–1,820 cal yrBP. Notably, a significant massive ground ice layer encountered at site G3 appears to have formed immediately after the Younger Dryas period. Analysis of the core lithology revealed distinct depositional environments: Site G1 showed shallow surficial peat overlying bedrock. Site G2 contained a deeper sequence of peat, gravel-rich sandy loam, and increasing pebbles towards bedrock at 2.65m. Site G3 featured the prominent massive ice layer overlying loess-like sediments with gravels and ice veins. These basic physical properties, combined with the initial chronological framework provided by radiocarbon dates, offer key insights into the varying sedimentary inputs (peat, loess, gravel), hydrological conditions, and periods of permafrost aggradation or degradation that shaped the landscape at these specific locations.

These initial findings highlight the diverse nature of permafrost archives over short distances on Sevuokuk Mountain and establish a crucial chronological and physical basis for future, more detailed paleoenvironmental reconstructions using multiple proxies. The collected cores represent valuable archives for further unraveling the Late Quaternary history of this key Beringian location.

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AN UPDATED AGE-DEPTH MODEL FOR ŻABIENIEC MIRE

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Abstract

The Zabieniec mire is located in central Poland, approximately 70 km south of the ice front of the Last Glacial Maximum (LGM). The Z-3 core (51°51'01.5" N; 19°46'39.3" E) was collected using a Więckowski piston core in 2018 (Petera-Zganiacz *et al.*, 2022). Geochronological analysis was carried out in the Gliwice Radiocarbon Laboratory. To complement previously selected samples (11 macroremains of terrestrial plants; Petera-Zganiacz *et al.*, 2022), additional samples were collected from depths ranging between 6.83 m and 10.80 m, with a resolution of 1 cm per sample.

The low carbon content in the older part of the core (pre-Younger Dryas, depths 9.98 m to 10.80 m) and the limited sample material from the younger part of the core (depths 6.83 m to 7.48 m) necessitated total carbon extraction. All samples underwent Acid-Alkali-Acid chemical pretreatment. The samples were graphitized via the hydrogen reduction method using the AGE-3 automated graphitization system equipped with an elemental analyzer (Wacker *et al.*, 2010). After graphitization, the samples, along with reference materials, were measured using the MICADAS spectrometer at the Gliwice Radiocarbon Laboratory (Ustrzycka *et al.*, 2024). Reference samples included samples from the latest Glasgow International Radiocarbon Intercomparison (Scott *et al.*, 2023) and two blank wood samples: fossil wood from the Szczerców opencast of the Bełchatów Lignite Mine (Jędrzejowski *et al.*, 2024), and subfossil wood (KIA 50439).

An age-depth model was created using the OxCal program (Bronk Ramsey, 2008) with the IntCal20 calibration curve (Reimer *et al.*, 2020).

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CHRONOLOGICAL RECONSTRUCTION OF LOESS-PALEOSOL SEQUENCES USING BIOSPHEROID RADIOCARBON DATING

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Abstract

The temporal evolution of paleosols and sedimentary systems plays an increasingly significant role in archaeological, pedological, paleoclimatic, and landscape evolution studies. Radiocarbon (^{14}C) dating remains a key method for determining the age of organic materials.

In many cases, age determination is challenging due to the lack of sufficiently preserved or abundant macrofossils (such as wood, charcoal, plant detritus, mollusks, or shells) in the sedimentary soil horizon. As an alternative, radiocarbon dating of secondary carbonates, including those formed by earthworm biospheroids, has gained attention. The earthworm family (Lumbricidae) includes a number of species which, although to varying degrees, are capable of producing and excreting carbonate biospheroids. Their radiocarbon analysis is made possible by the AMS (GIS) method, as the biospheroid are calcite spheres of only 0.5-2.0 mm diameter and 1-2 mg/piece mass.

Following a successful series of ^{14}C measurements on modern (recens) biospheroids from Chernozem soils in eastern Hungary (Kertész et al., 2025), conducted at the HEKAL AMS Laboratory in Debrecen, we extended the approach to fossil biospheroids preserved in paleosol layers dated between 15,000 and 30,000 years BP.

This methodological advance offers new insights into the formation processes and paleoenvironmental context of loess–paleosol sequences. The present study focuses on the loess-paleosol profile of Süttő, Hungary. A high-resolution chronological framework was established for a 6-meter-thick section using continuous sampling (every 10 cm, ~2.5–3 kg/sample), and integrated into the broader Quaternary paleoenvironmental evolution of the region.

This scientific study highlights the potential of biospheroid-based radiocarbon analysis in enhancing the temporal resolution of burial age reconstructions and loess-paleosol sequence studies.

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DEVELOPMENT OF THE RADIOCARBON-BASED CHRONOLOGY OF A LAKE BIWA SEDIMENT CORE USING CHEMOMETRIC METHODS

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Abstract

Lake Biwa, the largest freshwater lake in Japan, contains thick sediment sequences that have accumulated over hundreds of thousands of years, providing an invaluable archive for reconstructing past environmental and climatic changes. Sediment cores from Lake Biwa have been extensively analysed for various proxies—including pollen, diatoms, isotopic and organic compositions, grain size, and geomagnetic properties—demonstrating their significance for understanding regional and global variability in the past.

Radiocarbon dating is commonly employed to establish chronological frameworks for the upper layers of Lake Biwa sediment sequences dating back to 50 ka. However, terrestrial plant remains, which are the most suitable material for radiocarbon dating, are rarely found in these sediments. This scarcity limits the development of robust chronologies essential for paleoenvironmental studies.

To address this limitation, we modelled the radiocarbon age offset between the radiocarbon age of bulk sediment (total organic carbon, TOC) and the true depositional age by applying chemometric analysis to Fourier Transform Infrared Spectroscopy (FTIR) spectra from bulk sediments. Specifically, we quantified the temporal variation in the radiocarbon age offset for an 18-m-long core (BIW076) collected from the central part of Lake Biwa, thereby constructing a high-resolution age-depth model.

We systematically conducted radiocarbon dating of the TOC in the BIW076 core and corrected the radiocarbon ages based on our model. We offer a refined chronological framework that will advance paleoenvironmental research at both regional and global scales.

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THE CHRONOLOGY OF 13 M LONG ORGANIC DEPOSITS CORE FROM SERTEYA MIRE (WESTERN RUSSIA) – AN IMPORTANT GEOARCHIVE OF PALAEOENVIRONMENTAL CHANGES AND HUMAN-ENVIRONMENT RELATIONSHIPS ON EAST EUROPEAN PLAIN

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Abstract

The Serteya Mire (55°40′33.7″N, 31°30′32.1″E, 163 m a.s.l.) is situated in the eastern part of the Vitebsk Lakeland which belongs to the East European Plain. The mire is about 7.8 ha in size and has a catchment area of 48.7 ha. Its length (N-S) is about 500 m and its width (W-E) is up to 220 m. It is located on the left side of the Serteyka River valley (40 km long river, left tributary of the middle Daugava R.), but is not fed with river water due to its considerable height of ca. 10 m above the valley floor. The studied basin fills a kettle hole that has been formed in a small and deep closed depression after a melting of block of dead ice in the Late Weichselian. This depression is cut into the neighbouring glaciofluvial plains and filled with organic deposits, In the development of the depositional basin, the peat bog phase was preceded by a lacustrine phase and the lacustrine phase by the basal peat formation period. A unique feature of studied basin is the considerable thickness of the organic deposits, which is up to 13.5 metres.

In 2017, the core of organic deposits (named ST T3) was collected with the use of Instrof sampler 5×100 cm from the central part of the southern deeper basin of the Serteya Mire. The 13.5 m long core of organic deposits includes: sand with organic silt (13.5-13.22 m), basal peat (13.22-13.19 m), clayey gyttja (13.10-11.89 m), fine detritus gyttja (11.89-4.20 m) and *Sphagnum* peat (from 4.20 m a.s.l.).

Until now, 47 samples of selected terrestrial plant macrofossils or pollen concentration were collected for radiocarbon dating (^{14}C). The absolute age was determined using accelerator mass spectrometry (AMS). The plant macrofossils were chemically pretreated using the AAA (acid-alkali-acid) method. The mixture of graphite and Fe powder was pressed into a target holder and measured with the AMS system in the Laboratory of Ion Beam Physics ETHZ (ETH code), the Laboratory of Absolute Dating in Krakow (MKL), and the Laboratory of the Department of Geosciences, National Taiwan University (NTUAMS). Samples with a C mass lower than 0.2 mg were analyzed using the Gas Ion Source GIS AMS at the ETH

facility.

Calibrated radiocarbon ages (cal. yr BP) were generated using the IntCal20 radiocarbon calibration dataset (Reimer et al., 2020) and OxCal 4.4.4 calibration software (Bronk Ramsey, 2009). The chronology (age-depth curve) of the core is based on the OxCal Sequence model (Bronk Ramsey, 2008). A total of 35 radiocarbon dates were used to create of the age-depth model for the whole organic deposits sequence from 13.25 m b.g.l. up present-day surface. Changes in the accumulation pattern and palaeoecological conditions were considered when creating the age-depth model. Therefore, three boundary horizons were introduced, which were assigned to 9.70, 7.90 and 4.22 cm b.g.l., i.e ca. 9.7, 8.2 and 3.5 ka cal BP. Based on the age-depth model, we calculated the probability distributions of the modelled calendar ages for selected depths of the core and events related to the local palaeoenvironmental changes. Also, the changes in the mean rate of accumulation of organic deposits was calculated. The absolute chronology of these sediments shows that the entire core is a continuous record of 13,000 years of natural history of the area and the average rate of biogenic accumulation was in general 1 m per 1,000 years, and it was fluctuating between 0,3 and 5 mm/y. The age-depth model shows that the accumulation of organic deposits began from ca. 13,1 ky cal BP. It was started from sands with organic mud, basal peat and black clayey coarse detritus gyttja deposited in Late Allerød. In Younger Dryas grey-brown clayey gyttja were recorded. Then a brown fine detritus gyttja begins in the Late Weichselian/Holocene transition. The sedentation of *Sphagnum* peat started ca. 3.3 ky cal BP.

Detailed multi-proxy palaeoecological analyses allow for the study of past regional and local plant communities, climate and hydrological fluctuations, local burning episodes, and anthropogenic impacts. In concert with an analysis of archaeological and historical data, the development of human inhabitation of the lower Serteyka River Valley, and the surrounding area of the mid-Daugava River Valley can be reconstructed. Archaeological research in the surroundings of Serteya Mire resulted in documentation of over 60 archaeological sites: mostly the remnants of seasonal and permanent settlements of the Stone Age, few settlements from the Middle and Late Bronze Age, fortified settlements from the Early Iron Age, and small medieval settlements, accompanied by burial mounds. Characteristic is the long inhabitation (up until c. 4000 cal BP) of hunter-gatherer groups that were dependent on climatic and hydrological changes as well as local landscape diversity (Kittel et al., 2022).

The Serteya Mire core provides a reference point for both environmental history and human-environment relations over the last 13 000 years. Its palaeoecological record presents a reliable reference of environmental changes in the Late Weichselian and Holocene for the poorly researched East European Plain.

Acknowledgments

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^{14}C AND OSL MEASUREMENTS FOR REONSTRUCTING ENVIRONMENTAL CONDITIONS AT AL-KHASHBAH, OMAN.

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Abstract

This presentation gives an overview of the various radiocarbon (^{14}C) and optically-stimulated luminescence (OSL) measurements that contributed to the investigation of the environment surrounding the ancient site al-Khashbah, Oman. Although OSL is most reliable method to date sediment accumulation, the sediments in Oman provided various challenges. Because of few organic material preserved, charcoal fragments and occasionally snail shells were used for radiocarbon measurements to see whether they could help out where due to a lack of radioactivity to build up a signal OSL did not provide an answer for all samples.

The main lesson learned is the useful combination of various methods on various materials as each material and each method can contribute to a different answer providing a more complete view on the events that had taken place.

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RADIOCARBON-BASED AGE MODEL OF GROWTH PATTERN IN A CORALLIGENOUS ALGAL REEF

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Keywords: coralligenous, radiocarbon dating, temporal mapping, marine ecosystems, growth reconstruction

Abstract

Coralligenous bioconstructions primarily composed of calcareous red algae represent biodiversity hotspots and priority habitats within Mediterranean marine ecosystems. Despite their ecological significance, the accretion dynamics of these algal reefs remain poorly understood due to methodological limitations in accurately mapping and chronologically constrain their growth pattern. This study presents the first successful application of radiocarbon dating combined with spatial mapping to reconstruct the temporal growth pattern of a coralligenous formation, significantly enhancing our understanding of its development and ecological history.

The investigated site was located offshore the SE Sicilian coast at Marzamemi, where a representative coralligenous formation was selected at about 36 m depth, carefully collected by SCUBA and subsequently sectioned to expose a longitudinal section. This was meticulously divided into sectors using an XY coordinate grid, and from each defined sector, calcareous algal material was extracted with minimal disruption, ensuring accurate stratigraphic integrity. These samples then underwent a cleaning pretreatment and were chemically digested to extract the carbon fraction. Successively, the material was radiocarbon dated to provide temporal markers, enabling the detailed reconstruction of growth rates and developmental stages of the algal reef.

The results yielded a comprehensive chronological model of the coralligenous formation's growth, clearly delineating periods of accelerated or reduced growth and preferential growth directions.

This innovative approach represents a methodological advancement, setting a new methodology for future ecological and palaeoecological research on marine bioconstructions.

The integration of radiocarbon dating with systematic XY-grid spatial sampling offers a powerful analytical framework for further studies aimed at conservation planning and management of these ecologically valuable marine habitats.

HOLOCENE ACTIVITY OF THE SECONDARY STRAND OF THE TANNA FAULT REVEALED BY RADIOCARBON DATING OF SEDIMENTS AND GROUND PENETRATING RADAR PROFILING, THE IZU PENINSULA, JAPAN

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Abstract

The active left-lateral strike-slip Tanna Fault is one of the principal structures within the N–S-trending Kita-Izu Fault Zone, which ruptured during the 1930 Kita-Izu earthquake (M_{jma} = 7.3) (Headquarters for Earthquake Research Promotion, 2005). This fault zone is situated on the Izu Peninsula, at the northern tip of the Izu–Bonin–Mariana arc, approximately 100 km southwest of Tokyo, Japan (Research group for active fault of Japan, 1991). Understanding the characteristics of this active fault is crucial for earthquake hazard assessment and disaster mitigation in the densely populated Tokyo metropolitan area. To investigate the Holocene activity of the Tanna Fault—such as its detailed location and paleoseismic history—we conducted a near-surface structural survey of an offset valley across the fault. This was achieved through radiocarbon dating of sediments obtained from four arrayed drilling cores and ground penetrating radar (GPR) profiling.

The drilling sites were located across a NS-trending secondary strand that runs parallel to the northern part of the main strand of the Tanna Fault, approximately 50 meters to the west. Although the main strand ruptured during the 1930 earthquake, the Holocene activity of this secondary strand investigated in the our study has not been clarified in previous researches.The GPR surveys were conducted along the arrayed drilling survey transect. The GPR profiling data were acquired using a common-offset configuration with pulseEKKO PRO systems manufactured by Sensors and Software Inc. Additionally, common-midpoint (CMP) ensemble data were collected to estimate electromagnetic wave velocities used for the time-to-depth conversion of the GPR profiles.Several dipping horizons indicating sedimentary structures were interpreted on the geological cross-sections. These horizons were dated using accelerator mass spectrometry (AMS) radiocarbon ages of plant fragments and organic soil samples, with measurements conducted at the Carbon Analysis Laboratory (CAL) and the Korea Institute of Geoscience and Mineral Resources (KIGAM).

The GPR sections and radiocarbon ages revealed deformation structures within the Holocene strata, which were caused by faulting on the secondary fault strand. These deformed strata indicate vertical displacements associated with an oblique-slip faulting events that occurred before the 1930 earthquake on the Tanna fault. This evidence of Holocene activity of the secondary strand, which runs

parallel to the main strand, suggests that deformation within the Tanna fault zone is not confined to the main strand but is instead distributed across a broader shear zone.

Acknowledgments

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APPLICATION OF ^{14}C DATING TECHNOLOGY IN DETERMINING THE AGING DURATION OF LIUPAO TEA

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Abstract

Liupao tea, a renowned Chinese dark tea, is celebrated for its distinctive "red hue, rich flavor, aged aroma, and mellow taste," and has been designated as a tribute tea since the Jiaqing era (1796–1820 CE) of the Qing Dynasty. Its market value correlates significantly with aging duration, typically spanning 3–60 years for commercial products. However, current aging assessments rely heavily on subjective sensory evaluations, lacking objective chronological validation. This study established a novel ^{14}C dating protocol using 18 reference samples with documented aging histories from the Guangxi Academy of Agricultural Sciences. Samples underwent chemical pretreatment via the standardized acid-base-acid (ABA) three-step purification method, followed by CO_2 conversion to graphite targets using a Zn-Fe catalytic reduction process. Absolute age determination was performed using the 3 MV tandem accelerator mass spectrometer (GANA) at the Guangxi Key Laboratory of Nuclear Physics and Nuclear Technology. Results demonstrated exceptional precision (±1 year) in aging determination, with a deviation rate below 2.8% compared to archival records. This methodology addresses critical challenges in tea authentication by providing (1) the first quantifiable aging verification system for dark teas and (2) a scientific foundation for combating fraudulent labeling practices. The proposed ^{14}C dating framework holds potential as the first AMS-based authentication standard in China's dark tea industry, offering transformative implications for market regulation and quality assurance protocols.

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^{14}C ANNUAL VARIABILITY IN JAPANESE STONE PINE OF DIFFERENT ALTITUDE

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Abstract

Radiocarbon (^{14}C) is mainly produced through the interaction between neutrons, generated by primary cosmic rays, and atmospheric nitrogen (^{14}N) via the ^{14}N(n, p)^{14}C reaction. Once formed, ^{14}C is rapidly oxidized to carbon dioxide ($^{14}CO_2$), which then mixes with atmospheric CO_2 and becomes part of the global carbon cycle. Measurements of radiocarbon concentrations in different carbon reservoirs, such as plants in the atmosphere, corals in the ocean and sediments in the soil, help us understand carbon dynamics within the environment (Heaton et al. 2021). Following above-ground nuclear bomb tests, ^{14}C concentration in the atmosphere began rising around 1955 and had doubled compared with pre-1955 levels by 1963. Atmospheric ^{14}C concentrations have been decreasing since the signing of the Limited Test Ban Treaty in 1963 through diffusion and equilibration with the oceans and biosphere, and they are now approaching pre-1955 levels (Hua et al. 2023).

The measurement of ^{14}C concentrations in plants provides valuable insights into variations in cosmic radiation intensity, solar activity, and geomagnetic field. One of the most interesting phenomena observed in tree-ring analysis is the Miyake event, which refers to the sudden and anomalous increases in ^{14}C concentrations (Miyake et al. 2012). This event was first identified by Miyake et al. and is believed to be caused by extreme solar energetic particle (SEP) events from the Sun. Because SEP events could be a significant threat to modern society through increases in radiation levels around the Earth, further study of the frequency and intensity of additional Miyake events is critical. Currently, atmospheric ^{14}C concentrations are close to pre-1955 levels. Therefore, precise measurements of ^{14}C concentrations in modern plants can provide valuable data on relatively small SEP events and solar cycles, especially when compared with datasets obtained from satellites or ground-based observations.

In our previous work (Sakurai et al. 2013), we examined ^{14}C concentrations in plant leaves collected from three sites at different altitudes in 2011 and 2012 to investigate atmospheric mixing on a global scale. The sites included Yamagata in the mid-latitudes of the Northern Hemisphere (NH), Kenya in the equatorial region (EQ), and Chacaltaya in the Southern Hemisphere (SH), with altitudes ranging from 165 m to 5238 m. The results suggest that ^{14}C in free tropospheric atmosphere is well mixed on a global scale. Additionally, ^{14}C concentrations in plant leaves were used to estimate the local Suess effect.

In this study, we investigated ^{14}C concentrations in seeds and leaves collected from four different sites in Japan at various altitudes in 2018 and 2024. Table 1 and Figure 1 show the sampling sites, with altitudes ranging from 31 m to 2778 m. Japanese stone pine was selected as the sample species from Mt. Norikura (No. 1) and Mt. Zao (No. 2). This evergreen shrub grows at high altitudes, typically above the forest limit. Figure 2 shows the sampling site near the summit of Mt. Norikura, together with the pine cones and leaves of Japanese stone pine collected at this site. Red pine was used as the sample

species from Tendo City (No. 3) and Narimasu Tokyo (No. 4). Each seed of pines was extracted from the pine cones. The seeds and leaves from the samples were cut into small pieces and chemically treated using the acid-alkali-acid (AAA) method. The AAA-treated sample was then combusted at 1150 ˚C, generating CO_2 gas, which was trapped in a glass tube. The trapped CO_2 was subsequently reduced to graphite at 630 ˚C using hydrogen and an iron powder catalyst. The ^{14}C concentrations in the samples were measured using the Accelerator Mass Spectrometry system at Yamagata University. (YU-AMS, NEC1.5SDH-1). Figure 3 shows the ^{14}C concentrations in the seed and leaf samples obtained from four sites as a function of the year of collection. The ^{14}C concentrations in both samples from Mt. Norikura (No. 1) and Mt. Zao (No. 2) are almost the same, and they decrease with collection year. This suggests that the residual effects of nuclear bomb tests remain. The ^{14}C concentrations in Narimasu Tokyo were the lowest among all samples in each year, indicating that the local atmosphere is significantly affected by the Suess effect. These details will be presented at the conference.

References

Table 1 Location details of collected samples.

No.	Sample site	Latitude	Longitude	Altitude [m]
1	Mt. Norikura	36.1148	137.5513	2778
2	Mt. Zao	38.0919	140.2557	1667
3	Tendo city	38.2122	140.2307	111
4	Tokyo (Narimasu)	35.7833	139.6335	31

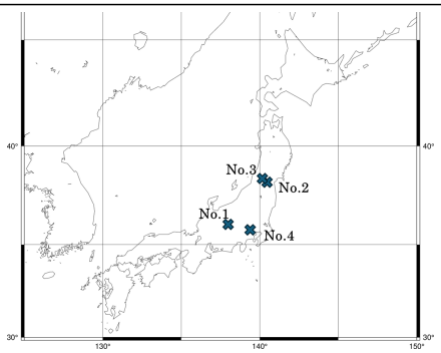

Figure 1 Map of sample collection locations.

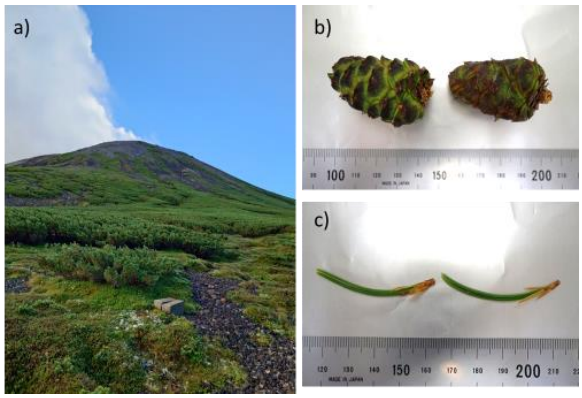

Figure 2 Photograph of site near the sumit of Mt. Norikura a). Photographs of the seeds b) and leaves c) of the Japanese stone pine collected from Mt. Norikura site.

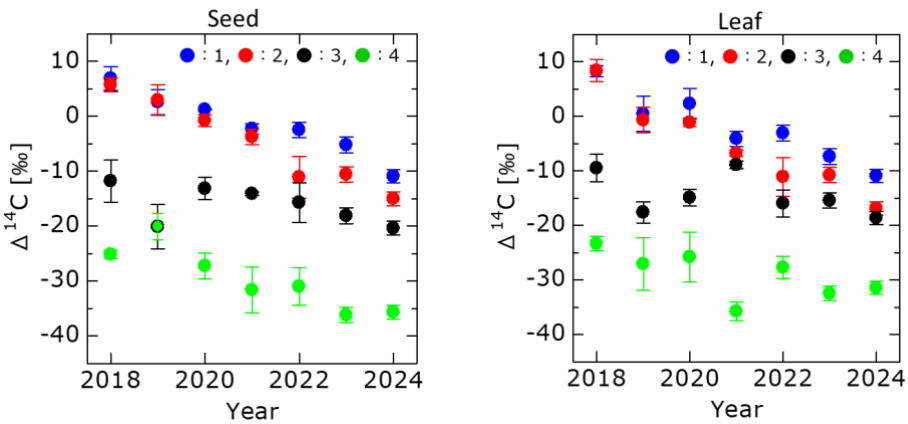

Figure 3 ^{14}C concentrations in seeds and leaves obtained from four sites as a function of the year of

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RADIOCARBON AGE OF YEDOMA ICE COMPLEX IN THE LOWER KOLYMA RIVER BASIN

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key words: Yedoma, Ice complex, Lower Kolyma, AMS ^{14}C dating

Abstract

The age limits and formation features of the four late Pleistocene Yedoma Ice Complex (IC): Bison, Zelyony Mys, Plakhinskii Yar, Duvanny Yar in the lower Kolyma River basin are considered. The sequences were studied according to methods elaborated for Yedoma IC [Vasil'chuk, 1992]. Radiocarbon dating was performed in the Geological Institute of the RAS, the Groningen University and Seoul National University. More than 150 radiocarbon ages have been analyzed. An alkaline extract, particulate organic carbon (POC), total organic carbon (TOC), pollen from ice wedges were dated using the AMS ^{14}C method. Dating of yedoma IC of the lower Kolyma River basin revealed significant reworking of organic material both in the yedoma and in ice wedges; however, the reworking affects the dating of ice wedges to a lesser extent. The youngest dates were obtained from POC and pollen concentrate in the Bison and Duvanny Yar ICs. It has been established that the visible part of Plakhinskii Yar IC started forming in the range of 30–27 cal. ka BP, and the Zelyony Mys IC accumulated in the range 48–15 cal. ka BP. The Duvanny Yar IC is dated from 50–45 to 13 cal. ka BP. It has been established that some of the inversions of radiocarbon dates in the Duvanny Yar are associated with the pseudo-terraces within the ice complex.

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RADIOCARBON CHRONOLOGY OF THE IZENDY CAPE, THE NORTHERN COAST OF THE FORMER ARAL SEA: INDICATION OF SEA LEVEL CHANGES IN THE LAST 1.5 KA

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Abstract

Changes in the level of the former Aral Sea in the Holocene and their relationship to changes in climate and river flow have attracted much attention of researchers in the context of the problem of drying of the sea at the turn of the XX/XXI centuries (Boomer et al., 2000; Boroffka et al., 2006). Especially interesting in this respect is the Late Holocene, which climate is closest to the modern epoch before the beginning of the modern phase of global warming (before 1970s). For the last 2000 years, it is assumed that the sea level never exceeded +54 +55 m asl, but in some episodes it could fall below +30 m asl during the so called Kerderi regression in the first half of the second millennium A.D. (Boroffka et al., 2006; Krivonogov, 2009). Krivonogov et al. (2010) reconstruct transgressive phases in VI-XII and XVI-XX c. and lowstands in XIII-XIV c. (Kerderi) and since 1960s.

The Kerderi regression is not clear about its beginning and end. Boroffka et al. (2006) attribute it to the XIV-XV c., Krivonogov (2009) refers its beginning to the XIII c., Krivonogov et al. (2010) consider that most probably it continued in the XII-XV c. At the same time, Krivonogov et al. (2010) point to the probability of an earlier beginning of the regression - in XI-XII c. - based on the presence of the corresponding ^{14}C date on the bones of domestic animals at the Kerderi II settlement, located on the dried bottom of the Aral Sea. Krivonogov et al. (2014) reconstruct deep regressions at ca. 2.1-1.3 (1.45) and 1.1 (0.85)-0.35 (0.45) ka cal BP, i.e. in mid II c BCE - mid VII (early VI) c CE and mid IX (early XII) - early XVII (early XVI) c CE.

The picture of the Aral Sea level change in the Late Holocene can be clarified by the history of the development of its coasts. One of the pronounced coastal landforms is found at the southeastern end of the Kulandy Peninsula (northern Aral coast). Here is the Izendy cape, shown already on Butakoff's first instrumental map (1848-1853). The cape consists of a rocky island with a peak rising up to 70 m asl, connected to the coast by an accumulative sandy isthmus - tombolo. The coastal bars on the tombolo rise to +55 +56 m asl , i.e. 2-3 m above sea level in 1960 (+53 m asl), after which its modern decline began. Well-preserved marine shells of *Cerastoderna glaucum* and *Dreissena polymorpha* were sampled from pits on the surface of the tombolo. Radiocarbon dating was carried out using the AMS method in two laboratories: Center for Applied Isotope Studies, University of Georgia, USA (UGAMS), and Shaanxi Key Laboratory of AMS Technology and Application, Xi'an, China (XA).

Five AMS dates were obtained from two locations: 1570±20 BP, or AD 490±35 (UGAMS-67627); 1556±13 BP, or AD 510±15 (XA-61380); 1196±14 BP, or AD 835±30 (XA-61379); 946±13, or AD 1100±15 (XA-61381); 430±20 BP, or AD 1455±15 (UGAMS-69694). Considering the reservoir age correction, which is estimated for the Aral Sea at -128±53 yr for mollusk shells (Kuzmin et al., 2007), the real age of events must have been 1-1.5 centuries younger than the calibrated dates. Therefore, the first four dates show that at least from the 7th to the early 13th centuries the level of the Aral Sea was 1-2 m higher than the level of the 20th century before the beginning of its modern decline, and the regression of the Kerderi

began not earlier than the beginning to the middle of the 13th century.

The latter date can be interpreted as the restoration of high sea level after the end of the Kerderi regression already in the mid- to late 16th century. The sea level probably did not reach and certainly did not exceed the level of the VII-XII centuries, since in this case the tombolo of Izenda could have been subjected to destruction, but the presence of shells of this age indicates that the sea shore was nearby. Such a date of the end of the Kerderi regression is in accordance with both historical data (Krivonogov, 2010) and with the findings in the area of the Kerderi-I mausoleum on the dried bottom of the Aral Sea of coins minted by Kichi-Muhammed Khan - the last ruler of the Golden Horde, 1432-1459 (Tazhikeev et al., 2023).

Thus, in the second half of the 1st millennium A.D. the Aral Sea level could reach +54 +55 m asl, 1-2 m above the mid-20th century level (+53 m asl). The Kerderi regression, one of the lowest in the Holocene, began in the 13th century AD and ended in the 16th century AD. After that the sea level probably did not reach the highstand of the end of the 1st millennium A.D. and remained up to the middle of the XX century at about +53 m asl, and in the 1960s began to fall rapidly. The current state of the Aral Sea is close to that during the Kerderi regression.

Acknowledgments

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INTERLABORATORY COMPARISON OF BIO-BASED CARBON CONTENT IN DISPOSABLE PACKAGING SAMPLES FROM PAKISTAN

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Abstract

Disposable packaging materials (DPMs) are used in everyday life around the world. Plastic food packaging impacts the environment in terms of energy consumption, greenhouse gas emissions, and the increase in waste (Jeżewska-Zychowicz and Jeznach 2015). Most monomers for the manufacture of plastics, such as ethylene and propylene, are derived from fossil hydrocarbons. Normally used plastics are not biodegradable. "Durability and resistance to degradation, which make plastics suitable for a wide range of applications, also make their assimilation into nature difficult (Geyer et al. 2017), thus causing the current white pollution.

The development of biodegradable packaging materials from renewable natural resources contributes to sustainable development and reduces environmental impact in waste management if properly managed (Davis and Song 2006). Green packaging is being developed to enable the use of lightweight, recyclable, reusable, biodegradable materials while prohibiting non-ecological products (Zhang and Zhao 2012). Industrial production or recycling of DPMs produces CO_2 emissions, which are considered to be hazardous. CO_2 emission can be reduced by the use of renewable (biogenic/bio-based) resources (Rodin et al. 2020). Producing new paper from waste paper requires less energy and emits fewer greenhouse gases than producing the same amount of paper from virgin materials. Thus, the recycling of waste paper could be beneficial to the environment (Merrild et al. 2008).

Radiocarbon analysis can distinguish fossil and modern carbon by detecting samples' $^{14}C/12C$ isotope ratio. After about 50,000 years, the sample does not contain ^{14}C isotopes because the half-life is 5700±30 years (Kutchera 2019) . In this research, the ^{14}C isotope concentration in DPMs from Pakistan was monitored by the radiocarbon method. Liquid scintillation counting (LSC) and accelerator mass spectrometry (AMS) technique at Gliwice ^{14}C and Mass Spectrometry Laboratory within the Institute of Physics – Centre for Science and Education, SUT, Poland and Centro Nacional de Aceleradores (CNA) Seville Spain, were used to make sure if, the materials contain modern carbon contributing to environmentally friendly recycling.

Each tested type of disposable packaging contained modern biocarbon. The AMS technique was used to analyse samples layer-wise in both laboratories. At Gliwice ^{14}C and Mass Spectrometry Laboratory, samples were analysed without pretreatment, whereas chemical pretreatment, acid base acid (ABA), was used at the CNA laboratory. Most of the samples show higher ^{14}C concentrations after pretreatment. The low concentrations of the ^{14}C isotope obtained for the outer layer of samples indicate that their

surface was most likely covered with a thin waterproof layer of plastic of fossil origin. The highest ^{14}C concentration values were obtained from the wood samples. (Gill et al. 2024).

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RAMPED THERMAL DECOMPOSITION DATING OF NEOLITHIC WHEELS FROM SW GERMANY

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Abstract

The effective removal of consolidant-derived contamination in conserved archaeological material is a persistent issue for radiocarbon dating (Brock et al. 2018, Crann and Grant 2019). For wood (waterlogged), polyethylene glycol (PEG) is the most common substance applied during conservation and poses significant difficulties for complete elimination and its detection (Barrett et al. 2021).

Excavations at the Neolithic lake dwelling Olzreute-Enzisholz (SW Germany) in 2009 revealed the remains of three large wooden (maple) disc wheels (diameters of approximately 58cm) from probably two carts (Schlichtherle 2016, 2019). Preserved and restored with PEG, samples from one wheel were later radiocarbon dated to 3438-3289 cal. BCE (95.4%) making them some of the earliest wooden wheels yet discovered. However, the age was significantly earlier than the dendrochronologically dated planks from 2900-2897 BCE they were lying on (context-dated). Given the significance of the early dates, samples from the wheel were re-examined via different pretreatment regimes (Soxhlet-solvent based approach and alpha cellulose extraction), ATR-FTIR characterization, routine dating, as well as the application of ramped pyroxidation/combustion (RPO/RC) (Barrett et al. 2021). Following both pretreatments, there was no definitive evidence of PEG in the FTIR analysis. The routine dates on both Soxhlet treated and alpha cellulose extracted material were in statistical agreement and also in good agreement with the original radiocarbon dates (pretreated by hot washes). However, application of RPO/RC to both demonstrated variation in radiocarbon ages with the temperature fraction of CO_2 captured. The results highlight the persistent presence of PEG contamination after different pretreatment methods, with the oldest radiocarbon ages (consistent with petroleum derived PEG) measured on temperature fractions near where pure PEG would be expected to thermally decompose. The youngest dates, and least contaminated fractions, were obtained at higher temperatures (>500°C) and for an alpha cellulose extraction. The youngest of these allows for a significantly later probable age for the wheels of 3350-2913 cal. BCE (99.7%), closer to the associated cultural horizon. However, complete removal of PEG cannot yet be established and, as such, the result should be treated as a *Terminus Post Quem* (TPQ). The analysis thus far highlights the potential value of ramped thermal decomposition techniques in both diagnosing the presence of persistent low-level contamination as well as providing refined age ranges for the associated material.

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GAS ION SOURCE AMS AT THE OXFORD RADIOCARBON ACCELERATOR UNIT

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Abstract

The low abundance of detectable ^{14}C and exacerbated effects of contamination on the final radiocarbon measurement pose a challenge for samples, such as foraminifera and products of compound-specific dating. Gas ion source accelerator mass spectrometry (AMS), whereby CO_2 samples are injected directly into the ion source of an AMS system without graphitisation, is being tested extensively at the Oxford Radiocarbon Accelerator Unit (ORAU). This will improve AMS measurement capabilities for ultra-small samples (10-30 µg C).

Introducing samples in a gaseous state minimises handling-related contamination and allows direct measurements of samples containing less than 50µg of carbon. A gas injection system equipped with cryogenic gas traps was designed at ORAU, attached to the Mini Carbon Dating System (MICADAS) and connected to an elemental analyser. This allows samples to be directly injected into the AMS ion source from online combustion, carbonate from acid hydrolysis or ampoules of CO_2. To test the efficiency of the system, the maximum $^{12}C^-$ currents (µA), background and cross-contamination measurements have been analysed corresponding to a range of sample sizes.

Currently, gas ion source at ORAU yields promising results with samples ranging between 20-100µg of carbon producing $^{12}C^-$ currents between 12µA-20µA. The system is developed to automatically inject samples from ampoules or online combustion with minimal supervision which minimises external contaminants and significantly decreases measurement time. The ORAU online-combustion gas handling system arrangement has proven successful in overcoming many of the limitations posed by graphitisation of very small ^{14}C samples.

FAST RADIOCARBON ANALYSIS OF METHANE

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Abstract

Methane is the one of the most abundant organic compound in the atmosphere and its influence on the global climate is subject to widespread and ongoing scientific discussion. Atmospheric methane originates from a variety of different sources, including our focus in the release of methane from the ocean seafloor, as well as from thawing permafrost.

In past years the origin, sediment and water column processes and subsequent pathways of methane have received growing interest in the scientific community. $^{13}C/^{12}C$ ratio measurements can be used to determine the methane source (biogenic or thermogenic), but potential formation processes by microbes are not yet fully understood.

Radiocarbon analysis can help to understand these carbon cycling processes. We here present a novel approach for the radiocarbon age determination of methane. A modified PreCon® unit is used to separate methane from other gases such as CO_2 in a gaseous sample. Afterwards, the purified methane is transferred to a furnace and oxidized to CO_2. The product of combustion is subsequently concentrated on a self-constructed molecular sieve trap system, which can be connected to a GIS system (by Ionplus AG) for direct CO_2 measurements at the MICADAS. These traps are attached to a multiport valve (VICI, Valco Instruments Co. Inc.) for time-efficient measurements.

Here we will present the new setup of the modified method, first results of the blank determination, comparison to established methods, as well as the precision observed for measurements of common standard gases.

ENHANCING MICADAS PERFORMANCE: EVALUATING RECESSED VS. FLUSH PRESSED GRAPHITE FOR SMALL SAMPLE RADIOCARBON ANALYSIS

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Abstract

The Ionplus MICADAS accelerator mass spectrometer (AMS) plays a crucial role in radiocarbon dating, where sample preparation methods directly impact measurement efficiency and accuracy.

In a previous study, recessed graphite pressing was shown to increase ion currents, suggesting improved performance. We attempted a similar experiment at ORAU, comparing recessed and flush-pressed graphite under comparable conditions. We observed similar ion currents for both pressing techniques. However, the recessed targets consistently delivered more stable and longer-lasting currents, potentially enabling longer run times and greater accuracy, particularly for smaller sample sizes. These results offer additional insight into graphite preparation strategies for optimizing AMS performance.

Acknowledgments

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IMPROVEMENTS ON THE ^{14}C IN-SITU LINE AT ETH -ZURICH

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Abstract

The growing interest in in-situ ^{14}C measurements for different applications such as Earth surface processes in critical zones, complex surface exposure dating in glacial settings, and the determination of soil production rates demands an improvement of the analytical techniques to increase the sample throughput of the extraction line at ETH-Zurich.

The main challenge during the extraction of small amounts of in-situ ^{14}C (<10^5 atoms/g) that is present in quartz from rocks or sediments is the suppression of potential sample contamination with ^{14}C from atmospheric gases. Therefore, a low and stable blank level is key to obtain reliable data for the various applications.

The extraction line at ETH-Zurich was built in 2019 (Lupker et al., 2019) using a high temperature (1650 °C) extraction furnace. The duration of one extraction is around 10h and runs fully automated. However, between samples a complete cleaning run for degassing was needed to reach the required background (another 10h). This reduced the effective throughput to three samples a week.

Here, we present improvements to the cleaning procedures of the existing ^{14}C in-situ line, that allowed to double the sample throughput. Improvements include, a pre-treatment procedure for the platinum crucibles that hold the quartz samples, and an increased number of flushing steps with pure He gas. Still, a very low background of 1.76 ± (0.69) x 10^4 atoms (n=8) is reached. Further, the memory effect for consecutive samples with highly different ^{14}C activities (high to low) is discussed.

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AWI'S RAMPED PYROLYSIS-OXIDATION SYSTEM: A VERSATILE TOOL TO REFINE ANTARCTIC SEDIMENT STRATIGRAPHY

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Abstract

Radiocarbon analysis (RA) of carbon bearing sedimentary components is an essential tool to reconstruct paleoenvironments, investigate carbon reservoir exchanges and transport mechanisms (Heaton et al., 2021; and references therein). It can provide calendar ages for sediment core layers deposited during the last ~50,000 years (Bronk Ramsey et al., 2012). In the marine realm, this is commonly achieved by analyzing the ^{14}C content of foraminifera tests isolated from key sedimentary facies (Broecker et al., 1988). If foraminifera are absent or poorly preserved, a novel analytical method can be applied, which utilizes the different thermochemical stabilities of distinct organic compounds. During Ramped Pyrolysis-Oxidation (RPO), acid-insoluble organic material is pyrolyzed to ~900 °C by applying a steady temperature ramp. Younger, more labile components have a lower thermal stability, leading to faster formation of pyrolysis products, while older, more recalcitrant components remain stable to higher temperatures. The pyrolysis products are oxidized to CO2 and subsequently graphitized, allowing for RA of the thermochemically distinct sediment fractions (Rosenheim et al., 2008). The age of the youngest fraction can be used as the sedimentation age.

