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EDITORIAL

The operation of the Laboratory of Ion Beam Physics (LIP) in 2020 was heavily impacted by the Covid-19 crisis and related restrictions and measures taken by the Government and ETH school board to limit its consequences. The effective lockdown in March ceased to a large extent our experimental work and the whole lab crew was sent to home office. An emergency operation plan was established and had been approved by the ETH school board, which allowed us to run minimum maintenance procedures in order to prevent damage to LIP infrastructure and to ensure that a normal operation mode can be launched as soon as the situation would stabilize.

The high degree of automation of the LIP accelerator facilities then enabled us to establish a minimal measurement operation so that we were able to meet the demands of our internal and external research programs while paying particular attention on the progress of our Ph.D. students, and on the continuation of our scientific collaborations. During the summer months, with the relaxation of the Covid-19 measures, the processing of sample materials could then be resumed in compliance with presence restrictions in effect.

Thanks to the high sense of responsibility of the entire LIP staff, we were able to comply with the hygiene and protection measures and did not have to report any Covid-19 infections in the laboratory. We are proud that despite the very specific working conditions, LIP scientific, technical, and administrative staff could maintain successfully operation of the laboratory. As a consequence, we are delighted to present this annual report which again demonstrates the broad diversity, the inter-disciplinarity, and the prosperity of science carried out or supported by LIP scientists. As always, we hope that you will enjoy reading and that some reports will capture your attention and may be stimulate your curiosity so that you might want to follow up with the related scientific literature.

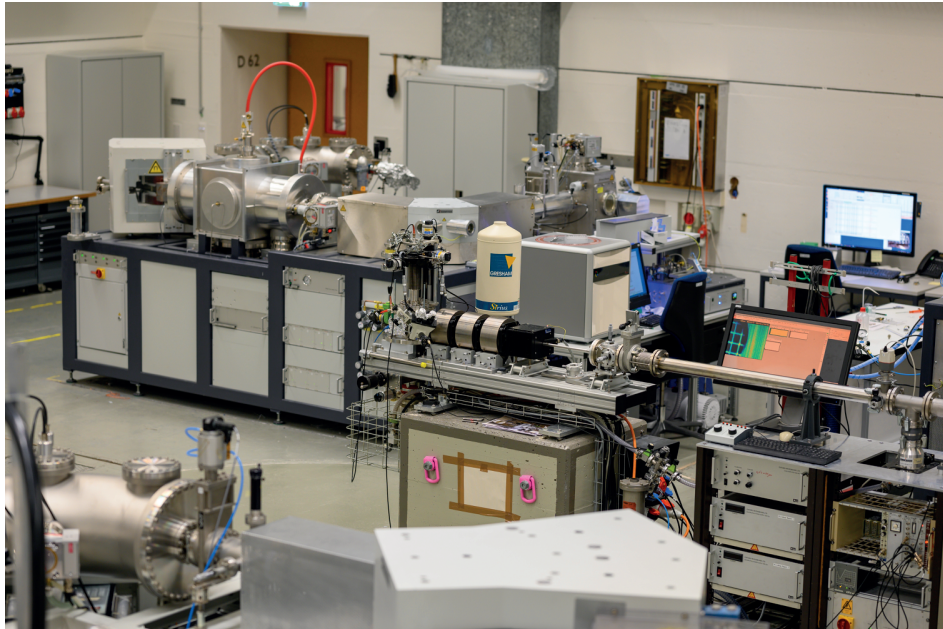
By fulfilling our mission of providing excellent service to external and internal users, we contribute significantly to their scientific output and careers. In addition, LIP scientists and staff are deeply engaged in the training of students and apprentices at all levels of their careers and in many different departments, which makes LIP an important player in fulfilling the educational mission of ETH.

Of particular importance for the future of our laboratory had been the renewal of the curatorial agreement among the LIP partner organizations: ETHZ, Empa, PSI, Eawag, and newly the WSL for the period 2021-2024. This will maintain the essential base funding of the laboratory for the next four years. During the general audit of the Department of Physics in October, the LIP was very positively assessed by the auditing commission and its cross disciplinary operating mode together with the strong fundament in the Department of Physics was particularly emphasized. With this support, LIP will be able to continue playing a leading role in the development of ion beam technologies and its applications and promote a more widespread use of these powerful techniques in various fields of sciences.

Finally, we want to thank all LIP users and collaborators for their contributions to this volume. It is their trust and confidence that motivates us to refine and further exploit the powerful opportunities of ion beam technology and the related applications.

Hans-Arno Synal and Marcus Christl

THE LIP ACCELERATOR FACILITIES



LE side of MILEA, Microbeam of the Tandetron and LIP MICADAS

Operation of the 6 MV Tandem accelerator

Tandetron operation and extension

Activities on the 0.5 MV Tandy system in 2020

Activities on the 0.3 MV Milea system in 2020

^{10}Be on the 0.3 MV Milea system

^{26}Al on the 0.3 MV Milea system

Radiocarbon on the 200 kV Micadas

Low energy AMS (LEA)

Gas measurements at LEA

OPERATION OF THE 6 MV TANDEM ACCELERATOR

Beam time statistics

C. Vockenhuber, scientific and technical staff, Laboratory of Ion Beam Physics

Contrary to many other experiences 2020 was a quiet year for the 6 MV Tandem facility. Due to the lab closures related to COVID-19 in spring, operation of the Tandem was not possible as running measurements required the presence of at least one person on shift. Nevertheless, we could continue to perform experiments and measurements during the rest of the year. While the operation time of the Tandem reached an all-time low with about 800 hours, the actual time was essentially 100% dedicated for experiments and measurements (Fig. 1).

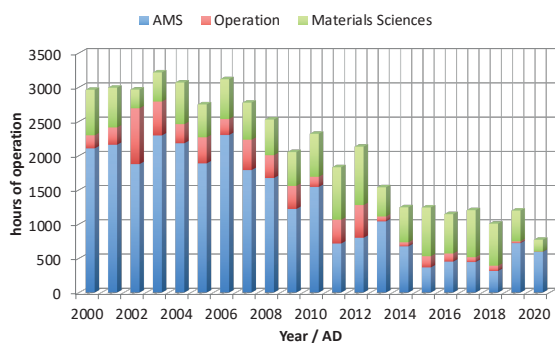


Fig. 1: Time statistics of the TANDEM operation subdivided into AMS (blue), materials sciences and MeV-SIMS (green), and service and maintenance activities (red).

No maintenance at the accelerator itself was necessary (a welcome difference to the experiences during belt operation and in the first years after the Pelletron conversion). Only routine maintenance work such as ion source revisions or replacing vacuum components along the beamlines were done in 2020.

In January we completed the upgrade of the electrostatic bouncing system at the LE magnet that was started at the end of 2019. It allows now to apply high voltage pulses up to +/- 10 kV and to inject up to three stable isotopes into the Tandem accelerator. This is required for the

measurement of ^{32}Si relative to its three stable isotopes ^{28}Si , ^{29}Si and ^{30}Si .

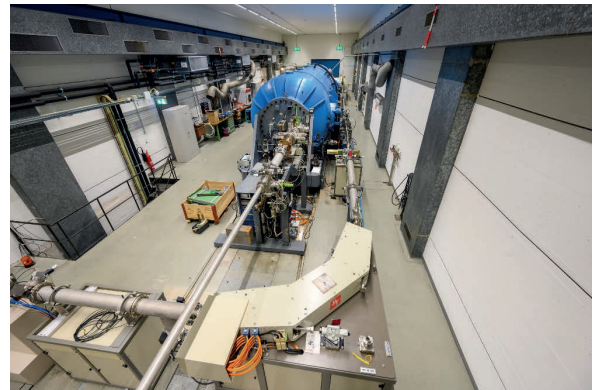


Fig. 2: View into the Tandem hall with the HE beamline of the 6 MV Tandem above the 90° HE magnet of the 1.7 MV Tandetron facility.

Over the past five years the beam time used for AMS has stabilized at around a few 100 hours, increasing in the last two years due to the PhD project for the development of ^{32}Si AMS. Routine ^{36}Cl analyses (total 266 samples) were performed using the Gas-Filled Magnet (GFM), requiring the Tandem to run at 5.9 to 6.0 MV.

Due to the complete transfer of the ion beam analysis activities to the 1.7 MV Tandetron facility in 2019 much less beam time was dedicated to material sciences. The installation of the 1.7 MV Tandetron side by side to the 6 MV Tandem allows for parallel operation of both accelerators at the same time (Fig. 2). Furthermore, the PhD project related to MeV-SIMS was wrapped up in 2020 with about 130 hours of beam time used for optimizations and measurements with the newly developed dual-polarity ToF spectrometer. Additionally a few irradiations were performed at high energies.

TANDETRON OPERATION AND EXTENSION

Materials science at the new 1.7 MV Tandetron

C. Vockenhuber, scientific and technical staff of LIP

The 1.7 MV Tandetron facility and its beamlines were operational most of the time in 2020. Only the Li charge exchange canal and the duoplasmatron ion source (HVEE 358) required some maintenance work at the beginning of the year. Both components are required for producing $^4\text{He}^-$ beam for RBS and PIXE measurements which dominate the beam time (~60%). The ^{127}I beam for most ERDA measurements is produced by the Cs sputter ion source (HVEE 860). Besides those two we used beams of ^1H for NRA analyses, and ^7Li , ^{11}B , ^{56}Fe , ^{63}Cu , ^{74}Ge , ^{127}I , ^{197}Au for various irradiations and implantations. ^{35}Cl was also used for an ERDA measurement to complement our standard analysis with ^{127}I .

Similarly to 2019, a total of approximately 1300 analyses and irradiations was performed in 2020. This number is comparable to those of earlier years and indicates that even with the partial lockdown due to COVID-19 in 2020 experimental work (mainly PhD theses) and industry continued to produce samples that required analysis by ion beam techniques. Fig. 1 shows a compilation of performed measurements sorted by experimental technique.

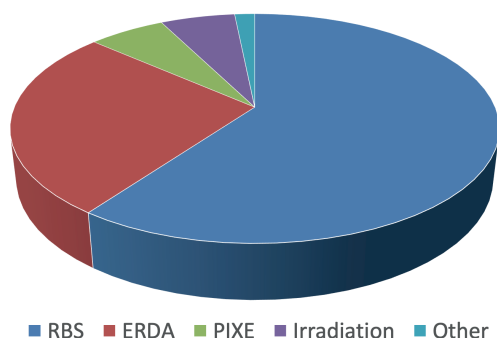


Fig. 1: Breakdown of the 1300 analyses and irradiations sorted by applied technique.

The installation of the Oxford Microbeam at the end of the straight beamline was completed (Fig. 2) and first test measurements with our

2 MeV $^4\text{He}^{++}$ standard beam were performed in the second half of 2020. It turned out that the air cooling of the quadrupole lenses must be improved because the microprobe was originally designed for light p beams. The precision object slits for the high-resolution mode are still missing, but will be installed in 2021.

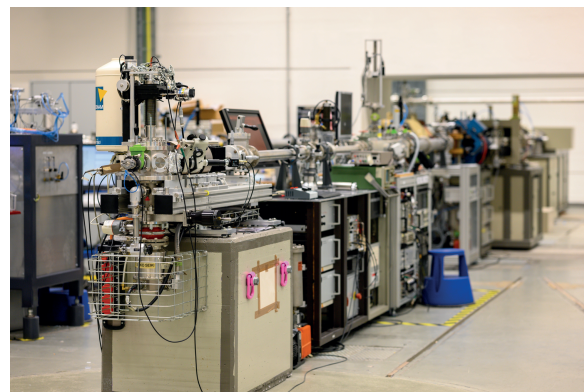


Fig. 2: The Oxford Microbeam at the end of the RBS/PIXE beamline of the Tandetron.

A significant fraction of the time during a measurement day is dedicated to mounting the individual samples (which come in all forms and sizes!) onto the sample holder. Especially thick samples require a special holder to mount the samples from the back side in order to keep the scattering geometry the same. We designed a new sample changer, with additional x-y positioning capability to compensate for sample thickness. Furthermore, the load-lock box with a small turbo pump should improve the vacuum and reduce the time to change sample holders, especially for ERDA measurements which require good vacuum for the MCP detectors. We will put the new sample changer in use at the beginning of 2021.

ACTIVITIES ON THE 0.5 MV TANDY SYSTEM

Beam time and sample statistics

M. Christl, scientific and technical staff, Laboratory of Ion Beam Physics

The operation of the Tandy in 2020 was without major problems and required only short routine maintenance activities. This year, we completely moved our routine measurements of ^{10}Be and ^{26}Al from the Tandy, where they have been analyzed for more than a decade, to the 300 kV MILEA system.

Since 2010, more than 10,000 ^{10}Be samples and almost 500 ^{26}Al samples (since 2013) were measured on the Tandy. Our decision to move was based on several reasons: the current output for BeO^- and Al^- is much higher from the MILEA ion source, the background is similar (Be) or lower (Al), and the second AMS system provides much more flexibility to respond to the increased sample load from our users (Fig. 1).

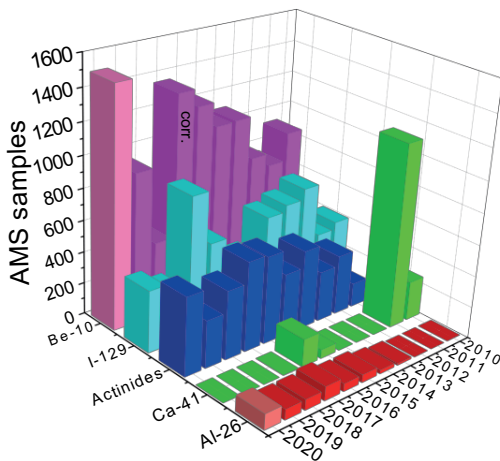


Fig. 1: Number of (unknown) AMS samples measured since 2010 sorted by nuclides; light colours indicate that the samples were measured on the MILEA system. The number of ^{10}Be samples in 2017 was corrected.

On the Tandy, almost 900 ^{129}I and actinide samples were measured for various projects in 2020 (Fig. 2). The majority of ^{236}U and ^{129}I samples were measured for our large in-house program on the application of anthropogenic

radionuclides as ocean tracers comprising samples from the Fram Strait, the Arctic and Atlantic Ocean. Several smaller collaborative studies were carried out with external users on ^{236}U and the novel AMS nuclide ^{233}U in the South Chinese Sea, on Pu-isotopes in air filters, on ^{244}Pu in sediments, and on the bioavailability of ^{236}U , and Am- and Pu-isotopes in marine marshland. In collaboration with the AMS group in Seville we analyzed several Arctic Ocean water samples and standard materials for ^{233}U .

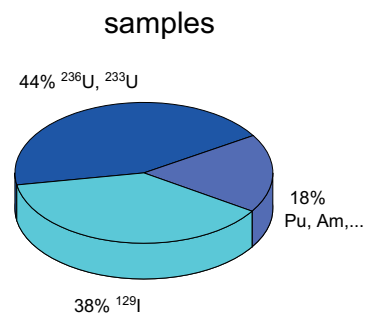


Fig. 2: Relative distribution of the number of AMS samples measured on the Tandy in 2020.

The collection of enough counting statistics for low level analyses of ^{233}U consumes very much beam time. That is the reason why the measurement of the U-samples (44% of all samples) consumed almost 60% of the total beam time in 2020 (about 2200 h).

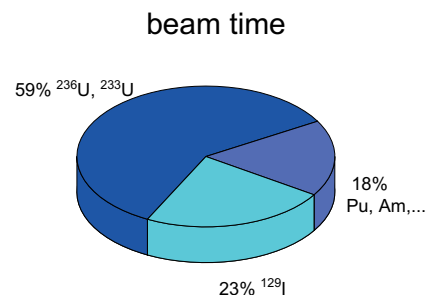


Fig. 3: Relative distribution of the TANDY operation time for ^{129}I and the actinides in 2020.

ACTIVITIES ON THE 0.3 MV MILEA SYSTEM

Beam time and sample statistics

M. Christl, P. Gautschi, scientific and technical staff, Laboratory of Ion Beam Physics

This year, again many test measurements were carried out to characterize the performance of the MILEA system for efficient AMS measurements of ^{10}Be , ^{26}Al , and the actinides. In parallel, all routine measurements of ^{10}Be and ^{26}Al were carried out on the MILEA system. This kept our newest AMS system quite busy. More than $\frac{2}{3}$ of the total 2700 beam time hours were allocated for routine AMS measurements while about 850 h were dedicated to research and development (Fig. 1).

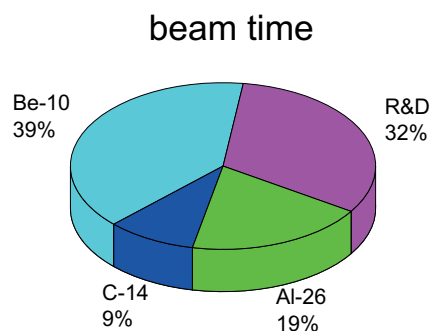


Fig. 1: Relative beam time distribution for the different operations on MILEA in 2020.

Research projects on MILEA had various aspects. Our internal studies focused on the investigation of charge state yields of Be and B at different energies [1] and on improving the efficiency of U and Pu measurements [2]. Furthermore, a collaborative research project with Czech Technical University intended to investigate the suitability of different fluoride matrices for more efficient AMS measurements of actinides [3] and of ^{26}Al [4].

A total number of 1800 AMS samples (unknowns) were measured on MILEA this year. The majority of samples were analyzed for ^{10}Be , but also almost 200 ^{14}C samples and about 100 ^{26}Al samples were measured (Fig. 2). Due to the increased output of BeO^- from the MICADAS-type ion source ^{10}Be measurements were very time

efficient [5]. This is represented by the fact that more than 80% of all AMS samples (^{10}Be) were analyzed in only 40% of the total beam time.

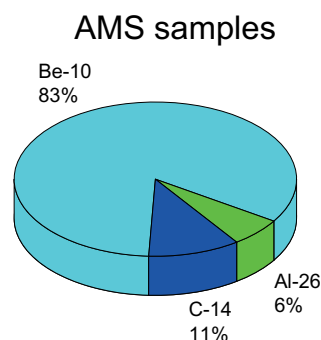


Fig. 2: Relative Number of AMS samples measured in 2020.

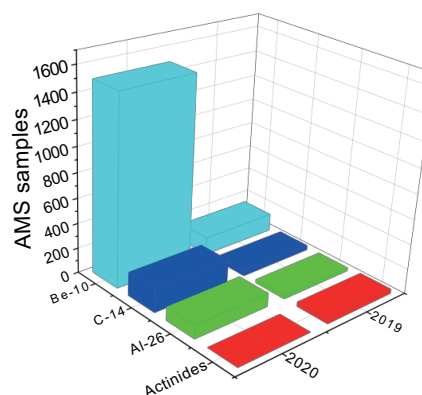


Fig. 3: Number of AMS samples (unknowns) measured on MILEA over time.

The first full year of routine AMS of ^{10}Be on MILEA started with a record. The absolute number of ^{10}Be samples analyzed per year has never been higher at LIP. This motivates us (and our users) to beat that record in 2021.

- [1] P. Gautschi et al., LIP Annual report (2020) 21
- [2] M. Christl et al., LIP Annual report (2020) 23
- [3] T. Prasek et al., LIP Annual report (2020) 22
- [4] K. Fenclova et al., LIP Annual report (2020) 24
- [5] M. Christl et al., LIP Annual report (2020) 12

^{10}Be ON THE 0.3 MV MILEA SYSTEM

The first full year of routine AMS of ^{10}Be on MILEA

M. Christl, P. Gautschi, H.-A. Synal

In the first year of routine AMS of ^{10}Be on MILEA a total number of 1498 user samples were analyzed. We therefore consider the transition of ^{10}Be AMS to MILEA a success. The high sample throughput was possible due to the high (up to 10 μA) output of BeO^- from the MICADAS type ion source (Fig. 1). The current distribution, however, is as heterogeneous as the sample materials our users processed in their labs mainly caused by varying chemical recoveries during sample preparation.

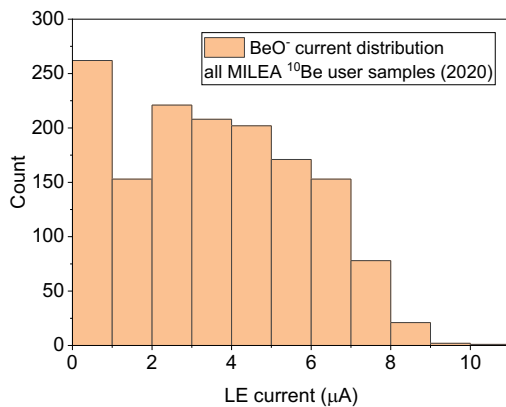


Fig. 1: Distribution of average BeO^- currents of all ^{10}Be user samples measured on MILEA in 2020.

In 2020, our ^{10}Be samples came from eight different laboratories in Switzerland and the rest of Europe. A majority of samples were prepared from polar ice cores with the intention to find so-called cosmic ray events. Another study used deposition changes of ^{10}Be in marine sediments as a time marker, while many smaller projects used the in-situ produced signal of ^{10}Be in rocks to extract information of erosion rates, glacier retreat, and landscape evolution.

The distribution of runtimes (Fig. 2) also reflects the different sample materials. While the meteoric ^{10}Be concentration in ice cores and marine sediments is relatively high, resulting in ca. 20-40 min measurement time, the analysis of

in-situ samples with very low ^{10}Be content took up to two hours per sample.

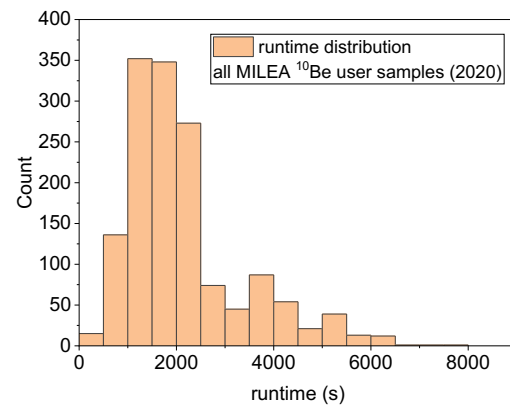


Fig. 2: Beam time distribution of all ^{10}Be user samples measured on MILEA in 2020.

A maximal over-all efficiency of 1‰ was calculated for the MILEA system based on the final uncertainties of the reported ^{10}Be data (Fig. 3). At the best, 1000 at of ^{10}Be in a sample result in one count in the detector (with 100% counting statistics error).

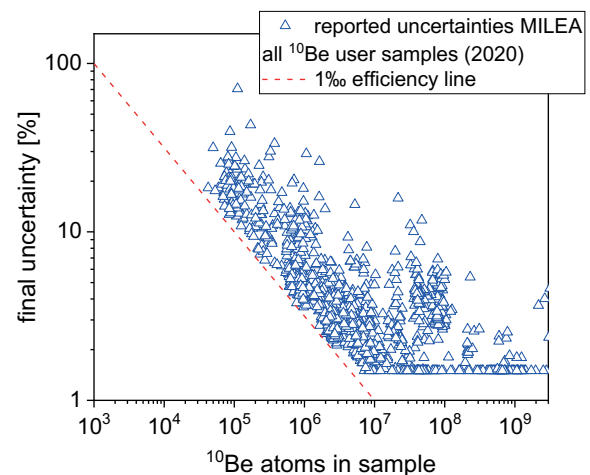


Fig. 3: Final uncertainty of reported ^{10}Be data vs. ^{10}Be atoms in the sample. The red dashed line indicates a detection efficiency of 1‰.

^{26}Al ON THE 0.3 MV MILEA SYSTEM

The first year of routine AMS of ^{26}Al on MILEA

P. Gautschi, C. Vockenhuber, H.-A. Synal

^{26}Al is the second AMS isotope besides ^{10}Be [1] which is now measured routinely on the new MILEA system [2]. A total number of 109 user samples were analyzed in 2020. Most samples originate from geochronological dating but one set of samples was used for investigation of a nuclear reaction.

We use Al^- as extracted ion which eliminates the ^{26}Mg interference, and on the HE side select the 2+ charge state because of the high transmission (~50%). The m/q interference of $^{13}\text{C}^+$ is stopped in a gas absorber in front of the gas ionization detector. The absorber/detector design of MILEA provides stable conditions for long measurement times of several weeks.

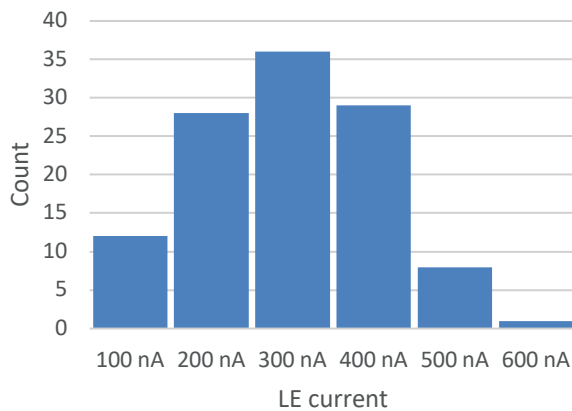


Fig. 1: Average Al^- current distribution of all ^{26}Al samples measured on MILEA in 2020.

The MICADAS type ion source produces average Al^- currents from Al_2O_3 samples mixed with Cu 1:4 typically between 100 – 500 nA (Fig. 1) with peak values up to 800 nA. From metal Al targets currents of up to a few μA can be observed.

The beam current paired with the often low $^{26}\text{Al}/^{27}\text{Al} < 10^{-13}$ ratios makes it necessary for longer measurement times compared to ^{10}Be [1] to reach the required precision (Fig. 2). The majority of the samples has therefore been

measured between 2 – 3 h, while some samples were measured up to 10 h.

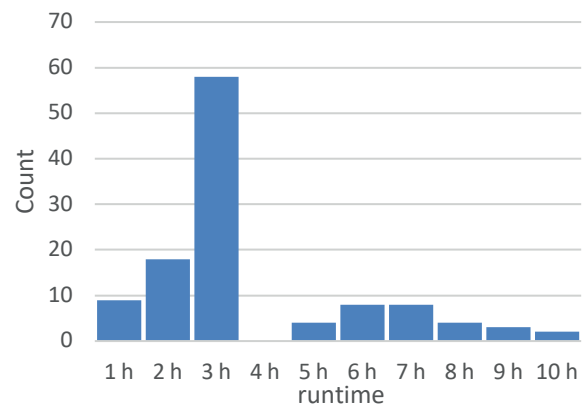


Fig. 2: Beam time distribution of all ^{26}Al samples measured on MILEA in 2020.

With long measurement times the overall efficiency reaches 0.2%, this together with the total number of ^{26}Al atoms in the sample determines the achievable precision based on counting statistics (Fig. 3).

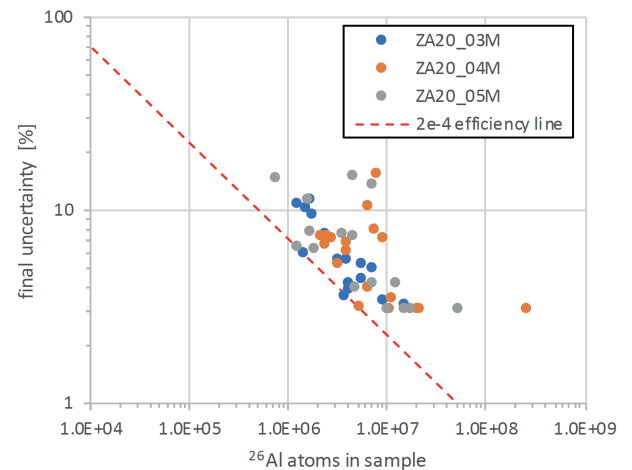


Fig. 3: Final uncertainty of reported ^{26}Al data vs. ^{26}Al atoms in the sample. The red dashed line indicates a detection efficiency of 0.2%.

[1] M. Christl et al., LIP Annual report (2020) 12

[2] M. Christl et al., LIP Annual report (2020) 11

RADIOCARBON ON THE 200 kV MICADAS

Performance and sample statistics

L. Wacker, C. Welte, N. Haghipour and scientific and technical staff of LIP

The SARS-Covid19 pandemic influenced the activities on the two MICADAS systems running at LIP in the year 2020 significantly. The lock-down in spring reduced measurement of research-based samples significantly, which is primarily expressed in the decreased number of gas samples analysed. This is primarily caused by the reduced number of samples (sediment/soil, water DIC or DOC, POC, carbonates, compounds) supplied from the Earth Science department (lowered by about 1500) because of cancelled fieldwork and cruises. In addition, all biomedical samples were analysed at Ionplus AG (Dietikon, Switzerland) with the new LEA (Low Energy AMS) instrument (reduction of about 1000 samples).

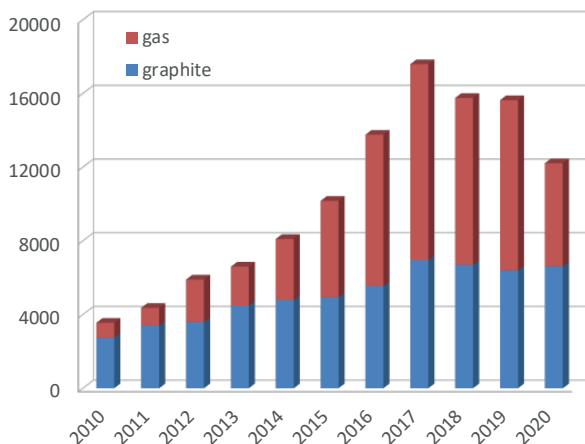


Fig. 1: The number of total measured radiocarbon samples per year decreased by 3500 samples in 2020 to still impressive 12000 samples.

A very positive development, especially given the special circumstances, are the rising numbers in high-precision measurements on solid graphite samples. Thanks to the great commitment and excellent self-organization of the preparation lab team during the lock-down, approximately 10% more solid samples were analysed in 2020 compared to 2019. 1500 high-precision graphite samples were measured for improving the IntCal

radiocarbon calibration curve (see eg. [1]), compared to 1000 in the previous year.

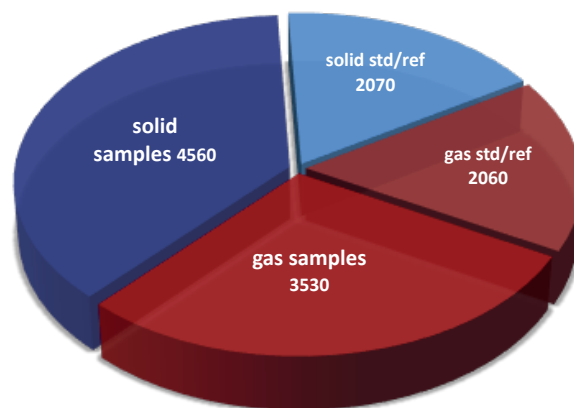


Fig. 2: Overview of all samples measured on the two MICADAS systems in 2020 at LIP. Graphite samples and standards are shown in blue. Red colours represent gas samples and standards.

It should be noted, that 2800 out of the 4560 solid samples were measured in the second half of 2020, when the restrictions due to the pandemic were loosened. Measuring such a high number within 6 months required an adaption of the measurement strategy: the negative carbon ion current out of the source was increased from typically achieved 60 μ A to more than 80 μ A. We have to note however, that measurements at higher currents tend to run less stable. As a consequence, frequent re-tuning of the instrument was required.

[1] N. Brehm, LIP Annual report (2020) 32

LOW ENERGY AMS (LEA)

Instrument performance and first measurements

D. De Maria, S. Maxeiner¹, A. Herrmann¹, S. Fahrni¹, H.-A. Synal

The performance of a first prototype of the LEA system, designed and assembled in collaboration with Ionplus AG (Dietikon, Switzerland), was investigated for radiocarbon analysis at stripping energies around 100 keV. This novel AMS instrument features the same detection principle for the rare ^{14}C isotope as the MICADAS system, but is characterized by a lower terminal voltage, between 50 keV and 65 keV, at the acceleration stage. This allows for a more compact design of the instrument at the high energy (HE) side. However, this should not hinder its performance, which is supposed to fulfil the same high standards required by precise radiocarbon dating as the MICADAS system.

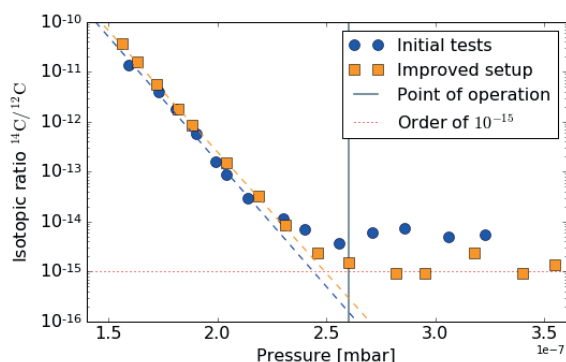


Fig. 1: ^{14}C to ^{12}C isotopic ratio measured for a sample of blank material (PhA) as a function of the residual pressure of the helium stripping gas within the accelerator chamber.

Initial tests were focused on the determination of the detection limit of the instrument. The interferences due to isobaric molecules are suppressed through a dissociation process taking place within a stripper canal filled with helium. A blank level corresponding to ^{14}C to ^{12}C isotopic ratios on the order of 10^{-15} was achieved at a stripper gas density of about $0.4 \mu\text{g}/\text{cm}^2$ (see Fig. 1). This means a dating capability of more than 50000 years.

Taking advantage of the high yield observed for the 1^+ charge state in helium at stripping energies around 100 keV, a resulting ion optical transmission above 70% was achieved at LEA with measured transmissions around 52%.

An optimized tuning of the system allows for stable $^{12}\text{C}^+$ currents at the HE-side of up to $35 \mu\text{A}$. The acceptance tests performed using samples of different reference materials (Oxa 1, Oxa 2, IAEA-C7) demonstrated the stability of the measurements under normal operation conditions. Measurements were collected to achieve a precision around 1‰ for the single standard samples. Fig. 2 shows the results of the analysis of a set of replicate samples generated from the standard material Oxa 2.

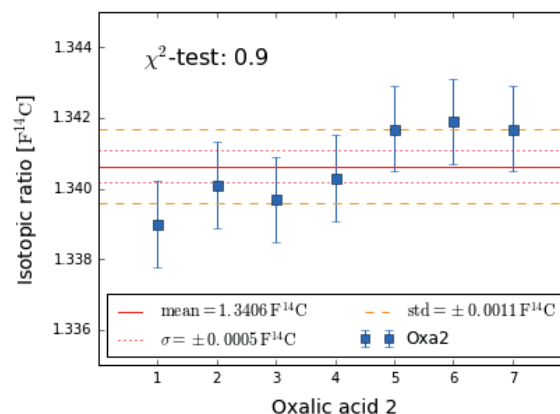


Fig. 2: Results of the measurements of 7 replicate samples of Oxa 2 standard material. More than 10^6 counts were collected to ensure the statistical precision of the measured values.

The obtained promising results encourage further developments of the LEA system. A more compact prototype is now envisioned, based on a direct beam injection into the accelerator without any intermediate focal point.

¹*Ionplus AG, Dietikon*

GAS MEASUREMENTS AT LEA

Performance and analysis of labelled biomedical compounds

D. De Maria, S. Fahrni¹, D. Ramrath¹, F. Lozac'h², C. Marvalin², H.-A. Synal

One of the original intentions for developing the LEA system was to provide a more compact and accessible instrument for external users interested in performing analyses of biomedical samples. Consequently, the LEA capability of performing fast analyses of samples in gaseous form is crucial. Preliminary tests of the properties of gas measurements at LEA were performed with both GIS and DTI gas interfaces. An elemental analyzer (EA) was used as sample combustion unit. The focus was initially on the determination of the optimum carbon mass flow into the ion source and on the analysis of standard (Oxa 2) and blank (PhA) samples. Fig. 1 shows a set of standard samples measured using the EA-DTI approach. The scatter around the average is within 1% deviation. A satisfactory blank level down to 0.006 F¹⁴C was obtained with both GIS and DTI. This level is comparable to the performance on a MICADAS system.

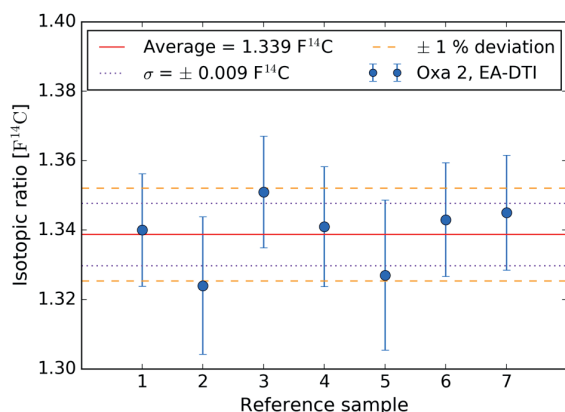


Fig. 1: Scatter of the standard (Oxa 2) samples measured at LEA with the EA-DTI coupling.

Good ions currents were obtained with both interfaces. In general, currents for the stable ¹²C⁺ isotope were in the range between 5 µA and 7 µA, but currents up to 9 µA were seen occasionally. Under these conditions, the counting statistics required for biomedical

studies could be easily obtained, even for fast sample analyses of 2 minutes only.

Subsequently, the routine for high throughput analyses based on the EA-DTI approach was evaluated for measurements with the LEA. A short campaign was designed in collaboration with Novartis Pharma AG (Basel, Switzerland). Samples were generated in triplicate by spiking two biological matrices (plasma and urine) at different concentrations. Fig. 2 shows the results of the measurements of the plasma replicates.

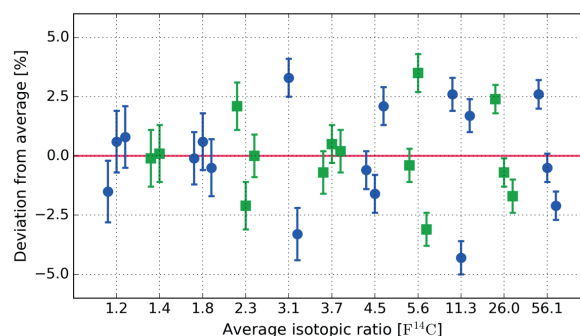


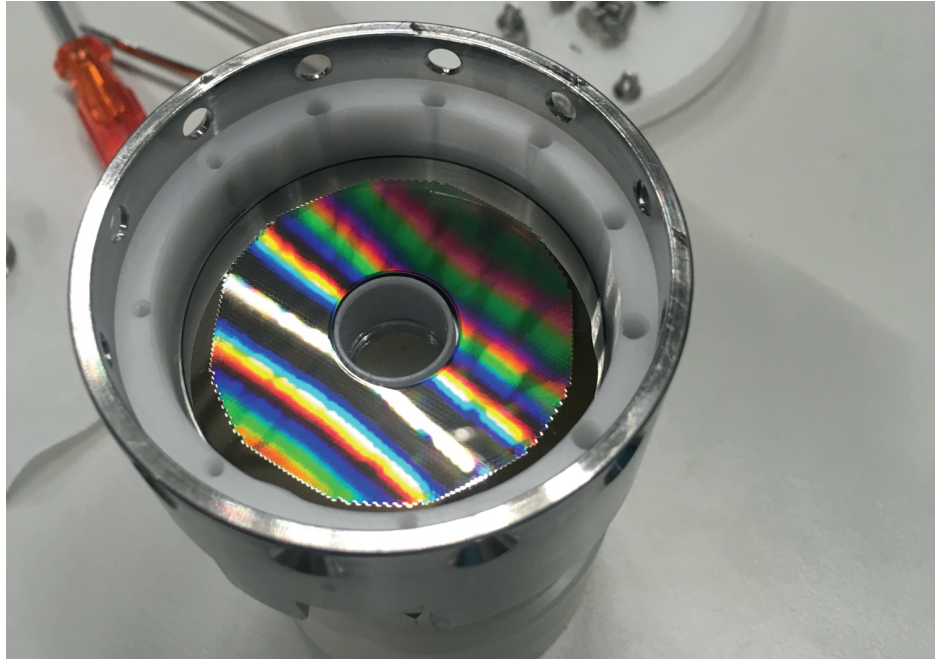
Fig. 2: Deviation of individual plasma samples from the average of the respective triplicates.

Most of the samples generated from plasma presented less than 2.5% deviation from the mean, independently from their radioactivity. Some individual urine samples were affected by contamination, leading to deviations up to 7.5% instead. However, if the statistical uncertainty of the individual samples is taken into account, several triplicates are in excellent agreement, demonstrating the good reproducibility of biomedical AMS analyses at LEA.

¹Ionplus AG, Dietikon

²Novartis Pharma AG, Basel

INSTRUMENTAL AND ANALYTICAL DEVELOPMENTS



Annular MCP for electron detection in the MeV-SIMS TOF setup

Measurement of all Si isotopes

Isobar separation for ^{32}Si

A new sample mount for dual-polarity MeV-SIMS

Stripping transmissions of beryllium and boron

^{236}U measurement with fluoride target matrices

Efficiency tests for U and Pu on MILEA

Fluoride target matrix for ^{26}Al analyses

MEASUREMENT OF ALL Si ISOTOPES

Towards stable conditions for the half-life measurement of ^{32}Si

M. Schlomberg, R. Gruber, R. Pfenninger, H.-A. Synal, C. Vockenhuber, P. Vogel

Within the SINCHRON collaboration, the LIP will perform measurements of the number of ^{32}Si atoms for the redetermination of its half-life. Therefore, an absolute and stable AMS measurement of the concentration of ^{32}Si in enriched ^{32}Si sample material produced by the PSI must be performed. There are two main challenges: Firstly, the clear identification of ^{32}Si in the presence of its intense isobar ^{32}S , high ion energies available from the 6 MV Tandem facility are necessary to perform this separation. Secondly, since there are no reference standards available for ^{32}Si , we must perform an absolute measurement of the number of ^{32}Si ions. This requires the knowledge of all potential changes to the measured isotopic ratio. Not only losses in the detection system of ^{32}Si are relevant, but also losses during the beam transport and mass-dependent stripping yields are relevant.

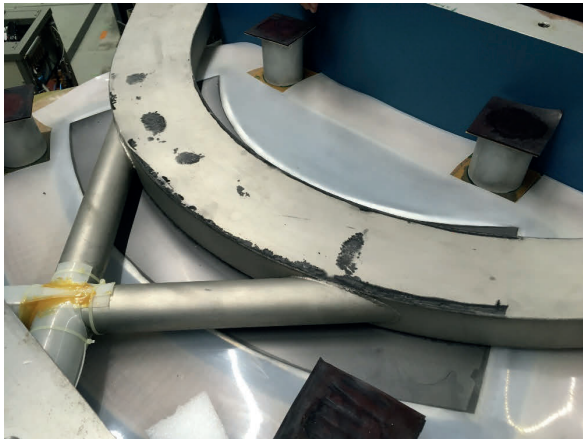


Fig. 1: Insulated vacuum chamber at the LE magnet.

Therefore, the fast-pulsing system at the LE magnet of the 6 MV Tandem was upgraded, enabling the quasi-simultaneous measurement of all three stable silicon isotope currents namely ^{28}Si , ^{29}Si and ^{30}Si . By measuring their isotopic ratios and comparison to the natural ratios, we can determine corrections due to fractionation

effects. The electrical contacts and the insulation of the vacuum chamber of the LE magnet was improved to apply high voltages up to ± 10 kV (Fig. 1). Furthermore, the electronics of the pulse timing and the current readout of the Faraday cups was extended for a third current measurement (pulse C).

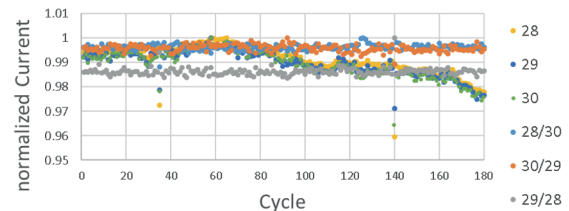


Fig. 2: Measurement of all stable Si isotopes and their ratios.

In first tests using a gas stripper in the accelerator with a terminal voltage of 3.7 MV and a silicon sample, we reproducibly achieved a stable isotopic ratio with a standard deviation of 0.1% despite changes in the absolute current of the stable isotopes. These measurements, of which one is depicted in Fig. 2, were typically of 30 min duration and make us therefore optimistic concerning the stability of our beam.

The ^{32}Si samples (irradiated and processed at PSI) are in the form of SiO_2 . The extraction of Si^- ions from SiO_2 by sputtering with Cs^+ requires mixing with a metal to prevent charging up. Among our mixing candidates of Ta, Ag, Fe, Nb and Al, Fe was producing the smallest amount of S. The most stable measurement conditions for SiO_2 are given by mixing SiO_2 with Fe in a ratio of 1:4 achieving a $^{28}\text{Si}^-$ current of up to 240 nA. Further investigations are necessary to improve the output of Si^- ions from SiO_2 samples from the ion source.

ISOBAR SEPARATION FOR ^{32}Si

Investigation of passive absorber and gas-filled magnet

M. Schlomberg, I. Mihalcea¹, D. Schumann¹, H.-A. Synal, M. Veicht^{1,2}, C. Vockenhuber, A. Wallner³

The separation of ^{32}Si from its isobar ^{32}S can be performed by utilizing the difference in stopping powers of Si and S. There are three possible approaches: 1) The current is diminished such that ^{32}Si and ^{32}S can be measured in a multi-anode gas ionization chamber (GIC), where the identification of Si is achieved in the detector. 2) A passive absorber in front of the GIC stops the ^{32}S ions and allows detection of the transmitted ^{32}Si ions at high rate. 3) A gas-filled magnet (GFM) causes different mean trajectories due to the different mean charge states and energy loss of the isobars. Therefore, most ^{32}S ions are spatially separated and can be blocked, while ^{32}Si can be measured in a GIC.

Method 1 can be used only if the intensities of ^{32}Si and ^{32}S are not too different. Since S is abundant and ^{32}S the most abundant isotope one of the other methods must be used.

