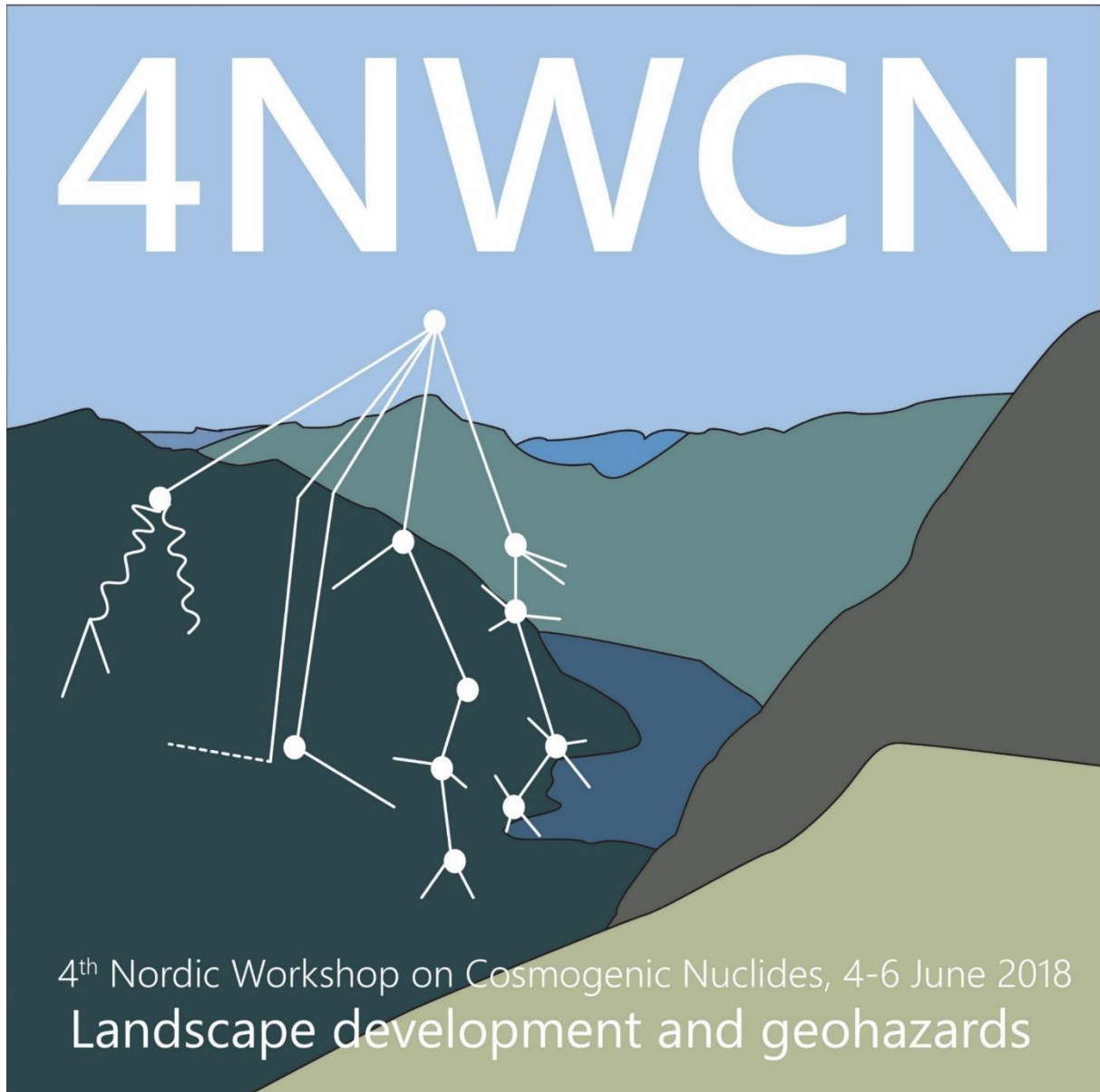


4th Nordic Workshop on Cosmogenic Nuclides

Landscape development and geohazards

4-6 June 2018
Geiranger, Norway





4th Nordic Workshop on Cosmogenic Nuclides (4NWCN)

Landscape development and geohazards

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Keywords: Cosmogenic nuclides, geochronology, geomorphology, landscape development, geohazards

ISBN: 978-82-8088-415-2

A pdf version of this document can be downloaded from Bergen Open Research Archive (BORA):

<http://hdl.handle.net/1956/17677>

Table of Contents

<i>Welcome to the 4th Nordic Workshop on Cosmogenic Nuclides (4NWCN)!</i>	1
<i>We thank our sponsors</i>	2
<i>Behind the 4NWCN</i>	3
<i>Organising Committee</i>	3
<i>Scientific Programme Committee</i>	3
<i>A-Z (Å) of 4NWCN</i>	4
<i>Climate</i>	7
<i>Geology</i>	8
<i>UNESCOs World Heritage site West Norwegian Fjords</i>	12
<i>Overview of 4NWCN</i>	13
<i>Pre-workshop programme Sunday 3 June</i>	14
<i>Programme Monday 4 June</i>	16
<i>Programme Tuesday 5 June</i>	17
<i>Programme Wednesday 6 June</i>	18
<i>Table of oral presentations</i>	19
<i>Table of poster presentations</i>	20
<i>List of participants</i>	81

Welcome to the 4th Nordic Workshop on Cosmogenic Nuclides (4NWCN)!

Cosmogenic nuclides are rare isotopes, produced in the Earth's atmosphere and upper surface via exposure to cosmic radiation. Measurement of cosmogenic nuclides in rocks and sediments has only been possible for about 30 years. To date, the Nordic Workshop on Cosmogenic Nuclides (NWCN) is the only dedicated international forum for discussion of this burgeoning technique, and has been organised every-second year since 2012. NWCN began as a Nordic initiative, emerging from research at the Bjerknes Centre for Climate Research, the Universities of Bergen, Stockholm and Aarhus, and the Geological Survey of Norway, but is now ***the foremost international arena*** for dissemination of the latest research, sharing of best practice, international network building among established and early-career researchers and technicians, and interdisciplinary collaboration.

Today, cosmogenic nuclides are used for - but not limited to - *direct dating* of rock surfaces, quantifying long-term *erosion rates*, and establishing total burial and exposure durations for surfaces with complex histories. The application of cosmogenic nuclides opens up possibilities to gain new insight into long-term and short-term processes; not least tectonic and climatic landscape development and geo-hazards. Investigation of the history of the land surface, spanning from deep weathering, eroded, buried and exhumed surfaces, to processes operating on today's surfaces, is relevant to many aspects in geoscience. We expect to see even wider application of cosmogenic nuclides in the near future. For example, combining dating or rate determinations using cosmogenic nuclides with low-temperature thermochronology, dating of secondary minerals, long sediment records and numeric modelling.

We are delighted to welcome you to Geiranger, western Norway, for the 4th NWCN, 4-6 June 2018. The workshop is jointly organised by the Department of Earth Science, UiB, and the World Heritage Foundation Geirangerfjord. For this 4th iteration the theme is '*landscape development and geohazards*'. During these three days together, ***we seek to focus on how cosmogenic nuclides are used to improve our understanding of geological processes and temporal aspects, and thus the mechanisms behind short- and long-term changes.*** The workshop's location serves a purpose in itself: Geiranger is at the head of a deep and narrow fjord, in a region where unstable mountain slopes are under continuous surveillance because of the high-risk of rockfall and associated tsunamis that have obliterated fjord settlements causing loss of life in the historic past. In Geiranger, landscape development and geohazards cease to be theoretical.

Students and Early-Career Researchers (ECRs) have been an important component of past-NWCNs, and we are very pleased to welcome two ECRs as keynote speakers (Marrero & Hippe). Thanks to sponsorship from the Geological Survey of Norway (NGU) and International Association of Cryospheric Sciences (IACS) we have been able to waive costs of the group travel and excursion for current students and ECRs (those who gained PhD in 2011 or later). In addition, we are also excited to announce there will be awards for the best talk and poster given by an ECR or student during 4NWCN. All eligible participants will be considered for the awards, which will be judged by members of the Scientific Programme and Organising Committees. Judging will be based on both scientific content, visual and oral presentation/communication of that content.

We are pleased to announce that the 4NWCN has 55 registered participants from institutions across 14 countries: Norway (17), Denmark (4), Sweden (3), Switzerland (8), France (5), Germany (3), Scotland (4), England (1), Austria (2), Poland (1), USA (3), Chile (2), New Zealand (1) and China (1). We have 30 ECR participants, and there is a near 50:50 gender-split for the meeting. The programme includes 5 invited keynotes and 44 peer-reviewed presentations (16 oral and 27 posters), discussions, as well as a half-day guided field excursion through the west Norwegian fjord landscape.

We wish you a stimulating, productive and enjoyable meeting in this spectacular location.

The Organising Committee

Henriette Linge (chair), Anna Hughes, Anne Hormes, Lars Evje, Thomas Thuesen, Mari Sæbø & Merete Rønneberg

We thank our sponsors:



AARAMS - Aarhus AMS Centre
Department of Physics and Astronomy, Aarhus University

**GEOLOGICAL
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NORWAY**
- NGU -

Behind the 4NWCN

University of Bergen (UiB) is one of nine universities in Norway. It is a medium-sized European university with 16,900 students and 3,600 employees. UiB is an internationally recognised for quality of its research activity, and the most cited university in Norway. The Department of Earth Science has 4 research groups, 36 permanent faculty staff, 32 technical/administrative staff, >50 Ph.D. candidates and postdocs, and >100 MSc students, and offers about 60 courses. The UiB Preparation Facility for Cosmogenic Nuclides is one out of 26 laboratories at the department.



Stiftinga Geirangerfjorden Verdsarv (World Heritage Foundation Geirangerfjord) was jointly created by the municipalities of Norddal and Stranda, and the county of Møre og Romsdal, and it is based in Geiranger at the Norwegian Fjord Centre (visitors' centre for the West Norwegian Fjords UNESCO World Heritage site). The foundation focus on outreach, promoting sustainable and green development of the area, conservation, competence building, and aims to be an arena for scientific research.



Organising Committee

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A-Z (Å) of 4NWCN

Climate

For information about the weather, visit <https://www.yr.no> and see for example: https://www.yr.no/place/Norway/Møre_og_Romsdal/Stranda/Geiranger/hour_by_hour.html or go outside. For information about the regional climate, see page 7.

Field excursion

A guided-tour through parts of the west Norwegian fjord landscape will take place on Wednesday 6 June. This is combined with return transport from Geiranger to Ålesund. The bus will depart from Hotel Union at **13:15 on Wednesday 6 June** after lunch. We expect to arrive at Ålesund airport (final stop) **by 19:20**. Weather can be variable, especially in early summer, please bring appropriate footwear (normal hiking/running shoes should be fine) and wet weather gear.

The trip will comprise:

- visiting local sites showing typical geomorphology of NW Norway (TBC, snow dependent)
- 1-hour ferry cruise from Geiranger to Hellesylt, departure at 15:30. Snacks are sold on the ferry
- drive from Hellesylt to Sykkylven with two stops (Ljøen, Velledalen/ Sykkylvsfjorden)
- a short ferry crossing from Ørsnes/Sykkylven to Magerholm (15 minutes)
- drop-off points at Moa and Ålesund bus terminals
- final stop at Ålesund airport

Geology

See page 8.

Hotel Union

Hotel Union is the main venue for 4NWCN.

Internet during the meeting

Open access to Internet is available everywhere at the hotel.

Icebreaker

When: Sunday 3 June 19:00 - 21:00

Where: At the **Norwegian Fjord Centre**, the official visitor centre of the UNESCO World Heritage site *West Norwegian Fjords*, about two-minute walk from Hotel Union.

Map of travel routes to and from Geiranger (page 6).

Norwegian Fjord Centre

Official visitors' centre for UNESCO World Heritage site, see page 12.

Presentations, oral

Oral presentations will take place in Geirangersalen, Hotel Union. Speakers (excluding keynotes) are allocated 20 minutes (with an additional 5 minutes question time). Talks will be run from a PC and presenters should ensure that their talk is uploaded before the start of the relevant session. Power-point and pdf formats are preferred. Both 16:9 and 4:3 screen format can be accommodated.

Remember to bring your presentation on a USB-stick!

Presentations, poster

Poster sessions will be in the same location as the talks, Geirangersalen. Posters can be up to A0 size (841 x 1189 mm) and ideally in portrait format. Posters should be put up on the morning of Monday 4 June and removed by the end of the final scientific session on Wednesday 6 June. Note all poster presenters are expected to give a 1-minute flash-presentation of their poster on **Monday 4 June 11:25-12:00**. If you wish to promote your poster with a slide please send this to thomas.thuesen@uib.no before 09:00 am on Monday 4 June. ONE SLIDE ONLY!

Meals

Meals are served buffet-style in the Restaurant *Fjorden*. Meal times:

Breakfast: 07:00 - 10:00 - if you are staying at Hotel Union the buffet is available during these hours

Lunch: 12:00 - 13:00 will be a 2-course meal, covered by 4NWCN

Dinner: 19:00 - 21:00 - the Union buffet, covered by 4NWCN

Note that breakfast is included in the cost of your room (if staying at Hotel Union), and that lunch and evening meals are covered by 4NWCN - but this does not include drinks.

Svele

Thick sweet pancake served with either brown cheese or sugar and butter. Recommended excursion food during ferry-crossings.