While the method has been utilized to provide accurate chronologies for sediment cores from western Antarctica (Rosenheim et al., 2013; Subt et al., 2017), the number of RPO-^{14}C data points is very low in both studies (5 samples in a 4.5 m core and 4 samples in a 2 m core respectively). Possible reasons for this are the time intensive sample preparation, RPO-measurement, post-combustion and graphitization, which amounts to a total of ~14 h per sample and the fact that the samples have to be sent to external facilities for ^{14}C analysis.

Here, we present our novel RPO system established at the radiocarbon dating facility of the Alfred Wegener Institute in Bremerhaven, Germany. Our system is composed of a commercial carbon analyser, the SoliTOC cube (Elementar Analysensysteme GmbH, Germany) which was modified to work in conjunction with self-constructed mobile zeolite trap systems. In contrast to other RPO systems, the CO2 produced by the SoliTOC is trapped on the zeolite traps, which can be coupled directly to a MICADAS (Ionplus AG, Switzerland), where the samples are analysed as CO2 gas. This approach limits the number of preparation steps, thereby reducing the number of potential blank sources and decreasing the total preparation and measurement time to 4 h. In addition, measurement of CO2 gas requires only a fraction of the amount of carbon needed for graphitization, which enables the analysis of samples with ultra-low total organic carbon content. As an application example we present results (uncalibrated ^{14}C-ages) from an 8 m sediment core obtained from the Nielsen Basin in East Antarctica and compare the RPO derived ages with three foraminifera ages from the same core. RPO ages range from 1700 years at the core top to 35000 years at the bottom. We find that RPO and foraminifera ages are in a comparable range but show deviations of up to 3300 years, with foraminifera ages always being younger. Possible reasons for

this could be a post-depositional alteration or displacement of the tests or the presence of older organic matter in the dated RPO fraction. Future work will focus on eliminating this discrepancy, as well as optimizing the determination of the temperature limits of the RPO fractions.

The advantages of our system and the method we established provide the opportunity to generate high-resolution RPO age determination for carbonate-free or -lean sediments in unparalleled processing speed. Our work aims at providing crucial data to allow the development of ^{14}C-based stratigraphies for sediments where this was previously not possible, refine Antarctic sediment stratigraphy and improve our understanding of climate driven ice sheet responses.

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FRACTIONATION RATIOS DURING GRAPHITIZATION VIA THE ZINC REDUCTION METHOD

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Abstract

In this work, we present the results of $^{13}C/^{12}C$ and $^{14}C/^{12}C$ isotopic fractionation ratios analysis observed during graphitization using the zinc reduction method. Combustion and graphitization were performed with the µGRAPHILINE system (Tudyka *et al.* 2024). AMS measurements were conducted at the Gliwice Radiocarbon and Mass Spectrometry Laboratory using the MICADAS spectrometer (Ustrzycka *et al.* 2025), while IRMS measurements were carried out with the IsoPrime 100 spectrometer. Primary and secondary standards, blanks and the other samples were tested, with changes in various parameters including zinc amount, graphitization temperature, combustion temperature, and sample mass.

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THE TEST AND PERFORMANCE OF THE HVEE GAS INTERFACE SYSTEM AT CEDAD-UNIVERSITY OF SALENTO

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Abstract

As part of the Pathogen Readiness Platform (PRP) initiative—supported by Italy's National Recovery and Resilience Plan (PNRR)—a state-of-the-art compact Accelerator Mass Spectrometry (AMS) system has been set up at CEDAD (Centre for Applied Physics, Dating, and Diagnostics), housed within the Department of Mathematics and Physics "Ennio de Giorgi" at the University of Salento.

The new setup is based on a ^{14}C-dedicated AMS system, the HVEE 4102Bo which incorporates an SO110-C hybrid multi-cathode ion source, capable of processing both solid and gaseous samples via a dedicated gas interface system (GIS).

In the GIS solid or liquid samples are transformed into CO_2 using an Elemental Analyzer (EA). The resulting CO_2 is captured in a zeolite-based CO_2 trap, which, when heated to a user-specified temperature—typically between 300 and 350 °C—releases the carbon dioxide. The released CO_2 is then then transferred into a syringe, where it is combined with a helium carrier gas and delivered to the AMS ion source at a controlled and constant flow rate through a capillary. Reference and blank samples stored in bottles can be connected for calibration purposes as well as for dilution of the pure CO2 samples.

The GIS is equipped with two CO_2 traps and syringes to reduce dead times and improving sample throughput. The system is completely automated and its control is fully integrated in the data acquisition software of the AMS system.

We present the performances of the gas interface in terms of achievable precision and background levels as well as the accuracy assessed through the measurements of certified reference materials.

EXPLORING THE POTENTIAL OF SCAR FOR RAPID ^{14}C ASSESSMENT IN ENRICHED PLANT MATERIALS

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Abstract

Laser spectroscopy measurement techniques have opened up new research opportunities in many areas. This is also true in the field of radiocarbon studies, where the SCAR (saturated-absorption cavity ring-down) technique provides a new alternative to AMS and LSC. This is particularly relevant for ^{14}C-enriched samples, as it requires faster and, in many cases, simpler sample processing than LSC, while achieving a level of accuracy similar to that of AMS (Delli Santi et al., 2022; Galli et al., 2013). To demonstrate this, we measured ^{14}C-enriched samples (115–2500 pMC), using the same CO_2 gas by both SCAR and AMS to determine the difference between the two methods. We used a brand-new SCAR prototype to measure the samples. This prototype is smaller than any previous instrument and provides fast measurements of ^{14}C-enriched samples. The size and power supply of the instrument can even lead in the near future to a portable, non-deployed instrument. Twenty samples were measured during a two-day campaign, with one calibration per day, using a fossil background and OXAII. The measurement setup implemented is a completely niche novelty, as the CO_2 measured by SCAR was later graphitized for AMS measurement, so the same sample was used for the comparison measurement, which thus includes any contamination added by SCAR sample preparation and measurement. The SCAR and AMS results show good agreement. This method is well-suited to estimating the ^{14}C load of environmental and plant samples.

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IMPROVEMENTS IN AMS CS-SOURCES

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Abstract

Recent developments in Cs-ion source technology have led to significant improvements in efficiency, stability, and ease of maintenance, making it a new standard for MICADAS, MILEA, and LEA accelerator mass spectrometers. A newly designed Cs-nozzle offers a compact and modular construction, allowing for efficient manufacturing and simplified maintenance. This optimized design enhances Cs vapor output, enabling a reduction in Cs reservoir temperature while maintaining high ionization efficiency. Additionally, a newly developed ionizer, fabricated in house, provides improved longevity and operational stability. A dedicated mounting platform ensures reproducible assembly and disassembly, streamlining maintenance and replacement procedures.

A key innovation is the integration of a precise target positioner, enabling real-time x-, y-, and z-axis adjustments during measurements. This allows for external manipulation of the target position within the ion source chamber, optimizing the ion beam without interrupting data acquisition. These enhancements collectively contribute to a more robust and efficient Cs-ion source, advancing the capabilities of accelerator mass spectrometry.

DEVELOPMENT OF A VERSATILE A-CELLULOSE-CAPABLE AUTOMATED PRETREATMENT SYSTEM FOR RADIOCARBON AND STABLE ISOTOPE ANALYSIS

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Abstract

α-cellulose has proven to be a reliable and widely used constituent of wood for recording tree ring isotope signatures. The extraction of α-cellulose from tree rings is crucial to reconstructing past atmospheric radiocarbon concentrations and allows for a number of other isotopic analyses. High precision accelerator mass spectrometry (AMS) radiocarbon dates of tree-ring α-cellulose facilitate refinements to the radiocarbon calibration curve as well as the study of single-year anomalies and other processes influencing the atmospheric radiocarbon record. Despite advances in pretreatment, α-cellulose extraction remains a labour-intensive process, typically involving a number of reagent washes and many rinses with demineralised water[1]. These steps have a large impact on the speed, cost and throughput of tree ring isotope analyses, and would thus benefit greatly from automation. We present a prototype of an automated pretreatment system capable of performing α-cellulose extraction with enhanced functionality, including reactions with up to four different reagents at controlled temperatures and ultrasonication under a controlled atmosphere. This automated system represents a significant advancement in α-cellulose extraction, reducing the labour investment and increasing sample throughput. By ensuring consistent and efficient sample preparation, this system has the potential to enhance the accuracy and reproducibility of radiocarbon and stable isotope analyses of tree rings.

Acknowledgments
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OPTIMISING SEALED TUBE ZN GRAPHITIZATION BY UTILIZING STABLE C ISOTOPE FRACTIONATION AT CIRCE LAB

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Many studies within the radiocarbon community have highlighted the critical importance of optimizing sample preparation protocols, particularly for applications involving small samples (Macario et al., 2017; Orsovszki et al., 2015). At the Center for Isotopic Research on Cultural and Environmental Heritage (CIRCE, San Nicola la Strada, Italy), the standard radiocarbon preparation protocol comprises three main stages: chemical pretreatment to isolate the carbonaceous fraction of interest, conversion to CO_2 via CuO combustion (for organic samples) or H_3PO_4 digestion (for carbonates), and graphitization using TiH_2, Zn, and Fe catalysts to produce solid graphite targets.

After more than a decade of routine use, with an annual average rate of c.a. 1000 samples, a significant increase in graphitization yield (inferred from cathodes analysed currents) variability was observed. This prompted a systematic reassessment of the graphitization procedure, with particular focus the iron catalyst pre-treatment. In the original protocol (Marzaioli et al., 2008), the iron catalyst undergoes a specific pre-treatment step, consistently yielding compact graphite. In the revised methodology, this pre-treatment step was omitted according to Rinyu (2013).

To investigate the impact of this modification, a controlled comparative experiment was performed in two phases. In the first phase, a set of 26 graphite targets was synthesized using varying quantities of Zn and TiH_2, while employing a pre-treated iron catalyst. In the second phase, an equivalent set of 26 graphite targets was prepared using the same Zn and TiH_2 amounts, but without iron pre-treatment. For both sets, carbon input was held constant at ~1 mg, and the IAEA C3 cellulose was used as reference material.

The resulting graphite targets were analyzed via Dual Inlet Isotope Ratio Mass Spectrometry (DI-IRMS) to determine $\delta^{13}C$ values, whose difference versus the certified value serves as a proxy for reaction efficiency. The results show a markedly reduced variability in $\delta^{13}C$ values in the samples prepared without iron pre-treatment. Specifically, the $\delta^{13}C$ values in the untreated set ranged from -22.83‰ to -28.00‰, compared to a wider range of -25.39‰ to -35.53‰ in the pretreated set, with observed isotope fractionation being decreased when TiH2 decreases.

AMS^{14}C measurements are currently ongoing to assess any changes in background levels associated with the revised protocol and will be compared with long-term historical data at CIRCE lab.

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APPLICATION OF HYDROGEN PYROLYSIS TO EVALUATE CHAR FORMATION DURING RAMPED OXIDATION

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Abstract

Charring effects have been previously observed with the ramped-oxidation-pyrolysis (RPO) method (Williams et al., 2014). These could produce unwanted artefacts by chemically changing components of the sample, increasing their thermal stability. For affected carbon, the temperature at which it was subsequently released as CO_2 would be a function of the degree of charring (i.e. polyaromatisation) during analysis, rather than solely arising from the inherent properties of the starting material. These effects therefore lead to mischaracterisation of the sample undergoing analysis. Here we present a method for systematically investigating the scale of this issue, using hydrogen pyrolysis (HyPy) to quantify the amount of polyaromatic carbon produced in different materials during the ramped oxidation process.

Samples of two organic ^{14}C standards (96H humin and TIRI barleymash (TBM)), and an in-house background standard (anthracite coal) were combusted to 300°C and 400°C (with a ramp rate of 5°C per minute) on the ROx instrumentation at the NEIF Radiocarbon Laboratory (Garnett et al., 2023, Ascough et al., 2024). These temperatures were chosen to reflect the reported peak combustion temperatures of cellulose and lignin (cellulose at 300-350°C, lignin at 400-450°C; Manning et al., 2008), given that these are significant components of plant-derived organic matter. The quantity of polyaromatic carbon in both the starting material and the residual material (i.e. after ROx) was determined using HyPy, and the results compared. The anthracite coal was included as a material that should not be vulnerable to charring effects, given its highly polyaromatic starting chemistry.

A comparison of HyPy results for semi-combusted versus uncombusted materials indicates that charring effects vary by sample type. 96H humin displayed no net increase in polyaromatic carbon following ROx, indicating that if charring affects this material, it is below detection limits. The results of analysis of a plant biomass sample (TBM) on the other hand, suggest significant charring can occur during processing at least some types of organic material. These results suggest that caution should be applied when analysing thermograms produced from ramped oxidation of some organic materials, and that quantifying the degree of potential thermal artefacts in this way is a useful part of characterising a ROx / RPO system.

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A NEW ^{14}C SAMPLE TREATMENT LABORATORY AT THE MARIA CURIE-SKLODOWSKA UNIVERSITY, Lublin, PL

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Abstract

The selection of a suitable sample and its preparation for radiocarbon dating are key steps that affect the accuracy and precision of the results. Proper preparation allows for the elimination of impurities that, by distorting the carbon isotope ratio, could lead to errors in determining the actual age of the sample. Different purification procedures and modifications are applied depending on the type of sample being subjected to radiocarbon dating. Each type of material requires an individual approach, considering its properties, state of preservation, and potential sources of contamination. Close collaboration between the researchers in the application fields of ^{14}C (archaeologists, earth scientists) is vital and needed from the first step of sample selection. University-based ^{14}C preparation laboratories focusing on selecting and treating the suitable ^{14}C material can facilitate such interdisciplinary exchange. Moreover, ^{14}C laboratories based at universities can help educate new generations of geochronologists.

In the last 2 years, a new preparation laboratory has been established at the Maria Curie-Skłodowska University (UMCS), located at Ecotech-Complex, Lublin. The first sediment samples, peat, wood, and charcoal, were separated and successfully analyzed at the ETH AMS facility in Zurich during this time. Our laboratory is equipped to prepare all the macroscopic samples and follows sample selection procedures described by Hajdas et al. (2024).

Samples of organic materials such as charcoal, wood, organic sediments, or peat are investigated using a binocular microscope. Removing contaminants before the chemical preparation stage increases the dating accuracy and minimizes the risk of erroneous results. A serious problem is the presence of plant root fragments, which may contain modern carbon. Binocular observation allows for the elimination of this problem in many samples. However, in the case of wood or charcoal overgrown with roots, complete removal is often impossible, and such samples are not accepted for ^{14}C analysis. Roots of contemporary plants from sediments or peat can be removed by sieving. Sieving is used to separate fine fractions (<125 µm), which can then be subjected to radiocarbon dating. Fraction >125 µm is checked for macro remains (leaves, seeds, charcoal), which can provide good material for ^{14}C dating.

Pre-prepared samples undergo chemical treatment. The primary purification procedure for organic samples is the ABA (Acid-Base-Acid) procedure. It involves successive acid and base treatments at elevated temperatures to remove carbonates and humic substances, followed by a final acid treatment to neutralize the sample. The basic procedure is often modified and adapted to the specific sample being

analyzed, such as by lowering temperatures and reducing contact time for samples with poorly preserved structure. When treating the sample with alkali at this stage, it is also possible to separate humic acids, which can be analyzed for ^{14}C.

Bones are another frequently studied sample type in radiocarbon dating. We follow the Longin (1971) and Ultra Filtration (Brown et al. 1988) procedures for separating and purifying collagen. Our modified procedure (Hajdas et al., 2024) includes pre-screening of bones using %N of bulk bone material. Only bones with %N>1 are considered for preparation. Purified dry gelatine is weighed and transferred to the AMS laboratory.

In our laboratory, we also prepare cremated bones for dating. We are currently conducting an archaeological project on the issue of the absolute chronology of selected cultures, which requires the preparation of 230 bones. Our preparation is based on the procedure of Lanting et al. (2001). The sodium hypochlorite removes organic material and acetic acid to eliminate carbonate ions and the more soluble apatite fractions. Finally, dry samples of cremated bones are pulverized and ready for submission.

The clean and dry samples are weighed (equivalent ca. 1 mg of C) and transferred to the AMS laboratory. At this point, if the remaining clean samples are very small an additional material can be prepared or samples that contain less than 100 µg of carbon can be measured using a Gas Ion Source (GIS) (Ruff et al., 2010).

Secondary standards and blanks are prepared alongside the 'unknown' samples. This paper will report on the first results obtained on samples prepared in the LBC14 laboratory.

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PRELIMINARY APPLICATION OF FTIR-GUIDED CALCIUM OXALATE EXTRACTION FOR RADIOCARBON DATING OF BRAZILIAN ROCK ART

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Abstract

Rock art sites can be interpreted as expressions of a distinct way of perceiving and interacting with both society and the natural world, conveyed through a visual language of symbols. In this context, indirect dating methods - such as calcium oxalate extraction from crusts overlaying/underlaying the paintings - can provide valuable chronological insights, especially when pigments lack sufficient organic carbon or direct sampling is not ethically feasible. These images often include naturalistic representations of animal and plant species, reflecting deep ecological knowledge of the surrounding environment. They also demonstrate an understanding of rock surfaces and mineral resources, as the selection of pigments and specific locations for pictograph production reveals a sophisticated awareness of materials suitable for graphic expression. Moreover, the placement of these sites is far from arbitrary, they are embedded within meaningful landscapes shaped by cultural preferences, such as particular topographies, rock types, proximity to water sources, and the presence of specific flora and fauna registered in the walls.

This study presents the implementation of the radiocarbon dating protocol proposed by Dumoulin et al. (2020) for calcium oxalate crusts at the Brazilian Radiocarbon Laboratory (LAC-UFF) in collaboration with the Laboratoire de Mesure du Carbone 14 (LMC14) established in 2023. The method integrates FTIR spectroscopy with a targeted chemical pretreatment to isolate pure calcium oxalate, aiming to verify the presence of calcium oxalate in the bulk sample and to validate the efficiency of the extraction protocol, thereby minimizing contamination and enhancing the reliability of AMS dating results. As part of a collaborative project with the Federal University of Bahia (UFBA), crust samples were collected near archaeological complexes in the Chapada Diamantina region of Bahia State, an area renowned for its rich heritage, with over one hundred rock art sites, many of which remain undated. All laboratory procedures were conducted at Fluminense Federal University (UFF), where the technique is currently being tested and refined for application in tropical rock art contexts.

FTIR spectroscopy results indicate that, despite variations in the geological conditions of the rock substrate between sites and the potential sources of calcium oxalate crusts, such as lichen or fungal activity and/or animal excretion, 14 out of 18 samples tested positive for calcium oxalate. This finding supports the applicability of the oxalate extraction protocol, and the results will contribute to developing a robust and reproducible method for the indirect radiocarbon dating of Brazilian rock art, enhancing our understanding of its broader archaeological and environmental context.

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HIGHLIGHTS AND CHALLENGES OF ^{14}C DATING MORTARS

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Abstract

The first attempts at dating mortars using the conventional counting method highlighted the potential and challenges in separating carbonate fractions to date the binders accurately. The significant development was only possible with the AMS measurement technique and the interdisciplinary work summarized by Ringbom et al., (2014). The interest in radiocarbon dating of mortars is indeed expressed in multidisciplinary fields: archaeology, art history, history of architecture, and conservation. Despite the challenges of dating mortars, the is an ongoing research effort toward understanding the material and development for successful dating. This paper will present a few ongoing studies illustrating the challenge and the potential of dating mortars and the methods applied (Hajdas et al., 2020).

The Roman mortars are known to be challenging (Lindroos et al., 2011), and samples from 2 sites illustrate this. One sample was collected from the Roman site located on the eastern Zürichsee lakeshore in Kempraten, Canton of St. Gallen, Switzerland. The second sample was mortar from the Aqueduct of Augusta Raurica, Augst near Basel, Switzerland.

The mortar samples were collected from the underground of the Fraumünster, a protestant church in the center of Zurich. We attempt to date the different phases of the construction. The first results are promising however the amount of carbonate separated was insufficient for graphitization though a new separation is needed to improve the precision.

A promising result has been obtained as a part of a pilot study in dating the Wawel Castle, Krakow. An ongoing project led by M Krąpiec (AGH) will provide more detailed chronologies of this prominent construction.

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ON DETECTION AND IMPACT OF SECONDARY CRYSTALLIZATION OF CALCITE FOR RADIOCARBON DATING OF MORTAR

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Abstract

In the aim of radiocarbon dating of mortar, a great deal of research has been conducted since the first publication on the topic (Labeyrie and Delibrias, 1964). The difficulty still remains due to the contaminants mixed into the mortar. They may be carbon sources with different ages than those of the $CaCO_3$ formed during mortar setting (anthropogenic carbonate). These contaminants are of various types (Urbanová et al., 2020), but the most impactful ones may be geogenic carbonates (dead carbon source) and secondary crystallizations of calcite, which are known as products of water and moisture circulation in masonry. They fill pores, small cracks and interstices, shortly or long after mortar setting.

The last interlaboratory research has shown the need of a precise preliminary characterization of mortar before any dating in order to identify, and if needed separate, potential contaminants from anthropogenic carbonate with current protocols (Hajdas et al., 2017; Hayen et al., 2017). Secondary calcite, mainly detectable on thin sections under a microscope, is difficult to spot but also to separate, especially when crystals are of micritic size (<10 µm), about the same order of magnitude as anthropogenic carbonate (Nonni et al., 2018; Toffolo, 2020).

In this work, we introduce a new way of detection of secondary calcite, based on UV-irradiation. Applied on both kinds of mortar, aerial and hydraulic, we show that the use of a UV lamp can reveal these crystallizations by fluorescence. Indeed, the calcite formed by precipitation in a medium containing organic acid from groundwater flow, shows a bluish/yellowish white photoluminescence that is similar to that observed on speleothems which have undergone the same conditions of formation linked to humic and fulvic acid (Shopov, 2004).

Using this method, we also present an insight into the impact of the presence of secondary calcite on dating. We have been able to isolate such crystals by hand-sorting crushed mortar under UV light after sample characterisation. We dated the CO_2 extracted from total acid hydrolysis of both secondary calcite and bulk mortar to compare their bias with the true archaeological dates. Two mortars have been used for this, both from the Rhône region, France: a Gallo-roman aqueduct from Lugdunum (Lyon), and a medieval mortar from Saint-Ferréol church, in Saint-Romain-en-Gal, France. These results also demonstrate the value of using UV fluorescence to evaluate mortars for ^{14}C dating.

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A-CELLULOSE EXTRACTION PROTOCOLS APPLIED TO WOOD AND FLAX: USEFULNESS AND DIFFERENCES

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Abstract

Egyptian archaeology is rich in a large quantity of well-preserved ancient textiles due to arid climate. The ANR iSOPALIN project aims to conduct a multi-isotopic study of flax fibers to identify possible isotopic modifications in the ultrastructure of ancient fibre due to its cultivation and/or its use. Indeed, Isotopic measurements (δ^2H, $\delta^{18}O$, $\delta^{13}C$) coupled with ^{14}C dating can make it possible to investigate the state of degradation of archaeological samples but also to restore ancient climates (paleoclimates) and determine environmental conditions in which flax grew. This project is led by the LMC14 in Saclay in collaboration with the French Institute of oriental archaeology in Cairo and the 'Institut des Sciences Analytiques (ISA) in Lyon. This presentation will focus on the protocol developed at the LMC14 for cellulose extraction prior to ^{14}C dating (Dumoulin et al.2024).

Different α-cellulose extraction protocols were experimented on flax samples (flax plant, woven flax, archaeological flax linen) and on known age wood samples (Firi H and Siri A). The extraction efficiencies were estimated by yield calculations and by a step-by-step monitoring of the elimination of hemicellulose and lignin by Fourier transform infrared spectroscopy (FT-IR) analyses. ^{14}C measurements were carried out to validate the application of the protocols. We showed that, unlike wood, the first step of chemical treatment (ABA) eliminates the majority of hemicellulose and lignin from flax, certainly because it contains very little lignin. We also demonstrated that a too strong α-cellulose extraction protocol (ABABAB) can almost completely destroy the most fragile samples for sometimes questionable gains.

This presentation will detail the samples, protocols and analytical methods used to investigate the preparation of flax fibres for isotopic analysis. We will discuss the importance of choosing a chemical protocol perfectly adapted to the nature and the state of preservation of the samples treated.

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IMPLEMENTATION OF RADIOCARBON WATER SAMPLE PREPARATION PROTOCOLS AT LAPA^{14}C, BRAZIL.

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Abstract

The Radiocarbon Sample Preparation Laboratory (LAPA^{14}C), associated with the Stable Isotope Laboratory (LISE) at the Federal University of Bahia (UFBA), represents a new Brazilian hub for the preparation of samples for radiocarbon analysis, with growing applications in dating and paleoenvironmental reconstruction studies. Implementing specific preparation methodologies for each sample matrix is a crucial step in consolidating laboratories of this kind. Given the scarcity of laboratories in Brazil capable of preparing water samples for carbon analysis, LAPA^{14}C has made significant progress in developing specific protocols, drawing on its previous experience with isotopic analyses in aquatic systems.

Radiocarbon analyses are performed via Single Stage Accelerator Mass Spectrometry (SSAMS) at the Radiocarbon Laboratory of the Fluminense Federal University (LAC-UFF) (Bragança et al., 2021; Oliveira et al., 2021). The LAPA^{14}C tested two preparation protocols, the precipitation protocol (Hüls et al., 2004; Uchida et al., 2020), comparing the performance of precipitate formation using two differet solutions, one of Na_2CO_3 and the other of Li_2CO_3, and another protocol using direct acidification in a glovebag. The methods tested were: i) **Direct acidification** method, i.e., creating a nitrogen atmosphere during the sample acidification procedure, ii) **Precipitation** method, i.e., using $Ba(OH)_2$ to precipitate carbonate from water as $BaCO_3$. Na_2CO_3 solutions were made to obtain 1, 2, and 3 milligrams of carbon (mgC). After the acidification procedure, CO_2 was extracted in the vacuum line, and it was observed whether the pressure was greater than 67 torr, which is equivalent to 1 mgC for the LAPAC line (Santos et al. 2025).

In addition to methodological development, the precipitation protocol was applied for the first time in a hydrogeological study of the Corrente River Basin in western Bahia (Brazil), where multiple overlapping aquifer systems occur. These systems are essential for domestic water supply, agricultural irrigation, and the maintenance of perennial river flow in the region.

Five groundwater samples were collected from deep tubular wells, each representing a distinct hydrogeological context: one sample from the sedimentary aquifer (SAU), one from the karst-fractured system, one from the crystalline basement, and two samples from wells with mixed capture (dual aquifer). Radiocarbon analysis of these samples aims to assess interactions among the aquifer systems and improve the understanding of groundwater circulation in the region, providing key information to

support the integrated and sustainable management of local water resources.

The protocol tests' results indicate that the use of Li_2CO_3 was more efficient in carbonate precipitation, even for smaller sample quantities. The successful application of this method in the Corrente River Basin hydrogeological study highlights its potential to enhance our understanding of groundwater circulation in complex aquifer systems. This work presents the first results of a radiocarbon measurement protocol specifically developed for water samples using ^{14}C-AMS at the Federal University of Bahia (UFBA), marking a significant step forward in the establishment of national capabilities in radiocarbon analysis.

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STATUS REPORT OF SAMPLE PREPARATION AT CEZA MANNHEIM (MAMS) OVER THE LAST 15 YEARS.

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Abstract

The AMS radiocarbon laboratory at the Curt-Engelhorn-Centre Archaeometry Mannheim emerged from the conventional radiocarbon laboratory of the Heidelberg Academy of Sciences in 2010. The sample preparation used was strongly influenced by the sample preparation of the conventional sample preparation of the various materials for the gas counting technique. Over the years, methods were adjusted and improved and research outcomes, also from the radiocarbon community, were taken into account. After a short wrap-up of the starting methods for the main materials wood, bone, charcoal, the development is described and the current methods laid out. This Poster is a stataus report.

COMPARISON OF REMOVAL PROTOCOLS FOR BONE CONSOLIDANTS AND PRESERVATIVES

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Abstract

Human or animal bone, teeth, ivory and antler archaeological finds have always been frequent samples submitted to radiocarbon laboratories. Nowadays, during excavation campaigns, increasing attention is devoted to the selection and handling of the most promising samples, considering subsequent scientific analyses, as well. However, in the past, this care was not in focus thus a lot of objects stored in museums had been chemically treated to preserve them for future. For this purpose, a wide range of natural and artificially produced substances has been applied in archaeology so the analyses and dating of these objects are still laborious At the Hertelendi Laboratory of Environmental Studies, we aimed to try to estimate the effect of the most applied consolidants and preservatives to the actual age of a reference bone sample. A humerus bone (Ursus spelaeus) was selected and split into fragments, which were then treated artificially by preservatives such as epoxy resin, superglue or polyvinyl acetate. After drying, the surface of the samples was chiselled in certain cases and the fragments were crushed. Regarding the chemical pre-treatment, the effects of the simple acid-base-acid (ABA) wash, a supplementary post-ABA ultrafiltration step, or a preceding Soxhlet-extraction were compared. After gelatinization, the produced samples were measured by a MICADAS AMS device. Based on our results, physical cleaning and the simplest chemical treatment may already represent a good approach of the actual age of bone, but better results can be achieved by supplementary protocols. Certain preservatives, such as superglue, cannot entirely be removed even using the most complex protocols either.

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A NON-TOXIC, LOW-COST, WATER SAMPLING METHOD FOR QUANTIFICATION OF DI^{14}C

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Abstract

Radiocarbon quantification of dissolved inorganic carbon in water (DI^{14}C) is widely used in Earth sciences to provide insights into aquifer dynamics, ocean circulation, and carbon cycling. Traditionally, water samples are poisoned—i.e., preserved by adding HgCl2—to prevent biological activity from altering the original ^{14}C content. However, HgCl2 is highly toxic not only to microorganisms in water, but also to humans and the environment. Because of the latter, non-toxic preservation methods have emerged over the past decades. Among them, freezing water samples collected in aluminum foil bags has shown good results, comparable to analyzes of poisoned samples (Bryant et al., 2013; Castrillejo et al., 2023). Nevertheless, this alternative is still not yet widespread and poisoning continues to be the norm. In addition, commercially available non-toxic sampling devices are relatively expensive, representing a barrier to high-resolution DI^{14}C studies.

In this work, we present an adaptation of the aluminum foil bag method using low-cost bags, based on protocols developed by the National Environmental Isotope Facility (NEIF) Radiocarbon Laboratory (UK). To validate this approach, we have conducted three sets of tests. In April 2024, several replicated samples were collected at one groundwater and one seawater site using both the adapted foil bags and established validated methods. Replicates were graphitized after storage periods of two weeks, six months, and one year. Additionally, in October 2024, an oceanic depth profile was sampled in the South East Pacific ocean with two or three replicates per depth, and is being graphitized after storage times of three months, six months, and one year. Graphitization of samples collected in aluminum foil bags was conducted in the Geochronology laboratory, Universidad de Magallanes, using Carbonate Handling System (CHS2) coupled to an Automatic Graphitization Equipment (AGE3) and analyzed at Keck Carbon Cycle AMS Laboratory (KCCAMS), University of California, Irvine. Each set included at least one poisoned control sample, which has been processed and analyzed at KKCAMS. Preliminary results show good agreement between the poisoned and foil bag samples in most cases. However, discrepancies of ~100 ^{14}C years have been observed between some of the poisoned and foil bag samples, indicating further investigation is needed to validate low-cost aluminum foil bags as a suitable sampling method for water.

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METHANE ^{14}C ANALYTICAL METHOD DEVELOPMENT: ONE-STEP GRAPHITIZATION AND DIRECT GAS ANALYSIS WITH A PIMS

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Abstract

Methane, akin to carbon dioxide, has a substantial greenhouse effect, making it a significant contributor to global environmental changes. The feedback from climate change also impacts both the sources and sinks of methane. The radiocarbon variation in environmental methane acts as an indicator of the sources of newly emitted methane gas and offers insights into changes in its behavior. Therefore, the radiocarbon isotope ratios of methane gas are of great interest, along with stable carbon and hydrogen isotope ratios and changes in methane gas concentration. Although ^{14}C analysis of methane holds significant potential, it encounters challenges owing to the complex processes involved and the requirement for extensive pretreatment. In the conventional methane ^{14}C analysis, methane gas in an environmental sample was first separated and purified. The purified methane gas must then be converted to CO_2, which must be further converted to graphite before ^{14}C analysis using the AMS. Hence, two steps (conversion of methane to CO_2 and subsequent CO_2 graphitization) are required for sample graphitization, and the pretreatment process is lengthy. To simplify and accelerate this complex and lengthy pretreatment process, we have attempted to develop two simpler pretreatment methods. Those are 1) one-step methane graphitization (AMS method) and 2) direct ^{14}C measurement of methane gas using a Positive Ion Mass Spectrometer (PIMS). In the 1) one-step methane graphitization (AMS method), we aimed to convert methane directly to graphite without CO_2 conversion. For this purpose, the following parameters were examined: A) Fe and α-Fe_2O_3 powders from different forms, B) Fe/α-Fe_2O_3 powder pre-reduction by hydrogen (pressure, temperature, and duration), and C) direct one-step methane graphitization (temperature and duration). Consequently, methane can be directly graphitized with a yield exceeding 80%. Although there remains a need for further enhancement of the yield, the direct graphitization of methane facilitates the ^{14}C analysis of methane in a more expedited manner compared to conventional methods. In the 2) direct ^{14}C measurement of methane gas using a Positive Ion Mass Spectrometer (PIMS), we aimed to optimize various parameters (singly charged carbon ion production rate, molecular/fragment ion production efficiency, charge exchange efficiency, molecular ion destruction efficiency, stripping gas type, and focusing) to perform direct ^{14}C analysis. CO_2 and methane gases were individually introduced into the ECR ion source. We then observed the mass spectrum of molecular, fragment, singly charged, or multiply charged ions by scanning a magnetic field. The Δ^{14}C values obtained using conventional AMS and those obtained using the new PIMS method were compared.

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DEATH IS NOT THE END: UNEXPLAINED >500Y DIFFERENCES IN THE ^{14}C AGES OF CLOSELY-RELATED INDIVIDUALS FROM ALTENDORF, GERMANY

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Abstract

In the early 1930s, at least 235 human skulls were recovered from a Late Neolithic gallery grave at Altendorf, Hesse, Germany. In the late 2010s, ^{14}C dating of 39 of these individuals at the Kiel laboratory showed that most dated, as expected, to the late 4th millennium BC calibration plateau, but almost a third dated to an unexpected second phase, beginning c.500y later and lasting over a millennium, with inhumations at regular intervals (Rinne, Drummer, & Hamann, 2019). Far from confirming this pattern, however, osteological examination (Meyer, Fuchs, & Rinne, in prep) and archaeogenetic analyses (da Silva et al., 2025; da Silva et al., in prep) demonstrate that some second-phase individuals were close relatives of first-phase individuals buried at Altendorf or nearby late-4th millennium gallery graves, such as Niedertiefenbach (Meadows et al., 2020). The weight of archaeogenetic data now available shows that about a third of the Altendorf ^{14}C ages are much too recent, but routine quality-control measures (collagen yields, %C, %N, δ^{13}C, δ^{15}N, FTIR spectra) give no hint that the second-phase samples were less well preserved than, or contaminated with different consolidants to, first-phase samples dated concurrently. Following van der Sluis et al. (2023), we tested 20 collagen extracts for non-human peptide sequences, but found no evidence that bone glues had been applied. To unravel this mystery, we analyse several new samples from each of two of the second-phase skulls.

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^{14}C DATING OF MORTAR – INTEGRATING IMPROVEMENTS IN CHARACTERIZATION AND PRETREATMENT

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Abstract

Radiocarbon dating of mortars provides a valuable tool for determining the age of historical constructions because it directly relates to the time of their construction (Ringbom et al., 2014). Although the method presents significant methodological challenges due to potential contamination from unburnt limestone (dead carbon) and incomplete carbonation during the setting process, different preparation techniques make it possible to exclude or limit their influence on the obtained ^{14}C measurement results (Hajdas et al., 2020; Michalska 2019). Advances in sample pretreatment protocols, such as sequential dissolution and stepwise thermal decomposition, have improved the isolation of the binder fraction, thereby enhancing the reliability of dating (Michalska et al., 2017; Ringbom et al., 2014). A multidisciplinary approach and the crucial role of preliminary characterization of samples are essential to identify the nature of the binder and to distinguish primary carbonate phases from secondary contaminants that would complicate and challenge ^{14}C measurement (Caroselli et al. 2024). The thin section petrographic analysis remains the primary analytical method for characterizing the binder and aggregates, but also OM-cathodoluminescence and other techniques such as Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS), X-ray Diffraction (XRD), Thermogravimetric Analysis/Differential Scanning Calorimetry (TGA/DSC), can be applied to provide a more in-depth characterization of mortars particularly at risk of contamination. In this project we will integrate and improve methods developed independently by our laboratories.

Sieving and sequential dissolution methods with additional thermal treatment are applied at the ETH laboratory. The grain size of 45-63 µm is separated through dry sieving, and approximately 100-200 mg of powder undergoes sequential dissolution (SDM) (Hajdas et al., 2020). Four fractions collected at 3-second intervals are graphitized, or, if smaller than 300 µg, analyzed using the Gas Ion Source (GIS) AMS. Additionally, for samples with a suspected or observed effect of contamination with younger CO_2 (recrystallization), a thermal treatment step is applied. Based on the TGA analysis of multiple samples, the sieved powder is heated to 580 °C for 3 hours in the muffle oven before SDM.

We will apply ramped thermal oxidation method using Online Ramped Oxidation (ORO) setup at ETH (Bolandini et al., 2025) which is designed to analyze samples with complex natural matrices. The samples will be analyzed under sequential thermal windows with a steady temperature ramp from 100 to 980°C at 5°C min^{-1}. The released CO_2 from Zeolite traps will be injected to GIS of LEA (Low Energy Accelerator) system and will be measured directly for ^{14}C content. The online set up eliminating the need for offline processing for CO_2 purification such as cryo-trapping or graphitization steps and can accept samples with low carbon content.

Future research will focus on integrating all the methods in studies of the most challenging mortars

identified in previous research projects.

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PRESERVATION OF CHARRED AND ORGANIC MATERIALS IN ARCHAEOLOGICAL PLASTERS AND MORTARS: INSIGHTS FROM JERUSALEM

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Abstract

This study investigates the preservation of charred and unburnt organic materials in archaeological plasters and mortars from different installation and construction in the Jerusalem region, spanning from 2000 BCE to 1600 CE (Regev et al., 2020, 2021, 2024). By analysing the chemical composition of plasters and mortars using FTIR spectroscopy, we identified key factors influencing the preservation of datable materials. Our results show that plasters with calcitic components, primarily composed of lime, crushed limestone and ash, tend to have well-preserved charred remains as indicated by the chemical pretreatment efficiency, carbon content and FTIR analysis. The ratio of clay to calcite and plant material type also affects general preservation of organic material. Notably, high phosphate or clay concentrations in specific mortars seems to help the preservation of fresh straw and uncharred plant remains. These findings provide valuable insights into the preservation of charred and fresh organic materials in archaeological contexts, enhancing our ability to date and interpret archaeological sites (Calandra et al., 2023).

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DEVELOPMENT OF AN AUTOMATED SYSTEM FOR THE PRETREATMENT OF SMALL AMOUNTS OF SAMPLES FOR RADIOCARBON MEASUREMENTS USING ACCELERATOR MASS SPECTROMETRY

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Abstract

Radiocarbon analysis by accelerator mass spectrometry requires the sample to be graphitized prior to analysis. Generally, a sample of about 1 mg carbon is required for AMS measurement, although in recent years the amount of sample required for AMS measurement has decreased due to improvements in AMS technology, and there are now cases where samples of about 20μg carbon have been measured (e.g. Yokoyama et al. 2022). This sample size is similar to that required for mass spectrometry of stable carbon isotope. This implies the possibility that the various pretreatment devices (e.g. elemental analysers) used in stable isotope mass analysis can also be used in AMS radiocarbon analysis. For a comprehensive sample preparation system, an automated graphitization system is required to produce graphite in conjunction with these pre-treatment devices. We have constructed a system that separates and purifies CO_2 gas from He as the carrier gas, by receiving electronic signals transmitted by the EA and other devices, and have evaluated the performance of this automated system using IAEA standards. In this presentation we will discuss the performance of this system and the possibility of coupling it with AMS pre-treatment equipment such as EA and carbonate treatment equipment. It is expected that the pre-treatment process for AMS analysis will become less labor intensive with the use of this system.