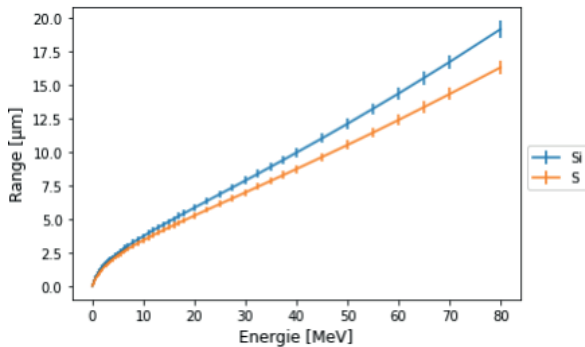


Fig. 1: Range vs. energy of Si and S in SiN foils.

The passive absorber method (2) is based on the range difference of Si and S in the absorber (Fig. 1). First, we tried to separate the two ions using a silicon nitride (SiN) foil stack, but due to the impracticability to adjust the absorber thickness, we switched to a CO_2 gas absorber. At 15 MeV, we were able to separate the peaks of Si and S, but since stopping is a statistical process, the tail of the high current ^{32}S peak made the separation of the isobars impossible. Better

separation is achieved at 30 MeV, however light recoils from the absorber materials (H, N, C, O), knocked out by the high intensity ^{32}S , produce a background. By using Ar as absorber gas, we could reduce this background and managed to achieve a preliminary identification of ^{32}Si .

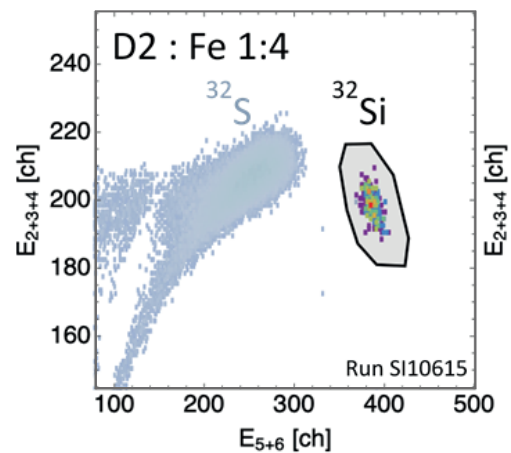


Fig. 2: Two-dimensional energy-spectrum of a ^{32}Si sample after the GFM.

We used the GFM method (3) to measure the $^{32}\text{Si}/\text{Si}$ ratios of ^{32}Si samples produced and diluted to expected ratios between 10^{-9} and 10^{-12} at PSI. At 44 MeV, we achieved a clear separation of the ^{32}Si and ^{32}S (Fig. 2). Of the stable isotopes, only the ^{30}Si current could be measured due to our beamline geometry. Assuming natural abundance and estimating the efficiency of our GFM (between 0.1 and 0.7), we could confirm the correct isotopic composition for the sample with the highest $^{32}\text{Si}/\text{Si}$ ratio (D2). Blank material showed no ^{32}Si counts corresponding to a ratio of $<10^{-13}$. However, the other samples showed ratios around 10^{-10} , indicating that the dilution material was contaminated. A new dilution series is currently being prepared.

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³ ANU, Canberra, Australia/HZDR, Rossendorf, Germany

A NEW SAMPLE MOUNT FOR DUAL-POLARITY MeV-SIMS

Optimizing the sample mount for symmetric dual-polarity extraction

K.-U. Miltenberger, M. Döbeli, C. Vockenhuber, J. Thut, H.-A. Synal

The Capillary Heavy Ion MeV-SIMS Probe (CHIMP) setup at LIP was recently upgraded with a simultaneous dual-polarity extraction mass spectrometer system with electron start [1], requiring a fine tuning of the extraction fields for stable and reliable operation. A good extraction efficiency for secondary electrons is of particular importance, since secondary electron detection provides the start signal for the Time-of-Flight spectra of secondary ions of both polarities. Thus, the experimentally optimized extraction voltages tend to be biased towards the negative polarity spectrometer.

Simulations of the electrostatic extraction field in front of the sample showed that the limited width of the initially used narrow omicron-type sample mount leads to a significantly degraded extraction. This problem becomes even more pronounced for measurements with a sample offset from the centered position as demonstrated in Fig. 1, left. Additionally, the sample surface is several 100 μm recessed behind the sample mount.

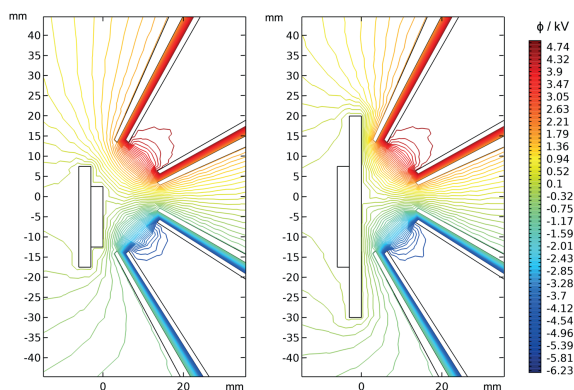


Fig. 1: 2D electric potential simulation of the extraction region in front of the 5 mm offset sample stage with initial narrow sample mount (left) and modified wide sample shield (right).

To mitigate these problems, a new sample mount was designed in which samples are recessed by

only 100 μm into a wide (50 mm) sample mount plate with cut out aperture. The front of the wide mount plate serves as a grounded shield shaping the extraction field towards both extraction cones even with the sample offset from the central position (see Fig. 1, right). This results in identical and reproducible extraction conditions and efficiencies even for different measurement spots distributed across a larger (ca. 8 mm x 11 mm) sample surface.

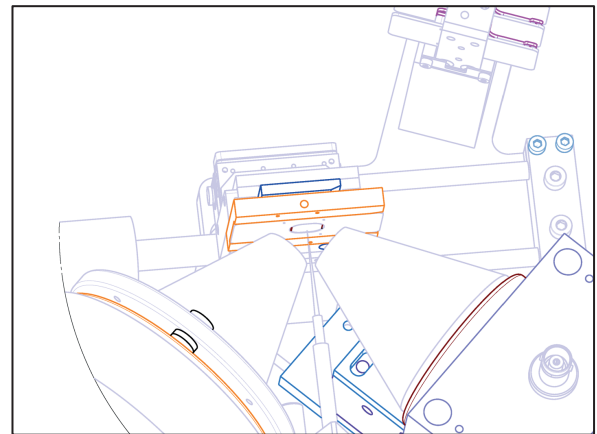


Fig. 2: 3D CAD drawing of the newly designed sample mount with integrated wide sample shield inside the CHIMP measurement chamber.

This newly designed wide sample mount is slotted into a fitting receptacle and secured with spring loaded pressure pieces. Additionally, a compatible wide sample magazine was designed to transfer five samples into the measurement chamber at once. Fig. 2 shows all elements of the new sample handling system integrated into the CHIMP measurement chamber.

Currently the new parts are manufactured by the D-PHYS workshop at ETH Zürich, the installation and first tests are scheduled for February 2021.

- [1] K.-U. Miltenberger et al., LIP Annual report (2019) 25

STRIPPING TRANSMISSIONS OF BERYLLIUM AND BORON

Extending transmission data towards lower energies

P. Gautschi, M. Christl, H.-A. Synal

Ion beam transmission through a He-gas stripper was investigated for both ^9Be and ^{10}B ions at stripping energies between about 55 keV and 110 keV. While charge state yields are known for B [1] and transmission data of Be in the 1+ and 2+ charge states has been presented for stripping energies down to around 100 keV [2], MILEA provides an ideal platform to extend the data towards lower energies.

For each measurement either $^9\text{BeO}^-$ or $^{10}\text{BO}^-$ was injected into the gas stripper of the accelerator. Then charge state 1+ or 2+ was selected using the first high-energy (HE1) magnet after the accelerator. The quadrupole tripled which is installed between the accelerator and the HE1 magnet allows for focusing of the selected charge states into the Faraday cup, located after the HE1 magnet.

For each selected energy a series of transmission data points for B and Be were measured while steadily increasing the gas density in the stripper tube. Figure 1 shows an example for Be transmission (1+, red and 2+, blue) at 117 keV stripping energy.

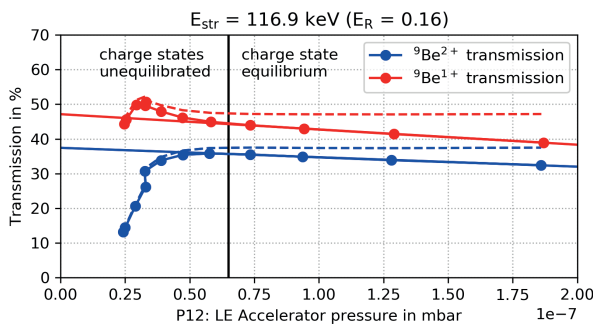


Fig. 1: Transmission of $^9\text{BeO}^-$ to Be^{1+} (red) and Be^{2+} (blue) at a stripping energy of 117 keV in dependence of stripper density.

The steep increase in transmission at low stripper densities for both charge states represents the

development of charge state equilibrium, indicated by the solid black line. The linear decrease in transmission after charge state equilibrium represents ion optical losses due to increased scattering and the limited beam acceptance of the system. For the final transmission values these losses were accounted for by extrapolating the transmission data to zero stripper density (lines).

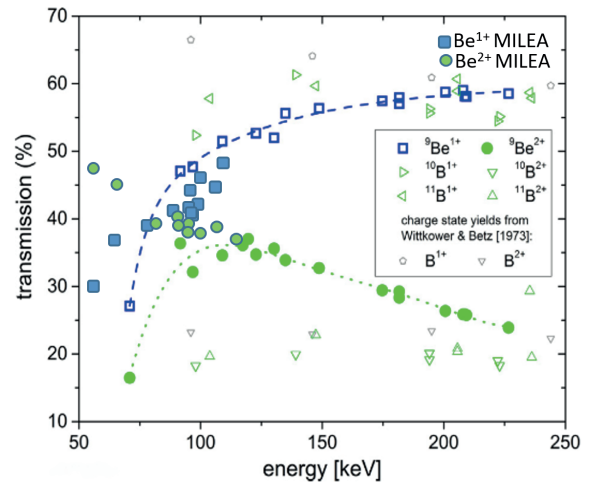


Fig. 2: Our newly measured MILEA data extends values measured at the Tandy [2] towards lower energies.

It was found that the transmission into the 2+ charge state of Be still increases towards lower energies while it decreases for 1+ (Fig. 2). Below 100 keV the 2+ becomes even dominant reaching transmission values of up to 48 %. On the other hand, the transmission rates for B stay much more constant at about 20% for the 2+ and around 60% for the 1+ charge state. For AMS measurements of ^{10}Be , going to lower energies has the benefit of increased B suppression by a factor of up to two.

- [1] A. B. Wittkower et al., ADNDAT (1973) 113
- [2] J. Lachner et al., NIMB (2014) 209

^{236}U MEASUREMENT WITH FLUORIDE TARGET MATRICES*

Evaluation of a new sample preparation procedure

T. Prasek¹, M. Nemec¹, K. Fenclova¹, M. Christl, P. Gautschi, C. Vockenhuber

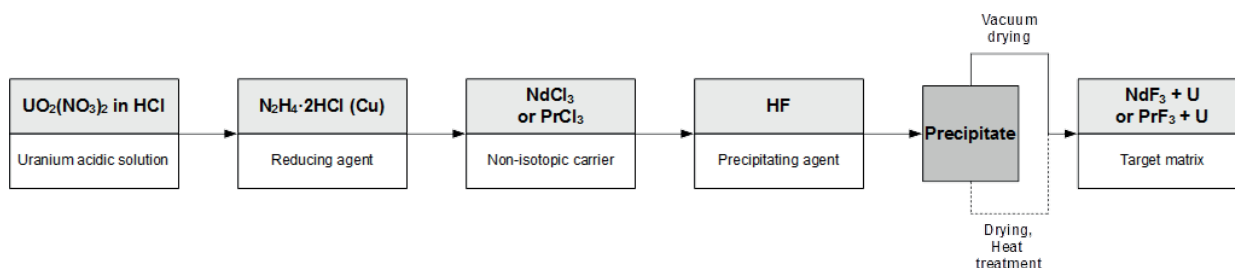


Fig. 1: Diagram of the suggested fluoride matrix preparation method for ^{236}U measurement

^{236}U is a valuable isotopic tracer, employed predominantly as a fingerprint of anthropogenic contamination for nuclear safeguards purposes. Recently, fluoride target matrices have been studied for actinides, including uranium, as a promising alternative to oxidic samples, routinely utilized in AMS measurements, providing significantly higher ionization yields over shorter sputtering periods when mixed with PbF_2 due to a formation of superhalogenide ions [1].

Viability and reproducibility of a newly developed uranium-fluoride target matrix preparation procedure (Fig. 1) [2], designed for ^{236}U determination with respect to preceding natural sample treatment, pre-concentration and TEVA-UTEVA actinide separation, were verified. A series of target samples prepared from Vienna KkU uranium standard, containing $\text{PrF}_3 + \text{U}$ and $\text{NdF}_3 + \text{U}$ matrices along with their admixtures with PbF_2 , was analyzed using a 300 kV MILEA AMS system. For each respective sample, several consecutive mass scans ranging from 250 to 360 AMU were acquired using the central FC behind the accelerator to obtain information on molecular ions extracted from the source (Fig. 2). Selected samples were further analyzed, involving U^{3+} ion current measurement on the high energy side together with the determination of their $^{236}\text{U}/^{238}\text{U}$ isotopic ratio, which represents one of the first complete measurements of this ratio with fluoride target

matrices and the very first of its kind on the MILEA device.

Based on the mass scans, $^{238}\text{U}^{19}\text{F}_5^-$ was identified as a most intensive ion on the LE side, which corresponds with previously published data [1, 2].

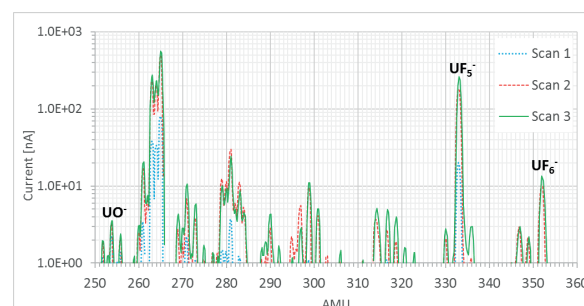


Fig. 2: Consecutive mass scans of a sample containing $\text{PrF}_3 + \text{U}$ and PbF_2 admixture, average scan time 21 min.

Overall U^{3+} ionization yields for the fluoride matrix admixtures reached typically 1.0 – 1.3 % over 4 hours, which is approximately 20 times higher than for the standard oxidic materials. Moreover, the average $^{236}\text{U}/^{238}\text{U}$ ratios obtained are presumably in agreement with the given standard value.

- [1] R.J. Cornett et al., NIMB 361 (2015) 317
- [2] T. Prasek et al., NIMB 472 (2020) 64

¹CTU in Prague, Czech Republic

*Supported by RADIATE TA

EFFICIENCY TESTS FOR U AND Pu ON MILEA

How efficiently do we extract UO^- and PuO^- from oxide matrices?

M. Christl, K. Kündig, P. Gautschi, H.-A. Synal

The efficiency of actinide measurements with AMS has continuously improved over the past decade. The implementation of He-stripping with low energy systems boosted the over-all transmission of compact AMS systems to more than 30% [1, 2]. However, the main bottleneck for more efficient actinide measurements is the formation of negative ions in the ion source. Traditionally, actinide samples are prepared as oxides. The material is co-precipitated with iron, transferred to the oxide form by heating and then mixed with a metal binder (e.g. Nb-powder). Typically, this method provides ionization efficiencies on the order of roughly one per mill. Recently, however, very high ionization efficiencies of more than 3% were reported from Pu samples prepared in an oxide matrix and mixed with Nb [2].

In this study, we determined the ionization efficiency of UO^- and PuO^- prepared in an oxide matrix using the MICADAS-type ion source of the MILEA system. Well-known amounts of a ^{233}U - and ^{242}Pu -spike were co-precipitated with different amounts of Fe, transferred to oxide form and mixed with various amounts of Nb-powder. The influence of the different matrices on the ionization efficiency of U and Pu is clearly visible in our results (Fig. 1). The sample precipitated with 1.5 mg Fe and mixed with 6 mg Nb-powder showed best performance reaching ionization efficiencies of 1.2%, which is still lower than the reported values indicating that the preparation method still may be improved. These first results are already a factor of four better than the ionization efficiencies obtained with the traditional actinide preparation method for the TANDY ion source (1.5 mg Fe, 3 mg Nb), indicating that AMS target preparation of actinides has to be modified to enable highly efficient routine measurements of actinides on the MILEA system.

Our best performing sample (Fig. 2) exhibited an average counting rate of about 30 cps over more than 17 h. Furthermore, our results consistently document the differential extraction of U and Pu over time, which seems to favor PuO^- over UO^- at the beginning (blue curve Fig. 2).

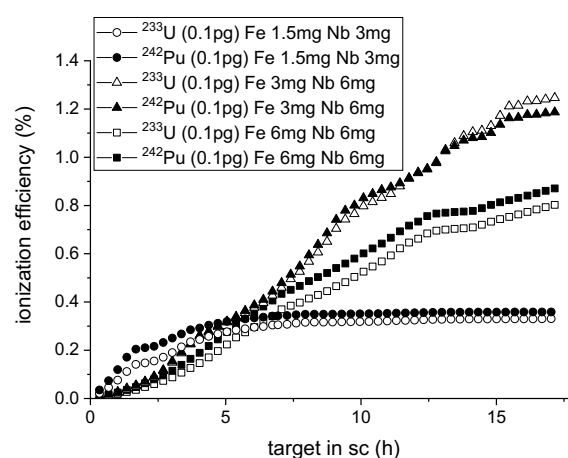


Fig. 1: Ionization efficiencies for 0.1 pg U and Pu dispersed in different oxide matrices over time.

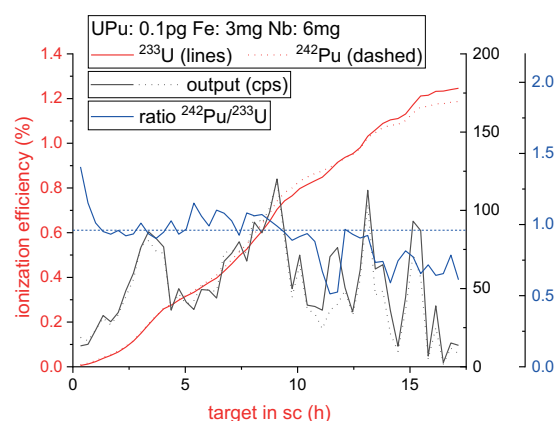


Fig. 2: Details of the best performing sample: evolution of ionization efficiencies (red), output in counts per second (black), and $^{242}\text{Pu}/^{233}\text{U}$ ratio (blue) over time.

- [1] C. Vockenhuber et al., NIMB 38 (2013) 294
- [2] M. Hotchkis et al., NIMB 70 (2019) 438

FLUORIDE TARGET MATRIX FOR ^{26}Al ANALYSES

Preliminary tests of Na_3AlF_6 as a target material

K. Fenclova¹, T. Prasek¹, M. Nemec¹, P. Gautschi, M. Christl, C. Vockenhuber

AMS measurements of $^{26}\text{Al}/^{27}\text{Al}$ are routinely performed by extracting the negative Al ion current from a Al_2O_3 sample material. In this case, the isobar ^{26}Mg is suppressed but the intensity of the Al^- current is significantly lower compared to other molecules [1]. In this study we tested the suitability of the more abundant super-halogenide AlF_4^- extracted from different Na_3AlF_6 based target materials for AMS of ^{26}Al .

After initial current tests at the Nuclear Physics Institute (Czech Academy of Sciences), the fluoride materials were measured on the MILEA system. Different sample matrices were analysed by recording LE mass scans with a Faraday cup (FC) behind the accelerator (Fig. 1). The most intense Al-peak ($^{27}\text{AlF}_4^-$, 103 AMU), was selected for further evaluation of matrices as it provided the highest currents from all aluminium-fluoride peaks (up to $2\ \mu\text{A}$). Several additives such as PbF_2 or Ag were tested to increase the extracted ion current and Na_3AlF_6 mixed with MgF_2 was used to investigate isobaric background. Production of interfering ions from the cathode material (Cu) was identified, but the occurrence of interfering MgF_4^- (102 AMU) was not observed in the LE spectra (Fig. 1).

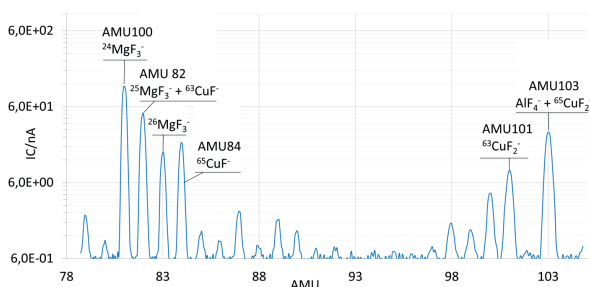


Fig. 1: LE mass spectrum of a sample of $\text{Na}_3\text{AlF}_6 + \text{PbF}_2 + \text{MgF}_2$ (1:1:1) in a Cu cathode.

Subsequently, charge state yields of ^{27}Al and background in the detector were investigated by injecting AlF_4^- into the accelerator and selecting the most abundant Al^{2+} with the HE magnet

($m/q=13$). The $^{27}\text{Al}^{2+}$ yields were measured with the HE FC. A gas absorber was used to eliminate a strong interference of $^{13}\text{C}^+$ before identifying ions in the gas ionization detector (GID) [2]. The signal of the two-anode GID revealed a strong interference in the expected detection region of $^{26}\text{Al}^{2+}$. This interference probably belongs to $^{26}\text{Mg}^{2+}$ originating from $^{27}\text{Al}^{26}\text{MgHO}_3$ or $^{26}\text{Mg}_2\text{H}_2\text{O}_3$. Furthermore, ions with higher energy but the same m/q (probably $^{39}\text{K}^{3+}$ or $^{52}\text{Cr}^{4+}$) are observed (Fig. 2), which are injected into the accelerator as a molecule with 102 AMU.

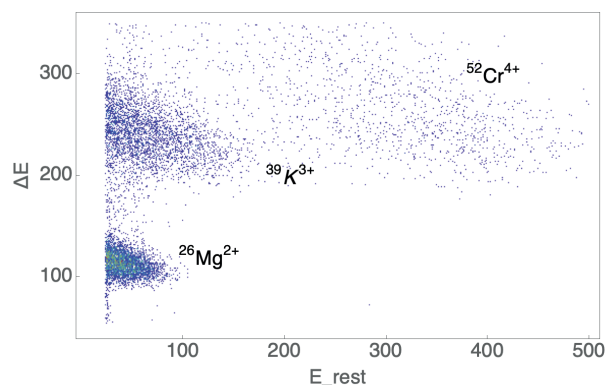


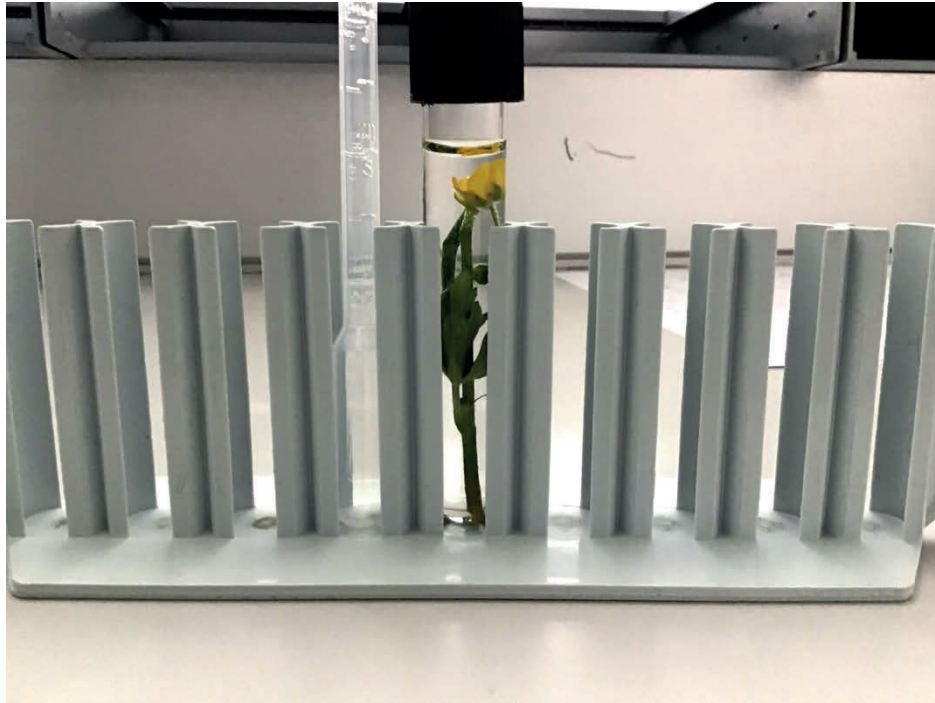
Fig. 2: 2D-spectrum from the GID, identifying $m/q=13$ ions. $^{26}\text{Al}^{2+}$ reaches just the first anode (y -axis), only ions with higher charge state and higher energy reach the second anode and show up in the 2D-spectrum.

The aluminium fluoride matrices provide high ion yields, however, the interference of magnesium represents a significant complication to be considered in further research.

- [1] R. Middleton, A Negative-Ion Cookbook (1989) 44
- [2] J. Lachner et al., NIM B 331 (2014) 209

¹CTU in Prague, Czech Republic

RADIOCARBON



First buttercup near HPK building records the above ground atmospheric ^{14}C content

^{14}C preparation lab

Radiocarbon measurements by laser ablation

What is a good bone blank?

^{14}C dating of ivory and bones

Re-dating of the Markelfinger mammoth tusk

New age calibration of the man in the ice

New solar event discovered in tree rings

Little stones – big bones

Receding glaciers - emerging trees

Time to change crops!

When was Matilda's castle of Canossa built?

From charcoal particles to river history

Lake paleoseismology in the Eastern Alps

Radiocarbon in the Southwestern Atlantic

Radiocarbon in the Fram Strait

The age of permafrost carbon in the peel Canada

Lateral particle supply over the NW Atlantic

Organic matter in marine oxygen minimum zones

^{14}C PREPARATION LAB

Overview of samples and laboratory activities

I. Hajdas, S. Bollhalder, N. Brehm, N. Cascurbata, M. Castrillejo, D. De Maria, P. Gautschi, G. Guidobaldi, N. Haghipour, K. Kündig, H.-A. Synal, L. Wacker, A.-M. Wefing, M. Wertnik, C. Welte, K. Wyss

The year 2020 in our laboratory started with reconstructions: a new hood has been added and dedicated to separation of cellulose (Fig. 1).



Fig. 1: A new hood (on the left) for preparation of cellulose samples; the Soxhlet system and solvents are located in the hood on the right.

Despite reconstructions some preparations were still possible and a visitor from Italy completed a study of mortars [1]. February was an intensive time with changes in laboratory staff and a visitor working on archeological bones. The reconstructions were completed promptly at the end of February, just in time before the virus forced us to reorganize again. Limiting the number of people per room and wearing masks were the reality of 2020.

Research	Targets
Archaeology	1180
Geochronology	739
Water	668
Art	123
Bomb peak	68
Reference material	159
Total	2937

Tab. 1: Number of samples prepared and analyzed in 2020 as graphite targets.

Nevertheless, we are looking back at the successful year with numerous samples analysed (Table 1) and various projects completed.

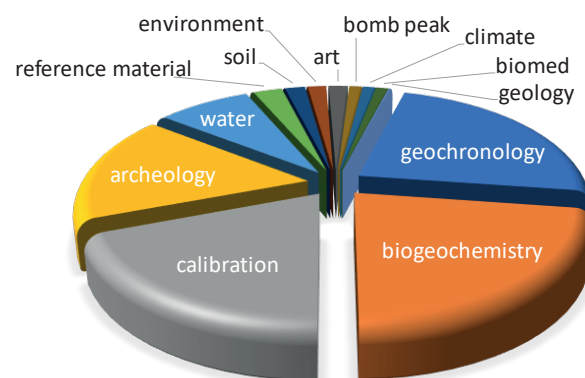


Fig. 2: ^{14}C analysis for various research disciplines during the last year

In addition, to traditional projects dedicated to climate research, archaeology and geochronology (Fig. 2), ^{14}C signature in water samples was successfully measured as a part of ocean studies [2-3].

- [1] G. Tirelli et al., LIP Annual report (2020) 37
- [2] M. Castrillejo et al., LIP Annual report (2020) 40
- [3] M. Castrillejo et al., LIP Annual report (2020) 41

RADIOCARBON MEASUREMENTS BY LASER ABLATION

The search for intra-annual signals in stalagmites

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We investigated STAM-4, a fast-grown stalagmite from Cloșani Cave in Romania using our custom laser-ablation-AMS setup. This stalagmite was collected in 2010, grew actively over a period of one hundred years and has an exceedingly high growth-rate varying between 200 – 1000 $\mu\text{m/a}$.

Ablating along a straight line with a scanning speed of 5 $\mu\text{m/s}$, we collected a scan over the whole stalagmite with 18 data points per mm. The scan was performed from the young part towards the old. However, as each data point corresponds to the ^{14}C counts in a 10 s period only, they come with a high degree of uncertainty.

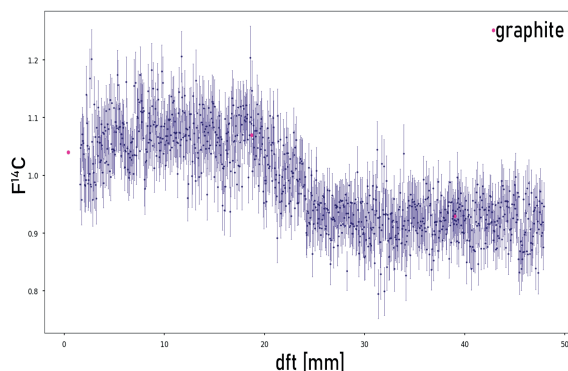


Fig. 1: Measured $F^{14}\text{C}$ from young to old versus dft (distance from top) in mm.

To make better sense of the data, a Savitzky-Golay filter [1] was applied. This is a smoothing filter that fits a low-degree polynomial to consecutive subsets of the data by method of least squares.

The filtered data now shows the development of the $F^{14}\text{C}$ over time much more clearly and fits well together with the previously taken graphite measurements. A second scan at lower scanning speed was also measured but only from 24 to 34 mm dft (not shown).

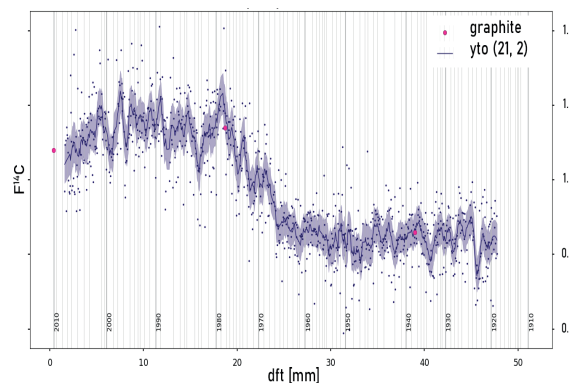


Fig. 2: (21,2) Savitzky-Golay filtered $F^{14}\text{C}$ vs dft in mm.

However, comparison between different scans remains a challenge. The offset in the distance from the central growth axis between scans leads to different layer thicknesses at the same dft. Thus, a next step will be to find a method for aligning multiple scans at different distances from the growth axis.

- [1] A. Savitzky & M.J.E. Golay, Anal. Chem. 36 (1964) 1627

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WHAT IS A GOOD BONE BLANK?

Comparison of different types of bone blank samples

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For dating old radiocarbon samples, it is necessary to correct the measured ¹⁴C concentration for extraneous carbon with a different ¹⁴C signature, that may have been introduced to the original sample material and not removed or even introduced by the sample preparation.

Here, we test different old, supposedly ¹⁴C-free bone samples for their ¹⁴C content after collagen isolation and purification. About 100 mg bone was first demineralized for 1 week with 1 M HCl at 6°C before they were washed for 30 min at room temperature with 1 M NaOH. Then the collagen was dissolved in 0.01 M HCl at 70°C for 1-2 hours. The solution was filtered before an Ultra-filtration (UF) step was performed, where the supernatant was freeze-dried and analyzed for ¹⁴C together with a small piece after demineralization.

ETH-	Label	¹⁴ C age (UF)	¹⁴ C age (demin.)
106615	Khanduga	50580 ±246	52590 ±281
106622	Oymiakon	53246 ±294	54912 ±326
109742	BRA3280A	44921 ±175	45528 ±182
86079	LQH12	38475 ±110	40165 ±131
86080	LQL15	46809 ±194	40808 ±136
86081	369	49045 ±211	44592 ±185
86082	387	41405 ±134	38698 ±118
86083	Yarnton	49117 ±228	45202 ±191
86084	RDTW 01 -59-	48146 ±212	50888 ±253
85905	Latdorf Horse	333 ±18	320 ±18

Tab. 1: ¹⁴C ages in yrs BP of the processed blank bone samples together with a horse bone from 1644 AD (IntCal20 for 1640 AD: 287±10).

The measured radiocarbon ages without blank subtraction are given in Tab. 1 for the fraction after UF and also for the demineralized bone. The obtained range of ¹⁴C ages of 38475 yr and 54912 yr is large. The oldest ages were obtained for well-preserved mammoth bones from Siberian permafrost soils. Here, the demineralized bones seem even older and we

thus conclude that the bones were not contaminated with younger material. We also note that the two bones were indistinguishable from untreated combustion blanks (52000 ± 1000 yr).

This is in contrast to the apparently somewhat younger bones LQL15, 367, 387, and Yarnton (mammoth, Bisons, and Bovinae) from England, where the demineralized fraction is significantly younger. It may be hypothesized that maybe not all contamination was removed by the collagen and UF treatment in those cases. Two supposedly blank samples were only measured around 40000 yr. Comparing to earlier measurements [1], we conclude that sample 387 is probably younger than 50000 yr, whereas we were unable to clean sample 369, which previously gave older ages (outlier?). The brown bear from Austria, BRA3280A, seems to have no young contamination but was also measured a bit younger than most other blank samples.

The age determination by ¹⁴C of old bone samples (>30000 yr) is complicated and it is crucial to have an appropriate blank to test the isolation and purification of collagen. Ages seem reliable, only when a sample is not too strongly contaminated. A ¹⁴C determination after demineralization in addition to the analysis after purification can give valuable information on the reliability of the ultimate age determination. Appropriate bone blanks are essential for accurate bone dating. Indications that the Latdorf horse from 1644 AD was measured too young compared to IntCal20 demand for further investigation.

[1] G.T. Cook et al., Radiocarbon 54 (2012) 845

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^{14}C DATING OF IVORY AND BONES

Results of intercomparison as a part of the IAEA forensic project

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Aboveground thermonuclear detonation tests carried out in different sites around the globe after the WWII resulted in the release in the atmosphere of different radionuclides including ^{14}C . Fig. 1 shows the curve (“bomb peak”) representing the ^{14}C concentration measured in the Northern atmosphere as a function of time obtained by analyzing atmospheric CO_2 [1].

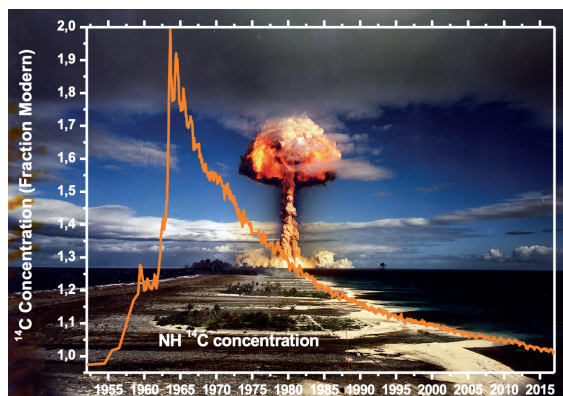


Fig. 1: ^{14}C concentration in the Northern Hemisphere (NH) (background image from <https://www.flickr.com/photos/7969902@N07/511103951/in/photostream/>).

This large excursion of the ^{14}C concentration has opened to ^{14}C -dating the applications in the forensics field which demands for high chronological resolutions, beyond the typical limits of the technique. Indeed, the detection in a sample of “bomb” ^{14}C levels and their comparison with the bomb peak curve used as reference results in resolution of a few years. Different studies have shown the potential of the method for different applications spanning from forensics anthropology, illicit drug analysis to the identification of contemporary art forgeries.

In order to address these issues IAEA (International Atomic Energy Agency) is supporting a work package (WP4) specifically dedicated to “Radiocarbon” within the Coordinated Research Projects: *Enhancing*

Nuclear Analytical Techniques to Meet the Needs of Forensic Sciences. In the frame of this program an intercomparison exercise was performed on bone and ivory samples which are among the sample material more commonly involved in forensics for issues related. The aim of the study was then to show the level of achievable precision and accuracy of the results for the analysis of samples of forensics interest [2]. Six bone and ivory samples were selected for the study with ages spanning from background (mandible of a woolly mammoth, >50 ka) to post bomb ivory samples.

The results demonstrated an extremely good agreement within the three laboratories and provide basis for promoting the AMS technique for forensic studies (Fig. 2).

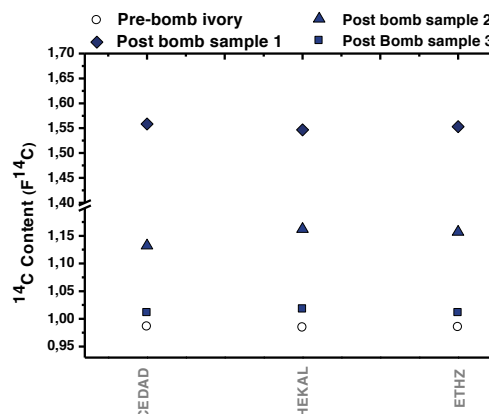


Fig. 2: ^{14}C concentrations measured in pre and post-bomb ivory samples.

[1] S. Hammer and I. Levin (2017), heiDATA

[2] G. Quarta et al., Radiocarbon (in press)

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RE-DATING OF THE MARKELFINGER MAMMOTH TUSK

Implications for the Last Glacial Maximum Rhine glacier chronology

S. Kamleitner, S. Ivy-Ochs, K. Wyss, I. Hajdas

The majority of radiocarbon ages that anchor the advance of the Rhine glacier to its Last Glacial Maximum (LGM) position in time, stem from animal bone or ivory [1]. Among them is the Markelfinger mammoth tusk. A tusk fragment found in 1978 at ~ 8 m depth in a gravel pit on the north shore of Lake Constance (Fig. 1). The surrounding outwash gravels were interpreted to have been deposited by the first LGM Rhine glacier advance into ice-free area and are covered by 4-6 m of till [2]. As most other samples in the Rhine chronology, the Markelfinger mammoth tusk was first dated in the 1980s and 1990s [1]. Original ^{14}C ages were reported as $18530 \pm_{925}^{1045}$ [2], which corresponds to 25.3-20.1 ka cal BP (OxCal 4.4., IntCal 20) .



Fig. 1: Recovery of the mammoth tusk at the Lerchentel gravel pit (Kreisarchäologie Landratsamt Konstanz, photo: Jörg Aufdermauer).

Contamination of bone and tusk samples during burial is possible, typically resulting in 'too young' ages. Combined with less experienced sample preparation, the issue of young carbon limits the reliability of early ^{14}C ages, and therewith the validity of the radiocarbon-based Rhine glacier chronology. To eliminate existing concerns, re-dating of the Markelfinger tusk was undertaken.

500 to 750 mg of ivory were sampled from two locations of the untreated tusk (Fig. 2). Samples were prepared using ultrafiltration method [3],

combusted, graphitized, and measured at the LIP MICADAS system.



Fig. 2: Markelfinger mammoth tusk in in-situ position (left, Kreisarchäologie Landratsamt Konstanz, photo: Jörg Aufdermauer); and 2019 during re-sampling at the Hegau Museum, Singen (right).

With a yield of 5-6%, collagen was found sufficiently preserved. C/N atomic ratios of 3.2 point towards good collagen quality. Dating results of both samples are in very good agreement with each other. ^{14}C ages are significantly older than the original age obtained in the 1980s [2], supporting an earlier advance of the LGM Rhine glacier.

Acknowledgement: Sabine Kuhlmann (Hegau Museum, Singen) and Jürgen Hald (Kreisarchäologie Landratsamt Konstanz) are thanked for providing the museum's collection for analysis.

- [1] O. Keller, E. Krayss, Vierteljahresschr. Naturforsch. Ges. Zürich. 150(3) (2005) 69
- [2] M.A. Geyh, A. Schreiner, Quat. Sci. J. 34 (1984) 155
- [3] I. Hajdas et al., Radiocarbon 51(2) (2009) 675

NEW AGE CALIBRATION OF THE MAN IN THE ICE

Improvements to the calibration curve for 3450-3050 BC

N. Brehm, L. Wacker, S. Bollhalder, I. Hajdas, N. Bleicher¹, K. Nicolussi², W. Tegel³, H.-A. Synal

Radiocarbon dating is a very useful tool to precisely date archeological findings. A major drawback of the radiocarbon dating method is that the resulting age is highly dependent on the shape of the radiocarbon calibration curve, that builds upon ^{14}C measured in tree-rings as an archive for past atmospheric ^{14}C concentrations. For instance, the man in the ice, "Ötzi", was dated to an age of 3359-3105 BC. This relatively large time range is a result of Ötzi's measured radiocarbon age falling into a "plateau" of relatively constant atmospheric ^{14}C concentrations, while we expect in principle lower concentrations when going back in time due to the decay of ^{14}C . The so-called "Ötzi plateau" originates most likely in a relatively high solar activity, that typically has a shielding effect in the relatively constant high-energetic cosmic ray flux that is responsible for the atmospheric ^{14}C production.

Until now, most of the calibration curve is relying on tree ring blocks of 10 years, which reduces the precision of the dating method in two ways. First, the curve relies on only about 20 measurements per century, and second it has a limited time resolution of only 10 years smoothes out fast changes of atmospheric ^{14}C changes.

We have now measured the time period between 3450-3050 BC with annual resolution by using state of the art AMS on precisely dated tree rings to construct a new, more detailed calibration curve. In Figure 1, the calibrations of the new radiocarbon age of Ötzi, an average of 10 recent radiocarbon analyses [1,2], is calibrated with the low resolution IntCal20 (Fig. 1 top) and our high-resolution curve (Fig. 1, bottom). With the newly measured annually resolved calibration curve we obtain a more structured and more precise age range, resulting in better confined calibration ages.

Nevertheless and as expected, we still cannot overcome the problem of the plateau in the calibration curve with a more precise radiocarbon age of the Ötzi as well as with a higher-resolved calibration curve. Despite the new effort it is still a big problem to precisely date the man in the ice, we still obtain a time range of nearly 250 yr for the age of Ötzi.

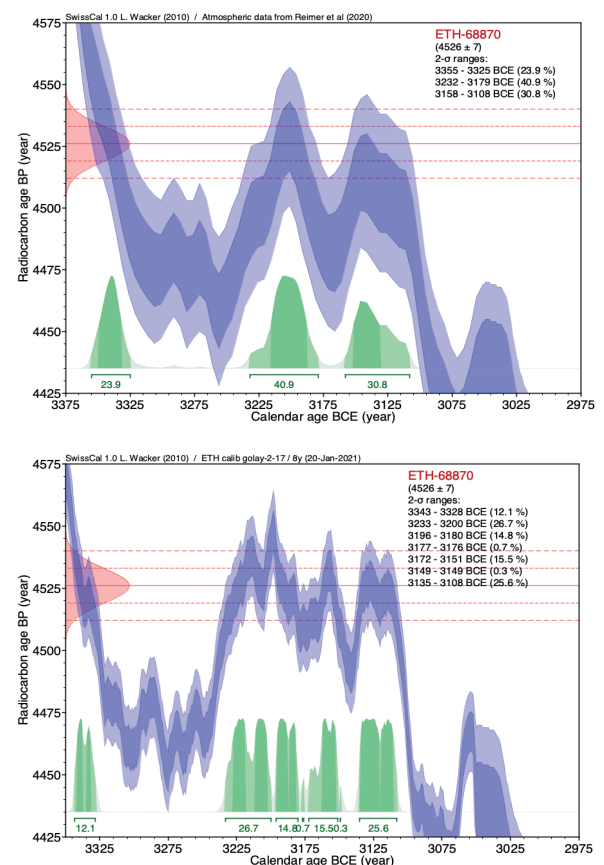


Fig. 1: Comparison of old and new calibrated age of Ötzi.

[1] I. Hajdas, Annual report (2016) 104

[2] G. Bonani et al., Radiocarbon 36 (1994) 247

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NEW SOLAR EVENT DISCOVERED IN TREE RINGS

Radiocarbon in tree rings reveals new solar proton event

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Our sun sometimes emits large quantities of highly energetic particles accelerated either by magnetic reconnection in solar flares or by shock waves associated with coronal mass ejections [1]. Such massive ejections are called solar energetic proton (SEP) events. The question arises, how often the sun emits such large amounts of energetic particles towards Earth which could cause major damage to satellites and could even disrupt transformers at the ground [2].

Since direct observations of SEP events are limited to the last few decades, cosmogenic radionuclides can be used to detect such events further back in time. The production rate of cosmogenic nuclides like radiocarbon is primarily dependent on the incoming flux of highly energetic galactic cosmic rays (GCR). Normally, solar protons shield the earth from GCRs, yielding a lower production of cosmogenic radionuclides, but when the sun expels large amounts of highly energetic particles into the interplanetary space, cosmogenic radionuclide production can suddenly be enhanced.

Until now there are only three findings of sharp increases confirmed in several radionuclide records (¹⁰Be, ³⁶Cl and ¹⁴C), which can be attributed to SEP events [3]. The reason for this is a lack of long annually resolved radionuclide records and strongly dampened or noisy signals that are hard to detect. However, when such spiked increases are found in different archives, such as ¹⁴C in tree rings or ¹⁰Be or ³⁶Cl in ice cores, they can be synchronized precisely to the year. To find and detect such events, we measured radiocarbon in tree ring records at annual resolution with accelerator mass spectrometry (AMS).