Tourist information about Geiranger

Fjord Norway: <https://www.fjordnorway.com/geiranger>

Tsunami, see Visualisation...

Visualisation of a geohazard event - rock-avalanche monitoring and tsunami risk assessment

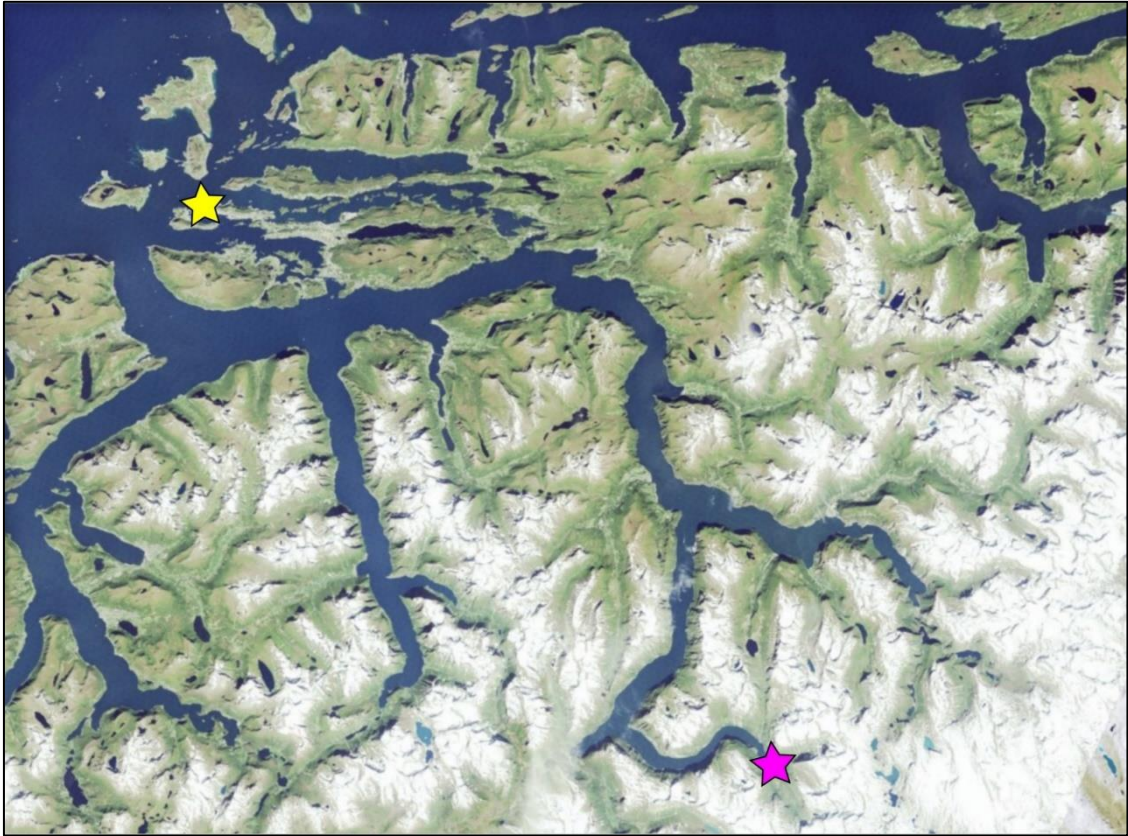
Before dinner on Monday 4 June there will be a showing of the film 'Bølgen', The Wave (in Norwegian with English subtitles), in our workshop location at the hotel.

Website of 4NWCN: <https://nwc2018.w.uib.no/>. Here you can find the latest information and updates.

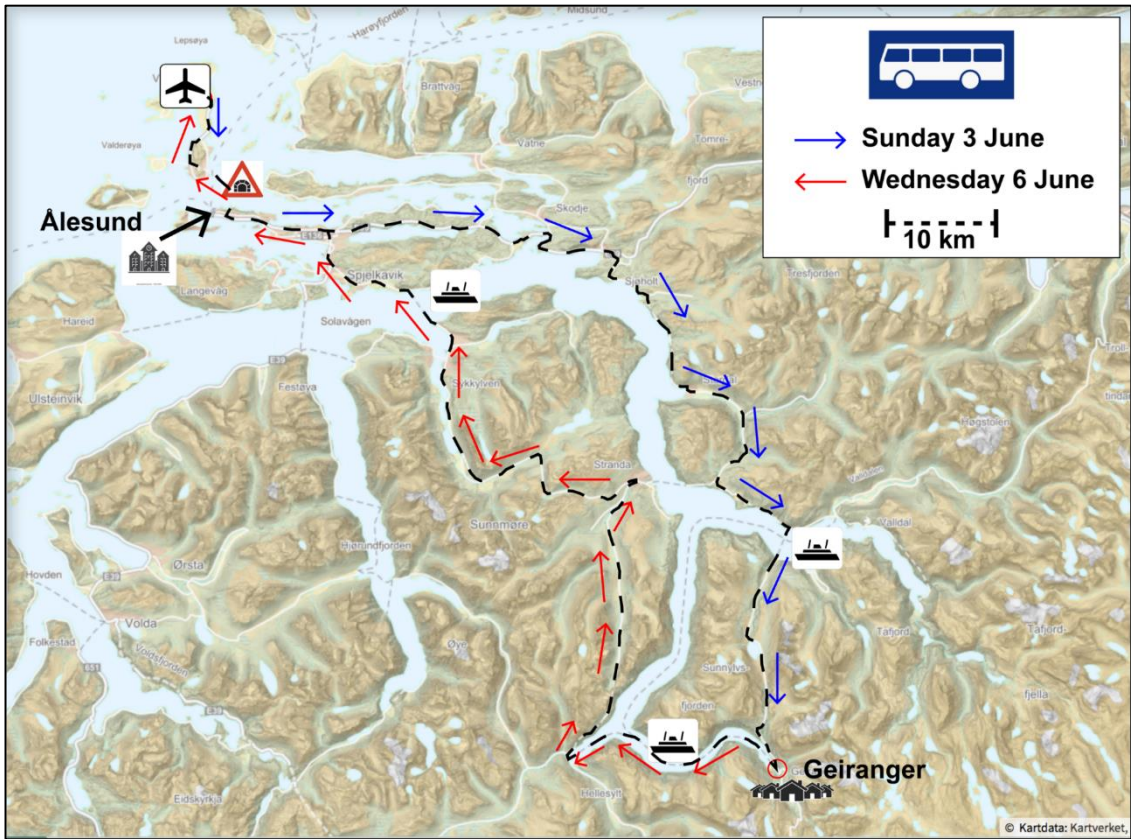
World Heritage Foundation Geirangerfjord and Norwegian Fjord Centre

On **Tuesday 5 June, 17:15-17:45**, Merete Rønneberg or Katrin Blomvik will give a presentation on the World Heritage Foundation Geirangerfjord in our workshop location at the hotel, Geirangersalen.

For visiting the Norwegian Fjord Centre: Our icebreaker will be held at the Norwegian Fjord Centre at **19:00-21:00 on Sunday 3 June**. Use this opportunity to walk through their exhibition on the natural and cultural landscape heritage.

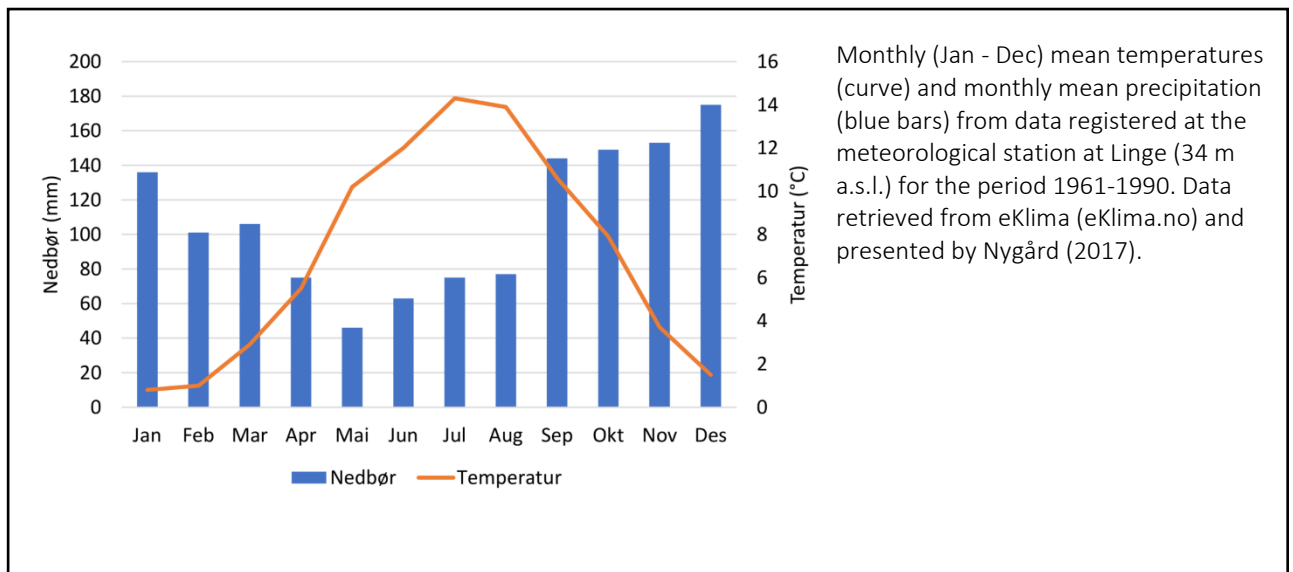
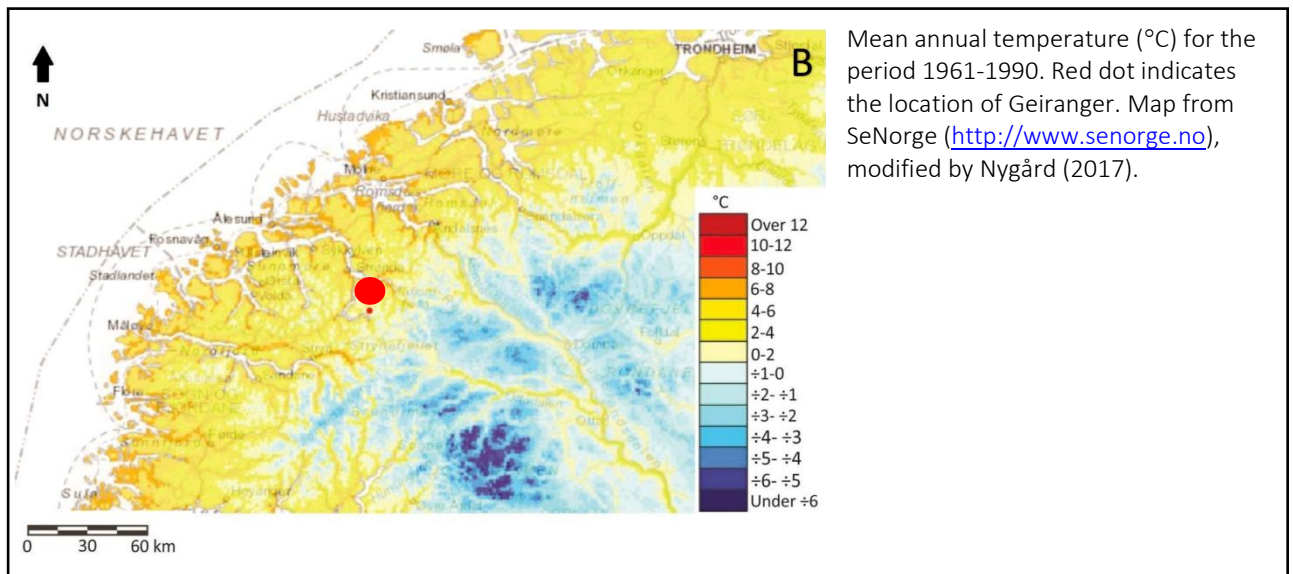
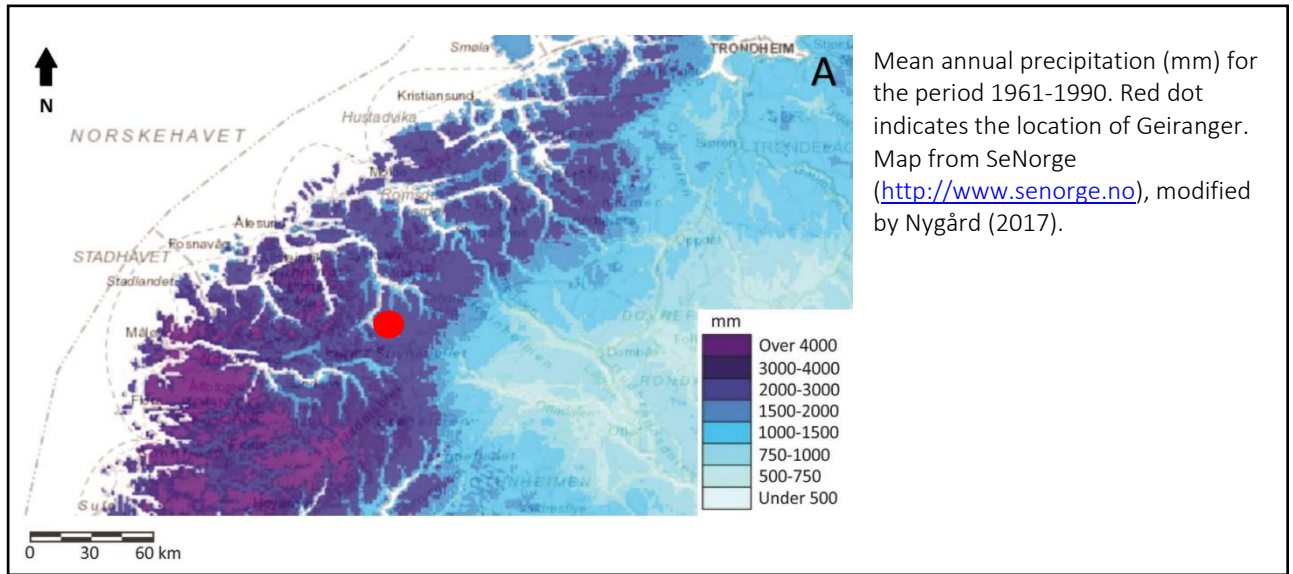


The little part of Møre og Romsdal county that you will experience between Ålesund (yellow star) and Geiranger (pink star) belongs to a region named **Sunnmøre**. Satellite image from <https://kilden.nibio.no> and www.norgebilder.no.