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COMPARING DIFFERENT METHODS OF COLLAGEN EXTRACTION FROM ARGENTINE ARCHEOLOGICAL BONES FOR ^{14}C DATING

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Abstract

Archaeological bones are one of the main samples used in the radiocarbon dating of archaeological sites through the extraction of the associated collagen. However, collagen often suffers the effect of diagenesis phenomena related to the geology and meteorology of the place where they were found. This leads to the fact that in certain regions the bones are better or worse preserved and give a collagen that is not suitable for dating or, in the worst case, does not contain enough collagen for measurement. For this work, collagen extraction was performed by means of a standard protocol on bone samples from three archaeological sites in Argentina, which are located in three regions differentiated by their geographical and environmental characteristics. Subsequently, the samples were subjected to other collagen extraction protocols that differed in the treatment conditions in some of the stages: variations in the conditions of demineralization, alkaline attack and gelatinization. Characterization of the bones and the extracted collagen was carried out using parameters of carbon content (%C), nitrogen content (%N), C/N ratio and collagen yield. Additionally, the collagens obtained were analysed by infrared spectroscopy. Finally, the collagens were graphitized for ^{14}C measurement. The results show that there are opposing effects between the different conditions evaluated and that they become more significant in the older samples; for example, yields increase with the duration of demineralization, and ages age with alkali application are more pronounced in the older samples. Thus, it is suggested that standardized protocols are suitable for better preserved and arid samples, while for samples from wet or more deteriorated areas it is better to proceed with alternative, milder protocols.

DIRECT REDUCTION OF CO GAS FROM MN SMELTING

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Abstract

Measuring the carbon balance of industrial processes is crucial for quantifying carbon emissions in a green economy. While solid products can easily be collected and analysed, sampling gases and volatile compounds that are released to air can be more challenging. Mn oxides from raw materials are reduced in submerged arc furnaces in a reaction with carbon reductant (Eidem et al. 2025). This leads to exhaust hast that typically consists of 70 % CO and 20 % CO_2 while the rest is mainly made up by H_2 and N_2. To measure the carbon emission in exhaust gas from manganese (Mn) production, we compared different methods to reduce the carbon to graphite usable for AMS measurement.

A regular treatment of the exhaust gas would be to combust and separate the resulting gases by freezing out water and CO_2 and pumping non-condensable gases. In this case, the combustion was achieved by expanding the sample gas into a closed reactor with MnO_2 as oxygen supplier. The reactor was then heated to 550 °C for the reaction (Janovics et al. 2018). The captured CO_2 would then undergo reduction in a reduction process with Zn and Fe (Seiler et al. 2019).

As the regular reduction process for CO_2 goes through a CO phase, we tried to reduce the gas mixture directly. The gas was expanded into the reactor of the Zn reduction system consisting of two heated tubes (Seiler et al. 2019). One tube is filled with Fe powder for reduction to solid graphite, and the other one with Zn powder for CO formation out of CO_2, as well as silver foil for absorption of sulphur compounds. We show the details of these systems and compare the ^{14}C results from the two methods used to reduce the sample showing that both methods give comparable results.

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A SMALL-MASS GRAPHITE TARGET PREPARATION TECHNIQUE AT GUANGXI NORMAL UNIVERSITY

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Abstract

Carbon-14 (^{14}C) measurement has become indispensable for carbon cycle studies and archaeological investigations. Conventional methodologies typically demand substantial carbon samples (~1 mg C), yet the rapid advancement of compound-specific radiocarbon analysis (CSRA) and micro-sample research (e.g., atmospheric carbonaceous aerosols, trace specimens from cultural relics) urgently requires the development of preparation techniques compatible with small-mass samples (<0.1 mg C). Traditional graphitization methods face critical technical challenges in processing micro-scale samples, including elevated background interference and low ion source efficiency. This study introduces an enhanced sealed-tube zinc reduction method utilizing the ^{14}C sample preparation system at Guangxi Normal University. This method achieves low-background and high-precision graphite targets from 10–100 μg C samples, with subsequent validation on the 3.0 MV Accelerator Mass Spectrometer (GANA). The established system provides a reliable platform for ^{14}C dating and environmental tracer studies involving trace carbonaceous materials.

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TOO DIRTY OR 'TOO CLEAN'? ARE HIGH C:N RATIOS OF PRE-TREATED BONE COLLAGEN NECESSARILY INDICATIVE OF RESIDUAL POST-DEPOSITIONAL CONTAMINATION?

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Abstract

As part of the "Horsepower" project (horsepowerproject.org), an on-going, extensive programme of radiocarbon (^{14}C) dating is currently underway that will inform upon early state formation in China, Mongolia and the Steppe during the first ~two millennia BC via explicit exploration of the trade in horses. This programme will complement the associated genetic analysis, an examination of the material culture associated with horseback riding or the driving of vehicles, and the metal supply from China to the north and northwest.

Within this broader remit, significant dating effort has been applied to a single khirgisuur site in central Mongolia – khirgisuurs representing an iconic element of the Late Bronze Age ceremonial mortuary landscape of the Eastern Eurasian Steppe – with >100 individual horse burials present. Preservation of the burials appears superficially 'good', with sufficiently high yields of both DNA and collagen extracted from the majority of samples. However, collagen extracted for ^{14}C dating often gave higher than expected C:N ratios, which is usually a 'red flag' in terms of quality assurance. Such findings are consistent with those of a previous study (Zazzo et al., 2019, Antiquity), wherein it was deemed that samples bearing high C:N ratios (in their case, >3.30) should be removed prior to subsequent analysis.

High C:N ratios of bone collagen are indicative of residual contamination that has not been removed from the samples during chemical pre-treatment and, hence, signify that the ^{14}C dates derived from such material could be unreliable. It is often assumed that any such residual contamination would be post-depositional – deriving from external carbon sources in the depositional regime. However, in the present study, we explore an alternative hypothesis as to whether the high C:N values for our Mongolian horse collagen are instead derived from the residual presence of lipids from the horse bones themselves; i.e., are the high C:N values indicative of 'poor' preservation or unusually 'good' preservation? And, if the latter, what implications might there be for the interpretation of the ^{14}C data obtained from such material?

FILTRATION IN THE BENZALKONIUM CHLORIDE ADDITION METHOD FOR WATER SAMPLE PRESERVATION IN RADIOCARBON ANALYSIS OF DISSOLVED INORGANIC CARBON

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Abstract

Dissolved inorganic carbon (DIC) concentration and carbon isotopic ratio (^{14}C and $\delta^{13}C$) in natural waters often change during sample preservation due to the microbial activity in water sample. As an alternative to mercury-based conventional sterilization, our group tested benzalkonium chloride (BAC). However, it has been confirmed that BAC is not sufficiently effective for certain samples, including seawater (Takahashi et al., 2019; Takahashi and Minami, 2022). While the underlying mechanism remains unclear, it has been suggested that the high salt content of the water samples might be contribute to the reduced efficacy of BAC (Takahashi et al., submitted). García et al. (2001) reported that biodegradation of BAC occurred due to marine bacterial populations, therefore, seawater likely contains microorganisms that BAC cannot inactivate. It should also be noted that BAC in water may be removed primarily by adsorption onto sludge rather than by biodegradation (Zhang et al., 2015). In this study, we examined the effect of suspended matter in water samples as one way of resolving these problems in using the BAC addition for sample preservation.

The investigation focused on the decline in bactericidal efficacy of BAC in the presence of mud in preserved samples. This decline was examined through a comparative analysis of seawater samples with and without mud, following BAC addition. Seawater samples, exhibiting no visible suspended particulate matter, were collected at the Pacific coast area. The mud were obtained from the tidal flat at the Bay area of the Pacific coast and subsequently sterilized in an autoclave at 120℃ for 1 hour prior to use. The results demonstrated that the DIC underwent a significant change during the preservation process in samples containing mud, while the change in DIC was minimal in samples without mud. This finding suggests that the presence of mud might mitigate the bactericidal effect of BAC. However, given the assumption that mud contains a substantial number of microorganisms, it is plausible that the addition of mud to the samples, if the sterilization process was not complete, could have led to a considerable increase in the microbial population. This increase in microorganisms relative to the BAC could have been contributed to the observed change in DIC. Further verification is necessary to reach a definitive conclusion.

The presence of mud appears to affect the effectiveness of BAC in suppressing DIC changes when the BAC was added for water sample preservation, whether due to the mud itself or the large amount of microorganisms contained in the mud. However, filtration is expected to improve the situation regardless of the underlying cause. A combined procedure involving BAC addition and filtration has been proposed as an effective method for suppressing biological DIC changes in ^{14}C analysis, including in seawater samples (Takahashi and Minami, 2024). Presumably, filtration plays a pivotal role in mitigating biological DIC changes in ^{14}C analysis when using the BAC addition technique for water sample preservation. Further research is needed to ascertain the optimal pore size for filtration and to assess the potential ramifications of filtration on other issues.

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Investigating the timing of the Arctic Ocean ^{230}Th Excess Minima by radiocarbon dating

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Abstract

Establishing robust age models for sediment cores from the Arctic Ocean presents significant challenges, particularly in central basin locations where the absence of foraminifera often rule out conventional radiocarbon (^{14}C) dating. Alternative methods, such as paleomagnetism, face interpretation uncertainties related to distinguishing between reversals and excursions, as well as potential diagenetic effects on the magnetic record. Furthermore, even foraminifera-based ^{14}C dates can be questioned due to the potential precipitation of authigenic calcite.

This study focuses on specific intervals in sediment cores from the Arctic Ocean (cores PS2138-1 and the GIK23065-3) characterized by unusually low levels of ^{230}Th excess and ^{10}Be. These intervals are central to a debated hypothesis suggesting they represent periods when the Arctic Ocean was covered by ice shelves which may have been grounded at the Iceland-Scotland ridge, potentially leading to an isolation of the Arctic Ocean from the North Atlantic and thus, freshening. One key question is the precise age of these events to place them within a chronological and stratigraphic framework. Paleomagnetic data from these cores show features that imply a temporal occurrence of the youngest event close to the Laschamps geomagnetic excursion (~40,000 years ago). However, it cannot be ruled out that these paleomagnetic data are affected by diagenesis, and thus, their use as a chronological anchor-point is uncertain.

To address this chronological ambiguity and evaluate the potential age of these low Th/Be intervals, our research utilized bulk organic carbon ^{14}C dating with the help of MICADAS at AWI. The application of ^{14}C dating is crucial as it allows us to test whether these intervals are younger or older than approximately 50,000 years, effectively discriminating between a Laschamps age (MIS 3) and older periods. We also compare these bulk organic carbon ^{14}C dates with existing foraminifera C14 dates in core PS2138 to assess potential offsets or the influence of pre-aged carbon input.

While existing few (foram) ^{14}C data and paleomagnetic indicators provisionally suggest a MIS 3 or a Laschamps age, our new bulk organic ^{14}C results will provide crucial confirmation and improve age control. The ^{14}C data support that the low Th/Be interval in the investigated sediment cores, which lie stratigraphically above this hypothetical Laschamps feature, are indeed relatively young (<50,000 years). Comparison with existing foram dates provides insight into the reliability of different carbon reservoirs for dating in this environment. Furthermore, the ^{14}C constrained age for these intervals allows us to contextualize associated proxy data and investigate if these intervals are coeval in both cores by extending C14 dating into deeper sections where existing dates are limited.

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KILIMANJARO MUMMIFIED ANIMALS AND THEIR ^{14}C AGES

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Abstract

Continental glaciers are unique records of the past environment and have been intensively studied over decades. These unique records are vanishing due to global warming; thus, fully exploring the archives is of key importance.

A component of climate and glacier fieldwork on Kilimanjaro glaciers (Feb. 2000 – Oct. 2023) included exploration of the broad summit area, seeking relevant observations. On multiple fieldwork trips with limited snow cover, mummified mammals and/or birds were found on the glacier surface or at the ice margin; both horizontal and vertical ice surfaces have experienced negative mass balance and recession in recent decades. Most of these animal discoveries were photographed and locations noted, and in some cases, tissue samples were obtained for potential radiocarbon dating. Field evidence suggests rapid burial by snow following death on the glacier, and continuous entombment within the ice. Thus, preservation within the ice reveals a record of the species presence at the summit, and potentially provides an exceptionally valuable tool for understanding glacier history, as radiocarbon dating of recently-exposed tissue offers an estimate of the burial date. Repeated observations of one specimen found emerging in 2004 showed that within about 5 years there was virtually no tissue remaining, only disarticulated bones.

The history of glaciers on Kilimanjaro remains uncertain and in dispute due to little supporting age-dating evidence (Thompson et al., 2002; Kaser et al. 2004). Following the failed attempt to obtain ice core drilling permits in 2022 (Ice Memory), additional ice dating opportunities are unlikely due to ablation. Therefore, any information which mammal dating might provide will be invaluable.

High elevations on the mountain are an alpine zone largely devoid of life. Air temperature on the summit glaciers remains below freezing, the mean annual temperature is -6.7°C, and these highest elevations are seasonally snow covered – an environment differing markedly from the forest or moorland zones where mammals reside or visit. The first known observation of mummified animal remains within the summit caldera was by Hans Meyer (1891):

"…we came upon what was perhaps as wonderful a discovery as any we made on Kilimanjaro. It almost savours of the fabulous, but here in this stern frost-bound region, at the very summit of a mountain 20,000 feet high, we lighted on the dead body of an antelope – one of the small species we had noticed on the pasture-lands below. How the animal came there is impossible to say. In all probability it had made its way upward by the same path as ourselves at a time when the ice was covered with its winter coating of snow, and, overtaken in these lofty solitudes by the fury of a mountain-storm, had paid with its life the penalty of its adventurous curiosity."

Another mammal at the summit was immortalized by Ernest Hemingway (1936) in his short story The Snows of Kilimanjaro: "Close to the western summit there is the dried and frozen carcass of a leopard. No one has explained what the leopard was seeking at that altitude."

We will present radiocarbon ages of four of the animals from which tissue samples were recovered. These were found either on the glacier's ice surface, or adjacent to a steeply-sloping glacier margin. Most were associated with the summit, north, or east sides of the Northern Icefield or the Eastern Icefield. The ages of the animals range from 15th century to the 21st century.

Acknowledgments

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A PORTABLE METHANE OXIDATION DEVICE FOR ^{14}C-ANALYSES IN REMOTE ARCTIC LANDSCAPES

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Abstract

The northern circumpolar regions are warming up to four times as fast compared to the global average (Rantanen et al., 2022), increasing the duration of annual thawing seasons and deepening of permafrost thaw. This puts previously freeze-locked carbon storages at risk to turn into a source for microbially respired greenhouse gases. After carbon dioxide (CO_2), methane (CH_4) is the second most important greenhouse gas with an up to 36 times larger greenhouse gas warming potential compared to CO_2 (Myhre et al., 2013). Furthermore, the global atmospheric CH_4 concentration has doubled since the industrial revolution during the 19th century and thus has an important influence on climate change and Arctic warming, because anthropogenic CH_4 sources are suggested to account for 30% of the anthropogenic greenhouse gas effective radiative forcing (IPCC, 2021). The global CH_4 budget, however, is still uncertain because anthropogenic and natural sources as well as sinks are poorly quantified (Saunois et al., 2020).

It is thus important to trace and quantify the sources of the increasing atmospheric CH_4 concentration. Different CH_4 sources have distinct ^{13}C and ^{14}C isotopic signatures, by which they can be identified, i.e. CH_4 from fossil sources contains no ^{14}C, whereas CH_4 from methanogenesis is depleted in ^{13}C and relatively enriched in ^{14}C.

While many studies over the last decades applied stable carbon isotopic analysis to identify CH_4 sources in the environment and fewer studies applied radiocarbon analysis, conducted in remote areas, such as the Arctic, to analyse CH_4 emitted directly from thawing permafrost deposits. Closing this data-gap could improve our understanding of the global CH_4 budget and of GHG-forming processes on Pedon scale that contribute to Arctic warming. Remoteness and lack of infrastructure are problematic, because CH_4 emissions and concentration are possibly orders of magnitude lower compared to CO_2 and the samples need to be stored for several weeks prior to analysis in the laboratory. Unfortunately, it is not possible to trap CH_4 under ambient conditions selectively and bulk gas samples in bags are prone to contamination with ambient air and/or are not suited for travel by plane due to air pressure differences at high altitudes. Furthermore, radiocarbon analysis of CH_4 via AMS is not directly possible, the widely accepted approach is the catalytic oxidation of CH_4 to CO_2 in the laboratory using specifically designed vacuum lines for this task, that firstly remove other carbon containing gases besides CH_4 and then oxidize and quantify the sample for AMS.

We approached these problems by adapting a portable, battery-powered CH_4 oxidation device, similar to Palonen et al. (2017) to Arctic conditions and capturing first environmental samples from thawing permafrost wetlands in the Greenlandic Arctic for subsequent radiocarbon analysis. The campaign took place in August of 2024 at Kuup Ilua (Blæsedalen or windy valley), located at the southern end of Qeqertarsuaq (Disko Island) in West Greenland. Kuup Ilua is a north-south oriented valley with periglacial features. It is at the transition between continuous and discontinuous permafrost and features tundra landscape. Two sampling locations, P3 and P7, in a wetland area were chosen, where CH_4 emissions were quantified during earlier field campaigns.

The system uses respiration chambers to collect soil respired gases, which are pumped through the system via a small membrane pump. The gas sample is dried using a Nafion membrane and CO_2 is removed by using online traps filled with sodalime. After CO_2 removal, CH_4 is pumped through a small glass tube filled with Pd/Al_2O_3, used as catalyst, installed in a small (5x5x5 cm) tube furnace heated to 600°C and subsequently oxidized to CO_2. The system operates at 24V supplied by two 12V, 100 Ah lithium batteries. The CH_4-derived CO_2 is then trapped on cartridges filled with 13X-zeolite and stored for ^{14}C-analysis in Germany. Batteries were transported separately to the sampling locations and are kept in the same case as the sampling device. Battery charges lasted for the whole campaign, with 8 hours of daily usage for 10 days with 48% charge remaining after the campaign, suggesting capacity could be scaled down to reduce weight. The whole setup is set in a water-proof case, strapped to a backpack-carrier and can thus be left in the field during the campaign. Gas concentrations in the sample are monitored by using a separate Li-7810 trace gas analyser, connected to the setup.

CH_4 emissions on the sites (300 to 400 ppb) were found to be below the local atmospheric concentrations (~2300 ppb) at the time of sampling, while CO_2 emissions were around 370 ppm. CO_2 could be removed completely from the gas stream, verified by trace gas analyser, before the oven was connected to the gas stream to oxidize the CH_4. As a result, sampling of 10-20 µg CO_2-C for micro-scale radiocarbon analysis took 3 to 4 hours per sample due to the low CH_4 emissions.

First data showed the fraction modern at P3 ranging between 0.610 ± 0.008 to 0.702 ± 0.007 $F^{14}C$ and 0.663 ± 0.006 to 0.869 ±0.008 $F^{14}C$ at P7.

Further tests in the laboratory were conducted to prove that the system is able to remove ambient CO_2 sufficiently from the gas stream and reaches sufficient CH_4-oxidation yields. Air mixtures were created using ^{14}C-enriched CO_2 and ^{14}C-depleted CH_4 with concentrations corresponding to those encountered in the field (~400 ppm CO_2; 300 ppb CH_4) and filled into a 170 L gas bag, acting as the respiration chamber used in the field.

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GLACIAL-MARINE HISTORY OF CENTRAL SPITSBERGEN-^{14}C DATING OF WHALE BONES FROM RAISED MARINE TERRACES ON THE WESTERN COAST OF PETUNIABUKTA

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Abstract

Petunia Bay represents the northernmost section of Billefjorden, flanked by mountain ranges on three sides, which feature complexes of raised marine terraces (Kłysz et al., 1989; Stankowski et al., 1989). The western shore of Petuniabukta, where the Elsa, Ferdinand, and Sven glaciers are situated, the terrace system is additionally complicated by the structure and tectonics of the rock mass (Karczewski et al. 1990, Dallmann et al. 1994). Numerous studies have been conducted to establish the curves of the course of post-Pleistocene sea level fluctuations in this region (e.g. Salvigsen 1984, Stankowski et al. 2013), primarily based mainly on the shells dating.

In the course of the 2023 expedition, whale bones were discovered on a terrace located 40 meters above sea level, nestled between the valleys of the Ferdinand and Sven glaciers. Dating result shows the age of this sample at (9780, 50) BP. During the expedition in 2024 other whale bones from the terrace 20 m above sea level were found and analysed.

These remains underwent radiocarbon dating analysis, contributing significant data to the ongoing research in this region.

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ACTIVATION OF AEOLIAN PROCESSES DURING THE LITTLE ICE AGE IN THE LIGHT OF ^{14}C AND OSL DATING IN POLAND.

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Abstract

The Little Ice Age (LIA) was a period of significant climatic changes that had a profound impact on the dynamics of geomorphological processes, including the activation of aeolian processes. The aim of this presentation is to analyze the intensification of aeolian processes in Poland during the LIA in light of radiocarbon (^{14}C) and optically stimulated luminescence (OSL) dating. The application of these methods allows for precise determination of periods of increased aeolian activity and their correlation with climatic changes and past environmental conditions.

Based on available field studies and laboratory analyses, it has been established that aeolian processes in Poland intensified during periods of increased aridification. This was due to a drop in temperature, an increase in the frequency of strong winds, and a reduction in vegetation cover. In particular, intensified mobilization of sandy sediments was observed in northern and central Poland, as well as in river valleys, leading to renewed accumulation of dunes and other aeolian forms.

Radiocarbon dating, used to analyze organic sediments found within dunes and aeolian covers, enabled the determination of time intervals during which intensive aeolian reworking of the land surface occurred. In turn, OSL dating of sandy deposits facilitated the reconstruction of deposition chronology and the identification of periods of increased aeolian transport. The results indicate that key episodes of aeolian activity occurred during the colder phases of the LIA, particularly in the 17th and 18th centuries, when forest cover was significantly reduced, and deflation processes were especially intense.

The analysis of results in the context of climate change suggests that the dynamics of aeolian processes in Poland during the LIA were strongly linked to regional and global climatic oscillations. The cooling climate affected hydrothermal conditions and landscape structure, leading to transformations in landforms that remain visible in Poland's landscape today. Contemporary geochronological studies allow for a more detailed understanding of the mechanisms behind the activation of aeolian processes and their potential implications for future environmental changes.

In conclusion, the research confirms that the Little Ice Age was a period of intense activation of aeolian processes in Poland. The combination of ^{14}C and OSL dating provided valuable insights into the chronology and conditions of these processes, contributing to a better understanding of the impact of climatic changes on Poland's landscape. These studies are of great significance for paleoclimatic reconstructions and the assessment of future environmental trends in the context of ongoing climate change.

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STUDY OF $\Delta^{14}C$ DISTRIBUTION MAP IN KOREA FROM 2010 TO 2022

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Abstract

Keyword: Fossil fuel, nuclear power plant, $\Delta^{14}C$, map

The annual distribution map of $\Delta^{14}C$ in Korea was made from $\Delta^{14}C$ of the ginkgo tree (corpseed ginkgo tree lynne) leaf samples taken from June to early July in Korea from 2010 to 2022. CO2 emitted from fossil fuel consumption can dilute $\Delta^{14}C$ and operations and accidents at nuclear power plants can increase $\Delta^{14}C$, so it is possible to estimate fossil fuel consumption and monitor the status of nuclear power plants. According to the annual distribution map of $\Delta^{14}C$ in Korea from 2010 to 2022, the overall $\Delta^{14}C$ decreased every year to the level of the 1940s, and the effect of nuclear power plants is becoming clearer as the years go by. The value of $\Delta^{14}C$ in the western part of Korea is lower than that in the eastern part of Korea. This is consistent with population and industrial patterns because there are many industrial complexes in the western part of Korea. In addition, the western wind blows into Korea and carries fossil fuel CO_2 from China, which can further lower $\Delta^{14}C$ in the western part of Korea.

^{14}C-OSL CHRONOLOGY OF THE POSTGLACIAL EVOLUTION OF THE WARTA RIVER VALLEY IN THE ŚREM BASIN – WESTERN POLAND.

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Abstract

The evolutionary process of lowland rivers at the end of the Last Glacial Maximum (LGM) was complex and multi-stage. During this period, a gradual transformation of river systems was observed, progressing from a braided river through an anastomosing system to meandering sequences, with a progressive decrease in meander radius in the younger phases of meandering development. This study focused on the final stages of the Warta River valley's transformation, especially the transition from the anastomosing phase to the subsequent meandering stages.

The formation of successive generations of meanders, combined with the river's incision into the riverbed, led to the development of successive paleomeanders, the abandonment of which can be associated with the onset of oxbow lake formation along their outer margins. This makes it possible, in a way, to date the time of functioning of the meanders by correlating the results of radiocarbon dating from the organic fills of the oxbow lakes with OSL dates obtained from the sandy sediments building the individual meander deposits.

Establishing a reliable geochronology for the transformation of river valleys based on radiocarbon dating is key to deepening our insight into the development of the Warta River valley in the Śrem Basin. Moreover, it provides a reference for earlier assumptions about the evolution of river valleys at the end of the Late Glacial and the beginning of the Holocene in the glaciated zone of the LGM.

As a result of this research, a model for the evolution of the Warta River in the eastern part of the Śrem Basin was developed based on radiocarbon and OSL dating. Additionally, the thickness of the organic fills in oxbow lakes located in the north-western part of the basin was found to be variable compared to those further south-east. This variability was interpreted as evidence of successive pulses of river incision into the basement.

Radiocarbon dating and sedimentological investigations were conducted during the study. The first results suggest that the so-called great meanders were formed somewhat later than hitherto assumed (Bølling interstadial), i.e. at the turn of the Allerød and Younger Dryas.

Keywords: radiocarbon dating, oxbow lake, fluvial system, meandering processes, anastomosing river

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DEVELOPMENT OF A VERSATILE A-CELLULOSE-CAPABLE AUTOMATED PRETREATMENT SYSTEM FOR RADIOCARBON AND STABLE ISOTOPE ANALYSIS

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Abstract

α-cellulose has proven to be a reliable and widely used constituent of wood for recording tree ring isotope signatures. The extraction of α-cellulose from tree rings is crucial to reconstructing past atmospheric radiocarbon concentrations and allows for a number of other isotopic analyses. High precision accelerator mass spectrometry (AMS) radiocarbon dates of tree-ring α-cellulose facilitate refinements to the radiocarbon calibration curve as well as the study of single-year anomalies and other processes influencing the atmospheric radiocarbon record. Despite advances in pretreatment, α-cellulose extraction remains a labour-intensive process, typically involving a number of reagent washes and many rinses with demineralised water[1]. These steps have a large impact on the speed, cost and throughput of tree ring isotope analyses, and would thus benefit greatly from automation. We present a prototype of an automated pretreatment system capable of performing α-cellulose extraction with enhanced functionality, including reactions with up to four different reagents at controlled temperatures and ultrasonication under a controlled atmosphere. This automated system represents a significant advancement in α-cellulose extraction, reducing the labour investment and increasing sample throughput. By ensuring consistent and efficient sample preparation, this system has the potential to enhance the accuracy and reproducibility of radiocarbon and stable isotope analyses of tree rings.

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ROCK DERIVED CARBON CONTRIBUTES RADIOCARBON-FREE ORGANIC CARBON TO SOILS ACROSS THE CONTINENTAL USA

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Abstract

Organic carbon (OC) stored in sedimentary rocks is one of the largest stocks of carbon in the lithosphere. However, it is unknown how much this petrogenic OC (OC_{petro}) enters the modern soil carbon cycle during soil formation and weathering. The presence of OC_{petro} in soil can significantly reduce radiocarbon (^{14}C) values, which are used to quantify soil carbon turnover times. Previous work estimated that soils developed on sedimentary rocks have a maximum OC_{petro} contribution of 38% to the total SOC pool. Yet, we currently do not have direct measurement of OC_{petro} in soils. We assessed the contribution of OC_{petro} to total soil OC in soils developed on sedimentary rock across the continental United States. We measured a total of 52 soil horizons from 26 soil profiles from the National Ecological Observatory Network (NEON), including soils developed on sedimentary (with OC_{petro}) and igneous (with no OC_{petro}) parent materials. Using a ramped thermal oxidation isotopic fractionation (RPO-^{14}C) we directly measured the amount of OC_{petro} in soils by quantifying the thermal reactivity and isotopic composition of evolved organic matter over targeted temperature ranges. We examined both the ^{14}C distribution and a distribution of activation energies, E (kJ mol^{-1}) in NEON soils from 10-30 cm and 30-100 cm depths to assess the relative contribution of OC_{petro} to both topsoil and subsoil. We found that OC_{petro} in different environments had a wide range of E distributions. Additionally, ^{14}C depletion varied across the thermal gradients and between soil profiles. OC_{petro} contribution varies in soils and could contribute to variably depleted ^{14}C signatures. We call for renewed assessment of OC_{petro} inputs to soils, to assess its impact on soil radiocarbon inventories and modeling of soil carbon turnover.

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ARCTIC GREENING: VEGETATION CONTROLS ON CO_2 EMISSIONS AND ^{14}C SIGNATURES IN THAWING PERMAFROST

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Abstract

The Arctic region is warming nearly four times faster than the global average, triggering profound changes in permafrost landscapes and accelerating ecological transitions across the circumpolar north. Among the most visible responses to this rapid warming is Arctic greening, i.e., an increase in vegetation productivity, biomass, and shrub expansion driven by elevated temperatures, longer growing seasons, and increased nutrient availability. While greening may enhance carbon uptake at the land surface, it may also enhance nutrient inputs and increase microbial activity in permafrost soils, raising concerns about accelerated decomposition of organic matter and the release of greenhouse gases such as CO_2. The net effect of these changes on greenhouse gas emissions is uncertain, particularly in dynamic thermokarst features such as retrogressive thaw slumps, where ancient and modern soil layers mix, creating complex biogeochemical environments.

To investigate how vegetation regrowth and shifts in vegetation type influence microbial carbon cycling in thaw-affected permafrost soils, we conducted a 13-week greenhouse experiment using soils from two distinct sites within a retrogressive thaw slump in northeastern Siberia. One site consisted of a recently exposed thaw mound composed of ~34,000-year-old loess-like permafrost sediment, called Yedoma, while the second represented a mixed layer combining this Pleistocene material with more recent Holocene-aged organic-rich deposits due to erosion processes. The mixed site exhibited significantly higher organic carbon content (4.3% vs. 3.6%) and a more acidic pH relative to the Yedoma sediment (ca. 5.4 vs. 7.1).

To simulate the ongoing greening, we established plantings of representative vegetation types including tundra dominated by shrubs (Salix lanata, Duschekia fruticosa) and by grassland (Carex umbrosa, Festuca ovina, Eriophorum vaginatum) as well as taiga (Larix gmelinii, Betula pendula), and monitored soil CO_2 production as a proxy for microbial respiration and carbon mineralization. Despite differences in substrate age, organic carbon content, and soil chemistry, both sites showed closely similar cumulative CO_2 emissions under all vegetation types during the first 7 week. This suggests a broadly comparable microbial activation phase likely driven by labile carbon inputs from plant roots and similar temperature and moisture conditions. However, after week 7, CO_2 production rates began to diverge in the mixed soil, with the lowest emissions recorded under taiga vegetation, followed by tundra and highest under grass. This differentiation may reflect vegetation-specific effects like slower-growing roots or more recalcitrant carbon inputs under taiga, whereas grass-dominated systems may stimulate microbial respiration via faster root turnover and higher-quality exudates.

To further resolve the sources of respired CO_2 and determine whether microbial communities were metabolizing ancient versus modern carbon pools, we initiated radiocarbon (^{14}C) analyses of CO_2 collected before and after vegetation establishment. These data, currently underway, will help distinguish the relative contributions of recently fixed plant-derived carbon and old permafrost carbon

to microbial respiration. This is critical for understanding whether Arctic greening promotes the release of ancient carbon stocks or primarily accelerates the cycling of newly introduced organic material.

Our results indicate that, under conditions of vegetation regrowth, microbial communities can become equally active in both ancient mineral-rich and younger organic-rich permafrost soils and highlight the dynamic interplay between soil properties, vegetation type, and microbial processes in regulating carbon fluxes in thaw-affected permafrost soils. As Arctic greening continues to progress, such interactions may play a critical role in determining whether these landscapes act as carbon sources or sinks.

RADIOCARBON ANALYSIS OF PHOSPHOLIPIDS TO ASSESS MICROBIAL CARBON ASSIMILATION IN SOILS

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Abstract

Understanding the turnover time of organic matter pools in soils is critical for understanding soil carbon cycle processes and has implications for the durability of carbon sequestered in soils. The turnover time of C used by active microbes in soil has been challenging to assess, and different methods (chloroform biomass extraction and respired CO_2 from lab incubations) have yielded divergent results (Finstad et al, 2024). Here, we propose the analysis of ^{14}C of bulk phospholipids extracted from soils as a new method to assess the turnover time of C assimilated by soil microbes. Initial results from a grassland site in California suggest that microbes living in the upper 50 cm of soil assimilate C that cycles on decadal to centennial timescales (fraction modern ^{14}C > 1). Below 50 cm, the ^{14}C of phospholipids is slightly depleted, suggesting a multi-centennial turnover time. This result contrasts with the ^{14}C values of bulk soil and total lipids below 50 cm, which suggest slower multimillennial turnover times (Grant et al., 2024). The depth profile of phospholipid ^{14}C values is similar to ^{14}C of water extractable carbon and respired CO_2 captured during laboratory incubations (Finstad et al., 2024; Grant et al., 2024). These combined results suggest that microbial communities preferentially assimilate young carbon in deep soils, while a larger, older carbon pool remains relatively inaccessible. In a next step, we plan to measure ^{14}C of specific phospholipid fatty acids (PLFAs) using high performance liquid chromatography (HPLC) and fraction collection to assess the age of C used by specific microbial groups.

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FLOOD: FRAMING THE LATE-PLEISTOCENE CHRONOLOGY OF ENVIRONMENTAL AND CULTURAL CHANGE IN DOGGERLAND.

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Abstract

During the last Ice Age, sea-levels were much lower than today. The landmass between the British Isles and the European mainland, known as Doggerland, was part of the Eurasian Mammoth Steppe, a continuous biome of grasslands and plains. It was a productive and fertile environment with rich resources and an attractive habitat for humans. With the warming temperatures of the early Holocene, the ice sheets melted, and rising sea-levels submerged Doggerland. Remains of this extinct world are often found on the beaches of the North Sea, and in the nets of fishermen. These finds generate great interest, both in society and in academia, and are being studied across various disciplines. Robust chronological frameworks are crucial for understanding cultural and environmental changes, especially when the stratigraphic context of finds is uncertain. Radiocarbon analysis of several bones from the North Sea has yielded unexpected results, with anomalously young dates for extinct megafauna, and marine mammals dating to periods when the North Sea was considered dry. It has been suggested that these dates are affected by contamination, but this was never formally investigated (Hijma et al. 2012; Rijsdijk et al. 2013; Busschers et al. 2014). FLOOD will directly address this issue using cutting-edge advances in radiocarbon dating, including compound-specific radiocarbon analysis of the amino acid 'hydroxyproline' in a collaboration between the Centre for Isotope Research at the University of Groningen, and the Oxford Radiocarbon Accelerator Unit of the University of Oxford. FLOOD will (re)date a selection of high-profile samples, with the aim to test the validity of previous dates, assess contamination, and to better understand Doggerland chronology. Results will have widespread implications for the study of sea-level fluctuations, climate change, archaeology, (marine) paleoecology and, importantly, for the field of radiocarbon dating.

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ADVANCING CHRONOLOGICAL RECONSTRUCTION OF MEDIEVAL CASTLES IN ITALY: A MULTIDISCIPLINARY APPROACH TO MORTAR DATING IN THE PRIN 2020 CASTLES PROJECT

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Abstract

The evolution of medieval castles, particularly within the Italian peninsula, represents a key area of investigation for European historical research. Specifically, the sequence of transformations from predominantly wooden fortifications to durable stone structures during the 11th and 12th centuries remains a subject of considerable complexity. Often hindered by imprecise documentation and broad dating of archaeological materials, understanding this transition requires a refined methodological approach. To bridge this research gap, the PRIN 2020 CASTLES Project (https://castles.unisi.it/) integrates a broad spectrum of disciplines, including archaeology, history, geology, conservation science, and physics, with a collaborative approach involving the University of Turin, the University of Florence, the University of Siena, and the University of Campania 'Luigi Vanvitelli'. Our multidisciplinary team selected key sites across Piedmont, Liguria, and Tuscany for archaeometric analysis and radiocarbon dating of mortar and charcoal samples, aiming to establish a refined chronology for the "*incastellamento*" phenomenon in northern Italy.

A multi-stage analytical process, encompassing minero-petrographic, chemical, and physical analyses (XRPD, PLM, phenolphthalein and penetrometric tests, SEM-EDS, OM-CL, ATR-FTIR), was employed to identify mortar samples suitable for radiocarbon dating. After characterization, selected samples then underwent CRYO2SONIC preparation at the iCONa lab (University of Campania "Luigi Vanvitelli") and AMS measurement at the CIRCE laboratory (Caserta, Italy). The sample preparation procedure currently in use at the CIRCE lab for ^{14}C measurements by AMS is described in Marzaioli et al. (2008).

To promote a reproducible methodological approach to radiocarbon dating of mortars, we analysed 120 samples from the study area, producing 840 material characterizations. This extensive dataset enabled us to pinpoint mortars best suited for radiocarbon dating, and the reliability of the obtained dates was confirmed through correlation with charcoal radiocarbon measurements. To illustrate our approach's outcomes, we present two case studies from the Tuscan castles of Montecchio Vesponi

(Arezzo) and Rocchette Pannocchieschi (Grosseto). These examples showcase a strong coherence between mortar mineralogical characterization and the resulting radiocarbon dating. This consistency validates the effectiveness of our methodology and underscores the importance of material analysis in establishing reliable chronologies.

Future goal of the CASTLES project is the realization of an interpretative statistical model, based on advanced algorithms of data analysis and processing, useful for narrowing the chronological dating range obtained from the 12th century radiocarbon calibration curve, thanks to the cross-referencing of the different multidisciplinary 'chronological calibrations' inferred from historical, archaeological and archaeometric data.

In conclusion, the PRIN 2020 CASTLES Project contributes to the advancement of mortar dating, providing a reproducible approach that significantly enhances our ability to reconstruct the chronological evolution of medieval castles in Italy and offers a valuable framework for broader application.

Acknowledgments
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IN PURSUIT OF CHRONOMETRIC DATE: PETROGRAPHIC CHARACTERISATION OF MORTAR FROM THE EARLIEST PHASE IN BENEDICTINE ABBEY HRONSKÝ BEŇADIK, SLOVAKIA

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Abstract

Aim of our research is chronometric dating of the earliest phase of stone masonry of Benedictine Abbey in Hronský Beňadik (district Žarnovica), one of the oldest extant monasteries in Slovakia, for which a written record *gives terminus a quo* 1075 AD.

On the second above-ground level in northeastern corner of the monastery complex a fragment of Romanesque stone masonry of crudely shaped blocks was identified. The masonry has two original small niches and the simple finish of interior wall surface with mortar smeared around the joints of the blockwork. This technique, so-called *pietra rasa*, was used in the wider European environment from antiquity until the 19th century and often occurs on pre-Romanesque and early Romanesque architecture. The masonry seems to have been protected by a roof for most of its time. The colour of mortar together with unburnt oak lintels of the niches testify that the masonry was not damaged by fire.

From the vicinity of the niches, we have sampled four types of materials of varying time relations to the construction. The *terminus post quem* for the wall construction give (1) two lintels of oakwood without sapwood and (2) small fragments of wood embedded in the mortar. The *terminus a quo* represents (3) anthropogenic calcite in the mortar close to and on the wall surface, and (4) fragile, small fragments of vegetative parts of grasses and herbs extracted from the mortar.

Here we bring the petrographic characterisation of the mortar that is crucial for interpretation of to-be-presented radiocarbon dates (Michalska 2019). To characterise the binder and aggregate we have used binocular microscopy, petrographic microscopy, and SEM-EDS on both bulk mortar and thin sections. The binder is heterogeneous with underburnt and overburnt dolomite or dolomitic calcite. Few small lime-lumps were observed in bulk mortar, one without recrystallization is also presented on the thin-section photomicrographs from binocular and petrographic microscopy. The aggregate consists of feldspar and quartz likely from the river Hron valley sands, and crushed pottery.

As for preparation of ^{14}C samples, the mortar was gently disintegrated and then automatically dry-sieved. The fractions less than 48, 48–63, 63–80, 80–100, and over 100 microns were obtained. We will present the radiocarbon dating result of sequential dissolution (Hajdas et al., 2020) and suspension measured in Zürich and Poznań radiocarbon laboratories, respectively. The earliest possible felling date given by the two oak lintels will be used as the *terminus post quem* reference when assessing the accuracy of the mortar radiocarbon dates.

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RADIOCARBON DATING OF ARCHAEOLOGICAL FINDS OF CATS IN SLOVAKIA

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Abstract

We present first results of the project focused on radiocarbon dating of archaeological finds of cats (*Felis* sp.) in Slovakia. The aim of the project is to acquire direct ^{14}C dates of this wild/synanthropic/domestic species and compare them with chronological classification of their archaeological contexts inferred from stratigraphy and typo-chronology of associated artefacts.

In the archaeofaunal assemblages from Slovakia we have morphoscopically determined bones of 23 cat individuals. The cat bones come from contexts classified as Eneolithic (4), Bronze Age (3), Roman Period (3), Early Middle Ages 8th–10th cent. (5), High–Late Middle Ages 14th–15th cent. (5), and Modern Era 16th–18th cent. (1). One cave find was labelled as of Holocene age and one find has remained archaeologically unclassified. Apart from one early mediaeval burial (late 7th–8th cent.), all come from the settlement contexts.