We have discovered a new strong increase in different trees from England and Austria grown more than 9000 years ago. The substantial

increase of ¹⁴C can be seen in each of four investigated trees (Fig. 1). A sudden rise of about 2% is seen within one year, which is more than the 1.5% increase found for the so far strongest known event 775 AD [4].

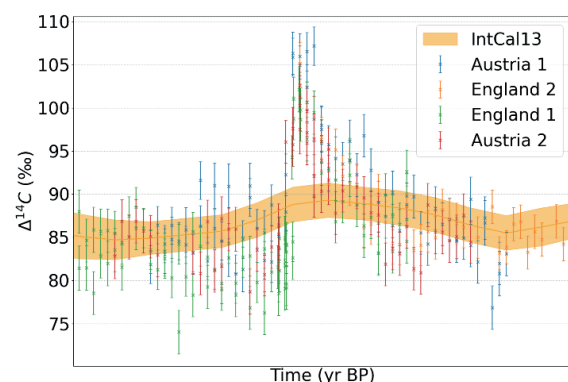


Fig. 1: Measured decay corrected ¹⁴C concentrations in rings of four trees from England and Austria in comparison with the IntCal13 calibration curve slightly more than 9000 years ago.

Further analysis will be required to better characterize this newly found event.

- [1] P. O'Hare et al., PNAS 116 (2019)
- [2] C.J. Schrijver et al., Space Physics 117 (2012)
- [3] F. Mekhaldi et al., Nat. Commun 6 (2015) 8611
- [4] F. Miyake et al., Nature 486 (2012) 240

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LITTLE STONES – BIG BONES

The Mesolithic Rock Shelter Flözerbändli in Muotathal (Switzerland)

U. Leuzinger¹, W. Imhof¹, G. Guidobaldi, I. Hajdas, K. Wyss

The speleologist Walter Imhof has been conducting archaeological surveys in the Muotathal community for over 15 years. In spring 2020, the researcher inspected a 140 m long ledge above the right bank of the Muota river. The site (740 m a.s.l.) is located 3 km from the well-described Mesolithic Berglibalm Rock Shelter [1]. In summer 2020, an exploratory archaeological excavation was completed under the overhanging rock (Fig. 1).



Fig. 1: Walter and Urs digging and sieving in the Flözerbändli. Photo: Franz Steinegger.

An early medieval fireplace from the 6th century AD was found at a depth of only a few decimeters. Underneath, several layers with fireplaces from the early Mesolithic and possibly even from the Late Paleolithic were excavated [2]. The charcoal found in fireplaces underwent anthracological and ¹⁴C analysis. In addition, a total of 24 stone artefacts (Fig. 2) and over 240 animal bones were discovered. Some bones, including ibex, and deer, were remains of the meals left by the Mesolithic hunter groups who rested in the Flözerbändli. On the last day of the excavation, the team discovered a decorated deer antler object (Fig. 3). The four ¹⁴C ages of the charcoal date the finds to the early Mesolithic and the late Paleolithic.



Fig. 2: Mesolithic stone artefacts: rock crystal, fine-grained quartzite, radiolarite and chert. Photo: Urs Leuzinger.

The decorated antler was dated to ca. 10.5 ka BC, which is somehow surprising. The sample was only 46 milligrams of antler and much older than associated charcoal dated to 8.5 ka BC. The reason for such an age offset is still under investigation, but the site's significance cannot be disputed.



Fig. 3: Two matching, decorated pieces of deer antler. Photo: Werner Müller.

- [1] U. Leuzinger et al., Archäologisches Korrespondenzblatt 50(3) (2020) 305
- [2] U. Leuzinger et al., Archäologie Schweiz 44(1) (2021) in press

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RECEDING GLACIERS - EMERGING TREES

Radiocarbon dating of fossil wood found at Morteratsch

C. Schlüchter¹, G.A. Godly², S. Bollhalder, G. Guidobaldi, I. Hajdas, L. Wacker, K. Wyss, K. Nicolussi³

Glaciers are a vital landscape element of the Alps. Today, they are essential factors for hydropower, science, tourism, recreation, and religion. They are often considered stable parts of the landscape, but they would have to be brought back to stability by all possible means if unstable in extent.

After the culmination of the most recent glacier advance in the 1980s and the ever more accelerating down- and back melting since that time, large quantities of subfossil wood and compressed peat have emerged from the base of many Alpine glaciers or are washed out by meltwater outbursts from underneath the ice.

Field campaigns in 2019 and 2020 to Morteratsch glacier in the Bernina area of the Upper Engadine Valley have resulted in collecting exceptional samples. By 2017 the glacier's main part had retreated behind a cross-valley bedrock ridge. Basal ice flow to the ice surface at the glacier terminus is well defined for transporting basal sediment to the front while basal compact till is pressed against the bedrock ridge. Two spectacular observations were made: (1) just to the north of the bedrock ridge's culmination ridge, two tree trunks were found, perfectly arranged in ice-flow direction, pressed into a depression in bedrock and partially covered by boulder till (Fig. 1). Due to the two trees' position, only the smaller one could be sampled for tree-ring analysis. The massive trunk was sampled in 2020. At that time, the lowermost part of the trunk with the spreading part of the roots was examined. The soil on which the tree was growing was still partially preserved in between the roots: evidence for tree growth on a weathered soil surface. (2) Ca. 20 m towards the glacier from site (1) a small terrace, formed by meltwater erosion, displayed basal deformation till with relics of soil with large amounts of wood pieces of centimeter to decimeter size. Six wood

clasts from this layer have been collected for radiocarbon dating.



Fig. 1: Detrital tree remnant in front of Morteratsch Glacier, sampled for ^{14}C dating and returned one of the oldest age so far (Photo P. Frommenwiler).

The smaller trunk of the site (1) has been sampled for radiocarbon dating. Furthermore, additional detrital logs that were exposed near site (1) in summer 2020 were also sampled for radiocarbon.

Radiocarbon dating of the tree samples and the material from the soil (site 2) revealed an overlapping calibration period covering the period ca. 10,700 to 10,250 cal yr BP. The age plateau at 9200 BP prevents high precision of calendar ages, and the oldest ^{14}C age of the large trunk (Fig. 1) is centered at the wiggle at 9300 BP.

A location with soil formation indicates that some of the subfossil trees have been sampled close to or at their growing position. The trees could only grow there when the Morteratsch glacier was smaller than today, which as our data suggest, was the case around 10,500 years ago.

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TIME TO CHANGE CROPS!

Dating agricultural dynamics among early farmers in Western Europe

H. Martínez-Grau¹, F. Antolín¹, R. Soteras¹, G. Guidobaldi, I. Hajdas, K. Wyss

The first farming communities of the Neolithic period (ca. 5900–2300 cal BC) had to make choices on which crops to grow, where, how and in which amount, taking climate and other potential hazards into account. Within the AgriChange project [1] (SNF, PP00P1_170515) we explore changes in crop choice and try to find the causes behind these choices, with the aim of reconstructing early farming resilience strategies such as opting for a broader agrobiodiversity or changes in food security strategies. To approach these questions, an important aspect of the research is focused on the timing of these changes. Radiocarbon dating of the agricultural dynamics is a crucial aspect, since it allows us to temporalize crop choices at different sites by dating archaeological evidence of cultivated plants, either grains or chaff remains (elements of the cereal ear) (Fig. 1).

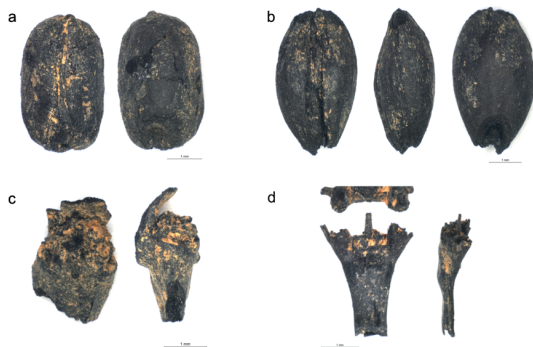


Fig. 1. Example of remains analysed. a=Naked wheat grain, b=Naked barley grain, c=Naked wheat rachis fragment, d=Naked barley rachis fragment.

Radiocarbon dating is not a new technique in archaeology, so we collected all the available radiocarbon dates associated to the Neolithic period for the study region (the northwestern Mediterranean and Switzerland) and we observed problems with the reliability of the dates (many based on unidentified charcoal

fragments of imprecise stratigraphic origin). In fact, only 1710 from more than 4000 dates can be considered reliable and only 129 were carried out on crop remains [2]. These observations only confirmed our need for dating cereal remains, not only for our research questions, but for a more accurate dating of Neolithic sites in the study area.

The AgriChange project has, so far, produced 106 new radiocarbon measurements. Until now, the new dates allow us to better contextualize the arrival and consolidation of these agricultural communities with a significant contribution to the period between ca. 5000–4700 cal BC and the beginning and end of the 4th millennium cal BC (Fig. 2).

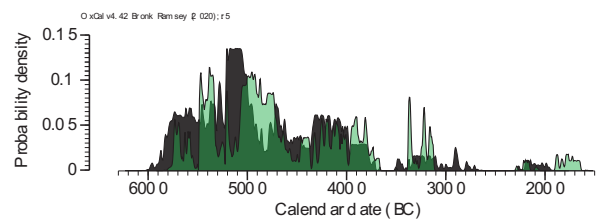


Fig. 2. Summed calibrated dates probability distribution of the published radiocarbon crop dates (black) and those carried out by AgriChange (green).

Our dating programme will not only allow observing the continued importance of agriculture during the 6th to the 3rd millennia cal BC but also singularize dynamics for different crops that can be coupled with climatic, environmental or cultural changes.

[1] F. Antolín et al., PAGES 26 (2018) 26

[2] H. Martínez-Grau et al., JOAD (submitted)

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WHEN WAS MATILDA'S CASTLE OF CANOSSA BUILT?

Lime mortar samples preparation for ^{14}C dating

G. Tirelli¹, I. Hajdas, S. Lugli¹

The Canossa castle (Reggio Emilia, Italy) was built in the middle of the 10th century, becoming the center of a complex defensive system for the control of the Northern Apennine valleys and the Po plain (Fig.1). Enlarged by Matilda the Great Countess, it is famous for the confrontation of the emperor Henry IV and Pope Gregory VII that happened here in 1077. The castle was repeatedly destroyed and rebuilt over the centuries. In order to determine the age of the ruins, we performed radiocarbon dating of lime mortars. Four samples were collected according to masonry stratigraphy and features.



Fig. 1: The Canossa Castle

The samples were prepared following the sequential dissolution procedure [1-2].

The samples have been fragmented with plastic covered pliers, avoiding hammering that can produce splinters from the aggregates (contaminants). The crushed material has been vibrated in a sieve series using increasingly fine mesh widths ranging between 75-500 μm (Fig. 2A). The grain-size fraction $<90\ \mu\text{m}$ has been subsequently wet sieved (Fig. 2B) and the grain-size fraction range of 46-75 μm has been used for dating. Prior to the sequential procedure the whole samples (bulk) has been dissolved in acid and graphitized for the AMS analysis. This step was performed to estimate the total carbon

content and to measure the age range of each sample. The sequential dissolution was performed using 10 ml of concentrated phosphoric acid (85% H_3PO_4) on about 50 mg of the mortar powder fraction in order to collect 4 consecutive CO_2 fractions after each 3 seconds. The rest of the CO_2 formed after 12 seconds has been also saved and the carbon content of each collected fraction was measured. The resulting 10–100 μg of C has been trapped in a 4 mm tube to be flame sealed for analysis using the Gas Ion Source (GIS) AMS facility at ETH Zurich, while samples containing more than 150 μg of carbon have been graphitized and measured using the MICADAS.

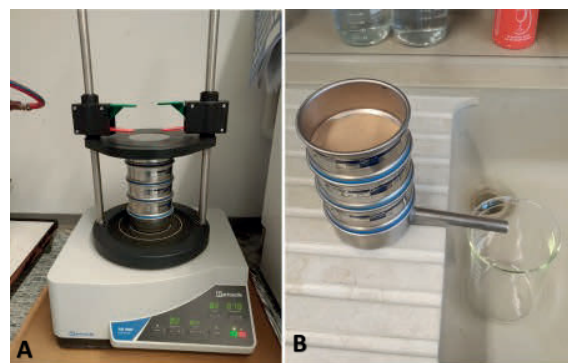


Fig. 2: A) Dry sieving and B) wet sieving

The resulting ages of two mortars and one charcoal samples confirm the 10th-11th century time span for the ruins.

- [1] A. Lindroos et al., Radiocarbon 49 (2007) 47
- [2] I. Hajdas et al., Radiocarbon 62 (2020) 591

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FROM CHARCOAL PARTICLES TO A RIVER HISTORY

Morpho-sedimentary evolution of the Inaouene wadi river (Morocco)

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As an earth surface dynamics team, we have been conducting geological exploration in the alluvial plan part of the Inouene wadi valley for over 2 years. This semi-arid area located in northern Morocco is the field of a doctoral research, which aims to define and understand the sedimentary activity evolution of this river, especially during the Holocene. For this purpose, an extension of 12 km² (Fig. 1) of low terraces (5m height difference as an average) was prospected and studied in autumn 2019. This mission allowed us to sample several charcoal particles that are dispersed or appear as fireplaces inserted in the alluvial sedimentary layers (Fig. 2).



Fig. 1: A low terrace in a meandering part of the Inaouene river.



Fig. 2: Fireplace charcoal lodged in an alluvial formation.

The next step was to purify these particles and treat them with a series of acid-base solutions to ensure removal of contamination and good quality results (Fig. 3). Most of ¹⁴C ages of these samples belong to the Holocene epoch, i.e., the last 11700 years, with a large number of ages centered around middle to late Holocene period.

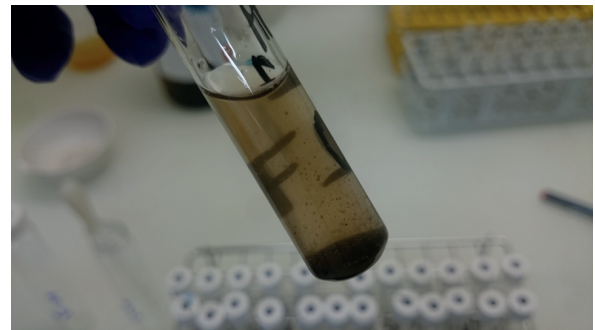


Fig. 3: Charcoal samples subjected to Acid-base-acid purification steps.

At first, these ages allowed us to correlate between the different sedimentary formations, in order to make a general scheme of the terraces distribution within the alluvial plain, and finally to estimate the incision and regional aggregation rate. The second important issue is a comparison in both space and time of the geodynamic activity of this river. Here, we are looking for any significant differences or similarities in order to elaborate a synthesis of natural and human parameters that govern both the style and the behaviour of rivers in this part of the world.

The sedimentary activity is also linked to the presence of humans in the river catchment area, the objectives of the same study include also tracking the archaeological history of this region.

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LAKE PALEOSEISMOLOGY IN THE EASTERN ALPS

Tracing strong prehistorical earthquakes in lake sediments

J. Moernaut¹, C. Daxer¹, P. Oswald¹, I. Hajdas, S. Fabbri², M. Strasser¹

The Eastern Alps are characterized by a low-to-moderate seismic hazards. This means that only a few strong and damaging earthquakes have been reported during historical times and it is unclear how often such geohazards take place and what could be their maximum magnitude. To fill this knowledge gap and improve seismic hazard assessments, we investigate the sedimentary infill in large lakes for traces of past strong earthquake activity. Our study targets are large lakes in Tyrol (Achensee, Plansee) and lakes in Carinthia (Woerthersee, Millstättersee). We map their infill with geophysical methods (e.g. multibeam sonar, sub-bottom profiler) and collect sediment cores that cover the past 12,000-17,000 years, i.e. dating back to the moment that these lakes were created after the last major deglaciation of the Alps.

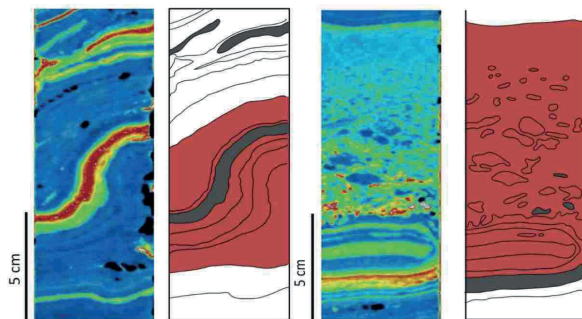


Fig. 1: Deformed sediments by strong earthquake shaking. Image created by medical X-Ray Computed Tomography (X-CT).

Strong earthquake shaking can induce deformation of sediment laminations (Fig. 1) and underwater landslides and mud avalanches (Fig. 2). In some cases, also the lake bottom itself can be ruptured by movement along the active fault as long as this is located under the lake and the earthquake was strong enough. To obtain the age of paleo-earthquakes a series of radiocarbon ages is obtained from organic macrofossils and the sedimentation evolution is modeled using

statistical techniques. Based on this, we deduce how often and how regular strong earthquake took place. Moreover, accurate age information is crucial for comparison of paleo-earthquake records in several lakes. This led us develop possible scenarios of how strong these earthquakes were and where their epicenter may have been located.

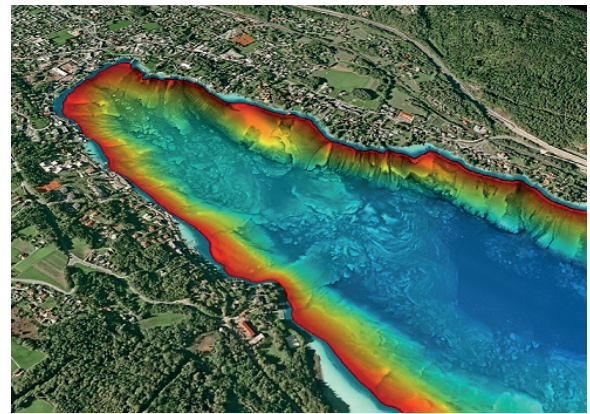


Fig. 2: Evidence for underwater landslides on the bottom of Woerthersee triggered by the strong earthquake of AD1348 [1].

First results indicate a very irregular pattern of strong earthquakes with marked phases of very frequent seismicity, alternated by long periods of seismic quiescence. Moreover, we find a strong correlation between strong earthquakes and the occurrence of large rockslides in the Eastern Alps, suggesting that large rock slope instabilities were likely triggered by rare strong earthquakes.

- [1] C. Daxer et al., J. Geol. Soc. Spec. Pub. 500 (2020) 235

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RADIOCARBON IN THE SOUTHWESTERN ATLANTIC

Temporal evolution since the GEOSECS program in 1972

M. Castrillejo, L. Wacker, S. Bollhalder, K. Kündig, M.G. Coto¹, F.F. Pérez¹

About 300 seawater samples were collected for the determination of $\Delta^{14}\text{C}$ in dissolved inorganic carbon in the southwestern Atlantic Ocean onboard the BIO Hespérides in April 2019. Samples were processed using the fully automated method recently developed at the Laboratory of Ion Beam Physics [1]. The main objective was revisiting the ocean sites sampled during the GEOSECS and SAVE programs in the 1970s and 1980s to evaluate the temporal evolution of seawater $\Delta^{14}\text{C}$ along the Ficaram cruise track between Ushuaia, Argentina, and the coast off Brazil in the Equatorial Atlantic (Fig. 1).

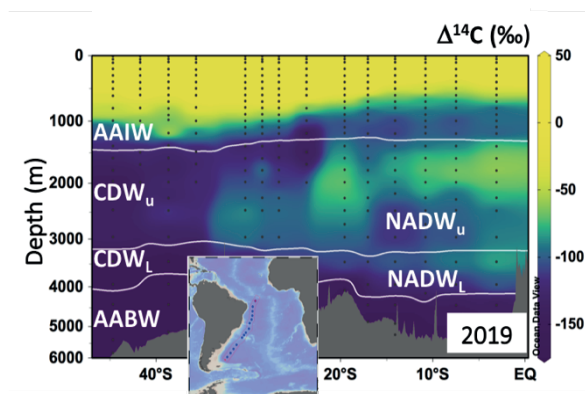


Fig. 1: Zonal distribution of $\Delta^{14}\text{C}$ in ocean waters along the Ficaram cruise track in spring 2019.

The zonal distribution of $\Delta^{14}\text{C}$ in 2019 (Fig. 1) shows high ^{14}C present in the upper 1000 m and relative ^{14}C maxima in the 1500-4000 m depth range between about 30°S and the Equator. While the high $\Delta^{14}\text{C}$ in shallow waters can mainly be explained by the atmospheric deposition of nuclear bomb- ^{14}C , a water mass analysis shows that the deep relative maxima are associated to the transport of bomb and natural ^{14}C by the upper and lower branches of the North Atlantic Deep Water, NADW_u and NADW_L, respectively. We compared the 2019 results to the $\Delta^{14}\text{C}$ distribution reported by GEOSECS in 1972 in Fig. 2. Among other results, we found a decrease of

50 to 100 ‰ $\Delta^{14}\text{C}$ in waters residing in the upper 100-300 m that is compensated by an increase of similar magnitude in the 100-1000 depth layer. The decrease of $\Delta^{14}\text{C}$ in the uppermost layer can be interpreted as the combination of two processes. Firstly, the penetration of bomb ^{14}C deposited in the 1970s through the water column. Secondly, the $\Delta^{14}\text{C}$ in the atmosphere has been progressively diluted due to burning of fossil fuels ("Suess effect"). Thus, the decadal transfer of CO_2 from air to sea expectedly results in the lowering of $\Delta^{14}\text{C}$ observed in shallow ocean waters.

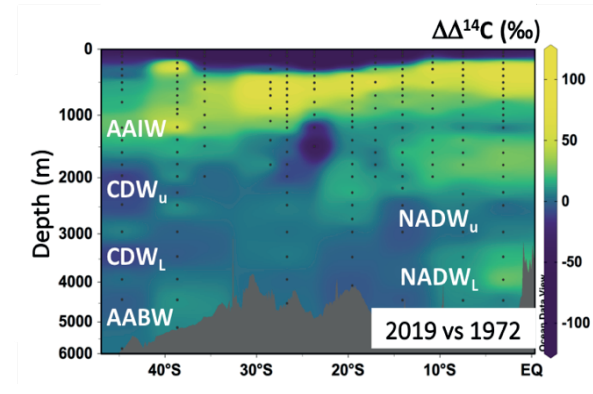


Fig. 2: Change of $\Delta^{14}\text{C}$ along the Ficaram cruise track from 1972 to 2019.

The increase in the NADW layer (up to 30 ‰) cannot be explained by natural variability in the atmospheric production of ^{14}C , but is instead associated with the transport of bomb- ^{14}C that was captured in the sea surface of the North Atlantic about 50 years ago.

- [1] N. Casacuberta et al., Radiocarbon 62 (2019) 13

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RADIOCARBON IN THE FRAM STRAIT

Temporal evolution between 2018 and 2019

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The Fram Strait, located between Greenland and Svalbard, is a fundamental gateway for water mass exchange between the Arctic Ocean and the Subpolar North Atlantic. Seawater was collected along a west-east transect in the Fram Strait onboard the Norwegian research vessel Kronprins Haakon in September 2018 and 2019 (Fig. 1). The sampling was part of the annual monitoring program conducted by the Norwegian Polar Institute in order to characterize the composition and changes of water masses exchanged through this gateway. $\Delta^{14}\text{C}$ was measured in the dissolved inorganic carbon fraction of seawater using the fully automated method developed at the Laboratory of Ion Beam Physics [1].

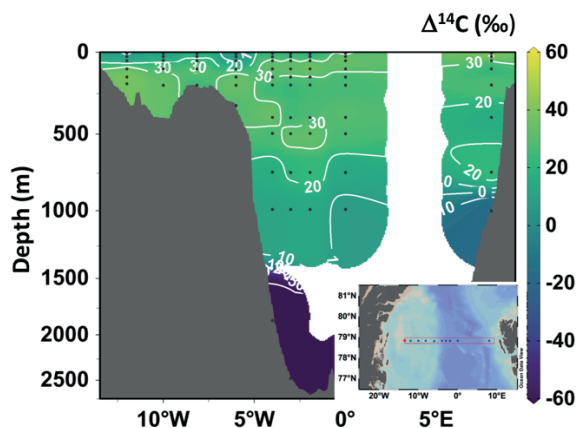


Fig. 1: Zonal distribution of $\Delta^{14}\text{C}$ across the Fram Strait in late summer 2019.

Fig. 1 shows the zonal distribution of $\Delta^{14}\text{C}$ in 2019. High $\Delta^{14}\text{C}$, around 10 - 35 ‰, was observed between the surface and about 1000 m depth. The elevated $\Delta^{14}\text{C}$ values appeared to penetrate deeper in the western side of the Fram Strait, where Arctic waters are transported southwards. $\Delta^{14}\text{C}$ was distinctly lower, about -60 ‰, in waters residing in the 1500 to bottom depth layer. Fig. 2 shows the time evolution of $\Delta^{14}\text{C}$ between 2018 and 2019 along the same cruise track. Positive

$\Delta^{14}\text{C}$ values indicate an enrichment of ^{14}C in the uppermost and easternmost side of the section. The rest of the section shows a decrease of $\Delta^{14}\text{C}$, especially in the upper 500 m residing west of the 0° meridian. The magnitude of the observed changes over one single year is in some cases significantly larger than the uncertainty of the measurement (<2‰).

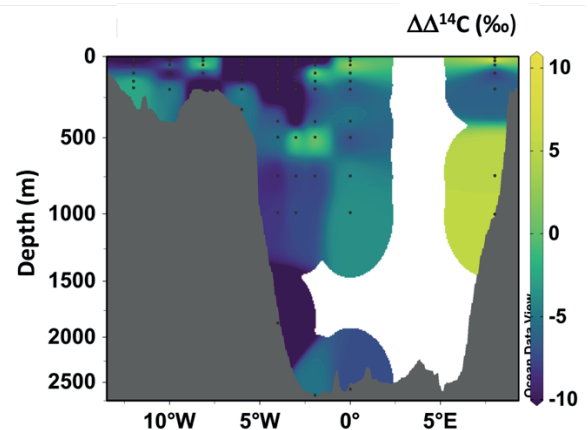


Fig. 2: Change of $\Delta^{14}\text{C}$ in the Fram Strait between 2018 and 2019. Positive values denote increase in $\Delta^{14}\text{C}$.

Waters entering the eastern part of the Fram Strait are dominated by Atlantic components enriched in ^{14}C , while Arctic Waters outflowing in the western part near the Greenland Shelf might also include Pacific Water with lower ^{14}C content. The decrease in $\Delta^{14}\text{C}$ in these waters could therefore be related to the increasing fraction of Pacific Waters observed in the Fram Strait since 2016 [2].

- [1] N. Casacuberta et al., Radiocarbon 62 (2019) 13
- [2] A.-M. Wefing, ETH Diss. 27466

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THE AGE OF PERMAFROST CARBON IN THE PEEL CANADA

Radiocarbon dating of particulate organic carbon

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Arctic regions are warming twice as fast as the rest of the planet, which has led to accelerated thaw of permafrost (i.e. perennially frozen ground) [1]. Permafrost stores organic carbon (OC, mean $\Delta^{14}\text{C}$ of Pleistocene permafrost -995‰ [2]) that, upon thaw, may be released to the atmosphere as greenhouse gases adding to ongoing climate warming [3].

The Peel watershed (Fig. 1), located in the Yukon and Northwest Territories, Canada, is underlain by discontinuous and continuous permafrost and covers a diverse set of landscapes varying from barren mountainous areas to flat wetlands. Part of the watershed undergoes abrupt permafrost thaw that releases OC mainly in the particulate form (POC) to the river network (Fig. 2).



Fig. 1: Peel watershed is underlain by permafrost. We tracked abrupt permafrost thaw by measuring ^{14}C in particulate organic carbon.

Radiocarbon dating of POC in the Peel River and its tributaries helps us to trace its sources (e.g. upper active layer with mean $\Delta^{14}\text{C}$ signature of 10‰, lower active layer -545‰, Pleistocene permafrost -995‰, terrestrial primary production 97‰ and *in situ* production -145‰ [2,4]) and ongoing changes in the watershed. Preliminary data show that the $\Delta^{14}\text{C}$ of POC from

the Peel River tributaries range from -40 to -910‰ (corresponding to uncalibrated ^{14}C ages of 290 to 19,200 years).



Fig. 2: Abrupt permafrost thaw releases particulate organic carbon that flows into the Peel River as thick sediment slurry.

By coupling different landscape characteristics, such as slope, vegetation cover and soil OC content, to POC composition in the river, we want to better understand the current and future changes imposed on the watershed by permafrost thaw.

- [1] B. Biskaborn et al., Nat. Comm. 10 (2019) 264
- [2] S. Shakil et al., Environ. Res. Lett. 114019 (2020) 15
- [3] E. Schuur et al., Nature. 171-179 (2015) 520
- [4] B. Wild et al., PNAS.10280-10285 (2019) 116

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LATERAL PARTICLE SUPPLY OVER THE NW ATLANTIC

Long-term sinking particle bulk ^{14}C values

M. Kim¹, N. Haghipour¹, S.J. Manganini², D.B. Montlucon¹, J. Toole², T.I. Eglinton¹

This study tried to examine lateral transport processes, focusing on the significance of aged POC associated with lithogenic material. We measured carbon isotopes on sinking particles that span vertically, temporally, and spatially distributed domains in order to answer two key questions: i) what is the nature and age of lithogenic matter-hosted POC within nepheloid layers? and ii) what are the mechanisms driving lithogenic matter-hosted POC transport?

The New England slope in the NW Atlantic is an ideal location to address these questions by high kinetic energy related to the complex interactions of two major current systems: the deep western boundary current (DWBC) and the Gulf Stream (Fig.1). Since 2001, a set of moored instruments (Line W program) and research cruises across the Gulf Stream have contributed to collect a set of observations and samples [1].

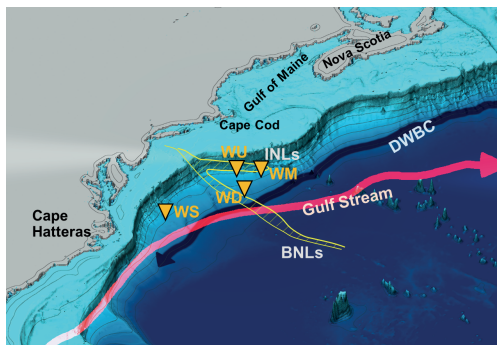


Fig. 1: Schematic map of the research sites showing the major current system, INL and BNL (yellow dash), and sediment trap locations.

A simple two end-member calculation to estimate the relative contribution of shelf- (~100 m water depth, $\text{PO}^{14}\text{C} = -140 \text{ ‰}$) and slope sediment resuspension (~3000 m water depth, $\text{PO}^{14}\text{C} = -260 \text{ ‰}$) to the sinking particle load based on a sinking particle study over a 3-year sampling interval at St. WM [2]. The estimated contribution of resuspended material to the

integrated sinking particle flux amount to 42%, 47%, and 63% at 1000 m, 2000 m, and 3000 m, respectively. The OC% of the resuspended sediment material estimated based on the relationship between PO^{14}C and the flux of biogenic and lithogenic components (1.4 % and 3 %, respectively) agree well [2].

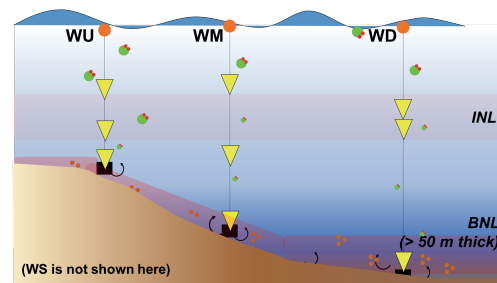


Fig. 2: Illustration of mooring lines across the slope including approximate water depths.

Our prior ^{14}C investigations based on sinking particles have indicated that lateral transport of aged POC between continental margins and the ocean interior is more important than previously assumed [2], and that the aged POC was closely associated with lithogenic material [3]. However, a detailed understanding of these processes is lacking, for instance, in relation to whether the intensity and direction of lateral transport exhibit temporal and spatial variability. We are expanding the sample coverage both spatially and temporally (Fig. 2), using organic and inorganic geochemical tracers.

- [1] J. Toole et al., DSR II 58 (2011) 1768
- [2] J. Hwang et al., JGR Oceans 122 (2017) 4539
- [3] J. Hwang et al., JGR Oceans 16802 (2020)

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ORGANIC MATTER IN MARINE OXYGEN MINIMUM ZONES

Surface core bulk and fraction-specific organic matter tracing with ^{14}C

E.T. Bruni¹, N. Haghipour, T.I. Eglinton¹

Oxygen exposure time (OET) is a key variable when it comes to organic matter (OM) preservation and degradation [1]. High-productivity systems over naturally occurring oxygen-depleted bottom waters have some of the highest OM concentrations in their sediment. A lot of this OM is protected from degradation by aggregation and interaction with mineral surfaces, which results in the decrease of the bulk sediment's density [2]. This low density increases the OM-rich aggregates propensity for resuspension [3], thus reintroducing the OM to conditions favorable for efficient, aerobic primary degraders. The remaining fraction of OM is more recalcitrant and more likely to be buried upon redeposition.

The differentiation between pristine and recalcitrant OM is possible by tracing the radiocarbon signals (among others) in the OM [4]. Similarly, this study measures the radiocarbon ages of 14 sites that are characterized by low-oxygen bottom waters and high (surface) productivity (Fig. 1). The samples were collected in independent sampling excursions and were stored at -20°C before freeze-drying, subsampling and analyzing.

Measurements are to be conducted on bulk core-top sediment, grain-size fractions, and density fractions. As most of the data is unpublished, we use the data from the Benguela upwelling system as a representative example. The bulk surface sediment is modern, with a depth and offshore aging trend, roughly following along-shore OM-enriched mud belts. Density fractions and grain size fractions indicate that young OM preferably accumulates in silt fractions. A quantitative analysis of total organic carbon is still to be conducted.

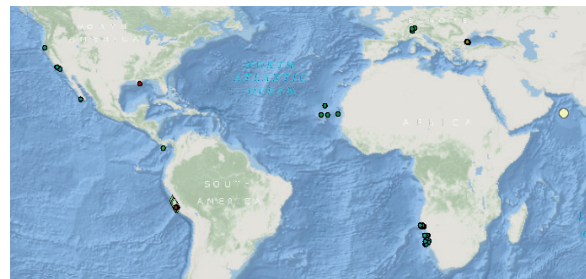


Fig. 1: Sample locations for this analysis (base map from [5]).

- [1] J.I. Hedges and R.G. Keil, *Marine Chem.* 264 (1995) 81
- [2] J.D. Hemingway et al., *Nature* 570 (2019) 228
- [3] L.M. Mayer, *Geochim. Cosmochim. Acta* 58 (1994) 1271
- [4] G. Mollenhauer et al., *Paleoceanography* 20 (2005) PA1016
- [5] ESRI (2011) *National Geographic World Map*.

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COSMOGENIC NUCLIDES



Sampling Deckenschotter for cosmogenic ^{26}Al - ^{10}Be isochron-burial dating in the Alpine foreland

Dating the oldest glaciofluvial sediments
Early Lateglacial ice decay in Swiss main valleys
The Quaternary period in Switzerland
In the forbidden field
The role of gorges in bedrock riegel formation
Millennial denudation rates across the Alps
Erosion of the Eiger north face
Rockfall recurrence at the Aiguille du Midi (FR)
Emplacement of the Molveno rock avalanche
The early holocene Buchwiese rock avalanche
Timing of the Akdag rock avalanche, Turkey
The uplift and slip rate of the Malatya fault
The last glaciation of the Jan Mayen volcanic Island
Holocene glacial history of Inglefield Land
Dating of large sorted stone stripes in Ethiopia

Blue ice moraines in Antarctica
The erosion rates of Madagascar escarpment
Erosion rates of tropical mountain ranges
Fluvial terraces in the Tropoja Basin, Albania
Paleo-outburst floods in the central Himalaya
Aggradation mode of braided river deposits
Landscape evolution of Serra da Estrela (PT)
Distribution of weathering fluxes at Lake Baikal
 ^{10}Be in Black Sea sediments from 40-60 ka BP
Improving the Baltic Sea sediment chronology
Improving past solar activity reconstruction
Testing “wastewater” for ice core measurements
Exploring the $^{36}\text{Cl}/\text{Cl}$ Input in arid environments
Plutonium-244 in deep-sea sediment

DATING THE OLDEST GLACIOFLUVIAL SEDIMENTS

Isochron-burial dating with ^{26}Al and ^{10}Be of the Swiss Deckenschotter

E. Bros, F. Kober¹, S. Ivy-Ochs, R. Grischott², M. Christl, C. Vockenhuber, C. Maden³

The oldest glaciofluvial sediments in Switzerland are called Deckenschotter (DS) and are found on numerous hilltops in the northern foreland. Based on the altitude, the DS are divided into two units, HDS (higher) and TDS (lower), with elevation difference implying a phase of incision of approximately 100-150 m [1]. An inverse chronostratigraphic relation indicates that the HDS is older, however, the knowledge of their exact age of deposition is crucial for understanding long-term landscape evolution scenarios. This is also important for ensuring safety of a planned deep geological repository for nuclear waste in northern Switzerland [2].

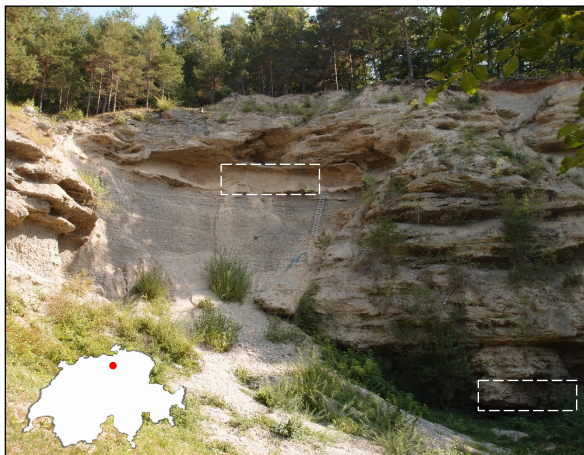


Fig. 1: Outcrop of Deckenschotter at the site Feusi with the gravel layer sampled in this study (bottom) and the previously dated diamict (top).

We implemented isochron-burial dating with a pair of cosmogenic nuclides ^{26}Al and ^{10}Be to determine the age of the Deckenschotter. A number of sites were selected for sampling. One of them is a former gravel pit Feusi (Fig. 1). It contains several gravel units with a diamict layer in the upper parts of the outcrop. Presence of clasts of quartz-rich lithologies makes these sediments suitable for the isochron-burial dating method. Previous dating of the diamict layer

indicates an age of 1.1 ± 0.2 Ma [3], which implies the presence of a glacier at that time. To complement these results, we sampled the so-called Egg Schotter at the base of the Feusi outcrop, described by Graf [1] as gray cemented glaciofluvial gravel with sandy matrix. More than twenty clasts of quartz-rich lithologies, of various shapes and sizes from the same stratigraphic horizon were collected (Fig. 2).



Fig. 2: Collection of quartz-rich clasts from the lowermost gravel layer of Feusi further processed for the isochron-burial dating with ^{26}Al and ^{10}Be .

Collected samples are being processed and isotopic ratios measured with the AMS system at LIP. Obtained results from Feusi and other locations will be useful for establishing sound long-term landscape evolution scenarios. It also gives a unique opportunity to compare the new dates from the base of the outcrop with the diamict dated in its upper layers taking into account the vertical difference between them. The results will complement our knowledge about sedimentology and chronology of the Deckenschotter times.

- [1] H.R. Graf, Univ. Zurich diss. (1993)
- [2] NAGRA, NTB 14-01 (2014)
- [3] NAGRA, NAB 19-025 (2020)

¹Nagra, Wettingen

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³Geochemistry and Petrology, ETH Zurich

EARLY LATEGLACIAL ICE DECAY IN SWISS MAIN VALLEYS

Glacier retreat into Rhine & Ticino Valley at the end of the last glaciation

S. Kamleitner, S. Ivy-Ochs, C. Scapozza¹, M. Christl

Complementary to the ongoing investigations on the Last Glacial Maximum (LGM) of Rhine and Ticino paleo-glaciers, we aim to reconstruct the glaciers' retreat histories at the end of the last glaciation. It is widely accepted that post LGM ice decay occurred rapidly. Although some dates are available for lake and peat settings [1, 2, 3, and referenced therein], these provide only minimum ages for deglaciation. Very little chronological data has been acquired for the configurations of the large downwasting glaciers that must have occupied the main inner-alpine valleys after retreat from the forelands.

Here we present ongoing work on the glacier retreat histories of Rhine and Ticino Valleys at the end of the last glaciation. The chronological sequence of post LGM ice decay is assessed by means of surface exposure dating.

Investigated study sites, lie about 90-110 km and 75-90 km behind the LGM ice margins in the big trunk valleys of Rhine and Ticino. Three respectively two rock samples were taken from erratic boulders deposited by the withdrawing Rhine glacier at Fläscherberg (Fig. 1) and Eschnerberg, two inselbergs protruding from the main valley floor. Along Ticino Valley, a total of four erratic boulders was sampled on a lateral moraine above Claro (Fig. 1), at Alpe Parusciana north of Castione and in the vineyards of Gudo just behind the Cugnasco stadial moraine.

Rock samples were crushed, sieved and processed for cosmogenic nuclide ^{10}Be . Both, chemical preparation and AMS measurement on the 0.3 MV MILEA system are executed at the Laboratory of Ion Beam Physics, ETH Zurich.



Fig. 1: Sampling of erratics in (A) Rhine Valley (Balzers, LIE) and (B) Ticino Valley (Claro, TI).

Results will allow to trace and compare the post LGM retreat pattern of two big paleo-glacier systems north and south of the Alps. New exposure ages will complement our chronological knowledge on early Lateglacial ice decay in the Alps and will yield novel insights into glacier configurations during that time. Our dating results will additionally provide minimum ages for collapse of the piedmont glaciers and the deglaciation of the forelands.

- [1] S. Ivy-Ochs, Cuad. de Investig. Geogr., 41(2) (2015) 295
- [2] J.M. Reitner, Quat. Int. 164–165 (2007) 64
- [3] C. Scapozza et. al., Geomorphol. Relief, Process. Environ. 4 (2014) 307

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THE QUATERNARY PERIOD IN SWITZERLAND

Glaciers shaped both the high mountains and the foreland

C. Schlüchter¹ N. Akçar¹, S. Ivy-Ochs

The evolution of the Swiss landscape during the Quaternary Period over the past 2.6 million years is controlled by multiple glaciations and deglaciations with at least 15 dramatic environmental changes between glacier advances (yearly average temperatures of -16°C compared to today) and warm phases (yearly average temperatures of $+2^{\circ}\text{C}$ compared to today). During the most extensive glaciation several hundred thousand years ago, Switzerland was almost completely covered by ice. During the warmest interglacial periods the glaciers were, most likely, completely gone [1].



Fig. 1: The trimline in the Grimsel area (BE): glacially polished granite below unglaciated high ridges [1].

A striking contrast in the Quaternary landscape in Switzerland is between the soft and smoothed areas covered by the glaciers of the Last Glacial Maximum (LGM) and the external areas where vertical erosion processes dominated. One example is the high-mountain landscapes above the glacial trimline, where mechanical weathering dominated, for example in the Grimsel area (Fig. 1). Surface exposure dating with ^{10}Be from this region has provided key data for reconstructing the onset of deglaciation reflected by LGM ice surface lowering already by

23 ka [2]. A magnificent example of a landscape in the Molasse bedrock, partially drowned by more recent accumulations (here of the LGM), is the “crest and earth pillar” morphology at Krauchthal (Fig. 2).



Fig. 2: An example of landforms beyond the limit of LGM glaciers: Molasse rock spires at Krauchthal (BE) [1].

Quaternary geology is stimulating because it is related to daily life. The extension of former glaciers is of primary interest, both scientifically and practically in engineering. Different landscape elements are typical and can be used to define the extent of paleoglaciations cosmogenic nuclides provide time constraints.

- [1] C. Schlüchter et al., 47-69 (2021) in: Landscapes and Landforms of Switzerland
- [2] C. Wirsig et al., J. Quat. Sci. 31 (2016) 46

¹Geology, Univ. of Bern

IN THE FORBIDDEN FIELD

The influence of glacial erosion on $^{10}\text{Be}/\text{in-situ } ^{14}\text{C}$ ratios

O. Steinemann, S. Ivy-Ochs, K. Hippe, M. Christl, N. Haghpor¹, H.-A. Synal

In cold-ice environments (e.g. Greenland, Antarctica), where glacial erosion was limited, combining cosmogenic ^{10}Be and in-situ ^{14}C has shown to be a unique tool to determine for how long a glacier was last covering the sampled site by taking advantage of the different half-lives of the radionuclides. While ^{10}Be concentrations accumulated during ice-free phases remain quasi stable ($t_{1/2} = 1.4 \text{ Ma}$) during subsequent glacier coverage, in-situ ^{14}C concentrations decrease rapidly ($t_{1/2} = 5.7 \text{ ka}$). Thus, the higher the $^{10}\text{Be}/\text{in-situ } ^{14}\text{C}$ ratio the longer the glacier coverage duration.