Map of Sunnmøre with indicated travel routes for Sunday 3 June (blue arrows) and Wednesday 6 June (red arrows). Map from <https://kilden.nibio.no/> and Kartverket.

Climate



Geology

The local bedrock is mainly composed of various types of gneiss belonging to a large geological unit labelled the **Western Gneiss Region**. The unit contains Precambrian basement that was deformed and metamorphosed (Fig. 1) during the Caledonian orogeny (c. 440-395 Ma). The region has attracted attention due to numerous examples of ultra-high-pressure metamorphism to eclogite-facies conditions (e.g. Young 2018). Common inclusions, in addition to eclogites, are amphibolite, dunite, serpentine and anorthosite. Large bodies containing olivine/peridotite are common and many have been mined and quarried in the past. Peridotite is currently quarried outside, but close to the Geirangerfjord.



Figure 1: Deformed gneiss.
Photo: H. Linge



Figure 2: Valderøya with the islands Giske (left) and Vigra (right) in the background. Photo: H. Valderhaug

At the coast, Sunnmøre is characterised by numerous islands of the Norwegian **strandflat** (Fig. 2). The strandflat is an uneven rock platform along large parts of the Norwegian west coast (e.g. Holtedahl 1998) comprising islands, skerries and shallow seas. In Sunnmøre, the general level of the strandflat coincides with the Late Weichselian marine limit and is characterised by a dramatic contrasts in relief. Mountains reaching several hundred meters are encircled by a rim of extremely flat low-land below. Well-developed knickpoints mark the transition between the strandflat and the steep mountain slopes. The origin and age of the strandflat are debated to this day (e.g. Larsen and Holtedahl 1985, Fredin et al. 2017).

Further inland, deep fjords, valleys and mountains dominate the landscape (Fig. 3). Valleys and fjords exhibit classic features and signs of glacial erosion, with U-shaped cross sections and longitudinal profiles, leading to offshore troughs and sills. Super-imposed on this glacial landscape created by repeated large-scale glaciation by ice sheets, cirques indicate erosion and deposition of sediment by smaller, local glaciers. Mountain summits are typically characterised by gently sloping, regolith-covered plateau surfaces or by peaks and arêtes where the cirques have incised from all sides.



Figure 3: View SE from Ålesund. Photo: H. Linge



Figure 4: View of the opening of Skjonghelleren from the cave. Photo: H. Linge

Close to Ålesund is the Norwegian type-site for the **Ålesund Interstadial** (38-34 ka, MIS3), and one of the most well-dated pre-LGM sites in Scandinavia. Skjonghelleren (Fig. 4), on the island Valderøya, is a 100 m long cave created by wave-abrasion where alternating layers of laminated sediments and diamictons have been deposited. The Laschamp paleomagnetic excursion was identified in sediments below interstadial sediments containing numerous fauna and shells, and the Mono Lake excursion is identified above. Numerous radiocarbon dates have been obtained for the younger part of the record. The cave is a short drive from Ålesund airport, with easy access following well-marked by signs from a footpath that snakes around the island. See Mangerud et al. (2003) and Mangerud et al. (2010) for the full story!

After the Ålesund Interstadial, the **Scandinavian Ice Sheet** expanded to cover the whole of mainland Norway and the continental shelf. Sunnmøre was glaciated until c. 16-15 ka when the ice sheet started to retreat inland. By the time of the Younger Dryas (12.7-11.6 ka) only innermost Sunnmøre was covered by the main ice sheet, in contrast to further south (close to Bergen) where the ice sheet re-advanced to reach the current-coastline (cf. Hughes et al. 2016). Cirques, often with clear terminal moraines, characterised the Younger Dryas stadial in Sunnmøre. Some of the cirque glaciers extended to the present-day sea level (Larsen et al. 1998), indicating lower relative sea levels. We might be able to see an example of this when we drive along Sykkylvsfjorden on our return to Ålesund.

Geohazards

Sunnmøre is also the first location where evidence for the **Storegga tsunami** was found. Now known to have been caused by a huge slide at the Norwegian continental-shelf edge at around 8.2 ka this is one of the largest known tsunami events of the early Holocene, with traces of found across the North Sea and as far away as Greenland (e.g. Bondevik et al. 1997; Bondevik et al. 2012).

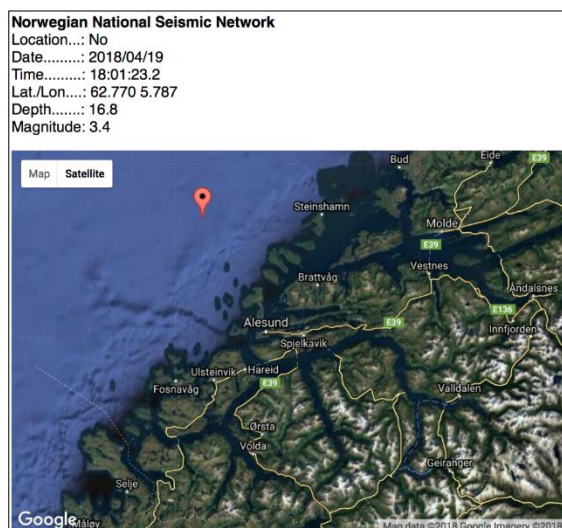


Figure 5: screenshot from Norwegian National Seismic Network, <http://nnsn.geo.uib.no/>.

The relief in Møre og Romsdal county is classified as belonging to the extreme alpine class by the Geological Survey of Norway (NGU). Numerous unstable, and potentially unstable, **rock slopes** have been identified and certain unstable slopes are under continuous surveillance by the Norwegian Water Resources and Energy Directorate (NVE). Longva et al. (2009) did a systematic inventory of large mass movement (slides, avalanches) deposits in Storfjorden (incl. Geirangerfjord). Of the >100 deposits, most occurred soon after the deglaciation, but there has also been mass movement activity during the Holocene and in historic times.

The southwest coast between Stavanger and Ålesund, is one of three regions with relatively high **seismic activity** in Norway. An earthquake of magnitude 3.4 was registered off-shore Møre og Romsdal on 19 April 2018 (Fig. 5).

Cosmogenic nuclides and information on landscape development

Sunnmøre and adjacent regions have not escaped the application of *In situ* cosmogenic nuclides. Aiming at providing new constraints on the thickness of the last Scandinavian ice sheet, Brook et al. (1996) calculated ^{10}Be and ^{26}Al exposure ages from bedrock samples along a vertical transect at Skåla, 28 km SW of Geiranger. Goehring et al. (2008) later generated ^{10}Be exposure ages from boulders along the same transect, although glacial erratic boulders do not exist all the way to the summit. The combined results revealed deglaciation ages from the boulders and a decline in glacial erosion with increased elevation from the bedrock samples. Hermanns et al. (2017 and references therein) have dated several rock avalanche deposits and scars in the region, showing that about half of the events occurred within the first few millennia after deglaciation.



In her MSc thesis, Nygård (2017) showed using erratic boulders located outside of the Younger Dryas extent of local glaciers and the Scandinavian ice sheet that the Geiranger area was ice free above 700 m by approximately 17 ka. A current MSc student (T. Horten) has mapped lateral moraines (Fig. 6) in Geiranger and Geirangerfjord. He aims to determine their age(s) using the ^{10}Be dated surfaces of Nygård (2017) to calibrate Schmidhammer R-values obtained from the same boulders and other rock surfaces of known age.

Figure 6: Lateral moraine ridge in a tributary valley to Geiranger, mapped and investigated by Horten (in prep.).

Unpublished ^{10}Be data (Brook, Nesje, Larsen, Linge) from weathered summits along Romsdalsfjorden, NE of Ålesund/Geiranger, indicate that apparent exposure ages decrease from c. 80 ka at the coast to c. 30 ka near the watershed (Fig. 7). Ongoing work in the inner part of Sunnmøre, related to glaciation and landscape evolution questions, includes; ^{10}Be dating of cirque moraines (Wilson et al. in prep) in Valldalen, analysis of ^{10}Be (boulder surfaces) and $^{10}\text{Be}/^{26}\text{Al}$ (bedrock surfaces) along fjord to summit (1850 m a.s.l.) transects outside/above the YD ice extent just north of Geiranger (Linge in prep.), as well as ^{10}Be analysis of boulders on high-elevation lateral moraines (Sæbø in prep.).

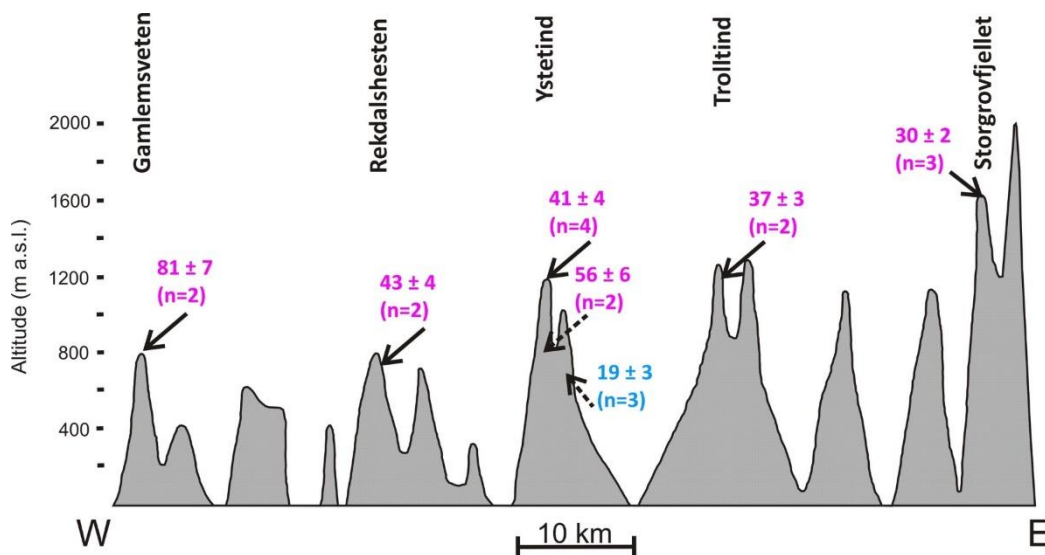


Figure 7: Mean ('apparent') ^{10}Be ages (in ka) from bedrock surfaces (pink) within blockfields, and glacially eroded surfaces (blue), from mountains parallel to the Romsdalsfjord. The age trend with elevation, and/or distance from the coast, can be interpreted as a result of higher denudation rates, of longer duration of shielding by cold-based ice or snow, or indicating that summits are prone to plucking. In contrast, glacially eroded surfaces are more likely to reveal the duration of continuous exposure after erosion, and provide 'true' surface exposure ages (Brook, Linge, unpubl.).

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Glacially eroded surface and glacial deposits, Tafjordfjella. Photo: H. Linge

UNESCOs World Heritage site West Norwegian Fjords

Fjord, a word of Norwegian origin, refers to a long, deep inlet of the sea between high cliffs formed by submergence of a glaciated valley. The West Norwegian fjord landscape stretches 500 km from Stavanger in the south to Åndalsnes in the north-east. Of the 200 fjords along the west coast of Norway, Nærøfjord and Geirangerfjord are the least affected by human activity such as hydroelectric dams and infrastructure.

UNESCOs type locality for fjords as world heritage landscapes is comprised of two fjords in south-western Norway, Nærøfjord north of Bergen and Geirangerfjord southeast of Ålesund. Both fjords are considered typical for fjord landscapes; developed in crystalline rocks, they are narrow and steep-sided with numerous waterfalls. They vary in breadth from just 250 m to 2.5 km wide. The relief is close to 2000 m with peaks reaching 1400 m a.s.l. and fjord basins extending down to 500 m b.s.l. The West Norwegian Fjords was inscribed to UNESCOs World Heritage list in 2005. In their description of Geirangerfjord and Nærøfjord as a World heritage site, UNESCO writes:

The West Norwegian Fjords are classic, superbly developed fjords, considered as the type locality for fjord landscapes in the world. They are comparable in scale and quality to other existing fjords on the World Heritage List and are distinguished by the climate and geological setting. The property displays a full range of the inner segments of two of the world's longest and deepest fjords, and provides well-developed examples of young, active glaciation during the Pleistocene ice age. The ice- and wave-polished surfaces of the steep fjord sides provide superbly exposed and continuous three-dimensional sections through the bedrock. The record of the postglacial isostatic rebound of the crust and its geomorphic expression in the fjord landscape are significant, and represent key areas for the scientific study of slope instability and the resulting geohazards.