Pretreatment and radiocarbon analysis were performed in the Czech Radiocarbon Laboratory (CRL). Bones were mechanically cleaned and chemically pretreated with modified Longin method (Longin 1971, Gupta and Polach 1985, Law and Hedges 1989, Jull et al. 2006, Brock et al. 2010). The isolated collagen was gelatinised (75 °C) and filtered through glass-fibre filter. Ultrafiltration (above 30 kDa) was used. Dried samples were burnt (CuO, 900 °C) and graphitised according to a procedure derived from existing protocols (Rinyu et al. 2015, Orsovszki and Rinyu 2015). The measurement of ^{14}C activity was done by AMS on the MILEA instrument (Kučera et al. 2022). IRMS analyses of $d^{13}C$ and $d^{15}N$ are currently being performed on Thermo Delta V with elemental analyser Flash IRMS in the CRL.

By now, seven samples from the contexts of the Bronze Age, Roman Period, and Early Middle Ages were processed. The earliest comes from the fortified Bronze Age tell-like settlement in Nitriansky Hrádok-Zámeček. The radiocarbon dates it to the 10th century calBC, what is in accord with the known habitation history of the site. As for two samples from the Roman Period contexts at rural settlements, both can be said to be broadly in line with archaeological classification of their find context (Štúrovo-Vojenské cvičisko: 3rd–4th cent. calAD; Veľký Meder-Vámostelek: 1st–2nd cent. calAD). A result from the only burial context, an Avar Khaganate burial in Obid-Fenyés árok (late 7th–8th cent. calAD) showed that the cat bones predate the human bone collagen of the deceased. Two samples artefactually classified as of 9th–10th centuries turned out to be broadly in accord with archaeological expectations being dated to the 8th–9th cent. calAD.

Alongside with the measured radiocarbon ages of the cat bones and dietary offsets, issues of small ecofacts migration in archaeological sediments will be discussed.

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OLD RESIN EFFECT IN RADIOCARBON DATING OF TAR AND PITCH

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Abstract

Pine and birch pitch or tar have been indispensable wood craft material since prehistory (Schmidt et al., 2023; Hennius, 2018; Kozowyk et al., 2017). The material was used as an adhesive for lithic and ceramic tools, sealant and protection of wood or pottery, for medical purposes or lubricant production (Regert et al., 2006; Woitsch, 2012) and the resin, tar and pitch residues have been detected in different types of artefacts, from surface residues to those absorbed in a porous wall of pottery vessels (Reber, Hart, 2008; Regert et al., 2006)

In the literature, the term pitch or tar is used rather interchangeably although tar refers to the liquid fraction and pitch is a more viscous product. Pitch and tar also differ in a production method and their chemical composition. Birch and pine tars are products of dry distillation of birch bark or pine wood. The tar fraction is formed at temperatures above 300°C. Pine tar contains mainly diterpenes and their thermal degradation markers, birch tar is rich mainly in triterpenes and their degradation markers (Rageot et al., 2019; Kozowyk et al., 2017).

The knowledge about the production of tars in Medieval Bohemia is of historical importance. Therefore, more than 60 samples of technical pottery fragments with a visible remnant of blackish residues from 13 Czech medieval tar production sites (13^{th}-15^{th} century AD) were extracted for absorbed organic compounds revealing high amount of birch or pine tar residues. As an accurate radiocarbon dating of tar kilns would be crucial not only for understanding economic history but also for historical anthropology and environmental history, a total of 8 purified extracts of the pine and birch residues were also radiocarbon dated resulting in radiocarbon ages falling well before the expected tar production in the studied sites, mainly to 10^{th} to 12^{th} century cal. AD.

One of the problems of the older dates obtained are probably properties of resin. Tree resin may not be formed annually as tree rings, but pines, spruces and other conifers form resin constantly in small amounts because it is part of their defence system. Resin is stored in so-called resin ducts (specialized cells in the wood, bark and needles). In radiocarbon dating of tar or pitch, the creation of original resin is dated, not the production event of tar or pitch. Moreover, during Medieval times the production of tar was already well-established technology with a massive production from large quantities of resinous wood, incorporating thus something we can call *old resin effect* similarly to *old wood effect* into resulting tar fraction. These effects would probably play different role in the case of pine wood or birch bark tars, and whether the material is tar or pitch. Therefore, we propose all these possible inputs should be considered and clarified when dating these wood craft materials, commonly encountered in various archaeological sites.

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COMMON FINDING, UNCOMMON SAMPLE: LESSONS LEARNED FROM RADIOCARBON DATING OF ARCHAEOLOGICAL POTTERY FORM THE CARPATHIAN BASIN

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Abstract

The aim of the present study was to investigate the reliability of radiocarbon dating of pottery samples from the Carpathian Basin. Seven samples of known archaeological age (1 Neolithic, 6 Bronze Age) and subphase (Körös/Criş and Hajdúbagos/Cehăluţ cultures) were selected from 3 sampling sites. Their ages were also confirmed by radiocarbon dating of associated bone samples from the same object. Based on the literature and previous experiments, the acid-base-acid (ABA) chemical pre-treatment was used to remove exogenous contaminants from the pulverised samples. To test the internal repeatability of the applied method, each sample was divided into 3 subsamples which were treated in parallel and combusted in 2-steps: at 400 °C (low temperature fraction: LT) and 800 °C (high temperature fraction: HT).

A total of 42 radiocarbon dates were obtained from the 7 pottery samples and these were compared with the radiocarbon dated associated bone samples (7) from the same archaeological units. As expected, following the literature, all HT carbon fractions of the pottery samples are older than the LT fraction radiocarbon ages. All the 3 parallel ^{14}C age results of the Neolithic pottery LT fractions are in good agreement with the expected period and its subphase. The agreement with the Bronze Age is about 50% in the case of LT fraction ages. They were even less consistent with the Hajdúbagos/Cehăluţ subphase, with an agreement of merely 28%.

When the measured LT fractions of the Bronze Age samples appeared to be younger, they may have remained somewhat contaminated with carbon from younger (soil) sources even after the applied ABA cleaning steps. Better results are probably obtained with stronger pre-treatment. The excellent correlation in the case of the Neolithic sample investigated, might be due to the organic temper of the clay, encourages further research within this archaeological period in a similar environment.

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IDENTIFICATION AND ^{14}C DATING OF PLANT TEMPER MATERIALS PRESERVED IN CERAMICS FROM THE NEOLITHIC PERIOD TO EARLY MIDDLE AGES IN NORTHWESTERN EUROPE (ORG-ID PROJECT)

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Abstract

Age determination of archaeological sites using ^{14}C dating can be challenging, due to poor preservation of organic remains, uncertain associations between organic remains and human activities or other issues such as the old wood effect and reservoir effect. Pottery is a durable and common artifact directly associated with human activities. From the Neolithic period to Early Middle Ages in NW Europe, plant material was frequently added as temper to pottery clays. Charred remains of these plant additives are often preserved within the pottery up to this day and provide a valuable, yet understudied, resource for AMS ^{14}C dating.

For this study, pottery with plant temper was sampled from 45 archaeological sites in Belgium, northern France and The Netherlands, dating to the Neolithic period, Iron Age, Roman period and Early Middle Ages. The first objective is to identify which plant species were used as temper during these different periods. For this purpose, the plant materials preserved inside the pottery are analysed using thin sections, X-ray µCT and SEM, in combination with microscopic analysis of the extracted plant remains. The second objective is to develop a protocol for the extraction and chemical pre-treatment of plant temper for AMS ^{14}C dating by testing various methods. Finally, the reliability of the obtained plant temper dates is evaluated by comparing them to other chronological data from the same sites.

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ZOOARCHAEOLOGY IN THE CARIBBEAN ISLANDS: CHRONOLOGICAL MODELING AND RODENT DISPERSALS AS PROXIES FOR HUMAN COLONIZATION

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Abstract

Over the past decades, researchers have devoted considerable effort to deciphering the routes and timing of human colonization in the Caribbean (Fitzpatrick 2006, 2015; Fitzpatrick et al. 2010; Giovas & Fitzpatrick 2014; Keegan & Hoffman 2017; Napolitano et al., 2019). However, much of this work has relied predominantly on ceramic typologies and mostly vegetal radiocarbon dates, often excluding animal remains from chronological modeling. In this study, we propose an innovative zooarchaeological approach that integrates radiocarbon dates from faunal remains—potentially domesticated or used as food sources—into Bayesian chronological models for several islands in the Lesser Antilles, including St. Martin, Antigua, Barbuda, Guadeloupe, and Martinique. Our focus is on rodents such as rice rats (Oryzomyini) and agoutis (Dasyprocta sp.), whose presence in archaeological contexts dated from ca. 500 BCE provides critical insights into human-animal interactions, potential translocations, and subsistence strategies. We propose island-specific chronologies using OxCal, drawing on both published radiocarbon datasets and new AMS ^{14}C dates from faunal and associated archaeological material. This framework will support a refined understanding of the temporal dynamics of Saladoid and Troumassoid cultural phases and their correlation with faunal introductions. In addition, we present preliminary marine reservoir correction (ΔR = -262 +- 140)^{14}C y obtained from paired marine and terrestrial samples from Barbuda. Based on the results for the different islands, we will address the spatial and temporal variability of ΔR in the Caribbean, as highlighted by recent studies (DiNapoli et al. 2021), and help correcting potential biases in calibrating marine-based radiocarbon dates. Together, this multidisciplinary approach strengthens chronological control and expands the scope of colonization models by including underutilized biological evidence, while also contributing to ongoing debates on migration pathways.

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DEVELOPMENT OF AGROPASTORALISM IN SOUTHWEST ASIA. CROSS-DATING OF ARCHAEOLOGICAL CERAMICS BY RADIOCARBON AND ARCHAEOMAGNETIC DATING

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Abstract

Key words: ceramic, compound-specific radiocarbon analyses, archaeomagnetic dating, chronological modelling, south-west Asia

The ERC-StG AGROCHRONO project studies the development of agropastoralism in the Indo-Iranian borderlands. The objectives are to specify the chronological, cultural, economic and environmental framework in which the first agropastoral populations in the region developed from the 7th millennium BC onwards.

Chronological data for the Neolithic and Chalcolithic periods are severely lacking in south-eastern Iran and Pakistan. An absolute dating programme is needed to clarify the chronologies of the region and the temporal relationships between the settlements dating to these periods. However, the classic types of remains usually used for ^{14}C dating are often rare or poorly preserved in this region. This is the case, for example with bone collagen, which is poorly preserved in arid environments. Archaeological ceramics provide a source of both relative and absolute dating that needs to be exploited. Ceramics provide absolute chronological information through their magnetic properties, which record the intensity of the earth's magnetic field during firing. Recently, major advances have also been made in the ^{14}C dating of archaeological ceramics, using a molecular approach to date the lipid remains from the use of the ceramics.

We therefore propose for the first time to combine two absolute methods on the same materials (ceramic vessels). These absolute measurements on ceramics and other ^{14}C dates on conventional materials will be calibrated and modelled to resolve the chronology of the region of interest.

NEW ^{14}C DATES FROM LA PLANCHE À PUARE, FRANCE: A BAYESIAN MODEL OF THE BELL BEAKER ATLANTIC NETWORK.

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Abstract

Despite the widespread influence of the Bell Beaker culture (BB) in France during the 3rd millennium BC, robust high-definition chronologies and ^{14}C dates remain scarce. This is especially the case for the Atlantic coast regions, where there are nearly no radiocarbon dates available gained from human bones. In this study, newly obtained ^{14}C dates from a secondary Beaker occupation of the megalithic passage grave La Planche à Puare on the Atlantic island L'Île d'Yeu are used together with legacy data to investigate the BB phenomenon along the French Atlantic coast.

In 2022, a new excavation at La Planche à Puare was conducted as part of the NEOSEA ERC StG project (Guyodo & Schulz Paulsson 2022), The excavation yielded few datable materials resulting in 15 new ^{14}C dates obtained from human bone and unspecific organic material ranging from the Late Neolithic to the Bell Beaker period (2460-1970 cal BC, 95.4%). This assumption is supported by Bell Beaker material uncovered by previous excavations such as a rare smoothed black beaker (Auger 1884; Baudouin 1915; Favrel 2022; Gadbois-Langevin 2013; Lemercier 2018; Rousseau 2015). These vessel are generally attributed to an intermediate Bell Beaker period, dating between 2350-2150 BCE (Favrel 2022).

These new radiocarbon dates are presented together with a compiled dataset of forty-five previously published ^{14}C dates from twenty-four sites including megalithic graves, settlements, and open-air sites). By applying chronological modeling together with a Bayesian statistical framework and a multiproxy isotopic analysis (C-13, N-15, sulphur) we want to contribute to a more robust chronology for understanding the arrival and spread of the Bell Beaker phenomenon along the Atlantic coast and its associated maritime network.

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IMPROVING THE DATING OF IRON SMELTING SITES IN WEST AFRICA BY COUPLING RADIOCARBON AND ARCHEOMAGNETISM: THE CASE OF THE APLAHOUÉ METALLURGICAL COMPLEX (MONO-COUFFO REGION, BENIN)

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Abstract

Despite numerous archaeological studies in the last decades, the development of ancient iron metallurgy in West Africa still suffers from chronological imprecisions, making it difficult to recognize its emergence during the first millennium BCE and its decline between the 15th and 20th century. This issue encompasses several problems. Although a large number of sites were investigated, very few were dated (11% of the sites), and most have only 1 or 2 dates. Moreover, radiocarbon dating, which was exclusively used in this area, has very low resolution in these periods due to plateau effects of the calibration curve.

To overcome this limitation, archeomagnetism represents a complementary method to radiocarbon for dating metallurgical sites containing fired clay remains, such as the walls of smelting furnaces. by combining these dating methods, archeomagnetism is expected to bring better precision for periods of high radiocarbon content disturbances while radiocarbon could offer chronological milestones to develop the West African archeomagnetic reference curve over older times.

This innovative methodology was deployed in the Mono-Couffo region (South Benin), renowned for its significant iron production in the last millennium. Previous surveys and excavations started in 2021 revealed a vast metallurgical complex in the Aplahoué locality, where iron ore extraction pits, slag heaps, smelting furnaces and domestic occupations were identified in four archaeological sites: Dolomey, Kpeta 1, Kpeta 2 and Domy.

A total of 60 radiometric dates were produced from charcoals collected in the different levels, charcoals extracted from iron slags and one bone. Charcoals were subjected to anthracological identification to select twigs when possible and avoid "old wood effect". Archeomagnetic dating was applied to furnace walls, tuyeres, and ceramics.

In Dolomey and Kpeta 1, where no smelting furnaces were discovered, fieldwork focused on slag heaps. A stratigraphic sampling of charcoals for radiocarbon and clay artefacts for archeomagnetism (tuyeres and fragments of furnace walls with 4-5 samples per stratigraphic layer) was conducted to elucidate the duration of the slag heap formation.

In Domy where two smelting furnaces were discovered, ^{14}C dates on charcoals collected in both structures seem to show that their activities were not contemporaneous. These results are supported by the archaeomagnetic measurements obtained on the furnaces walls.

The Kpeta 2 mound, identified as a domestic place, was radiocarbon dated using charcoals and human bones. The spatial proximity and synchronicity of radiocarbon dates of Kpeta 2 with nearby metallurgical sites such as Kpeta 1 and Domy suggest that this settlement could have been occupied by ancient blacksmiths.

This communication will present the context of this metallurgical complex and detail the sampling strategy adopted for both dating methods, radiocarbon and archeomagnetism. It will discuss the results obtained and the chronological hypotheses they suggest for the activity of this metallurgical district.

Acknowledgments

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RE-OPENING THE JAR WITH FROZEN TISSUE OF "ÖTZI" THE ICE MAN

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Abstract

More than 3 decades ago remains of a frozen and mummified body were discovered on the Hauslabjoch in the Ötztaler Alps (near the Similaun Mountain), South Tyrol, Italy in September 1991. The first step in the investigation of this Ice Man was to find out how old it was. Acceleration mass spectrometry (AMS) was used for age determination because the smallest amount of the sample had to be used for dating. A fragment of tissue and the bone were submitted to the laboratory at ETH Zurich. In addition, a small piece of grass was found in the Ice Man's tissue and analyzed. The mean value of all the all the measurements was 4550 ± 27 BP (Bonani et al. 1994).

The samples from the Ötztal were kept in a glass jar since November 1991. In the first decade of the 21st century, school programs included special days for primary school kids. During the visits, the kids were able to look at the tissue using the binocular microscope. Inspired by these projects, new analysis on the remaining material that had been stored frozen for 25 years were completed. First, the sample was controlled for contaminants by examination under the binocular microscope. In 1991 such observation allowed determination and separation of pieces of grass mixed into the skin and muscle tissue (Bonani et al., 1994). Tissue samples are fragile and can easily dissolve in the base washes. Therefore, the normal acid-base-acid (ABA) treatment was monitored to avoid loss of the sample (Hajdas et al., 2024). The agreement with the first analysis shows that frozen organic matter can be dated even after decades.

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AGE OF THE VALLEY ARCHAEOLOGICAL STRUCTURE IN BIEBRZA AND NAREW VALLEY (NE POLAND) BASED ON RADIOCARBON DATA

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Abstract

Laser scanning (LIDAR) studies in northeastern Poland have revealed a network of 27 Prehistoric earthworks located in the valleys of the Biebrza, Narew and their tributaries. They are invisible in the modern relief of valley floor or bottom of glacial depression. Each structure is circular in shape, with a central, flat square surrounded by one to three rings of ramparts and moats. Their function is unknown.

One of the research aims was to synthesize previous datings and create a chronology of objects and settlement networks. Out of 27 objects, five (19%) were subjected to dating: 19 radiocarbon analyses (^{14}C) and one optical luminescence (OSL) measurement. One of the dated objects has two concentric lines of ramparts (Jatwież Duża), the other four – three rings. An abstract should be self-contained and understandable without needing to refer to the full text. It must be accurate, concise, and objective, avoiding any new information or claims not present in the main body of the work. Given that the length of an abstract is usually limited to a specific word count, careful attention to brevity and clarity is essential.

The Jatwież Duża feature provided three ^{14}C dates – from the fill of the storage pit, the rampart facing and the inner moat – which indicate construction before 1018/922–839/817 cal. BC and abandonment before 756/413 cal. BC. The OSL date from fluvioglacial sediments from beneath the moat (2.93±0.44 ka) fits into this chronology.

At Horodnianka a set of six ^{14}C dates illustrates a phase of activity from about 1000/800 to 850/720 cal. BC, with stratigraphic differences and a plateau of the radiocarbon curve making it impossible to narrow down the dating. Kościuki (594/570–407/358 cal. BC), Jednaczewo (594–401 cal. BC) and Podosie (753–410 cal. BC) are three-ring features with dates spanning the Late Hallstatt and Early Iron Age. The extended period of Podosie's activity may be the effect of a radiocarbon plateau in 750–420 cal. BC.

Archaeological materials from Jatwież Duża, Kościuki and Horodnianka indicate a high degree of cultural homogeneity. Pottery from all sites represents the Lusatian culture, locally associated with the Surash subgroup, which is part of the Mazovian-Podlasie group. These communities functioned from the Late Bronze Age (BR IV) to the Hallstatt period (HaD/HaC), which corresponds to the time of construction of the analysed structures. These structures were created simultaneously with Biskupin-type settlements, known mainly from Pałuki and individual sites in Germany and Czech Republic. These were regularly planned, fortified settlements of a "proto-urban" nature, built in response to military threats or climatic changes. However, the influence of nomadic people did not reach the north-eastern areas of Poland directly, therefore the construction of the structures there resulted from internal processes of the Surash subgroup.

Analysis of radiocarbon dates and pottery from Jatwież Duża and Horodnianka sites indicates that the two-ringed object at Jatwież Duża is older (before 1018/922–839/817 cal. BC), while the three-ringed one at Horodnianka functioned in the years 1000/800–850/720 cal. BC. Subsequent, younger three-

ringed structures were created in the Narew River valley (Podosie, Janczewo, Kościuki). It can be hypothesized that the single-ringed objects may be even earlier, which assumes of evolution from simpler to more complex forms. Alternatively, the multi-ringed forms may have been the original ones, and the single-ringed ones may have been their simpler inspiration. The distribution of dates and geographical distribution (older objects in the north, younger in the south) may indicate the spread of the idea of construction and the complexity of the structures over a period of over 300 years. It is possible that the studied objects did not form a single, simultaneously functioning network, but several independent systems created in different periods, but within the same cultural tradition. The final decision and confirmation of any of the hypotheses requires further research and dating of the remaining sites.

AMS RADIOCARBON DATES FROM THE MUYU MUYU SITE (AREQUIPA DEPARTMENT, PERU)

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Abstract

Muyu Muyu is an archaeological site located in southern Peru (Condesuyos province, Arequipa dep.) most likely associated with the cult of the nearby Solimana volcanic peak during the Inca period. The site includes the main complex consisting of two large platforms divided by a plaza and covered with stone structures, as well as scattered collective burials in shallow rock shelters located on the mountainside immediately east of the complex. As part of the excavations carried out at Muyu Muyu in 2022 and 2023, samples from both the main part of the site (charcoal) and from the burials (human teeth) were collected and subjected to radiocarbon dating. The main purpose of the analysis is to provide data necessary to verify the hypothesis of the site's pre-Inca origin and to determine for the first time the chronology of Muyu Muyu. An abstract is a concise summary of a larger work, such as a research paper, thesis, review, or conference presentation. It provides a brief overview of the work's key elements, enabling readers to quickly grasp its essence.

ABSOLUTE CHRONOLOGY OF THE PILE-DWELLING CONSTRUCTIONS AT SERTEYA II SITE (WESTERN RUSSIA) AND PALAEOECOLOGICAL CONTEXT

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Results of archaeological research at the Serteya II site revealed the use of the area by hunter-fisher-gatherer communities from the Mesolithic, through the Early Neolithic until the Mid- and Late Neolithic. Numerous remains of wooden structures and artefacts were found at this site, allowing establishing an accurate absolute chronology. The wooden objects dated to the end of the 6th - 5th millennia BC are attributed to the Early Neolithic. The remains of the Late Neolithic pile-dwellings deposited within lacustrine sediments are of particular interest due to a good preservation and rich sets of artefacts and ecofacts. The archaeological layer, at a depth from ca. 80 to ca 150 cm b.s.l. within coarse detritus gyttja, was excavated using underwater and wetland archaeological methods. Until now, three pile-dwellings were identified that had been rebuilt and reconstructed many times, with well-preserved floor remains made from large wooden bark placed on poles and wooden planks, as well as fireplaces with sand bases, were discovered. The accompanying artefacts were attributed to the Zhizhitsa Culture (ca. 2500–2200 BC). The archaeological layers are also rich in ecofacts, e.g.: faunal remains, different types of consumed plants. Due to the particularly good preservation conditions, many organic artefacts made of bone and antler as well as objects of plant material could also be recovered, e.g. wicker baskets, nets, fish traps, and lime-bast textiles.

Dendrological analyses of 94 samples showed that they came from young trees. The majority of them were less than 50 years old. Twenty-one specimens were qualified for dendrochronological analyses: 5 larches, 4 pines, 3 elms, 7 oaks, and one hornbeam and beech each. Local chronologies were developed based on the correlated dendrochronological sequences of the samples: larch S_Larix – 54 years, pine S_Pinus_0 – 53 years, and oak and elm S_Q&U – 112 years. They were absolutely dated using the wiggle matching procedure. Radiocarbon dating showed that the pile dwelling was at its heyday between 2470 and 2200 BC.

The archaeological investigations were complemented by multiproxy palaeoecological research with high resolution analyses undertaken on-site and off-site. The study includes palaeobotanical (palynological, plant macrofossil, anthracological), palaeozoological (Chironomidae, Cladocera, molluscs, fishes), Bacillariphyta (diatom), geochemical and sedimentological analyses. AMS radiocarbon dating of selected terrestrial plant macrofossils and pollen concentration allow for an elaboration of an accurate depth/age model of organic deposits' sedimentation. Palaeoecological analyses' results allowed for a precise reconstruction of the local and regional vegetation changes, a quantitative reconstruction of palaeohydrological and palaeoclimate changes, a qualitative and quantitative reconstruction of human-environment relationships.

The archaeological and palaeoenvironmental contexts suggest that pile dwelling constructions functioned in a palaeolake shore zone with seasonal(?) water table fluctuations. The disappearance (or at least a decrease in the importance) of the pile-dwelling settlement coincided with the 4.2 ka BP

cooling event, resulted in an increase of palaeolake water table.

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MORTAR PETROGRAPHY AS A TOOL FOR ASSESSING CHALLENGES IN DETERMINING THE TRUE AGE OF THEIR PRODUCTION: IMPLICATIONS OF DEAD CARBON AND RECRYSTALLIZATION

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Abstract

The composition of mortars is crucial when it comes to the possibility of dating the age of a given structure. Usually, the composition of mortars is related to the local geological structure, as well as the chosen preparation technique and the purpose of the mortar itself. Knowledge of the local geological structure and its comparison with the petrographic composition of mortars greatly facilitates the interpretation of components carrying the so-called "dead carbon" (Caroselli at al., 2023; Hayen et al., 2016; Michalska et al., 2017; Nawrocka et al., 2005). Mortar composition is also often used to determine relative chronology if we have a long-standing history of a structure at a given site. The mortars components, especially carbonates, including magnesium and those that impart hydraulic properties to mortars, are of great importance in the preparation and dating of mortars. This article will show the different compositions of mortars and indicate their influence on the result of ^{14}C measurement (aging or rejuvenating age).

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AN UPDATED CHRONOLOGY FOR THE MIDDLE TO LATER STONE AGE SEQUENCE AT TAFORALT, MOROCCO

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Abstract

We present an updated chronology for the stratigraphic sequence in Sector 2 at the cave site of Grotte des Pigeons, Taforalt, Morocco. Taforalt has provided one of the longest continuous records of Late Pleistocene sediments with human occupation in North West Africa. Multiple dating strategies have been used at the site, including radiocarbon, luminescence, U-Series, bio-stratigraphic correlation, and tephrochronological methods (Barton et al. 2015). Here, we present an updated synthesis of these approaches, with a chronological focus on layers relating to the Middle Stone Age and overlying "intermediate" industry (Barton et al. 2016). The updated chronology is based on a new series of radiocarbon dates on charcoal and seeds from Sector 2 at Taforalt. Radiocarbon determinations are calibrated and further constrained by Bayesian modelling. Using the updated chronology and estimates for the emergence and duration of these Palaeolithic industries, we compare the timing of behavioural changes at Taforalt to other North African archaeological sequences, along with palaeoenvironmental reconstructions for this region and period. Finally, we consider the influence of palaeoenvironmental change on human populations during Marine Isotope Stage (MIS) 4, MIS 3, and the beginning of MIS 2.

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STRATIGRAPHY OF BIŚNIK CAVE: NEW DATA AND INTERPRETATIONS

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A new series of 26 radiocarbon (AMS) dates were obtained to the Biśnik Cave, one of the most important Central European sites. This new AMS dates contributed to a more precise stratigraphic model for the complex sequence of sediments in this site. Received results showed, that the layer 1a is younger than 15 kya, and layers 1b, 1 and 2 are dated on 25-15 kya. Layers 4-3 were dated on 40-35 kya, while layers 7-5 on 70-40 kya. Layer 7 is the first and the uppermost strata in the whole profile out of the radiocarbon method. The new re-examination of chronology and fauna shed new light on the history of Biśnik fauna.

CARBONATE-CLAY BINDER IN ^{14}C DATING

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Abstract

The composition of mortars is important in context of their radiocarbon dating and the accurate determination of construction periods in historical structures. A representative example is the mortar samples from Góra Przemysła Castle in Poznań, which exhibit a carbonate-clay binder, a heterogeneous aggregate composition, sporadic fragments of unburned limestone, and evidence of recrystallization processes. The presence of clay minerals in these mortars can be attributed to the local geological context. On the geoenvironmental conditions in the Old Town of Poznań, the outcrops of Poznań clays are in relatively close proximity and sometimes even directly by the Przemysł's Hill (Chmal 1990; Klęsk et al., 2023). This geological setting influenced the raw materials used in mortar production, thereby impacting their mineralogical and chemical properties. A measurement of percentage content of the calcium carbonate in all mortars showed a similar concentration of $CaCO_3$ for most mortars, giving an average of ~22%. It is significant that this measurement refers to the total concentration of carbonates, both in the binder and in the aggregate. The calcium carbonate content was measured using a simplified Scheibler method both for whole mortars and to their grain fractions. Measurements were also performed on different grain fractions, giving e.g. for the fractions of 45-80μ ca.71% of carbonates, The composition of the aggregate was dominated by quartz grains, feldspars, fragments of limestone, crushed ceramics and singular fragments of crystalline rocks occurred as well. Certain samples show recrystallisation of carbonates which in the case of radiocarbon dating of the samples could "rejuvenate" the results obtained from the measurement. For ^{14}C measurement different pretreatment was applied (Hajdas et. al., 2020; Michalska et al., 2017).

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ABSOLUTE DATING OF THE CASTLE AND HILLFORT AT THE KOZIEGŁOWY ARCHAEOLOGICAL SITE

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Introduction

The castle in Koziegłowy is an extremely valuable monument of military architecture both historically, archaeologically, and in terms of landscape value. Its uniqueness is emphasised by the fact that it was built in the centre of a ring of ramparts of an early medieval hillfort and surrounded by imposing ditches fed from the nearby river.

The purpose of archaeological excavations initiated during last years is to re-expose the oldest archaeological layers (located both in the area of the maypole and constituting the construction of the ramparts). These works will attempt to establish the time of the erection and expansion of the hillfort. At the same time, it is extremely important to determine the exact time of construction of the castle. This castle was built on the initiative of a famous knight, a close companion of Władysław Jagiełło – Krystyn of Koziegłowy. Nevertheless, individual elements of the castle were most probably erected in several stages. Therefore, the objective of the presented research is to define as precise as possible the age of the castle and hillfort from the Koziegłowy archaeological site.

Material and Methods

Several types of samples were collected within the site: 5 organic macro-remains, namely debris of seeds and megaspores, 13 animal bones, 7 fragments of wood – all these samples excavated from levels of archaeological layers located directly below the castle foundations, as well as 2 pieces of wood and 1 fragment of charcoal (divided into three subsamples) – taken from structural elements of the castle. All these samples underwent radiocarbon dating.

During chemical preparation, the standard acid-alkali-acid (ABA) procedure was applied using hydrochloric acid and sodium hydroxide reagents (Michczyńska et al., 2018). Macro-remain samples and subsamples of charcoalified wood have been purified in this way. Wooden samples, after ABA pre-treatment, were subjected to an additional bleaching process using acidified sodium chlorite solution to extract holocellulose fraction (Jędrzejowski et al., 2024). In the case of bone samples, gelatine was isolated using hydrochloric acid and sodium hydroxide solutions (Piotrowska and Goslar, 2002).

Samples were combusted in the VarioMicro elemental analyser (Elementar TM) coupled with AGE-3 graphitization system (Wacker et al., 2010). Radiocarbon concentration measurements were performed using MICADAS spectrometer (Synal et al., 2007). The obtained results were calibrated using OxCal v4 software (Bronk Ramsey, 2009) and IntCal20 calibration curve (Reimer et al., 2020). All measurements were conducted at the ^{14}C and Mass Spectrometry Laboratory of the Silesian University of Technology in Gliwice (Ustrzycka et al., 2025).

Results

Calibrated age ranges were estimated at 68.3% confidence level.

- The radiocarbon dating of most bone samples fell within the period 1262–1405 AD, with only three

samples dating slightly later, between 1426–1617 AD.
- The macro-remains samples were dated to 1300–1406 AD, except for one significantly older sample (133–310 AD), likely due to soil profile disturbances and material mixing from older layers.
- The seven wood samples from archaeological layers situated directly beneath the castle foundations were dated to 1283–1403 AD.
- The age of the wood from the castle construction elements was determined to be 1328–1424 AD for the charred beam and 1310–1425 AD for the two other wooden samples.

As archaeological excavations at the Koziegłowy site continue to yield new research material, the final dating results of individual objects will only be confirmed after the completion of all field and laboratory work. Nevertheless, the results obtained so far are promising and suggest that the stated research objectives—precisely determining the age of both the hillfort and the castle at the Koziegłowy archaeological site—are achievable.

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PROJECT "BALANCING THE CENTER AND THE LOCAL: MOBILIZATION AND PRODUCTION OF THE INKA AND COLONIAL STATE IN COCHABAMBA, BOLIVIA" - NEW RADIOCARBON DATES FROM COTAPACHI

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Abstract

This project investigates the sociopolitical, economic and demographic changes during the Late Intermediate Period (LIP), the Late or Inka Horizon and the early Colonial Period in the Cochabamba Valley. Changes in the three scenarios took place within less than 200 years' time, and for a comprehensive understanding of the relatively short Inka episode exact dating is crucial. This is a challenge for radiocarbon dating, as the standard deviation of calibrated dates can be higher than 200 years (Gabelmann et al. 2009).

Yet, according to available dates from Incarracay (1417–1435 AD, 1σ) and Kharalaus Pampa (1415–1458 AD, 1σ) it seems that Inka influence may have started earlier than ethno-historical data suggest (Gyarmati 2001:5,7; Gyarmati and Varga 1999:40). Our recent project yields radiocarbon dates from the Cotapachi site that may indicate that at least some of the *qollqas* (deposits, silos) may have been constructed around 1452-1496 AD (1σ) indicating thus an earlier Inka occupation than the generally assumed date of 1470 AD for the first Inka influence by Inka Tupac Yupanqui in the region.

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RESULTS OF ABSOLUTE DATING OF MEDIEVAL VILLAGE CHURCHES OF WESTERN POMERANIA – POSTER

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Abstract

State formation of Western Pomerania (currently north-western Poland) took place in the 11th and 12th centuries. Following two missions of Otto, the bishop of Bamberg, at the beginning of the 12th century Pomerania was converted to Christianity which meant its inclusion in European civilisation. The final stage of the process of Christianisation was the rebuilding of the duchy within the so called rural colonisation and urbanisation (c. 1230-1350), when a church was erected in almost every organised village and every town. A few hundred medieval rural churches, which have not been subject to any systematic studies aiming at their precise dating as yet, survived down to our times. It concerns first and foremost the oldest structures built using granite stones, which were generally dated to the period between the 13th and 14th centuries. They make up a concise complex of buildings located along the southern border of the former Duchy of Pomerania. Therefore, some questions arose whether the surviving historical substance allows more precise dating, and if yes, whether it will be possible to narrow down the period in which they were erected and indicate certain consistency and processes which would provide for complementing our knowledge to date.

In churches earmarked for research original elements made of wood such as roof truss, locking bars, gibs and window frames were found and samples were collected. Thanks to the use of absolute dating, dendrochronology and carbon-14 dating a precise and exact chronology of a number of structures was established. The results of dendrochronological analyses showed that the structures subject to study were erected in the second half of the 13th century, especially in the 1460s. This period was also determined by radiocarbon dating. Moreover, the analyses also allowed to determine the period of rebuilding/refurbishing of individual structures (e.g. after the Thirty Years' War) and further stages of intense church building in the 15th and at the beginning of the 16th centuries.

Thanks to comprehensive research carried out within the project connected to the 900th anniversary of Christianisation of Pomerania a range of dendrochronological and radiocarbon dates has been obtained which complemented our knowledge not only about the time these structures were erected, but also the time a number of settlements – about which there were no other source materials, either from excavations or documents – were established. Radiocarbon dating complemented research whenever wood samples which would allow the use of dendrochronology were available.

Research carried out considerably extended our knowledge about settlement processes and investments relevant to them such as the construction of churches towering over villages, which took place in Western Pomerania in the Middle Ages. They also allowed to observe individual investment waves, to which there was no premise that would provide for specific dating. Results which were obtained also allowed to observe processes which so far have been dated using relative methods only (change of styles or construction methods).

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RADIOCARBON DATING AND STRONTIUM ISOTOPE ANALYSIS OF CREMATED BONES FROM THE BINMAN-JI ISHOBOTOKE-DANI SITE IN TAGA, SHIGA PREFECTURE, JAPAN

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Abstract

Numerous cremated bones have been excavated from the Ishibotoke-dani archaeological site of Binman-ji Temple in Taga Town, Shiga Prefecture, Japan. These remains are believed to belong to monks affiliated with Binman-ji Temple. According to historical documents, the Ishibotoke-dani site was in use from the 12th to the 16th century, until it was destroyed by fire during the latter part of that period. Due to the limited availability of written documentation, geochemical analyses are essential for understanding the individuals buried at the site.

In this study, radiocarbon dating (^{14}C), strontium isotope analysis ($^{87}Sr/^{86}Sr$), and trace element analysis were performed on approximately 30 cremated remains excavated from Areas A, D, F, and G in the Ishibotoke-dani site, to investigate the age and dietary habits of the buried individuals.

Radiocarbon dating revealed chronological variation among the burial areas: Area A dated from the late 11th to 14th centuries; Area D, the late 13th century; Area F, the late 11th to 13th centuries; and Area G, the 14th century. Area A showed the widest range of ^{14}C dates, suggesting it was used over a longer period. The grave types in Area A also differ from those in other areas, indicating that this section may have been reserved for ancestral Buddhist monks or other influential individuals.

Overall, the findings suggest that the Ishibotoke-dani site was actively used from the 11th to 14th centuries. The variation in burial areas reflects different groups and generations, likely residents or affiliates of Binman-ji Temple, interred across distinct phases of the site's history.

The $^{87}Sr/^{86}Sr$ ratios of the cremated bones (0.70938–0.71079), when compared with geochemical samples from nearby rivers including stream sediment, soil, and stream water, closely matched the local soil at the Ishibotoke-dani site and the water of the Seri River, the closest river to the site. This geochemical alignment suggests that the individuals buried there primarily consumed crops grown in the surrounding region, indicating a strong affiliation with the local territory around Binman-ji Temple and the Seri River.

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POSIDONIA VERSUS SHELLS, MARINE RADIOCARBON RESERVOIR CORRECTIONS FOR THE MEDITERRANEAN SEA. GEOARCHAEOLOGICAL IMPLICATIONS.

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Abstract

A chronological problem at the site of Alexandria (Egypt) was the starting point of this work. After a core drilling campaign in coastal geoarchaeology, we dated the stratigraphic units using posidonia samples (underwater plants) which appeared younger than the results obtained on marine shells. The observed difference was about 320 years. For instance, the results for stratigraphic unit I-26 obtained on both a shell and a Posidonia were respectively 2320 ± 35 BP and 2040 ± 30 BP (26 to 352 cal AD and 384 to 656 cal AD using marine curve 20 [1]). If we use the continental curve [2] to calibrate the I-26 Posidonia, we obtained an age of 151 cal BC to 62 cal AD), slightly closer to the shell.

These results highlight a methodological problem already encountered on other coastal archaeological sites between Posidonia and shells.

The present study aims to compare radiocarbon ages of pre-bomb posidonia and shells in order to reassess their precision in terms of dating supports in coastal gearchaeological context. The dataset includes published and unpublished radiocarbon measurements of 41 posidonia materials and 54 marine shells, sampled along the Mediterranean coast from 14 countries. The marine shells come from reference collections and the Posidonia seagrass has been collected from the seagrass beds of several Natural History Museums in Europe. Mean ($\bar{x}$) and standard deviation (σ) values of the marine reservoir effect (delta R) were used to assess their chronological precision. The results clearly demonstrate a better dating precision for the posidonia samples than the shells. The posidonia have lower inter-specific variability comparing to shells and thus can be reliably used in chrono-stratigraphic studies. Moreover, each specific part of the posidonia (rhizome, leaf etc.) give almost the same radiocarbon values allowing a better inter-sites comparison for the Mediterranean scale.

Keywords: posidonia, shell, Mediterranean sea, marine reservoir age, palaeoenvironments, geoarchaeology, radiocarbon.

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AN UPDATED CHRONOLOGY FOR THE MIDDLE TO LATER STONE AGE SEQUENCE AT TAFORALT, MOROCCO

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Abstract

We present an updated chronology for the stratigraphic sequence in Sector 2 at the cave site of Grotte des Pigeons, Taforalt, Morocco. Taforalt has provided one of the longest continuous records of Late Pleistocene sediments with human occupation in North West Africa. Multiple dating strategies have been used at the site, including radiocarbon, luminescence, U-Series, bio-stratigraphic correlation, and tephrochronological methods (Barton et al. 2015). Here, we present an updated synthesis of these approaches, with a chronological focus on layers relating to the Middle Stone Age and overlying "intermediate" industry (Barton et al. 2016). The updated chronology is based on a new series of radiocarbon dates on charcoal and seeds from Sector 2 at Taforalt. Radiocarbon determinations are calibrated and further constrained by Bayesian modelling. Using the updated chronology and estimates for the emergence and duration of these Palaeolithic industries, we compare the timing of behavioural changes at Taforalt to other North African archaeological sequences, along with palaeoenvironmental reconstructions for this region and period. Finally, we consider the influence of palaeoenvironmental change on human populations during Marine Isotope Stage (MIS) 4, MIS 3, and the beginning of MIS 2.