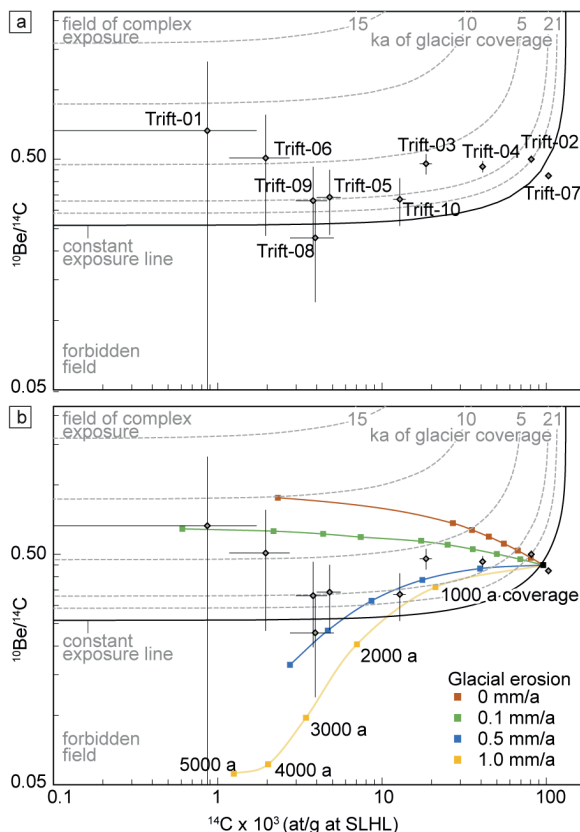


Fig. 1: a: All sample ratios plot near the line of constant exposure or in the field of complex exposure suggesting that all samples were recently glacier covered. b: Numerical modelling highlights that we cannot determine the duration

of glacier coverage of the samples because glacial erosion has a significant influence on the $^{10}\text{Be}/\text{in-situ } ^{14}\text{C}$ ratio as illustrated by the colored lines which were modelled using different glacial erosion rates and different durations of glacier coverage. Figure modified from [1].

In temperate glacier settings this approach has been rarely used because glacial erosion affects the ratio drastically [1], but it has never been shown how big the influence is. In the forefield of the Trift glacier (BE) we analysed 10 samples for both nuclides. The results (Fig. 1a) in combination with numerical modelling (Fig. 1b) highlight the complexity of interpreting $^{10}\text{Be}/\text{in-situ } ^{14}\text{C}$ ratio in areas with high glacial erosion rates. With high erosion rates ($> 0.5 \text{ mm/a}$) even ratios plotting in the forbidden field are possible. This underpins earlier findings that $^{10}\text{Be}/\text{in-situ } ^{14}\text{C}$ ratios can only be used to determine glacier coverage durations in areas with little glacial erosion or vice versa; glacial erosion can only be determined if the coverage duration can be reconstructed from an independent proxy.

[1] O. Steinemann et al., Geomorphology 2021 (in press)

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THE ROLE OF GORGES IN BEDROCK RIEGEL FORMATION

Gleaned from the glacial erosion rate study at Trift glacier

S. Ivy-Ochs, O. Steinemann, K. Hippe, M. Christl, N. Haghipour¹, H.-A. Synal

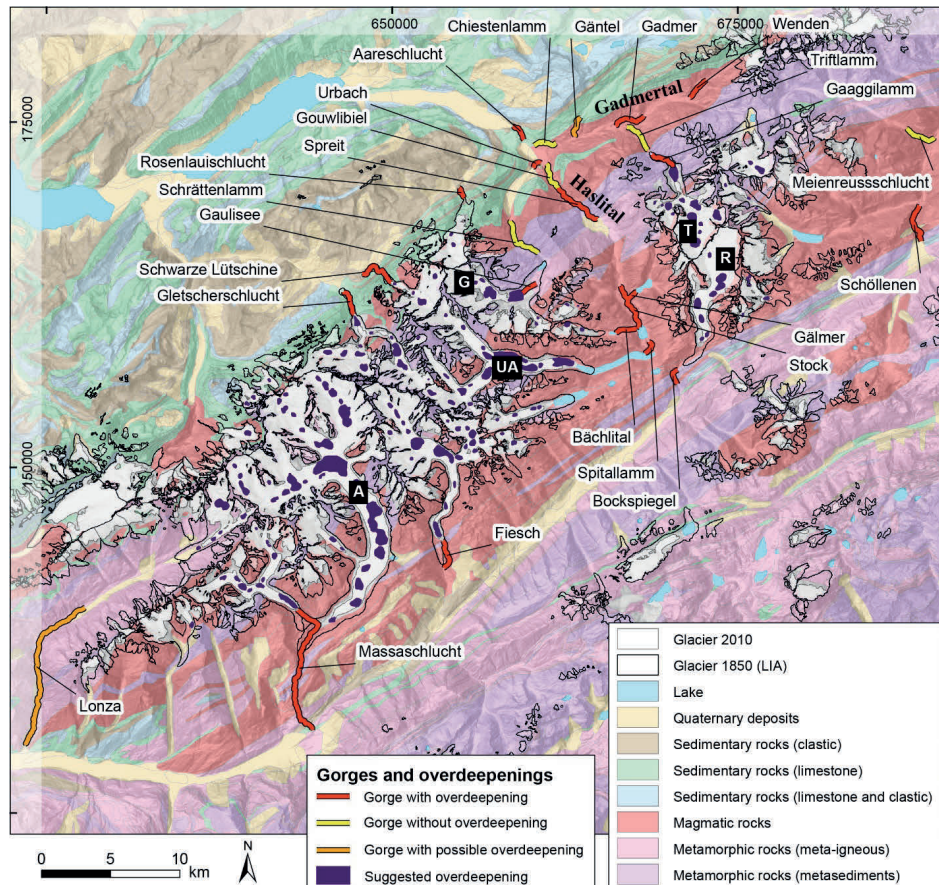


Fig. 1: Overview of gorges in the Central Alps. Abbreviations A: Grosser Aletsch glacier, UA: Unteraar glacier, G: Gauli glacier, T: Trift glacier, R: Rhône glacier. For details on compilation see [1].

In our recent cosmogenic ^{10}Be and in situ ^{14}C investigation [1] of the remarkably high (150 m) cross-valley bedrock riegel and the associated overdeepening located in front of the Trift glacier (BE), we identified the gorge as a decisive factor for the presence there of an ‘overdeep’ overdeepening. The gorge lowers the threshold for the subglacial meltwater, thereby decoupling the height of the riegel from the depth of the overdeepening. To further understand the role of gorges in Alpine topography we made a brief survey of gorges in the Central Alps (Fig. 1). Gorges in limestones are generally longer and deeper than gorges in crystalline rocks; subglacial

meltwater incision takes advantage of structurally controlled (paleo) karst features. A similar configuration, exceptionally deep overdeepening, high riegel and deep gorge, is mainly found at sites where, as at Trift, crystalline lithologies of varying erodibilities alternate along a dominant structural trend that is perpendicular to the glacier flow direction.

[1] O. Steinemann et al., *Geomorphology* (2021) in press

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MILLENIAL DENUDATION RATES ACROSS THE ALPS

When in-situ ^{10}Be in stream sediments reveals how mountains grow

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Tens of studies conducted over the last 15 years have used concentrations of in-situ produced ^{10}Be measured in the quartz fraction of stream sediments to quantify catchment-wide denudation rates over millennial timescales within the European Alps. In a recent compilation [1], the in-situ ^{10}Be concentration of 375 samples, >90% of which were analyzed at the ETH Zürich AMS facility, was used to explore how denudation rates distribute across the European Alps (Fig. 1) and to identify the respective contributions of internal and external forcing.

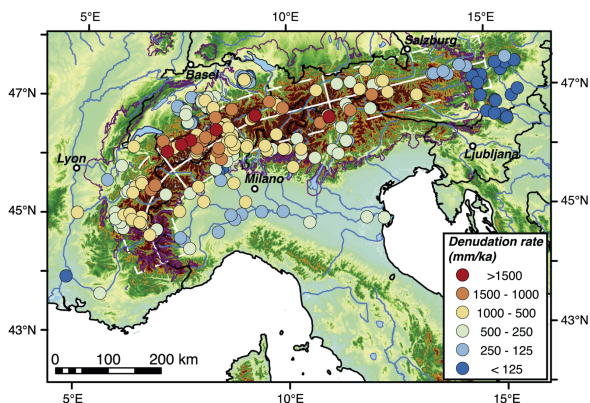


Fig. 1: ^{10}Be catchment-wide denudation rates at river-sediment sample locations used in [1]. Colors of circles indicate denudation rate.

The main findings show that (i) rock properties and modern climate parameters (including precipitation and runoff) do not influence the distribution of erosion across the Alps, while (ii) the Alpine topographic metrics do exert a significant control. In particular, a functional relationship between catchment-wide denudation and mean catchment slope angle is constrained, illustrating the glacial imprint on modern erosion dynamics. Finally, (iii) an apparent link between geodetic rock-uplift and denudation is observed, yet with a large scatter

(Fig. 2). Interestingly, this compilation provides a detailed picture of the surface response to deep geodynamic mechanisms prevailing in the different Alpine regions.

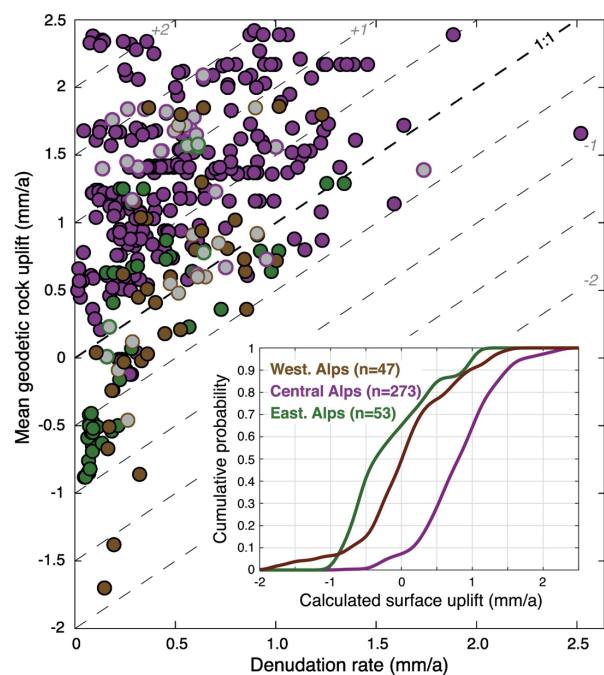


Fig. 2: Relationship between mean catchment geodetic rock uplift and denudation rate. Inset shows the distribution of surface uplift across the Alps.

[1] R. Delunel et al., Earth Sci. Rev. 211 (2020)

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EROSION OF THE EIGER NORTH FACE

Cosmogenic nuclides yield a new picture about erosional mechanisms

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We have measured the patterns of long-term erosion rates of Mt. Eiger using concentrations of in-situ cosmogenic nuclides on the North and South flanks of this mountain [1,2]. To this extent, we combined the cosmogenic nuclide-based denudation rate data with the patterns of fractures and faults and the temperature conditions at the cosmogenic study sites (Fig. 1). We integrated this information into a conceptual model, which considers the erosional mechanisms accomplished by frost cracking processes [2].

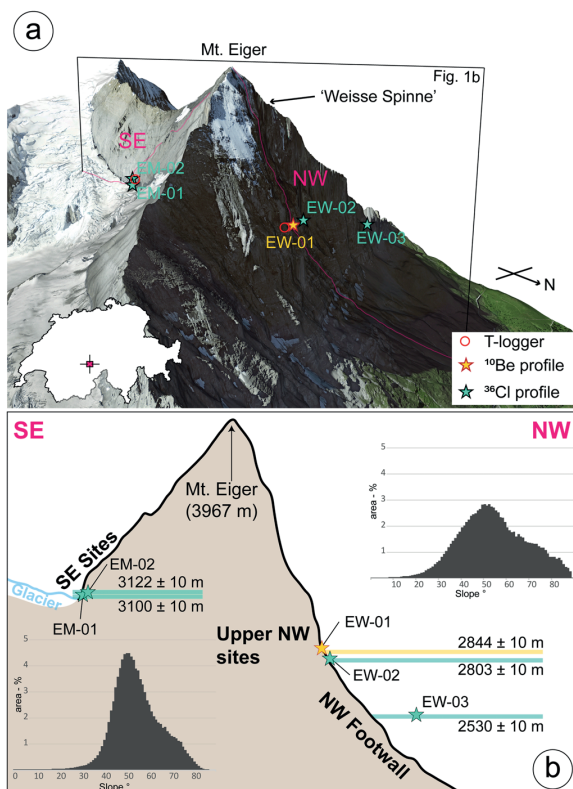


Fig. 1: (a) 3D view of Mt. Eiger with the cosmogenic sites on the N and S headwalls, and (b) section through Mt. Eiger with slope distribution on the north and south flanks [2].

We found that the denudation rates are low in the upper part of the N-face, but much higher at lower elevations on the same N-face and also on the S-flank. Because the patterns and fractures are identical at all sites, we do not consider a bedrock control on these difference rates. Instead, we interpret that the contrasts in insolation and temperature conditions between the upper and lower regions of the N-face, but also between the N-face and S-face themselves, largely explain the denudation rate pattern. This inference is supported by the results of the frost-cracking erosion model (Fig. 2), that predict lower cracking intensities in the upper part of the N-face where temperatures and insolation are low, but much higher frost cracking intensities in the lower part of the N-face and also in the S-face where mean annual temperatures, temperature variations and insolation are much higher.

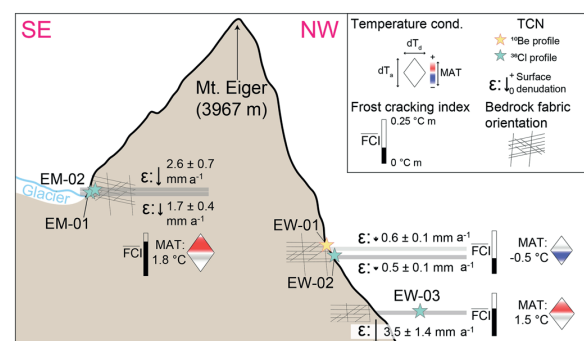


Fig. 2: Denudation rates at the sites on Mt. Eiger, temperature conditions and predicted frost cracking intensities [2].

[1] D. Mair et al., Sci. Rep. 9 (2019) 11023

[2] D. Mair et al., Earth Surf. Dyn. 8 (2020) 637

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ROCKFALL RECURRENCE AT THE AIGUILLE DU MIDI (FR)*

Using in situ ^{14}C to identify rockfall depth and frequency

D.P. Dennis¹, D. Scherler^{1,2}, K. Hippe²

Calculating long-term erosion rates of steep bedrock hillslopes with cosmogenic nuclides is complicated by stochastic rockfall events that account for the majority of the erosive “work”. Because the production rates of in situ cosmogenic ^{14}C and ^{10}Be vary at depth according to the dominant production mechanism (Fig. 1), the $^{14}\text{C}/^{10}\text{Be}$ is non-uniform at depth. Steady-state erosion rates yield unique (calculable) $^{14}\text{C}/^{10}\text{Be}$ ratios. When the measured $^{14}\text{C}/^{10}\text{Be}$ ratio deviates strongly from the expected one, we can infer that stochastic erosional processes occurred. We test the sensitivity of this application using samples from a site with a well-characterized erosional history.

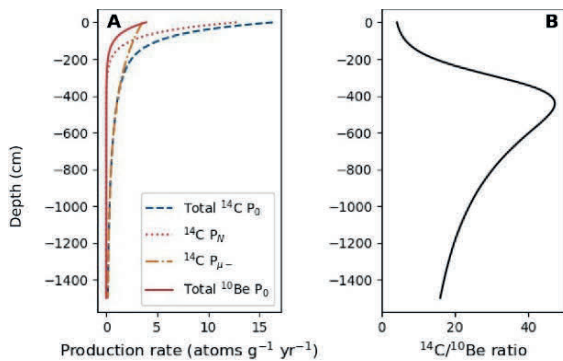


Fig. 1. ^{14}C and ^{10}Be production rate terms (A) and $^{14}\text{C}/^{10}\text{Be}$ ratio (B) plotted at depths below the surface.

Samples for ^{14}C - ^{10}Be analysis were collected in January 2019 from the summit spire of the Aiguille du Midi (ADM). An additional sample (LR-CMQ-01) was collected from the Arête des Cosmiques, following a recent rockfall of well-constrained depth. The samples were processed and measured for in situ ^{14}C at LIP [1].

In order to accurately predict an “expected” $^{14}\text{C}/^{10}\text{Be}$ ratio, accurate knowledge of bedrock physical properties and topographic orientation are necessary, including rock density, surface orientation and surface slope. The modelled

results (Fig. 2) reflect our preliminary values for topographic shielding and surface slope.

Because all samples except LR-CMQ-01 are amalgamated samples, robust analyses in the future will likely require the use of weighted means for surface production rate parameters. We therefore interpret the ADM results conservatively, and suggest that the offset between measured and modeled results may reflect some stochastic effects, but is likely within the range of uncertainty given the production rate. The LR-CMQ sample, however, shows considerable offset from the $^{14}\text{C}/^{10}\text{Be}$ expected under constant erosion. We suggest that our amalgamated ADM-derived erosion rates are not strongly biased by stochastic events, in contrast to the rockfall (CMQ) sample. We assert that the $^{14}\text{C}/^{10}\text{Be}$ ratio is a useful indicator of stochasticity for bedrock surface samples. Future work includes deriving more accurate erosion rates from stochastic-event-affected samples using the $^{14}\text{C}/^{10}\text{Be}$ ratio via numerical modeling.

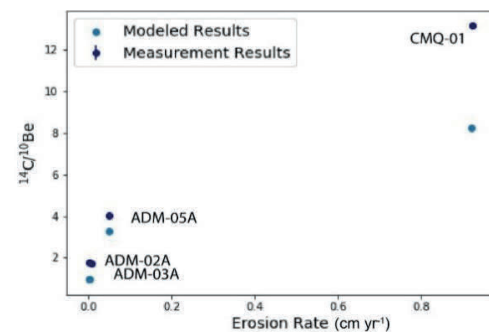


Fig 2. Modeled $^{14}\text{C}/^{10}\text{Be}$ for the measured samples compared against measured $^{14}\text{C}/^{10}\text{Be}$.

- [1] M. Lupker et al., Nucl. Instrum. Methods Phys. Res. B 457 (2019) 30

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*Supported by RADIATE TA

EMPLACEMENT OF THE MOLVENO ROCK AVALANCHE

^{36}Cl surface exposure dating and runout modelling

J. von Wartburg¹, S. Ivy-Ochs, J. Aaron¹, S. Martin², K. Leith¹, M. Rigo², C. Vockenhuber, P. Campedel³, A. Viganò³

Rock avalanches are rare event that nevertheless alter landscape profoundly. Constraining the timing, volume and emplacement dynamics of prehistoric rock avalanches is crucial for understanding the hazards posed by these events. Here we perform cosmogenic nuclide dating, topographic reconstruction and runout modeling of the Molveno rock avalanche (vol. = 600 Mm³), located in the Province of Trento, Italy [1]. The unique morphology of the deposits, which features numerous large scarps and prominent lineaments (Fig. 1, 2), led previous researchers to interpret the Molveno rock avalanche as being the result of multiple events.

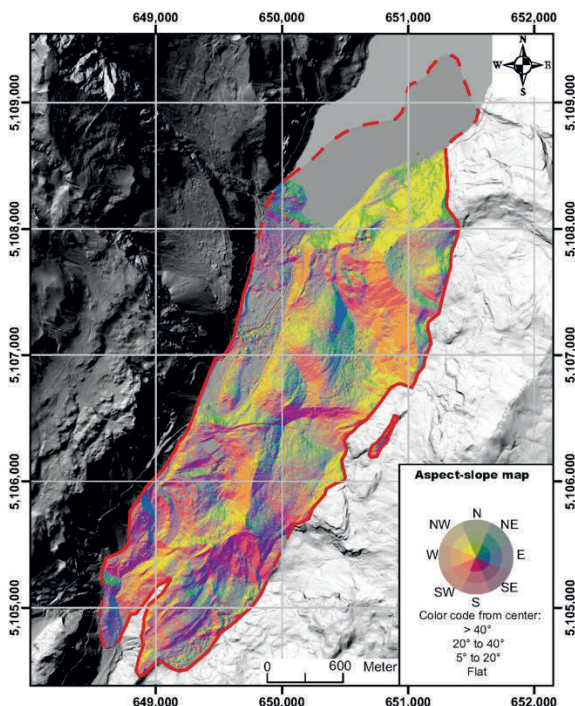


Fig. 1: Landforms of the Molveno rock avalanche, internal scarps are well visible.

^{36}Cl cosmogenic nuclide dating results shows that the deposits were emplaced as a single event at 4.8 ± 0.5 ka, and suggests that the unique deposit

morphology is due to the emplacement processes acting during and soon after failure.

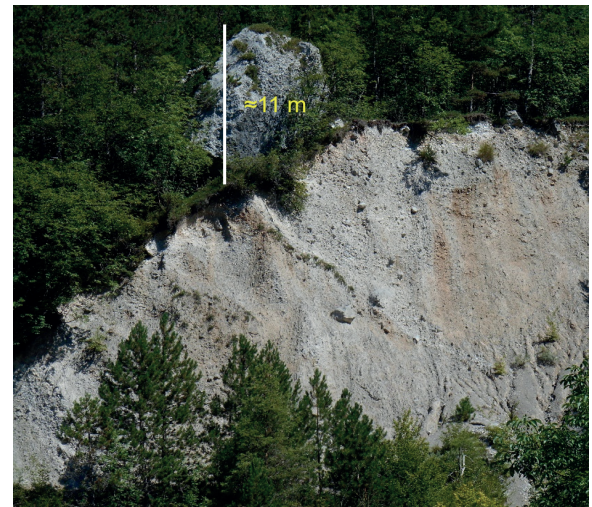


Fig. 2: Internal structure of the Molveno rock avalanche deposits with huge boulder on top.

Numerical runout modeling shows that this morphology could have resulted from a combination of runup and extensional spreading of the debris along the complex valley floor topography. The ages we determined for this event are coincident with the nearby Marocca Principale rock avalanche (5.3 ± 0.9 ka, [2]), which may suggest a common trigger. Our results have important implications for interpreting the morphology of rock avalanche deposits, and contribute to the evolving understanding of rock avalanche processes in the Alps.

- [1] J. von Wartburg et al., *Frontiers in Earth Science* 8 (2020) 164
- [2] S. Ivy-Ochs et al., *Quat. Sci. Rev.* 169 (2017) 188

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THE EARLY HOLOCENE BUCHWIESE ROCK AVALANCHE

Surface exposure dating of boulders with ^{36}Cl

J.M. Reitner¹, S. Ivy-Ochs, O. Steinemann, C. Vockenhuber

We reconstructed the Buchwiese rock avalanche in the Lienz Dolomites in Eastern Tyrol (Austria) [1]. We used a multi-method approach combining geological field mapping, the analysis of digital elevation model (DEM) data, cosmogenic ^{36}Cl exposure dating, and a geoelectrical survey to unravel the detachment mechanisms, emplacement processes and timing of the Buchwiese rock avalanche. According to the results of the ^{36}Cl exposure dating, the event took place at 10.8 ± 0.9 ka during the Early Holocene. The failure of a rock mass with a volume of $27 \times 10^6 \text{ m}^3$ was enabled by a dip-slope in strata of the Kössen Formation (limestone, marls, claystone). With the reconstructed drop height (H) of 1200 m and runout length (L) of 3.5 km, the Buchwiese rock avalanche has a Fahrböschung angle α of 19° and H/L ratio of 0.36.



Fig. 1: View from the opposite Drau Valley flank towards south on the study area and surroundings. The yellow dashed line shows the run of the scarp of the Buchwiese rock avalanche followed by the deposition area surrounded by the white line. The locations of the four sampled boulders for ^{36}Cl exposure dating (Lienz 5-8) are indicated.



Fig. 2: Sample site Lienz 7 within a megaboulder cluster. Encircled head of a person for scale. Note the giant boulder in the background (red X).

We regard fatigue of the fine-grained rocks of the Kössen Fm. (claystone, marl), typical slaking rocks, since the Last Glacial Maximum (ca. 26 - 19 ka) as the major cause for this catastrophic rock slope failure. Due to the geological conditions, the initial failure occurred as a plane slide. In the deposition area, we observe strong control of lithological properties, topographic conditions, and substrate materials along the pathway on the morphology and sedimentology of the rock avalanche deposit. Longitudinal ridges, indicating spreading of an unconfined flow, are comprised mostly of massive limestone. Preserved source stratigraphy within the dilated rock mass indicates predominantly laminar rock avalanche movement. All the morphological and sedimentary evidence supports a dynamic fragmentation model as the best mechanical explanation for the Buchwiese rock avalanche.

- [1] J.M. Reitner et al., Alpine Med. Quat. 33 (2020) 165

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TIMING OF THE AKDAG ROCK AVALANCHE, TURKEY

Surface exposure dating of rock avalanche deposits with ^{36}Cl

C. Bayrakdar¹, T. Gorum², Z. Çilgin³, C. Vockenhuber, S. Ivy-Ochs, N. Akçar⁴

Occurring on the southern slope of the Akdag Massif in the western Mediterranean region, the Akdag landslide is a complex phenomenon covering a surface area of approximately 9.8 km² [1]. The landslide developed under the impetus of multiple factors and involves more than one type of movement. Because the slope failure was initiated at the point of contact between carbonates and flysch, the total mass of displaced material has been calculated as 300 Mm³. This volume makes it the largest bedrock landslide known in the Western and Central Taurus Mountains. This study focuses on the formation and geomorphological activity of the Akdag landslide complex located on the southern slope of Mount Akdag, SW Turkey (Fig. 1). We employed detailed mapping in the field, spatial and morphometric analysis using GIS and remote sensing technologies. We used surface exposure dating with cosmogenic ^{36}Cl to reconstruct the chronology of the landslide complex.

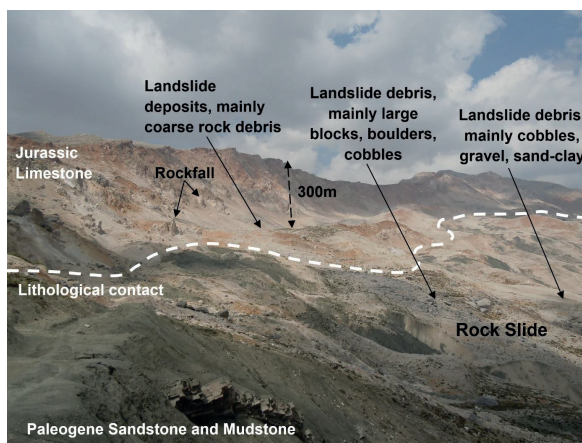


Fig. 1: View of the head scarp zone and blocky deposits of the Akdag landslide complex.

The surface exposure ages show that there were two major events: the first is a rock avalanche dated to 8.3 ± 1.4 ka, and the second is a rockslide dated to 1.1 ± 0.2 ka. The rock avalanche event is closely related to karstic depressions in the upper

parts of Akdag Massif and wetter conditions prevailing at the beginning of Holocene. The landslide is still active and is enlarging toward the sides and upper slopes (Fig. 2).

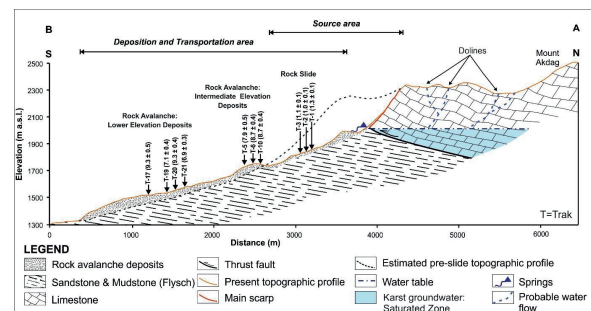


Fig. 2: Cross-section of the Akdag rock avalanche with ^{36}Cl surface exposure ages.

Although the first major failure of the Akdag rock avalanche dates to the early Holocene, the presence of new landslides observed in several field campaigns indicates that the landslide mass is currently active. As well as forested and residential areas, there are many important roads and water pipeline routes within the landslide area. Depending on the progress of landslide activity, the residential areas and roads are constantly in danger and frequently damaged causing loss of life, property and resources that cannot be recovered.

- [1] C. Bayrakdar et al., *Frontiers in Earth Science* 8 (2020) 295

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THE UPLIFT AND SLIP RATE OF THE MALATYA FAULT

Cosmogenic isochron and depth-profile dating of terraces

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Controversy remains over when the present-day configuration of the Anatolia boundary faults came into existence, and the issue of what are the driving forces of the Anatolian westward motion. The NW-oriented dextral and NE-oriented sinistral second-order strike-slip faults at the eastern part of the Anatolian Scholle play a crucial role within these long-lasting discussions, and the NE-oriented sinistral Malatya–Ovacık Fault Zone (MOFZ) is particularly important in this ongoing debate (Fig. 1).

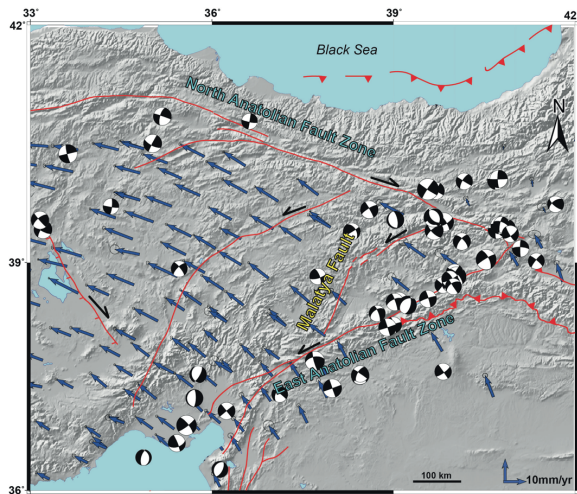


Fig. 1: Major active tectonic structures of eastern Turkey.

The MOFZ was attributed to an active inter-plate fault from the latest Miocene to mid-Pliocene and was inactive during the last ca. 3.5 Ma. This study provides results from the first morphochronology-based uplift and slip rate estimates on the Malatya Fault within the southern section of the MOFZ. The cosmogenic isochron burial and ³⁶Cl depth-profile ages from the sinistrally offset Tohma River remnant terraces enabled us to calculate 1.0 ± 0.01 and 1.12 ± 0.01 mm/yr as minimum and maximum horizontal slip rates, respectively, for the last 1.4

± 0.1 Ma (Fig. 2). Furthermore, we conclude that the 96 ± 11 m/Ma mean uplift has been driven by the Malatya Fault [1].

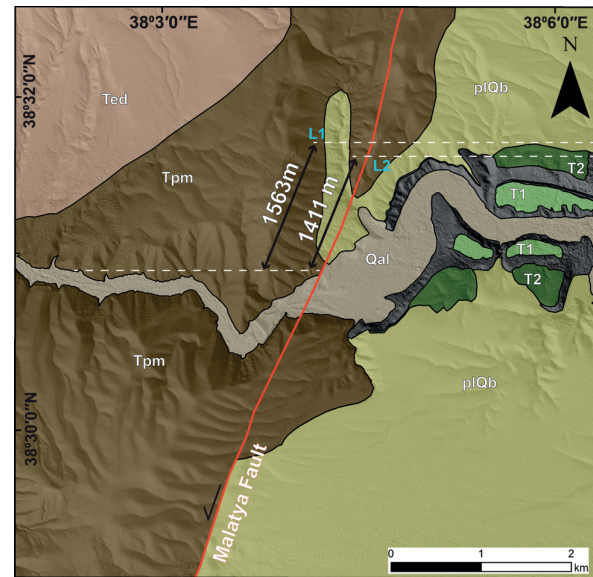


Fig. 2: The offset scenario of Tohma River according to the northern modern channel margin at locations west of the fault and northern margin of the T2 terrace.

Integrated interpretation of the findings of this study and available data on both the MOFZ and other strike-slip faults at the eastern part of the Anatolian Scholle support the hypothesis that they are plate-boundary related active deformation belts that originated from paleotectonic structures during the tectonic escape of the Anatolian Scholle [1].

[1] T. Sançar et al., J. Asian Earth Sci. 188 (2020) 104901

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THE LAST GLACIATION OF JAN MAYEN VOLCANIC ISLAND

Reconstructing the glacial chronology with cosmogenic ^{36}Cl

A. Lyså¹, E. A. Larsen¹, J. Anjar², N. Akçar³, M. Ganerød¹, A. Hiksda⁴, R. van der Lelij¹, C. Vockenhuber

The Arctic island of Jan Mayen, remotely located in the Norwegian-Greenland Sea, was covered by a contiguous ice cap during the Late Weichselian. Until now, it has been disputed whether the entire island was ever glaciated. At present the only glaciers on the island, are located on the 2277 m-high Beerenberg volcano in the northern part of the ca. 54 km long island (Fig. 1).



Fig. 1: Volcanic rocks and tephra dominate the landscape of Jan Mayen. View towards the glacially covered Beerenberg volcano.

Jan Mayen is entirely built up of volcanic rocks. This all took place late in the Quaternary as evidenced by the oldest K-Ar ages of 564 ± 6 ka from the island (unpublished own data). Still, the volcanism is active. The extensive distribution of postglacial volcanic rocks poses a challenge to document and date the existence of a former glacial ice sheet over the island. Glacially formed landscape, for example glacially eroded surfaces, abandoned meltwater channels, till cover and erratics (Fig. 2), are widely found in pockets in-between postglacial volcanic rocks and tephra.



Fig. 2: Boulder-rich till with moss is found on glacially eroded surfaces in between postglacial lava formations. Erratic boulders and glacially eroded bedrock surfaces were sampled and dated with cosmogenic ^{36}Cl dating.

Extensive field work was carried out during 2014–2019, and glacially eroded bedrock surfaces and erratic boulders were sampled for ^{36}Cl dating. Results, including 28 ^{36}Cl dates in addition to a few ^{14}C , K-Ar and ^{40}Ar – ^{39}Ar dates, indicate that the ice sheet which covered Jan Mayen during Late Weichselian, attained its maximum sometime before 21.5 ± 2.6 ka, and that deglaciation was underway 21.5–19.5 ka. All dates are listed and discussed in Lyså et al. [1] where also the extent of the ice sheet onto the shelf area southeast of Jan Mayen is discussed.

[1] A. Lyså et al. *Boreas* (2020) in press

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HOLOCENE GLACIAL HISTORY OF INGLEFIELD LAND*

In-situ ^{14}C and ^{10}Be surface exposure dating of boulders in Greenland

A.S. Søndergaard¹, N.K. Larsen², O. Steinemann, J. Olsen³, S. Funder², D. Egholm¹, K. Kjær²

Determining the sensitivity of the Greenland Ice Sheet (GrIS) to Holocene climate changes is key for understanding the future response of the ice sheet to global warming. However, there are still areas in Greenland where the Holocene deglaciation chronology is poorly constrained and where especially inland exposure ages are unavailable [1]. This is particularly true for North Greenland including the large ice free area Inglefield Land (Fig. 1). The aim of this study was to constrain the Holocene glacial history of the GrIS in Inglefield Land.

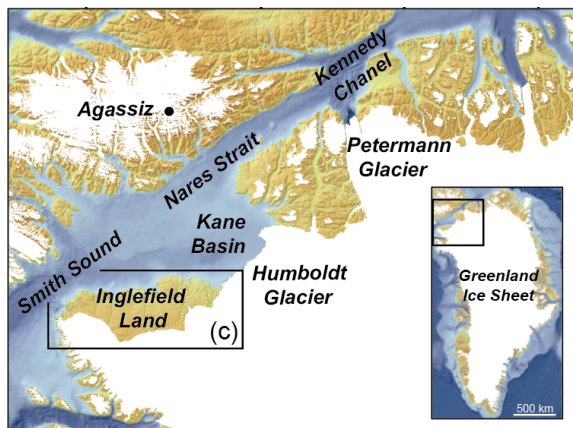


Fig. 1: Location of the study area Inglefield Land in North Greenland.

We mainly used ^{10}Be and in-situ ^{14}C exposure dating to constrain the timing of deglaciation in the area from the coast to the present day ice margin. We used radiocarbon dating of reworked molluscs and wood fragments to constrain when the ice sheet possibly retreated behind its present-day extent during the Holocene.

The 27 ^{10}Be ages were scattered ranging from ca. 92.7 to 6.8 ka whereas the four in-situ ^{14}C ages range from c. 14.2 to 6.7 ka (Fig. 2). Almost half of the apparent ^{10}Be ages predate the Last Glacial Maximum and up to 89% are to some degree affected by nuclide inheritance.

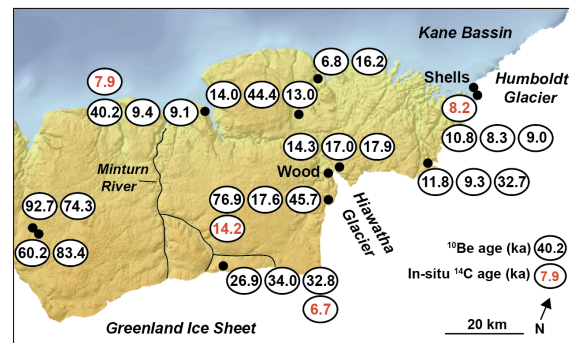


Fig. 2: In-situ ^{14}C and ^{10}Be exposure ages from Inglefield Land. Figure modified from [2].

Relying mainly on the in-situ ^{14}C exposure ages and radiocarbon ages from this and previous studies, we find that the deglaciation along the coast commenced ca. 8.6–8.3 cal ka BP in the western part and ca. 7.9 ka in the central part, following the opening of Nares Strait and arrival of warm waters. The ice margin reached its present-day position ca. 8.2 ka at the Humboldt Glacier and ca. 6.7 ka in the central part of Inglefield Land. Radiocarbon ages of reworked molluscs and wood fragments show that the ice margin was behind its present-day extent from ca. 5.8 to 0.5 cal. ka BP. After 0.5 cal. ka BP, the ice advanced towards its Little Ice Age position [2].

Overall, this study highlights past ice sheet sensitivity to Holocene climate changes in an area where little information was available just a few years ago.

- [1] G. Sinclair al., Quat. Sci. Rev. 145 (2016) 243
- [2] A.S. Søndergaard et al., Climate of the Past 16 (2020) 1999

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DATING OF LARGE SORTED STONE STRIPES IN ETHIOPIA

^{36}Cl exposure dating of relict stone stripes on the Sanetti Plateau

A.R. Groos¹, N. Akçar², C. Vockenhuber, H. Veit¹

The central Sanetti Plateau (6.8 °N, 39.8 °E) of the volcanic Bale Mountains in the southern Ethiopian Highlands comprises Africa's largest continuous area above 4000 m a.s.l. Numerous erratic boulders encircle the highest peak of the Sanetti Plateau and provide evidence for an extensive ice cap during the Late Pleistocene [1]. In the southern and western part of the plateau - outside the formerly glaciated area - unique large sorted stone stripes exist (Fig. 1). These geomorphic features consist of very large clasts (up to 3 m long) and are up to 2 m deep, 15 m wide, and 1000 m long. Sorted stone stripes of this size are generally rare and have so far only been reported from the mid-latitudes and polar regions, but not from the tropics.



Fig. 1: Large sorted stone stripes on the western Sanetti Plateau in the Bale Mountains.

Situated in the inner tropics, the stone stripes on the Sanetti Plateau constitute an enigma since similar periglacial landforms of this size are commonly associated with seasonal ground temperatures variations, oscillating around 0 °C. Recent measurements on the elevated plateau show that the modern mean annual ground temperature at the location of the stripes is ca. 11 °C. If cyclic frost heave and sorting were the main drivers of stone stripe genesis, their presence indicates a past ground temperature depression of ca. 11 °C and points to unprece-

dent palaeoclimatic and palaeoenvironmental changes on this tropical mountain [2]. To assess the period of distinct cooling, we attempted to exposure date the stabilization phase of two stripes using the cosmogenic nuclide ^{36}Cl (Fig. 2).

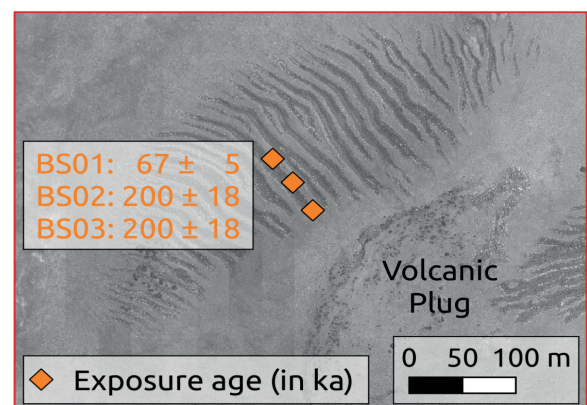


Fig. 2: ^{36}Cl exposure ages of one stone stripe on the slightly inclined southern Sanetti Plateau.

The ^{36}Cl concentrations obtained for the two stripes are very high (up to 120×10^6 at g^{-1}) and translate into non-erosion corrected ages of 70-200 ka for the southern and of 400-800 ka for the western stripes. The “old” ages contradict the hardly weathered surfaces of the sampled boulders and most likely reflect an inherited signal from exposure prior to the formation. Hence, the ^{36}Cl ages reject none of the following two scenarios: a formation of the stone stripes beyond the paleo ice cap during MIS 3/2 due to seasonal frost heave and sorting or over multiple cold phases during the Pleistocene.

- [1] A.R. Groos et al., Sci. Adv. (in press)
- [2] A.R. Groos et al., Earth Surf. Dyn. (in revision)

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²Geology, Univ. of Bern

BLUE ICE MORAINES IN ANTARCTICA

Their build-up and chronology with multiple cosmogenic nuclides

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Blue ice moraines are common supraglacial landforms in Antarctica and they are considered to record the ice volume fluctuations. In this study, we use photogrammetry and the analysis of multiple cosmogenic nuclides (¹⁰Be, ²⁶Al, and in-situ ¹⁴C) in boulders on three blue ice moraines to explore the timing of ice volume fluctuations in the Sør Rondane Mountains, Queen Maud Land (Fig. 1), and provide insights into the role of sediment sources in the reconstruction of their chronology. In the field, we observe that the blue ice moraines are composed of subglacially and supraglacially transported sediments.

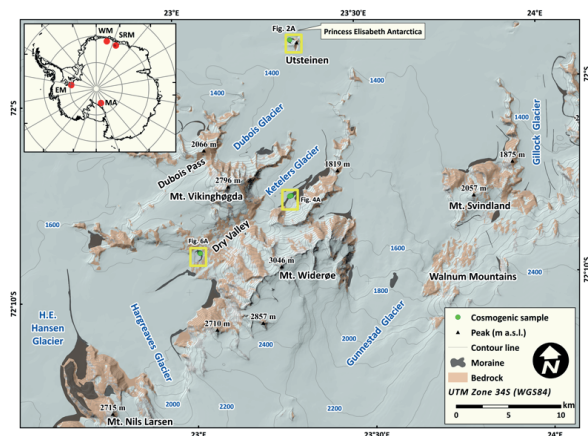


Fig. 1: Map of the western Sør Rondane Mountains with locations of study sites [1].

Cosmogenic ¹⁰Be and ²⁶Al exposure ages of 14 surface samples, collected from boulders on three blue ice moraines (Fig. 2), range from 15.4 ± 1.1 to 659.5 ± 33.9 ka. ²⁶Al/¹⁰Be ratios vary between 3.53 ± 0.20 and 7.01 ± 0.32 , and many of these ratios indicate complex exposure histories. In contrast, among nine in-situ ¹⁴C exposure ages, five vary between 4.2 ± 0.1 and 22.0 ± 1.3 ka, and four are saturated. We conclude that the accumulation of these blue ice moraines commenced before or during the global Last Glacial Maximum [1]. Our ¹⁰Be and ²⁶Al chronology is in line with the existing blue ice

moraine chronologies. However, our younger in-situ ¹⁴C chronology with respect to the ¹⁰Be and ²⁶Al chronology suggest that the cosmogenic ¹⁰Be and ²⁶Al chronologies may not be competent enough to resolve the blue ice moraines' timing of their accumulation and evolution, and thus, cosmogenic ¹⁰Be and ²⁶Al without in-situ ¹⁴C may potentially lead to misinterpretations.

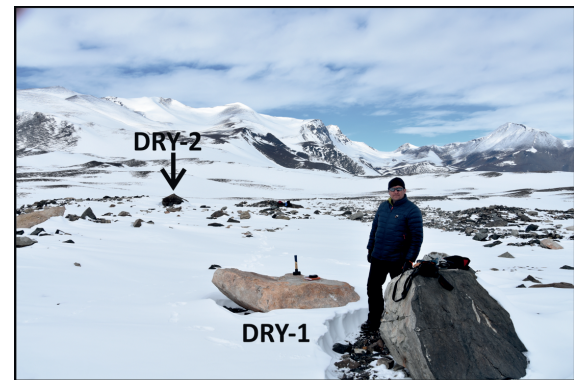


Fig. 2: Surface exposure dating samples DRY-1 and DRY-2 on the Dry blue ice moraine.

Based on these results, we conclude that the application of in-situ ¹⁴C analysis in the investigation of the blue ice moraines is essential and certainly will be key tool in discovering their evolution during the last 100 ka, especially in the last 30 ka. Nonetheless, blue ice moraines bear the records of ice sheet fluctuations, trap wind transported micrometeorites, and host evidences life's evolution in Antarctica. Therefore, they merit special attention in discovering the Antarctic glaciation, and related global changes.

[1] N. Akçar et al., Qua. Sci. Adv. 100012 (2020)

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THE EROSION RATES OF MADAGASCAR ESCARPMENT

Dating of river sediment with ^{10}Be

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The eastern margin of Madagascar has a prominent relief change from the flat coastal plain to the low-relief high plateau, characterizing a typical great escarpment topography at a passive margin (Fig. 1). A quantification of the spatial distribution of erosion rates is necessary to understand the rate of landscape evolution. Concentrations of ^{10}Be measured from river sediment are interpreted as catchment-averaged erosion rates [1].