The two fjord areas include all features that typically characterise a fjord landscape and its geological evolution. These include deep rock basins reaching depths far below sea level, prominent rock thresholds, high and steep cliffs, slide scars and avalanche deposits, moraines, till deposits, hanging valleys, so-called fish-hook or agnor valleys (formed by river capture), glaciers, rivers, waterfalls and surrounding mountain and catchment areas. Each fjord has a different morphology and geology and displays a different range of geomorphological features. Taken together, the Nærøfjord and Geirangerfjord areas provide most of the features in their natural relationship that could be expected of a fjord landscape and its geological evolution. The boundaries of the serial property are appropriately defined to protect the geological features and the areas required to maintain the scenic qualities of the property. Legislation, staffing, budget and institutional structures in place are adequate to ensure its integrity.

Source: <https://whc.unesco.org/en/list/1195/>



Overview of 4NWCN

DAY	TIME	ACTIVITIES
Sunday	– 16:30	Arrivals
3 June	c. 16:30 – 18:30	Transport from Ålesund airport to Hotel Union, Geiranger
	19:00 – 21:00	Icebreaker at the Norwegian Fjord Centre. <i>Light meal.</i>
Monday	09:00 – 12:00	Welcome, Keynote 1 (Owen), Talk (Neuhuber)
4 June	10:25 – 10:55	<i>Coffee</i>
	10:55 – 12:00	Talk (Margreth), Idea (Hormes), 1-minute poster presentations
	12:00 – 13:00	<i>Lunch</i>
	13:00 – 14:40	Keynote 2 (Hippe), Discussion, Talks (Lupker, Zerathe)
	14:40 – 15:40	<i>Coffee & Posters</i>
	15:40 – 17:15	Talks (Hilger, Gallach), Keynote 3 (Hermanns)
	17:30 – 19:30	Disaster film with tsunami. Introduction (Nesje)
	19:30 – 21:00	<i>Dinner</i>
Tuesday	08:30 – 09:45	3 Talks (A. Binnie, Geiger, Mohren)
5 June	09:45 – 10:45	<i>Coffee & Posters</i>
	10:45 – 12:00	Keynote 4 (Willenbring), Discussion.
	12:00 – 13:00	<i>Lunch</i>
	13:00 – 14:35	Keynote 5 (Marrero), Discussion, Talk (S. Binnie)
	14:35 – 15:05	<i>Coffee & Posters</i>
	15:05 – 16:45	Discussion, Talks (Mendelova, Whitmore, Fredin)
	16:45 – 17:30	<i>Coffee & Posters</i>
	17:30 – 18:00	World Heritage Foundation Geirangerfjord (Rønneberg/Blomvik)
	19:00 – 21:00	<i>Conference Dinner</i>
Wednesday	09:00 – 10:15	Talks (Garcia, Søndergaard, Svendsen)
6 June	10:15 – 10:45	<i>Coffee</i>
	10:45 – 12:00	Discussion and Closing
	12:00 – 13:00	<i>Lunch</i>
	13:15 – 15:00	Excursion - local sites around Geiranger
	15:30 – 16:35	Ferry cruise Geiranger - Hellesylt
	16:35 – 19:20	Drive Hellesylt, Sykkylven, Ålesund, Ålesund airport

Pre-workshop programme Sunday 3 June

- 16:30 Group transport departs from Ålesund airport
 Pick-up at bus terminals (Ålesund, Moa) if notice is given in advance
- 18:30 Estimated arrival time at Hotel Union, Geiranger
 Check in
- 19:00- 21:00 Icebreaker at the Norwegian Fjord Centre (2-minutes from Hotel Union)
 Soup, finger-food, refreshments, access to exhibition



Overview location of Hotel Union and the Fjord center. Slightly modified drone image from norexplore.no/geiranger.

MONDAY 4 JUNE

09:00 – 09:15	Welcome Henriette Linge	13:50 – 14:15	Paired ¹⁰ Be and <i>in-situ</i> ¹⁴ C measurements in Himalayan catchments: tracers of landslide sediment inputs? Maarten Lupker
09:15 – 10:00	KEYNOTE Successes and challenges in applying cosmogenic and luminescence dating methods for paleoseismic and slip rate studies along active faults Lewis Owen	14:15 – 14:40	Dominance of climate upon seismicity on giant landslide triggerings along the hyper-arid western Andes Swann Zerathe,
10:00 – 10:25	Cosmogenic Al and Be inventory from terrace deposits of the Central Vienna Basin: implications on the source area from cosmogenic ²⁶ Al and ¹⁰ Be ratios Stephanie Neuhuber	14:40 – 15:40	---COFFEE and Posters
10:25 – 10:55	---COFFEE---	15:40 – 16:05	Implications of inherited isotope concentrations when dating landslides with terrestrial cosmogenic nuclide dating Paula Hilger
10:55 – 11:20	Pleistocene and Holocene evolution and weathering of coastal landscapes in Norway Annina Margreth	16:05 – 16:30	TCN dating of Holocene and Lateglacial rockfalls in the Mont Blanc massif. Development of GRIGRI: a new method of surface exposure age dating using reflectance spectroscopy Xavi Gallach
11:20 – 11:25	Ideas on funding Anne Hormes	16:30 – 17:15	KEYNOTE How do rock slope failures in Norway fit into and how do they contribute to the landscape development? Reginald Hermanns
11:25 – 12:00	1-minute flash-presentation of posters	17:30 – 19:30	Tsunami film , introduced by Atle Nesje
12:00 – 13:00	--- LUNCH---	19:30 – 21:00	---DINNER---
13:00 – 13:25	KEYNOTE Constraining changes in Holocene surface erosion rates with in situ ¹⁴ C- ¹⁰ Be analyses Kristina Hippe		
13:25 – 13:50	Discussion		

TUESDAY 5 JUNE

08:30 – 08:55	Evidence for the Middle-Pleistocene Transition in Northern Chile Ariane Binnie	14:10 – 14:35	Initial measurements of CoQtz-N: a quartz reference material for terrestrial in-situ cosmogenic ¹⁰ Be and ²⁶ Al Steve Binnie
08:55 – 09:20	Developing a geochronology of ice sheet extent and thickness in the hyper-humid fjords of south-western Chile (52-55°S) Alessa Geiger	14:35 – 15:05	---COFFEE and Posters
09:20 – 09:45	Using cosmogenic nuclides to trace a steep climate gradient over a short distance in hyperarid northern Chile Joel Mohren	15:05 – 15:30	Discussion on posters
09:45 – 10:45	---COFFEE and posters	15:30 – 15:55	Extensive early mountain glaciation in central Patagonia during marine isotope stage 5 Monika Mendelova
10:45 – 11:25	KEYNOTE Not feeling the buzz: tectonic limits to mountain heights and geomorphic feedbacks maintain subdued topography Jane Willenbring	15:55 – 16:20	New record of ice surface elevation changes for tucker glacier in Victoria Land, Antarctica Ross Whitmore
11:25 – 11:55	Discussion	16:20 – 16:45	Changes in vertical ice extent along the East Antarctic ice sheet margin in Western Dronning Maud Land – first field and modelling results of the "Magic DML" collaboration Ola Fredin
12:00 – 13:00	---LUNCH---	16:45 – 17:30	---COFFEE and posters
13:00 – 13:40	KEYNOTE Filling in the gaps: the recent evolution of chlorine-36 and uses in changing landscapes Shasta Marrero	17:30 – 18:00	World Heritage Foundation Geirangerfjord Merete
13:40 – 14:10	Discussion	19:00 – 21:00	---CONFERENCE DINNER---

WEDNESDAY 6 JUNE

09:00 – 09:25	The local LGM in the Patagonian Andes: insights from new ¹⁰ Be and OSL moraine and outwash chronologies at 39-44°S Juan L. Garcia	09:50 – 10:15	Uncertainties associated with the use of cosmogenic nuclide exposure dating (¹⁰ Be) for reconstructing the timing of ice sheet retreat in southern Norway John Inge Svendsen
09:25 – 09:50	Ice marginal fluctuations of the Greenland ice sheet and local ice cap in McCormick fjord, NW Greenland Anne Sofie Søndergaard	10:15 – 10:45	---COFFEE
		10:45 – 12:00	Discussion and closing remarks
		12:00 – 13:00	---LUNCH---

Programme Monday 4 June

09:00 – 09:15 Welcome (Henriette)

09:15 – 10:00 **Lewis Owen**, University of Cincinnati, USA

K#1: *Successes and challenges in applying cosmogenic and luminescence dating methods for paleoseismic and slip rate studies along active faults: examples from the western Cordilleras of the America and the Himalayan-Tibetan orogen* (page 21)

10:00 – 10:25 **Stephanie Neuhuber**, BOKU, Austria

T#1: *Cosmogenic Al and Be inventory from terrace deposits of the Central Vienna Basin: implications on the source area from cosmogenic ^{26}Al and ^{10}Be ratios* (page 22)

10:25 – 10:55 **Coffee**

10:55 – 11:20 **Annina Margreth**, Geological Survey of Norway

T#2: *Pleistocene and Holocene evolution and weathering of coastal landscapes in Norway* (page 24)

11:20 – 11:25 **Anne Hormes**, University of Tromsø. *Ideas on funding*

11:25 – 12:00 1-minute flash-presentation of posters (all poster presenters)

12:00 – 13:00 **LUNCH** (covered by 4NWCN)

13:00 – 13:25 **Kristina Hippe**, ETH Zürich, Switzerland

K#2: *Constraining changes in Holocene surface erosion rates with in situ ^{14}C - ^{10}Be analyses* (page 26)

13:25 – 13:50 Discussion

13:50 – 14:15 **Maarten Lupker**, ETH Zürich, Switzerland

T#3: *Paired ^{10}Be and in-situ ^{14}C measurements in Himalayan catchments: tracers of landslide sediment inputs?* (page 27)

14:15 – 14:40 **Swann Zerathe**, IRD - ISTERre, France

T#4: *Dominance of climate upon seismicity on giant landslide triggerings along the hyper-arid western Andes* (page 28)

14:40 – 15:40 **Coffee and Posters**

15:40 – 16:05 **Paula Hilger**, Geological Survey of Norway

T#5: *Implications of inherited isotope concentrations when dating landslides with terrestrial cosmogenic nuclide dating* (page 30)

16:05 – 16:30 **Xavi Gallach**, EDYTEM Lab, Université Savoie Mont Blanc, France

T#6: *TCN dating of Holocene and Lateglacial rockfalls in the Mont Blanc massif. Development of GRIGRI: a new method of surface exposure age dating using reflectance spectroscopy* (page 31)

16:30 – 17:15 **Reginald Hermanns**, Geological Survey of Norway

K#3: *How do rock slope failures in Norway fit into and how do they contribute to the landscape development?* (page 33)

17:30 – 19:30 Tsunami (disaster) film with introduction by Atle Nesje, University of Bergen

19:30 – 21:00 **DINNER, Union buffet** (covered by 4NWCN)