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RADIOCARBON DATING OF ORGANIC RESIDUES FROM CERAMIC ARTIFACTS AT ARCHAEOLOGICAL SITES IN THE AMAZON BASIN

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Abstract

Ceramic artifacts represent one of the most significant archaeological materials and, in many instances, the only surviving evidence at excavation sites. In regions where charcoal, shell, or bone remains are absent or poorly preserved due to environmental conditions such as high soil acidity, as observed in much of Brazil. Radiocarbon dating of ceramic-associated residues becomes a crucial chronological tool. This study presents radiocarbon dating results of organic residues extracted from ceramic fragments recovered at circular archaeological sites within the Amazon Basin, specifically in the Purus River basin, tributarie on the right bank of the Solimoes River, in the state of Acre (Bellido & Latini, 2013; Latini et al., 2001). These ancient populations are characterized using cauxi (a freshwater sponge), cariape (tree bark), and charcoal as tempering agents in ceramic production (Costa et al., 2009). Charcoal residues embedded in the ceramic matrix were dated by Accelerator Mass Spectrometry (^{14}C-AMS) at the Radiocarbon Laboratory of Fluminense Federal University (LAC-UFF) (Oliveira et al., 2021). The obtained radiocarbon ages range from 488 ± 68 to 658 ± 49 years BP, aligning well with previous thermoluminescence dating of similar ceramic materials. In addition to corroborating existing chronologies, these results contribute new data for the temporal contextualization of understudied archaeological sites in the southwestern Amazon Basin.

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THE IRON AGE SETTLEMENT IN ZABORÓW (CENTRAL POLAND) IN THE LIGHT OF RADIOCARBON AND LUMINESCENCE DATING

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The settlement in Zaborów, Leszno community, was part of a vast barbaric centre of mass iron production, which operated in late antiquity. It was located in what is now western Masovia (Central Poland). The site was discovered in 1964 during fieldwalking conducted by Stefan Woyda. Since 2021, the site has been studied by a team of archaeologists associated with the Faculty of Archaeology of the University of Warsaw and the Stefan Woyda Museum of Ancient Masovian Metallurgy in Pruszków, as part of an interdisciplinary scientific project Terra Ferrea. Its goals include studies on the chronology and significance of the phenomenon of local iron metallurgy, which - in light of the current state of research - seem exceptionally enigmatic.

During the works, excavations were carried out on an area of ca. 275 square meters of the settlement and three hectares of its surface were examined using non-invasive methods (e.g. magnetic prospection). As a result, relics of intensive iron production and other industrial objects (lime kilns, clay pits, etc.) were discovered. The archaeological materials obtained (mainly ceramics) made it possible to distinguish two main horizons of the site's functioning: the older one (early pre-Roman period), associated with the population of the so-called Jastorf culture and the younger one (late pre-Roman period – beginning of late Roman period) – attributed to the Przeworsk culture. The relative chronology of the site was verified by a series of radiocarbon and luminescence datings, performed at the Institute of Physics, Silesian University of Technology. These activities were undertaken to the greatest extent for objects that could not be dated using archaeological methods, because they did not contain historical material (including relics of bloomery furnaces). An optically stimulated luminescence (OSL) dating was applied to selected samples from two excavation objects, including ceramic fragments, furnace remains, and sediment samples.

This study presents the development of the settlement in Zaborów based on radiocarbon and luminescence dating results.

Preliminary results of radiocarbon dating of seeds and charcoal coming from the remains of smelting furnaces and their surroundings have shed the new light on the origins of local metallurgy, dating back to the 4th – 2nd century BCE. They also constitute a valuable contribution to research on the issue of the emergence of large centralized metallurgical centers operating in the areas of the so-called "barbarian Europe" at the end of the ancient era in general. In the light of the results obtained, the roots of Masovian iron metallurgy should not be sought in the environment of the Przeworsk culture, as previously thought, but in the settlement horizon of the Jastorf culture, which preceded it by at least a century. This is of paramount importance for understanding the complex settlement processes that covered the lands of western Masovia in the last four centuries BCE.

CHRONOLOGY OF DOMINICAN MONASTERY IN SANDOMIERZ, POLAND

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Abstract

The Dominican Monastery in Sandomierz, founded around 1226 on the foundations of an earlier Romanesque church, is a rare example of early Dominican architecture in Poland and notable for its pioneering use of ceramic-framed brick wall construction. Despite its architectural significance, understanding the complex's chronological development has been hindered by historical disruptions, multiple reconstructions, and insufficient archival documentation. Although previous studies across architectural history, archaeology, and conservation have generated important insights, the sequence and dating of construction phases remain unresolved.

To address this, a new interdisciplinary investigation was launched in March 2025, applying radiocarbon dating (^{14}C) to construction mortars to clarify the timeline of architectural changes. This scientific approach focuses on the carbonaceous binder and embedded charcoal particles in mortars, providing dating accuracy beyond what traditional methods offer, particularly in heritage sites with complex histories.

Eleven mortar samples were extracted from the monastery and church, including the eastern wing, basement rooms unearthed in 2019, and key structural areas such as the chancel, nave, plinth, crypt. Samples were carefully selected to avoid heavily restored areas and ensure both historical relevance and minimal visual impact. Due to the high aggregate content and local loess admixture, the samples underwent additional decomposition testing before radiocarbon analysis.

The study aims to determine the absolute chronology of construction phases, distinguish original 13th-century elements from later interventions, and integrate scientific data with architectural and archaeological context. The results are expected to resolve long-standing uncertainties about the monastery's transformation and establish a model for similar heritage studies in Europe, where radiocarbon analysis of mortars is still underused.

This work demonstrates the potential of combining scientific dating methods with architectural and historical interpretation to fill critical gaps in the understanding of medieval ecclesiastical structures. The findings will significantly refine the historical narrative of one of Central Europe's most important religious complexes.

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CHRONOLOGY OF THE EARLY ROMANESQUE STRUCTURES FROM THE WAWEL ROYAL CASTLE (KRAKOW, POLAND)

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Abstract

The architectural complex on Wawel Hill in Kraków, Poland, holds some of the most significant early medieval structures in Central Europe. This study focuses on four key elements of Wawel's early medieval architecture: rotunda of Holy Virgin Mary (rotunda of Sts. Felix and Adauctus) the basilica of St. Gereon, the so-called "hall with 24 pillars,"Stołp" and the Danish Tower These structures present complex construction histories that have remained difficult to date through traditional archaeological and architectural analysis.

A multidisciplinary laboratory approach was applied to mortars sampled from these sites to evaluate their composition and chronological potential. Initial analyses included petrography (thin-section microscopy), scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS), and other analysis. These tests revealed considerable heterogeneity in mortar types, including a distinct group with gypsum-based binders, which are unsuitable for radiocarbon analysis.

Carbonate-based mortars were selected for radiocarbon dating using a rigorous pretreatment protocol. Mechanical fractionation through sieving allowed for the isolation of specific grain-size fractions, followed by suspension techniques and controlled thermal decomposition. These steps were designed to minimize contamination from aggregate material and secondary carbonate phases, thereby isolating the primary binder carbon for accurate ^{14}C measurement.

The integration of material characterization and targeted radiocarbon dating enables a refined interpretation of the construction phases of these early medieval monuments. The resulting chronological framework contributes new evidence for understanding the technological practices and architectural development on Wawel Hill during the early Middle Ages, offering a model for the application of ^{14}C dating to complex historical mortars in heritage structures.

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RADIOCARBON DATING OF THE CHURCH OF ST. VENDEL IN PATINCE (SLOVAKIA): INTERNATIONAL CONSORTIUM RESULTS

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Abstract

The church of St. Vendel is located in Patince village in southwest Slovakia, east of the district town of Komárno, close to the Danube river. It is only a few kilometers from the biggest Roman castellum in present-day Slovakia called Celemantia (mentioned in the second century by Claudius Ptolemaios), which was abandoned in around 400 CE.

The findings associated with the church represent an archaeological discovery of the year 2024 in Slovakia. It is a single-nave church built in a pure Romanesque floor plan, with all openings in the south wall. It was expected that the church was built in the 13th Century, however, recent discoveries found under the floor (including Roman tombstones which were used in basement constructions), may suggest earlier origin. The church was built from well-cut stone blocks made of andesite tuff, which were perfectly arranged in the walls with minimum layer of mortar between the stones. The church burned down during Tatar and Turkish invasions and often stayed without a roof. After several reconstructions, it was rebuilt in the 18th century in Baroque style that is preserved to the present. Minor reconstructions of the church were also carried out in the 19th and 20th centuries. The church is presently again under restoration, therefore we had a chance to collect samples of wood, charcoal, bones, mortar and plaster and submit them for radiocarbon dating. We also collected samples found under the floor of the church interior, including mortar from foundations of construction, and human bones.

Because of the archaeological and historical significance of the church, and to exclude possible discussions on results obtained only by a single national radiocarbon laboratory, a consortium of radiocarbon laboratories from neighbouring countries (Austria, Hungary and Czech Republic) and 3 world laboratories (two from USA and one from Switzerland) has been organized.

The ^{14}C results obtained from dating samples of wood, charcoal, bones and mortar in the different laboratories as well as between the different sample types were in reasonable agreement. The preliminary range of ^{14}C calibrated ages of several wood and charcoal samples

collected in the church is 991-1270 AD. Although the ^{14}C results from participating laboratories have very good precision, the specific character of the calibration curve caused a wide range of the calibrated ages.

NEW AMS RADIOCARBON DATES FROM VILLA FRONTERA SITE IN ARICA, NORTHERN COAST OF CHILE

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Abstract

The objective of this work is to obtain the occupation sequence of the Villa Frontera site, located in the region of Arica, northern Chile, by AMS radiocarbon dating. Arica is a northern desert coastal area of Chile, bordering Peru and Bolivia, that has recorded human occupations since the Archaic period (Castelleti et al., 2024). The first recorded evidence of natural mummification corresponds to 2 individuals with a radiocarbon date of 8774-7516 cal BC, near the coastal strip of the port of Arica at the mouth of the Quebrada de Acha (Muñoz et al. 1996).

Other occupations correspond to the Chinchorro culture, known for its mummification practices, covering a period between 9000 and 3000 cal BC (e. g. Standen et al., 2004). Among other domestic deposits near funeral areas at coastal sites in Arica, mention can be made of Quiani 1, dating to a period between 3000 and 2500 cal BC (Dauelsberg, 1974; Muñoz and Chacama, 1982) and El Morro 1 with a human occupation from 7090 to 6733 cal BC (Castelleti et al., 2024). Although most of these works correspond to the Archaic Period (9000-3700 cal BC), occupations have also been revealed in the Lluta and Azapa valleys (Santoro et al., 2004), the Arica foothills (Muñoz and Briones, 1996) and the Morro de Arica (Castelleti et al., 2024), during the Late Intermediate Period (800-1450 cal AD).

We present new results of AMS radiocarbon dating of 20 samples collected in the Villa Frontera Site, belonging to four different wells located at the same depth level.

Samples are distributed as pairs of charcoal and marine shells of filter-feeding bivalves. They were also used to determine the reservoir effect of the coastal zone (http://calib.org/deltar/). The obtained results aim to provide new delta R measurements that could be used as a reference for future research in the region, considering that according to the Marine Reservoir Correction Database, the closest reliable reservoir effect measurements are more than 300 km away (Latorre et al., 2017).

Charcoal samples underwent standard acid–base–acid pretreatment, while CO2 from the shells was extracted by digestion with orthophosphoric acid; then it was reduced to graphite in a carbonate handling system (CHS) (Ion Plus). Graphite was analyzed using a HVEE 1MV at the Mexican AMS laboratory (LEMA-UNAM). Calibration was performed with OxCal v4.2.4.

Obtained results were entered into the OxCal program to obtain a Bayesian model of the pits. The calibrated dates, except for pottery moments surface dates, show a contemporaneity relationship between most of the charcoal-shell units and place an early occupation between 5197-3370 cal BC (charcoals) and 5192-4219 cal BC (shells), corresponding to the Middle Archaic period. Nevertheless, the deposit shows an anomalous date of 11526-11368 cal BC at the base, which could correspond to the use of old wood or paleoenvironmental strata. The research carried out at Villa Frontera provides information about the earliest human domestic occupations in this territory.

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INTEGRATING DENDROCHRONOLOGY AND RADIOCARBON DATING IN ANDEAN ARCHAEOLOGY: A METHODOLOGICAL APPROACH TO INCA CHRONOLOGY

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Abstract

The aim of this presentation is to provide a theoretical and methodological reflection on integrating dendrochronology and radiocarbon dating within Inca high-altitude ritual contexts, focusing on capacocha offerings. The presentation highlights the potential and limitations of applying precision-dating methods to archaeologically and symbolically rich, yet methodologically complex situations contexts.

Capacocha rituals—such as those performed on Mount Ampato in southern Peru—are characterized by deposits of human sacrifices accompanied by various organic materials, including wooden elements likely employed during ritual ascents. These materials present unique opportunities to test advanced calibration techniques, including wiggle-matching, provided that dendrochronologically useful wood can be reliably obtained selected.

The goal is to critically examine key methodological challenges: the “old wood” problem, the ecological and climatic variability of Andean tree species, and the broader issue of creating localized calibration sequences in Andean regions. Using capacocha contexts as a conceptual and analytical testbed, we advocate for developing more nuanced, interdisciplinary frameworks for high-resolution dating in Andean archaeology. This contribution is intended as a theoretical intervention into current debates on chronological precision, emphasizing methodological innovation over empirical reporting. At the same time, this marks the initial step of the project, which aims to establish a larger-scale chronology of the Inca state, based on wooden artifacts like those from the capacocha context.

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RADIOCARBON DATABASE OF NORSE GREENLAND

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Abstract

The Norse occupation of Greenland has been the subject of extensive radiocarbon dating effort by various researchers throughout the years. As a result, an enormous number of results have been published in a wide range of publications.

In an effort to reuse such legacy data, in conjunction with new radiocarbon dates from various sites, the first phase of this PhD project has focused on gathering as many published and unpublished results from Norse Greenlandic sites as possible. This has led to the creation of an extensive and comprehensive database of all the radiocarbon data. The database includes contextual information such as settlement, site, geographic coordinates, archaeological features, stratigraphy (where available), laboratory and collection reference numbers, type of material dated, other analytical results (e.g. $\delta^{13}C$ and $\delta^{15}N$), associated comments, and DOIs for source publications. The dates were compiled by reviewing available academic publications and site reports, and discussions with different institutions that have conducted work on Greenland.

In addition to collating the data, the quality of the results was also assessed. There were two aspects to this reviewing process. The first focused on chronometric hygiene. Here, each date was given a Grade from 1 to 4 based on how likely it was to contain an unsystematic offset. The second review focused on archaeological context to ensure the result was accompanied by sufficient information to place it correctly in relation to the events. The grading protocol was created specifically for the Norse Greenlandic material but is primarily based on previously published protocols[1].

This poster provides an overview of the radiocarbon database for the Norse period in Greenland. The intention from here is to incorporate these data with new radiocarbon dates and analyse them within a Bayesian framework to create the most comprehensive and precise chronology of the Norse occupation of Greenland.

Acknowledgments
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^{14}C-AMS DATING OF PLANT FIBERS FROM PRE-COLUMBIAN ARTIFACTS FROM MEXICO

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Abstract

This study investigates the plant fibers used in the manufacture of pre-Hispanic artifacts—primarily footwear, textiles, and baskets—recovered from archaeological contexts in central and northern Mexico, specifically the Balsas River basin (Morelos and Guerrero), and the desert region of Cuatrociénegas, Coahuila. The research is motivated by questions concerning antiquity, botanical origin, and possible biological residues associated with these objects.

The primary objective is to identify the plant species used in artifact production and establish a reliable chronological framework through radiocarbon (^{14}C) dating by accelerator mass spectrometry (AMS). Additional aims include assessing DNA preservation and conducting genetic analyses to characterize plant and potential human biological and microbiological traces.

Before AMS analysis, samples underwent physical and chemical pretreatment, combustion, and graphitization at LEMA (IFUNAM). Calibrated ^{14}C dates place the Balsas artifacts between the Preclassic (731–228 BCE) and Postclassic periods (up to 1376 CE), while Cuatrociengas dates varied from 4500 years BC to 1385 years AD. Carbon isotopic analysis suggests using both C_3 and C_4 plants. Morphological and molecular evidence indicates the presence of taxa from the Asparagaceae family (e.g., Agave, Yucca, Dasylirion, Brahea) and cotton (Gossypium, Malvaceae), commonly used in pre-Hispanic textile production. Within the group of archaeological materials, a textile from the Balsas River basin of Morelos stands out, manufactured with grass (Poaceae), an uncommon raw material for an archaeological textile garment.

Preliminary genetic analyses involved successfully extracting ancient DNA (aDNA) from selected artifacts, with quantification and purity confirmed via UV-visible spectrophotometry and Polymerase Chain Reaction (PCR). Amplification of plant, bacterial, and human genetic markers was achieved, and next-generation sequencing (NGS) is being employed to taxonomically classify the biological content and determine photosynthetic pathways (C_3 vs. C_4). The microbial communities associated with the samples are also characterized to provide further paleoenvironmental context.

This interdisciplinary effort contributes to a more comprehensive understanding of ancient fiber technology, resource use, and bioarchaeological conditions. It highlights the value of integrating radiocarbon dating, archaeobotany, and molecular biology in the study of organic archaeological materials.

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RADIOCARBON DATING OF PRE-HISPANIC ORGANIC SAMPLES FROM THE CHICOASÉN II SALVAGE ARCHAEOLOGY PROJECT, CHIAPAS, MEXICO

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Abstract

This study presents preliminary radiocarbon (^{14}C) results from organic samples recovered during salvage excavations at the Chicoasén II hydroelectric project in Chiapas, Mexico. The project was directed by the archaeologist María Rebeca Yoma and coordinated by the Dirección de Salvamento Arqueológico (INAH). The assignment was launched in response to infrastructure development along the Grijalva River. Remote sensing using LiDAR, followed by field verification, identified several pre-Hispanic sites with architectural features such as platforms, plazas, kilns, and ritual structures.

Charred wood, charcoal, and mixed organic residues were sampled from 9 sites (e.g., Ixtumbú, Tzatac, Caracoles), mainly from kiln contexts. Samples underwent standard acid–base–acid pretreatment and graphitization at the LEMA Laboratory (IFUNAM) and were analyzed using an HVEE 1MV AMS system. Calibration was performed with OxCal v4.2.4 using the IntCal20 calibration curve.

The radiocarbon (^{14}C) results indicate a broad chronological range for the samples analyzed. Most samples date back to the Late Classic to Postclassic periods, approximately AD 250 to 1400. However, there are two significant outliers: one sample (LEMA 2261) dates to between 255 and 409 cal AD (with a 95% confidence interval), while another sample (LEMA 2260) is from the modern era, which likely represents contamination or disturbance.

These initial findings provide the first absolute chronological framework for Chicoasén II, suggesting a prolonged and possibly multi-phase occupation of the site. Future analyses will incorporate typological and stratigraphic data and additional dating methods to refine the chronologies for sites across the region.

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A RADIOCARBON DATABASE FOR CHINESE ARCHAEOLOGY

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Abstract

We present a new online, open-access database of published radiocarbon dates from Chinese archaeological contexts, the 'Chinese Archaeology Radiocarbon Database' (CARD), which is fully compatible with the calibration, Bayesian chronological modelling, and mapping functionality of the OxCal software. Over 6,500 radiocarbon dates are included, accompanied by their detailed archaeological and geographic information.

The database was collated under the auspices of the "Horsepower" project (horsepowerproject.org), an on-going, extensive programme of radiocarbon (^{14}C) dating that is currently underway to inform upon early state formation in China, Mongolia and the broader Steppe region during the first ~two millennia BC via explicit exploration of the trade in horses. This programme will complement the associated genetic analysis, an examination of the material culture associated with horseback riding or the driving of vehicles, and the metal supply from China to the north and northwest.

BIOARCHAEOLOGICAL ANALYSIS OF LATE BRONZE AGE INHUMATIONS FROM THE GREAT HUNGARIAN PLAIN

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Abstract

Sárrétudvari-Hízóföld is a Bronze Age cemetery of two rites (inurned and inhumation) in the central part of the Great Hungarian Plain. The 7 skeleton graves, which are the subject of our research, were scattered over an area of 3400 m2, beside 22 cremated burials. The urn graves belong to the so-called Hajdúbagos–Cehăluţ pottery tradition, a sub-group of the Tumulus culture. The pottery tradition spanned from the very end of the Middle Bronze Age to the Late Bronze Age IIa (Central European chronology) covering the period between the *tell*-cultures (e.g. the Ottomány-Füzesabony Cultural Circle) and approx. the Urnfield period (the Gáva culture in the region) in the northeastern Carpathian Basin. Notably, the cremated remains were not preserved and therefore cannot be examined. Based on the few grave goods found next to the deceased, it is also difficult to say whether the burials of the two rites can be linked to a single community. Therefore, AMS radiocarbon dating was performed on the anthropological remains of the inhumation graves.

But why were these people not buried in urn burials, which were dominant in the area at that time? Could injury, sacrifice or illness be linked to the different rite? Did their diet show any signs of discrepancy? Were they distinguished by their origin?

To answer these questions, we attempted to extract as much information as we could from their bones using bioarchaeological methods. Physical anthropological examination was conducted to estimate biological sex and age at death, as well as to determine the presence of any diseases or trauma. For two individuals, biological sex could only be determined by amelogenin protein analysis of enamel samples. In addition, stable ^{13}C and ^{15}N isotope analysis was carried out on the collagen fraction of ribs to gain dietary information. The $^{87}Sr/^{86}Sr$ isotope ratios were determined from the first molars. These were then compared with the local baseline to estimate the proportion of local births.

Based on our results, the radiocarbon ages of the individuals buried with the inhumation overlap the period of the Hajdúbagos–Cehăluţ pottery tradition. All the individuals examined were female, but

seemingly half of them were born locally and the other half were born elsewhere. No traces of trauma or infectious disease were detected, and the age tree is completely covered by the estimated ages. No outliers in dietary customs were observed, but $d^{13}C$ values were well aligned with the increased use of millet in the diet, which could be detected from the transition of the Middle and Late Bronze Age. The practice of divergent burial rites might be associated with the Tumulus culture, of which the impact is also manifest in the find assemblage.

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ABSOLUTE DATING OF WOOD FROM THE GOLD MINE AND OLD SMELTER IN ZŁOTY STOK (SOUTHERN POLAND)

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Abstract

Złoty Stok is home to one of the oldest known mining sites in Poland and Central Europe, with documented mining activity dating back to the 10th century. Archival records referencing mining operations begin in 1273 AD. This study presents the results of absolute dating of wooden elements recovered from a range of historical mining features in the Złoty Stok region, including the Prince's Adit, Upper and Czarna Dolna Inclines, Okrągła Adit, Ochrowa Adit, Lisa Adit, Nad Złotym Jarem Adit, Naciekowa Adit, Smocza Adit, Pod Młynem Adit, Nowa nad Złotym Jarem Adit, the Mistrzów Adit, a shaft at the collapse zone in Czarna Dolna Incline, and the primary metallurgical facility—Stara Huta (Old Smelter) in Schlakenthal (Złoty Jar Valley).

Wood was found in the form of mine supports, dewatering and transport installations, and tools. Despite generally poor preservation—most samples were waterlogged and decayed—over 50 wood samples were collected, mainly from coniferous species including Picea abies (spruce, dominant), Abies alba (fir), and Pinus sylvestris (Scots pine). Dendrochronological analysis was conducted at the AGH University of Kraków. Tree-ring sequences ranged from 26 to 76 rings, with most samples yielding short sequences between 30 and 50 rings. The dated timbers span from the 13th to the 20th century.

The oldest identified wood came from fir boards found in the original smelter near the stream in Schlakenthal, dated to the 13th century. A local dendrochronological chronology was established for 1200–1287 AD, supported by radiocarbon calibration results of 1120–1288 cal AD. Timber from the Naciekowa Adit dates to the late 16th–early 17th centuries (1590–1615 cal AD), aligning with archival references. In the Ochrowa Adit, both 16th- and 18th-century wood was identified—suggesting initial construction in the early 1500s (e.g., 1526, 1591 AD) and later modifications or repairs in the 1700s. No samples preserved the outermost tree-ring, making all dates terminus post quem. The youngest wood, a spruce board from the Lisa Adit, was dated to the 19th–20th century (1805–1935 cal AD), likely from modern intervention.

The absolute dating of wooden remains in historic mining features contributes significantly to the understanding of medieval and early modern mining technologies and practices. Through dendrochronology, radiocarbon dating, and integration with mining archaeology and historical records, this research reconstructs the chronological development of mining in Złoty Stok and provides a model for similar studies in other historical mining regions.

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WHEN TWO PEOPLE DO THE SAME THING, IT'S NOT THE SAME THING: SAME CHURCHES, SAME ^{14}C DATA, DIFFERENT ABSOLUTE AGES.

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Abstract

The earliest churches in Central Europe, specifically in Slovakia and Czechia, are dated—based on archaeological, stylistic, and historical evidence—to the late 9th and 10th centuries. To confirm this dating and clarify the construction sequence, some of these churches have been radiocarbon dated using samples of wood from the construction, as well as mortars and charcoal embedded within the mortars.

This paper presents two case studies: the St George Rotunda at Nitranska Blatnica (SK) and the St Peter and Paul Rotunda at Budeč (CZ). In both cases, the primary ^{14}C data indicated similar conventional ages. However, the data were approached and interpreted differently. In the first case, the interpretation selectively emphasised a portion of the calibrated time interval to shift the construction of the church to an earlier chronological horizon than previously assumed and the results remain open (Povinec et al. 2021; Robak 2024). In the second case, the primary ^{14}C data were assessed more critically, taking into account the results of petrographic analysis of the mortars, as well as archaeological and written sources (Válek et al. 2025) .

The aim of this paper is to demonstrate how differing approaches to the interpretation of ^{14}C data can influence the absolute dating of early church construction in Central Europe. Moreover, it seeks to highlight the importance of a critical approach to the interpretation of primary data, and the need to consider the archaeological context within the interpretive process.

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RADIOCARBON DATING OF MEDIEVAL TREASURES FROM UPPER SILESIA

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Introduction

Research on the medieval cultural heritage of the eastern areas of Upper Silesia and the border with Lesser Poland was conducted jointly by historians and archaeologists. The subject of detailed analyses was the history of two local administrative centres, as well as places where silver and lead were extracted – Bytom and Siewierz. Radiocarbon dating is an important tool in the study of cultural heritage, enabling to indicate the period of functioning of individual facilities and to determine the absolute chronology of monuments. The research was focused on dating such a spectacular objects as the early medieval hillfort located on St. Margaret's Hill in Bytom (a castellan's castle, and possibly also a prince's residence) and the foothills of the prince's (later bishop's) castle in Siewierz. The studies also concerned the chronology and use of wax tables, as well as other relics found on the market square in Bytom. The analyses were based on historical, cartographic and demographic sources, as well as on radiocarbon dating of samples from archaeological works carried out in the area.

Methodology

Radiocarbon dating was performed using the accelerator mass spectrometry (AMS) technique, following commonly accepted protocols (Piotrowska, 2013; Ustrzycka et al., 2024). Before measurements all samples underwent chemical pre-treatment to remove potential contaminants from the sedimentary environment. A standard acid-base-acid (ABA) preparation with hydrochloric acid and sodium hydroxide solutions was applied. In the case of the wood samples, additional steps were added to ABA purification – an extraction with organic solvents (toluene and ethyl alcohol) to remove resins as well as bleaching process with application of acidified sodium chlorite to obtain holocellulose, which is the suitable fraction for radiocarbon dating (Hajdas et al., 2017). After chemical procedures, the samples were combusted and graphitized using the AGE-3 system, equipped with the Vario Micro Cube elemental analyser (Němec et al., 2010; Wacker et al., 2010). They were then subjected to radiocarbon concentration measurement using the MICADAS accelerator mass spectrometer, manufactured by IonPlus (Synal et al., 2007). The resulting radiocarbon ages were calibrated using the IntCal20 calibration curve (Reimer et al., 2020) and the OxCal v.4 calibration program (Bronk Ramsey, 2009).

Results

Based on the obtained radiocarbon dates for wax table (sample GdA-8068) its age was determined to be as early as 12th century or even 11th century. Dating indicates the years 1032-1175AD with 95.4% probability level. Three analyses for charcoal from the archaeological excavations at the Bytom main square (samples GdA-8070, GdA-8071, GdA-8072) give results from the 7th to the early 11th century. Age determination gives a time range of 896-1025 AD, 660-774 AD, 662-774 AD, respectively, all given with

95.4% confidence interval. Visibly, charcoal from the sample GdA-8070 is the youngest, being dated around 10th century. In turn, the radiocarbon age of the fourth charcoal sample (GdA-8069) falls within the period of the 18th-19th century when the wiggles of the calibration curve preclude determining a precise calendar age.

According to the current state of knowledge, the settlements in Bytom were founded in the 11th century. The reported results could support the assumption that there was an even earlier human occupation. Field and laboratory work is still in progress to provide further findings which will enable a better interpretation of the research results obtained so far, and more precise dating of the archaeological sites from the analysed Upper Silesia region.

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THE LOST CONTEXT OF THE MUSEUM CEREAL GRAIN COLLECTION: IDENTIFICATION BASED ON ^{14}C AMS DATES AND STABLE ISOTOPES

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Abstract

The State Historical Museum in Moscow keeps two archaeobotanical assemblages of cereal grains. After the change of the exposition and reconstruction of the museum in the 1980–1990s, the botanical, chronological and cultural contexts of these archaeobotanical remains were lost, though some of the grains were displayed in showcases that contained other exhibits associated with Eneolithic Trypillia culture producing forms of economy. There were only paper-based catalogue cards left which specifically refer to two cereal assemblages, one assemblage coming from 'the Kiev province, Trypillia village, from Khvoyka's excavations', and the other assemblage transferred from the Chernovtsy Museum in 'the Bessarabia province' (Chernovtsy region, Zastavna district, Doroshiltsy village' [presently Doroshovtsy]. However, it was difficult to assign these two cereal collections to the Trypillia culture; besides, it was not clear how the collections had ended up in the State Historical Museum in Moscow. The study of the earlier published data on the cereal grain finds at the Trypillia sites and the preserved archival documents provided an opportunity to correlate the grains that, presumably, were transferred to Moscow from the Kiev National Historical Museum (Context 1) with the archaeobotanical assemblage collected by V. Khvoyka during his excavation at Khalepye in 1895. However, we could not determine what Trypillia site the cereal grains the Chernovtsy Museum had been discovered (Context 2).

To restore the lost contexts of these two archaeobotanical assemblages, we initiated our study, that included archaeobotanical examination, ^{14}C AMS-dating of five grain samples and identification of the nitrogen and carbon isotope values of 10 single cereal grains from Khalepye. The comparative analysis used published isotopic composition of ^{15}N and ^{13}C on the wheat samples from several Trypillia sites, the Eneolithic–Early Bronze Age Chobareti site in the southern Caucasus (Schlütz et al. 2023; Messager et al. 2015) and the early Iron Age Alekseyevskoye site in northern Kazakhstan.

Based on the archaeobotanical analysis all grains from the two analyzed grain assemblages kept in the State Historical Museum were assigned to Tr. aestivum subsp. aestivum and Tr. turgidum L. subsp. dicoccum (Schrank ex Schübl.) Thell. The radiocarbon dates obtained helped verify their chronological position.

The Chernovtsy assemblage can be dated to an earlier interval, i.e. 4249/4050–4038/3889 BC (1σ) or 4023/3998–4145/3205 BC (2σ) whereas the Khalepye assemblage can be dated to a later period 3969/3676–3741/3491 BC (1σ) or 4449/3660–3760/3049 BC (2 σ). These chronological intervals are correlated with the modern chronology of the Trypillia culture based on a rather large AMS-data dataset (Kirleis et al., 2024). The analysis performed has verified the cultural attribution of the cereal grain from the State Historical Museum in Moscow and ascribed it to the Trypillia culture.

The comparative analysis of the stable nitrogen and carbon isotopic composition of the wheat from Khalepye confirms that this assemblage is likely to be linked to the tradition of Trypillia crop management when a system of organic fertilizers (animal manure) aimed to intensify farming was put in place.

Acknowledgments
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EXCAVATING THE PAST, (RE)MODELING THE PRESENT, AND ACCELERATING TOWARD THE FUTURE WITH THE RADIOCARBON SAMPLE ARCHIVE AT THE CENTER FOR APPLIED ISOTOPE STUDIES, UNIVERSITY OF GEORGIA, ATHENS, GEORGIA, USA

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Abstract

The University of Georgia has continuously operated a radiocarbon dating facility since 1968, which was later incorporated into the Center for Applied Isotope Studies (CAIS) in 1977. By 1972, the laboratory had established a practice of retaining sample remnants. However, the process for archiving samples lacked standardized curation practices, with inconsistent labeling, packaging, and cataloging. In 2016, the CAIS began a large-scale project to revitalize and rehabilitate this collection according to modern curation standards. In the process, we have learned about the history of CAIS itself. Accompanying records, which include result reports, sample submission forms, sample logs, invoices, correspondence, and raw data measurements, constitute a primary-source archive of the history of CAIS and radiocarbon science, particularly in North America, over the past 50+ years. Through digitizing, cataloguing, and linking records to physical specimens, we identified trends in sample volume, sample type, and origin of samples over time. Presently, the collection is entirely catalogued, with workflows in place to integrate samples directly into the collection following analysis and reporting. The collection consists of approximately 39,000 samples, and is about 400 cubic feet in volume. Samples are identified by laboratory number, and are split into the UGa- collection, which were analyzed by liquid scintillation counting between ca. 1968 and the early 2000s, and the UGAMS- collection, which were analyzed by accelerator mass spectrometry between the early 2000s and the present. We highlight the costs of sample curation thus far alongside the scientific, ethical, and educational benefits that maintaining the sample collection has brought to CAIS. Finally, we discuss future plans for the collection, including long-term storage for both the artifacts and records, conservation measures for fragile samples, database solutions, sample retention policy changes, and options for sample return and disposition.

BIOGRAPHIES OF THREE COPTIC TEXTILE PIECES

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Abstract

Coptic fabrics constitute a separate stylistic group of textiles that were found in Christian funerary contexts (necropolises) in ancient Egypt. They were produced in the first millennium, between the 3rd century AD and (depending on the source) the 7th-9th century AD. The dry conditions in Egypt helped preserve these delicate fabrics, which often are in a fragmentary condition. The textile fragments are decorative panels or roundels (*orbiculi*) woven in the tapestry technique with ornamental motifs and compositions, and most likely pieces from Roman-Byzantine tunic garments. Iconography includes, for example, gods, goddesses, saints, dancers, animals, vegetation and rosettes. Following archaeological excavation, they were often separated from the tunics they decorated, frequently being cut out and distributed separately.

We present the results of radiocarbon and stable isotope measurements on different materials of three woven textile fragments recovered from excavations in Egypt. These brilliant, beautifully decorated textile fragments are currently in the collections of the Norwegian National Museum of Decorative Arts and Design in Trondheim, Norway. All three pieces were acquired by the museum in the late 1960s.

Two of the examined fragments are monochromatic, made using linen threads and woollen yarn. The third is multi-coloured, woven exclusively in dyed wool. Two fragments have been backed with a piece of the same brown woven wool fabric. Until now, these textiles have been dated based on formalistic style-based chronologies, and our goal has been to confirm and refine their production date. Furthermore, dating the cotton threads and the glue used to mount them onto the supporting woolen fabric provides the opportunity to trace and document subsequent interventions.

Due to the high value, delicate condition and small size of the textiles, the material removed was limited to loose threads still partially attached to the fragment. Such fibres were found along the frayed edges and on the reverse side. Identification of fiber type was carried out by microscopic examination prior to radiocarbon and isotope analyses.

Isotope studies of the wool provide information about the environment and management of the sheep herds, e.g. $\delta^{13}C$ distinguishing C3 and C4 plants, or elevated $\delta^{15}N$ values reflecting water stress/aridity. This might help to test hypotheses about the wool's geographical origin (such as Egypt vs. Greece) and allows us to reconstruct even more details of the objects' biographies.

Radiocarbon dating of the fibre samples from the decorated tapestries and the fabrics on which they are attached, fit perfectly into the "Coptic period". Two of the fabrics date to the 5th-6th century and one dates to the 7th century, with the underlying fabrics dating to the 6th century. These differences between the dates of the decorated fragments and their supporting fabric invite further interpretation about both the origin, function and modification of these museum objects.

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OPEN-SOURCE EQUATIONS FOR RADIOCARBON DATING

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Abstract

The analysis and interpretation of radiocarbon dates often involves many steps, such as switching between time-scales (cal BP, cal BC/AD, ^{14}C BP, F^{14}C, pMC, Δ^{14}C), inspecting calibration curves, calibrating dates, applying marine or other offsets, estimating the impacts of contamination, calculating probabilities from calibrated distributions, and summarising multiple dates.

Here, I present *rice*, an open-source *R* package (Blaauw 2024) which enables users to perform such calculations within *R*, thus enabling most of the steps from data entry to calibration, age-modelling and subsequent analysis and interpretation of time-series to be performed within a widely-used, multi-platform, single, transparent, licence-free and reproducible software environment. All calculation steps are documented and can be inspected by the users. The package could thus prove useful in both educational and research settings.

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HOW TO IMPROVE AN AGE-DEPTH MODEL BY CONSIDERING SEDIMENTATION RATE?

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Abstract

Sedimentary sequences offer valuable insights into historical climate changes. Although individual radiocarbon dates may lack precision, the analysis of a series of such dates combined with associated stratigraphic data, such as depth, through the development of an age-depth model (Ramsey 2008), typically improves the resolution of individual dates. Accurately assessing uncertainty is important in the construction of age-depth models (Telford et al. 2004; Trachsel and Telford 2017; Lacourse and Gajewski 2020).

One aspect of model uncertainty is often overlooked - in some cases, not all radiocarbon dates used to construct the age-depth model are from layers of the same thickness. Typically, dated material is extracted from layers 1–2 cm thick. However, in some cases, especially when organic material is scarce, it is necessary to sample layers up to 5 cm thick to obtain sufficient material for radiocarbon dating. This introduces variability that should be taken into account – e.g. by adjusting the uncertainties of radiocarbon dates accordingly.

In this study, we assess whether a two-step modelling approach can improve age-depth models based on radiocarbon dates derived from variably thick sediment layers. In the first step, a preliminary age-depth model is constructed, and sedimentation rates are estimated from radiocarbon dates relative to depth. In the second step, the uncertainty associated with layer thickness—calculated using sedimentation rates—is incorporated into the radiocarbon age uncertainty. A revised age-depth model is then produced in a second iteration. This method aims to better account for uncertainty introduced by non-uniform sample thicknesses in radiocarbon-dated sequences.

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SIMPLE AND COMPLEX METHODS TO ADDITIVELY EXPAND QUOTED ERRORS TO ACCOUNT FOR LONG-TERM EFFECTS

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Abstract

In radiocarbon, the quoted error (*QE*) typically corresponds to the $F^{14}C$ uncertainty which consists of a propagation of the isotopes measurement uncertainties of the blanks and standards. These uncertainties arise from instrument instability, target inhomogeneity and the inherent detection uncertainty corresponding to the short measurement time (couple of days). In the long-term (several months), there are other unknown sources of uncertainty that affect the variability (*LT*) of the measured $F^{14}C$ of replicates that are not accounted inside the quoted error. The error multiplier (Scott et al. 2007) has been usually used to capture these unknown components for replicates of sample treatments within intercomparisons (Scott et al. 2018), Calibration curve construction (Heaton et al. 2020) and long-term studies. In this work, we propose a simple and a sophisticated method to additively expand the quoted error using an excess error in order to make it comparable, in average, with the long-term variability; show a defined and confined range of possible excess error values as the robustness of the complex method and the results of the complex and simple method are quite similar.

The simple method was based on the 7-year data length of Salazar et al. 2021 for the University of Bern where the average QE was obtained for several secondary standards. LT was estimated as the standard deviation of each secondary standard long-term control chart. The quadrature difference between LT and QE is defined as the excess uncertainty (ε) which magnitude depends linearly on the $F^{14}C$ consensus value, thus ε is characterized by a slope and intercept (ε_0, ε_{slope}). The complex method is original to this work and carries out a more robust statistical analysis to infer ε_0 and ε_{slope}. The complex method systematically variates the initial values of ε_0 and ε_{slope} to minimize the global reduced χ^2 calculated as the variability of measured $F^{14}C$ of a certain standard relative to the additively expanded QE with ε. The global χ^2_{red} is the average of the χ^2_{red} of all the secondary standards. The χ^2_{red} is minimized using algorithms from the ***R*** program. The initial values of ε_0 and ε_{slope} were selected near and centred to the values obtained from the simple method but with a strong wide distribution and then minimizing the global χ^2_{red} repeating the process many times in a Monte Carlo fashion. A second analysis was done randomly initializing the ε_0 and ε_{slope} but using a fraction of the whole data each time in a bootstrapping fashion. The fraction of the data was also random. The distributions of the optimum ε_0 and ε_{slope} values were our main interest.

We obtained for the simple method for a 2-year data from the Andre Lalonde facility the values of ε_0 of 6.0 and 4.6 ($x10^{-4}$ $F^{14}C$) for the years 2022-2023 and 2023-2024 respectively. The ε_{slope} was 9.4 and 10.6 ($x10^{-4}$). The complex method showed ε_0 of $(6.3\pm1.3)x10^{-4}$ $F^{14}C$ for 2022-2023 and $(4.6\pm0.6)x10^{-4}$ $F^{14}C$ for 2023-2024. ε_{slope} was $(9.7\pm2.6)x10^{-4}$ for 2022-2023 and $(10.5\pm3.0)x10^{-4}$ for 2023-2024. The distribution were close to Gaussian distributions.