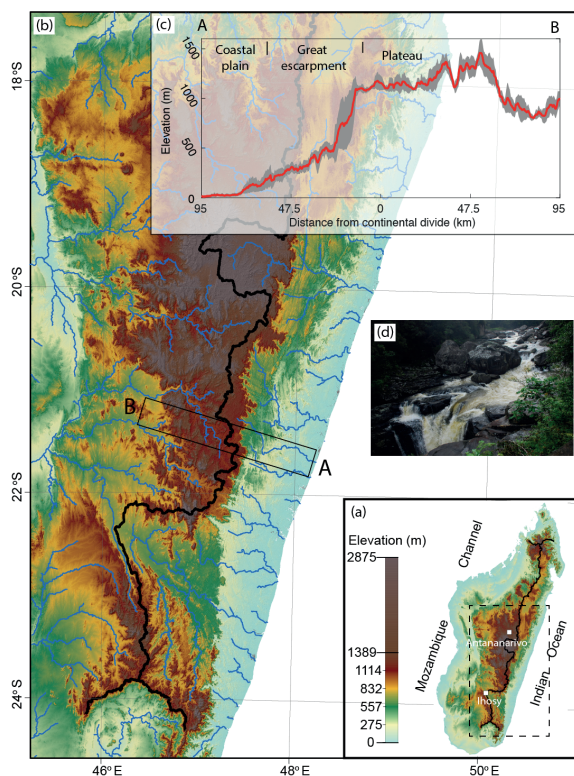


Fig. 1: (a) Geographic location of Madagascar. (b) SRTM-90 meter digital elevation model of Madagascar showing the continental water divide (thick black line), major rivers (blue lines) and the asymmetric escarpment topography of the escarpment. (c) Swath profile A-B shows the topographic gradient of distinctive morphological zones. (d) Field observations of an escarpment river in the Ranomafana National Park, Madagascar.

Our sampled cosmogenic nuclide ^{10}Be basins systematically cover distinct morphological zones of the escarpment. Erosion rates calculated from ^{10}Be concentrations are differentiated across the escarpment, where the high plateau and the coastal plain are slowly eroding with an average rate of 9.7 m/Ma, and the steeper escarpment basins are eroding faster with an average rate of 16.6 m/Ma. The northern escarpment segment is disrupted by an active graben which is referred to as the Alaotra-Ankay Graben. The Alaotra-Ankay Graben is active since the Pliocene [2]. The graben related basins have the highest erosion rate with an average rate of 27 m/Ma in our study area.

The slow erosion rates of the highland and the coastal plain are consistent with observations of intensive weathering, ubiquitous presence of thick saprolite layers and low-relief land surface. Erosion of the escarpment is dominated by fluvial erosion. Differential erosional processes among the morphological zones and inferred erosion rates from ^{10}Be indicate a slowly eroding landscape of the great escarpment of Madagascar. The landscape in a large scale is probably in an isostatically equilibrium state, which is the same as its conjugate margin of western India [3].

- [1] D. Lal, *Earth Planet. Sci. Lett.* 104 (1991) 424
- [2] T. Kusky, *Gondwana Res.* 18 (2010) 274
- [3] S. Mandal et al., *Earth Planet. Sci. Lett.* 425 (2015) 154

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EROSION RATES OF TROPICAL MOUNTAIN RANGES

Erosion rates over annual, decadal, and millennial timescales

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Although mountainous catchments make up a relatively small proportion (estimated at ~10%) of the global terrestrial surface, they account for about 45% of the global sediment discharge to the oceans. Tropical mountain regions are prone to high erosion rates, as the combination of high uplift rate, high relief, and rocks fractured by seismic activity can produce very high erosion rates up to 350 mm kyr^{-1} [1]. Landslides are recurrent phenomena and often considered as the dominant erosion process on the hillslopes and the main source of sediment [2].



Fig. 1: Increased landslide hazards after deforestation of Andean forest.

In this study in the Tropical Andes, we quantified erosion rates based on field data of landslide inventories (Fig. 1), sediment gauging data and cosmogenic nuclide (in-situ ^{10}Be) inventories of river sediments. The field-based study was done in the Western Cordillera of Ecuador where we obtained an exceptionally long time series of hydrometeorological data (1974-2009).

Landslide inventories that were established from remote sensing data enabled us to quantify the annual landslide mobilisation rate that ranged between $0.95^{+0.35}_{-0.13}$ and $2.53^{+1.35}_{-0.49}$ mm per year. The landslide-related erosion rates are similar to the millennial ^{10}Be -derived erosion rates, indicating that landslides are likely to be the

principal source of sediment in the Western Cordillera.

Our study (Fig. 2) reports significant underestimation of decadal erosion rates that were derived from gauging data of hydrological stations [3]. Gauging-based sediment yields are roughly one order of magnitude lower than the landslide-related sediment fluxes and the ^{10}Be -derived erosion rates.

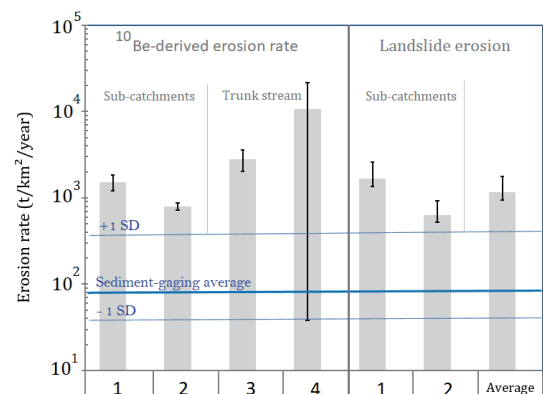


Fig. 2: Comparison of erosion rates over annual, decadal and millennial timescales.

Although the use of gauging data is a widely accepted technique to infer sediment discharge, our study reports significant underestimation of catchment-average erosion rates from gauging data.

- [1] V. Vanacker et al., *Geomorphology* 228 (2015) 234
- [2] F. Clapuyt et al., *Solid Earth* 10 (2019) 1489
- [3] V. Vanacker et al., *Pirineos* 175 (2020) 051

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FLUVIAL TERRACES IN THE TROPOJA BASIN, ALBANIA*

Surface exposure dating using ^{36}Cl depth profiles

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The Tropoja Basin shows a complex drainage system that is the product of several processes modifying its morphology. In the basin plain, three generations of extensive terraces developed along the main rivers, Valbona and Bushtrice, point to recent drainage configuration changes. So far, these landforms have not been dated, nor have the circumstances of their formation been investigated. Their location in the hanging wall of the Shkoder-Peja Normal Fault makes them an important site to study the potentially active tectonics [1].

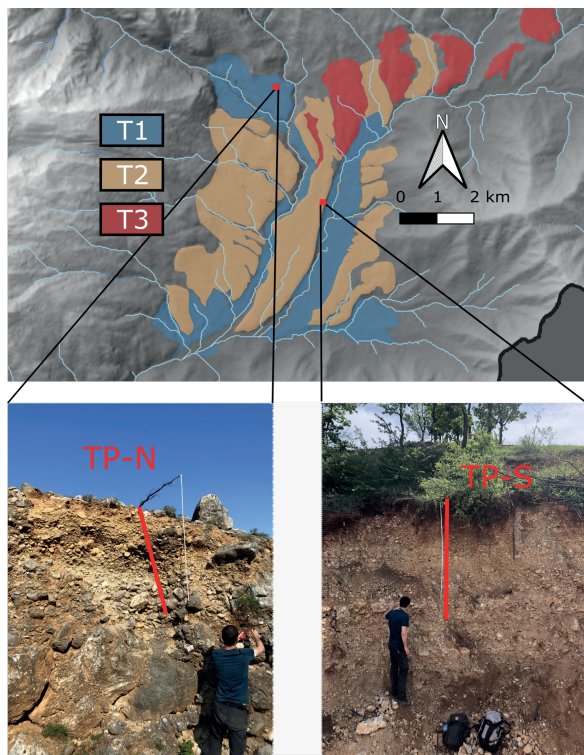


Fig. 1: Terrace levels in the Tropoja Basin, sampling locations, and outcrop photos for profiles TP-N (T1) and TP-S (T2). The red line indicates the sampled depth profile.

We used cosmogenic ^{36}Cl depth-profile dating to date the abandonment of the terrace surfaces at 15.4 ka ($+38.4$ -6.3) for the medium level T2, 56 m

above the present-day river, and 8.8 ka ($+20.5$ -2.3) for the lower T1, 12 m above the river. The incision rate of the Valbona River between the two levels lies in the order of 6.6 mm/yr. Exposure ages and inheritance were calculated using Monte Carlo simulations [2, 3].

The formation of the higher terrace after the Last Glacial Maximum (LGM) and the fast incision rates point to increased sedimentation during arid, cold phases and rapid removal of material following deglaciation. This allows for three possible explanations for terrace formation:

- (1) It is controlled by climatic fluctuations. Terrace generation T2 was formed in response to an early Lateglacial cold phase. Terrace generation T1 formed in response to a later perturbation such as the 8.2 ka event.
- (2) Fluvial terrace formation is the result of active fault slip along the Shkoder-Peja Normal Fault. The fault creates accommodation space, which is rapidly filled with material from the footwall, primarily through landslides along the fault trace. Fast incision rates could be explained as an effect of sediment removal and thus would not be representative of the surface uplift.
- (3) Fluvial terraces result from autogenic processes, such as self-accelerating entrenchment and bank collapse following rapid sediment evacuation after the LGM or damming at the outlet of the basin.

- [1] M.R. Handy et al., *Tectonics* 38 (2019) 2803
- [2] A.J. Hidy et al., *Geochem. Geophys.* 11(9) (2010)
- [3] D. Mair et al., *Sci. Rep.* 9 (2019) 11023

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*Supported by RADIATE TA

PALEO-OUTBURST FLOODS IN THE CENTRAL HIMALAYA

Exposure dating of the emplacement of large and exotic boulders

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Lake outburst floods (LOFs), whereby large volumes of impounded water are suddenly released into the fluvial network, are significant hazards in mountainous regions. The resulting floods are also relevant to landscape evolution by generating bank erosion and channel incision [1].

In this study, we surveyed two large rivers in the central Himalaya of Nepal to understand past catastrophic floods [2]. In these reaches, large boulders in or near active channels are common (Fig. 1).



Fig. 1: This 30-meter large gneiss boulder near the modern-day channel of the Sunkoshi River (Nepal) has an exposure age of ca. 13 kyrs. This lithology outcrops 13 km upstream and beyond, implying long-range transport.

The surveyed boulders are found well below Last Glacial Maximum glacier extent, and their exotic lithology implies tens of kilometers of fluvial transport. Modeling paleo-discharges required to move these boulders based on boulder size and valley cross-sectional shape indicates that intense precipitation during the monsoon season is unlikely to generate the required 10^3 - 10^5 m³s⁻¹ discharges. These high discharges suggest LOFs are the likely mechanism for boulder emplacement.

We exposure dated 16 boulders using ¹⁰Be, obtaining exposure ages reaching 14 kyrs (Fig. 2).

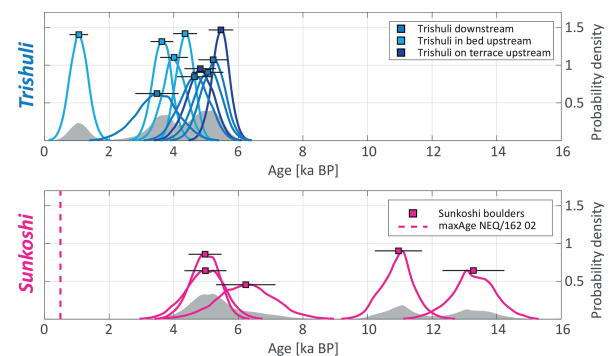


Fig. 2: Probability density function of boulder ¹⁰Be exposure ages in two central Himalayan valleys (Trishuli & Sunkoshi).

Boulder ages cluster between 4.5 and 5.5 kyrs in two different valleys, suggesting a common regional triggering mechanism. This period is co-eval with a broader weakening of the Indian summer monsoon and the retreat of glaciers in the central Himalaya after the Early Holocene Climatic Optimum. This timing suggests that glacier lake outburst floods (GLOFs) following glacier retreat during the Holocene is the most likely emplacement cause. Therefore, this study proposes that exceptional erosion and sediment transport events in the Himalaya are modulated by climate and occur during the transition to drier climates rather than during exceptionally wet periods.

- [1] K. Cook et al., Science 362 (2018) 53
- [2] M. Huber et al., E-Surf 8 (2020) 769

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AGGRADATION MODE OF BRAIDED RIVER DEPOSITS

^{10}Be depth profiling as a tool to reconstruct sediment deposition history

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Fluvial sediment sequences can preserve relevant information on paleoclimatic and physiographic conditions under which the sediments were deposited. Absolute dating of Quaternary fluvial deposits is increasingly done with in-situ produced cosmogenic radionuclides. In constantly exposed and undisturbed sediments with no erosion, the in-situ ^{10}Be or ^{26}Al concentration will increase over time with the maximum concentration observed at the surface.

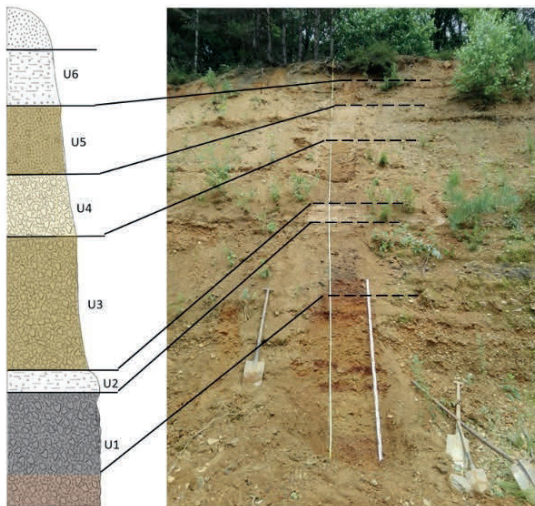


Fig. 1: Sampling site in the Hermans quarry (51°00'N, 5°35'E) where the gravel sheet is exposed over a thickness of about 7 m.

Fluvial gravel sheets deposited by braided river systems are often characterized by erratic deposition modes. The geochronology of gravel deposits with complex aggradation histories remains challenging [1]. In this study, we explore how we can apply cosmogenic radionuclides to reconstruct the sediment deposition history of braided river deposits. We selected a study site in northwestern Belgium [2] where Quaternary fluvial deposits of the main terrace of the Meuse River are exposed (Fig. 1).

We collected 15 bulk samples from different layers within the 7 m-thick fluvial deposits.

Granulometry, bulk chemistry and ^{10}Be concentrations were determined on all samples. The grain size analyses show a clear succession of sand and gravel dominated units (Fig.1). In the lower part of the sedimentary sequence (5.5 m - 6.5 m), iron and manganese coatings and concretions are observed. The in-situ produced ^{10}Be concentrations do not show a monotonic decrease with depth (Fig. 2). Instead, four distinct subsurface maxima were detected at depths of about 0.70, 1.50, 3.30, and 5.50 m, corresponding to the upper boundaries of four major sedimentological units (Fig. 1).

Analysing the covariation of grain size, elemental chemistry and ^{10}Be concentrations with depth can be promising to unravel the depositional history of Pleistocene fluvial landforms.

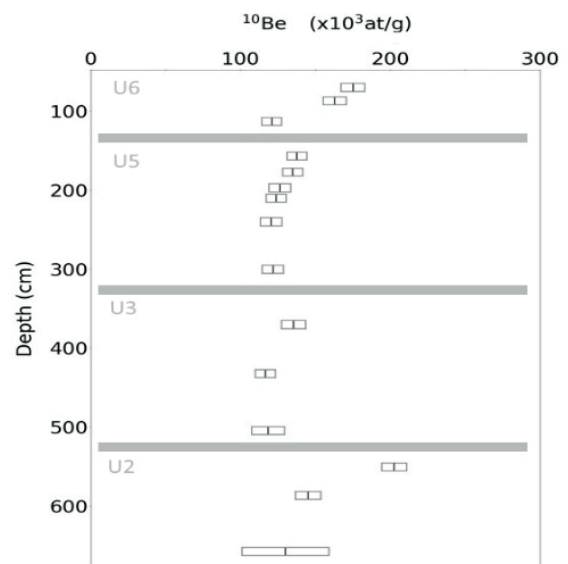


Fig. 2: In-situ produced ^{10}Be concentration depth profile in the 7 m-thick gravel sheet.

- [1] E. Laloy et al., Earth Surf. Dyn. 5 (2017) 331
- [2] K. Beerten et al., Quat. Int. 556 (2020) 144

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LANDSCAPE EVOLUTION OF SERRA DA ESTRELA (PT)

Rock tors dating using combined in-situ cosmogenic ^{14}C - ^{26}Al - ^{10}Be

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The granite landscape of the Serra da Estrela in Portugal is characterised with a large variety of scattered residual rock towers that are still attached to the bedrock. These rock forms, so called tors, are the centre of the research project TERRA NOVA.

In recent years, tors became of interest to geomorphologists as a new suitable archive to determine surface lowering of the regolith and, thus, soil erosion and denudation rates [1]. The uniqueness of using tors lies in the possibility to quantify Earth surface dynamics within an eroding landscape itself. Usually, sediments in distant deposition zones are used for such evaluations. However, sediments are prone to relocation and erosion.

So far this, “Tor Exhumation Approach – TEA” has been solely tested in ice free environments. The TERRA NOVA project aims to determine if this investigation technique can also be used in formerly glaciated areas. For this particular objective, the UNESCO Geopark Estrela (Fig. 1) was the most suitable investigation area from a geological point of view. Past glaciated and non-glaciated areas are closely connected and exhibit a rich variety of rock tors.

The TERRA NOVA team collected rock samples along the vertical face of six tors in formerly glaciated and non-glaciated parts of the upland in the summer 2020. With the combination of multiple terrestrial cosmogenic isotopes (^{10}Be , ^{26}Al , in-situ ^{14}C), the complex exhumation process of the tors will be determined. As a result, the surrounding spatio-temporal variation of soil surface denudation will be quantified. First results of in-situ ^{10}Be dating show that the rock surfaces have an age from about 240,000 yr to 7000 yr (some data is given in Fig. 2). We are therefore confident to provide a detailed picture of the local landscape dynamics from Late/Mid Holocene to Pleistocene times.

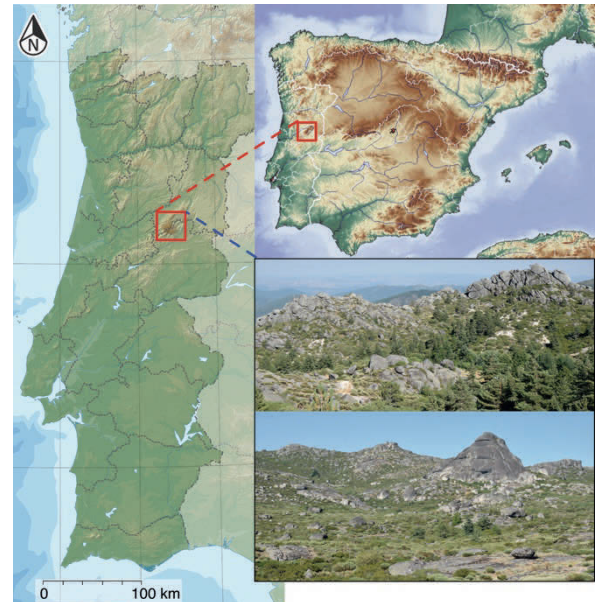


Fig. 1: Investigation area (UNESCO Geopark Serra da Estrela) and the typical tor landscape.

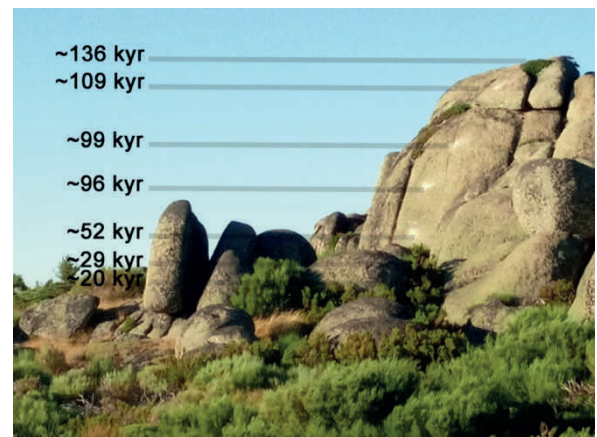


Fig. 2: Example of an exposure age profile (in-situ ^{10}Be) along a rock tor in the UNESCO Geopark at Serra da Estrela.

[1] G. Raab, Dissertation UZH (2019)

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DISTRIBUTION OF WEATHERING FLUXES AT LAKE BAIKAL

Reflection of varying climatic, pedologic, and geomorphic settings

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Lake Baikal is the world's largest (by volume), deepest, and oldest (30-40 Ma) lake. In the catchment, climate varies from arid to semi-arid to arctic-boreal with extreme seasonal and spatial differences in temperature and precipitation [1]. Elevation ranges from 450 to 3000 m a.s.l., resulting in a large range of geomorphic settings. The catchment has also been affected by periodic Quaternary glaciations, particularly in the northern areas [2]. Although the geology of the catchment is diverse and contains igneous, metamorphic and sedimentary rocks of Archean to Cenozoic ages, the most prominent lithologies are granitoids and gneisses with only minor carbonate contributions [1]. Lake Baikal is therefore a promising site to study the impact of different climates on silicate weathering rates.

The weathering regime at Lake Baikal appears to show an interesting dichotomy. Although a positive correlation between chemical weathering and physical erosion rates is expected below a certain threshold [3], chemical weathering rates are higher in the northern river catchments that have comparatively low $^{10}\text{Be}/^9\text{Be}$ derived denudation rates [4]. Permafrost in the northern part of the lake catchment [1] likely has a stabilizing effect on soils by preventing erosion, explaining the low denudation rates. Although speculative, recent thawing of permafrost soils may contribute to elevated chemical fluxes.

The difference between estimated erosion rates from riverine particulate loads and denudation rates derived from $^{10}\text{Be}/^9\text{Be}$ is particularly large for the Selenga river. This might be caused by channel and floodplain storage of sediments [5], preventing some of the denudation flux from reaching the river mouth. The low chemical weathering rates are most likely the result of low runoff from arid Mongolia [6].

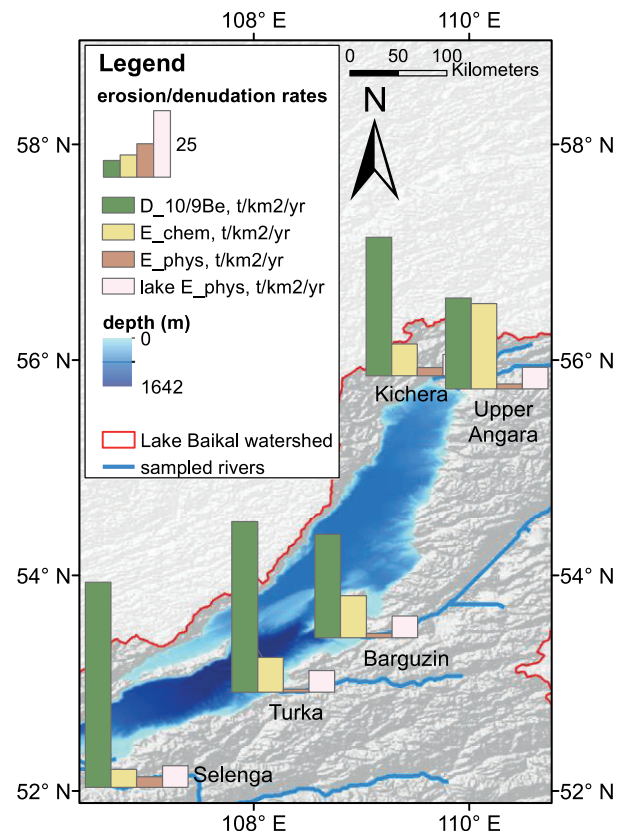


Fig. 1: Estimates of denudation ($D_{10/9\text{Be}}$) and chemical/physical erosion rates ($E_{\text{chem}}/ E_{\text{phys}}$) for the sampled tributaries of Lake Baikal.

- [1] E.A. Zakharova et al., CG 214 (2005) 223
- [2] E.B. Karabanov et al., QR 50 (1998) 46
- [3] A.J. West, Geology 40 (2012) 811
- [4] F. von Blanckenburg et al., EPSL 251 (2012) 305
- [5] S.R. Chalov et al., EES 73 (2015) 663
- [6] E.L. Goldberg et al., PPP 294 (2010) 16

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^{10}Be IN BLACK SEA SEDIMENTS FROM 40-60 Ka BP

Solar activity proxy and synchronisation tool for paleoclimate studies

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In climate research the varying Sun and its influence on our climate belongs to one of the most debated topics. Cosmogenic radionuclide records are at present the most reliable proxies to gain information about the activity of the Sun before the period covered by instrumental measurements and observations [1] and can serve as a synchronization tool between different paleoclimate records [2]. However, investigations during glacial periods are rare and our knowledge about Sun-climate linkages within these times is at its beginning. During this project high-resolution ^{10}Be time series from Black Sea sediment cores MSM33_64-1 and M72/5_640-1 (Fig. 1) will be produced during a period of distinct Dansgaard-Oeschger (DO) variability from 40-60 ka BP to contribute to a better understanding of potential Sun-climate connections and the synchronization of paleoclimate archives across the hemisphere [3].

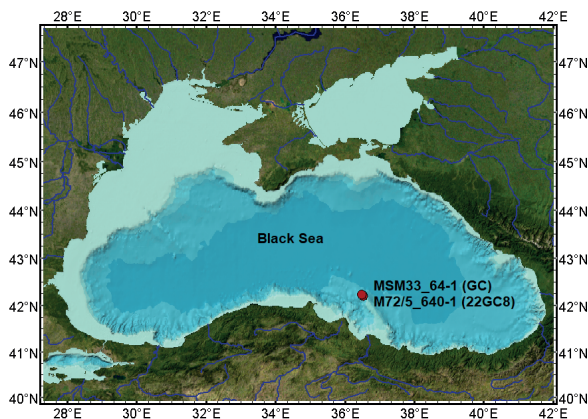


Fig. 1: Map of the Black Sea indicating sediment core positions on the Archangelsky Ridge.

High-resolution XRF data (Fig. 2) from these two sediment records as well as results from previous studies on these cores like the TEX_{86} -based temperature record [4] show strong variability associated with DO cycles.

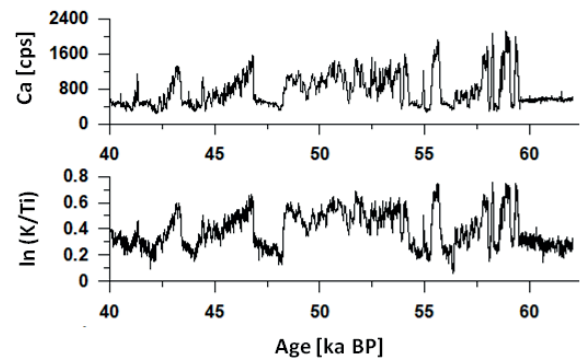


Fig. 2: High-resolution XRF measurements of the elements Ca and K/Ti from sediment cores MSM33_64-1 and M72/5_640-1.

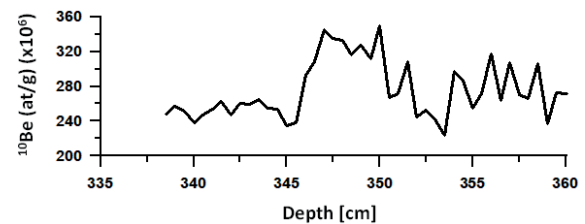


Fig. 3: First ^{10}Be data of the study interval from Black Sea sediment core MSM33_64-1.

The first ^{10}Be measurements of this study (Fig. 3) will be extended to cover the whole study interval and, subsequently, corrected for non-production influences introduced by environmental and paleomagnetic variability.

- [1] R. Muscheler et al., *Quat. Sci. Rev.* 26 (2007) 82
- [2] F. Adolphi et al., *Clim. Past* 14 (2018) 1755
- [3] M. Czymzik et al., *PNAS* 117 (2020) 28649
- [4] A. Wegwerth et al., *Geophys. Res. Lett.* 19 (2015) 8147

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IMPROVING THE BALTIC SEA SEDIMENT CHRONOLOGY

Using ^{10}Be to place Baltic Sea sediments on the ^{14}C time-scale

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Utilizing the sub-decadal resolved environmental information stored in deep Baltic Sea sediments requires their placement in a precise chronological framework. This placement is presently hampered due to centennial chronological uncertainties, mainly caused by varying ^{14}C reservoir ages [1]. In an attempt to improve the Baltic Sea sediment chronology, we measured a ^{10}Be record at 20-year resolution from Baltic Sea sediment core M86-1a/33-4-GC (western Gotland Basin, Fig. 1) covering the period 5700-5000 a BP. Our ^{10}Be record was corrected for environmental influences by using geochemical XRF Br, Ti, Mn and Si/Ti profiles from the same archive [2] (Fig. 2). Strong similarities between the corrected ^{10}Be records and the atmospheric ^{14}C curve support the preservation of the ^{10}Be production signal in the investigated Baltic Sea sediments (Fig. 2).

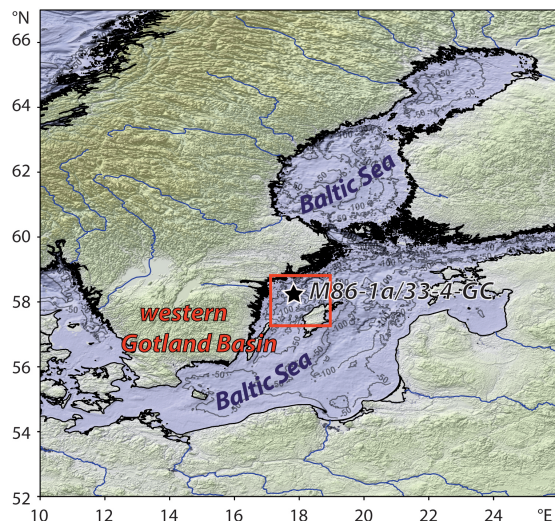


Fig. 1: Bathymetric map of the Baltic Sea with locations of the western Gotland Basin and sediment core M86-1a/33-4-GC (101 m water depth).

We apply the globally common cosmogenic radionuclide production rate variations to place our Baltic Sea ^{10}Be record on the absolute dated

atmospheric ^{14}C production time-series from the IntCal13 calibration curve using automated curve fitting [2,3] (Fig. 2a). This placement allows to reduce the initial centennial chronological uncertainties of the investigated Baltic Sea sediments to ± 10 -15 years (Fig. 2b).

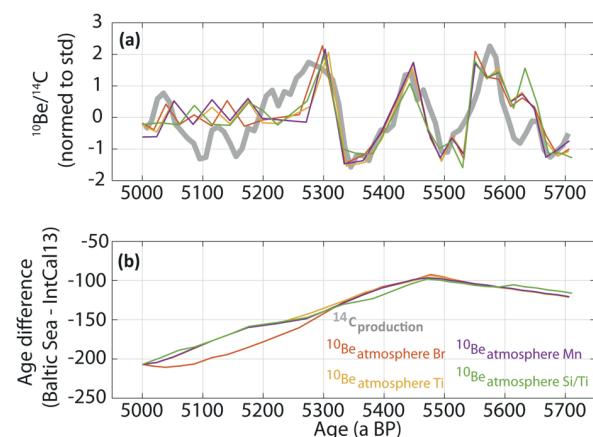


Fig. 2: Placement of the ^{10}Be record from Baltic Sea sediment core M86-1a/33-4-GC on the ^{14}C production rate time-series from the IntCal13 calibration curve. (a) Alignment of 5 environment-corrected ^{10}Be realizations from Baltic Sea sediments with ^{14}C production rates. (b) Inferred chronological offset of the initial Baltic Sea chronology, compared to the ^{14}C time-scale.

- [1] B.C. Loughheed et al., Quat. Sci. Rev. 42 (2012) 43
- [2] M. Czymzik et al., PNAS 117 (2020) 28649
- [3] R. Muscheler et al., Quat. Sci. Rev. 106 (2014) 81

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IMPROVING PAST SOLAR ACTIVITY RECONSTRUCTION

A Bayesian framework to reconstruct solar activity from radionuclides

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The reconstruction of past solar activity from radionuclides, such as ^{14}C and ^{10}Be , relies on the well-established relationship between their production rate, solar modulation and the geomagnetic field intensity [1]. This method normally requires that the past geomagnetic field intensity is known. Therefore, the uncertainties in the geomagnetic field intensity reconstructions are directly transferred to the reconstructed solar modulation. This traditional approach ignores the autocorrelation characteristics of the temporal variability of solar and geomagnetic field activity, and leads to an upper limit of the absolute errors [2]. For example, the sun exhibits a typical cycle of around 11 years and can also change on centennial timescales. Meanwhile, the changes in geomagnetic dipole field intensity occur slowly on centennial to millennial timescales.

In this project, we are developing a novel improved reconstruction method that utilizes the autocorrelation characteristics to reduce the reconstruction uncertainties. The model generates random realizations of solar modulation and geomagnetic field intensity variations. These realizations can then be selected to best fit with the observed radionuclide data via a Bayesian framework. Fig.1 shows how this Bayesian method performs on synthetic data. From the autocorrelation models we generate 10,000 years of solar modulation and geomagnetic field intensity (grey lines in fig. 1b and 1c). A solar realization and a geomagnetic field realization is then randomly selected to compute the synthetic ^{14}C production rate (orange lines in Fig.1). We then use realistic uncertainty estimates to resample the synthetic ^{14}C production rate (blue points in fig. 1a). Our Bayesian method is then able to disentangle the solar and geomagnetic field influences from this resampled ^{14}C production rate (blue bands in

Fig. 1 show the 2- σ range of the reconstructions).

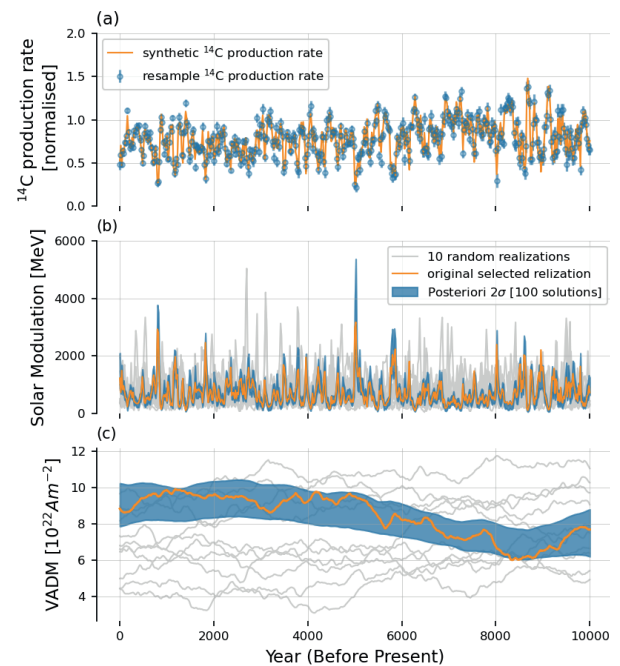


Fig. 1: Bayesian method performance on synthetic data.

Besides the IntCal20 ^{14}C data we plan to apply this method to the available ^{10}Be records from Greenland and Antarctica, and the new medium resolution ^{10}Be record from RAID drill chips samples obtained via the Beyond-EPICA project measured at ETH Zurich. The aim is to more robustly assess the long-term changes in solar activity via the combination of all available data with our prior knowledge about solar and geomagnetic field variability.

- [1] J. Masarik and J. Beer, J. Geophys. Res. 104 (1999) 12099
- [2] M. Vonmoos et al., J. Geophys. Res. 111 (2006) 10105

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TESTING “WASTEWATER” FOR ICE CORE MEASUREMENTS

^{10}Be and ^{36}Cl measurements in excess water from CFA measurement

C. Paleari¹, R. Muscheler¹, T. Erhardt², F. Adolphi², F. Mekhaldi¹, C. Vockenhuber, M. Christl

Ice cores are valuable natural archives that provide a wealth of information about the past that can be assessed with a large variety of methods. Unfortunately, sample material is limited and hence, there is a competition for ice samples, especially around interesting periods and for the older ice when the layers are thinned and less ice is available for measurements.

For this project, we aim at using “excess” meltwater from valuable ice samples for the measurement of ^{10}Be and ^{36}Cl . In particular, we focus on testing the use of meltwater samples from Continuous Flow Analysis (CFA) that would otherwise be discarded. CFA has now become a widespread method for the measurement of impurities in ice cores, providing high-resolution records of aerosols that can resolve seasonal variability [1]. The main problem when measuring impurities is the risk of contamination. In order to avoid this, CFA continuously melts vertical sticks of ice (Fig. 1), discarding the outer part, more exposed to contamination such as drill fluid. This “excess water” may be suitable for cosmogenic radionuclide measurements.

It is the first time this method is used to measure cosmogenic radionuclides in ice. The excess water flows into 50 ml vials through a small plastic tube connected to the CFA system. While a direct contamination from other samples is highly unlikely, a memory effect, that is the contamination from previous samples that left traces in the tube, could generate a smoothing effect. Furthermore, loss of ^{10}Be to the inner walls of the tube might lead to a systematic offset to clean ice samples.

To study the reliability of the method, we collected CFA meltwater samples from a firn core from the EastGRIP site, in Greenland. We will compare the ^{10}Be records from excess water

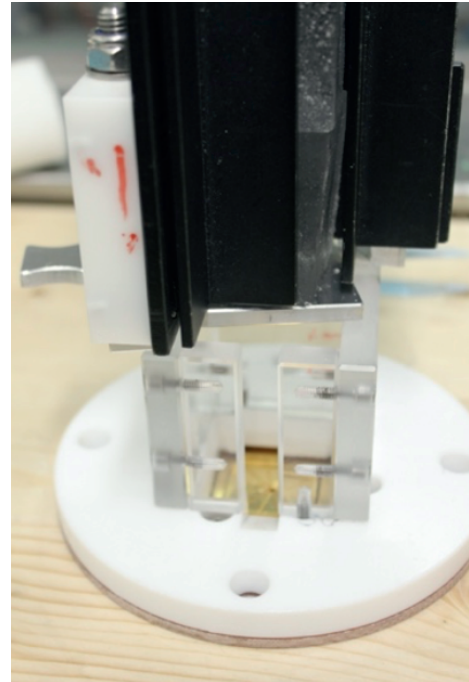


Fig. 1: Ice core melting to be measured in the CFA system.

to clean firn samples. The parallel ^{10}Be measurements of CFA excess water and clean firn from the same core will provide a key tool to assess the uncertainties of the method.

More than 10,000 CFA samples have already been collected for the deep EGRIP ice core with about 1 yr resolution, dating back to the beginning of the Holocene. If successful, the possibility to use the excess water samples will allow us to build up a valuable archive for the study of cosmogenic radionuclides in ice, allowing us, for example, to reconstruct past production rate changes.

- [1] T. Erhardt et al., *Environ. Sci. Technol.* 53 (2019) 13275

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EXPLORING THE $^{36}\text{Cl}/\text{Cl}$ INPUT IN ARID ENVIRONMENTS*

New insights from ^{81}Kr dating in deep aquifers of the Negev Desert

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Measurements of the long-lived ^{81}Kr and ^{36}Cl radioisotopes (half-lives of 229 ka and 301 ka, respectively) in the deep aquifers of the Negev Desert (Israel) were used to assess the $^{36}\text{Cl}/\text{Cl}$ input ratio for paleorecharge in the currently hyperarid southern Levant [1].

An initial $^{36}\text{Cl}/\text{Cl}$ ratio of 50×10^{-15} was concluded based on relatively fresh, young (2.5×10^4 ka) groundwater collected from some local aquifers in the region. The reconstructed $^{36}\text{Cl}/\text{Cl}$ input for paleorecharge is lower than expected from atmospheric fallout but in agreement with values found in recent rainwater (Fig. 1).

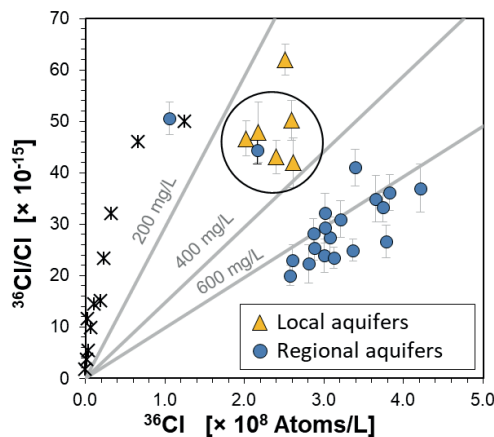


Fig. 1: ^{36}Cl abundance versus $^{36}\text{Cl}/\text{Cl}$ ratios in the Negev Desert groundwater and in Israel's rainwater (stars) [2]. Cl^- -equal lines are shown in grey. Most groundwater samples with low (< 400 mg/L) Cl^- content are clustered (circled).

This is observed despite possible changes in the climatic conditions and the ^{36}Cl production rates in the atmosphere over this timeframe, suggesting a lithogenic and temporally constant mechanism. This similarity in values is explained by the previously underestimated role of recirculating near-surface soil material that is affected by sea spray Cl but also by the exposure to cosmic rays over prolonged timescales. These

factors dominate the hydrochemistry of rains, floods and the consequent groundwater recharge. With the better defined initial $^{36}\text{Cl}/\text{Cl}$ ratios, the subsurface processes influencing ^{36}Cl and Cl^- concentrations in the deep, confined regional aquifers could then be further constrained by means of the $^{81}\text{Kr}/\text{Kr}$ data (Fig. 2).

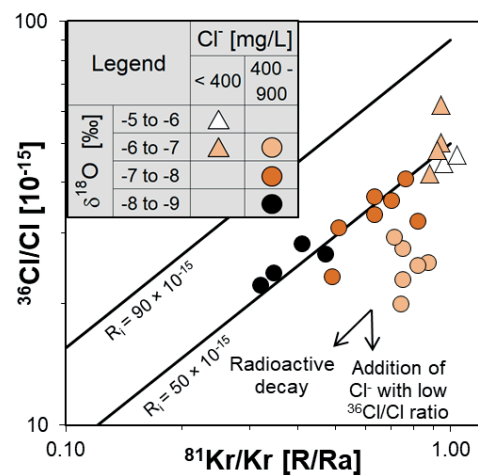


Fig. 2: Measured $^{36}\text{Cl}/\text{Cl}$ versus $^{81}\text{Kr}/\text{Kr}$ ratios in groundwater samples from the Negev Desert. Solid black lines demonstrate a predicted decrease in $^{36}\text{Cl}/\text{Cl}$ and $^{81}\text{Kr}/\text{Kr}$ ratios due to radioactive decay solely with initial $^{36}\text{Cl}/\text{Cl}$ ratios of 90×10^{-15} and 50×10^{-15} .

- [1] R. Ram et al., Sci. Total Environ. 762 (2021) 144106
- [2] B. Herut et al., Earth Planet. Sci. Lett. 109 (1992) 179

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PLUTONIUM-244 IN DEEP-SEA SEDIMENT

Search for interstellar r-process radionuclide

Y. Wu¹, X. Dai¹, M. Christl

According to the current stellar nucleosynthesis studies, about half of the elements heavier than iron in solar system could be produced through r-process (rapid neutron capture process). Although binary neutron star mergers and core-collapse supernovae are considered as the two most likely astrophysical sites for r-process element production, no unambiguous signatures of heavy element production from these two classes of events have yet been detected. The observation of ^{244}Pu , a long-lived ($T_{1/2} = 81.1 \pm 0.3$ Ma) and pure r-process nuclide, would add important information to test and refine our understanding of the r-process nucleosynthesis. Since the interstellar medium (ISM) is expected to become steadily enriched with fresh nucleosynthetic products, it may also contain ^{244}Pu produced in r-process nucleosynthesis, which may be deposited on Earth and finally be accumulated in sediments at the ocean floor. However, the latest measurements on deep-sea samples have not yet revealed a clear ^{244}Pu signal to confirm such an interstellar r-process input [1].



Fig. 1: Sampling of the deep-sea sediment.

In this work, a deep ocean sediment core collected from West Pacific at water depth of 6389 m was obtained, and the very bottom fraction of the sediment column (from 280 to

334 cm) was divided to two layers for Pu isotopic analysis. The two sediment samples (~200 g each) were completely dissolved, chemically processed to separate Pu, and the concentrations of ^{239}Pu , ^{240}Pu and ^{244}Pu were finally measured using the compact accelerator mass spectrometry (AMS) system TANDY. Excellent detection limits of $\sim 1 \times 10^{-20}$ g/g for ^{244}Pu and $\sim 1 \times 10^{-19}$ for ^{239}Pu and ^{240}Pu have been achieved, respectively.

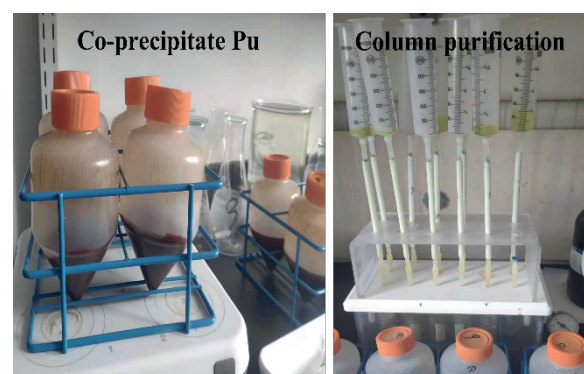


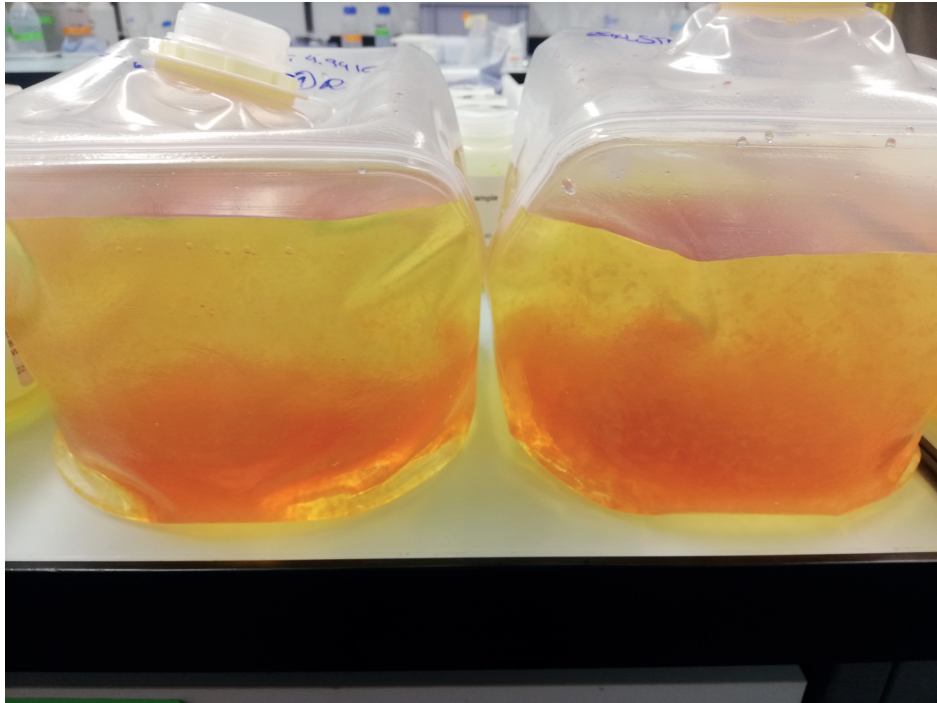
Fig. 2: Sample preparation

In both of the two sediment samples, 3 counts of ^{244}Pu were detected, whereas all the procedural blanks showed zero ^{244}Pu counts. Meanwhile, no global atmospheric fallout $^{239/240}\text{Pu}$ signature and anthropogenic Pu contamination were found in the two sediment samples. Further investigations would be required to explain the ^{244}Pu signals detected in the sediment samples.