Programme Tuesday 5 June

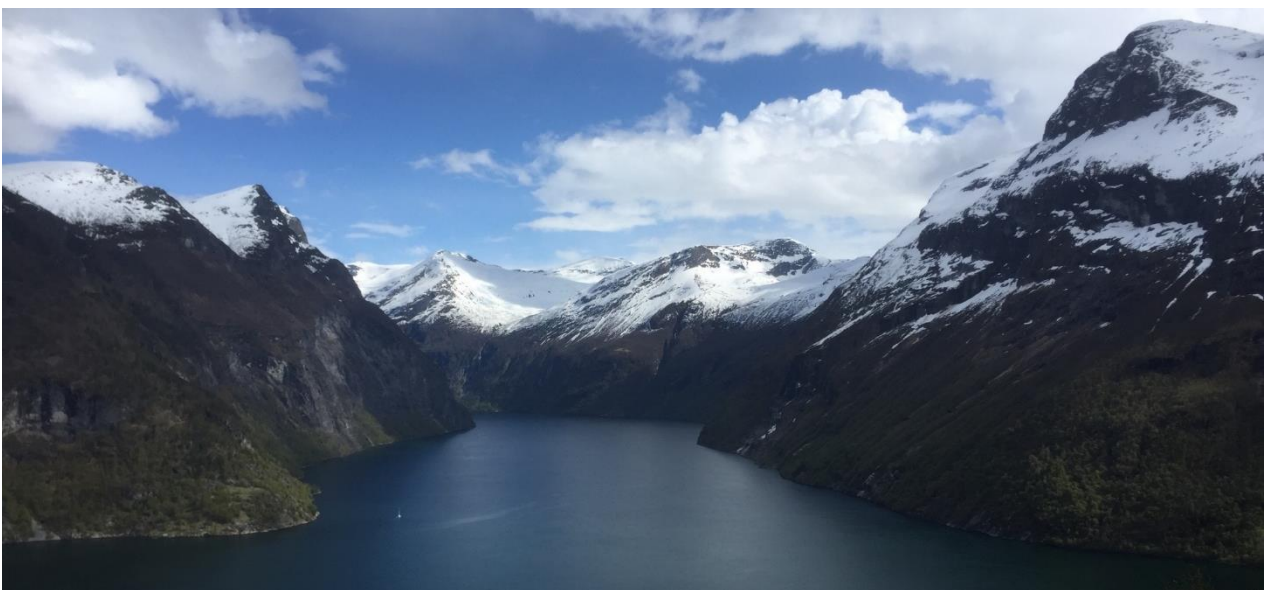
- 08:30 – 08:55 **Ariane Binnie**, University of Cologne, Germany
T#7: *Evidence for the Middle-Pleistocene Transition in Northern Chile* (page 34)
- 08:55 – 09:20 **Alessa Geiger**, Universidad Católica de Chile
T#8: *Developing a geochronology of ice sheet extent and thickness in the hyper-humid fjords of south-western Chile (52-55°S)* (page 35)
- 09:20 – 09:45 **Joel Mohren**, University of Cologne, Germany
T#9: *Using cosmogenic nuclides to trace a steep climate gradient over a short distance in hyperarid northern Chile* (page 37)
- 09:45 – 10:45 Coffee and Posters**
- 10:45 – 11:25 **Jane Willenbring**, Scripps Institution of Oceanography, University of California, USA
K#4: *Not feeling the buzz: tectonic limits to mountain heights and geomorphic feedbacks maintain subdued topography* (page 38)
- 11:25 – 11:55 Discussion
- 12:00 – 13:00 LUNCH** (covered by 4NWCN)
- 13:00 – 13:40 **Shasta Marrero**, University of Edinburgh, Scotland
K#5: *Filling in the gaps: the recent evolution of chlorine-36 and uses in changing landscapes* (page 39)
- 13:40 – 14:10 Discussion
- 14:10 – 14:35 **Steven Binnie**, University of Cologne, Germany
T#10: *Initial measurements of CoQtz-N: a quartz reference material for terrestrial in-situ cosmogenic ^{10}Be and ^{26}Al* (page 40)
- 14:35 – 15:05 Coffee and Posters**
- 15:05 – 15:30 Discussion on Posters
- 15:30 – 15:55 **Monika Mendelova**, University of Edinburgh, Scotland
T#11: *Extensive early mountain glaciation in central Patagonia during marine isotope stage 5* (page 41)
- 15:55 – 16:20 **Ross Whitmore**, Victoria University of Wellington, New Zealand
T#12: *New record of ice surface elevation changes for Tucker glacier in Victoria Land, Antarctica* (page 42)
- 16:20 – 16:45 **Ola Fredin**, Geological survey of Norway
T#13: *Changes in vertical ice extent along the East Antarctic ice sheet margin in Western Dronning Maud Land – first field and modelling results of the "Magic DML" collaboration* (page 43)
- 16:45 – 17:30 Coffee and last chance to see POSTERS**
- 17:30 – 18:00 World Heritage Foundation Geirangerfjord (Merete or Katrin)
- 19:00 – 21:00 CONFERENCE DINNER, Union buffet** (covered by 4NWCN)

Programme Wednesday 6 June

- 09:00 – 09:25 **Juan L. García**, Universidad Católica de Chile
T#14: *The local LGM in the Patagonian Andes: insights from new ^{10}Be and OSL moraine and outwash chronologies at 39-44°S* (page 44)
- 09:25 – 09:50 **Anne Sofie Søndergaard**, Aarhus University, Denmark
T#15: *Ice marginal fluctuations of the Greenland ice sheet and local ice cap in McCormick fjord, NW Greenland* (page 45)
- 09:50 – 10:15 **John Inge Svendsen**, University of Bergen, Norway
T#16: *Uncertainties associated with the use of cosmogenic nuclide exposure dating (^{10}Be) for reconstructing the timing of ice sheet retreat in southern Norway* (page 46)
- 10:15 – 10:45** Coffee
- 10:45 – 11:45 Discussion
- 11:45 – 12:00 Closing remarks (Linge)
- 12:00 – 13:00** LUNCH (covered by 4NWCN)

Excursion and group travel to Ålesund and Ålesund airport

- 13:15 – 15:00 Local sites around Geiranger
TBC - dependent on snow conditions
- 15:30 – 16:35 Ferry cruise, Geiranger - Hellesylt
- 16:35 – 18:00 Drive Hellesylt - Sykkylven
- 18:10 – 18:15 Ferry Sykkylven - Magerholm
- Drop-off: Moa and Ålesund bus terminals
- 19:20 Arrive Ålesund airport



Head of the Geirangerfjord, May 2017. Photo: A.Nesje

Table of oral presentations

Number	Presenter	Title	Page
1	Lewis Owen	KEYNOTE 1: Successes and challenges in applying cosmogenic and luminescence dating methods for paleoseismic and slip rate studies along active faults: examples from the western Cordilleras of the America and the Himalayan-Tibetan orogen	21
2	Stephanie Neuhuber	Cosmogenic Al and Be inventory from terrace deposits of the Central Vienna Basin: implications on the source area from cosmogenic ²⁶ Al and ¹⁰ Be ratios	22
3	Annina Margreth	Pleistocene and Holocene evolution and weathering of coastal landscapes in Norway	24
4	Kristina Hippe	KEYNOTE 2: Constraining changes in Holocene surface erosion rates with in situ ¹⁴ C- ¹⁰ Be analyses	26
5	Maarten Lupker	Paired ¹⁰ Be and in-situ ¹⁴ C measurements in Himalayan catchments: tracers of landslide sediment inputs?	27
6	Swann Zerathe	Dominance of climate upon seismicity on giant landslide triggerings along the hyper-arid western Andes	28
7	Paula Hilger	Implications of inherited isotope concentrations when dating landslides with terrestrial cosmogenic nuclide dating	30
8	Xavi Gallach	TCN dating of Holocene and Lateglacial rockfalls in the Mont Blanc massif. Development of GRIGRI: a new method of surface exposure age dating using reflectance spectroscopy	31
9	Reginald Hermanns	KEYNOTE 3: How do rock slope failures in Norway fit into and how do they contribute to the landscape development?	33
10	Ariane Binnie	Evidence for the Middle-Pleistocene Transition in Northern Chile	34
11	Alessa Geiger	Developing a geochronology of ice sheet extent and thickness in the hyper-humid fjords of south-western Chile (52-55°S)	35
12	Joel Mohren	Using cosmogenic nuclides to trace a steep climate gradient over a short distance in hyperarid northern Chile	37
13	Jane Willenbring	KEYNOTE 4: Not feeling the buzz: tectonic limits to mountain heights and geomorphic feedbacks maintain subdued topography	38
14	Shasta Marrero	KEYNOTE 5: Filling in the gaps: the recent evolution of chlorine-36 and uses in changing landscapes	39
15	Steven Binnie	Initial measurements of CoQtz-N: a quartz reference material for terrestrial in-situ cosmogenic ¹⁰ Be and ²⁶ Al	40
16	Monika Mendelova	Extensive early mountain glaciation in central Patagonia during marine isotope stage 5	41
17	Ross Whitmore	New record of ice surface elevation changes for Tucker glacier in Victoria Land, Antarctica	42
18	Ola Fredin	Changes in vertical ice extent along the East Antarctic ice sheet margin in Western Dronning Maud Land – first field and modelling results of the "Magic DML" collaboration	43
19	Juan L. García	The local LGM in the Patagonian Andes: insights from new ¹⁰ Be and OSL moraine and outwash chronologies at 39-44°S	44
20	Anne Sofie Søndergaard	Ice marginal fluctuations of the Greenland ice sheet and local ice cap in McCormick fjord, NW Greenland	45
21	John Inge Svendsen	Uncertainties associated with the use of cosmogenic nuclide exposure dating (¹⁰ Be) for reconstructing the timing of ice sheet retreat in southern Norway	46

Table of poster presentations

Number	Poster presenter	Title	Page
1	Anjar, Johanna	Cosmogenic surface exposure dating of the deglaciation of Finnmark and northern Finland	47
2	Blomdin, Robin	The global last glacial maximum in Central Asia	48
3	Braucher, Régis	Towards a better cleaning of chert samples for better ^{10}Be and ^{26}Al measurements	49
4	Braucher, Régis (Sartégou, A.)	Quantifying incision rates since the early Miocene using TCN into caves: methodological issues, solutions and expectations	50
5	Braucher, Régis (Sartégou, A.)	When TCN meet high school students: deciphering western Cévennes landscape evolution (Lozère, France) using TCN on karstic networks	51
6	Bros, Ewelina	When did glaciers disappear from the High Tatra Mountains?	53
7	Darvill, Christopher M.	Exposure dating ice retreat and landscape change on Canada's western coast	54
8	Egholm, David L.	Glacial erosion and relief production on gneiss-granite plateaus	55
9	Fredin, Ola (Romundset, A.)	Lateglacial retreat chronology of the Scandinavian ice sheet in Finnmark, northern Norway, reconstructed from surface exposure dating of major end moraines	56
10	Geiger, Alessa	Glacial geochronology of north-eastern Patagonia using ^{10}Be and ^{36}Cl : implications for southern hemispheric palaeoclimate	58
11	Gheorghiu, Delia	Burial dating of fluvial terraces using cosmogenic nuclides, Arieş River (Romania)	59
12	Grischott, Reto	Constraining further Swiss Deckenschotter sites with cosmogenic ^{10}Be - ^{26}Al isochron burial dating	60
13	Hein, Andrew	Regional mid-Pleistocene glaciation in central Patagonia	62
14	Heyman, Jakob	How good (or poor) is published glacial cosmogenic data?	63
15	Heyman, Jakob	Glacial erosion of Forsmark, east-central Sweden, based on bedrock ^{10}Be and ^{26}Al	64
16	Hormes, Anne	Detecting and monitoring past and present movement rates of slope deformations in Lienz (Tyrol, Austria)	66
17	Hughes, Anna	Constraining the evolution of the Eurasian ice sheets; How useful are more cosmogenic nuclide dates?	67
18	Ivy-Ochs, Susan	Spatial and temporal distribution of large landslides in the Alps: Trentino	69
19	Knudsen, Mads F.	Exploring the secrets of the banana – the new landscape histories arising from linking paired ^{10}Be and ^{26}Al to variable erosion rates	71
20	Kronig, Olivia	Subglacial erosion in limestone bed at Tsanfleuron Glacier, Switzerland	72
21	Larsen, Nicolaj K.	Instability of the northeast Greenland ice stream over the last 45,000 years	73
22	Linge, Henriette	UiB cosmogenic nuclide preparation facility	74
23	Mariotti, Apolline	^{10}Be -derived present-day and paleo denudation rates of the Var catchment, southern French Alps	75
24	Mettler, Katja	Deglaciation and isostatic uplift in Finnmark	76
25	Regard, Vincent	Neogene basin infilling from cosmogenic nuclides (Be -10 and Ne -21) in Atacama, Chile: implications for paleoclimate and copper supergene enrichment	77
26	Schide, Katherine	Evaluating the role of coseismic landsliding on cosmogenic nuclides, erosion rates, and topographic evolution in mountainous landscapes. A case study of the MW 7.8 Gorkha earthquake, Nepal	78
27	Yi, Chaolu	Geochronology of Quaternary glaciations in Puruogangri, the largest icecap in the Tibetan Plateau	79

SUCCESSSES AND CHALLENGES IN APPLYING COSMOGENIC AND LUMINESCENCE DATING METHODS FOR PALEOSEISMIC AND SLIP RATES STUDIES ALONG ACTIVE FAULTS: EXAMPLES FROM THE WESTERN CORDILLERAS OF THE AMERICAS AND THE HIMALAYAN-TIBETAN OROGEN

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The development of terrestrial cosmogenic nuclide (TCN) surface exposure dating methods over the past few decades have helped accelerate interest in tectonic geomorphology, particularly because now many landforms that could not be previously dated with radiocarbon methods, due to the lack of organic material, can be relatively easily dated. Moreover, the TCN method, mainly using Be-10, Al-26, Cl-36, and Ne-10, can allow landforms from a few decades to several million years old to be dated, far beyond the radiocarbon range of about 30–50 ka. Advances in luminescence dating, specifically optically stimulated luminescence (OSL) dating, have paralleled those of TCN methods. In particular, luminescence methods have now been very successfully applied to date landforms and essentially sediments in fault trenches for paleoseismic studies and have a dating range from a few decades to many hundreds of thousands of years. However, both these sets of methods have inherent complexities and limitations. Two sets of factors contribute to the TCN dating uncertainty. Firstly, problems are introduced in calculation of the production rate and scaling models for TCNs. Recently programs have greatly help reduce this set of uncertainties. Geological factors introduce the second set of uncertainty. These include weathering, exhumation, prior exposure, and shielding of the surface by sediment and/ or snow. With the exception of prior exposure, these factors generally reduce the concentration of TCNs in surfaces, which results in an underestimate of the true age of the landforms. Episodes of prior exposure result in an overestimate of the true age. Uneven distribution of these geological processes can produce a large spread in apparent exposure ages on a landform. Researchers commonly assess these effects by collecting multiple samples on a surface to examine the range of ages and/or undertaken depth profiles measurement. Challenges associated with luminescence dating includes insufficient bleaching of sediment before its deposition, which effectively does not reset the sediment and results in older ages, and poor sensitivity of the mineralogy which reduces the effectiveness of sediment minerals to store a useful luminescence signal. TCN and luminescence dating methods that been applied widely through most major active plate margins, particularly the Himalayan-Tibetan orogeny and western cordilleras of the Americas that illustrate the challenges and successes of using these methods. Informative studies include ones along the San-Andreas and associated faults, the faults of the Eastern California Shear Zone, Walker Lane, the Basin and Range, the Pre-Cordillera of Argentina, and the Kararkoram fault and associated faults including the Chaman fault. These studies are aiding in defining the slip rates and the understanding of partitioning of deformation along and across these plate boundaries, and earthquake recurrence, and are helping to quantify tectonic and geomorphic models. In particular, these studies are helping to determine the degree to which fault loading and strain release rates are constant (or non-constant) in time and space, and are allowing comparisons of short-term geodetic data with very long-term (million year) global plate motion.