The slope for the simple and complex methods in average are quite close, within 9.4-10.6 ($x10^{-4}$) independently of the year range and the statistical method. The intercepts for the year 2022-2023 range are quite close for the simple and average of the complex method, within 6.0-6.3 ($x10^{-4}$ $F^{14}C$). The same happens for the year 2023-2024 range for both methods are similar, 4.6 $x10^{-4}$. This means that the results of the simple and complex method are quite compatible. However, between year ranges, both methods show that there is a difference in the intercept. This means that for the year range 2023-2024, the long-term variability close to the radiocarbon blank is lower than the long-term variability of the blank for

2022-2023. This improvement was due to a change of policy within our laboratory and it was decided to clean the ion source with higher frequency since the start of 2023.

We demonstrated that because the simple and complex method output very similar results then future users do not need to carry out the complex method, saving time and efforts. Furthermore, the user can be confident that the results of the simple method will be quite similar to a more robust statistical method. We have demonstrated statistically that by changing the ion source cleaning frequency, we have improved our quality controls.

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DEEP STRATOSPHERIC INTRUSION EVENTS IN CHINA REVEALED ON THE GROUND BY COSMOGENIC $^{10}BE/^{7}BE$

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Abstract

Given the impact of deep stratospheric intrusion on air quality, the development of more extensive trace substances to quantify stratospheric intrusion intensity can better distinguish between stratospheric ozone pollution and anthropogenic factors. The ratio of cosmogenic beryllium-10 to beryllium-7 ($^{10}Be/^{7}Be$), primarily generated in the stratosphere, has the potential to identify stratospheric air masses on the ground. Here we constructed a $^{10}Be/^{7}Be$ time-series (July 2020 to September 2021) in rainwater and aerosols from Xi'an, China. Combining in-situ pollutants, reanalysis data, and model calculations support a stratospheric origin for increased $^{10}Be/^{7}Be$ and identify it as a means of quantifying intrusion intensity. It was found that anticyclones formed by the Asian summer monsoon drive a sudden increase in deep stratospheric intrusion in spring, exacerbating ozone pollution beyond China's air quality standards. Based on the sufficiently sensitive $^{10}Be/^{7}Be$, it further indicates the process of six weak upper atmosphere intrusions in Xi'an during winter.

Key words: $^{10}Be/^{7}Be$ ratio; Stratospheric Intrusion; weak intrusion events; AMS

FIRST RESULTS USING THE STACKED FOIL METHOD FOR 10BE DETECTION

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Abstract

10Be analysis using accelerator mass spectrometry (AMS) is a commonly used method for dating geological rocks. AMS analyses are conducted by converting dating samples into BeO targets from which negative ions can be produced in a Cs sputter ion source. The negative ions are accelerated using an acceleration potential of 1 MV and are charge-stripped from negative (BeO^-) to positive ions (Be^+). A magnetic field is then used to separate the ion beam by mass.

Since the presence of ^{10}Be is extremely low ($<10^{-10}$ %), a gas ionization detector is used to detect individual ^{10}Be atoms. To purify the mass-10 ion beam from the isobar ^{10}B, a degrader foil (150 nm SiN) is used. This takes advantage of the fact that the energy loss for ^{10}B and ^{10}Be differs, allowing ^{10}Be to pass through to the ionization detector via an electrostatic filter (E/q). Because the electrostatic filter only permits passage of ions with a specific energy-to-charge ratio, Be^{2+} is selected, which results in an overall efficiency of about 8% [1].

In 2019, Steier et al. [2] proposed replacing the SiN degrader foil with a composite SiN foil placed at the entrance to the ionization detector. The idea behind the composite SiN foil is that its thickness should be sufficient to stop $^{10}B^+$, while allowing a significant portion of Be^+ to pass through to the ionization detector. This increases the efficiency since all charge states of Beryllium can be detected. The experiment carried out by Steier et al. [2] with an acceleration potential of 3 MV increased the efficiency by a factor of 2–3. Others have suggested a gas-filled chamber to stop ^{10}B while allowing ^{10}Be to pass through [3].

Here we present the first results using a newly developed stacked foil holder for the Aarhus 1MV Tandetron. Further we present the SRIM simulation of the foil thickness and expected gas detector pressure.

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A NEW SAMPLING TECHNIQUE USING HORIZONTAL DRILLING FOR THE DEPTH-PROFILE METHOD OF SURFACE EXPOSURE DATING

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Abstract

In situ terrestrial cosmogenic nuclides (TCNs) are essential for quantitatively understanding landform development processes. Surface exposure dating using TCNs enables the dating of gravelly sediments and exposed bedrocks, which are difficult to date directly using other dating methods, such as radiocarbon dating or tephrochronology. When we apply the surface exposure dating, the depth-profile method is effective for determining the amount of TCNs accumulated during sediment transport and prior to deposition, known as inheritance (Gosse and Phillips, 2001). This method is particularly important for sedimentary surfaces such as fans and terraces. It is also important for boulders and bedrocks, where the amount of inherited TCNs is expected to be minimal or negligible. First, we can check whether a large boulder has overturned after deposition. Second, the measurement results can be evaluated for internal consistency. However, drilling unweathered boulders or bedrock to sufficient depths (~3 m) is time-consuming and expensive. So, we attempted horizontal drilling to access deeper material more efficiently and evaluated its applicability.

The target area is the Cape Ashizuri, located at the southwestern tip of Kochi Prefecture, Japan. It is known that many marine terraces are distributed throughout the area. Among them, the relatively wide and continuous marine terrace surface extends over the region at an elevation of approximately 40-50 m and is considered to have formed during MIS 5e (Koike and Machida, 2001). However, no direct dating results have been reported due to the absence of marine strata on the terrace surface. Yokoyama et al. (2023) attempted cosmogenic exposure dating of the MIS 7 surface and demonstrated the applicability of this dating method in this area. Most of the Cape Ashizuri area is mountainous and hilly, and the coastline is often characterized by cliffs. So, the MIS 5e surface, which forms a relatively broad and flat surface, is commonly used for residential areas and agricultural fields. This situation makes it difficult to find original topographic surfaces that have not been artificially altered. However, scattered large boulders and bedrock tors (tower-like bedrock outcrops) are present near Cape Ashizuri, including on the MIS 5e surface. It is highly possible these features remained unaffected by artificial modification and have been continuously exposed since abandonment. Therefore, we collected samples from a tor to date the marine terrace.

The targeted tor is roughly rectangular solid, approximately 3 m wide, 2 m thick, and 3.5 m in relative height. Similar tors are clustered within an area of 4 m x 7 m. Based on their distribution, it is considered unlikely that the tor has overturned. However, we employed a depth-profile method to account for the potential effects of lateral exposure and surface erosion. A boring machine was needed to collect

samples from the top to a depth of about 3 m. The small, curved area at the top of the tor made it impractical to install the drilling platforms. In addition, the top was largely covered by tree branches, preventing machine setup. In contrast, the walls of the tor were nearly vertical, which led us to attempt horizontal drilling to collect deep samples. Therefore, we used a small mobile boring machine to collect samples using a core drill with a diameter of 66 mm. The top 0-5 cm was sampled by vertical drilling. Three samples were collected at depths of 30, 60, and 90 cm, and five samples were collected every 50 cm from 150 cm to 350 cm, 40 cm from the sidewall, for seven cores. For the samples at 0, 30, 90, 200, and 350 cm, the 30-40 cm interval from the sidewall was processed separately to reduce the influence of lateral exposure. Sample processing was conducted at the Atmosphere and Ocean Research Institute, the University of Tokyo, and Beryllium was extracted according to the protocol of Kohl and Nishiizumi (1991). $^{10}Be/^{9}Be$ measurements were conducted at the MALT, the University of Tokyo.

The concentration distribution shows an exponential decay trend, with nuclide accumulation of approximately $3.3*10^5$ at/g in the surface layer 0-5 cm and $0.4*10^5$ at/g in the deepest sample (350 cm). Based on this result, the exposure age of the targeted tor was successfully determined, yielding an exposure age approximately corresponding to MIS 5e. The obtained depth profile enabled high accuracy dating of the marine terrace in this area and demonstrated that rock tors can serve as effective targets for surface exposure dating. This study confirmed that this technique can be used to generate reliable depth profiles using smaller, more mobile equipment than vertical drilling into boulders or bedrock. This technique is particularly effective when the target, such as a bedrock cliff, boulder, or rock tor, has a nearly vertical wall.

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SAMPLE STABILITY FOR ORGANICALLY BOUND TRITIUM (OBT)

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Abstract

Organically bound tritium (OBT) in biota is increasingly investigated since it is a mean of detecting past tritium releases in the environment. While tritium in water molecule tends to be released from the body quickly, tritium bounded on carbon (as OBT) is preserved and in long term scale contributes to accumulated dose of beta radiation. With the development of small nuclear and fusion reactors that can release tritium in the environment, the health risk of long retention of tritium in organism needs to be evaluated.

The methods for isolating OBT and measuring tritium activity of OBT in body are still developing. In that respect, it is challenging to find a representative reference material. In attempt to find a reference material samples of apples have been tested for stability.

The stability has been tested on apples sampled in 2022 and 2023 on the same location near a nuclear power plant. The first sample was kept at room temperature for two years, while the second one was tested in different packaging modes at room temperature and at -20 °C and monitored during one-year period. The initial OBT activity for the first sample was 32 Bq/l and for the second was 12 Bq/l which is much higher that the activity of environmental water (0.8 – 1.2 Bq/l). OBT activity in both cases decreased after two and one year, respectively for samples stored at room temperature in sealed bags. However, considering different ways of packing samples, preliminarily data show that the best way to store sample for OBT analysis is in vacuum sealed bag on -20 °C or in a plastic box with a seal lid at room temperature.

Keywords: organically bound tritium, biota, sample stability, reference material

PROGRESS IN THE ENVIRONMENTAL TRACING STUDIES USING CHINESE LOESS ^{10}BE

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Abstract

Chinese loess-paleosol sequences are considered as one of three pillars for the global change research, together with the marine sediments and ice cores. However, paleomagnetic studies showed that almost all of the Quaternary geomagnetic polarity reversals recorded in Chinese loess, such as the Matuyama/Gauss (M/G) reversal (a key time marker for Quaternary/Neogene boundary), Brunhes-Matuyama (B/M) reversal etc. were found to be asynchronous with those in marine sediments. Such asynchroneities led to a long-standing debate over the uncertainties of the loess time scale and climatic correlation between terrestrial and marine records. To resolve these problems, we innovatively developed the Residual Trace Approach (RTA) to disentangle the geomagnetic and climatic signals intertwined in Chinese loess ^{10}Be, and reinvestigated the M/G and B/M reversal boundaries, as well as the positions of the upper and lower boundaries of the Jaramillo subchron using ^{10}Be from loess sections. The results showed that these geomagnetic polarity boundaries traced by ^{10}Be were all in fact synchronous with the records from marine sediment, settling the long-disputed question of the apparent asynchroneities of geomagnetic reversals between terrestrial and marine sediments. We further reconstructed geomagnetic field variations for the last ~870 kyr and, for the first time, identified 13 consecutive geomagnetic excursions in loess. These results provided key time markers for Chinese loess-paleosol sequences chronology. In addition, since the fallout flux of atmospheric ^{10}Be to the ground depends strongly on the wet precipitation amount, we also established method to quantitatively reconstructed multi-time scale Asian monsoon (AM) rainfall using loess ^{10}Be. We proposed that the AM rainfall was mainly modulated by the low latitude inter-hemispheric insolation gradients and the Earth's eccentricity can modulate the amplitude of the precession signal in AM rainfall. Finally, based on the ^{10}Be-derived geomagnetic and monsoon climate records, we suggested that the climate may affect the geomagnetic field through global ice volume changes.

TREE RINGS RECORDS FROM CROATIA AND BOMB PERIOD CALIBRATION ISSUES

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Croatia is situated between 42° 23′ and 46° 33′ north latitude, and 13° 30′ and 19° 27′ east longitude. Due to its position within the boundary between NH1 and NH2 zones (Hua et al. 2022), the calibration of radiocarbon results for samples from the bomb period raises an issue regarding the choice of the calibration curve. To resolve this issue, radiocarbon analyses of three rings from Croatian wood were performed. Wood was sampled at two locations Zagreb (N45°49′′, E15°59′′) and Crna Mlaka (N45°34′′, E15°46′′). 20 tree ring samples were radiocarbon analysed from each location. A time frame of analyzed samples was 1940 -2016 for Zagreb wood and 1894 – 2014 for Crna Mlaka wood. After the extraction of alpha-cellulose, samples were measured by AMS technique. Average values of absolute differences between radiocarbon results ($\Delta^{14}C$) from both locations and NH1 and NH2 radiocarbon values were calculated. The average of absolute differences between zones and location Zagreb for zone NH 1 is 45.96 ‰, while for zone NH 2 it is 41.98 ‰. At the Crna Mlaka location, the average of absolute differences between zones and the location for zone NH 1 is 83.18 ‰, and for zone NH 2 is 84.04 ‰. The preference for NH zone 2 is significant for Zagreb location, and for Crna Mlaka location preference for zone NH 1 is observed, but it is not significant. The largest differences relative to NH zones occur around the peak of the bomb pulse, which can be attributed to the fact that even small deviations in the time domain lead to large deviations in $\Delta^{14}C$, meaning the sensitivity of $\Delta^{14}C$ to the year of measurement around the bomb pulse is high. Additionally, it is observed that Zagreb location tracks both NH zones much more faithfully compared to Crna Mlaka. Since, the presented results do not give the clear answer which NH zone should be used, additional analyses should be perforemd.

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STABLE OXYGEN ISOTOPE CHRONOLOGY FROM THE PERIOD 1439-1329 BC BASED ON SUBFOSSIL OAK WOOD FROM RUCIANKA PEAT BOG (NE POLAND)

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Abstract

Annual growth rings in trees represent a valuable archive of environmental data, particularly the isotopic composition of carbon and oxygen. These records enable the high-resolution reconstruction of palaeoenvironmental conditions in the temperate climate zone.

This study investigates the oxygen isotope composition ($\delta^{18}O$) in the annual growth rings of a subfossil oak (Quercus sp.) recovered from the Rucianka raised bog in northeastern Poland (54° 15′ 34″ N, 19° 44′ 00″ E). Isotopic measurements were performed on α-cellulose extracted from individual growth rings of a specimen dated to 1439–1329 BC. The α-cellulose was isolated using the method of Green (1963), with modifications following Nemec et al. (2010), Pazdur et al. (2005), and Wiktorowski et al. (2020).

The resulting dataset provides a continuous, annually resolved $\delta^{18}O$ record for this previously unexplored period in NE Poland, offering new insights into past hydroclimatic variability in the region.

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RADIOCARBON OFFSETS SUGGESTED BY A 260-YEAR MEDIEVAL *TAMARIX* SEQUENCE FROM THE HYPER-ARID TARIM BASIN OF NORTHWEST CHINA

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Abstract

Dendrochronological-radiocarbon studies in desert lands are sparse due to the low availability of wood samples and the challenging environment. Here we report a 260-ring sequence of a subfossilised medieval *Tamarix* wood, retrieved from the hyper-arid eastern Tarim Basin (Lop Nur), northwest China. The single-ring samples were pretreated using AAA (n=21) and alpha cellulose extraction (n=27) techniques, respectively; 8 of them were replicated by both methods. The objective was to build up a fixed chronology for the sequence using wiggle-matching with the aid of the 774/775 CE Miyake event. Each pretreatment type was modelled separately. However, modelling issues were encountered and persistent until an offset was introduced to the data (*Delta_R* function in OxCal with IntCal20). Allowing for an offset, satisfactory agreement indices ($A_{model\text{-}AAA}$ = 155.4, $A_{model\text{-}alpha}$ = 152.5) and good agreement in the outer ring age estimate were obtained: AAA—843-857 CE (95.4%), median = 850 CE; Alpha—842-853 CE, median = 848 CE. Offsets were modelled/found with respect to the IntCal curve (i.e. laboratory/regional offsets) and with respect to each other (i.e. pretreatment associated differences). For the AAA data, ΔR = 10.0-39.5 ^{14}C yr (95.4%) and median=24.5 ^{14}C yr; for the alpha cellulose data, ΔR = -21.5-4.0 ^{14}C yr (95.4%) and median= -8.4 ^{14}C yr. The results highlight a significant difference between both pretreatment methods, i.e. 32.9 yr, but with alpha cellulose less offset and statistically within range of the calibration curve. The results suggest that *Tamarix* wood (from similar environments) should be pretreated with an alpha cellulose extraction for more accurate calibration otherwise significant offsets may be present. For alpha cellulose, the offset is small and may be accounted for by laboratory offsets or small regional ^{14}C concentration variations.

INTRA-ANNUAL VARIATIONS OF RADIOCARBON AND STABLE CARBON ISOTOPE IN TREE RINGS TO STUDY THE IMPACT OF SEVERE DROUGHTS IN MEXICAN FORESTS

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Abstract

Northern Mexico has experienced severe and prolonged droughts during the last decades. These droughts have diminished forest productivity, affected tree growth, and increased mortality. The effects and frequency of droughts in Mexico have been studied through dendrochronology with annual resolution using centennial-long datasets of tree-ring widths (Cerano-Paredes et al. 2011, 2021; Stahle et al. 2016); however, there is still a lack in understanding how the meteorological and seasonal variations affect tree growth and physiology, as most Mexican tree-ring records have annual resolution. In recent years, some researchers have explored the intra-annual variations of stable isotopes (mainly carbon and oxygen) in tree-ring cellulose to try understanding plant responses to meteorological changes along the growing season (Miyahara et al. 2024).

In this contribution we present stable carbon isotope ($\delta^{13}C$) on α-cellulose extracted from *Pseudotsuga menziesii* tree rings sectioned in three intra-annual segments (Early wood-1, Early wood-2, and Late wood) for the period 1976 – 2022 from two forests in Northern Mexico. We use these intra-annual $\delta^{13}C$ observations to explain the tree response to changes in meteorological conditions during the growing seasons. Additionally for some selected years we measure radiocarbon concentrations on the three intra-annual segments to better understand the time of carbon assimilation and formation for each tree-ring section. Preliminary results for one of the sites show potential to detect changes in correlation patterns amongst tree-ring sections. For example, the correlation between $\delta^{13}C$ in Late wood and Early wood-1 of the following growth year is significant for the period 1993 – 2010, but drastically changes for the period 2007 – 2022, when severe droughts have affected the area. These results suggest that trees exposed to prolonged hydric stress do not use carbon reserves in the subsequent growing seasons. We expect to further confirm this with the radiocarbon results.

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ANNUALLY-RESOLVED MULTI-PARAMETER ASSESSMENT OF CLIMATE VARIABILITY AND SOLAR ACTIVITY DURING THE 8.2 KA BP EVENT

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Abstract

The 8.2 ka BP event stands out as one of the most prominent and abrupt climate fluctuations of the Holocene, triggered by the catastrophic drainage of the Laurentide Lakes and subsequent freshwater influx into the North Atlantic. While the event's broad climatic impacts across the North Atlantic region are well recognized, substantial uncertainties remain regarding the precise onset, duration, and internal variability of the event, particularly in continental Europe. The project aims to present an annually-resolved reconstruction of hydroclimate variability from 6650–5950 BC, based on stable isotope ratios ($\delta^{13}C$, $\delta^{18}O$, δD) of subfossil oak tree rings (from the Hohenheim tree-ring archive) from southern Germany. Complementary radiocarbon (^{14}C) data provide an independent record of solar activity, supporting an assessment of the interplay between solar forcing and climate variability. The complete radiocarbon record spanning 700 years of single tree-ring data from 6650 to 5950 CE will be presented at the conference. The record represents a critical contribution to the IntCal calibration dataset, improving chronological precision for Holocene radiocarbon dating. Moreover, the ^{14}C data show the presence of resolve solar variability – specifically the 11-year solar cycle.

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THE HISCAR PROJECT: HIGH-RESOLUTION ^{14}C ANALYSIS FOR SOLAR, CLIMATE AND ARCHAEOLOGICAL RESEARCH

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Abstract

Radiocarbon analysis has revolutionized both archaeology and environmental science, and its potential to transform solar physics and climate research is now being realized. The HISCAR project provides high-resolution radiocarbon (^{14}C) measurements from annually resolved tree rings to those fields of research. Allowing the reconstruction of past solar variability, investigating links to climate fluctuations, and adding to the calibration dataset IntCal for improved ^{14}C dating in archaeology.

Focusing on two critical periods, HISCAR will deliver new insights into the 1st millennium CE and the Early Bronze Age (2600-1700 BCE) — both archaeologically and climatologically significant. The 1st millennium CE captures a time of major societal transformations in Europe and beyond, coinciding with large-scale migrations, while also encompassing solar events such as the renowned 774 CE cosmic radiation spike. The Early Bronze Age period covers the emergence of complex societies in the Mediterranean and early state formation in China, punctuated by the 4.2 ka climatic event.

Using one of the world's longest continuous tree-ring archive, the Hohenheim tree-ring archive, the project will generate annually resolved ^{14}C datasets (and extending existing data records) for these two critical windows, improving both archaeological chronologies and reconstructions of solar activity.

We will present the first ^{14}C results of the HISCAR project – annually resolved ^{14}C datasets from more than 600 tree-rings, covering the early 1st millennium CE. These data, combined with new solar and carbon cycle modeling approaches developed in collaboration with the University of Groningen, will enable the extraction of solar-driven ^{14}C signals from terrestrial carbon cycle.

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TRACING HUMAN IMPACT IN FOREST ARCHIVES: CARBON ISOTOPE SIGNALS IN PINE FROM NORTHEASTERN POLAND

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Abstract

Isotopic methods are valuable tools in environmental research, allowing the reconstruction of air quality, climate, and human influence. Tree rings offer high-resolution records of such changes. Since the industrial revolution, atmospheric $\delta^{13}C$ has declined due to fossil fuel emissions (Keeling, 1979). Pollutants like SO_2, NO_x, and O_3 also affect $\delta^{13}C$ in tree-ring cellulose by altering stomatal conductance and photosynthetic processes.

This study analyzes $\delta^{13}C$ in α-cellulose extracted from annual rings of Scots pine (*Pinus sylvestris* L.) from the Suwałki region — an ecologically clean area in northeastern Poland. The $\delta^{13}C$ signal was influenced by both climate (temperature and precipitation) and anthropogenic factors, especially during peak industrial activity. After correcting for climatic effects, $\delta^{13}C$ variations still indicated fossil fuel impact, though in a qualitative manner.

Additionally, $\Delta^{14}C$ was measured in wood samples from the same region using the liquid scintillation method. The resulting ^{14}S values aligned with $\delta^{13}C$ trends, supporting the conclusion that both isotopic systems effectively trace human activity related to fossil fuel combustion.

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RADIOCARBON CONCENTRATION AROUND 774/775 CE IN SUB-ANNUAL TREE RINGS FROM KUJAWY NEAR KRAKÓW

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Abstract

The rapid increase in radiocarbon concentration between 774-775 CE, reported by Miyake et al. (2012, M12), was the first confirmed such phenomenon. A significant increase within one year, of 12‰ in $\Delta^{14}C$ value has been noted. This event has been confirmed independently by several authors (Jull et al. 2014, Güttler et al. 2015a,b, Rakowski et al. 2015, Büntgen et al. 2018) in dendrochronologically dated annual tree rings from different places around the world, which indicates its global character. Single-year samples of dendro-chronologically dated tree rings of deciduous oak (Quercus robur) from Kujawy, a village near Krakow (SE Poland), spanning the years 765–796 CE, were collected and their ^{14}C content was measured using the AMS system. The results presented early in Rakowski eta al. 2015 show a rapid increase of 9.2 ± 2.1‰ in the ^{14}C concentration in tree rings between 774 and 775 CE. In the present study, annual rings between 771 and 778 CE were divided to early wood (EW) and LW (late wood) sub-samples and were measured to determine the occurrence of the event.

Acknowledgments
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RADIOCARBON CONCENTRATION BETWEEN 1258 – 1291 CE IN ANNUAL TREE RINGS FROM KUJAWY NEAR KRAKÓW

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Abstract

Changes in radiocarbon concentration ($\Delta^{14}C$) has been measured in annual dendrochronologically dated tree rings of English oak (*Quercus robur* L.) from Kujawy village near Kraków (southern Poland). Analyzed samples spanning the years 1258 – 1291 CE. Samples were subjected to dendrochronological analysis, which led to the construction of a local chronology (Krąpiec 2001). α-Cellulose was extracted from individual annual growth rings using a multi-step chemical process (Nemec et al. 2010), and graphite samples were prepared for radiocarbon dating using the EnvironMICADAS AMS system (Molnar et al. 2016). Our results indicated increases in $\Delta^{14}C$ values in years 1261/62 CE, 1268/69 CE, and 1279/80 CE, occurring just before the Wolf minimum, like results presented in literature (Miyahara et al. 2022). The possible origins of those events are still not confirmed, including SEP, γ-rays from supernova or GRB, or weak solar minimum. Information about changes in the production of ^{10}Be and ^{36}Cl during these periods, could be helpful to determinate the origin of each event.

Acknowledgments

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ANNUAL RINGS OF *NELTUMA PALLADA* TREE BETWEEN XIII AND XIV CENTURY CE FROM NORTHERN PERU

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Abstract

Currently, the dendrochronological potential of algaroba has been recognised (Rodríguez et al., 2005). Its use in recording events related to the El Niño Southern Oscillation (ENSO) provides important information for climatology, ecology, and dendroarchaeological research (Ghezzi et al., 2002; López et al., 2006; Salazar et al., 2018). In Peru's dry coastal forest, ENSO creates short wet periods (1–2 years) with significant changes in precipitation and temperature. ENSO events can increase rainfall up to tenfold compared to normal years and can influence plant productivity for multiple subsequent years (Holmgren et al., 2006). The frequency and intensity of ENSO events can be studied using tree-ring data from algaroba. However, as with other tropical species, careful adjustments are necessary to account for double and missing rings (Paredes-Villanueva et al., 2013).

This study examines *Neltuma pallida* wood from the Cerro Laguna archaeological site in coastal Peru to establish a floating chronology and absolute dating. Ten cross-sections yielded a 70-year sequence (CLAA1). Five single growth rings from one sample underwent α-cellulose extraction and radiocarbon dating, then wiggle-matching in OxCal v4.4 using SHCal20 (Bronk Ramsey et al. 2001). Results place the youngest ring at 1314–1330 CE (95.4% probability), situating the full sequence between 1253 and 1322 (±8) CE. Statistical analyses show a robust dendrochronological signal, and ring-width data suggest strong El Niño Southern Oscillation (ENSO) events around 1300 CE. These findings confirm Cerro Laguna's Late Intermediate Period occupation and refine Southern Hemisphere calibration curves for radiocarbon dating.

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DENDROCHRONOLOGY OF ALGARROBO TREE FROM NORTHERN PERU

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Abstract

There are reports of visible, annual, climate-sensitive growth rings in trees of the genus Prosopis from Argentina, Bolivia, Chile, and Peru (Ghezzi et al., 2002; Rodríguez et al., 2005; Morales et al., 2012). Therefore, there is potential for the development of dendrochronological sequences in areas where species of the genus grow. In northern Peru, our study area, previous research (Ghezzi et al. 2015) has collected dozens of samples from well-preserved, *in* situ, lintels or columns made from the algarrobo tree (*Prosopis sp.*) in three sites of different age: Chankillo, IIIrd century BC and Cerro Laguna, XIVth century, both in the Casma valley, and Capilla Doctrinal de Morrope, XVIIth century, in the Lambayeque valley. The dendrochronological study of samples from these sites confirms the presence of visible, annual growth rings that cross-date well and correspond in size to annual climate fluctuations, especially ENSO (Ghezzi and Rodriguez, 2015). Their pilot research demonstrated the potential for building floating dendrochronological series from this tree, and of dating them by fitting to the calibration curve (wiggle matching) radiocarbon assays obtained every 10 rings along the series. We have used the bomb curve to proof the annual character of the rings formed by those trees.

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IMPACT OF POLAR STRATOSPHERE DYNAMICS AND SEASONAL PROCESSES ON BOX MODEL INTERPRETATION OF MIYAKE EVENTS

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Abstract

A carbon cycle box model is a simplified representation of the global carbon system, dividing it into interconnected compartments, or 'boxes', representing major carbon reservoirs (like the atmosphere, oceans, and land biosphere) and simulating the fluxes of carbon between them. Box models have proven valuable tools for investigating the causes and mechanisms behind past rapid atmospheric ^{14}C increases, known as Miyake events, and have become a standard approach since the discovery of these phenomena.

However, over-reliance on simpler box models introduces risks for the interpretation of results, as they often represent broad atmospheric averages and may omit crucial dynamic features. Specifically, commonly used models lack a distinct polar stratosphere box. This is a significant omission as this region is not only the primary ^{14}C production site during solar energetic particle events but also remains relatively isolated dynamically for much of the year (e.g., within the polar vortex), limiting mixing with the rest of the stratosphere. Furthermore, these models often neglect seasonal processes like the significant spring injection of stratospheric ^{14}C into the lower atmosphere, particularly linked to the polar vortex breakdown in the Northern Hemisphere.

In this study, we address these limitations by enhancing a carbon cycle box model. We introduce a separate polar box with distinct exchange rates connecting it to the rest of the stratosphere and the troposphere. Furthermore, we explicitly model the pulsed nature of the stratospheric spring injection, account for different photosynthetic sampling periods reflecting geographically varying growing seasons and incorporate the influence of trees' internal carbon reservoirs.

Our findings demonstrate that incorporating these additional features allows the model to generate a wider range of ^{14}C responses corresponding to different geographical settings and local physiological factors. This suggests that observed differences between ^{14}C records could be explained by the combination of atmospheric and biological processes included in our model. For instance, this approach might offer a simpler explanation for the peculiarities of the 660 BC event, often hypothesized to result from multiple successive solar events.

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RECONSTRUCTION OF PALEOCLIMATIC CHANGES DURING THE HALLSTATT PERIOD (830–650 BCE) BASED ON STABLE OXYGEN ISOTOPE ANALYSIS IN SUBFOSSIL OAK WOOD FROM THE VISTULA RIVER VALLEY (POLAND)

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Abstract

This study focuses on reconstructing paleoclimatic changes during the period from 830 to 650 BCE, when the so-called Hallstatt catastrophe occurred - a dramatic shift in climate from warm and dry to cool and humid, which had a significant impact on the environment and the development of societies at that time. This period also coincides with the beginning of a plateau in the radiocarbon calibration curve. The research material consisted of subfossil oak wood, with laboratory codes G24 and G58, extracted from the Vistula River valley during gravel quarrying in Grabie near Kraków. By analyzing the oxygen isotope composition in α-cellulose, extracted from annual growth rings, we were able to identify variations in tree responses to climatic and environmental factors, allowing us to reconstruct the conditions prevailing at that time. The study identified characteristic periods of worsening climatic conditions, mainly in the 8th century BCE, and pinpointed indicator years with the lowest $\delta^{18}O$ values, particularly around 745 and 720 BCE. These results align well with dendrochronological measurements and previous studies on stable carbon isotopes. This research provides valuable insights into the climate dynamics during this crucial historical period and helps us better understand how climate changes affected the environment and human life in that era.

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ANCILLARY STABLE ISOTOPES IN SINGLE BARLEY GRAIN FROM 1852 TO 2020

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Abstract

Radiocarbon ($F^{14}C$) and stable carbon ($\delta^{13}C$) values have been measured in single grains of spring barley (*Hordeum vulgare L.*) from the sample archive from two adjacent sites of the Long-term Experiments (LTEs) Hoosfield Spring Barley at Rothamsted Research (Harpenden, Hertfordshire, UK), covering the growing periods (March to September) of 1852 to 2020 (Dunbar et. al, 2024). The measured $\delta^{13}C$ values revealed a different temporal decline over the pre-bomb and post-bomb timescale, with evidence suggesting a clear breakpoint in $\delta^{13}C$ data occurring in 1995.

Sulfur concentrations in grain are generally very low (ca. 0.1-0.2%) compared to nitrogen and carbon concentrations (ca. 2% and 40%, respectively), presenting an analytical challenge for simultaneous $\delta^{15}N$, $\delta^{13}C$ and $\delta^{34}S$ analysis, and has previously required one sub-sample for $\delta^{15}N$ and $\delta^{13}C$ and a second, larger sub-sample, for $\delta^{34}S$ to obtain sufficient signal and data precision.

Recent advances in Elemental Analysis Isotope Ratio Mass Spectrometry (EA-IRMS) have facilitated rapid, accurate and precise analysis of sulfur at concentrations less than 10 µg, whilst simultaneously acquiring data for and $\delta^{15}N$ and $\delta^{13}C$ (Sayle et al, 2019). As a result, smaller samples are required for analysis, which is also more time and cost efficient. To supplement the existing $F^{14}C$ and $\delta^{13}C$ data set, we present ancillary $\delta^{15}N$, $\delta^{13}C$ and $\delta^{34}S$ data measured simultaneously on the remaining material from each barley grain.

Analysis of the results shows clear temporal trends in the stable isotopes, which also differ in the two adjacent sites. The average $\delta^{15}N$ value at site 1 is 8.9‰ and is 3.5‰ at site 2, while the$\delta^{34}S$ values are 1.2‰ and 2.8‰, respectively. Nitrogen and sulfur have average percentage values of 1.7% and 0.13% (site 1), and 1.5% and 0.12% (site 2), respectively. For $\delta^{15}N$ values, the temporal trend is broadly increasing, while for $\delta^{34}S$ values, the relationship is more complex (decreasing then increasing). Relationships between the N, S and C isotopes are also apparent.

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OCEAN RADIOCARBON AT TWO NUCLEAR WEAPON TESTING SITES

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Abstract

The United Kingdom exploded 3 nuclear weapons in the Montebello Islands, Australia in 1952 and 1956. The first test called test occurred on Oct. 3, 1952 code named Hurricane had a yield of 25Kt and was located in the hull of a ship. The second and third test (May-June 1956) were from a tower and had a yield of 15Kt and 98kt respectively (code named Mosiac G1 and G2). In this study, Porites corals have been collected 10km of the tests. Radiocarbon analyses from ~1950 to 1958 have been undertaken. Two distinct radiocarbon excursions are reproduced in a coral just north of the tests and are record at the appropriate time periods. The radiocarbon rises from a pre-bomb Delta14C value of -70‰ to a maximum of +73‰ in 1952. The second two tests appear as a single peak in the coral and have a maximum value of +90‰. This is compared to a coral collected in Enewetak Atoll where tests (3, total 104kt) in 1948 and 1951(4, total 399kt) show a Delta14C value of +200‰ and +700‰ respectively.

TRACING OF THE SUESS EFFECT INITIATING CO_2 RELEASE SOURCES IN THE URBAN ENVIRONMENT OF VILNIUS CITY

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Abstract

The Suess effect, first described by Suess (1955), refers to the decline in the atmospheric $^{14}C/^{12}C$ ratio caused by CO_2 emissions from fossil fuel combustion. While this effect was once prominent in the early 20th century, it was temporarily obscured by nuclear weapons testing and nuclear energy development. Atmospheric radiocarbon (^{14}C) activity peaked in nuclear weapons testing but has since declined steadily as ^{14}C is absorbed by the biosphere and oceans. Today, its levels have nearly returned to the natural background of approximately 100 pMC (Pabedinskas et al., 2019) with localized deviations in areas of high fossil fuel emissions. Suess effect is particularly evident in highly industrialized and urban areas. Studies have shown significantly lower radiocarbon concentrations in these regions (Rakowski et al., 2001) due to the intense emissions of carbon dioxide from industrial facilities, vehicles, and other common sources. The extent of this effect on ^{14}C concentration varies depending on the proximity to CO_2 emission sources.

This study aims to explore the Suess effect in Vilnius, Lithuania, with a focus on attempt to identify anthropogenic CO_2 contamination sources, primarily from vehicle emissions or heating and electricity producing installations, using ^{14}C as a tool to distinguish between contemporary and fossil-derived carbon. Atmospheric air samples were collected hourly during 7 days in spring, about 30 cm of the ground, near two of the busiest streets in Vilnius and deep within a park as a background area. CO_2 was sampled using a NaOH trapping method, followed by graphitization (AGE-3, Ionplus AG) and radiocarbon measurements with a Single-Stage Accelerator Mass Spectrometer (SSAMS, NEC, USA). The findings reveal that in early spring, the Suess effect in Vilnius reaches approximately 10 pMC, highlighting the significant impact of fossil fuel emissions on urban air quality, caused mostly by high traffic. The emission sources were identified by using atmospheric dispersion backward modelling with HYSPLIT software. Atmospheric dispersion backward modelling using HYSPLIT software confirmed that vehicle exhaust was the major source of emissions in this case.

Tracing of the isotopic shifts in environmental carbon provides insights into pollution sources and atmospheric carbon transport pathways, providing valuable information for an urban air quality management. These findings contribute to broader climate change mitigation efforts by emphasizing the need for sustainable urban development and emission reduction strategies.

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CARBON-14 IN THE ENVIRONMENT NEAR THE BELARUSIAN NPP AND THE IGNALINA NPP IN 2016-2024

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Abstract

Due to the mobility, well-known atmospheric abundance, and biological incorporation of radioactive ^{14}C during photosynthesis, it is important to investigate the ^{14}C excess in the environment surrounding nuclear facilities. The study area in eastern Lithuania included two nuclear power plants located relatively close to each other (98 km): the Belarusian NPP (BelNPP) and the Ignalina NPP (INPP). The Belarusian NPP is located in the northwest of Belarus, in Neris (Viliya) River catchment, near the Belarusian-Lithuanian border, approximately 18 km from Ostrovets and 53 km from Vilnius. Unit 1 was put into physical operation in November 2020, Unit 2 – in April 2022. The INPP, located in the north eastern Lithuania, near the borders with Belarus and Latvia, is currently in the process of decommissioning. Lake Drūkšiai served as a cooling pond for the INPP for 26 years. Unit 1 was operated from December 1983 until its shutdown on December 31, 2004, and Unit 2 – from August 1987 until its shutdown on December 31, 2009.

As previously shown in many studies, traces of ^{14}C, originating from the INPP, are present in Lithuanian terrestrial and aquatic ecosystems near the INPP. We hypothesized that ^{14}C and especially ^{3}H may be present in the environment of BelNPP during its normal operation. In the period 2016-2024, we conducted an extensive study on the distribution of ^{14}C in the vicinity of the BelNPP during its pre-operational stage and initial period of operation, and in the vicinity of the long-stopped INPP.

In the case of BelNPP, it was possible to collect samples from eight points in the vicinity of the BelNPP (inside of the 30-kilometer zone near the border). To represent terrestrial ecosystems of INPP, 4-5 sampling points were selected in the immediate vicinity of the industrial zone (0-5 km) and 8-10 sites in the zone further from INPP (5-30 km). At these selected sites, samples of mugwort stems (*Artemisia* sp.) were collected at the end of growing season nearly every year from 2016-2024. Aquatic biota samples were collected from the Neris River in immediate proximity of the state border with Belarus and included: arrowhead (*Sagittaria* sp.), flowering rush (*Butomus umbellatus*), European bur-reed (*Sparganium* sp.), pondweed (*Potamogeton* sp.), frogbit (*Hydrocharis morsus-ranae*), Canadian waterweed (*Elodea canadensis*), etc. Similar aquatic biota species, but only to a limited extent, were collected from Lake Drūkšiai. To determine ^{14}C in the Neris River water, in the case of the BelNPP, water samples were taken at two points – in the same place where biota samples were taken, and also in sampling point in Vilnius, and in the case of the INPP – also from Lake Drūkšiai. To determine the activity of ^{14}C in water, dissolved inorganic carbon (DIC) was precipitated from large or small volume water samples using appropriate quantities of NaOH and $CaCl_2$.

After standard pre-treatment of corresponding material, the specific activity of ^{14}C in samples of biota and DIC was measured using the liquid scintillation counting (LSC) method. A conventional procedure for benzene synthesis was applied for all biota samples and part of DIC samples. The remaining DIC samples were converted into CO_2, which was captured in a scintillator for absorbing and counting labelled CO_2 (OXYSOLVE C-400). The method with OXYSOLVE C-400, compared to benzene, provides a significantly higher detection limit, but sufficient for rapid assessment. ^{14}C activity counting in benzene and in OXYSOLVE C-400 was performed with a TriCarb 3170 TR/SL. In total, about 90 determinations of

^{14}C using the benzene method and about 160 determinations of ^{14}C using the OXYSOLVE C-400 method were performed in the vicinity of the BelNPP. In the INPP vicinity, about 70 determinations of ^{14}C were carried out using the benzene method.

The mean value of ^{14}C specific activity in mugwort (± standard deviation, SD) in the Lithuanian part of the BelNPP 30-km zone for the period of observations 2018–2024 for different years was as follows: 101.0±0.7 pMC in 2018, 100.5±1.2 pMC in 2019, 100.3±0.6 in 2020, 98.5±0.7 pMC in 2021, 98.5±0.8 pMC in 2022, 99.5±0.9 pMC in 2023, and 97.5±0.5 pMC in 2024. All these data sets do not differ statistically significantly, and the mean value of ^{14}C specific activity in mugwort can be taken for the terrestrial ecosystem as a ^{14}C background value with no traces of BelNPP origin. Very similar data sets are available for 5-30 km zone of INPP, where mean value of ^{14}C specific activity in the same specie for different years was as follows: 101.4±1.3 pMC in 2016, 100.2±0.6 pMC in 2018, 100.5± 0.7 in 2020, 99.3±0.8 pMC in 2022, 100.1±0.5 pMC in 2023, and 98.8±0.5 pMC in 2024. If we compare these data with the data on ^{14}C for the 5-30 km zone of the INPP, then here we have a slight excess of ^{14}C (2-3 pMC) even at a time when the INPP has been in the process of decommissioning for a long time.