[1] A. Wallner et al. Nat. Commun. 6 (2015) 6956

¹ China Institution for Radiation Protection, Beijing

ANTHROPOGENIC RADIONUCLIDES



Co-precipitation of uranium isotopes with iron hydroxides

A new era of transient tracers in the ocean

The first time series of ^{236}U in the Fram Strait

^{129}I and ^{236}U as quantitative water mass tracers

^{233}U to identify Pacific waters in the Arctic Ocean

^{236}U - ^{237}Np as fingerprints of radioactive effluents

Anthropogenic radionuclides in BATS station

Evolution of $^{236}\text{U}/^{238}\text{U}$ in the Southwest Atlantic

^{236}U and ^{233}U in the South China Sea

Distribution of ^{129}I in the geotraces GP15 line

DGT-induced actinide fluxes & bioaccumulation

New plutonium-based forensic insight

A NEW ERA OF TRANSIENT TRACERS IN THE OCEAN

The use of ^{129}I , ^{236}U , ^{39}Ar and ^{14}C in future expeditions

N. Casacuberta, A.M. Wefing, M. Castrillejo, M. Christl, M. Karcher¹, M. Oberthaler²

Climate change is triggering profound changes in the marine environment, especially in the Arctic Ocean (AO) and subpolar North Atlantic (SPNA), two key areas playing a crucial role in feeding the main engine of the global oceans: the Atlantic Meridional Overturning Circulation (AMOC). Despite the importance of AMOC for the climate system, there are still many open fundamental questions regarding its physical mechanisms, water mass pathways, and transport or ventilation timescales.

With the aim to improve our understanding of AMOC, a new quartet of transient radionuclide tracers (^{129}I , ^{236}U , ^{39}Ar and ^{14}C) will be used in future expeditions (Fig 1) as a tool to study processes that span from a few years to millennia.

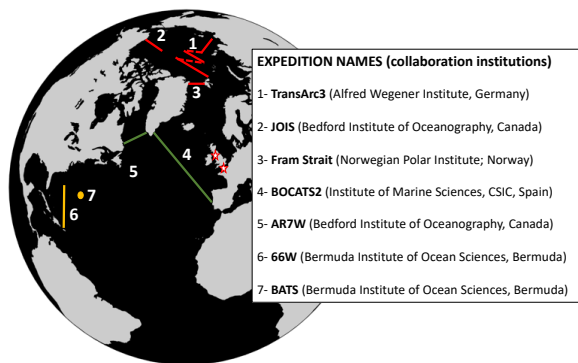


Fig. 1: Schematic representation of the expeditions planned in the following years (2021 – 2026) in collaboration with the different international institutions.

While the combination of the two nuclear reprocessing-derived isotopes ^{129}I and ^{236}U will help to investigate the shorter transport mechanisms (<100 y) of Atlantic waters in the AO and deep-water convection in the SPNA, the natural ^{39}Ar and ^{14}C will provide answers for the ventilation of intermediate and deep waters (>100 y) (Fig 2).

Newly available techniques will allow the implementation of ^{39}Ar to unprecedented possibilities, closing the time gap between the artificial transient tracers (CFCs, SF_6 , ^{129}I , ^{236}U) and natural ^{14}C .

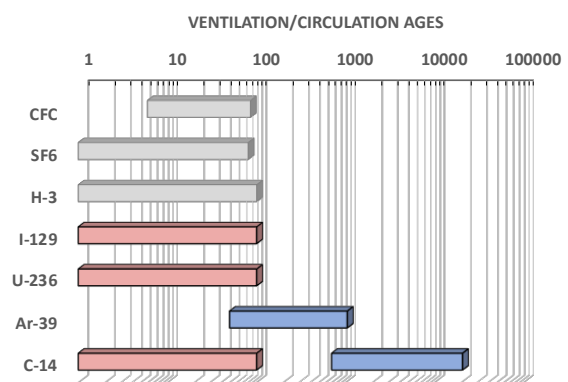


Fig. 2: Ranges of ventilation/circulation times of the naturally occurring tracers (in blue) and the artificial transient tracers (in red) of TITANICA compared to other popular transient tracers (in grey).

This project, based in the Department of Environmental Systems Science (ETHZ) will go beyond the state-of-the-art as it combines cutting edge analytical techniques (Accelerator Mass Spectrometry and Atom Trap Trace Analysis) with novel data analysis methods developed at the Laboratory of Ion Beam Physics in the last years.

The new data generated and the strong collaboration with European and international partners will result in a new era of transient tracers in the Arctic and Atlantic Oceans.

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THE FIRST TIME SERIES OF ^{236}U IN THE FRAM STRAIT

A compilation of ^{236}U data from 2016, 2018 and 2019

A.-M. Wefing, N. Casacuberta, M. Christl, P.A. Dodd¹

The Fram Strait is a fundamental gateway between the Arctic and the North Atlantic Ocean, bound by Greenland to the west and Svalbard to the east. A two-way exchange of water masses between both Oceans takes place in the Fram Strait, featuring the inflow of warm Atlantic Water in the eastern part as well as the outflow of cold and fresh Polar Water in the western part. The composition and properties of these southward-flowing waters vary over time and are therefore subject to ongoing research.

A novel and promising tracer especially for Atlantic-origin water in the Arctic Ocean is the long-lived anthropogenic radionuclide ^{236}U . It has mainly been introduced into the marine environment by atmospheric nuclear weapon tests conducted in the last century and by liquid discharges from European nuclear reprocessing plants. Recent studies highlighted the potential of ^{236}U to study water mass ages as well as water mass composition in the Arctic Ocean [1,2].

To investigate the temporal variability of Polar Water flowing through the Fram Strait, seawater samples for the measurement of ^{236}U have been collected along a section across the Fram Strait in 2016, 2018 and 2019. All samples have been processed and $^{236}\text{U}/^{238}\text{U}$ ratios have been measured at LIP over the last years.

The three-year time series of $^{236}\text{U}/^{238}\text{U}$ ratios across the Fram Strait (Fig. 1) shows temporal changes in the tracer distribution. $^{236}\text{U}/^{238}\text{U}$ ratios decreased over time, especially in the uppermost 50-100m of the water column. Additional research showed that this decrease is not caused by the temporally changing input of ^{236}U into the oceans alone, but must be due to a change in the water mass composition. Most probably, the proportion of Pacific-origin Water compared to Atlantic-origin Water increased, diluting the strong Atlantic Water signal of ^{236}U .

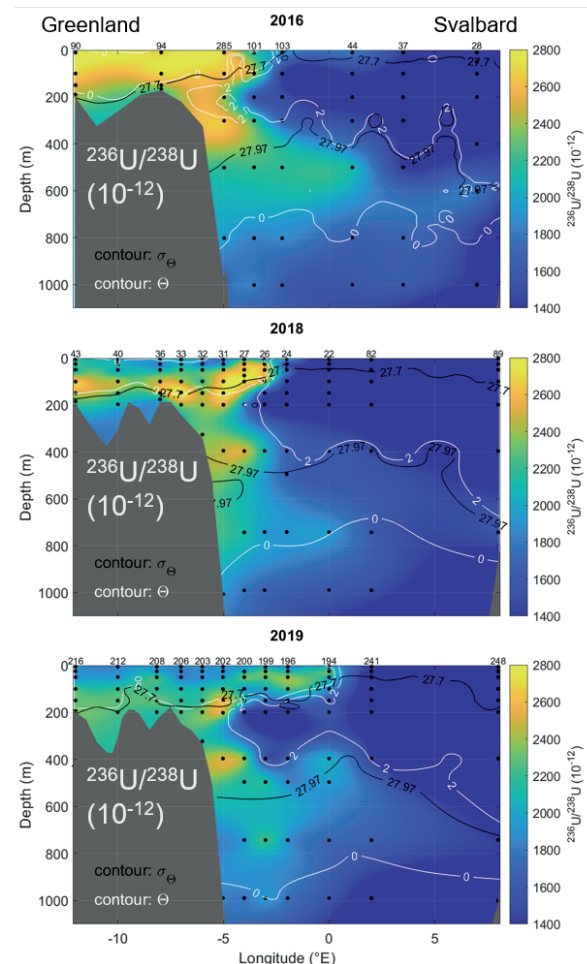


Fig. 1: Distribution of $^{236}\text{U}/^{238}\text{U}$ across the Fram Strait in 2016, 2018 and 2019.

In the future, the combination of ^{236}U with a comprehensive dataset of ^{129}I and other chemical tracers collected during the same expeditions shall be used to further quantify the water mass composition and origin in the outflowing waters.

[1] A.-M. Wefing et al., Ocean Sci. 17 (2021) 111

[2] A.-M. Wefing et al., LIP Annual report (2020) 80

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¹²⁹I AND ²³⁶U AS QUANTITATIVE WATER MASS TRACERS

Understanding water mass composition in the central Arctic Ocean

A.-M. Wefing, N. Casacuberta, M. Christl

The upper water column of the Arctic Ocean is generally considered to be composed of four different water masses: Atlantic Water, Pacific Water, sea-ice meltwater and meteoric water (including river runoff, glacial meltwater, and precipitation). While waters of Atlantic origin are the dominant component in the upper layers of the Eurasian Basin (Fig. 1), Pacific Water inflowing through the Bering Strait makes up the largest proportion of surface waters in the Canadian Basin. The location of the interface between Atlantic and Pacific Water in the central Arctic, however, is known to vary over time, depending on the prevailing circulation regime [1].

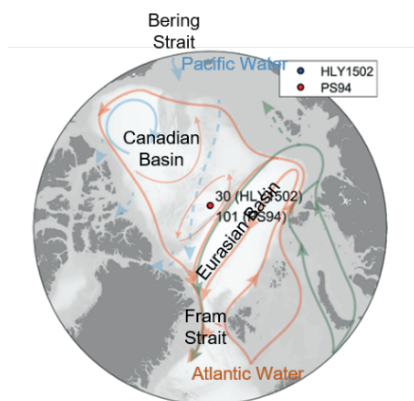


Fig. 1: Map of the Arctic Ocean including main circulation features and the station location.

A suite of chemical tracers has been used in the past to quantify proportions of the different water masses, including salinity, stable oxygen isotopes ($\delta^{18}\text{O}$), and nutrient relationships. Especially the distinction between Atlantic- and Pacific-origin water, however, remains challenging since most tracers cannot be considered conservative with regard to biogeochemical processes happening in the Arctic Ocean.

As a novel approach, the two long-lived anthropogenic radionuclides ¹²⁹I and ²³⁶U, which

are conservative in seawater, have been investigated as quantitative tracers to distinguish Atlantic- from Pacific-derived waters. A strong signal of both tracers is associated to Atlantic Water, whereas Pacific Water only carries a weak signal [2].

Fractions of Pacific Water have been derived from the combination of each radionuclide with salinity and $\delta^{18}\text{O}$ for a station in the central Arctic Ocean (Fig. 2). Corresponding Pacific Water fractions are comparable to those obtained from other tracers, though generally lower.

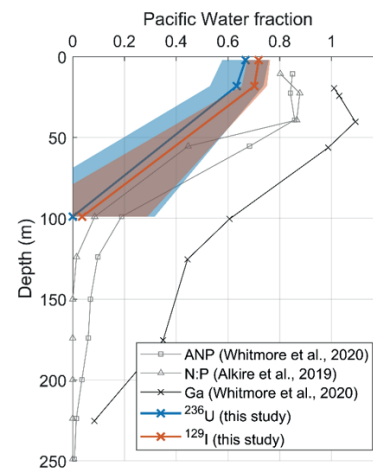


Fig. 2: Pacific Water fractions obtained from different tracers for a station in the central Arctic Ocean (location shown in Fig. 1).

In the future, these new tracers might help to better understand water mass circulation processes, their connection to atmospheric circulation regimes, as well as potential changes arising as a consequence of anthropogenic climate change in the Arctic Ocean.

- [1] M. Karcher et al., J. Geophys. Res. Oceans 117 (2012)
- [2] N. Casacuberta et al., Earth Planet. Sci. Lett. 440 (2016) 127

^{233}U TO IDENTIFY PACIFIC WATERS IN THE ARCTIC OCEAN

$^{233}\text{U}/^{236}\text{U}$ unravels Pacific and Atlantic waters in the Amerasian basin

E. Chamizo¹, M. Christl, M. López-Lora^{1,2}, N. Casacuberta, A.M. Wefing, T.C. Kenna³

In the Arctic Ocean (AO), waters from the Pacific and Atlantic meet. Pacific Waters (PW) are mostly present in the western AO down to 150 m depth. The main core of Atlantic Waters (AW) dominates the 250-800 m depth layer. Radionuclides released by European Nuclear Reprocessing Plants (NRPs) have been extensively used to trace AW into the AO. PW unique tracers are, on the other hand, not so well established.

Recently, $^{233}\text{U}/^{236}\text{U}$ atom ratio (AR) has been proposed to disentangle anthropogenic U sources. In contrast to ^{236}U , ^{233}U would not have been massively introduced by NRPs but by global fallout (GF). Thus, the ratio in the AO would be a mixture of the one in PW containing only GF ($1.4 \pm 0.15 \times 10^{-2}$ [1]) and the one in AW, where the ratio would be lower due to the presence of NRPs-derived ^{236}U .

In this work, we faced the challenge of measuring ^{233}U and ^{236}U in 5-L seawater aliquots collected during the GN01 US GEOTRACES expedition to the AO crossing the Amerasian basin in 2015 (Fig. 1), as a collaboration effort between LDEO, CNA and ETH.

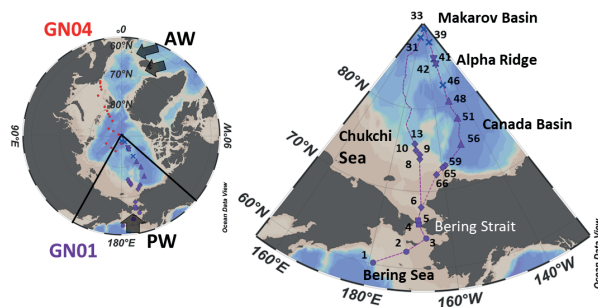


Fig. 1: Left: location of samples from the GN04 and GN01 GEOTRACES expeditions in 2015. Right: GN01 stations with ^{233}U and ^{236}U data.

Fig. 2 displays the obtained average $^{233}\text{U}/^{236}\text{U}$ AR and ^{236}U concentrations in the marine regions in

Fig. 1 for both surface waters (10-35 m depth) and mid-depth AW (250-800 m depth). Values for surface waters consistently distribute along PW (entering from the Bering Strait) and pure AW (as estimated from literature data) mixing line. Mid-depth AW show similar results in the three studied deep stations (56, 43 and 48), and approach the endmember estimated value for pure AW, featuring a $^{233}\text{U}/^{236}\text{U}$ AR of $(0.60 \pm 0.06) \times 10^{-2}$ and a ^{236}U concentration of $(24 \pm 1) \times 10^6$ atoms/L.

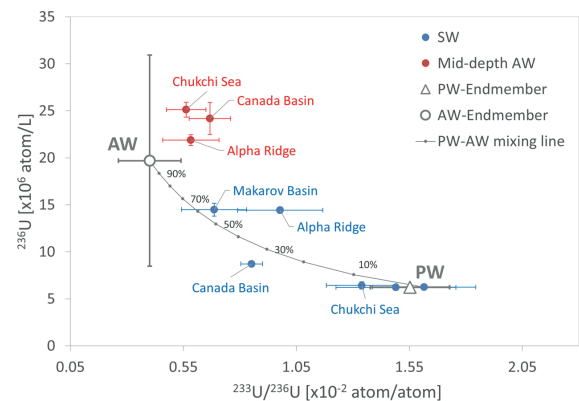


Fig. 2: Average ^{236}U concentrations and $^{233}\text{U}/^{236}\text{U}$ ARs in surface waters (SW) and mid-depth Atlantic Waters in the marine regions in Fig. 1.

Our results demonstrate the potential of the $^{233}\text{U}/^{236}\text{U}$ AR to identify PW in the AO. However, more data regarding AW are needed to establish the use of these ratio as a tracer to constrain water mass sources.

[1] K. Hain et al., Nat. Commun. 11 (2020) 1275

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³Lamont-Doherty Earth Observatory (LDEO), Columbia Univ., USA

^{236}U - ^{237}Np AS FINGERPRINTS OF RADIOACTIVE EFFLUENTS

Study regions: Arctic Canada Basin and Mediterranean Sea

M. López-Lora^{1,2}, E. Chamizo¹, I. Levy³, M. Christl, N. Casacuberta, T.C. Kenna⁴

In this work, anthropogenic radionuclides ^{236}U and ^{237}Np were analysed in seawater samples to study their potential as water mass tracers. Seawater samples were collected from two different regions: i) the Canada Basin (Arctic Ocean, AO), where Atlantic Waters (AW) carry the signal of Sellafield (United Kingdom) and La Hague (France) Nuclear Reprocessing Plants (NRPs); and ii) the western Mediterranean Sea, directly impacted by Marcoule NRP (France). Two and one full-depth seawater profiles, respectively from each domain, were processed and analysed by Accelerator Mass Spectrometry (AMS) at the CNA and ETH (Fig. 1).

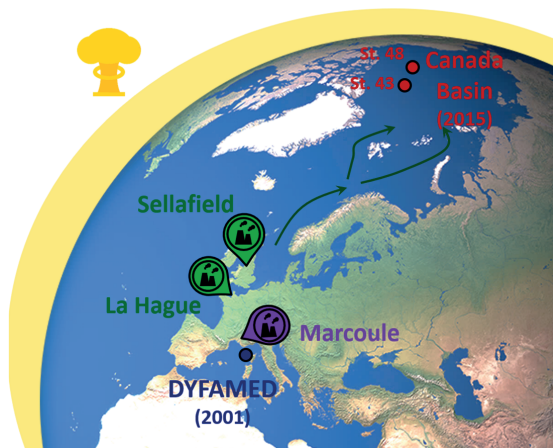


Fig. 1: Location of the three sampling stations studied in this work and of the key ^{236}U and ^{237}Np sources. [1]

At the Canada Basin, AW showed the highest ^{236}U and ^{237}Np concentrations. $^{237}\text{Np}/^{236}\text{U}$ ratios agreed with the estimated values for North AW entering the AO and tagged with global fallout (GF) and European NRPs signals [2] (Fig. 2). These results may reflect the impact of the documented releases for the 1990s.

In the Mediterranean Sea, enhanced levels of ^{236}U were observed and, thus, depleted $^{237}\text{Np}/^{236}\text{U}$ ratios. Interestingly, the shallowest

values approached the predicted endmember for Marcoule NRP effluents, which is presumably the source of the excess of ^{236}U (Fig. 2).

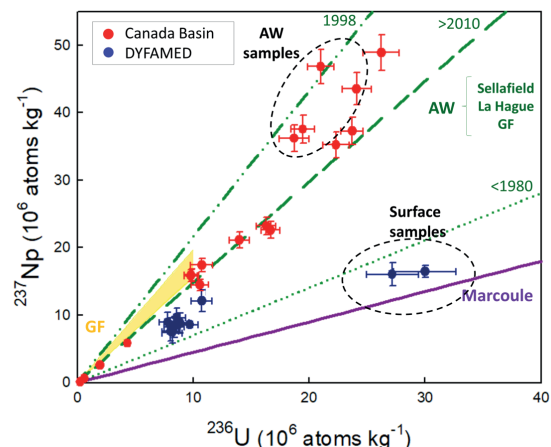


Fig. 2: ^{237}Np concentrations against ^{236}U concentrations at the 3 studied stations (Fig. 1). Endmembers for GF, Marcoule NRP effluents, and AW entering the AO including a mixture of Sellafield, La Hague and GF signals according to [2] are also shown.

Overall, the dual tracer ^{236}U - ^{237}Np has the potential to be an additional tool to understand transient oceanographic processes, but more accurate information on the ^{236}U and ^{237}Np sources are needed to exploit its use.

- [1] M. López-Lora et al., Sci. Total Environ. 1-12 (2020) 765
- [2] N. Casacuberta et al., J. Geophys. Res. Ocean. 124 (2018) 882

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ANTHROPOGENIC RADIONUCLIDES IN BATS STATION

^{129}I and ^{236}U reached the equatorial Atlantic Ocean

N. Casacuberta, M. Christl, M. Castrillejo, A.-M. Wefing, A. Schlatter¹, R. Johnson², N. Bates²

The Bermuda Atlantic Time-series Study (BATS) is a long-term time-series study that aims examining biogeochemical cycles in the Sargasso Sea near Bermuda. It consists of a set of stations located south and south-east of Bermuda in an area where the major deep-water currents from the Arctic and Antarctic regions meet (Fig. 1).

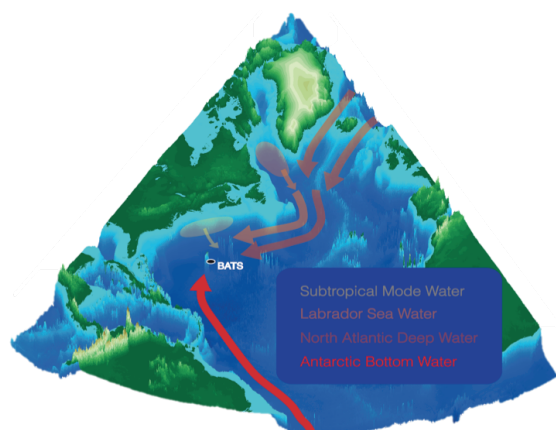


Fig. 1: Location of BATS relative to major deep-water currents from the Arctic and Antarctic.

In 2019, three profiles of seawater samples were taken during one of the expeditions to the BATS station (and hydrographic stations 3 and 11) for the analysis of ^{129}I , ^{14}C and ^{236}U . The aim was to see whether the anthropogenic signal of ^{129}I and ^{236}U from the nuclear reprocessing plants of Sellafield and La Hague would have reached the subtropical Atlantic Ocean through the interior pathways of the North Atlantic Deep Waters (NADW).

Preliminary results of ^{129}I and ^{14}C were presented in [1] but the three profiles of ^{129}I are shown here for completeness (Fig. 2 - right). A first peak of ^{129}I at 1500m depth corresponded to the deep waters formed at the Labrador Sea. The second peak at 3500m depth most likely pointed to the presence of Denmark Strait Overflow Waters (DSOW), as already observed by other authors [2] in a similar location between 2004 and 2014.

Preliminary results of $^{236}\text{U}/^{238}\text{U}$ atom ratios support the two peaks observed in the ^{129}I profiles, corresponding to the Labrador Sea Water (LSW) and the DSOW (Fig. 2 – left), although the $^{236}\text{U}/^{238}\text{U}$ ratios in the DSOW were lower than in the LSW. This was not the case for ^{129}I . Another feature observed in the ^{236}U profile that differs from the ^{129}I is the peak observed at 400 m (mixed layer), indicating the atmospheric input of ^{236}U that happened during the atmospheric weapon testing in the 1960s.

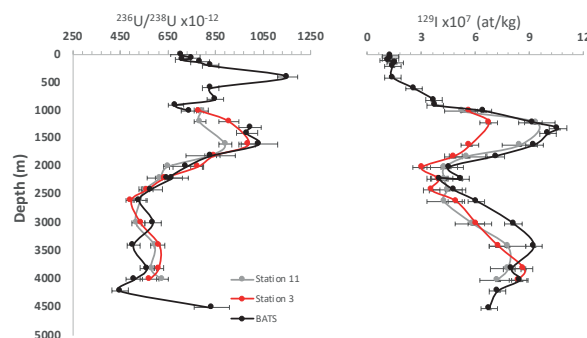


Fig. 2: Profiles of ^{129}I concentration (right) and $^{236}\text{U}/^{238}\text{U}$ ratios (left) at the BATS station and hydrographic stations 3 and 11.

This pilot study is a proof that the peak of ^{129}I and ^{236}U reached the subtropical North Atlantic and these tracers will now be included in the BATS time-series to understand the pathways, nature and timescales of NADW formed in the subpolar North Atlantic and its further transport southwards to Bermuda.

- [1] N. Casacuberta et al., LIP Annual Report (2019) 90
- [2] J. Smith et al., J. Geophys. Res. Oceans 121 (2016) 8115

¹EAWAG, Dübendorf

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EVOLUTION OF $^{236}\text{U}/^{238}\text{U}$ IN THE SOUTHWEST ATLANTIC

Revisiting Ficaram stations six years after 2013

M. Castrillejo, A.-M. Wefing, M. Christl, C. Vockenhuber, N. Casacuberta, M.G. Coto¹, F.F. Pérez¹

In spring 2013 about 100 seawater samples were collected on board the Spanish research vessel BIO Hespérides for the determination of anthropogenic radionuclides between Argentina and Spain. The Ficaram-15 expedition allowed the first mapping of ^{236}U (Fig. 1) and ^{129}I distributions in the South Atlantic Ocean.

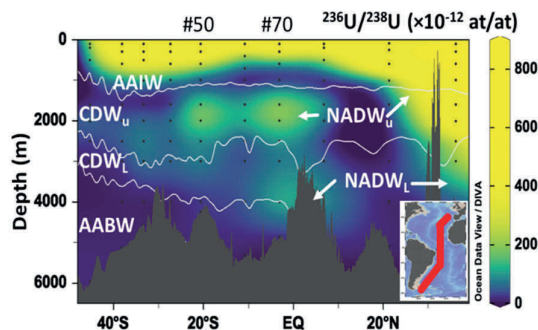


Fig. 1: Zonal distribution of the $^{236}\text{U}/^{238}\text{U}$ ratio along the Ficaram cruise track in 2013.

Wefing et al., [1], found the largest presence of anthropogenic radionuclides in the upper 1000 m along the entire cruise track, and local maxima at deeper depths north of 20°N, near the Equator and at about 20°S. The higher $^{236}\text{U}/^{238}\text{U}$ atom ratios in the upper ocean were caused by atmospheric deposition of ^{236}U from atmospheric nuclear weapon tests fallout in the 1960s. The analysis of salinity and potential temperature allowed to overlay the water mass structure in Fig. 1. The sinking of ^{236}U north of 20°N and the relative maxima at depth appeared to be related to the upper (NADW_u) and lower (NADW_l) branches of North Atlantic Deep Water.

NADW plays an important role in climate by transporting heat and carbon from the shallow ocean into all ocean basins' interior. However, the identification of NADW pathways is challenging in the South Atlantic Ocean [2]. Therefore, the fact that we could recognize the pathways using the $^{236}\text{U}/^{238}\text{U}$ ratio encouraged us

to revisit station 50 and 70 in the 17th repetition of the Ficaram cruise in spring 2019.

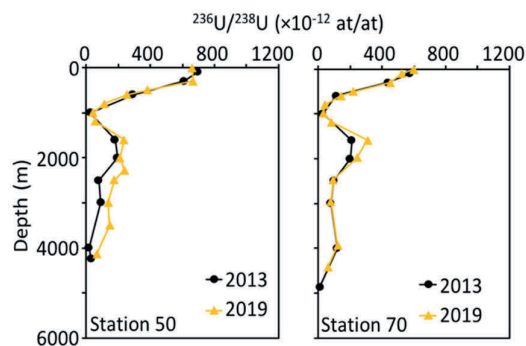


Fig. 2: $^{236}\text{U}/^{238}\text{U}$ ratios in the Southern (St. 50) and Equatorial (St. 70) region of the Atlantic Ocean between 2013 and 2019.

The temporal evolution of the $^{236}\text{U}/^{238}\text{U}$ ratio at the two sites between 2013 and 2019 is shown in Fig. 2. In some depth ranges (e.g., upper 1000 m), the $^{236}\text{U}/^{238}\text{U}$ ratio remained constant between both sampling years. This result suggests stationary circulation in this part of the ocean. In addition, the agreement of $^{236}\text{U}/^{238}\text{U}$ ratios in the upper 1000 m at St. 50 and below 2500 m depth at St. 70 is also an indicative of an overall reproducibility of the radiochemistry and the AMS measurement. At other depth ranges corresponding to NADW, however, the $^{236}\text{U}/^{238}\text{U}$ ratio was more elevated in 2019 than in 2013. In the future, we intend to use this temporal evolution of the $^{236}\text{U}/^{238}\text{U}$ ratio to provide further insight on the timescales of NADW circulation.

- [1] A.-M. Wefing et al., LIP Annual report (2018) 82
- [2] E. Frajka-Williams et al., Front. Mar. Sci. 6 (2019) 260

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^{236}U AND ^{233}U IN THE SOUTH CHINA SEA*

Level and distribution in the surface water

X.L. Hou^{1,2}, Y.Y. Wang^{2,3}, M. Christl, S.D. Zhu³, M.T. Zhang², H. Jiang², X. Wang²

Surface seawater collected from the South China Sea (Fig. 1) in Aug-Sept. 2018 was analyzed for ^{233}U , ^{236}U and ^{238}U to investigate their level, distribution and sources of anthropogenic uranium in this region. ^{238}U concentrations in seawater were measured using ICP-MS (Agilent 8800). Uranium pre-concentrated from 20 L seawater using co-precipitation was separated using UTEVA column as reported elsewhere [1]. The separated uranium with $\text{Fe}(\text{OH})_3$ was baked at 850°C , mixed with about 4 mg Nb powder and pressed into the AMS target holder. The atomic ratios of $^{233}\text{U}/^{238}\text{U}$ and $^{236}\text{U}/^{238}\text{U}$ in the samples were measured at the TANDY AMS facility. The concentrations of ^{233}U and ^{236}U were calculated using the measured ^{238}U concentrations.

In total 65 seawater samples were analysed in this work, the measured $^{233}\text{U}/^{238}\text{U}$ and $^{236}\text{U}/^{238}\text{U}$ atomic ratios were normalized to the ETH in-house standard "ZUTRI" and corrected for the procedure blanks. The $^{236}\text{U}/^{238}\text{U}$ atomic ratios in the surface water in the South China Sea fall into a narrow range of $(0.96\text{--}1.15)\times 10^{-9}$, with the ^{236}U concentrations of $(7.35\text{--}10.4)\times 10^6$ atoms/L. This is similar to the values observed in the surface seawater in the North Hemisphere, without direct influence from discharges of reprocessing and nuclear facilities, such as those observed in the Japan Sea and Pacific Ocean [2,3]. This might indicate that ^{236}U in the surface water in the South China Sea mainly originated from global fallout from the atmospheric nuclear weapons tests. Much lower and a relatively large variation of $^{233}\text{U}/^{238}\text{U}$ atomic ratios of $(6\text{--}50)\times 10^{-12}$ were measured in the same seawater samples. The corresponding $^{233}\text{U}/^{238}\text{U}$ atomic ratios of $(0.56\text{--}4.8)\times 10^{-2}$ are similar to the reported weapons testing signals of $(0.3\text{--}5.6)\times 10^{-2}$, but much higher than the reprocessing signal (about 0.13×10^{-2}) [4]. This

confirmed that the anthropogenic uranium (^{233}U and ^{236}U) originated from global fallout of the atmospheric nuclear weapons tests.

The ^{236}U concentrations in the surface seawater in the South China Sea (Fig.1) show a relative unified distribution, no increased ^{236}U level in the estuary region of Pearl River and Mekong River was observed, indicating the input of ^{236}U from river flow is not significant.

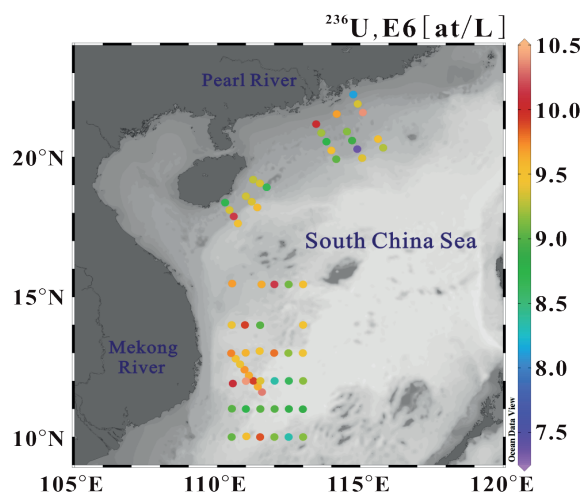


Fig. 1: Distribution of ^{236}U in the surface seawater in the South China Sea.

- [1] Y.Y. Wang et al., Talanta, 224 (2021) 121882
- [2] A. Sakaguchi et al., Earth Planet. Sci. Lett. 333-334 (2012) 165
- [3] R. Eigl et al., J. Environ. Radioact. 162-163 (2016) 244
- [4] K. Hain et al., Nature Comm. 11 (2020) 1275

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*Supported by RADIATE TA

DISTRIBUTION OF ^{129}I IN THE GEOTRACES GP15 LINE

Is Hanford Site a source of ^{129}I to the Pacific Ocean?

N. Casacuberta, K. Kündig, J. Kenyon¹, K.O. Buesseler¹

In 2015, seawater samples were collected in the GO-SHIP P16 line (Fig. 1) for the analysis of artificial radionuclides. The purpose of that work was to study the distribution of ^{137}Cs , ^{134}Cs and ^{129}I derived from the Fukushima Dai-ichi nuclear accident (March 2011) and assess their potential as tracers of ocean circulation in the Pacific Ocean.

Concentrations of ^{129}I from this transect in 2015 ranged from $0.3 \pm 0.2 \times 10^7$ at kg^{-1} to $120 \pm 2 \times 10^7$ at kg^{-1} . High values ($>25 \times 10^7$ at kg^{-1}) were observed in the northern part of the section, particularly in the Alaska Current (Fig. 2a). However, the distribution of ^{129}I concentrations had no correlation to the unequivocal signal of Fukushima-derived ^{134}Cs (and ^{137}Cs) measured in these samples [1].

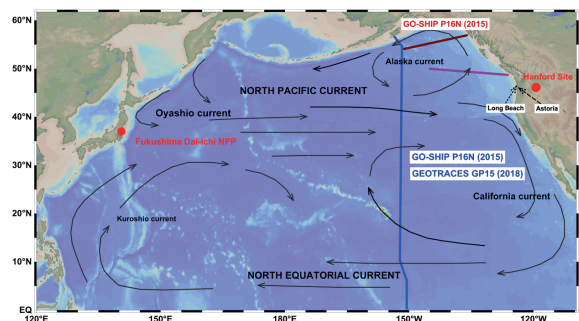


Fig. 1: Map showing the section sampled in 2015 and 2018. Two samples were also taken in 2017 at the mouth of the Columbia River (in Astoria and Long Beach). Red dots represent the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) and the Hanford Site (HS). Black arrows represent ocean currents.

This lack of correlation clearly pointed to an alternative source of ^{129}I for the northeast Pacific Ocean. Could the Hanford Site be a major source of ^{129}I ? Two samples taken at the mouth of the Columbia River (Astoria) and Long Beach (Fig. 1) in spring 2017 pointed to high concentrations of ^{129}I ($10\text{--}11 \times 10^7$ at kg^{-1}), but these would not fully

explain the high ^{129}I concentrations observed in the Alaska Current in 2015.

In order to explore this further, another set of samples were taken during the GEOTRACES expedition (GP15) in 2018, that followed the exact same transect as in 2015.

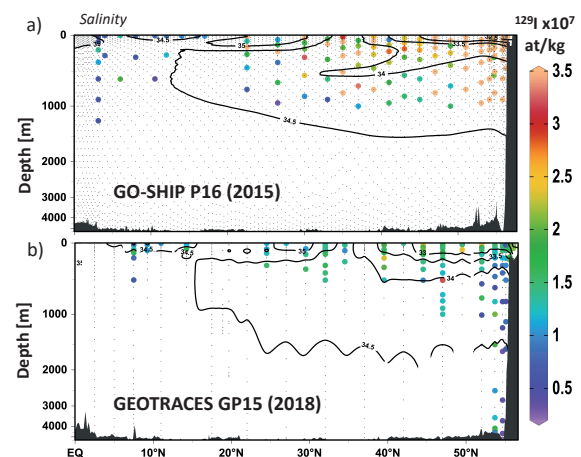


Fig. 2: Section plot showing the distribution of ^{129}I in 2015 and 2018. Section corresponds to the blue line in Fig. 1.

Results obtained from the samples taken in 2018 were all below 3.5×10^7 at kg^{-1} (Fig. 2b), thus showing no evidence anymore of another prominent source of ^{129}I to the Pacific Ocean other than the global fallout. Whether Hanford Site is (or has been) a source of artificial radionuclides still remains unclear. If the high levels of ^{129}I observed in 2015 came from Hanford Site, the only preliminary conclusion is that this source is not constant in time and that any uncontrolled releases to the Pacific Ocean get diluted in timescales of at least, a few years.

- [1] N. Casacuberta et al., LIP Annual Report (2018) 86

¹Woods Hole Oceanographic Institution, USA

DGT-INDUCED ACTINIDE FLUXES & BIOACCUMULATION

Observing the remobilisation of U, Pu, and Am using novel DGT

J. Chaplin¹, M. Christl, A. Cundy², P. Warwick², F. Bochud¹, P. Froidevaux¹

Having completed the development of the novel DGT sampling configurations, which we described in last year's LIP annual report (p. 95), we manufactured several batches of samplers and deployed them in marsh sediments of the Ravensglass Estuary (UK) between August and September 2020. Legacy nuclear discharges derived from the Sellafield Facility (around 15 km to the North) are known to have contaminated the marshes here with various non-conservative radionuclides which have high k_d for the particulate. By introducing DGT samplers into sediment, the local geochemical environment is disrupted; a diffusive flux of labile actinide species (in accordance with Fick's law) is induced to the DGT resin-gel, where the actinides are bound for analysis (Fig.1).

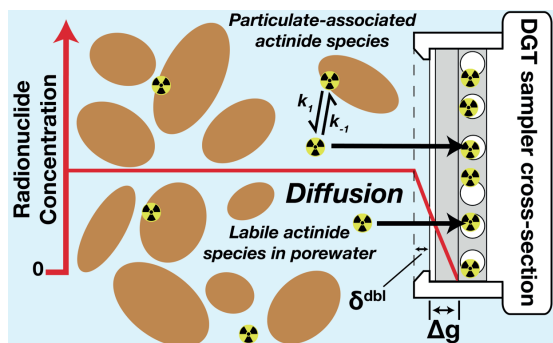


Fig. 1: Sedimentary DGT theory in line with our environmental deployments

Based on this theory, our deployments have allowed us to produce, for the first time, localised remobilisation fluxes of Sellafield-derived U, Pu and Am between the particulate-associated phase and the Irish Sea. This was made possible by combining the sub-femtogram-level actinide detection of LIP's compact 0.6 MV TANDY AMS system [1] with the enhanced selectivity of our DGT configurations for UO_2^{2+} , Pu(IV+V) and Am(III) . At these detection limits, we succeeded in analysing resin-gel segments at high spatial resolution (3 cm vertical x 1 cm width segments)

following a 14-day deployment period, including the detection of ^{236}U and ^{241}Am in our resin-gel segments in the order of several femtograms. This represents what we believe to be the first analysis of ^{236}U by a passive sampling technology, and the first time that DGT has been applied to Am in an environmental context. The resulting fluxes of ^{236}U and ^{241}Am to the DGT resin gels in lower-concentration areas of the marsh were in the order of several attograms $\text{hr}^{-1} \text{cm}^{-2}$. Additionally, we observed significant variations between high and low marsh environments. Our data will contribute to the construction of a comprehensive geochemical model of the Sellafield environment, which we intend to complete following a further sampling campaign in 2021.

We also examined the content of our target actinides in various marsh vegetation and periwinkles, allowing us to evaluate our hypothesis that DGT can predict concentration factors in these organisms more validly than standard spot sampling. $^{240}\text{Pu}/^{239}\text{Pu}$ atom ratios between the biota and the Pu accumulated in the samplers (from the top 17 cm of marsh sediment) are characteristic of the signature of the legacy Sellafield reprocessing discharges, strongly indicating that the biota in the area is bioaccumulating radionuclides from this source.

Further measurements using TANDY, which will include marine and sediment DGT deployments in addition to ultrafiltration work with seawater, are planned for 2021 depending on international restrictions due to the COVID-19 pandemic.

[1] M. Christl et al., NIMB 294 (2013) 29

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²Ocean and Earth Science, National Oceanography Centre, Univ. of Southampton, UK

NEW PLUTONIUM-BASED FORENSIC INSIGHTS

Local and global trace plutonium estimates on a former fast breeder site

M.J. Joyce¹, J. Andrew², M. Christl, M. Castrillejo, C. Degueldre¹, K.T. Semple³, C. Tighe¹

The Dounreay nuclear site (Scotland) was host to three nuclear reactors: the Dounreay Materials Test Reactor, the Dounreay Fast Reactor and the Prototype Fast Reactor. It was in operation from 1958 to 1994 and is now subject to extensive decommissioning, being scheduled to enter a care and maintenance phase in 2036. For this to be achieved, the benefits and detriments of large-scale remedial excavation need to be considered, especially in the context of the origins of trace plutonium contamination present in the soil on site.

It is known that contamination from operations will be present from authorized discharges (such as from the gaseous discharge stacks) permitted under the various authorizations and permits that the site has operated under. However, the proportion of this contamination that originates from activities on site, in contrast with that which derives from atmospheric nuclear weapons tests, was not known prior to this work [1].

Mass concentrations of ^{239}Pu were measured in soil samples from the Dounreay site (Fig. 1). This indicated two outliers, relative to the on-site average and the concentrations of controls not associated with the site: one high and one low.

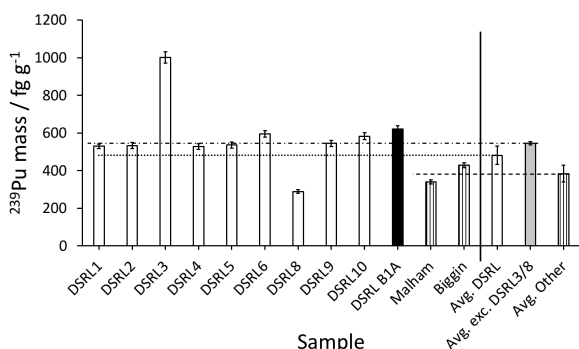


Fig. 1: ^{239}Pu mass abundance [1] for Dounreay samples (DSRL1-10) and controls (Malham/Biggin).

$^{240}\text{Pu}/^{239}\text{Pu}$ estimates (Fig. 2) indicate a ratio consistent with the site average for the low outlier, suggesting low elemental trace abundance for the low outlier (DSRL8), whereas the sample high in ^{239}Pu (DSRL3) has a low ratio.

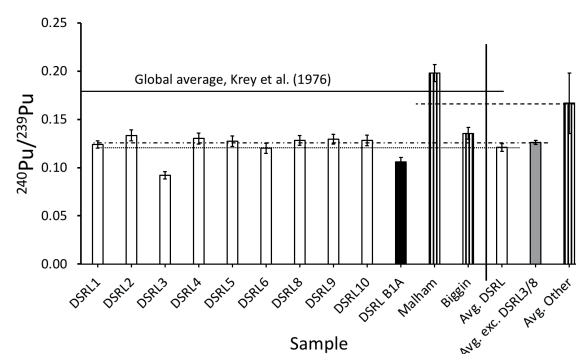


Fig. 2: $^{240}\text{Pu}/^{239}\text{Pu}$ ratio [1] for Dounreay samples (DSRL1-10) and controls (Malham/Biggin).

Consideration of the mass balance, the global average for $^{240}\text{Pu}/^{239}\text{Pu}$ [2] and assuming DSRL3 is party to an excess of the same local material derived from the site as for the other on-site samples, yields estimates for the local and global proportions of ^{239}Pu of $(34\pm1)\%$ and $(66\pm3)\%$, respectively. The local $^{240}\text{Pu}/^{239}\text{Pu}$ was estimated at (0.05 ± 0.04) , consistent with independent simulations [3].