COSMOGENIC Al AND Be INVENTORY FROM TERRACE DEPOSITS OF THE CENTRAL VIENNA BASIN: IMPLICATIONS ON THE SOURCE AREA FROM COSMOGENIC ^{26}Al AND ^{10}Be RATIOS

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In the Vienna Basin, Austria, a combination of varying rates of sediment input, erosion, and tectonic displacement control the formation of fluvial terraces deposited by the Danube river. One Middle Pleistocene terrace located in the central Vienna Basin was dated to an age of terrace abandonment of 140 ± 170 ka by combining burial (isochron) and luminescence dating.

The cosmogenic nuclide data set is – apart from assigning a numerical age - interesting from a methodological point of view: four of ten samples have $^{26}\text{Al}/^{10}\text{Be}$ ratios above the surface production ratio. Those samples were excluded from age calculation, but were investigated closely to find possible causes for the increased ratios.

Often, when measured nuclide concentrations lead to increased ratios, the quality of sample preparation and AMS measurements is questioned. Therefore possible analytical errors such as chemical protocols, carrier characterization, native Beryllium, and errors in ICP-OES aliquot measurements were checked and excluded.

Therefore we suggest a process-based explanation for the dataset. Rapid exhumation of fresh bedrock increases the importance of muons as nuclide production pathway prior to exposure. Braucher et al. (2013) measured a muon-influenced production ratio of approximately 8.3 for a depth range of 0–6500 g/cm²; Akçar et al. (2017) calculated a $^{26}\text{Al}/^{10}\text{Be}$ of ca. 8.4 at 10 m depth decreasing gradually to a value of 6.75 towards the surface. When rock is abraded rapidly and exposed for a short time, its nuclide inventory has not reached equilibrium with the surface ratio. Thus, samples from glacial areas are likely to contain an increased muon production signal and thus an increased $^{26}\text{Al}/^{10}\text{Be}$ ratio. In comparison, estimated denudation rates in the Northern Calcareous Alps range between 30–180 m/ Ma (Kuhlemann, 2007) which stresses the rapid uplift of this area. In addition, low absolute nuclide concentrations were found in most samples, which might be another indicator for a glacial source area with muon production as a relevant process.

Four samples had elevated $^{26}\text{Al}/^{10}\text{Be}$ nuclide ratios, whereas the remaining samples could be used for isochron age calculation and are in excellent agreement with the luminescence data. The presence of two separate clast populations could be explained by one set that originates from slowly to moderately exposed surfaces – either from a source in the Variscan Bohemian Massif that was ice-free during the last glacials– or from re-deposited older gravel, and another set derived from rapidly exposed rock, presumably from the Alps.

Burial ages derived from samples originating from glacial areas need to be calculated using an increased initial nuclide ratio, which captures the pace of erosion in the source area and the muon signal saved in the samples. The determination of the correct initial nuclide ratio of those areas is challenging and appears to lie somewhere in the spectrum between 6.75 and 8.4. For our dataset we can use the terrace age derived from luminescence dating and isochron burial dating to back-calculate initial ratios in the source area of samples affected by glacial erosion to an initial surface ratio.

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Thanks to the Austrian Science Fund (FWF): P23138-N19 and the BOKU Career Advancement Scholarship (Förderungstipendium)

PLEISTOCENE AND HOLOCENE EVOLUTION AND WEATHERING OF COASTAL LANDSCAPES IN NORWAY

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The traditional scientific view is that the deep incision of fjords into a pre-Quaternary landscape was caused by extensive erosion of Pleistocene ice sheets and glaciers. Polished and striated bedrock surfaces bear evidence for negligible Holocene weathering of glacially eroded landscapes. However, in areas where no glacially polished and striated bedrock surfaces are found, it is more difficult to assess the amount of Holocene erosion or weathering. Here, we present new cosmogenic nuclide data from three coastal localities in Norway that allow to reconstruct the Quaternary evolution of the landscape.

In northern Norway, the iconic summit of Stetind has been regarded as a remnant of the pre-Quaternary “palaeic surface” that has escaped Pleistocene glacial erosion as a nunatak (Reusch, 1901). The 1400 m asl peak of Stetind is blockfield-mantled, indicating periglacial weathering and erosion that may lower the plateau surface. This inference is supported by new ¹⁰Be and ²⁶Al data obtained from three large gneiss-slaps, which reveal complex exposure histories constrained to the late Quaternary. 25 km west of Stetind, the c. 500 m asl mountain ridge of Bogvetten has a grussic weathering mantle. Up to 2 m tall rock plinths, composed of Hornblende-Biotite-Gneis, rise above the current erosion surface, yet the tops of these plinth are often flat and conform to the surrounding topography (Fig. 1a). Newly obtained ¹⁰Be data from three of these plinths indicate that these top surfaces were eroded during the last glaciation and weathering and erosion of the surrounds left the plinths elevated above the current erosion surface.

In western Norway, bedrock (augengneiss and metagabbro) near Kråkenes lighthouse (35 m asl) on Vågsøy Peninsula is clearly affected by tafoni weathering. Tafoni and caverns are often >50 cm in diameter and chemical analyses of detritus collected in the tafoni indicate minimal alteration of the rock. Several sample-pairs of bedrock and boulders on bedrock show more or less concordant ¹⁰Be ages, which are consistent with the deglaciation of the region as determined by additional samples from boulders in till or from moraines. The formation of tafoni thus postdates deglaciation, indicating rapid weathering controlled by saline sea spray and aerosols.

Finally, in southern Norway, a classic locality (5 m asl) exhibiting suggested pre- Weichselian weathering of an Ordovician limestone xenolith in larvikite, described first by Reusch (1878), was sampled within and outside of the area, where fresh limestone was exposed by glacial plucking (Fig. 1b). Using ³⁶Cl, we plan to test the hypothesis that there will be significantly higher concentrations (older ages) in the area affected by the rillenkarren compared to the apparent glacially-plucked surface.

Each of the studied weathering phenomena enables a glimpse into the different local surface processes that have taken place during the Pleistocene and Holocene. Cosmogenic nuclides constrain, within their implicit limitations, the exact timing and rates of these processes and hence contribute to the understanding of Quaternary landscape evolution in Norway.

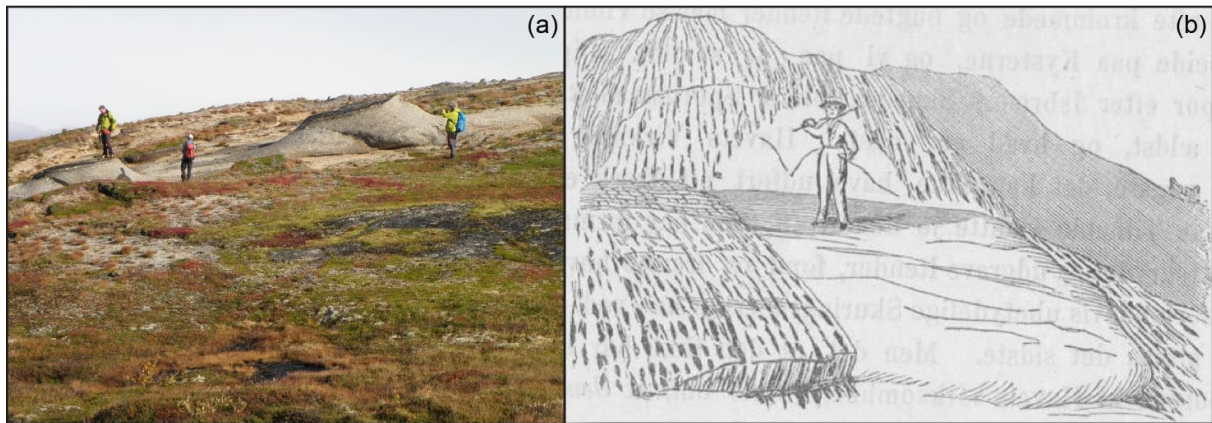


Fig. 1 Studied weathering phenomena. **a)** Bogvetten: $<2\text{m}$ tall gneiss-plinths with flat tops mimicking the surrounding topography rise above the current grussic weathering mantle. ^{10}Be samples were collected from the flat tops of three plinths. **b)** Drawing by Reusch (1878), who concluded that the rillenkarren in the Ordovician limestone xenolith must have formed prior plucking of a bedrock block during the Weichselian glaciation. Three samples were collected each from the plucked limestone and from the rillenkarren.

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CONSTRAINING CHANGES IN HOLOCENE SURFACE EROSION RATES WITH *IN SITU* ^{14}C - ^{10}Be ANALYSES

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Quantifying the amplitude and frequency of past changes in surface erosion rates is key to our understanding of the response of the Earth's surface to environmental changes. The short half-life of the *in situ* cosmogenic ^{14}C isotope makes it highly sensitive to recent (Holocene) short-term changes in surface erosion and, thus, provides a uniquely versatile tool to investigate landscape transience in actively eroding settings. Coupling the short-lived *in situ* ^{14}C nuclide to the long-lived ^{10}Be allows us to determine the timing and magnitude of erosion rate change, or the timing and thickness of mass removed during an instantaneous mass erosion event, e.g. in the case of soil stripping. This approach has the notable benefit that landscape transience can be detected directly on the hillslopes or ridgetops. It offers a distinct advantage over assessing erosion rate changes from sedimentary records, which can be biased due to ineffective source-to-sink coupling and long sediment transit times.

We have used combined *in situ* ^{14}C - ^{10}Be analysis on hilltop samples from the semi-arid eastern Altiplano (Bolivia). Preliminary results show very good agreement between both nuclides, i.e. steady-state conditions, for samples taken from the erosion-resistant quartzitic bedrock. In contrast, sediment samples collected from the rounded hilltops developed in less resistant lithologies show a pronounced mismatch between *in situ* ^{14}C and ^{10}Be , mainly very low *in situ* ^{14}C concentrations. We interpret this as evidence of landscape transience due to a drastic increase in surface erosion rates during the Holocene. Using Markov Chain Monte Carlo (MCMC) modelling we explore the possible range of initial and changed erosion rates as well as the timing of when the change occurred (Fig. 1). Additionally, the possibility of concomitant soil stripping is modelled. The results will be discussed in the light of i) regional Holocene climate variability, i.e. wet-dry cycles, and ii) a possible anthropogenic impact from land use.

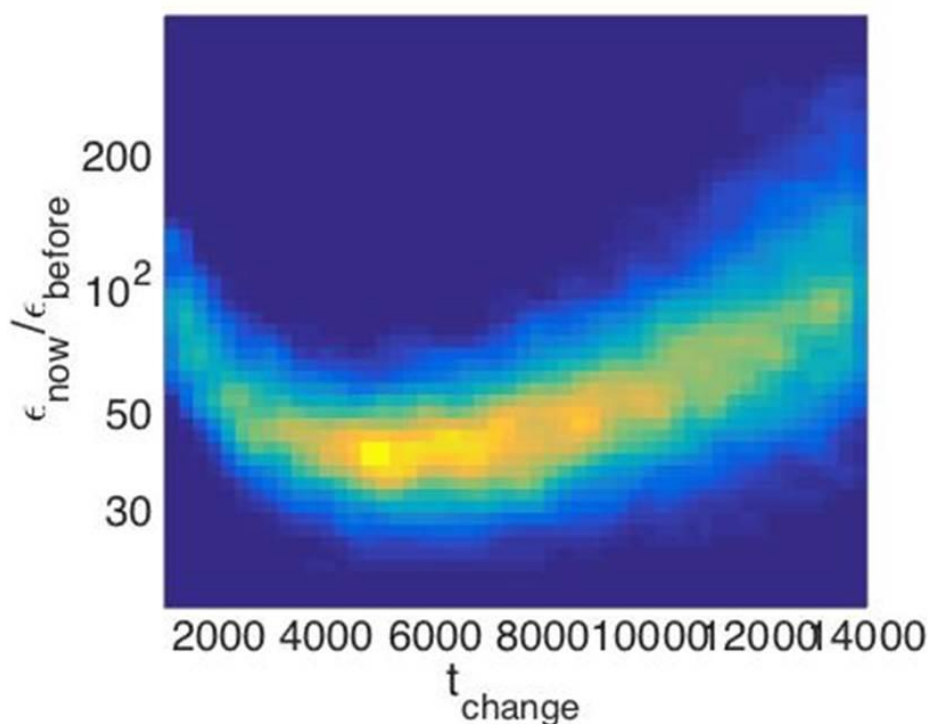


Fig. 1: Results from the MCMC model based on the measured *in situ* ^{14}C and ^{10}Be concentrations of one hilltop sample. The model shows that the change in erosion rates (given as ratio $e_{\text{now}}/e_{\text{before}}$ on the y-axis) is smallest when the event occurred during the Mid-Holocene (given as t_{change} on x-axis).