The data on ^{14}C in macrophytes from Neris River showed significant variability depending on the ecological group of macrophytes: from 76.9±0.7 pMC in Canadian waterweed to 99.6±0.7 pMC in a flowering rush. Different ecological groups of macrophytes are influenced to a varying degree by the freshwater reservoir effect (FRE). During the entire period of research, only one event, when there was a noticeable release of ^{14}C from the Belarusian NPP into the Neris River, was observed in September 2022. Then ^{14}C excess in two macrophyte species from Neris River was as follows: 4.5±0.8 pMC for *Hydrocharis morsus-ranae*, and 6.4±0.8 pMC for *Potamogeton* sp. A similar excess of ^{14}C can be estimated in the macrophytes of Lake Drūkšiai. The ^{14}C activity in water (DIC) from the Neris River was mostly below 100 pMC, only during the 2022 event it reached 619±3 pMC. The ^{14}C activity in water (DIC) from the Lake Drūkšiai varied within the range of 110-113 pMC.

The obtained results allow us to conclude that in the terrestrial ecosystem at the outer boundary of the 30-kilometer zone during the initial period of operation of the Belarusian NPP, there was no excess of ^{14}C, as in the case of the INPP. However, in the case of the INPP, even 15 years after its shutdown, a small ^{14}C excess is observed in the closest zone (0-5 km). Unfortunately, we do not have data on ^{14}C for the near zone of the BelNPP. In aquatic ecosystems in both cases – the Neris River and Lake Drūkšiai – there is an excess of ^{14}C, the source of which is nuclear power plants.

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TRANSFORMATIONS OF THE RELIEF IN THE BIAŁA NIDA AND CZARNA NIDA VALLEY CONFLUENCE SECTIONS IN THE LIGHT OF RADIOCARBON DATING

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Abstract

The study area includes a fragment of the Biała Nida and Czarna Nida valleys at their confluence near the town of Żerniki. The study area is located in the southern part of the Mesozoic margin of the Holy Cross Mts. The Biała Nida and Czarna Nida catchments have so far been covered by detailed geomorphological and archaeological studies (e.g. Hakenberg, Lindner 1973, Krupa 2015, Maturlak 2024, Przepióra et al. 2024). Archaeological issues in the study area primarily included the Nida bloomery center region located here (Przychodni 2006), which is a small exclave of the main center of the Prehistoric metallurgical industry of the Holy Cross Mts. (Orzechowski 2013).

The aim of the work is to analyze the geological structure and relief of the Biała Nida and Czarna Nida valleys at their confluence and to characterize the influence of natural factors and human activity on the evolution of the study area. The research was based on the results of geomorphological studies, cartographic and historical materials and, above all, archival (Śnieszko 1978) and new radiocarbon dating. DEM and precise drone surveys are used to identify complex, various age paleochannel systems.

Relief in the study area is very diversified. The main factor influencing this is primarily the geological structure. Numerous slopes and tectonic horsts constituting outcrops of the Upper Jurassic rocks (limestones, marls and flints) have limited the lateral migration of Biała Nida and Czarna Nida to some extent over the years. The course of both valleys is determined, among others, by the tectonics of the study area. The terraced bottom of the valleys with the various aged oxbow lakes occurring here indicate different stages of changes in the development of the channel of both rivers (large meanders, small meanders, anastomosis). In the Holocene, lateral migration of the channel was and still is an important factor shaping the valley bottom. At the confluence of the Biała Nida and Czarna Nida, avulsion had a major impact. There are smaller systems of the Holocene oxbow lakes of Czarna Nida (M3 - 4230±70 BP, cal. 3011-2581 BC) within the Late Glacial macromeanders and some cut and fill of the Biała Nida River with channel changes dated to 8100±90 BP, cal. 7443-6699 BC and 7700±100 BP, cal. 6901-6272 BC and changes of sedimentation type dated to 5720±80 BP, cal. 4774-4363 BC.

An important aspect transforming the Biała Nida and Czarna Nida valleys in the Subatlantic was, among others, human activity. The occurrence iron microspherules in the alluvium at the confluence of the Biała Nida and Czarna Nida (Maturlak 2024) and in the middle section of the Czarna Nida (Przepióra et al. 2024) can be associated with the Prehistoric metallurgical activity from the Roman period. They were redeposited from nearby archaeological sites of a production nature in the Biała Nida valley and from

the Czarna Nida basin (Przychodni 2006). In the confluence section, iron microspherules were detected in much younger sediments, while in the middle section of the Czarna Nida River, spherules were also found in the fillings of oxbow lakes from the Roman period. In the sediments dated to the same period upstream of the Biała Nida River, no traces of iron microspherules were found, which is consistent with the lack of bloomerie sites in the area. The iron microspherules discovered in the alluvium allow for the recognition and interpretation of changes in sedimentation and the system of the riverbeds of both rivers at their confluence over the last 2000 years. Currently, in the confluence section of the Biała Nida and Czarna Nida valleys, intensive sand and gravel exploitation is developing, where mining activity is erasing former traces of river activity.

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INFLUENCE OF CO_2 SAMPLING TECHNIQUES ON ^{14}C-BASED BIOGENIC CARBON QUANTIFICATION IN WASTE-TO-ENERGY EMISSIONS

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Abstract

The alteration of the carbon (C) cycle by fossil fuel burning has climatic implications, requiring accurate partitioning of the fluxes of fossil vs biogenic (=renewable) carbon (C) in various applications (eg: Carbon (C) in bioplastics, CO2 emitted by waste to energy plants).

The most reliable and sensitive tool to do that is the usage of ^{14}C combined to AMS high precision measurements. The ASTM D7459 and UNI EN 13528 standards set the methods to quantify the CO2 emissions from waste-to-energy plants by using ^{14}C analyses. One of the crucial points in these methods is the sampling techniques, that can be divided in two categories: "time integrated" sampling, using NaOH or KOH or soda lime (i.e. a mixture of CaO, NaOH and KOH) to trap CO_2 for 6-48 hours, and "instantaneous" sampling, using glass (flasks) or plastic (tedlar bags) canisters to trap flue gas for only a few tens of seconds. The methods accept both sampling techniques without discussing the potential differences that may arise when comparing sampling techniques of different durations.

To address this concern, we have measured the ^{14}C-CO_2 emitted by a waste-to-energy plant (Acerra, southern Italy). Sampling campaigns has been performed monthly for c.a. 6 years (from 2019 to 2025), from 3 gas emission lines using plastic Tedlar bags and glass flasks, or NaOH and soda lime, respectively, for continuous or instantaneous sampling. The ^{14}C content has been measured by Accelerator Mass Spectrometry (AMS).

Preliminary results showed that the percentage of biogenic C ranged from 43 to 53 % (49 % on average), with an uncertainty associated with the sample preparation procedure (CO_2 extraction and analysis) of 0.3 %. No significant differences were found among the 3 emission lines in terms of ^{14}C inferred biogenic fraction suggesting homogeneity in the flue gas production by the plant. An increase in the biogenic fraction in gaseous samples taken during 2023 was observed when sampling with soda lime. Work is in progress to investigate the influence of the sampling technique on the measured fraction of biogenic vs fossil Carbon.

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THE IMPACT OF COVID-19 CONFINEMENT ON PM_1 SOURCES IN VILNIUS, LITHUANIA REVEALED BY DUAL CARBON AND SULFUR ISOTOPE TRACERS

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Abstract

Particulate matter pollution remains a critical environmental concern in urban areas, where its levels can fluctuate significantly due to varying anthropogenic emissions and the implementation of pollution control measures. Submicron aerosol particles (PM_1) are of significant scientific interest due to their profound impacts on climate systems, air quality degradation, atmospheric visibility reduction, and human health risks (Kulmala et al., 2004; Landkocz et al., 2017; Moreno-Ríos et al., 2022). The COVID-19 pandemic introduced an unprecedented global reduction in human activity, providing a unique opportunity to assess changes in air pollution sources and atmospheric processes. Understanding these changes is essential for evaluating the effectiveness of emission reduction strategies and their long-term implications for air quality.

One of the key approaches to identifying PM_1 pollution sources is the use of isotope ratio analysis, which allows for the differentiation between fossil and non-fossil contributions. Radiocarbon (^{14}C) measurements enable the quantification of contemporary (biogenic) versus fossil-derived carbon (Dusek et al., 2013; Garbarienė et al., 2016; Szidat et al., 2009), while stable sulfur isotope ($\delta^{34}S$) analysis provides insights into sulfate origins, distinguishing between sources such as coal combustion, biomass burning, and marine or industrial emissions (Górka et al., 2017; Han et al., 2016).

In this study, we investigate the sources and composition of PM_1 collected at a suburban site in Vilnius, Lithuania, during the COVID-19 quarantine period (November 2020 – March 2021). By applying dual carbon (^{14}C, $\delta^{13}C$) and sulfur ($\delta^{34}S$) isotope analyses, we quantify the contribution of fossil and non-fossil emissions to both carbonaceous and sulfur-containing PM_1. The results are compared to pre-pandemic data to assess shifts in emission patterns. This study aimed to quantify the influence of transboundary air pollution on fossil-derived PM_1 carbonaceous species and sulfate in Lithuania.

Our findings indicate that the fossil fuel contribution to total carbon (TC) in PM_1 decreased to 23 ± 6% and was on average 1.3 lower, compared to previous levels reported in 2014–2015. Fossil fuel emission reductions in Vilnius, Lithuania were possibly attributable to mobility restrictions during confinement. The isotopic composition of stable carbon ($\delta^{13}C$) suggests changes in source contributions, likely influenced by reduced transportation emissions. Furthermore, sulfur isotope analysis reveals that coal combustion (60 ± 10%) and biomass burning (40 ± 10%) were the dominant sulfate sources during the study period. Notably, biomass burning became the primary local source (up to 60%) of PM_1-associated sulfate in winter likely due to increased household heating.

This study provides valuable insights into the evolution of emission patterns during pandemic-related restrictions, highlights the role of isotope analysis in air pollution source apportionment.

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ATMOPSHERIC $^{14}CH_4$ MEASUREMENTS AT THE SWISS ALPINE SITE JUNGFRAUJOCH

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Abstract

CH4 is the second most important anthropogenic greenhouse gas after CO2. While biogenic emissions of CH4 (from agriculture, waste management or wetlands) contain present-day atmospheric radiocarbon (^{14}C) levels, CH4 derived from fossil sources is ^{14}C-free so that $^{14}CH4$ measurements can be used for source apportionment. A dedicated setup to analyse $^{14}CH4$ was developed at the Laboratory for the Analysis of Radiocarbon with AMS (LARA), University of Bern. Typical samples are 60L of atmospheric air collected in bags, which, after extraction result in about 60µg carbon in CH4-derived CO2 form, enough for a ^{14}C gas measurement on an accelerator mass spectrometer equipped with a gas interface system.

Since 2019, biweekly air samples have been collected at the Swiss high-altitude research station Jungfraujoch considered as a European continental background station. In parallel, an atmospheric $^{14}CH4$ transport model was developed to simulate $^{14}CH4$ values for each sample. It is based on the Lagrangian particle dispersion model FLEXPART, CH4 emission inventories, a priori $^{14}CH4$ signatures for each emission type and the regional weather model COSMO. Moreover, ^{222}Radon gas measurements were used as a proxy to detect recent land contact of the troposphere, thus distinguishing atmospheric conditions primarily influenced by the free tropospheric conditions from those influenced by the planetary boundary layer exposed to NPP releases.

This contribution will present the in situ $^{14}CH4$ measurements as well as corresponding simulations to emphasize that the emissions and transport of $^{14}CH4$ emitted from European NPPs are influencing the overall signal measured at Jungfraujoch, despite its high elevation and background characteristics.

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TRACKING URBAN CARBON: HIGH-RESOLUTION MONITORING OF CO_2 AND RADIOCARBON ISOTOPES IN THE ATMOSPHERIC AIR IN GLIWICE

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Abstract

The primary objective of our research is to monitor carbon dioxide concentrations and conduct in-depth analyses of the carbon cycle using mass spectrometry techniques within an urban biosphere in southern Poland. Sampling sites in urban areas play a crucial role in assessing both commonalities and variations in CO_2 levels and their sources. Previous studies (Sensuła et al., 2023) emphasize the need for continuous monitoring, while additional investigations into carbon isotopes in the atmosphere could significantly enhance our understanding of carbon dynamics in these regions.

In 2022, a new laboratory was established in Gliwice (Silesia, Poland) to facilitate precise CO_2 monitoring. This setup enables high-resolution measurements of atmospheric CO_2 concentrations, as well as the collection and analysis of air samples. Additionally, extracted CO_2 is subjected to radiocarbon (^{14}C) analysis via the MICADAS system, providing valuable insights into the isotopic composition of both atmospheric and biospheric carbon.

This study presents the initial results, compiling a dataset of CO_2 and $^{14}CO_2$ molar fractions in atmospheric air samples collected from Gliwice between August 2023 and April 2025. CO_2 levels were recorded using the CARBOCAP GMP-343 sensor, a cost-effective yet reliable measurement tool, while ^{14}C concentrations were determined using the MICADAS technique. Our observations in 2024 revealed that ^{14}C values in air samples varied from -55‰ to -24‰, whereas the monthly CO_2 molar fraction ranged between 428 and 469 ppm, influenced by seasonal patterns.

In January 2025, we initiated the calibration of a new analytical system based on cavity ring-down spectroscopy (CRDS) to investigate the stable isotopic composition of atmospheric gases (CO_2 and CH_4). This advancement is expected to refine our understanding of carbon and methane dynamics in urban ecosystems.

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HIGH-RESOLUTION, SEASONAL STUDIES OF CARBON SOURCES IN ATMOSPHERIC DUST IN SILESIAN VOIVODESHIP, USING THE RADIOCARBON METHOD

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Abstract

Air pollution has a very negative impact on the human cardiorespiratory system including reducing resistance to bacterial or viral infections (Urrutia-Pereira et al., 2020). Particulate matter is a major contributor to overall air pollution. It consists of solid and liquid particles suspended in the atmosphere. PM2.5 and PM1, which refers to particles smaller than 2.5 µm and 1 µm in diameter, respectively, are particularly dangerous.

Gliwice (50°17'37.1'' N 18°40'54.9'' E) is located in southern Poland, within the Silesian Voivodeship in the highly industrialized region of Upper Silesia, which is a densely populated. Due to the high levels of air pollution, the Silesian region has the shortest life expectancy, as well as the highest rates of premature births and genetic birth defects in Poland (Brągoszewska and Mainka, 2022).

Radiocarbon analysis to assess the carbon emission sources in Poland, has been applied so far only in Kraków. The lack of such measurements in the Silesian region, a notably polluted area, indicates a significant knowledge gap. Addressing it will allow the identification specific carbon sources contributions to atmospheric pollution.

We present, here, the first results of radiocarbon measurements of suspended particulate matter in Upper Silesia. The samples were collected on quartz filters between autumn 2024 and spring 2025. We measured the radiocarbon concentration of total carbon collected on the filters. We also attempted to measure organic (OC) and elemental carbon (EC) separately. For this, we tested different methods for removing carbonates and for the separation of OC and EC.

The average value of radiocarbon concentration in the samples measured so far is $F^{14}C$ = 0.46, which corresponds to the 6 200 ^{14}C years. A significant difference is visible after removing carbonates. The combined OC and EC fractions gave an average $F^{14}C$ of 0.28 (10 200 ^{14}C years). Due to the too small mass of EC (<0.1 mg) after thermal separation, we were unable to perform measurements for EC separately thus far but are hopeful that we will be able in the future.

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CONTRIBUTION OF CO_2 FROM BIOMASS BURNING IN MEXICO CITY ESTIMATED USING A MULTI-ISOTOPE APPROACH

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Abstract

Mexico City has substantial CO_2 emissions, mostly attributed to fossil fuels like any other megacity. About 68% of these emissions originate from transportation, with additional contributions from industrial activities, according to the regional emissions inventory of the Metropolitan Area of the Valley of Mexico (SEDEMA, 2023). Given this high reliance on fossil fuels, radiocarbon (^{14}C) serves as a useful tracer to distinguish fossil-fuel-derived CO_2 sources, as per the Suess effect. However, previous studies, particularly those by Beramendi-Orosco et al. (2015, 2018) question the sole effectiveness of using ^{14}C as a tracer in Mexico City due to the complex diversity of CO_2 emissions sources, including seasonal biomass burning from wildfires and agricultural activities, as well as year-round emissions from industrial processes and residential biofuel use.

To address these complexities, we conducted a year-long monitoring of radiocarbon and stable isotope composition ($\delta^{13}C$, $\delta^{18}O$) in atmospheric CO_2, with biweekly sampling. Radiocarbon was captured using NaOH solution traps and analyzed via Accelerator Mass Spectrometry (AMS), while stable isotopes were extracted from air samples in a vacuum line and analyzed using Isotope Ratio Mass Spectrometry (IRMS). Additionally, the HYSPLIT backward frequency trajectory model was employed to track air mass origins and assess wildfire influence (data provided at FIRMS-NASA website) within 3 days prior to the monitoring.

For the mass balance calculations ($\Delta^{14}C_{(obs)}CO_{2(obs)}=\Delta^{14}C_{(bgd)}CO_{2(bgd)}+\Delta^{14}C_{(fossil)}CO_{2(fossil)}+\Delta^{14}C_{(bio)}CO_{2(bio)}$), we accounted for different burned biomass components, including trees, grasses, litter, and soil, following previous considerations from Tangarife-Escobar et al. (2024). This resulted in an estimated mean $\Delta^{14}C_{(bio)}$ value of 384 ± 10 ‰ for the biomass burned, as trees reflect atmospheric radiocarbon levels from the current and past decades, grasses from the current and past year, litter from several decades, and soil, rich in organic matter, may contain radiocarbon formed during the bomb peak era.

Under these considerations, our results reveal that during the dry season, wildfires in surrounding states severely impacted Mexico City's atmospheric CO_2 composition. Radiocarbon mass balances indicated that in March and April—the peak wildfire months—biomass burning contributed approximately 66% and 69% (± 2.5%), respectively, to the total CO_2 in Mexico City. This contradicts expectations of a dominant fossil fuel contribution, highlighting the substantial impact of wildfires and other biomass-burning activities.

Moreover, stable isotope analysis further supported the influence of biomass burning. Keeling plots showed that CO_2 sources included not only fossil fuels but also biomass burning, from C3 and C4 plants

origins, since the observed atmospheric CO_2 isotopic composition $\delta^{13}C$ in Mexico City was a value in between the isotopic fingerprints of fossil fuels and biomass. However, stable isotopes alone could not fully quantify biomass burning's contribution, as C3 plant combustion and fossil fuel combustion produce overlapping $\delta^{13}C$ signatures. Whereas $\delta^{18}O$-CO_2 values were largely influenced by atmospheric conditions, with relative humidity and temperature playing significant roles.

Overall, our findings demonstrate the complementary roles of radiocarbon and stable isotopes in identifying CO_2 sources. They also reveal the great impact of biomass burning—both seasonal and year-round—contrary to what emissions inventories report. Therefore, these results suggest a need for reassessment in the current emission factors since they may underestimate biomass burning emissions, and adjusting them could improve greenhouse gas mitigation strategies and advise policies aimed at reducing CO_2 emissions beyond fossil fuel combustion.

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NOVEL APPLICATIONS OF RADIOCARBON ISOTOPE ($\Delta^{14}C$) IN TRACING CO_2 SOURCES

The radiocarbon isotope ($\Delta^{14}C$), with its unique advantage in distinguishing fossil-derived CO_2 from biogenic CO_2, has become a critical tool in urban carbon cycle research. This study demonstrates the potential of $\Delta^{14}C$ technology in refined CO_2 source apportionment through two innovative case studies, covering the quantitative assessment of human respiration emissions and traffic emissions, thereby providing scientific support for urban carbon budgeting and emission reduction policies.

(1) Quantification of Human Respiratory CO_2 (CO_{2hr}): By integrating $\Delta^{14}C$ measurements with metabolic models, this study systematically determined the CO_2 emission rates (CERs) of different age and gender groups in China for the first time. Taking Beijing as an example, the combination of bottom-up datasets and $\Delta^{14}C$ tracing revealed the contribution of CO_{2hr} to urban atmospheric CO_2: the daily winter emissions reached 22.2 ± 0.6 kt CO_2, accounting for 7.5% of fossil fuel emissions (CO_{2ff}), with the proportion doubling in summer. CO_{2hr} increased atmospheric CO_2 concentration by approximately 2 ppm, contributing 14% to winter biogenic CO_2 (CO_{2bio}).

(2) Optimization of Vehicle Emission Factors (EFs) in Traffic Tunnels: Mobile monitoring and $\Delta^{14}C$ tracing were employed to improve traditional tunnel models. The study found that CO_2 concentrations in tunnels are influenced by the "piston effect," leading to a 27% underestimation of EFs using conventional two-point sampling. Non-vehicle sources (e.g., external air infiltration) contributed 11.3% to tunnel CO_2 enhancement. $\Delta^{14}C$ technology effectively corrected such errors, enhancing EFs estimation accuracy by 10.2%. The optimized EFs were 114.2 ± 9.5 g/km/veh (weekdays) and 95.3 ± 8.9 g/km/veh (weekends).

$\Delta^{14}C$ technology overcomes the limitations of traditional CO_2 source apportionment, enabling the precise identification of complex urban emission sources. Its applications in human respiration and traffic emissions highlight that CO_2hr in megacities is a non-negligible emission source and should be incorporated into regional carbon budget assessments. The refined calculation of traffic EFs provides robust data support for low-carbon transportation policies. Future efforts should integrate long-term $\Delta^{14}C$ observations with multi-source data fusion to further optimize urban carbon neutrality pathways.

BIOLOGICAL PROFILING FROM LIMITED REMAINS: A SINGLE-TOOTH AND NAIL APPROACH

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As unidentified cadavers continue to challenge forensic investigations, there is growing demand for methods that maximize information while minimizing destruction of bodily material. By way of a unique collaboration between the ^{14}C Laboratory at the University of Groningen, the Netherlands Forensic Institute, Dutch National Police, Amsterdam University Medical Centre, and the Geology and Geochemistry cluster at Vrije Universiteit Amsterdam, the power of interdisciplinary science was explored for the reconstruction of biological profiles from only a single tooth and a toenail.

Using these minimal samples, from consenting donors with documented medical histories, we applied a combined protocol that included radiocarbon dating (^{14}C), stable isotope analysis (Sr, Pb, O, C), DNA profiling, toxicology, and trace element (TCA) analysis. The approach enabled the extraction of key forensic indicators, including year of birth, year of death, age, sex, DNA profile, childhood and late-life geographic origin, and drug exposure.

With a success rate of 80%, this protocol proved highly effective and applicable to real forensic contexts. Importantly, the results showed strong agreement with known biological data, supporting both the reliability and relevance of the approach. This study demonstrates the potentials of conducting parallel forensic analyses on minimal material, offering a much less destructive alternative for much modern forensic casework.

COMPLEMENTARY METHODS TO FORENSIC RADIOCARBON DATING

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Abstract

The investigation of poaching, wildlife trade, and other environmental crimes requires the application of forensic methods to non-human biological samples, for instance, for species identification, determination of geographic origin, or time of death. Many of the forensic techniques used in this context are derived from human criminal forensics but require further adaptation for the specific properties of animal or plant tissues. Radiocarbon dating is one such technique. Compared to DNA analysis, adapting radiocarbon dating from human to non-human tissues is relatively straightforward and cost-effective. However, from a forensic perspective, this method suffers, or will soon suffer, from a significant drawback - the decline of atmospheric radiocarbon levels to pre-nuclear testing levels. This leads to a worsening of temporal resolution, expanding the problematic dating range of 1650–1950 to also include samples postdating 2020. To ensure the continued forensic utility of radiocarbon analysis, it is therefore necessary to identify a complementary analytical method capable of at least distinguishing between these two sample groups.

In our preliminary research, we tested two non-standard complementary methods: strontium-90 analysis and electron paramagnetic resonance (EPR).

Most anthropogenic Sr-90 in the environment originates from nuclear weapons testing or nuclear accidents. With a half-life of 28.79 years and chemical behaviour analogous to biogenic calcium, Sr-90 can be incorporated into biological tissues such as bones. In this pilot study, we selected three ivory artefacts of unknown origin, dated them using radiocarbon analysis on the AMS system Multi-Isotope-Low-Energy AMS System (MILEA), and measured Sr-90 levels using the Vienna Environmental Research Accelerator (VERA) combined with Ion-Laser InterAction Mass Spectrometry (ILIAMS).

EPR is a non-destructive method for studying systems with unpaired electrons and is traditionally used in dating and emergency dosimetry. So far, its use has been limited to materials that are either very old or have received a high dose of ionizing radiation. However, this limitation may be overcome with new helium-cooled EPR technology. We demonstrate the latest developments using an ivory sample as a case study.

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THE USE OF RADIOCARBON DATING OF ANIMAL EYES IN WILDLIFE CRIME

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Abstract

The illegal trade, killing, obtaining, and possession of animals and plants in violation of the law is known as wildlife crime. The motivation for this criminal activity often lies in obtaining valuable animal parts, such as teeth, claws, skin, horns, or entire hunting trophies, which can then be sold on the black market. The trade in endangered species of animals and plants ranks among the most profitable areas of organized crime, alongside human trafficking, drug trafficking, and the trade in counterfeit goods. Low penalties, fines, the low probability of arrest, and weak law enforcement in wildlife crime contribute to the attractiveness of this illegal activity. However, this form of crime does not only threaten specific animal species but also has serious consequences for entire ecosystems, biodiversity, socioeconomics, and may also pose risks to human safety and health.

To effectively detect and solve wildlife crime, it is necessary to use various forensic methods, such as morphology, genetic analysis, toxicology and pathology. Radiocarbon dating, although not commonly used, can be crucial in certain cases, especially in determining the age of specimens, i.e. the time that has passed since their death. In some regions, the concentration of radiocarbon ^{14}C has reached pre-bomb levels, so it is appropriate to use tissues that gradually grow, such as ivory, bones, teeth, and claws, for dating purposes. For correct application and to reduce ambiguity in the results it is necessary to understand the process of tissue growth. Animal eyes can be considered as chronological tissues, because different parts of the eye are of varying ages due to development and metabolic processes. For example, the lens of a vertebrate eye contains metabolically inactive crystalline proteins synthesized during prenatal development, while the metabolically active retina contains proteins from the time close to the individual's death. The eye therefore holds information about both the individual's birth date and the date of death. This information can be useful in verifying the age and legality of protected animal carcasses stored by hunters or taxidermists, whose activities are investigated by law enforcement.

In our pilot study, the eyes of five different mammals (lynx, leopard, lion, seal, and bison) were analyzed. The sclera, cornea, retina, and individual parts of the lens (inner, outer, and capsule) were dissected from each eye. The results indicate that the oldest part of the eye is the lens. The youngest part of the eye was different among the analyzed animals. For further development of the study and a more comprehensive understanding of the issue, it will be necessary to analyze a larger number of mammalian eyes. Nonetheless, it can be concluded that radiocarbon dating of eyes, in combination with other forensic techniques, can provide valuable information in the fight against wildlife crime.

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RADIOCARBON DATING AND BAYESIAN ANALYSIS IN THE IDENTIFICATION OF SEIZED IVORY USING SCHREGER PATTERN SAMPLING AT LACUFF

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Abstract

This study aims to strengthen efforts to combat ivory trafficking by analyzing modified pieces seized by the Brazilian Federal Police. In collaboration with the Radiocarbon Laboratory at the Fluminense Federal University (LACUFF), a protocol was developed to determine the age of these modified pieces, assessing whether they can legally enter commercial circulation. According to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), ivory pieces dated after 1975 are prohibited from trade.

Since samples with pMC greater than 100 are classified as modern, this indicates that they date to post-1950. This methodology of radiocarbono dating not only enhances forensic investigations conducted alongside the Brazilian Federal Police to combat ivory trafficking but, when integrated with geolocation techniques, also serves as a valuable tool for enforcement agencies working against elephant poaching.

When a complete tusk is available, it is possible to determine both the most recent and the oldest growth layers using the Schreger pattern. However, for modified ivory pieces, the feasibility of this technique depends on their geometric shape. In many cases, this approach is not applicable, as a significant portion of seized ivory consists of altered or carved pieces.

By incorporating prior knowledge and updating it with new evidence, this approach provides more accurate chronological reconstructions, enhancing forensic assessments and regulatory decision-making.

Additionally, Bayesian analysis allows for the estimation of the annual growth of the piece. To preserve the structure of the tusk, only two sampling points are typically taken. However, in modified ivory pieces, additional sampling points are often necessary to determine the growth sequence based on the chronological model. For this approach to be effective, it is crucial to analyze a piece whose age spans the bomb peak, allowing for a more precise chronological reconstruction.

Complementary to this, forensic isotope analysis provides geolocation data through isotopic signatures. When combined, these techniques allow for a precise determination of the piece's growth rate, origin, and age, ultimately improving the Ivory ID database. The radiocarbon dating analysis was conducted using a Single Stage Accelerator Mass Spectrometry System, manufactured by NEC, operating at 250 kV, installed at LACUFF. These results will be further discussed in this study.

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FORENSIC ANALYSES AT THE SUERC RADIOCARBON LABORATORY

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Abstract

During the last 15 years the SUERC Radiocarbon Laboratory has analysed over 600 samples of potential interest to police or legal investigations. This covers a range of different sample types, with casework including discovered human remains, wildlife crime and counterfeiting.

The majority of these 'forensic' cases involve discovered human remains, where initial AMS measurement can confirm whether the subject was alive during the nuclear era (post-1955). Further analyses on individuals falling on the 'bomb peak' may help narrow the year of death or suggest the year of birth, with supplementary information provided by dietary and ancillary isotopes.

An overview of the laboratory procedures for forensic samples is presented (including the selection of additional confirmatory analyses where appropriate), along with summary statistics of the types of samples received, and range of results, over the last 15 years.

DATING OF LIME AND DOLOMITIC LIME ANGLO-SAXON AND EARLY MEDIEVAL CHURCH MORTARS USING RAMPED PYROLYSIS

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Abstract

The ability to directly date lime and dolomitic lime mortars is critical to understanding the chronological development and organization of Anglo-Saxon and early medieval ecclesiastical structures across the British Isles.

Ramped pyrolysis (RP) radiocarbon dating was applied to lime lumps (LL) retrieved from 6 bulk mortars, across 4 different sites. The sites are English Anglo-Saxon and early medieval churches and include Ripon Cathedral crypt, believed to be the earliest surviving structure of any English Cathedral (its foundation is associated with St. Wilfred in the mid-7th century AD). The mortars analysed include both lime and dolomitic lime mortars. For the latter, this is the first application of ramped pyrolysis.

For each lime lump sample, 3-6 fractions of CO_2 were trapped at increasing temperatures during ramped pyrolysis thermal decomposition (typically in the range 600-800°C) and subsequently graphitized and radiocarbon dated. Wood and charcoal fragments were also extracted from several of the bulk mortars and dated.

Four of the six mortars provided well-behaved or acceptable age-temperature curves with a series (≥3) of radiocarbon dates in statistical agreement and providing an age estimate for the associated structure. These estimates are in good agreement with archaeological interpretations. In particular, for Ripon cathedral, an age estimate of 598-666 cal. AD (95.4%) provides the first secure scientific dating of the crypt and confirms its 7th century foundation.

The results from Kirk Hammerton church (late 12th century cal. AD) demonstrate the promising application of RP to dolomitic mortars. The presence of layered double hydroxides (LDH) in the thermal decomposition curves (%CO2) at lower temperatures (< 600°C) are striking. The results confirm their removal/negation by trapping higher temperature fractions. Radiocarbon dates on these LDH fractions also demonstrate their association with slow and prolonged CO_2 capture (i.e. younger dates).

Radiocarbon dates on wood/charcoal are older than associated lime lumps on the order of 1-2 centuries. These can only be regarded as *Terminus Post Quem* dates on account of potential old wood effect.

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CHARACTERIZATION OF POLYMERS BIO-BASED CONTENT AND ELEMENTAL COMPOSITION USING ^{14}C AND ICP-OES TECHNIQUES

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Abstract

Plastics are one of the anthropogenic era's dominant materials, widely used in many areas of industry and life over the years due to their versatility and low costs. More than a third of the world's plastic production is used for packaging that comes into contact with food and the human body. Environmental concerns and the limited availability of fossil resources mean that plastics from renewable sources are becoming increasingly important. The present study presents a combined analysis of partly fossil and partly bio-based polymers using accelerator mass spectrometry radioactivity (C-14) and inductively coupled plasma optical emission spectrometry techniques. Different types of polymer samples were analysed, including raw materials, commercially available final products and selected materials from recycling plants. Elemental analysis was used to determine the amounts of selected elements (Ag, Al, B, Ba, Bi, Ca, Cd, Co, Cu, Cr, Fe, K, Li, Mg, Mn, Na, Ni, P, Pb, Pd, S, Sb, Sn, Sr, Ti, Zn). The measured concentration results give a good indication of the quantitative relationships of the additives added during the manufacturing processes and the importance of Ca. When the concentrations of lead and cadmium in the samples were compared with the limit values of the EU legislation, it was found that only one bin liner with a lead concentration of 294 mg kg-1 exceeded the limit value of 60 mg kg-1. The bio-based carbon content of each fossil and bio-based polymer tested by our C-14 measurements was within the expected quantitative ranges. In the case of the PLA-based samples, we observed products that differed from the expected, 100 % bio-based value . By comparing the two analyses, it was concluded that despite the lack of a close relationship, a much more comprehensive picture of the polymers can be obtained by combining the two measurement techniques.

ISOTOPE FRACTIONATION CORRECTION IN RADIOCARBON DETERMINATIONS REVISITED

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Abstract

Problems with isotope fractionation correction in radiocarbon determinations in mixtures are a significant consideration in industrial applications of radiocarbon dating. These corrections are necessary to account for variations in the ^{14}C concentration that occur during the transfer of carbon from atmospheric CO_2 to the medium in which the ^{14}C / ^{12}C ratio is measured. Depending on the analytical technique, this medium may be graphite or CO_2 for AMS and PIMS, or CO_2, CH_4, or C_6H_6 for GPC or LSC. Nearly all steps involved in transferring carbon atoms from atmospheric CO_2 to the counting medium introduce isotopic fractionation. Fractionation correction is mandated by European and American standards (e.g., ASTM D6866-16, EN 16640:2017, EN 16785-1:2016-01). The correction for ^{14}C fractionation is based on $\delta^{13}C$ measurements in the counting medium and assumes a constant difference between ^{14}C / ^{12}C and ^{13}C / ^{12}C fractionation. However, several authors have indicated that this assumption is not well-established. Even when assuming known and constant differences in ^{14}C / ^{12}C and ^{13}C / ^{12}C fractionation, the correction method proposed by Stuiver and Polach (1977) can, in certain cases, lead to systematic errors exceeding the statistical uncertainty of modern ^{14}C concentration or radioactivity determinations. This issue is particularly significant for mixtures containing a "dead" carbon substrate, which is commonly encountered when determining the proportion of bio-components in a product.

The poster discusses this issue and proposes a solution involving making sure there is a dead carbon admixture in the sample, using radiocarbon measurement to estimate pMC without $\delta^{13}C$ correction, estimating the share of no-dead carbon in the mixture, measuring $\delta^{13}C$ for the "bulk" mixture, estimating $\delta^{13}C$ in the dead carbon admixture, calculating $\delta^{13}C$ for the correction, and applying the calculated $\delta^{13}C$ to the Stuiver & Polach formulas for isotopic fractionation correction.

Acknowledgments

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DETERMINATION OF RADIOCARBON CONTENT IN LIQUID FUEL BLENDS IN THE GLIWICE RADIOCARBON AND MASS SPECTROMETRY LABORATORY

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Abstract

The increase in biobased material usage requires the methods of verification to investigate the actual content of biocarbon in such materials, including liquid fuels. The determination of biocarbon in liquid samples using ^{14}C required adaptation of existing sample preparation methods (Baranyika et al. 2022). In this study, both accelerator mass spectrometry (AMS) and liquid scintillation counting (LSC) methods were used to determine the content of ^{14}C in six different liquid fuel blends produced from purely bio-based hydrotreated vegetable oil (HVO) and a ^{14}C-free petrodiesel sample (ON/UF-BC). The results obtained for pure petrodiesel provided background values. The results indicate a good agreement between LSC and AMS, and a linear correlation between the ^{14}C measurement results for blended samples and HVO content affirmed the reproducibility between the two methods (Baranyika et al. 2024). The minor differences between AMS and LSC may result from the different carbon conversion efficiency during the benzene production, although the corrections were made for carbon isotope fractionation effect. However, due to the observed discrepancy of results obtained for blend-15 during the reproducibility test using the LSC method, this sample was subjected to further studies with AMS. The repeatability of AMS results was tested on 10 aliquots, and the results were reproducible.

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RESULTS FROM THE FIRST INTERNATIONAL COMPOUND-SPECIFIC RADIOCARBON INTERCOMPARISON: BULK AND COMPOUND-SPECIFIC FATTY ACID ANALYSES OF BOG-BUTTER STANDARDS

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Abstract

Interlaboratory comparison exercises have underpinned accuracy and trust in radiocarbon dating for decades, from the early International Collaborative Study (Scott et al., 1990) to the recent GIRI exercise (Scott et al., 2022). These broad exercises, and others focussed on single sample types have established robust statistical benchmarks and greatly improved our understanding of consistency among ^{14}C laboratories. Until now, however, compound-specific radiocarbon analysis (CSRA) has not benefited from a dedicated intercomparison exercise. We present the design and outcomes of the first compound-specific radiocarbon intercomparison exercise. This exercise consisted of three samples; two newly developed bog butter standards (largely consisting of $C_{16:0}$ and $C_{18:0}$ fatty acids (Casanova et al., 2021), and a third 'blind' sample comprised of a mixture of these.

In this intercomparison, five laboratories with CSRA capabilities each received identical aliquots of the three bog butter samples to process and analyse. Sample preparation techniques and target sizes were not specified and it was left for each lab to apply their own methods best suited to their current applications. Laboratories were encouraged to report replicate dates for the $C_{16:0}$ and $C_{18:0}$ fatty acids in each sample in addition to bulk dates for the bog-butters.

Our statistical approach was modelled upon that of the recent GIRI exercise. We report consensus values and uncertainties derived from the collective dataset and an analysis of the effects of sample size and other factors on the accuracy and precision of measurements. Importantly, the intercomparison has provided robust consensus values for these standards, which will be made available to the wider community as QA/QC standards.

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EVALUATING ^{14}C BACKGROUND AND CONTAMINATION SOURCES IN A MODIFIED PREP-GC SYSTEM FOR CSRA AT THE NEIF RADIOCARBON LABORATORY

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Abstract

We report recent developments in compound-specific radiocarbon (^{14}C) analysis (CSRA) at the NEIF Radiocarbon Laboratory, SUERC, UK. Our methodology applies preparative gas chromatography (Prep-GC), which combines analytical gas chromatography with post-column sample collection, enabling efficient isolation and recovery of volatile target compounds from complex sample matrices.

Initial efforts employed a Gerstel GC Preparative Fraction Collector (PFC) equipped with a heated transfer line, a Deans Switch (1:10 split), and a Large Volume Injector (LVI). Typical analytical protocols included multiple injections of 10 µL, with a solvent vent method optimized according to compound concentration. Target compounds were collected using solventless traps consisting of quartz tubes plugged with quartz wool (1).

We found that trapping efficiency was consistently low under the above configuration which we addressed by replacing the Deans Switch with a cross-piece assembly configured to achieve a 1:99 split ratio between the GC and the PFC. This modification resulted in a significant improvement in compound collection yield. However, it also altered the transfer path between the GC and fraction collector, necessitating a comprehensive assessment of contamination sources and ^{14}C background levels introduced by the revised system. Using ^{14}C-dead standards, a correlation was observed between collected sample volume and ^{14}C content, with smaller volume samples (e.g., 0.37 ml) demonstrating increased susceptibility to contamination.

Carbon contamination is most likely derived from various primary sources, including: (i) carbonaceous impurities introduced by the quartz wool used in compound traps; (ii) degradation products from the stationary phase of the GC column ("column bleed"); and (iii) cumulative contamination arising from repeated sample injections. These findings highlight the critical importance of system configuration and material selection in minimizing contamination and maximizing the reliability of CSRA measurements.

Acknowledgments
We acknowledge support from the UK Natural Environment Research Council via the National Environmental Isotope Facility (NEIF) grant funding (NE/S011587/1).

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EXPLORING COMPOUND-SPECIFIC APPROACHES FOR RADIOCARBON DATING OF CHARCOAL – DEVELOPING A FRAMEWORK FOR CHALLENGING SAMPLES

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Abstract

Established methods for dating charcoal from an archaeological context at the Oxford Radiocarbon Accelerator Unit (ORAU) include acid-base-acid (ABA) and acid-base-wet oxidation with stepped combustion (ABOX-SC) (Bird et al., 1999; Wood et al., 2012). Both techniques have their advantages with ABOX-SC especially useful at removing younger carbon contamination which is problematic for dates exceeding 25 ka BP (Higham et al., 2008). However, these methods can be extremely destructive where poorly preserved material is treated. This is especially relevant for charcoal from hot and humid regions which rarely survive these pretreatment approaches, and so there is demand in the community to develop alternative approaches.