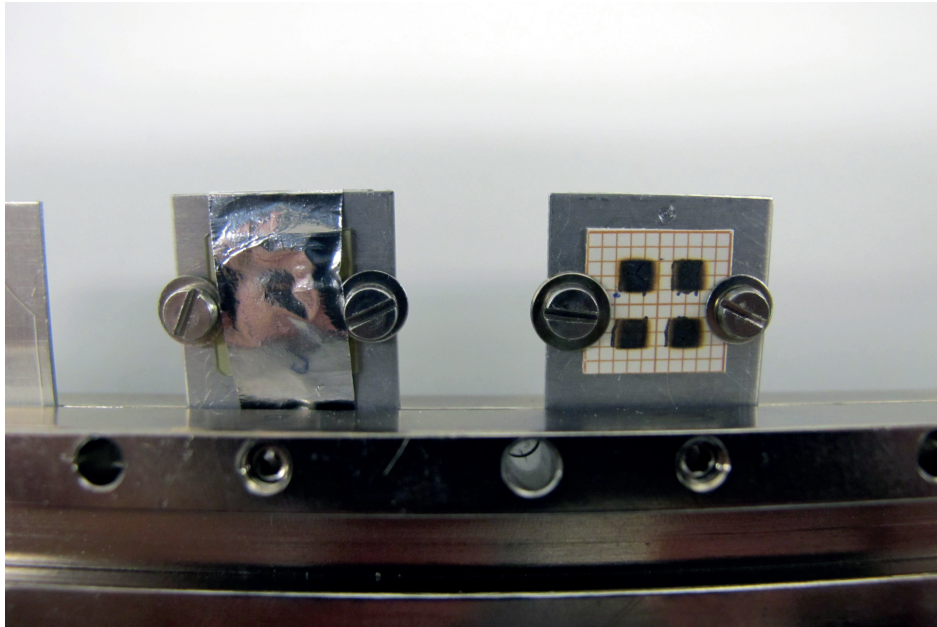
- [1] C. Tighe et al., Nature Comm., 2021 (accepted)
- [2] P.W. Krey et al., Report IAEA-SM-199/390 (1976) 671
- [2] S.S. Chirayath et al., Nucl. Eng. Des. 239 (2009) 1916

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³Lancaster Environment Centre, Lancaster Univ., UK

MATERIALS SCIENCES



Ion irradiation of zinc oxide sample. A template is produced on scale paper

Cluster effects in MeV-SIMS

Dual-polarity MeV-SIMS yield ratios

Ceramic thin films for solid state batteries

Lithium-ion transport in $\text{Li}_4\text{Ti}_5\text{O}_{12}$ epitaxial

films Electroless deposition of Ni-Fe alloys

Strain induced multiferroic properties

Thin film zirconium oxide-nitride multilayers

Stoichiometry of pld optoelectronic films

Barium titanate films for electro-optic devices

CLUSTER EFFECTS IN MeV-SIMS

Nonlinear yield effects in secondary ion emission from cluster impacts

K.-U. Miltenberger, M. Döbeli, C. Vockenhuber, H.-A. Synal

In conventional keV-SIMS the use of primary cluster ions was shown to enhance molecular secondary ion yields at least linearly with cluster size [1]. To also examine the effect of cluster ions on the secondary ion desorption and ionization in MeV-SIMS for the first time, measurements with a range of C_n and Cu_n cluster ions were performed on different sample materials. While different materials show specific behavior according to their breakup and ionization properties [2], the main effects can be observed in the data for C_n on Arginine.

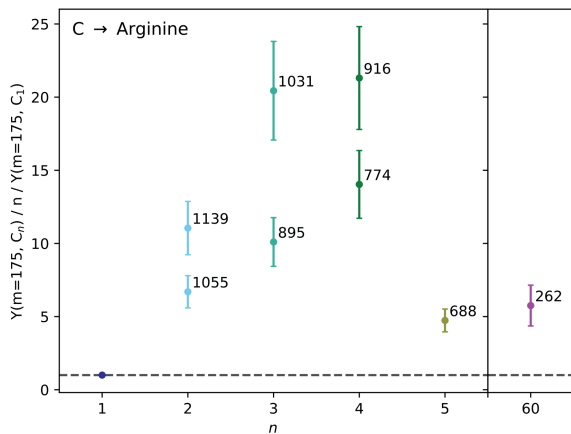


Fig. 1: Yield per cluster $Y(m = 175 \text{ u}, C_n)$ divided by n times the yield induced by a monoatomic ion $Y(m = 175 \text{ u}, C_1)$ at comparable electronic stopping power as a function of cluster size n . Individual measurement points are annotated with their respective $(dE/dx)_e / n$ in MeV/mm.

To better illustrate nonlinear cluster effects, the secondary molecular ion yields measured are normalized to the cluster size n of the primary ion and the secondary ion yield induced by a monoatomic ion at a comparable electronic stopping power [2]. In Fig. 1 the resulting yield ratios are plotted as a function of primary cluster size n . The data shows a significant cluster effect with a nonlinear enhancement of secondary ion yields with increasing cluster size (up to 25 times)

for small clusters ($n < 5$), while larger clusters induce a smaller but still significant yield enhancement.

In a second step, the induced fragmentation by the primary cluster ion impact can be studied by looking at yield ratios of a lower-mass fragment ion normalized to the molecular secondary ion. Fig. 2 shows the resulting fragmentation for the Arginine fragment ion of mass $m = 70 \text{ u}$.

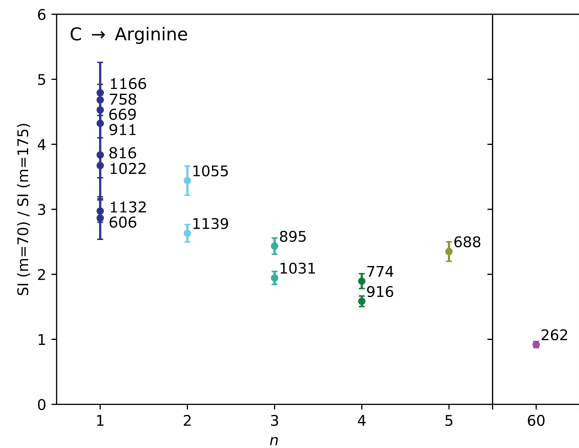


Fig. 2: Fragment ion mass peak $m = 70 \text{ u}$ normalized to the full molecular mass peak $m = 175 \text{ u}$ for primary cluster ion beams C_n as a function of cluster size n . Annotation is identical to Fig. 1.

The observed fragmentation clearly decreases with increasing cluster size, with fragmentation induced by C_{60} cluster ions being up to 5 times lower than for monoatomic C ions. Similarly to the cluster effect for secondary ion yield enhancement, this fragmentation reduction effect saturates for larger cluster ions.

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DUAL-POLARITY MeV-SIMS YIELD RATIOS

Positive/negative ion ratios dependent on primary cluster size

K.-U. Miltenberger, M. Döbeli, C. Vockenhuber, H.-A. Synal

After upgrading the MeV-SIMS setup CHIMP to a dual-polarity Time-of-Flight mass spectrometer system capable of simultaneous detection of secondary electrons as well as negative and positive secondary ions [1], a first series of measurements was conducted to study the ratios of negative and positive secondary ions.

Dual polarity MeV-SIMS spectra of arginine were measured using a range of primary cluster ions C_n of varying size but with an identical primary ion energy of 7 MeV. From the recorded spectra two corresponding pairs of negative and positive ions were selected: The peaks at mass $m = 43$ u (positive) and $m = 41$ u (negative) correspond to the negative and positive ions of the fragments C_2H_3N respectively CH_3N_2 . Meanwhile, the full molecular mass peaks of arginine appear at masses $m = 175$ u (positive, $(M+H)^+$) and $m = 173$ u (negative, $(M-H)^-$).

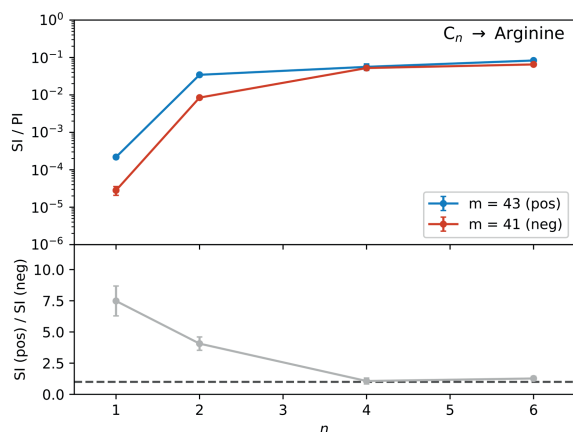


Fig. 1: Positive and negative yields per primary ion for secondary ions of masses $m = 43$ u and $m = 41$ u sputtered from arginine and their yield ratio as a function of primary C_n cluster size.

The yields of these secondary ions were determined and are shown in Fig. 1 (fragment) respectively Fig. 2 (full molecule) in the upper panel of the figure. In the lower panel the ratio

of the corresponding positive and negative ion yields is plotted.

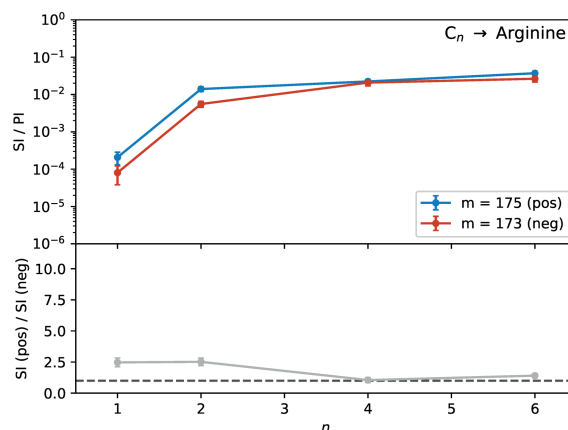


Fig. 2: Positive and negative yields per primary ion for secondary ions of masses $m = 175$ u and $m = 173$ u sputtered from arginine and their yield ratio as a function of primary C_n cluster size.

Despite their significant differences (molecular vs. fragment ion) both corresponding ion pair ratios show the same overall behaviour: For monoatomic C primary ions positive ion yields are significantly higher than the ones from their corresponding negative ion. However with increasing size of the primary C_n cluster ions, the ion yield ratio approaches values close to parity. That this effect is observed for both fragment and molecular secondary ions suggests a change in the ionization process of the desorbed secondary ions when primary cluster ions are used. This change occurs in parallel to the fragmentation reduction that was also observed with increasing primary cluster ions [2].

- [1] K.-U. Miltenberger et al. LIP Annual report (2019) 25
- [2] K.-U. Miltenberger et al. LIP Annual report (2020) 90

CERAMIC THIN FILMS FOR SOLID-STATE BATTERIES

Submicron $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ electrolyte films with high Li-ion conductivities

J. Sastre¹, A.N. Tiwari¹, Y.E. Romanyuk¹, M. Döbeli

High ionic conductivity and wide electrochemical stability of the lithium garnet $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ (LLZO) make it a promising solid electrolyte for all-solid-state lithium batteries with superior capacity and power densities. Contrary to common ceramic processing routes of bulk pellets, thin film solid electrolytes could enable large-area fabrication, and increase energy and power densities by reducing the bulkiness, weight and critically, the area-specific resistance of the electrolyte. Submicron thick LLZO films were fabricated by co-sputtering from Li_2O and LLZO ceramic targets with a subsequent post-annealing in oxygen atmosphere (Fig. 1). This approach allows to introduce Li excess into as-deposited films to compensate the lithium losses occurring during the deposition and crystallization steps. The final composition of the material was determined by RBS and Heavy Ion ERDA, the latter being especially suited to measure quantitative Li depth profiles.

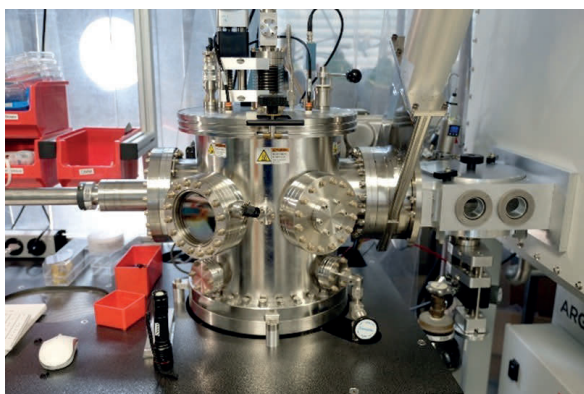


Fig. 1: Magnetron sputtering system employed to fabricate LLZO thin films.

The effect of Al and Ga dopants on film properties was investigated. The addition of dopants plays a role in the stabilization of the highly-conductive cubic phase, assists film densification and improves stability of the material in air.

Ionic conduction of the films was determined by in-plane impedance spectroscopy. The 500 nm thick Ga-doped LLZO films exhibit an ionic conductivity of $1.9 \times 10^{-4} \text{ S/cm}$ which outperforms previously reported thin film values by an order of magnitude (Fig. 2). This closes the performance gap to thick LLZO pellets sintered at high temperatures. This value also outperforms typical conductivities reported for LiPON, the electrolyte material that is commonly employed in the development of thin film batteries, by about two orders of magnitude.

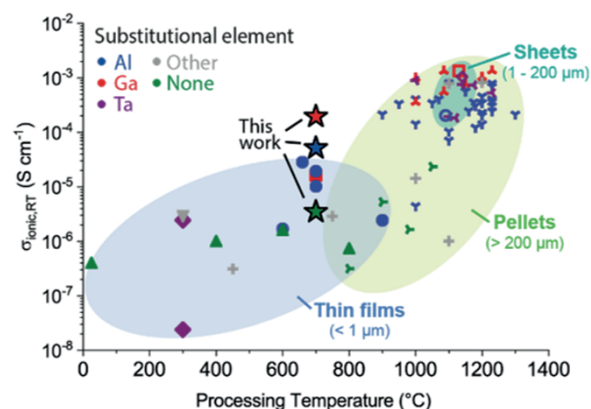


Fig. 2: Ionic conductivities achieved in this work compared with state-of-the-art values reported for LLZO pellets, sheets and thin films as a function of processing temperature.

The method developed in the project employs post-annealing temperatures of about 700°C, which is more than 400°C lower than the typical temperatures in the standard ceramic sintering approaches employed for the fabrication of LLZO pellets.

- [1] J. Sastre et al., Adv. Mater Interfaces 7 (2020) 2000425

¹Laboratory for Thin Films and Photovoltaics, Empa, Dübendorf

LITHIUM-ION TRANSPORT IN $\text{Li}_4\text{Ti}_5\text{O}_{12}$ THIN FILMS

Epitaxial lithium titanate as anode material for Li-ion batteries

F. Pagani¹, C. Battaglia¹, M. Döbeli

Lithium titanate ($\text{Li}_4\text{Ti}_5\text{O}_{12}$) is employed commercially as anode material for lithium-ion batteries in applications for which fast-charging capability and cycling stability are more important than energy density.

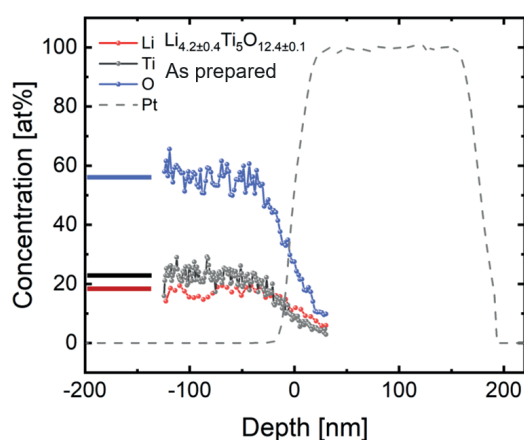


Fig. 1: Li, Ti, O, F, C (ERDA), and Pt (RBS) concentration profiles vs depth for the as-deposited epitaxial film. Red, grey, and blue horizontal reference lines represent the nominal stoichiometry for $\text{Li}_4\text{Ti}_5\text{O}_{12}$.

We previously demonstrated that epitaxial $\text{Li}_4\text{Ti}_5\text{O}_{12}$ films behave like an ideal ionic conductor well described by a parallel RC equivalent circuit, with room temperature ionic conductivity in the low range of 10^{-9} S/cm [1]. In this project, we investigate electrochemically-lithiated epitaxial single-crystal lithium titanate thin films grown by magnetron sputtering on epitaxial platinum current collectors. They serve as model system to elucidate Li transport behavior as a function of charge state. Structure and composition of $\text{Li}_4\text{Ti}_5\text{O}_{12}$ films are confirmed by out-of-plane and in-plane X-ray diffraction and elastic recoil detection analysis (Fig. 1). Electrochemical impedance spectroscopy was employed to determine Li-ion conductivity.

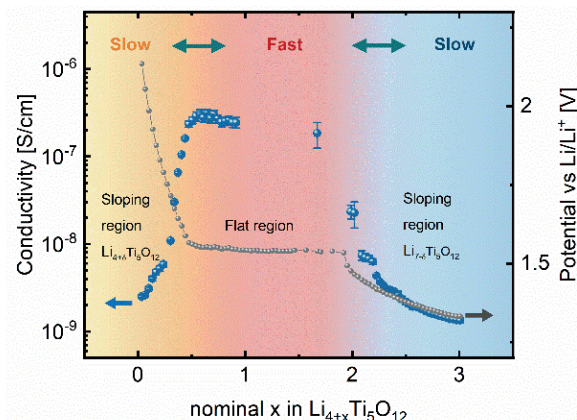


Fig. 2: Ionic conductivity of $\text{Li}_{4+x}\text{Ti}_5\text{O}_{12}$ as a function of charge state obtained by fitting of electrochemical impedance spectra.

Compared to lithium titanate particle electrodes or polycrystalline thin films, epitaxial electrodes enable the acquisition and precise fitting of high quality impedance spectroscopy data. This allows us to extract the lithium-ion conductivity as a function of charge state from impedance spectra over the entire technologically relevant range of electrochemical lithiation ($0 < x < 3$) [2]. We find and show for the first time that lithium-ion conductivity increases monotonously by more than two orders of magnitude from $2.6 \cdot 10^{-9}$ S/cm for $\text{Li}_4\text{Ti}_5\text{O}_{12}$ to above $3 \cdot 10^{-7}$ S/cm between $\text{Li}_{4.5}\text{Ti}_5\text{O}_{12}$ and $\text{Li}_6\text{Ti}_5\text{O}_{12}$ and drops again to $1.3 \cdot 10^{-9}$ S/cm for $\text{Li}_7\text{Ti}_5\text{O}_{12}$ (Fig. 2).

- [1] F. Pagani et al., ACS Appl. Mater. Interf. (2018) 44494
- [2] F. Pagani et al. Batteries & Supercaps 2020, DOI: 10.1002/batt.202000159

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ELECTROLESS DEPOSITION OF Ni-Fe ALLOYS

Fabrication of complex structures for 3D nanomagnetism

P. Pip^{1,2,3}, C. Donnelly⁴, M. Döbeli, C. Gunderson¹, L.J. Heyderman^{2,3}, L. Philippe¹

There is a growing interest in three-dimensional (3D) nanomagnetism due to a number of predictions for exciting new physics and advanced applications. Curvature in magnetic thin films has been predicted to lead to curvature-induced anisotropy, magnetochirality and domain wall automotive effects. Even the basic components of three-dimensional geometries such as cylindrical nanowires and nanotubes are expected to lead to equally fascinating consequences which has been confirmed by first experimental realisations involving cylindrical magnetic nanowires.

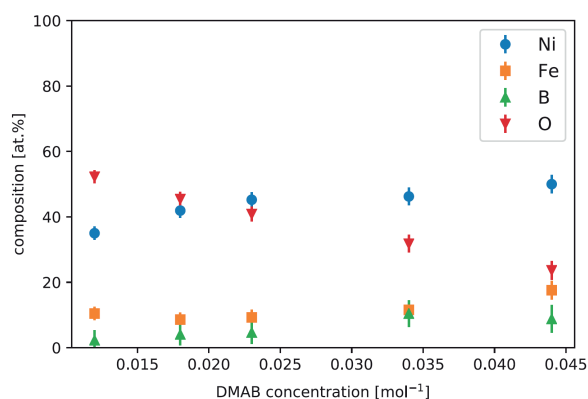


Fig. 1: Composition of the electroless deposited Ni-Fe(B) films as a function of DMAB concentration, determined with a combination of RBS, PIXE, and ERDA measurements.

Finding an appropriate fabrication technique for 3D magnetic nanostructures is crucial. In this project we follow the route of electroless deposition of NiFe(B) magnetic films on 3D scaffolds prefabricated by two-photon laser lithography. For determination of the thickness, composition, and magnetic properties of the material flat Si substrates were coated by NiFe(B) thin films with different concentrations of dimethylamine borane (DMAB) reducing agent ranging from 0.012 mol/l to 0.044 mol/l at a temperature of 60 °C [1]. The material

composition as a function of DMAB concentration was analysed by RBS, PIXE, and Heavy Ion ERDA measurements (Fig. 1). Film thickness and saturation magnetization was measured by X-ray reflectometry and superconductive quantum interference device vibrating sample magnetometry (SQUID-VSM). The deposited films exhibit soft-ferromagnetic behaviour similar to permalloy. Finally, the fabrication of 3D magnetic microstructures was demonstrated by applying the optimized deposition technique on non-conducting polymer architectures of different shapes, as shown in Fig. 2. A smooth homogeneous deposition over the surface of the 3D structures can be observed, confirming the success of our approach.

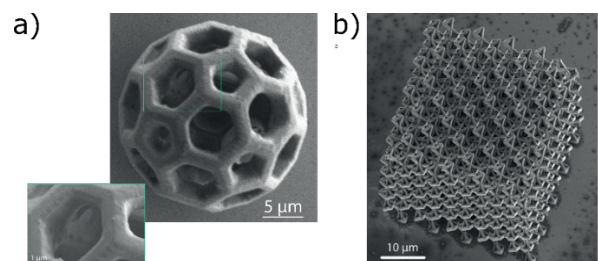


Fig. 2: 3D polymer nanostructures with magnetic NiFe(B) coating: a) buckyball structure with close-up of the surface, b) artificial pyrochlore lattice.

[1] P. Pip et al., Small (2020) 2004099

¹Mechanics of Materials and Nanostructures, Empa, Dübendorf

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³Multiscale Materials Experiments, PSI, Villigen

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STRAIN INDUCED MULTIFERROIC PROPERTIES

Optimization of DyFeO₃ magneto-electric thin films

B. Biswas¹, C.W. Schneider¹, T. Lippert^{1,2}, M. Döbeli

The search for materials being simultaneously ferroelectric and ferromagnetic, so-called multi-ferroic (MF) materials, at room temperature gained interest about a decade ago. These materials would be beneficial for potential applications in energy efficient electronic devices [1]. Orthorhombic bulk rare-earth ferrite (RFeO₃) shows strong magneto-electric coupling below 10 K. An elegant way to change and modify material properties in RFeO₃ is growth-induced strain when growing these materials as thin films [2,3]. Theoretical calculations for bulk RFeO₃ have shown that these materials can have a large electric polarization of up to 90 $\mu\text{C}/\text{cm}^2$ at room temperature under large lattice misfit strain. The aim of this project is to grow DyFeO₃ thin films using Pulsed Laser Deposition (PLD) to modify its bulk property by introducing lattice strain in the as-grown film.

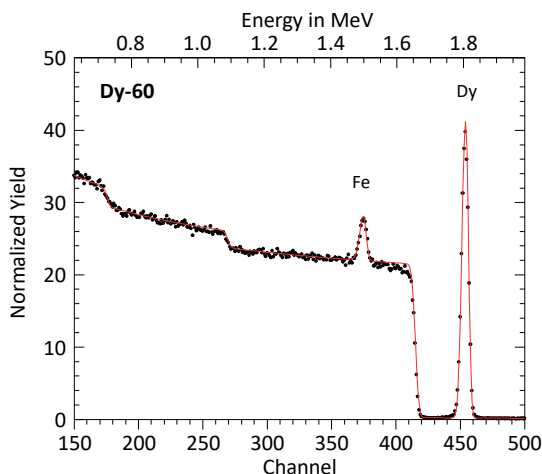


Fig. 1: 2 MeV ⁴He RBS spectrum of a DyFeO₃ film on YAlO₃ with stoichiometric composition.

To engineer these MF properties, it is crucial to grow thin films with the correct composition. Although PLD is known to transfer ablated material congruently, an optimization of the growth condition is important to achieve thin

film growth with the proper composition. The combination of RBS (Fig. 1) and ERDA allows to accurately determine the stoichiometric ratio of Dy:Fe:O in our thin films as well as possible contaminations. Deposition parameters like background gas pressure and target-substrate distance play a crucial role to obtain the proper R/Fe ratio in orthoferrite films. An example of magnetic properties for films with different Dy:Fe ratios is shown in Fig. 2. Only for stoichiometric films a magnetic Dy ordering peak around 4.7 K is consistently observed while the spin reorientation temperature (SRT) seems unaffected by the differences in composition.

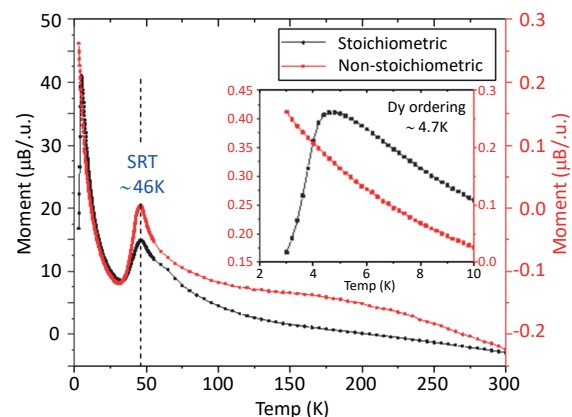


Fig. 2: Zero Field Cooled (ZFC) moment vs magnetic field for two different films. The stoichiometric (black) and Dy-deficient (red) film have the same spin reorientation transition temperature of ~ 46 K but only the stoichiometric film shows Dy ordering at 4.7 K.

- [1] G. Shirane et al., J. Phys. Soc. Japan 14 (1959) 1352
- [2] S. Ishiwata et al., Phys. Rev. B 81 (2010) 100411
- [3] S. Kenta, ETH Thesis Nr. 23787 (2016)

¹ Multiscale Materials Experiments, PSI, Villigen

² Inorganic Chemistry, ETH Zurich

THIN FILM ZIRCONIUM OXIDE-NITRIDE MULTILAYERS

A refractory, chemically-modulated hyperbolic metamaterial

J.L. Ocana-Pujo¹, H. Galinski¹, M. Döbeli, R. Spolenak¹

Hyperbolic Metamaterials (HMMs) are structured optical nanomaterials that exhibit optical topological transitions (OTTs) due to their intrinsic anisotropy [1]. The most studied HMMs are obtained by combining layers of two different materials fabricated by physical vapor deposition techniques [2]. Common material combinations with hyperbolic behavior include metals such as silver and gold, which are scarce and present relatively low melting temperatures or semiconductors and dielectrics which need to be synthesized by slow vapor deposition techniques [3]. Trying to overcome these limitations, we propose and fabricate a refractory, chemically modulated hyperbolic metamaterial (CM-HMM) based on earth-abundant Zr.

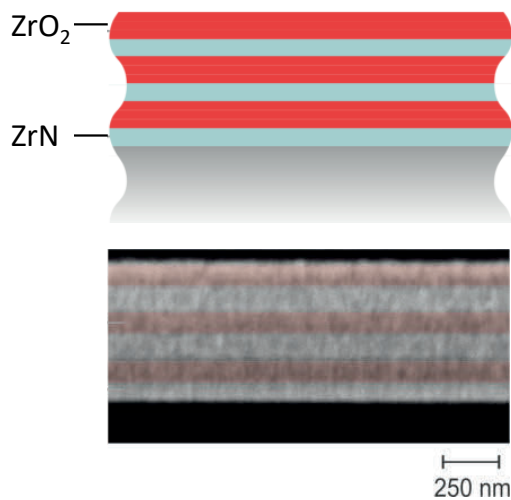


Fig. 1: Schematic representation (top) and electron micrograph (bottom) of a ZrO_2/ZrN multilayer system.

Thin film ZrN/ZrO_2 multilayer systems (Fig. 1) were deposited by solely controlling the flux of nitrogen and oxygen gas into the chamber. The use of a single target and the deposition rates in the order of tens of nanometers per minute renders the fabrication process both fast and scalable [3]. RBS confirmed the presence of a

multilayer structure with limited intermixing, with phases with characteristic densities. ERDA was used to study how the nitrogen and oxygen content is modulated through the multilayer (Fig. 2). The results confirm that there is still a sizable amount of oxygen in the nitridic layers. This is consistent with the observed change in the optical properties of the multilayer system upon annealing in a reducing atmosphere, and hence paves the way to further tune the optical response of the system.

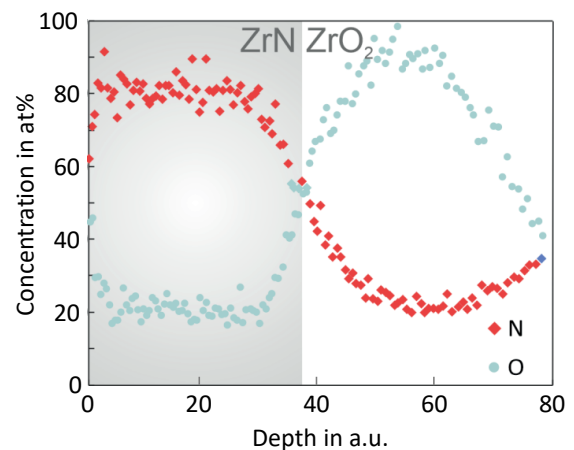


Fig. 2: ERDA concentration depth profile of the first pair of nitride/oxide films of a ZrN/ZrO_2 multilayer system.

- [1] H.N.S. Krishnamoorthy et al., Science 336 (2012) 205
- [2] A.N. Poddubny et al., Nature Photonics 7 (2013) 948
- [3] M. Ohring, Materials Science of Thin Films, Elsevier 2002

¹Nanometallurgy, ETH Zurich

STOICHIOMETRY OF PLD OPTOELECTRONIC FILMS

Transparent conductive oxides and halide perovskites for solar cells

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Sputtered transparent conducting oxides (TCOs) are widely accepted transparent electrodes for several types of high-efficiency solar cells. However, the high kinetic energies of the arriving species during sputter deposition may damage sensitive functional layers beneath. Conversely, pulsed laser deposition (PLD) is operated at higher deposition pressures promoting thermalization of particles. This reduces the kinetic energy of ablated species. However, difference in growth conditions may lead to the distinct preferential crystal orientation of IZO thin films [1] as seen in Fig. 1.

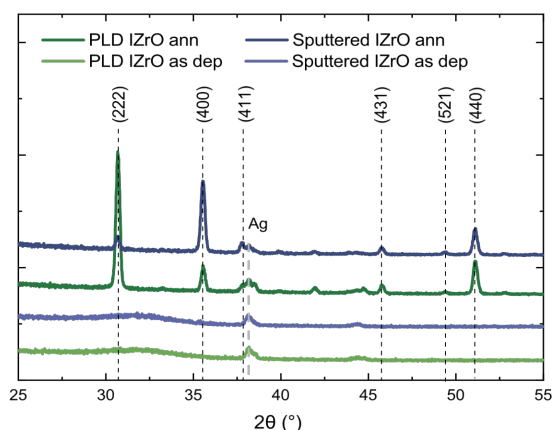


Fig. 1: GI-XRD scan of the as-deposited and annealed IZO films grown by PLD and RF-sputtering.

These differences might be related to the stoichiometry of the films. Crystallization of In_2O_3 in the presence and absence of water vapor was demonstrated to depend on the oxygen content of the film [2]. RBS and ERDA were employed to determine the hydrogen and oxygen composition of the films and find possible correlations between stoichiometry and microstructure.

On the topic of solar cell absorbers, halide perovskites have gained increased importance in

the PV and optoelectronic fields. Currently we are exploring the potential of PLD as a single source vacuum deposition of halide perovskites. We have demonstrated [3] the fabrication of CsSnI_3 films by PLD with optimal optoelectronic properties (band gap of 1.3 eV and sharp absorption edge). RBS and PIXE measurements were used to determine the composition of the films. Complementing STEM-EDX cross-section measurements (Fig.2), confirmed stoichiometric transfer of the elements from the solid Cs-Sn-I target to the CsSnI_3 thin film and uniform distribution of the elements across the thickness of the films.

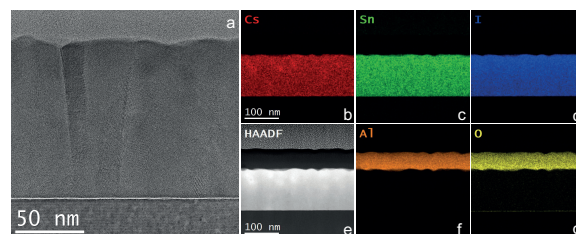


Fig. 2: Cross-section EDX-STEM of the PLD-grown CsSnI_3 films. Figure from reference [3].

- [1] Y. Smirnov et al., Adv. Mater. Technol. (2020) in press
- [2] M. Wang et al., Thin Solid Films 518 (2010) 2992
- [3] V. Kiyek et al., Adv. Mater. Interf. 7 (2020) 11

¹Univ. of Twente, MESA+ Institute, The Netherlands

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BARIUM TITANATE FILMS FOR ELECTRO-OPTIC DEVICES

Rapid film growth by high-vacuum chemical vapor deposition

W. Szmyt^{1,2}, J. Geler-Kremer^{1,3}, P. Hoffmann^{1,2}

This project is focused on utilization of advanced inorganic crystalline functional oxide ferroelectric materials to facilitate the advancements in electro-optic devices, data storage and rapid signal processing. A material showing great promise in this context is barium titanate (BaTiO_3 , BTO), as it exhibits ferroelectric properties of extraordinary magnitude. Basing novel devices on this material is expected to enable high signal processing speed at low power consumption.

We are carrying out optimization of film growth by high-vacuum chemical vapor deposition (HV-CVD) for the desired elemental composition of the films (stoichiometric BaTiO_3), crystallite size, crystal orientation, growth rates, film porosity, surface topography, and study the impact of film properties on their electro-optic performance. The HV-CVD process allows for film synthesis on a wafer scale (Fig. 1) at growth rates surpassing molecular beam epitaxy, typically employed in this application. Moreover, HV-CVD requires lower temperatures, enabling a more streamlined and cost-effective integration of tailored thickness adapted films.



Fig. 1: BTO film grown on a Si wafer by HV-CVD.

Film composition is one of the critical factors for the electro-optic performance. Therefore, among the characterization techniques employed in the film analysis, we use ERDA and RBS, which give precise information about the elemental composition of the samples studied. Furthermore, film crystallinity is studied by X-ray diffraction, film morphology by scanning electron microscopy (SEM, see: Fig. 2) and atomic force microscopy. The optimized films will be utilized to fabricate electro-optical microdevices.

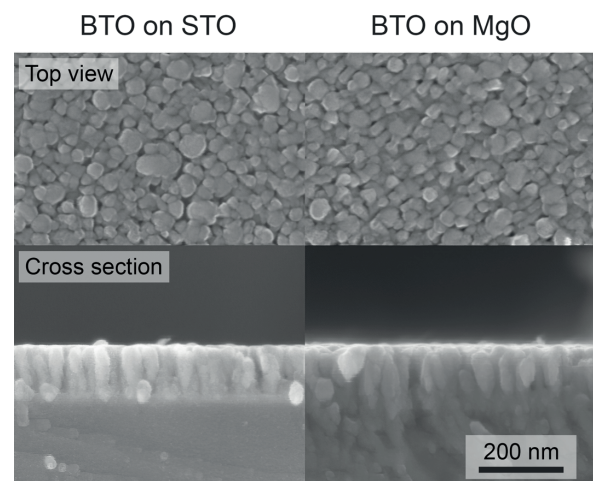


Fig. 2: Top-view and cross-section SEM images showing film morphology of BTO films epitaxially grown on crystalline STO and MgO substrates.

¹Advanced Materials Processing, Empa, Thun

²Photonic Materials and Characterization, EPFL, Lausanne

³IBM Research-Zurich, Rüschlikon

EDUCATION AND OUTREACH



Examples of 2020 on-line meetings and conferences

LIP under the COVID-19 pandemic regime

The LIP-AMS seminar

Gender diversity and equality in the geosciences

Is the future a hybrid?

Accelerator lab practice from a distance

Education of physics laboratory assistants

RADIATE Transnational Access activities

Obituary of Georges Bonani

LIP UNDER THE COVID-19 PANDEMIC REGIME

Impressions of a special year

LIP staff members

Like any other ETH research group, LIP operation in 2020 was heavily impacted by the restrictions and measures taken by the ETH school board to limit the consequences of the COVID-19 crisis. The effective lockdown from March ceased to a large extent the experimental work and the total lab crew was sent to home office. An emergency operation plan was prepared and approved by the ETH school board which allowed us to run minimum maintenance procedures in order to prevent damage to LIP infrastructure and to ensure that a normal operation mode can be launched as soon as the situation stabilizes.



Fig. 1: Our sample preparation laboratories were lonely and deserted during the lockdown period. Where there is usually bustling activity, only the whirring of the vacuum pumps could be heard.

The strange working environment and the lack of social exchange was certainly the biggest challenge under these circumstances. So, we tried to maintain a minimum of social contacts in online meetings and virtual coffee rounds.

However, the high degree of automation of the LIP accelerator facilities then enabled us to establish a minimal measurement operation so that we were able to meet the requirements of our internal research program, in particular to projects related to our PhD and MSc students, as

well as the needs of our scientific collaborations and thus continue the essential projects. During the summer months, with the relaxation of the COVID-19 measures, the processing of sample materials could then be resumed in compliance with the specified presence restrictions. Thanks to the high sense of responsibility of the entire LIP staff, we have been able to comply with the hygiene and protection measures and have not had to report any COVID-19 infections in the laboratory in 2020.



Fig. 2: The abandoned LIP experimental hall during the lockdown in April.

As a result of the great commitment of all the people involved, we were then able to process the accumulated samples quickly and thus step by step reduce the backlog. By having two multi-nuclides AMS instruments available for routine operation, we mainly used the Tandy instrument for ^{129}I and actinides analyses. Measurements of ^{10}Be and ^{26}Al samples were made at the Milea system where we improved overall uncertainties significantly due to the longer measurement time of the individual samples in combination with the extraordinary stability of the analytic process at this instrument. In the end, we were able to fulfil the analytic demand of our internal research as well as for projects related to our collaboration partners at the same level of non-COVID-19 years.

THE LIP-AMS SEMINAR

The new hybrid format will most probably survive COVID-19

M. Christl, H.-A. Synal

The year 2020 was very special also or particularly regarding teaching at ETH Zurich and our Department of Physics (D-PHYS). In February 2020 Spring term started regularly but COVID-19 case numbers were steeply rising and Switzerland went into its first lockdown in March. D-PHYS decided to move all essential lectures to a full video mode with effect March 16, 2020 (Fig 1).

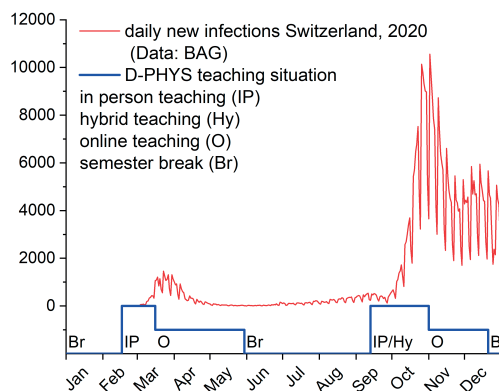


Fig. 1: Daily COVID-19 new infections in Switzerland (red) [1] and teaching situation at D-PHYS, ETH Zurich (blue).

After the summer break, the COVID-19 situation seemed under control and the Fall term 2020 started almost normal: Lecturers and students were partly present in the lecture halls but with many safety measures in effect. Larger lectures were broadcasted and recorded in parallel to allow the students to recap the lesson or to follow it entirely from home. This new (hybrid) form of teaching was a challenge for all of us but it also offered new opportunities. Due to the drastic increase of cases in October ETH had to go back to online teaching again (Fig. 1).

Also our LIP AMS seminar went through all phases of in person, online, and hybrid teaching (Fig 2). After a normal start in February, we followed D-PHYS recommendations to suspend

all non-mandatory research seminars and resumed only in May with an online only format.

Equipped with two headsets, two laptops and an iPhone we were able to offer our seminar in a hybrid format from Fall semester on. This turned out to be very successful because in addition to the allowed 18 in person attendees we could attract many online participants from in and outside Switzerland including groups from Sweden and Czech Republic who regularly joined our seminar. The success of the hybrid seminar encourages us to continue this format beyond the COVID-19 phase.

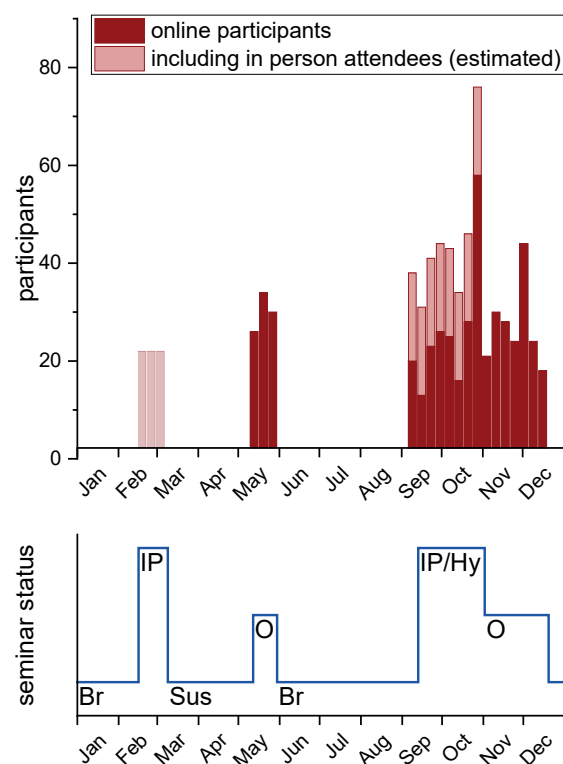


Fig. 2: Seminar participants over the various teaching phases (Sus: suspended).

[1] BAG, Schweiz, www.bag.admin.ch

GENDER DIVERSITY AND EQUALITY IN THE GEOSCIENCES

An analysis of the Swiss Geoscience Meetings from 2003 to 2019

F. Piccoli¹, G. Guidobaldi

Data availability is essential for establishing a constant monitoring of the gender diversity and equality evolution in the academic environment. In our study [1], commissioned by the geosciences platform of SCNAT, with the support of the University of Berne, ETH Zurich and the GEODES committee, we focused on the evolution of gender distribution in the geosciences by looking at the participation data of the Swiss Geoscience Meeting (SGM), held every year since 2003. Participants were considered in terms of gender and academic stage (i.e., student/scientist). Gender distribution was evaluated among participants, poster/talk contributions (i.e., gender of the first author), involvement as chair/convenor and in the program/organizing committees. Vertical and, when possible, horizontal gender segregation were also evaluated.

has steadily increased, reaching a peak of 37% in 2019. Nevertheless, a relevant fraction of female participants is represented by students, while female scientists are often less than 25% (Fig. 1), suggesting a significant drop out of female academics after the PhD. Hence, particular attention has to be focused on the early stages of women academic careers. In addition, we found that men outnumber women in decision making positions, such as committee members, and as invited speaker for the plenary sessions, where female proportion is in most cases significantly lower than among SGM participants. Overcoming gender imbalance in such leading positions is crucial to offer more diverse role models to undergraduate students and junior scientists.

Female representation among Earth Sciences students in Switzerland has significantly increased over the last 17 years (+10%), reaching a close to 50-50 gender balance for BSc and MSc students and a good balance (43% females, 57% males) for PhD students. Nevertheless, horizontal gender segregation still persists in the geosciences. A strong variability was also observed in prizes awarded at the SGM, suggesting that, in some cases, women are less likely to be nominated for awards.

Overall, the analysis of the 17 years-dataset of the SGM revealed a positive trend towards a more inclusive environment in the geosciences. A significant step forward is expected in the next years, after the introduction by the SCNAT of new guidelines for the SGM to promote gender diversity, equity and inclusion.

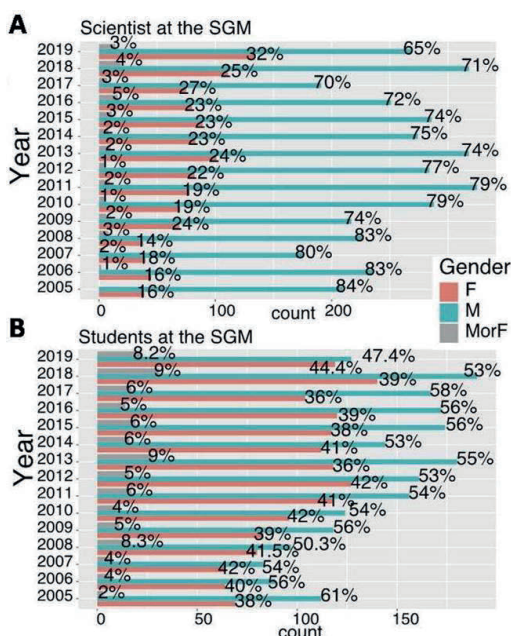


Fig. 1: Scientist (A) and student (B) populations at the SGM since 2005, classified by gender.

Over the last 17 years, participation at the SGM has almost doubled and the presence of women

[1] F. Piccoli and G. Guidobaldi, Swiss J. Geosci. 114 (2021) 1

¹Univ. of Bern

IS THE FUTURE A HYBRID?

Pros and cons of online conferences—one year without travel

I. Hajdas

Travel to conferences, workshops, summer schools and field trips became an essential part of a 21st-century researcher's life. Recent climate policies and regulations imposed by the universities marked the shift to more environment friendly travel by train and discussions about reduced travel. However, non of the measures envisaged scientific travel being 'frozen' entirely as it happened in February and March 2020. The outbreak of Covid-19 pandemic forced authorities to close the borders and suspend flights. What was going to happen with all the conferences planned for 2020?: At least three meetings (REI-III Radiocarbon in Environment, Gliwice; AMS-15 Sydney; ¹⁴C and Diet, Oxford) important for the radiocarbon/AMS community were effected and postponed by one year to 2021 as the severity of the situation unfolded.

Some organizers have chosen to held the planned conferences online using the available online platforms. Soon the Zoom or Teams meetings and lectures became part of home office activities. One of the first large meetings which was in full preparation in February 2020 was the General Assembly of the European Geosciences Union (EGU). As the virus struck, the program encompassing over 18 thousand abstracts was being finalized. Only couple of months separated us from the planned conference. Instead of canceling it the Programme Committee and the Copernicus office undertook a huge task of transforming this big conference into #shareEGU.