PAIRED ^{10}Be & IN-SITU ^{14}C MEASUREMENTS IN HIMALAYAN CATCHMENTS: TRACERS OF LANDSLIDE SEDIMENT INPUTS?

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Cosmogenic nuclides in detrital river sediments have been widely applied to derive denudation rates and sediment fluxes across entire catchments. Nuclides such as ^{10}Be allow the derivation of denudation rates integrated over several hundreds to thousands of years, but single isotopic systems often provide little information on the intricate processes and dynamics that dominate sediment export.

In actively eroding landscapes, landslides are often proposed to be the main source of sediments but quantitative estimates of their contribution to large scale fluxes remain rare. In this contribution we explore the use of paired ^{10}Be and in-situ ^{14}C measurements in river sediments in an attempt to constrain catchment-wide landslide characteristics. The concentration profiles of ^{10}Be and in-situ ^{14}C at the Earth surface vary uniquely with depth and exposure duration (or erosion rate). In theory, it is therefore possible to use paired ^{10}Be and in-situ ^{14}C measurements to distinguish surface erosion from landslide inputs and even to constrain both the average landsliding depth and recurrence time.

We measured ^{10}Be and in-situ ^{14}C in sediments from two large catchments in the central Himalaya (Narayani and Kosi catchments in central Nepal). Our preliminary $^{14}\text{C}/^{10}\text{Be}$ data show that sediments from these rivers plot clearly away from the theoretical concentrations for steady-state surface erosion and suggest large landslide-derived sediment inputs. However, the interpretation of this data is not straightforward as possible sediment storage and poor mixing might also influence the $^{14}\text{C}/^{10}\text{Be}$ ratio of exported sediments.

DOMINANCE OF CLIMATE UPON SEISMICITY ON GIANT LANDSLIDE TRIGGERINGS ALONG THE HYPER-ARID WESTERN ANDES

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Deciphering the respective roles of seismicity and/or climate variations regarding paleolandslide triggerings has been proved challenging. This mainly results from the fact that: (1) seismicity and climate variations are often concomitant in the studied reliefs; and (2) paleolandslide reconstructions are mostly limited to the last ten of thousand years which does not allow to investigate more than one or two cycles of events.

The complete failure history of a giant landslide complex located in the southwestern Peruvian Andes has been reconstructed using high resolution DEMs and surface exposure dating based on multiple cosmogenic nuclides. The particularity of the investigated site, the Caquilluco landslide, is its size (length > 40 km long and volume >15 km³) and its exceptional state of morphological conservation which allows the identification and mapping of several deposits corresponding to distinct episode of failures. Indeed, the hyper-aridity characterising this region (Atacama Desert) strongly limit surface denudation processes which allows the landscape to be preserved for several millions of years.

However, the lack of quartz in the mafic lithology of this site (mostly ignimbrite), hampers the routine use of the ¹⁰Be-quartz couple to constrain the chronology of the Caquilluco landslide evolution. An alternative approach, that will be presented, based on ¹⁰Be concentrations measured in feldspar and cross-calibrated against ³He concentrations measured in cogenetic pyroxene had thus to be developed. Forty-six boulders cosmic-ray exposure ages were then determined to reconstruct the complete landslide evolution history. At least six independent and successive giant failure events that occurred between ca. 100 and 600 ka ago were identified. The recurrence time between the landslide episodes ranging from a dozen to hundreds of kilo-years contrasts with typical recurrence time of high magnitude earthquakes (Mw>8, subduction and crustal) which is in this region on the order of 200 years. Instead, a striking correlation between the failure events and the known climate reversals chronologies is observed. According to the obtained data, the landslides of the Atacama Desert are likely triggered during short but extreme wet events occurring during interglacial periods. This hypothesis seems to be corroborated by several local and global proxies such as: phases of high lake levels on the Altiplano and in the Atacama Desert; deposits of thick alluvial terraces filling valleys adjacent to the landslide; and, synchronous peak of high sea surface temperatures of the Pacific that may control the occurrence of extreme El Niño (ENSO) events.

The results to be presented challenge previous published studies claiming that landslide triggerings in the western Andes were only controlled by seismicity and suggest, on the contrary, that seismicity should be considered as background noise.

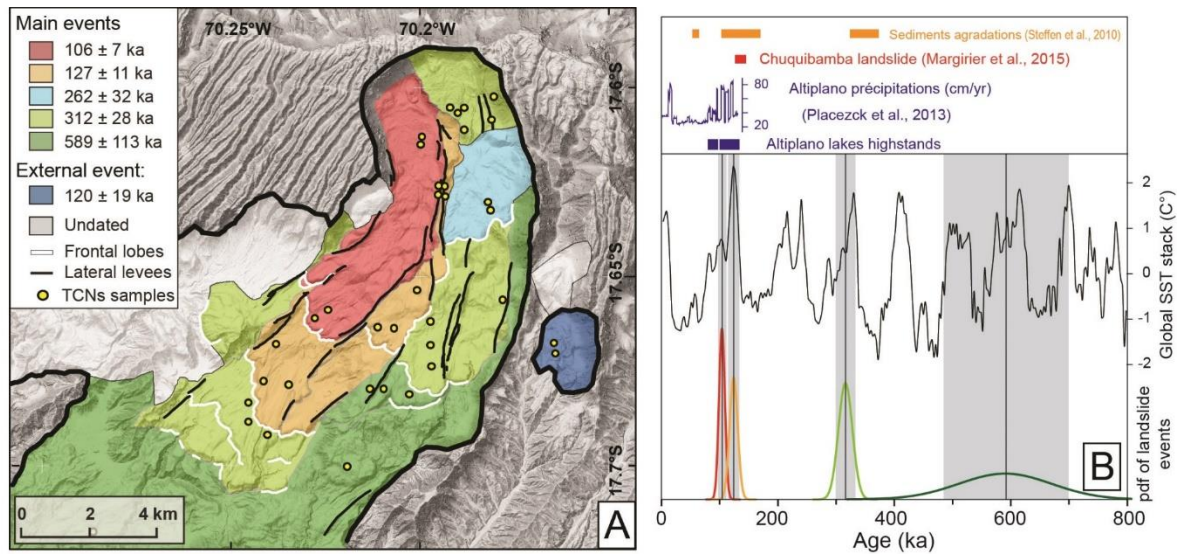


Figure: Synthesis of results on the Caquilluco landslide. A) Mapping of landslide morphologies, location of sampled boulders and reconstruction of the failure chronology. B) Correlation between the timing of failures and various climate proxies. Failures occurred during interglacial phase characterized by extreme precipitations events (e.g. Ouki event at 100-120 ka).

IMPLICATIONS OF INHERITED ISOTOPE CONCENTRATIONS WHEN DATING LANDSLIDES WITH TERRESTRIAL COSMOGENIC NUCLIDE DATING

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Throughout the last decade terrestrial cosmogenic nuclide (TCN) dating has become one of the most widely used techniques for the absolute age determination of landslides. However, the method is still connected to challenges such as age overestimations through inheritance or underestimations through boulder toppling or erosion. The challenge of inherited TCNs in landslide boulders is often discussed qualitatively, but was never addressed quantitatively. Through our approach of dating rock-avalanche boulders of known age, we show that 1) the ¹⁰Be isotope is suitable to date surfaces younger than 500 years and 2) the overestimation through inherited isotope concentrations can be systematic when dating landslides.

We dated six boulders of rock-avalanche deposits in Aysén Fjord, Chile, using the ¹⁰Be-isotope. The rock-avalanche was triggered nine years earlier by a swarm of shallow earthquakes. ¹⁰Be concentrations of five samples averaged 1.2 ± 0.3 kat/g ($\pm 1\sigma$) after subtraction of the ¹⁰Be process blank concentration of 9.53 kat/g and 9 years of post-depositional exposure (ca. 35 at/g, ignoring temporal production rate variations in that decade). An outlier clast yielded 7.0 ± 1.7 kat/g, which was sampled below a secondary failure scarp of the valley slope along the debris avalanche run-out track. Consequently, the resulting apparent surface exposure ages represent the amount of inheritance.

Assuming no unaccounted systematic measurement error, the inheritance provides important information regarding the source of the boulders. On the basis of a reconstructed pre-failure surface, we approximated the distribution of the ¹⁰Be concentration with depth. For this, we presumed a surface concentration that was set to zero by extensive glacial erosion. However, scenarios of different erosional histories and time spans since deglaciation have been considered. For the scenario of 12,000 years post-glacial exposure, all boulders must have originated from a depth shallower than 14 m inside the pre-slide cliff face. Considering a more conservative scenario, with 50 ka pre-exposure and only 10 m erosion during glaciation, the pre-slide boulder depths don't exceed 30 m. This is less than 30% of the maximal depth of the failure mass with 110 m based on volume and simple geometry. The secondary rockslide is with 10-50 m depth generally shallower where the outlier clast seems to originate from < 3 meters depth. This suggests that large boulders, which are usually chosen for TCN sampling when dating landslides, likely originate from rather shallow depths and are therefore affected systematically by inheritance.

TCN DATING OF HOLOCENE AND LATEGLACIAL ROCKFALLS IN THE MONT BLANC MASSIF. DEVELOPMENT OF GRIGRI: A NEW METHOD OF SURFACE EXPOSURE AGE DATING USING REFLECTANCE SPECTROSCOPY

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Rockfalls and rock avalanches are active processes in the Mont Blanc massif, with infrastructure and alpinists at risk. Thanks to a network of observers (hut keepers, mountain guides, alpinists) set up in 2007 current rockfalls are well surveyed and documented. Rockfall frequency has been studied over the past 150 years by comparison of historical photographs, showing that it strongly increased during the three last decades, likely due to permafrost degradation caused by the climate change. In order to understand the possible relationship between rockfall frequency and the warmest periods of the Lateglacial and the Holocene, we study the morphodynamics of some selected high-elevated (>3000 m a.s.l.) rockwalls of the massif on a long timescale.

Since rockfall deposits in glacial areas are evacuated by the glaciers, our study focuses on the rockfall scars. ¹⁰Be TCN dating of a rockwall surface gives us the rock surface exposure age, interpreted as a rockfall age. Here we present a dating dataset of 80 samples carried out between 2006 and 2016 at six high-elevated rockwalls in the Mont Blanc massif. The resulting ages vary from present (0.04 ± 0.02 ka) to far beyond the Last Glacial Maximum (c. 100 ka). Three clusters of exposure ages are correlated to i) the Holocene Warm Period, ii) the Roman Warm Period, and iii) the Little Ice Age and post-LIA. Ages of this last one are generally related to small rockfall volumes (< 15000 m³), considered as the normal erosion. A 4th cluster at 4.2-5.0 ka is not associated with any evident global climate period.

Furthermore, a relationship between the colour of the Mont Blanc granite and its exposure age has been established: fresh rock surface is light grey (e.g. in recent rockfall scars) whereas weathered rock surface is in the range grey to orange/red: the redder a rock surface, the older its age. Reflectance spectroscopy is used to quantify the granite surface colour. We explored the spectral data in order to find an index to measure the rock weathering evolution along time, thus allowing to date the rock surface exposure age using reflectance spectroscopy.

The G^{Re}en-Infrared GRanite Index (GRIGRI), based on the Remote Sensing-used Vegetation Indices, uses the ratio between the Green and Photographic Infrared reflectance. The resulting index is directly related ($r^2=0.863$) to the granite exposure age. The GRIGRI method has been tested for 8 samples where TCN dating failed and for two samples where ¹⁰Be exposure age are considered outliers. The resulting ages, according to the geomorphology of the scars and their surroundings, are plausible.



Figure 1: Rockfall scars in the Pyramide du Tacul (Mont-Blanc massif), with surface exposure ages of 7 samples. Relative chronology of the rockwalls surface exposure age is represented, from older (dark orange rock) to younger (grey rock), as follows: T1>T2>T3>T4.

HOW DO ROCK SLOPE FAILURES IN NORWAY FIT INTO AND HOW DO THEY CONTRIBUTE TO THE LANDSCAPE DEVELOPMENT?

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We sampled deposits of rock slope failures over large parts of western Norway and Troms county. Results obtained spread from the Older Dryas over the entire Holocene. Although the ages distribute over this time span there is no clear clustering of ages when looking on the total ages. This picture changes dramatically when plotting the distribution of ages in time after deglaciation. In both western Norway and Troms county ages cluster strongly in the first two millennia after deglaciation. Several of the slopes have failed repeatedly. While some slopes failed with large temporal gaps of several thousand years did two slopes failed in temporal clusters. Such temporal clustering of failures occurred at the Vora mountain in Sogn og Fjordane county after deglaciation and at the Mannen site in Møre og Romsdal once after deglaciation but also a second time in the mid Holocene.

We also sampled sliding surfaces of active rock slides for TCN dating. Similarly do our TCN ages of the deposits do TCN ages at the top of multiple sliding surfaces of large unstable rock slopes from Western Norway suggest a start of sliding directly following deglaciation. An alternative interpretation of our older post glacial ages of the start of sliding is that rock slopes could have slid prior to glaciation and traces of deformation got eroded by the ice sheet. This does not count for rockslides that initiated at the thermal maximum of the Holocene or in the mid Holocene.