One potential solution is to carry out compound-specific radiocarbon dating on compounds with known sources, avoiding the issues of sample loss, so long as sufficient quantities of key biomarkers can be collected. Here we outline a framework to investigate the utility of key pyrolysis biomarkers in charcoal. Levoglucosan, a six carbon-ring anhydrosugar is a current candidate for radiocarbon dating as it is readily produced during the pyrolysis of wood and formation of charcoal. Levoglucosan has been previously detected using both GC-MS and LC-MS using both derivatised and underivitised approaches, but further development is needed to make this compound amenable for preparative fraction collection and ^{14}C AMS. Burning of wood also produces a suite of polycyclic aromatic hydrocarbons (PAHs) due to incomplete combustion which are known to have been previously ^{14}C dated for atmospheric fossil fuel source apportionment studies (Fu et al., 2024), but limited work has been done directly on charcoal as a dating tool.

We report on progress at the ORAU to extract, purify and separate these key compounds which constitute a key fraction of charcoal, assessing the advantages and challenges of these approaches.

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CARBONATE REMOVAL FROM RADIOCARBON SAMPLES USING A "NO LEACH" ACID PRETREATMENT TO RETAIN MOBILE ORGANIC CARBON

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Abstract

Radiocarbon (^{14}C) samples, such as sediments and soils, often contain carbonate. This carbonate must be removed prior to combustion when ^{14}C analysing the organic component of samples, otherwise it could be a significant contaminant. A standard approach to remove carbonate from organic samples is hydrolysis with an acid (e.g. HCl), with excess acid being rinsed away using water. Unfortunately, rinsing can also leach mobile organic carbon, therefore potentially altering the ^{14}C content of the sample, especially if the mobile organic carbon has a different ^{14}C content to the bulk organics. This is a particular concern for carbon cycle studies because removal of a 'young' mobile fraction could significantly affect calculations of carbon turnover time.

To avoid this issue, carbonate removal from organic samples can be undertaken using acid fumigation. At the NEIF Radiocarbon Laboratory, this involved using concentrated HCl to fumigate water-moistened samples over a period of three days, followed by neutralisation in the presence of KOH for a further three days, before freeze drying. While this approach was generally effective at removing carbonate, the use of highly concentrated acid poses a health and safety risk to the operator as well as potentially damaging equipment during the freeze-drying process if a large amount of HCl remained in the sample.

Here, we report a "no leach" acid pretreatment to remove carbonate but retain mobile organic carbon fractions, prior to combustion and radiocarbon analysis. Our "no leach" method requires samples to be weighed into initially unsealed exetainers and reacted overnight with 0.2 M HCl. The exetainer is then sealed and flushed with high purity nitrogen gas, injected with further 0.2 M HCl, and after 4 h tested for the presence of CO_2 in the headspace using a non-dispersive infrared CO_2 sensor. If no CO_2 is detected in the headspace of the exetainer it indicates that carbonate removal is complete, and the sample can proceed to freeze-drying and combustion. If the sensor detects the presence of CO_2 decarbonation is unlikely to have been completed, and further hydrolysis and testing is undertaken until no CO_2 is detected.

Our "no leach" method has been found to be effective for removing carbonate and tests using standard materials of known ^{14}C and $\delta^{13}C$ content, with and without carbonate addition, have provided results in agreement with consensus values. Sample processing is more rapid compared to our acid fumigation method, and the addition of the headspace test with the CO_2 sensor provides us with confidence that samples have been completely decarbonated. Moreover, replacing the use of concentrated HCl with 0.2 m HCl provides a significant improvement for staff safety.

Acknowledgments

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NEW REDUCTION SYSTEM IN THE TRONDHEIM RADIOCARBON LABORATORY

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Abstract

We purchased a new automated reduction system for the Trondheim radiocarbon laboratory to supplement the existing two systems (one automated and one manual). The CORgiS system manufactured by UAB Barnas was installed in late 2024. It uses a zeolite trap to capture CO_2 gas from an Elemental Analyzer and reduces the gas to graphite with a hydrogen reaction on Fe powder. The graphite produced is measured at the Trondheim 1MV accelerator (Nadeau et al. 2015).

For maximal flexibility in running measurements at the accelerator, our different reduction systems (Seiler et al. 2019) should produce comparable graphite so that samples from the different systems can be measured together in the same wheel. This means adjusting sample sizes and Fe amounts so that the extracted ion current is similar for all systems, as well as assuring complete reduction of the gas to avoid any fractionation.

Besides the direct performance of the reduction process, we show the results of standard and blank samples from our new reduction system including background values corresponding to >48000 yrs BP. We also compare the results to samples of our previous reduction system with respect to current output, lifetime in the ion source, Li content and accuracy of the measurement results.

Acknowledgments
This purchase of the reduction system has been supported by NTNU's strategic funds, project number 949024114.

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25 YEARS OF AMS AT THE UNIVERSITY OF GEORGIA

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Abstract

The Center for Applied Isotope Studies (CAIS) was originally founded in 1968 as the University of Georgia Geochronology Lab. In 1977, the name was changed to better reflect its expanded mission and broader focus. In 2000, CAIS installed one of the first NEC compact AMS system in the US: a 500KV 1.5SDH-1 Pelletron equipped with 134-cathode MC-SNICS (CAMS) negative ion source. In 2011, the Center acquired a 250KV NEC Single Stage AMS (SSAMS) also equipped with the similar ion source. The CAIS AMS laboratory supports both the Geochronology Radiocarbon Lab and the Natural Products and Biobased Analyses Lab, determining bio-based content in industrial fuels and products in accordance with ASTM D6866-24.

Over the years, with the support of NEC, the original source design was modified to significantly increase the current out of the source and dramatically improve precision. An updated extractor unit developed by NEC was also tested, which slightly increased the current, but developed electrical conduction between insulated elements and failed within a few months. As a result, it was replaced with the original unit, which continues to function effectively. After nearly 20 years of service, the CAMS injection magnet chamber developed vacum leak due to sputtering of the side wall by Fe^+ ions and had to be replaced with a refurbished chamber donated by the UC Irvine AMS Lab. The original injection magnet isolation on the SSAMS was thin and was perforated after a few years, so it was replaced with a thicker material. Both machines also underwent computer system upgrades, which were challenging but ultimately successful. The Center also became accredited under ISO/IEC 17025:2017 for ^{14}C and stable isotopes in 2020.

The Center is equipped with four manual graphitization lines (each with 12 reactors), two AGE3 systems, one of which includes an Elementar IRMS system for simultaneous analysis of stable isotopes, and a carbonate handling system that produces CO_2 from carbonate and water samples for graphitization. When everything operates smoothly, this equipment is capable of producing up to 100 graphite samples per day. However, periodic issues do arise, such as communication problems between the IRMS and AGE systems. On average, the CAIS produces approximately 60 graphite samples per day.

Over the past 25 years, the Center's capacity has expanded significantly, growing from just a few hundred samples per year to over 11,000 unknowns plus about 4,000 standards and backgrounds annually by 2024.

OXFORD RADIOCARBON ACCELERATOR UNIT: STATUS REPORT

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Abstract

The Oxford Radiocarbon Accelerator Unit (ORAU), established in the early 1980s, forms part of the UK Natural Environment Research Council's (NERC) Natural Environmental Isotope Facility and in addition undertakes research and development, as well as collaborating on external projects. Since the foundation of ORAU, the Unit has reported over 45,000 radiocarbon dates and currently produces dates on around 2,000 unknowns per year. In January 2019 the Unit accepted a MICADAS 200 kV AMS (Number 23, Ionplus AG, CH). Here we provide updated methods, and procedural and instrumental backgrounds associated with the MICADAS.

CRONO AUSTRAL: THE FIRST RADIOCARBON SAMPLE PROCESSING AND GRAPHITIZATION LABORATORY IN CHILE – STATUS REPORT

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Abstract

Crono Austral is the first graphitization laboratory for radiocarbon dating in Chile, established as a spin-off from the University of Magallanes (UMAG). It was developed with equipment acquired by the *Centro de Investigación GAIA-Antártica* (CIGA), UMAG, through funding from the Chilean Ministry of Education (MINEDUC). The laboratory operates across two facilities: a wet laboratory in Concepción, where organic matter is chemically pre-treated, including holocellulose and collagen extraction; and the main facility in Punta Arenas, where samples are graphitized using an Elementar Analyzer and a Carbonate Handling System (CHS2, IonPlus) connected to an Automatic Graphitization Equipment (AGE3, IonPlus).

Crono Austral processes a wide range of environmental samples, including organic matter, bones, sediments, carbonates, and water. Together with the unknown samples, the primary standard OX-II, processing blanks, and secondary standards selected to match the material and age of the unknown samples are processed routinely. Since 2022, the laboratory has processed 589 unknown samples, primarily for archaeologists in Chile, followed by earth science researchers. The mean background value so far is 44,829 ^{14}C years BP (n=97), and OX-II results show a mean fraction modern value of 1.3401 ± 0.0040 (n=105), aligning with the reference value (1.340119 ± 0.000184; Wacker et al., 2019).

After graphitization, samples are sent for AMS radiocarbon quantification, mainly to the W. M. Keck Carbon Cycle Accelerator Mass Spectrometer Facility from the University of California, Irvine (79%), with additional submissions to the Center for Applied Isotope Studies at the University of Georgia (13%) and Direct AMS (8%). As the first facility of its kind in Chile, Crono Austral represents a significant advancement for national research, enabling greater accessibility to radiocarbon dating. Ongoing projects include optimizing methodologies for water sampling and storage, as well as processing diverse samples from the Atacama Trench. Here we present the status report of the first three years of functioning of the Crono Austral laboratory, sample processing protocols and results.

Acknowledgments
Special acknowledgement to *Centro de Investigación GAIA-Antártica* (CIGA), the University of Magallanes, the Chilean ministry of Education for funding for the graphitization laboratory equipment. Additional thanks to the *Laboratorio de Oceanografía Microbiana (LOM), Universidad de Concepción* and *Laboratorio de Química de Productos Naturales* for collaborating with laboratory equipment for processing of samples; to Francisca Santana for her aid in establishing collagen extraction methodologies; and to KCCAMS for their advices aimed at improving results.

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SAMPLE PRE-TREATMENT, GRAPHITIZATION AND AMS UPDATES FROM THE ANU RADIOCARBON FACILITY

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Over the 17 years of operation, the ANU Radiocarbon Facility has trialed different sample pretreatment methods, different graphite preparation methods and AMS settings. This presentation will discuss the various processes we have employed and detail our current procedures for a measurement from start to finish. We will discuss sample size requirements and errors associated with sample size. We will also update AMS operations and 6 months using the new NEC hardware for operations.

STATUS REPORT OF THE NOSAMS MICADAS: 3-YEAR UPDATE

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The National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility at the Woods Hole Oceanographic Institution provides ^{14}C-AMS analyses and expertise in support of the US oceanographic and earth science communities. NOSAMS measures on average 7,300 unknowns per year on two unique AMS instruments: the CFAMS system, based around a 500 kV NEC Pelletron tandem accelerator with a modified 134-position NEC MC-SNICS ion source, and an IonPlus 200 kV MICADAS with gas interface and associated sample introduction peripherals (elemental analyzer and carbonate handling system) installed in 2022. Here, we provide an update on the NOSAMS MICADAS three years on, including quantification of system accuracy and precision with both solid and gaseous samples, comparison of data from materials measured as both graphite and CO_2 gas, and optimization of protocols and operating conditions. We also discuss ongoing issues with variable sample sizes.

STUDY ON ACCURACY AND PRECISION OF AGE DATING OF SAMPLES WITH AGES OF NEAR/OVER 50,000 YRBP USING AMS MEASUREMENT

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Abstract

Accelerator Mass Spectrometer (AMS) is widely used to determine sample ages through isotopic-ratio measurements of radiocarbon. It is often required to measure very old samples, which produce small signals from counting system of AMS. To ensure accurate and reliable measurements of these small signals, it is crucial to investigate the minimum detectable signal size that can be measured with appropriate accuracy and precision. Additionally, stability of the blank signal should be examined to assess the confidence level of small signal measurements.

The upper limit of the ages that can be obtained using modern AMS facilities is around 50,000 yrBP, which is approximately nine times the half-life of radiocarbon (5730 years). Therefore, it is easy to estimate that AMS can measure isotopic ratios of ^{14}C to ^{12}C as small as the $1/2^9$ (or 1/512) of the modern ratio. Because the typical isotopic ratio of radiocarbon in modern samples is 1×10^{-12}, the maximum achievable age with AMS corresponds to a radiocarbon isotopic ratio of 1.95×10^{-15}. This value is very close to the blank values observed with modern AMS systems across various AMS laboratories.

In this study, the fluctuation of blank values of the KIGAM AMS system, 1 MV HVEE AMS (Hong et al., 2010), was evaluated precisely to assess the stability of the multiple blank values. The minimum measurable isotopic ratio (MMIR) was defined as 10 times standard deviation of blank values. The maximum age that can be obtained with our AMS system was then calculated based on the MMIR. Furthermore, a case study of an ancient meteor crater in Korea is presented as an application example.

Acknowledgments
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A NEW 1MV MULTI-ELEMENT AMS AT BNU

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Abstract

A new 1MV accelerator mass spectrometry (AMS) system has been established at the State Key Laboratory of Earth Surface Processes and Hazards Risk Governance (ESPHR) of Beijing Normal University (BNU) of China in 2024. BNU-AMS system has the high sensitivity characteristic for all AMS trace amount of radioisotopes from berillium-10 to plutonium-240. Through half a year of commissioning, the routine measurement of ^{10}Be, ^{14}C, ^{26}Al, ^{41}Ca, ^{129}I, ^{239,240}Pu and ^{236}U is now a reality. For radiocarbon analyses a precision of better than 0.2% with 1-σ value in the ratio of $^{14}C/^{12}C$ for the standard OX-II samples and the background level of 7×10^{-17} from commercial graphite targets without sample preparation have been achieved. Both IAEA-C5 and FIRI-D are confirmed to match the reference value within the 1-σ range.

Acknowledgments
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10 YEARS MICADAS FOR ANALYSIS OF REGULAR AND SMALL SAMPLES AT TANDEM LABORATORY, UPPSALA UNIVERSITY

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We report on 10 years of operation of a MICADAS accelerator for radiocarbon analysis at the Tandem Laboratory national research infrastructure at Uppsala University. In this contribution we detail method development and optimizations in our sample preparation, measurement and data-analysis routines.

The volume of samples has continuously risen in the past. To cope with sample numbers of up to 5000 per year, a set of programs has been developed, vastly improving efficiency in database operations, sample registration, statistical analysis as well as reporting results. In total, about 36500 unknown samples have been reported since installation.

A particular focus in our development lies in the measurement of graphitized archaeological and modern samples with carbon masses between 10 to 100 µg. Several optimizations and routine adjustments have been implemented to achieve these capabilities: For example, we investigated the effects of pre-baking iron for graphitization, employing low carbon aluminium balls for sample pressing or a rigorous Faraday-Cup offset correction routine. The very small carbon amounts obtained from low sample masses cause very low ion currents that cause current dependent deviations in the isotopic ratios as well as an increased impact from possible contamination. To correct for those nonlinear deviations and disentangle their individual contribution, two set of standards have been found: One set is well-suited for modern biological samples: salmon DNA (96.2 pMC , CAS-No: 100403-24-5, Sigma Aldrich), SRM-4990C (134.07 pMC, oxa2) and IAEA-C6 (150.61 pMC) together with a graphite standard to monitor the machine background. Another set covers a larger range, suitable for small archaeological samples: IAEA-C7 (49.53 pMC) and SRM-4990C (134.07 pMC, oxa2) together with a dead carbon sample, phthalic anhydride (Sigma Aldrich, PA) to assess background caused by sample processing in the graphitization processes. In addition, we employ correction models for sample current correction as well as contamination mass and F14C, enabling us to reliably measure ^{14}C concentrations of graphitized samples down to a mass of approximately 10 µg. Recent efforts have been also directed toward improving the understanding of external target scatter used in the statistical analysis of the BATS software. We found that a target scatter estimation by standard scattering in a single magazine is insufficient to reflect real external target scatter whereas an estimate based on long term observation found superior.

Currently, we are working on increasing our efficiency for pre-treatment of carbonate and cremated bone samples as we observe an increased demand for these sample materials. We also investigate improvements of the current correction for archaeological samples that will allow us to even more reliably determine BP-ages for samples of about 200 µg C.

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A SEMI-AUTOMATED GRAPHITIZATION SYSTEM – FIRST RESULTS

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Abstract

Presented here is a semi-automated graphitization system. The design of the system is inspired by semi-automated graphitization system in use at the A.E. Lalonde Accelerator Mass Spectrometry (AMS) Laboratory. The system is made from stainless steel with VCR fittings and orbital welded joints and consists of 20 graphitization units connected to a common vacuum system. The graphitization ovens are made with quick-fit joint to ease operation. Further the ovens are well insolated having an outer surface temperature of c. 30 deg when operated at core temperature of 550 deg. The system is controlled by a National Instruments real-time computer. This ensures continues monitoring of the system as well as ensuring a high degree of safety in terms on oven and vacuum interlocks. A gas inlet system with three channels for H2, Ar and CO2 enables the introduction of H2 for CO2 reduction and Ar for venting tube-crackers and reactors. CO2 is used for calibration and testing. This line may in the future be replaced by O2 for pre-combustion of reactors for improved ^{14}C backgrounds. The real-time FPGA unit ensures fast (ns) measurements of gas inlet flow rates and pressure to ensure quick shutdown of gasses in case of malfunctioning. The user interface (UI) is made using LabView and runs on a separate PC which can lock-on to the real-time system. The UI is built with database access and with a user-friendly look to ensure safe and easy operation. Here the first results from secondary standards and blanks will be presented

CARBONUS: STATUS REPORT OF THE ^{14}C DATING FACILITY AT THE UNIVERSITY OF SALAMANCA, SPAIN

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The ^{14}C dating facility at the University of Salamanca, based on the compact MICADAS (Mini Carbon Dating System) [1], has been in operation for over three years. This work presents a detailed status report on the facility's performance, sample preparation methodologies, and statistical validation of results.

A wide variety of materials have been processed, including collagen, corals, wood, charcoal and sediments. For sediments, different pretreatment methods are commonly used for ^{14}C dating, such as acid-alkali-acid (AAA), acid dissolution, and carbonate removal through fumigation [2]. In our facility, we have employed the fumigation method for sediment pretreatment, which has been proven effective for sample decontamination while preserving the integrity of the organic fraction. We present results obtained at different stages of method optimization, ensuring the highest accuracy and reproducibility. We describe the rigorous procedures to perform this pretreatment, including sediment homogenization to ensure consistent measurements. To ensure reliability, we perform three replicates of each sample, allowing us to detect potential issues such as poor homogenization, which is particularly challenging when dating organic carbon in sediments. Statistical analysis of replicates confirms high reproducibility, with deviations well within expected uncertainties, demonstrating not only the robustness of our methodology but also the precision and effectiveness of its implementation in our laboratory.

Overall, the facility has achieved an average background value of 42,560 ± 4,060 years B.P., reaching up to 50,000 years after ion source cleaning. For standard samples, the facility has achieved average F14C values of 1.3407 ± 0.0026 for OxII, 0.2302 ± 0.0016 for IAEA C5, and 0.0031 ± 0.0013 for IAEA C9. Furthermore, we present results from the GIRI intercomparison samples [3] and collagen samples of known ages have been successfully dated, reinforcing the system's reliability.

In conclusion, this article provides updated technical specifications of the AMS system, details on our quality control measures and results of the optimised fumigation method in our facility. These enhancements underscore the utility of this AMS facility for research in archaeology, geology, and climate science.

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STATUS UPDATE: CELEBRATING A DECADE OF RADIOCARBON SAMPLE PREPARATION AND AMS EXPERTISE AT THE UNIVERSITY OF OTTAWA

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Abstract

The Andre E. Lalonde National Facility in Accelerator Mass Spectrometry (AEL-AMS) at the University of Ottawa has been operational since 2014, utilizing HVEE 3MV and MICADAS AMS systems. The sample preparation laboratory has processed over 30,000 samples for users from Canada and abroad for ^{14}C analyses. Sample matrices include diverse organic materials (i.e. wood, charcoal, plant macrofossils, sediment, peat, bone), and inorganic solids (e.g. shells, foraminifera, calcined bones), as well as dissolved inorganic and organic carbon (DIC/DOC) in surface and groundwater samples, and samples of CO_2 and CH_4 in gas mixtures. In 2021, a dedicated radiocarbon AMS (MICADAS by Ionplus AG) was added to meet the growing demand for radiocarbon analysis. Here, we review recent updates and improvements to our radiocarbon sample processing protocols, including enhanced QA/QC results for historical performance from routinely measured reference materials measured on the MICADAS. Routine processes such as acid-alkali-acid and direct combustion yield low procedural blanks ($F14C_{AVG}$ = 0.0022, σ=0.0006). Improvements to bone collagen extractions have resulted in increased collagen yield and a reduction in procedural blanks ($F14C_{AVG}$ from 0.0040 to 0.0025). Although some processes are bound by higher blanks due to the inherent nature of sample preparation (i.e. DOC by wet oxidation), progress has been made to keep blanks low ($F14C_{AVG}$ <0.0041) and consistent (σ<30%). Graphite samples in the range of 400-1300ugC have been routinely run, with size-matched runs possible in the intermediate range of 200-400ugC. Future updates, such as implementing bone pre-screening via FTIR, status of small sample measurement (<200ugC) by gas ion source, automating sample processing and managing databases, will be outlined.

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TERRA-MICADAS AT UC IRVINE'S KCCAMS FACILITY: PLUSES AND MINUSES, AND HOW TO OVERCOME THE LATTER

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Abstract

A MIni CArbon DAting System termed "Terra" was added to the KCCAMS facility at the University of California, Irvine, to analyze radiocarbon (^{14}C) of regular-sized samples as graphite (0.2 - 1.0 mg C) with high precision, and of smaller CO_2-derived samples (< 0.2 mg C equivalent) in support of climate change and air quality research.

A set of supporting instruments, i.e., an element analyzer (EA) to evolve CO_2 and quantify a sample's carbon and nitrogen content (%C, %N), an automated graphitization equipment (AGE3) for producing graphite for subsequent ^{14}C analysis, and a stable isotope ratio mass spectrometer (IRMS) that measures a sample's stable isotope composition ($\delta^{13}C$, $\delta^{15}N$), were also added to an existing wet lab. Specific accuracy/precision requirements based on lab's primary science mission and our 20+ years of AMS experience were entered into purchasing contract regarding all pieces of instrumentation. Here, we describe our experiences regarding instrumentation and software packages training, equipment performances, and continuous IonPlus IP support.

We detail the many in-house tests we have performed on those instruments after the acceptance-test period phased out, and what we have learned. When using the manufacturer's recommended tuning specifications, we were unable to accurately measure graphite in the 0.2 - 1.0 mg C range in tandem. The issue appears to be associated with loss of ^{12}C on the mass range selected for normalization. Upon consultation with colleagues at ETH, and continuous in-house experimentation, we determined the best criteria for instrument optimization. Best practice recommendations would be shared on: (i) spectrometer tuning and data analysis of 0.2 - 1.0 mg C for graphite targets run in a single cassette, and < 0.2 mg C CO_2-mode measurements (this presentation), and (ii) EA-IRMS-AGE3 evaluations and accuracy/precision on continuous measurements (Wang et al., this meeting).

Using optimized graphite production and our best practices protocols, the Terra spectrometer has been producing high quality data, rigorously traceable to standards without the need for beam current or time corrections available in the BATS software. Currently, the Terra-MICADAS at the KCCAMS facility is running a wide variety of organics samples and aerosol particles materials with precision of 3‰ or better on regular-sized modern samples and of 0.6‰ on samples with < 0.2 mg C as CO_2.

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Wang et al. (this meeting) Performance of an EA-IRMS-AGE3 at the new Terra-MICADAS laboratory of UC Irvine's KCCAMS Facility

PERFORMANCE OF AN EA-IRMS-AGE3 AT THE NEW TERRA-MICADAS LABORATORY OF UC IRVINE'S KCCAMS FACILITY

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Abstract

A set of instruments has recently been added to the "Terra" laboratory of the KCCAMS facility at the University of California, Irvine, to characterize and prepare samples for radiocarbon (^{14}C) analysis with a new Ionplus MIni CArbon DAting System (MICADAS, Ionplus AG) (Santos et al. this meeting). This set consists of three coupled instruments: (1) An element analyzer (EA, Elementar) to evolve CO_2 and quantify a sample's carbon and nitrogen content (%C, %N), (2) a stable isotope ratio mass spectrometer (IRMS, Elementar) to measure a sample's stable isotope composition ($\delta^{13}C$, $\delta^{15}N$), and (3) a graphitization system (AGE3, IonPlus) for producing filamentous graphite for ^{14}C analysis. For flexible workflow, the instruments were configured in three modes: EA-IRMS, EA-IRMS-AGE3, and EA-AGE3. Since acceptance testing following the installation of the instruments focused solely on the EA-IRMS and EA-AGE3 modes, we subsequently conducted in-house performance testing of all three modes.

Tests were divided according to the configurations: (1) For the EA-IRMS mode, besides evaluating overall system linearity and stability, we also determined isotopic data precision and reproducibility as well as drift behaviour. For the last two, we used internationally recognized reference materials (i.e., IAEA-600, USGS-61, -65, and -66) and in-house secondary standards (amino acids); (2) For the EA-IRMS-AGE3 mode, we also included two additional reference materials: FIRI-H (subfossil wood) and OX-I (oxalic acid I; NIST NBS SRM 4990B). This allowed us to evaluate the $\delta^{13}C$ values measured by EA-IRMS and the graphite products produced by EA-AGE3, besides the full software handling the three devices; (3) For the EA-AGE3 mode, we performed two experiments. First, we compared the radiocarbon results of a synthetic ^{14}C-free carbon powder (Lot#3380117, Carbone) pressed directly into target holders with the same material graphitized via the EA-AGE3 mode. Aliquots of both samples (non-graphitized carbon powder and graphitized one) were measured for their ^{14}C signatures. For our second experiment, we evaluated EA capsule types (Sn and Al) for their combustion efficiency and purity using the ^{14}C-free carbon powder and IAEA-C7 (oxalic acid). Comparisons also included evaluating EA combustion efficiency when handling labile and recalcitrant organic compounds that display distinct sensitivity to temperature in a sequence.

Results show that (1) the EA-IRMS mode can derive %C and %N concentrations with 0.1% uncertainty, while isotopic values of $\delta^{13}C$ and $\delta^{15}N$ are within 0.2 and 0.3‰, respectively. (2) After modifications applied to the EA-IRMS-AGE3 software, all modes can run in series or simultaneously. This means that we can analyse samples with EA or EA-IRMS while the AGE3 is performing other tasks (i.e., pre-conditioning the Fe powder for graphitization or graphitizing). The stable isotope ratio ($\delta^{13}C$ and $\delta^{15}N$) and graphite results from the EA-IRMS-AGE3 mode are overall consistent with those obtained when using just the EA-IRMS or the EA-AGE3. (3) Filamentous ^{14}C-free graphite produced by EA-AGE3 are typically 4 kyrs younger than the non-graphitized carbon powder pressed into target holders, but overall, ages vary from 48 and 53 kyrs BP. No significant differences were detected in the age of ^{14}C-free graphite targets produced by the EA-AGE3 when using Sn or Al capsules. However, we determined that the use of Al capsules with both short or longer oxygen dosing times (e.g., 50 or 120s) may lead to incomplete combustion and subsequent contamination. This is particularly important for recalcitrant organics such as graphite, charcoal, and sediment followed by labile organics. In contrast, Sn capsules combined with

just 80 s oxygen dosing enhance combustion efficiency and data quality. Together, our assessment shows that the EA-IRMS-AGE3 allows for comprehensive sample analysis and graphite production in the Terra-MICADAS lab of KCCAMS facility.

Acknowledgments
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Santos et al. (this meeting) Terra/MICADAS at KCCAMS/UCI facility: pluses and minuses, and how to overcome the latter

A NEW 3.0 MV HIGH-PRECISION ACCELERATOR MASS SPECTROMETER (GANA) FOR ^{14}C MEASUREMENT

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Abstract

A new 3.0 MV Accelerator Mass Spectrometer-GANA (Guangxi Accelerator for Nuclear Analysis), has been developed at Guangxi Normal University (GNU) for high-precision and ultra-low background analysis of ^{14}C at a terminal voltage of 3 MV. GANA is equipped with a 50-sample ion source, a high-resolution 120-degree injection magnet, a 90-degree high-energy analysis magnet, a 65-degree electric analyzer with a 1.7 m radius, and a 4-channel gas ionization detector. To minimize the pressure within the acceleration tubes, a differential pumping system featuring two turbomolecular pumps is mounted on the terminal. A post-acceleration pump restriction limits the flow of stripper gas into the high-energy side analyzing beamlines, maintaining a pressure of low 10^{-8} mbar. This effectively reduces low-angle scattering from gas particles, thereby achieving high abundance sensitivity for ^{14}C. The rare ions of interest are identified in a multi-anode gas ionization chamber, while stable ions are measured as current in offset Faraday cups, utilizing an internal slit system to stabilize the terminal voltage. These advanced features enable GANA to achieve a ^{14}C measurement sensitivity of 1.2×10^{-16} and a measurement precision of 0.8‰.

Acknowledgments
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STATUS REPORT: 7 YEARS OF MICADAS OPERATION AT THE JENA ^{14}C LABORATORY

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The Jena ^{14}C laboratory at the MPI for Biogeochemistry started routine operation with MICADAS in 2018. Almost 1000 batches were measured. The available data was used to investigate the performance in routine operation.

MICADAS INSTALLATION IN THE TIME LAB AT THE LABORATORY OF TREE-RING RESEARCH (UNIVERSITY OF ARIZONA)

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Driving new applications for single year radiocarbon and stable isotopes in tree-rings

The TIME Lab is a newly constructed radiocarbon (^{14}C) and stable isotope measurement facility in the Laboratory of Tree-Ring Research (LTRR) at the University of Arizona (Tucson, AZ). With its foundation in the home of tree-ring science and aided by new technologies, the TIME Lab will contribute to the international research community, specializing in high-precision measurements on long tree-ring time series.

The 43rd MICADAS instrument, or "Mini Carbon Dating System," built by IonPlus (Dietikon, Switzerland) has recently been installed in the LTRR and began acquiring samples in 2025. The TIME Lab facility houses the new MICADAS, an AGE 3 system (Automated Graphitization Equipment by IonPlus), a new Sercon Isotope Ratio Mass Spectrometer equipped with laser-ablation capabilities (LA-IRMS), and a preparation laboratory specialized for cellulose extractions from tree-ring samples. The MICADAS system also includes the Gas Interface System and Carbonate Handling System (GIS and CHS) offered by IonPlus for alternative sample inputs in addition to solid graphite for ^{14}C measurement.

The TIME acronym stands for "Tree-ring Innovations in Mass spectrometry for Earth Systems." We plan to utilize the high resolution and precision capabilities of the MICADAS and LA-IRMS in research projects that require annually resolved data from tree-rings as well as other sample types, such as marine bivalves. Data generated will contribute to the International Radiocarbon Calibration Curve and be used in a range of high-resolution dating applications utilizing samples from the LTRR tree-ring archive and beyond. Planned projects will explore solar activity, atmospheric radiocarbon distribution, radiocarbon offsets, and the precision dating of a range of archaeological and paleoenvironmental samples. A strong focus will be seismic and volcanic chronology.

The TIME Lab will be a center of training for undergraduate and graduate students interested in laboratory methods and instrumental analysis, and commercial measurement services will be available when capacity allows. The TIME lab will also provide public outreach and teaching opportunities via new exhibit spaces and guided tours in conjunction with the LTRR tree ring archive and existing outreach programs.

We will present information and photographs of the installation and instrumentation in the TIME Lab, the initial performance and results from samples run thus far, and information on current and future research projects that will utilize the lab for transdisciplinary research projects.

Acknowledgments
The MICADAS Instrument purchase was made possible by NSF Award 2213949, and the purpose-built TIME Lab facility was funded by the University of Arizona.

TESTING AND ASSESSMENT OF HIGH-PRECISION AND HIGH-ACCURACY AMS-RADIOCARBON MEASUREMENTS AT NANJING UNIVERSITY, CHINA

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Abstract

An Ionplus 200 kV MIni-CArbon DAting System (MICADAS) Accelerator Mass Spectrometer (AMS) was installed at the Laboratory of AMS Dating and the Environment, Nanjing University (NJU-AMS Laboratory), China. The NJU-AMS Laboratory is largely devoted to research on radiocarbon dating and ^{14}C analysis in fields of earth, environmental and archaeological sciences. The laboratory has successfully employed various pretreatment methods, including routine pretreatment of tree rings, buried wood and subfossil wood, seeds, charcoal, pollen concentrates, organic matter, and shells. In this study, operational status of the NJU-AMS is presented, and results of radiocarbon measurements made on different sample types are reported. Measurements on international standards, references of known age, and blank samples demonstrate that the NJU-AMS runs stably and has good reproducibility on measurement of single samples. The facility is capable of measuring ^{14}C in samples with the precision and accuracy that meet the requirements for investigating annual ^{14}C changes, history-prehistory age dating, and Late Quaternary stratigraphic chronology research.

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STATUS REPORTS OF A RADIOCARBON SAMPLE PREPARATION LABORATORY IN NORTHEASTERN BRAZIL

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Abstract

Establishing a laboratory for radiocarbon analysis is an extremely complex challenge. The need to isolate equipment and sample preparation systems, as well as strict precautions to avoid contamination of materials, chemicals, and consumables used during various sample preparation steps, makes setting up a laboratory for this purpose a mission centered on ensuring result quality. In this context, the Laboratory for Radiocarbon Sample Preparation – LAPA^{14}C (associated with the Stable Isotopes Laboratory – LISE), located at the Federal University of Bahia (UFBA), has undergone several structural modifications to achieve high performance in radiocarbon sample preparation. To assess the quality of results produced by LAPA^{14}C, an intercomparison test was conducted with the Radiocarbon Laboratory (LAC) at the Fluminense Federal University (UFF), a Latin American reference in radiocarbon analysis. This test involved the preparation of five international standards (IAEA-C1, -C2, -C6, -C9, and OXII), which were graphitized by zinc reduction in LAPA^{14}C and subsequently analyzed using the AMS single stage system at LAC-UFF. The results obtained were consistent with reference values, demonstrating reproducibility and quality, and indicating low contamination levels during the chemical and graphitization processes. However, a small enhancement in the background signal was observed during the measurements, and a new set of C1 and coal samples is being prepared under optimized conditions aiming to reduce this background value. The laboratory has demonstrated satisfactory development toward the implementation of radiocarbon protocols and aims to expand analyses to include soils, sediments, water, carbonates, and bones, all related to paleoenvironmental and archaeological studies. The lab is also specializing in water analysis using the precipitation method; soil analysis through humin fraction extraction; and determination of the biogenic fraction in materials from renewable sources, such as bioplastics and biofuels. Furthermore, LAPAC is conducting experimental evaluations of petroleum contamination levels in sediments.

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RADIOCARBON TREE-RING STANDARDS FOR AD 1586, *C.* 27 kA, AND *C.* 42 kA

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Abstract

Standard materials are fundamental for accurate radiocarbon dating but must be available in sufficient quantities for all AMS facilities worldwide to use as required.

MAG-C63 is an oak beam removed from the Great Tower at St Mary Magdalen College, Oxford (51.75N, 1.25W), which is 6.1m long, by 0.3m square and weighs over a metric tonne. It has been dated by ring-width dendrochronology as spanning AD 1487–1629. The ring selected for use as a tree-ring standard is 2.76mm wide and formed in AD 1586. Whole rings have been dissected, each sample being split across the ring so that it contains roughly equal amounts of earlywood and latewood. Samples weigh approximately 50mg.

Following a survey undertaken at the 24th Radiocarbon Conference in 2022, Historic England and the National Institute of Water and Atmospheric Research Ltd, New Zealand (NIWA) have set up a research collaboration to source suitable late Pleistocene tree-ring standards. FIN09 is a subfossil kauri that was extracted from a farm owned by the Finlayson family along the west coast of Northland, New Zealand (35.81S, 173.63E) near Kai Iwi Lakes. A significantly large cross-section is available from this tree. A ring-width sequence has been measured from Fin09, although it does not currently cross-match with any ring-width series from coeval kauri (Cooper et al. 2021). A bi-decadal block spanning rings 4921–4940 of the measured Fin09 sequence aligned with a pre-identified radiocarbon plateau has been selected for use as a tree-ring standard. Wood has been removed from the cross-sectional offcuts adjacent to the primary plinth used for ring-width measurements, and material within the 20-year span has been homogenised using a clean Retsch grinder similar to the pre-processing undertaken for high-precision liquid scintillation dating (Hogg et al. 2022). Work is also underway to select a suitable subfossil kauri specimen for a tree-ring standard at c. five radiocarbon half-lives from the Waipu site in Northland which has yielded material between 27ka – 35ka cal BP.

All standards will be made available to the radiocarbon community by Historic England over the coming

years at the cost of purchase, dissection and shipping.

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A NOVEL MEAN-VALUE-BASED APPROACH FOR CORRECTING RADIOCARBON AGE ANOMALIES IN TERRESTRIAL GASTROPODS

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Abstract

Terrestrial gastropod shells are valuable materials for radiocarbon dating of Quaternary loess deposits, but their reliability is challenged by age anomalies caused by the limestone effect. This study examines two gastropod species, Cathaica rossimontana and Succinea sp., collected from loess sequences in Central Asia and the Tibetan Plateau, aiming to quantify and correct such anomalies. The results reveal distinct species-specific age offsets: Cathaica rossimontana shows a substantial anomaly of 1788 ± 240 years, while Succinea sp. displays a significantly smaller offset of 492 ± 100 years. These differences are linked to variations in shell size and calcium demands. Analyses of stratigraphic layers and contemporary specimens indicate that under stable environmental conditions, conspecific gastropods incorporate limestone-derived carbon with low variability (coefficient of variation: 0.10–0.22), enabling systematic correction. A mass balance model further identifies the carbonate contributions, ranging from 17.5% to 26.8% in Cathaica and 6.0% to 7.8% in Succinea. By employing linear regression modeling and average limestone effect values, the corrected shell ages closely correspond to reference charcoal ages in the BST and GG loess sections, underscoring the robustness of the proposed method. Compared to the conventional modern-value correction, the mean-value correction approach offers broader applicability and greater reliability, particularly in regions lacking modern reference specimens. This study provides a solid theoretical framework for addressing limestone-induced age anomalies and highlights the potential of gastropod shells as precise chronological markers in loess research across arid Central Asia and high-altitude environments.

Key words: age anomalies, terrestrial gastropods, mean-value-based approach

RADIOCARBON INTERCOMPARISONS- WHAT NEXT?

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Abstract

Global radiocarbon intercomparisons have been held at regular intervals since the 1980s (Scott et al, 2022). The most recent was reported in 2023 (Scott et al, 2023). These have been designed with a variety of different materials representing those which are more commonly dated and spanning the age range of radiocarbon dating while also including some background samples. Participation has been open to all, at no cost. Benefits to laboratories which participate have included laboratory benchmarking, opportunities for self-checking and quality assurance, and troubleshooting. An archive of materials has been created and hosted at the SUERC radiocarbon laboratory giving laboratories ongoing access to well characterised reference materials (subject to availability). Funding for past inter-comparisons has come from a variety of sources, including UK research council grants, European funds, and most recently from English Heritage. Past intercomparisons have been ambitious, distributing between 10 and 15 samples per laboratory, and have relied on the generosity and community spirit of the individual sample providers (e.g. from New Zealand, UK, USA and Russia).

Nonetheless, to move forward and to make the intercomparisons sustainable, new funding models and approaches need to be take into consideration.

Here some potential intercomparison models will be considered, covering the nature and number of samples needed, how we might finance participation, minimum reporting requirements and most importantly what the community wishes.

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SINGLE-YEAR RADIOCARBON MEASUREMENT OF TREE RINGS COVERING THE YAYOI PERIOD IN JAPAN.

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Abstract

The Yayoi period is critical in Japanese archaeology because it marks the beginning of rice cultivation in wet rice fields and the associated changes in social structure. We continue the radiocarbon dating of Japanese tree rings to clarify the start of the Yayoi period and the transition to the Kofun period, the following significant social change.

At the Ikegami-Sone site, Osaka prefecture, one of the most representative sites of the Yayoi period, several remains of wooden pillars were discovered that had formed a large embedded-pillar building. The results of dendrochronological dating based on annual ring width and oxygen isotope ratios showed that trees from different periods were used despite a single building[1]. As a result, we obtained tree-ring material spanning 1000 years, almost to the first century BCE.

The sample was cellulose bleached using the plate-like extraction method[2]. Although the material had been preserved with polyethylene glycol, the agent did not fully penetrate the interior and could be removed by organic solvent washing with a Soxhlet extractor. Radiocarbon measurement of material from a period that included events around 660 BCE reproduced the peaks and verified the dendrochronology.

Single-year radiocarbon measurement of Japanese tree rings is underway around the 10th century BCE, before and after 1 CE[3], and to fill in the gaps between them[4,5]. The wooden pillar roots excavated at the Ikegami-Sone site are expected to serve as material to link these results.

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