Instead of traveling to Vienna in the first week of May (4-8th) participants from 134 countries sat at their PCs and laptops at home and were taking part in chat sessions and discussions with colleagues around the world. During five days over 22 thousand registered users wrote more than 200 thousand chats. It was an enormous

effort on behalf of the organization and participants. In a online event on Friday evening, 400 people summarized the week as a tremendous experience that was open and free to all scientists worldwide. Many agreed and suggested that a hybrid of online and in-person conference should be implement in the future annual EGU meetings. At the start of 2021 we already know that, this year, the only possible version is an online #vEGU21 meeting (Fig. 1). The experience of the 2020 online conferences have shown technical potential for sharing science without travel. It increased inclusion of scientists with little funding for travel. However it remains to be seen how many participants the upcoming #vEGU21 will gather and if the 2022 will allow for a hybrid.

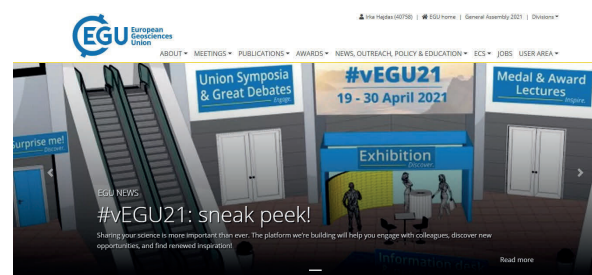


Fig. 1: The virtual hall at the #vEGU21 resembles the hall of the Austria Center Vienna (ACV) in Vienna, Austria.

Hopefully, some conferences planned for fall of 2021 might be first to test hybrid organizations. Nevertheless, the new gate for reducing travel is unlocked and the technical tools improving quality of such meetings are developed (Fig. 1).

ACCELERATOR LAB PRACTICE FROM A DISTANCE

Remote teaching of “hands-on” IBA student courses

D. Bleiner¹, M. Döbeli, K.-U. Miltenberger, C. Vockenhuber

For almost 20 years LIP has offered practical laboratory courses on Ion Beam Analysis techniques extending over one or two days. This has been organized for ETH students, for master courses of the University of Berne, and as workshops for international participant groups. Courses have always been divided in three parts: introductory lessons, hands-on experiments at the accelerator lab, and data analysis and interpretation exercises.

In a first, fast reaction to the COVID-19 campus access restrictions a remote course for ETH students was held in April 2020 by simply replacing the hands-on part by photographic material of lab equipment and canned spectra substituting actual data taking. In November 2020 a more elaborate scheme was applied for a practical exercise with students attending a lecture course on chemical microanalysis at the University of Zurich and Empa Dübendorf.



Fig. 1: Screenshot of the Zoom webinar showing the live start-up of the RBS/PIXE measurement.

A lab tour, sample preparation, set-up of the experiment and actual measurements were performed live with three LIP staff members on-site acting as host, cameraman and operator. Using the Zoom video communication software, the meeting screen (Fig. 1) was switched between the video camera used to show the tour

and experimental preparations and remote desktops of the accelerator control and data acquisition computers (Fig. 2).

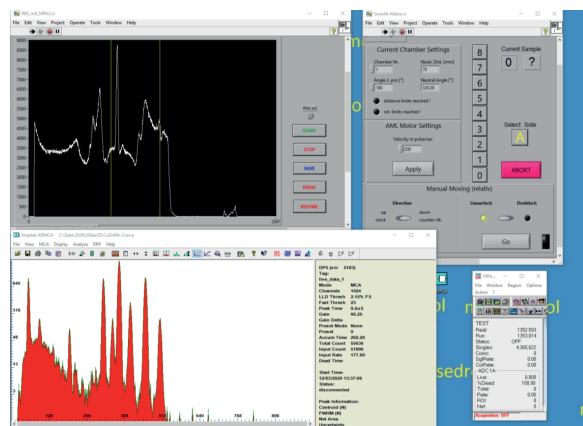


Fig. 2: Remote desktop access to the data acquisition system.

With this approach, participants were always able to ask questions to the host and lecturer and direct the camera to show details they were interested in. Equally, the lecturer could interactively discuss and interpret the live data taking. Student reports handed in after an additional question and answer session related to data analysis were of very good quality and did not significantly differ from results obtained previously from in-person participants.

VPN connections to the ETH network would easily allow students to take over experimental equipment controls themselves. Due to safety concerns this has not yet been done. However, such a procedure also enables external users to take part in sample preparation and perform their own IBA measurements with only one LIP member on-site.

¹Advanced Analytical Technologies, Empa, Dübendorf

EDUCATION OF PHYSICS LABORATORY ASSISTANTS

Towards a new graphitization line for ^{14}C analysis

L. Wacker, P. Gautschi, S. Zimmermann, S. Marty, D. Sonderegger

The Laboratory of Ion Beam Physics (LIP) educates apprentices of physics laboratory assistants. The students learn in our group how to engineer scientific equipment.

In 2020 Severin Zimmermann finished successfully his education. In his final practical exam, Severin was designing and engineering a prototype sample combustion system for a new graphitization line.

The new sample combustions system (SCS) should allow for faster and more efficient sample combustion with minimal risk of sample contamination. It should also better fit to the graphitization equipment and be more cost efficient compared to an elemental analyser that is presently used as a combustion system.



Fig. 1: The sample combustion system constructed by Severin within 120 working hours.

The result of Severin's practical exam, that he conducted to a large extent during the COVID-19 lockdown in spring, is shown in Fig. 1. The system is significantly more compact than the so far used

elemental analysers from Elementar, that are already the most compact systems of its kind.

The system is equipped with two furnaces, one for combustion running at temperatures up to 1000°C and one for reduction (removal of excess of oxygen) running typically at 550°C.

The SCS still needs to be equipped with a gas handling system (supply of He carrier gas and oxygen for combustion) and an autosampler. The system will next be completed by Damian Sonderegger. In his final practical exam he will build an autosampler for the sample introduction.

Apart from the sample combustion system, Severin and Damian also designed and engineered a new graphitization line, called NewAge, that will convert the CO_2 after sample combustion to graphite. Their work was supported by Samuel Marty, who worked as a student apprentice on a web interface to control the NewAge. The NewAge will be a more compact and with its ten reactors extended system compared to the presently used AGE3 graphitisation lines. The NewAge system is nearly finished and will be tested soon.

RADIATE TRANSNATIONAL ACCESS ACTIVITIES

Providing 1500 hours of beam time to external users

C. Vockenhuber, H.-A. Synal

RADIATE (Research And Development with Ion Beams – Advancing Technology in Europe) is a project of 18 European partners which received a 9.9 M€ funding from the European Union's Horizon 2020 research and innovation programme and runs for 4 years from 2019 till 2022 (www.ionbeamcenters.eu/radiate). The goal is to advance ion beam technology and strengthen the cooperation between European ion beam infrastructures; additionally, it provides easy, flexible and efficient access for experiments or measurements at participating facilities via Transnational Access (TA) after a successful external proposal review process.

Within the 4 years of RADIATE LIP offers 1500 hours of TA for experiments or measurements using our infrastructure. After the first half we received 18 individual proposals with proposed 1323 TA hours of which 1140 hours were granted. As of end of 2020 a majority of 11 proposals with 652 hours could be completed (Fig. 1).

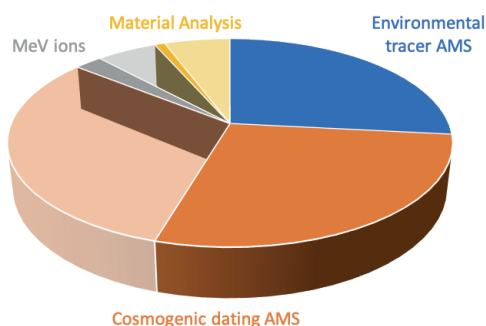


Fig. 1: Distribution of the 1140 granted TA hours at LIP according to the RADIATE TA categories in the period 2019-2020. Filled sections indicate already completed projects.

The submitted proposals cover a large range of our activities: material analysis with RBS and NRA, implantation and irradiation with swift heavy ions (MeV ions), environmental tracer

AMS and cosmogenic nuclide dating AMS. Routine radiocarbon analysis is excluded within the programme, because there are already established support structures, however we provide access to our unique possibility to extract and measure in-situ ^{14}C for cosmogenic nuclide dating to complement the measurements of the classical cosmogenic radionuclides.

The completed TA proposals utilized all of our accelerator facilities: we used the **6 MV EN Tandem** for irradiations for the development of new polycarbonate foil materials for the next generation of polycarbonate track-etched membranes and various ^{36}Cl AMS analyses: water samples from the Negev Desert of Israel, clast samples from fluvial terraces of the Tropoja basin in northern Albania, ice core samples from NGRIP in Greenland for search of solar storms in Early and Mid-Holocene; at the **1.7 MV Tandetron** we performed RBS analyses of materials for hybrid perovskite solar cells and irradiation of germanium waveguide-based photodetectors with various MeV ions; the **500 kV Tandy** was used for ^{236}U measurements in samples from the South China Sea for investigation of ocean circulation; at the **300 kV MILEA** facility we performed ^{10}Be AMS measurements of NGRIP ice core samples and systematic tests of uranium-fluoride matrices to improve ^{236}U at small AMS; the in-situ ^{14}C extraction line and the **200 kV MICADAS** were used to investigate high-alpine rockfall at the Aiguille du Midi, Mont Blanc massif in France, investigate the catchment-wide landslide activity at the South Island of New Zealand, using sediments to understand the deep history of the Greenland Ice Sheet and for studies of ice bed properties and erosion rates in Inglefield Land, north Greenland.

Some of the completed TA proposals are reported in this year's annual report and marked with an asterisk in the title.

OBITUARY FOR GEORGES BONANI

In memory of his outstanding achievements for AMS

H.-A. Synal, M. Suter

On 26 October 2020, Georges Bonani passed away after a long and serious illness. He was one of the most influential persons who contributed outstanding achievements to the ETHZ AMS program and in particular to the development of radiocarbon dating by AMS technology. Deeply committed to ETHZ and the Laboratory of Ion Beam Physics, he was a major force in shaping our laboratory into one of the world's leading centers of radiocarbon dating.



Fig. 1: Dr. Georges Bonani, April 3rd, 1946*–October 26, 2020†.

Born in Brig/VS, he finished school in 1967 and subsequently started his physics studies at ETH in Zurich. Already in the course of his diploma thesis, which he carried out under the supervision of Dr. R. Balzer his special feeling for physical concepts and his pronounced technical talent became apparent.

He joined Prof. W. Wölfli's group and developed one of the first proton microprobes in his

doctoral thesis which he applied for PIXE analyses of trace elements in environmental samples. In 1977, when AMS technology was discovered [1,2], W. Wölfli, M. Suter and G. Bonani, started the Zurich AMS project and converted the Zurich 6 MV EN Tandem accelerator into a versatile dedicated AMS spectrometer. Not least the extraordinary skills of Georges Bonani contributed to the fact that this AMS system was able to deliver the most accurate ^{14}C data at the time [3], and was commonly referred to as the Swiss AMS clock. He was deeply involved in many prestigious projects such as the dating of the Shroud of Turin [4]. Despite his remarkable contributions to all his projects, he always remained modestly in the background.



Fig. 2: Georges Bonani's hands, cutting the seal cord fibres of the "Goldene Handfeste" of the city of Berne.

With his determination, untiring commitment, reliability, and wealth of ideas, he was a role model for us and many others. We are missing him.

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Environmental Research Letters **15** (2020) 074012.

O. Steinemann, S. Ivy-Ochs, S. Grazioli, M. Luetscher, U.H. Fischer, C. Vockenhuber, H.A. Synal

Quantifying glacial erosion on a limestone bed and the relevance for landscape development in the Alps

Earth Surface Processes Landforms **45** (2020) 1401 - 1417

O. Steinemann, J.M. Reitner, S. Ivy-Ochs, M. Christl, H.-A. Synal

Tracking rockglacier evolution in the Eastern Alps from the Lateglacial to the early Holocene

Quaternary Science Reviews **241** (2020) 106424

S. Sun, V.D. Meyer, A.M. Dolman, M. Winterfeld, J. Hefter, W. Dumann, C. McIntyre, D.B. Montluçon, N. Haghipour, L. Wacker, T. Gentz, T. Van der Voort, T.I. Eglinton, G. Mollenhauer

¹⁴C blank assessment in small-scale compound-specific radiocarbon analysis of lipid biomarkers and lignin phenols

Radiocarbon **62** (2020) 207 - 218

J. Syvitski, C.N. Waters, J. Day, J.D. Milliman, C. Summerhayes, W. Steffen, J. Zalasiewicz, A. Cearreta, A. Gałuszka, I. Hajdas, M.J. Head, R. Leinfelder, J.R. McNeill, C. Poirier, N.L. Rose, W. Shotyk, M. Wagreich, M. Williams

Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch

Communications earth & environment **1** (2020) 32

G. Tirelli, S. Lugli, A. Galli, I. Hajdas, A. Lindroos, M. Martini, F. Maspero, J. Olsen, Å. Ringbom, E. Sibilía, L. Panzeri

Integrated dating of the construction and restoration of the Modena cathedral vaults (Northern Italy): preliminary Results

Radiocarbon **62** (2020) 667 - 677

C.A. van den Bosch, A. Cavallaro, R. Moreno, G. Cibir, G. Kerherve, J.M. Caicedo, T.K. Lippert, M. Doebeli, J. Santiso, S. Skinner, A. Aguadero

Revealing strain effects on the chemical composition of perovskite oxide thin films surface, bulk, and interfaces

Advanced Materials Interfaces **7** (2020) 1901440

J. Von Wartburg, S. Ivy-Ochs, J. Aaron, S. Martin, K. Leith, M. Rigo, C. Vockenhuber, P. Campedel, A. Viganò

Constraining the age and source area of the Molveno landslide deposits in the Brenta Group, Trentino Dolomites (Italy)

Frontiers in Earth Science **8** (2020)

L. Wacker, E.M. Scott, A. Bayliss, D. Brown, E. Bard, S. Bollhalder, M. Friedrich, M. Capano, A. Cherkinsky, D. Chivall, B.J. Culleton, M.W. Dee, R. Friedrich, G.W.L. Hodgins, A. Hogg, D.J. Kennett, T.D.J. Knowles, M. Kuitens, T.E. Lange, F. Miyake, M.-J. Nadeau, T. Nakamura, J.P. Naysmith, J. Olsen, T. Omori, F. Petchey, B. Philippsen, C.B. Ramsey, G.V.R. Prasad, M. Seiler, J. Southon, R. Staff, T. Tuna

Findings from an in-depth annual tree-ring radiocarbon intercomparison

Radiocarbon **62** (2020) 873 - 882

A. Walmsley, V. Serneels, I. Hajdas, A. Mayor

Variability of Early Iron Production in the Falémé Valley Region, Eastern Senegal

African Archaeological Review **37** (2020) 225 - 250

A.-M. Wefing, N. Casacuberta, M. Christl, N. Gruber, J.N. Smith

Circulation timescales of Atlantic Waters in the Arctic Ocean determined from anthropogenic radionuclides

Ocean Science Discussions (2020) 1 - 29

A. Wolter, C. Roques, J. Gröble, S. Ivy-Ochs, M. Christl, S. Loew

Integrated multi-temporal analysis of the displacement behaviour and morphology of a deep-seated compound landslide (Cerentino, Switzerland)

Engineering Geology and Environment (2020) 105577

Q. Wu, M. Döbeli, T. Lombardo, K. Schmidt-Ott, B. Watts, F. Nolting, D. Ganz

Does substrate colour affect the visual appearance of gilded medieval sculptures? Part II: SEM–EDX observations on gold leaf samples taken from medieval wooden sculptures

Heritage Science **8** (2020) 1 - 13

W. Xiao, Y. Xu, N. Haghipour, D.B. Montluçon, B. Pan, Z. Jia, H. Ge, P. Yao, T.I. Eglinton

Efficient sequestration of terrigenous organic carbon in the New Britain Trench

Chemical Geology **533** (2020) 119446

C. Yeman, M. Christl, B. Hattendorf, L. Wacker, C. Welte, N. Brehm, H. Synal

Unravelling quasi-continuous ^{14}C profiles by laser ablation AMS

Radiocarbon **62** (2020) 453 - 465

J. Zasadni, P. Kłapyta, E. Broś, S. Ivy-Ochs, A. Świąder, M. Christl, L. Balážovičová

Latest Pleistocene glacier advances and post-Younger Dryas rock glacier stabilization in the Mt. Kriváň group, High Tatra Mountains, Slovakia

Geomorphology **358** (2020) 107093

TALKS AND POSTERS

N. Akçar, S. Yeşilyurt, K. Hippe, M. Christl, C. Vockenhuber, V. Yavuz, B. Özsoy

Evolution of blue ice moraines in Queen Maud Land, Antarctica

Istanbul, Turkey, 22.10.2020, 4th Turkish Polar Workshop

N. Brehm, M. Christl, H.-A. Synal, R. Muscheler, F. Adolphi, A. Bayliss, T. Knowles, E. Casanova,

K. Nicolussi, L. Wacker

Detection of solar proton events by using radiocarbon in tree-rings

Austria, Vienna, 08.05.202, EGU General Assembly 2020

L. Bröder, K. Keskitalo, S. Zolkos, S. Shakil, S. Tank, T. Tesi, B. van Dongen, N. Haghipour, T. Eglinton, J. Vonk

Characterization of mobilized sediments and organic matter in retrogressive thaw slumps on the Peel Plateau, NWT, Canada

Austria, Vienna, 05.05.2020, EGU General Assembly 2020

L. Bröder, C. Hirst, S. Opfergelt, N. Haghipour, T. I. Eglinton, J. Vonk, J. Fouche

Tracing particulate organo-mineral export by a large glacio-nival river and a small headwater stream in Zackenberg valley, Greenland

USA, Online everywhere, 07.12.2020, AGU Fall Meeting

F. Calitri, M. Egli, M. Sommer, D. Tikhomirov, M. Christl

Complex soil mass redistribution along a catena using meteoric and in-situ ^{10}Be as tracers

Austria, Vienna, 05.05.2020, EGU General Assembly 2020

N. Casacuberta, M. Castrillejo, A.-M. Wefing, S. Bollhalder, K. Kündig, H.-A. Synal, L. Wacker

Rapid and high precision C-14 analysis in small DIC seawater samples and its future application as an ocean tracer

Austria, Vienna, 08.05.2020, EGU General Assembly 2020

N. Casacuberta, J. Smith, A.-M. Wefing, M. Castrillejo, M. Christl, E. Chamizo, M. Lopez-Lora, W. M. Smethie Jr

Understanding Circulation Processes in the Arctic and sub-Arctic Regions Using a Combination of Anthropogenic Chemical Tracers

USA, San Diego, 18.02.2020, Ocean Science Meeting 2020

M. Castrillejo, C. A. Richardson, R. Witbaard, R. Dekker, C. Welte, L. Wacker, C. Yeman, N. Casacuberta, H.-A. Synal, M. Christl

Sea shells record large biases from the marine bomb- ^{14}C curve in NW European seawater between the late 1960s and 2019

Austria, Vienna, 08.05.2020, EGU General Assembly 2020

F. Clapuyt, V. Vanacker, F. Schlunegger, M. Christl, K. Van Oost

Integrating space and time scales to assess the propagation of landslide sediment pulses in Alpine catchments

USA, Online everywhere, 12.07.2020, AGU Fall Meeting

M. Cybulska, A. Cieřlik, T. Dzieńkowski, I. Hajdas, M. Wołoszyn

Gródek upon the Bug River (Early Rus' Volyn') – basic data on the site and presentation of silk finds
Germany-Poland, Leipzig-Rzeszow, 18 - 20.11.2020, Beauty, Power, Mystery-Silk in the Byzantine Commonwealth and beyond

M. Czymzik, N. Nowaczyk, O. Dellwig, A. Wegwerth, R. Muscheler, M. Christl, H. Arz

Bipartite response in the Black Sea sediment record to Greenland-Interstadial 10
Austria, Vienna, 05.05.2020, EGU General Assembly 2020

C. Dieleemann, M. Christl, C. Vockenhuber, N. Akçar

The Timing of the Most Extensive Glaciation in the Northern Swiss Alpine Foreland
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

M. Döbeli

Introduction to Secondary Ion Mass Spectrometry (SIMS)

Switzerland, Zurich, 28.10.2020, CCMX Workshop on Advanced Characterization of Materials

J. Elkadi, B. Lehmann, G. E. King, O. Steinemann, S. Ivy-Ochs, M. Christl

Quantifying post-glacial erosion at the Gorner glacier, Switzerland, using OSL and ^{10}Be surface exposure dating

Austria, Vienna, 08.05.2020, EGU General Assembly 2020

L. Forster, J.L. Ocana-Pujol, H. Gallinski, J. Sendra, M. Döbeli, R. Spolenak

Active Layered Hyperbolic Metamaterials using Metal Induced Crystallization

Online everywhere, 25.06.2020, 2nd Photonics online Meet-up 2020

I. Hajdas, Ch. Schlüchter, R. Haller, K. Nicolussi

Old lime kilns buried in Val Chavagl (Swiss National Parc)

Austria, Vienna, 06.05.2020, EGU General Assembly 2020

I. Hajdas, M. Isler, R. Turck, U. Leuzinger

Material conservation and radiocarbon dating

Hungary, Budapest, 26 - 30.8.2020. 26th EAA Annual Meeting

I. Hajdas

Radiocarbon dating of silk

Germany-Poland, Leipzig-Rzeszow, 18 – 20.11.2020, Beauty, Power, Mystery-Silk in the Byzantine Commonwealth and beyond

I. Hajdas

^{14}C dating of Pazyryk and Ulandryk Kurgans and the importance ^{14}C dating has for the protection cultural heritage

Russia, St. Petersburg, 23. -25.11.2020, Radiocarbon in Archaeology and Paleoecology: Past, Present and Future

C. Heusser, C. Welte, B. Hattendorf, D. Montluçon, D. Günther, T. I. Eglinton

Purification of Organic Compounds Using Microsublimation for ^{14}C Analysis

Austria, Vienna, 08.05.2020, EGU General Assembly 2020

C. Heusser, C. Welte, B. Hattendorf, D. Montluçon, D. Günther, T. I. Eglinton
Purification of Organic Compounds Using Microsublimation for ^{14}C Analysis
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

D. Jong, L. Bröder, G. Tanski, M. Fritz, H. Lantuit, T. Tesi, N. Haghipour, T. I. Eglinton, J. E. Vonk
Nearshore zone dynamics determine pathway of organic carbon from eroding permafrost coasts
Austria, Vienna, 05.05.2020, EGU General Assembly 2020

S. Kamleitner, S. Ivy-Ochs, G. Monegato, F. Gianotti, N. Akçar, M. Christl, C. Vockenhuber
New insights into timing and extent of the LGM Ticino-Toce glacier, Swiss-Italian Alps
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

D. Mair, A. Lechmann, R. Delunel, S. Yeşilyurt, D. Tikhomirov., C. Vockenhuber, M. Christl, N. Akçar, F. Schlunegger
Millennial scale denudation of the steep Eiger headwalls through thermo-cryogenic pre-conditioned rockfall
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

K.-U. Miltenberger, M. Döbeli, C. Vockenhuber, H.-A. Synal
Capillary microprobe for MeV-SIMS
Slovenia, Bled, 15.09.2020, 17th International Conference on Nuclear Microprobe Technology and Applications (ICNMTA 2020)

M. Mödler, E. Godfrey, A. Kairiss, I. Hajdas
Formulating a Code of Ethics: Expert Evaluation of Archaeological Materials
Hungary, Budapest, 26 – 30.8.2020, 26th EAA Annual Meeting

G. Monegato, F. Gianotti, S. Kamleitner
Nuovi dati cronologici sull'Ultimo Massimo Glaciale tra le Alpi Cozie e Lepontine
Italy, Verbania, 04.02.2020, Seminar Istituto di ricerca sulle acque, CNR

R. Paque, I. Alomia-Herrera, M. Christl, F. Zehetner, V. Vanacker
Understanding and quantifying physical erosion processes in the volcanic island of Santa Cruz (Galapagos, Ecuador)
USA, Online everywhere, 10.12.2020, AGU Fall Meeting

G. Raab, F. Scarciglia, K. Norton, A. Martin, M. Christl, M. Ketterer, M. Egli
Surface denudation and soil erosion over 300 ka at the Otago upland (New Zealand) using ^{10}Be and $^{239+240}\text{Pu}$
Austria, Vienna, 08.05.2020, EGU General Assembly 2020

G. Raab
The Tor Exhumation Approach (TEA) – Dealing with continuous and reversed exhumation patterns to determine surface denudation rates
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

A.P. Martin, K.P. Norton, M. Christl, F. Scarciglia, M. Egli
Subsidence or uplift stage? Surface denudation variations of the Otago upland (New Zealand)
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

M. Egli, A.P. Martin, K.P. Norton, C. Lukens, M.E. Ketterer, R. Wanner, F. Scarciglia
Aeolian soil erosion assessment ($^{239+240}\text{Pu}$) within a dry-oceanic area (Otago, New Zealand)
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

G. Raab

Can I interest you in TEA?

Germany, Online everywhere, 30.10.2020, 14th International Young Geomorphologist Meeting Digital Edition

F. Scarciglia, K.P. Norton, A. Martin, M. Christl, M. Ketterer, M. Egli
Surface Denudation and Soil Erosion over 300 ka at the Otago Upland (New Zealand) using ^{10}Be and $^{239+240}\text{Pu}$
Austria, Vienna, 06.05.2020, EGU General Assembly 2020

M.N. Repasch, J.S. Scheingross, .N Hovius, M. Lupker, H. Wittmann, N. Haghipour, T.I. Eglinton, D. Sachse, O. Orfeo
Balancing the Fluvial Organic Carbon Budget: Integrating Sediment Transit Time and Channel Mobility into the Equation
USA, Online everywhere, 07.12.2020, AGU Fall Meeting

V. Rime, A.Foubert, R. Fentimen, H. Negga, A. El Korh, T. Adatte, I. Hajdas, B. Atnaf, T. Kidane
Evaporites reveal Pleistocene basin dynamics in the Danakil depression (northern Afar, Ethiopia)
Austria, Vienna, 06.05.2020, EGU General Assembly 2020

O. Steinemann, S. Ivy-Ochs, K. Hippe, M. Christl, H.-A. Synal
In the forbidden field: how glacial erosion influences the ^{10}Be /in-situ ^{14}C ratio
Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

O. Steinemann, S. Ivy-Ochs, K. Hippe, M. Christl, H.-A. Synal
Limestone vs. gneiss: the influence of the lithology on glacial erosion rates and landscape evolution
Switzerland, Bern, 28.09.2020, Exogene Geology and Quaternary Global Change Seminar

T. J. Suhrhoff, J. Rickli, M. Christl, E. G. Vologina, E. V. Sklyarov, D. Vance
Weathering signals in Lake Baikal and its tributaries
Austria, Vienna, 07.05.2020, EGU General Assembly 2020

T. J. Suhrhoff, J. Rickli, M. Christl, E. G. Vologina, E. V. Sklyarov, D. Vance
Weathering signals in Lake Baikal and its tributaries
Austria, Vienna, 06.05.2020, EGU General Assembly 2020

N. Vandermaelen, V. Vanacker, M. Christl, K. Beerten
Constraining aggradation of fluvial deposits based on in-situ ^{10}Be depth profiles and forward modelling
France, Paris, 02.05.2020, Quaternaire 12-Int. Conference on Quaternary

P. Vinsova, M. J. Simpson, T. Yuan, I. Hajdas, L. Falteisek, T.J. Kohler, J. C. Yde, J. D. Zarsky, M. Stibal
The origin and fate of organic matter in circum-Arctic subglacial ecosystems
Austria, Vienna, 05.05.2020, EGU General Assembly 2020

A.-M. Wefing, N. Casacuberta, M. Castrillejo, M. Christl, P.A. Dodd, P. Lherminier, M. Rutgers v.d. Loeff
Understanding circulation processes in the Arctic and Subarctic using a combination of anthropogenic chemical tracers

Iceland, Hafnarfjörður, 28.09.2020, Arctic-Subarctic Ocean Fluxes (ASOF) Meeting

A.-M. Wefing, N. Casacuberta, M. Christl, J.N. Smith, P.A. Dodd, E. Chamizo, M. López-Lora, H.-A. Synal
The long-lived anthropogenic radionuclides ^{129}I and ^{236}U as tracers of water mass provenance, circulation timescales and mixing in the Arctic Ocean and Fram Strait

Austria, Vienna, 07.05.2020, EGU General Assembly 2020

A.-M. Wefing, N. Casacuberta, M. Christl
A time-series of ^{236}U (and ^{129}I) in the Fram Strait

Switzerland, Zurich, 29.10.2020, Group Seminar Environmental Physics

C. Welte, J. Fohlmeister, L. Wacker, M. Wertnik, C. Spötl, C. Yeman, B. Hattendorf, M. Christl, T. I. Eglinton, H.-A. Synal

Combined $\delta^{13}\text{C}$ and Laser Ablation radiocarbon analysis of a high alpine stalagmite - a hint to an old organic carbon pool?

Austria, Vienna, 08.05.2020, EGU General Assembly 2020

M. Wertnik, C. Welte, L. Wacker, C. Yeman, B. Hattendorf, J. Koch, M. Christl, J. Fohlmeister, D. Riechermann, H.-A. Synal, T.I. Eglinton

Rapid, continuous radiocarbon analysis of carbonate archives using laser ablation

Austria, Vienna, 08.05.2020, EGU General Assembly 2020

M. Wertnik, C. Welte, L. Wacker, J. Koch, M. Christl, J. Fohlmeister, H.-A. Synal, T. Eglinton

Rapid, Continuous Scans of Radiocarbon Archives by Laser Ablation

Switzerland, Zurich, 07.11.2020, 18th Swiss Geoscience Meeting

Y. Wu, X. Dai, M. Christl, S. Xing, H.-A. Synal, S. Hou

An ultra-sensitive analytical method for direct searching primordial ^{244}Pu in bastnaesite

China, Huizhou, 04.12.2020, Annual Meeting of China Society of Radiation Protection

S. Yeşilyurt, O. Fredin, A. Romundset, M. Christl, C. Vockenhuber, N. Akçar

Post-glacial isostatic uplift and relative sea level changes in northern Norway

Turkey, Istanbul, 22.10.2020, 4th Turkish Polar Workshop

S. Yeşilyurt, U. Doğan, S. Ivy-Ochs, C. Vockenhuber, N. Akçar

Local Last Glacial Maximum in the eastern Anatolia mountains

Turkey, Istanbul, 20.10.2020, TURQUA 2020 Turkish Quaternary Symposium

SEMINAR

'CURRENT TOPICS IN ACCELERATOR MASS SPEKTROMETRY AND RELATED APPLICATIONS'

Spring semester

19.02.2020

Boštjan Jenčič (ETHZ), Elemental and molecular imaging of biological tissue at subcellular level

26.02.2020

Jeremy Caves Rugenstein (ETHZ), A variable silicate weathering feedback and implications for land surface reactivity and Cenozoic cooling

04.03.2020

Anne-Sofie Sondergaard (Aarhus University), The glacial history of the northwest Greenland Ice Sheet based on ^{10}Be and in-situ ^{14}C exposure and radiocarbon dating

13.05.2020

Anne-Marie Wefing (ETHZ), Using ^{129}I and ^{236}U to investigate the flow of Atlantic Waters in the Arctic Ocean

20.05.2020

Alexander Groos (University of Bern), Glacial history of the Bale Mountains in Ethiopia

27.05.2020

Maxi Castrillejo (ETHZ), Rapid and high precision DI^{14}C analysis in small seawater samples and its future application as ocean tracer

03.06.2020

Klaus-Ulrich Miltenberger (ETHZ), Secondary ion emission in MeV-SIMS

Fall semester

09.09.2020

Klaus-Ulrich Miltenberger (ETHZ), Secondary ion emission in MeV-SIMS

16.09.2020

Matthias Schlomberg (ETHZ), Towards the absolute measurement of Si isotopic ratios and its relevance for the ^{32}Si half-life measurement

23.09.2020

Nicolas Brehm (ETHZ), Detection of solar proton events by using radiocarbon in tree-rings

30.09.2020

Franziska Lechleitner (University of Bern), Coupled reconstruction of past climate and ecosystem changes using stalagmite ^{14}C

07.10.2020

Philip Gautschi (ETHZ), On the road to routine AMS with MILEA

14.10.2020

Catharina Dieleman (University of Bern), New insights on the Deckenschotter Landscape

21.10.2020

Daniele De Maria (ETHZ), LEA - Radiocarbon AMS at 50 kV

28.10.2020

Simon Fahrni (Ionplus AG), MICADAS at Ionplus: Developments and Results

04.11.2020

Toste Tanhua (IFM Geomar), Chronological transient tracers to quantify ocean ventilation

11.11.2020

Wang Yanyan (ETHZ), Interpretation of detrital cosmogenic nuclide concentrations into non-vertical mass flux and its application in great escarpments at rift margins

18.11.2020

Melina Wertnik (ETHZ), Coupling of Laser Ablation AMS with a stable isotope mass spectrometer for online analyses of carbon isotopes

25.11.2020

Gino Caspari (University of Bern), Tunnug 1 / Arzhan 0 – research on the oldest royal Scythian tomb

02.12.2020

Rienk Smittenberg (Stockholm University), Terrestrial carbon dynamics through time - insights from downcore radiocarbon dating

09.12.2020

Mirco Brunner (University of Bern) and Rouven Turck (University of Zurich), ^{14}C -Data mining: Reconstruction of living and mining activities in prehistoric Grisons

16.12.2020

Anne Bernhard (FU Berlin), $^{10}\text{Be}/^9\text{Be}$ Ratios in marine sediments offshore Chile - Marine authigenic clay formation or terrestrial denudation signal?

THESES (INTERNAL)

Term papers/Bachelor

Flavia Gantenbein

Mapping of Landslide Phenomena in Brienz/Brinzauls, GR

ETH Zürich (Switzerland)

Andreas Henz

Last Glacial Maximum ice flow direction in Hegau: reconstruction using volcanic erratic boulders

ETH Zürich (Switzerland)

Joel Scheuchzer

Reconstructing and understanding the Malta paleoglacier during the Gschnitz stadial

ETH Zürich (Switzerland)

Diploma/Master theses

Christian Heusser

Microsublimation as a Purification Method for Fatty Alcohols, Long-Chain Alkanes and Lignin Phenols for

¹⁴C Analysis

ETH Zürich (Switzerland)

Giacomo Ruggia

Reconstructing the Luterer valley landscape and palaeoclimate after the LGM

ETH Zürich (Switzerland)

Stephan Wartenweiler

Climatic and Anthropogenic Influence on Hillslope Activity and Colluviation in the Northern Apennines (Italy) and the Swiss Plateau (Switzerland)

ETH Zürich (Switzerland)

Doctoral theses

Klaus-Ulrich Miltenberger

Secondary ion emission in MeV-SIMS

ETH Zürich (Switzerland)

Olivia Steinemann

Using cosmogenic nuclides to understand rockglacier dynamics during the Lateglacial and to quantify glacial erosion on limestone and gneiss in the Alps

ETH Zürich (Switzerland)

Christiane Yeman

Advancements in Laser Ablation Accelerator Mass Spectrometry for online Radiocarbon analysis

ETH Zürich (Switzerland)

THESES (EXTERNAL)

Diploma/Master theses

Ewerton da Silva Guimarães

Surface Response to the Differential Uplift in the Plessur Drainage Basin, SE Switzerland

University of Bern

Jelena Wohlwend

Probing Plasmon Resonances using photons and electrons in Disordered Nanonetworks formed through Chemical Dealloying of Al-Cu-Sn thin films

ETH Zürich (Switzerland)

Doctoral theses

Enrico Bertero

'Green' Cr(III)-based electrodeposition of stainless steel-like FeCrNi: synthesis, mechanisms, material properties of films and micro-nanocomponents for bio-medical applications

EPFL Lausanne (Switzerland)

Lars Gerchow

Positronium Annihilation Spectroscopy Characterization of Novel Nano-porous Materials with Advanced Functionalities

ETH Zürich (Switzerland)

Alexander Groos

Glacial and periglacial history of the Bale Mountains, southern Ethiopian Highlands

University of Bern

Craig Lawley

Protagonists and spectators during photocatalytic solar water splitting with oxynitride photocatalysts

ETH Zürich (Switzerland)

Lena Markli

Fluxes and pathway of carbon export associated with Himalayan erosion

ETH Zürich (Switzerland)

Francesco Pagani

Lithium ion transport in epitaxial Li₄Ti₅O₁₂ model anodes and implications for high-power lithium-ion batteries

ETH Zürich (Switzerland)

Florent Sahli

Development of Highly Efficient Perovskite-on-Silicon Tandem Solar Cells

EPFL Lausanne (Switzerland)

Melissa Schawb

Radiocarbon constraints on carbon dynamics in river basins

ETH Zürich (Switzerland)

Xiao Yuan

Probing the Size and Rate-dependent Deformation Mechanisms in fcc Metals: Pure Elements to Multicomponent Alloys

ETH Zürich (Switzerland)

COLLABORATIONS

Australia

University of New South Wales, Earth Science, Sydney

Austria

AlpS - Zentrum für Naturgefahren- und Riskomanagement GmbH, Geology and Mass Movements, Innsbruck

Austrian Academy of Sciences, Institute for Oriental and European Archaeology, Vienna

Geological Survey of Austria, Sediment Geology, Vienna

International Atomic Energy Agency, Vienna

University of Innsbruck, Institute of Geography, Geology and Botany, Innsbruck

University of Salzburg, Geography and Geology, Salzburg

University of Vienna, VERA, Faculty of Physics, Vienna

Vienna University of Technology, Institute for Geology, Vienna

Belgium

Royal Institute for Cultural Heritage, Brussels

Université catholique de Louvain, Earth and Life Institute, Louvain-la-Neuve

Belgium

Bermuda Institute of Ocean Sciences, Bermuda

Canada

Bedford Institute of Oceanography, Bedford Institute of Oceanography, Halifax

Chalk River Laboratories, Dosimetry Services, Chalk River

China

China Institute for Radiation Protection, Dosimetry Services, Taiyuan city

Czech Republic

Czech Technical University, Nuclear Chemistry, Prague

Denmark

Danfysik A/S, Taastrup

Risø DTU, Risø National Laboratory for Sustainable Energy, Roskilde

TU Denmark, Nanophotonic Devices, Lyngby

University Southern Denmark, Department of Physics, Chemistry and Pharmacy, Odense

Finnland

University of Jyväskylä, Physics Department, Jyväskylä

France

Aix-Marseille University, Collège de France, Aix-en-Provence

Commissariat à l'énergie atomique et aux énergies alternatives, Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Gif-sur-Yvette Cedex

IFREMER, Laboratoire D ' Oceanographie Physique et Spatiale, Brest

Université de Savoie, Laboratoire EDYTEM, Le Bourget du Lac

Germany

Alfred Wegener Institute of Polar and Marine Research, Marine Geochemistry, Bremerhaven

Continental GmbH, Limbach

Freie Universität Berlin, Earth Sciences, Berlin

GFZ German Research Centre for Geosciences, Earth Surface Geochemistry and Dendrochronology Laboratory, Potsdam

Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Particle Physics, Dresden

Hydroisotop GmbH, Schweitenkirchen

Leibniz-Institut für Ostseeforschung Warnemünde, Marine Geologie, Rostock

Potsdam-Institut für Klimafolgenforschung, Complexity Science, Potsdam

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University of Hannover, Institute for Radiation Protection and Radioecology, Hannover

University of Heidelberg, Geosciences, Heidelberg

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Geological Survey of the Provincia Autonoma di Trento, Landslide Monitoring, Trento

INGV Istituto Nazionale di Geofisica e Vulcanologia, Sez. Sismologia e Tettonofisica, Rome

Südtiroler Landesverwaltung, Land- und Forstwirtschaft, Bozen

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University of Salento, Department of Physics, Lecce

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Liechtenstein

OC Oerlikon AG, Balzers

Oerlikon Surface Solutions AG, Balzers

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Norwegian Geological Survey, Trondheim

Norwegian Polar Institute, Tromsø

Norwegian Radiation Protection Authority, Tromsø

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Rogaland Fylkeskommune, Stavanger

The Bjerkness Centre for Climate Res., Bergen

The University Museum of Bergen, Bergen

Univeristy of Oslo, Department of Archaeology, Conservation and History, Oslo

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Lund University, Department of Earth and Ecosystem Sciences, Lund

Switzerland

ABB Ltd, Lenzburg

Amtcor Flexibles, Rohrschach

Amt für Kultur Kanton Graubünden, Archäologischer Dienst, Chur

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Dendrolabor Wallis, Brig

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ENSI, Brugg

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Evatec AG, Trübbach

Geneva Fine Art Analysis Sarl, Lancy, Geneva

Haute École-Arc, Ingénierie des surfaces, La-Chaux-de-Fonds

IBM Research, Rüschlikon

Kanton Graubünden, Kantonsarchäologie, Chur

Kanton Solothurn, Kantonsarchäologie, Solothurn

Kanton St. Gallen, Kantonsarchäologie, St. Gallen

Kanton Turgau, Kantonsarchäologie, Frauenfeld

Kanton Zug, Kantonsarchäologie, Zug

Kanton Zürich, Kantonsarchäologie, Dübendorf

Labor für quartäre Hölzer, Affoltern a. Albis

Laboratoire Romand de Dendrochronologie, Cudrefin

Lumiphase AG, Zurich

Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (NAGRA), Wettingen

Office et Musée d'Archéologie Neuchâtel, Neuchâtel

Oxyphen AG, Wetzikon

Paul Scherrer Institut (PSI), Hot Laboratories, Materials Group, Mesoscopic Systems, Labor für Radio- und Umweltchemie, Villigen

Rhysearch, Buchs

Stadt Zürich, Amt für Städtebau, Zurich

Stiftung Pro Kloster St.-Johann, UNESCO Welterbe, Münstair

SUPSI, Dipartimento ambiente costruzioni e design (DACD), Lugano

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Landscape Dynamics, Dendroecology and Soil Sciences, Birmensdorf

Swiss Federal Institute of Aquatic Science and Technology (Eawag), SURF, Dübendorf

Swiss Gemmological Institute, SSEF, Basel

Swiss Institute for Art Research, SIK ISEA, Zurich

University of Basel, Departement Altertumswissenschaften und Institut für Prähistorische und Naturwissenschaftliche Archäologie (IPNA), Basel

University of Bern, Institute of Geology, Climate and Environmental Physics, Oeschger Center for Climate Research, Bern

University of Freiburg, Faculty of Environment and Natural Resources, Freiburg

University of Geneva, Department of Anthropology and Ecology, Geology and Paleontology, Geneva

University of Lausanne, Department of Geology, Lausanne

University of Zurich, Institute of Geography, Abteilung Ur- und Frühgeschichte, Institute of Evolutionary Medicine, Zurich

Zollverwaltung, Zürich

Taiwan

National Taiwan University, Department of Geosciences, Taipei

The Netherlands

NIOZ, Coastal Systems Sciences , Texel

Twente University, Nanotechnology, Twente

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Dokuz Eylül University, Department of Geological Engineering, Izmir

Istanbul Technical University, Faculty of Mines, Istanbul

Tunceli Üniversitesi, Geology Department, Tunceli

United Kingdom

Brithish Arctic Survey, Cambridge

Cambridge University, Geography, Cambridge

Durham University, Department of Geography, Durham

Histrorical England, London

Queen Mary University of London , School of Geography, London

Sheffield University, Energy & Enviromental Science, Sheffield

University of Aberdeen, School of Geosciences, Aberdeen

University of Bristol, School of Earth Sciences School of Chemistry, Bristol

University of Lancaster, Nuclear Engineering, Lancaster

University of Oxford, Department of Earth Sciences, Oxford

USA

Lamont-Doherty Earth Observatory, Department of Geochemistry, Palisades

NOAA Fisheries, Pacific Islands Fisheries Science Center, Honolulu

University of Utah, Geology and Geophysics, Salt Lake City

Woods Hole Oceanographic Institution, Center for Marine and Environmental Radioactivity, and Marine Chemistry and Geochemistry, Woods Hole

VISITORS AT THE LABORATORY

Hippe Kristina

Germany

06.01.2020 - 14.01.2020 / 17.02.2020 - 21.02.2020

Tirelli Giulia

University of Modena and Reggio Emilia, Modena, Italy

05.01.2020 - 19.01.2020

Raab Gerald

University of Zurich, Zurich, Switzerland

27.01.2020 - 30.01.2020

Pawelczyk Fatima

Silesian University of Technology, Gliwice, Poland

30.01.2020 - 29.04.2020

Dennis Donovan

GFZ German Research Centre for Geosciences, Potsdam, Germany

17.02.2020 - 26.02.2020

Muscheler Raimund

Lund University, Lund, Sweden

28.02.2020

Jan Kučera

Czech Academy of Sciences, Prague, Czech Republic

10.08.2020

Mojmír Němec

Czech Technical University Prague, Prague, Czech Republic

10.08.2020

Roda-Boluda Duna

GFZ German Research Centre for Geosciences, Potsdam, Germany

06.09.2020 - 18.09.2020

Kateřina Fenclová

Czech Technical University Prague, Prague, Czech Republic

14.09.2020 - 25.09.2020

Tomáš Prášek

Czech Technical University Prague, Prague, Czech Republic

14.09.2020 - 25.09.2020

Joshua Chaplin

CHUV - Institut de radiophysique, Lausanne, Switzerland

30.10.2020 - 11.11.2020 / 07.12.2020 – 08.12.2020

TRAINEES AND STUDENTS AT THE LABORATORY

Zimmermann Severin
ETH Zurich, Switzerland
01.01.2021 – 30.06.2021

Bhattacharya Arushi
Kantonsschule Wettingen, Switzerland
17.02.2020 - 06.03.2020

Grünenfelder Leandra
Kantonsschule Wettingen, Switzerland
17.02.2020 - 06.03.2020

Marty Samuel
Kantonsschule Uster, Switzerland
20.07.2020 - 31.08.2020

Sonderegger Damian
ETH Zürich, Switzerland
17.08.2020 - 31.12.2020

Kuriger Yanis
EAWAG, Dübendorf, Switzerland
17.08.2020 - 31.12.2020

Fortunato Melissa
Universität Zürich, Switzerland
01.07.2020 - 31.10.2020