Flat, highly elevated paleosurfaces show a large extent in northern Norway and some of these paleosurfaces are dissected by rock slides today. ²¹Ne dating of depth profiles provided minimum ages for three of those all being >> than 100 kyr, indicating that the Scandinavian ice sheet was non-erosive during the LGM on those surfaces. The Litledalen and Nomedalstinden DSGSDs developed on such high flat mountains and their back scarp intersects such mountain plateaus. Cosmogenic nuclide ages for the Litledalen plateau resulted in an age >100 kyr and the back scarp predates deglaciation. The top of Normandalstinden has an age prior to LGM and the top sample of the Nomedalstinden back scarp predates deglaciation also, while the lower samples postdate deglaciation. Both DSGSDs are strongly deformed and the surface is covered by rock glaciers, although some of the lobes might represent rock-avalanche deposits, as they are related to a pronounced depletion zone above the deposit and the lateral rims of the lobes cross rock glacier deposits. We sampled one lobe on the flanks of each of these DSGSDs. While the ages of the Litledalen deposit gave ages ranging from preglacial to shortly after deglaciation suggesting thus that this deposit is rather generated by surface processes that recycle surface material effectively (rock glacier) resulted the Nomedalstinden lobe in coeval ages shortly after deglaciation. Thus this deposit might represent the deposit of a rock avalanche. Thus these ages suggest that DSGSD in Norway can survive glacial cycles and get reactivated.

We also sampled the Gammanyunni plateau, the dissected plateau edge and the Gamanjunni 3 sliding surface. While the plateau has an age > 100 kyr, has the plateau edge only an age slightly older than LGM. The Gamanjunni 3 sliding surface has ages that are Holocene and young towards the bottom of the sliding surface. Ages cluster during climatic periods characterized by warmer temperatures suggesting, that the slide accelerates during warmer climatic periods and slows down when rock temperatures decrease. Displacement measurements today indicate slide velocity double the velocity of the average slip rate in the Holocene indicating that the rockslide is accelerating at present.

EVIDENCE FOR THE MIDDLE-PLEISTOCENE TRANSITION IN NORTHERN CHILE

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The Middle Pleistocene Transition (MPT, also called the Mid-Pleistocene Revolution) describes a shift in the periodicity of global climate cycles from obliquity driven 41 kyr cycles to higher amplitude 100 kyr cycles. The transition is thought to have occurred over a period of several hundred thousand years, beginning 1.2 Myr ago. Following the MPT, global ice volumes increased and were typified by slower rates of ice build-up, followed by more rapid melting. The geomorphological effects of the longer, more severe, ice ages of the post-MPT have been observed throughout the world, for example, an increased input of terrestrial sediments to the western coast of Africa, the doubling of sediment input into the Provencal Basin and the onset of intense river incision in Europe, Britain and China. Moreover, large-scale earth surface processes, such as variability in the subpolar North Atlantic Drift and a global acceleration of uplift, are also considered to correspond to the MPT. However, while the effects of this climatic transition appear profound, there have been problems to robustly date events correlated to the MPT, making it difficult to appreciate its true impact. In this study, we show that the timing of deposition of large volumes of glaciofluvial sediments in the lower valley of the Huasco River of northern Chile (~28°S) corresponds with the inferred global onset of the MPT and discuss the implications this has for the regional climate and tectonics.

Cyclical climate changes play a significant role in controlling the aggradation and incision patterns of rivers and thus climate change and its effects can be revealed by dating river terrace formation. Using cosmogenic ¹⁰Be analysis we dated pebbles from an abandoned, well preserved, upper-level fluvial terrace cut into the glaciofluvial sediments of the Huasco River valley, approximately 30 km upstream of the river mouth. Twenty-five ¹⁰Be measurements from three separate locations on the terrace, around 130 m above the current channel, give an arithmetic mean exposure age of 1.24 ± 0.27 Myr.

The more expansive glaciations that occurred following the beginning of the MPT would have extended into previously non-glaciated terrain, providing the potential for more erosion and sediment generation and also increased meltwater discharge during deglaciation. The ages we measure agree well with the timing proposed for the onset of the MPT, while the associated increase in the duration of climate cycles can explain the presence of the thick sedimentary deposits at the Huasco river-mouth. There are two key implications of our observations. Firstly, they imply that there were significant amounts of ice in the headwaters of the Huasco catchment within the high Andes, prior to around 1.2 Myr ago. Secondly, the amounts of sediments transported offshore to the Pacific Ocean may have spiked in response to the onset of the MPT. This hypothesis has implications for the large-scale tectonic processes of northern Chile that are influenced by sediments lubricating the subduction zone.

DEVELOPING A GEOCHRONOLOGY OF ICE SHEET EXTENT & THICKNESS IN THE HYPER-HUMID FJORDS OF SOUTH-WESTERN CHILE (52-55°S)

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During the last glacial cycle the Patagonian Ice Sheet (PIS) extended approx. 1800 kilometres east and west of the Andean Cordillera. Whilst a number of detailed geochronological constraints exist for the horizontal and vertical dimension of the PIS during the last glacial, all but two chronologies have been established at the former eastern terminating margins (Davies et al., in prep.). The western portion of the PIS covered the terrestrial-marine transition area where glacier dynamics are likely to have differed to the semi-arid eastern terrestrial counterparts. Strong correlation exists ($r=0.8$) between southern westerly wind strength and precipitation west of the Andes (Garreaud et al., 2013), making glacier chronologies from the PIS' former western terminating margin more suitable to answer question about local to hemispheric palaeoclimatic shifts during the Quaternary. In order to better understand glacier-climate dynamics in southern Patagonia comprehensive chronologies of glacier expansion and recession across longitudes and latitudes are needed. During Polarstern cruise 97 (ANT-XXXI/3) erratic boulder, bedrock and pebble samples were collected marking glacier extent/thickness at selected sites in the western-most Chilean Fjords (55-52°S), specifically: Isla Cabo de Hornos, Londonderry, Desolacion & Narborough (Fig. 1). Cosmogenic surface exposure dating (^{10}Be , ^{26}Al , ^{36}Cl) is being applied in conjunction with Optically Stimulated Luminescence exposure dating to determine sample specific weathering rates and exposure histories. The output provides insight into the suitability of the geochronological approach as well as a first order understanding of latitudinal (a)synchronicity of glacier extension in the hyper-humid Fjords of south-western Patagonia.

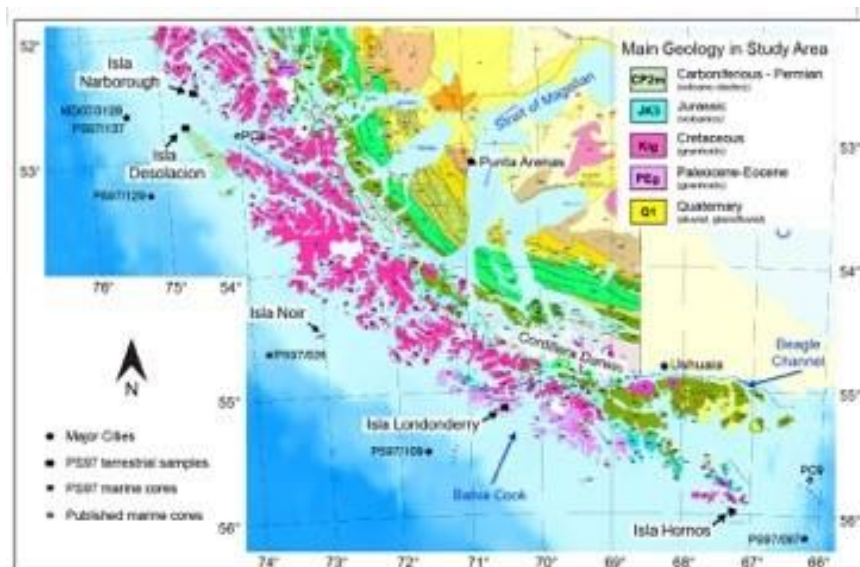


Fig. 1 | Geological map of southern South America, adapted from Sernageomin (2000). Marine & terrestrial samples collected during Polarstern cruise (PS97, ANT-XXXI/3) indicated as well as published marine core records.

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USING COSMOGENIC NUCLIDES TO TRACE A STEEP CLIMATE GRADIENT OVER A SHORT DISTANCE IN HYPERARID NORTHERN CHILE

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Long-term and persisting aridity has preserved an almost relict landscape in northern Chile. Thus, the region provides excellent conditions for the study of paleoclimate and the impact of climate and climate change on Earth-shaping processes and topography formation.

Here we present a set of catchment-wide denudation rates along a short E-W transect on the northern rim of the Río Loa Canyon in the Coastal Cordillera of northern Chile (latitude 21.4°S). In the study area, a flat sedimentary surface consisting of unconsolidated conglomerates of Miocene age becomes increasingly dissected and changes into a badland-like topography within a few kilometers of distance. We derived the denudation rates from cosmogenic ¹⁰Be in amalgamated samples from channel quartz pebbles. The denudation rates increase from east to west within ~3 km of distance, indicating the presence of a steep time-integrated climate gradient in this area. When related to major geomorphologic parameters, the denudation patterns point towards the presence of two different erosional regimes, which are sharply bounded against each other, separating a detachment-limited erosion regime in the eastern portion from a transport-limited regime to its western portion. Only the westernmost catchments show signs of sub-recent discharge. The gradient in landscape modification by fluvial activity evolved over multiple stadial/interstadial cycles. It is likely that the development of the observed geomorphic gradient is accelerated during wetter periods, such as during stadials, when wetter zones shift northward (Lamy et al., 2000). To test this hypothesis we measure in-situ cosmogenic ¹⁴C in the pebbles to distinguish between long-term Quaternary (¹⁰Be) and Holocene (¹⁴C) denudation rates.

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NOT FEELING THE BUZZ: TECTONIC LIMITS TO MOUNTAIN HEIGHTS AND GEOMORPHIC FEEDBACKS MAINTAIN SUBDUED TOPOGRAPHY

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The potential to rapidly denude topography at and above the glacier Equilibrium Line Altitude (ELA), irrespective of uplift rates, rock type or pre-existing topography, is explored in the *glacial buzzsaw* hypothesis. This hypothesis emerged from correlations between mountain heights and ELAs and has been fuelled by numerical landscape evolution models that show that glacial erosion can ultimately control mountain height. Some of the interest in this hypothesis has foundations in a separate hypothesis that global cooling during the onset of Northern Hemisphere glaciation during the Plio-Pleistocene is thought to increase rates of erosion in mountain belts. This *climate-driven erosion hypothesis* has the potential to feedback to long-term climate by accelerating silicate weathering and the sequestration of atmospheric CO₂, further decreasing temperatures. Together, the effects of these two hypotheses (if both true) would send the Earth into a deep freeze.

In this talk, we offer evidence from cosmogenic nuclide data and numerical models that (1) topography can persist in a state of transience for millions of years through feedbacks that can promote and maintain subdued topography dissected by valleys and that (2) the *glacial buzzsaw* cuts down—not across. The first of these observations is important because it offers an explanation for the misleading correlation of topography and ELAs rather than causation through glacial erosion. Around the world, and even in the original *buzzsaw* locality around Nanga Parbat, the pre-existing, pre-Pleistocene topography sets the height of high plateaus. The second observation, that the glacial buzzsaw cuts down—not across, supports the idea that glacial and periglacial processes become *less* effective at high elevations on plateaus and in mountains due to inhibition of glacial and periglacial processes by intense cold and lack of moisture and ice-shedding peaks. The *glacial buzzsaw* actually increases mountain relief.

Finally, we compiled tectonic, topographic, and erosion rate data from Arc-Continent convergent margins (Andes, Central America, Cascadia, British Columbia, Alaska, Taiwan, and Makran). We regressed plate convergence against average and maximum mountain heights and erosion rates from porphyry copper data. Erosion rates and elevation maxima and mean elevations correlate linearly with plate convergence rates. Importantly, mountain peaks in three heavily glaciated mountain ranges (Alaska, Cascadia, and South Chile) do not deviate from the trend which includes unglaciated mountain ranges such as the Central Andes and Taiwan. That mountain ranges with different climatic characteristics fall within the same trend implies that tectonics is the primary control of mountain range mass and heights—not glaciers.

FILLING IN THE GAPS: THE RECENT EVOLUTION OF CHLORINE-36 AND USES IN CHANGING LANDSCAPES

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Cosmogenic chlorine-36 plays a key role in investigating landscape change in many situations where other nuclides cannot be used. This happens most often for basalt and carbonate lithologies and in situations where a shorter half-life is preferred. Despite its utility, progress for chlorine-36 has sometimes lagged behind other nuclides, ironically because the multiple production pathways that make the technique so versatile also make it more complicated. Recent work has started to fill in the gaps. In addition to new production rates and calculators, we now have the first comprehensive inter-laboratory study for chlorine-36 using two new intercomparison materials. The results highlight agreement across the participating labs despite differences in the preparation and measurement procedures used in each lab.

Chlorine-36 has always filled in the gaps left by other nuclides. In Antarctica, new chlorine-36 results from carbonates fill in erosion rates from a previously missing lithology, making the comparison across all nuclides more valuable. Looking at hazards, chlorine-36 provides dates on numerous landslides in the Alps that have occurred in carbonate areas. The recent strides within the chlorine community will help to boost confidence in the use of chlorine-36, promote the advantages of the technique, encourage the development of useful tools, and inspire additional applications, like more joint use with other nuclides. Now that we have filled in the gaps and we are forging ahead - what's next?

INITIAL MEASUREMENTS OF CoQtz-N: A QUARTZ REFERENCE MATERIAL FOR TERRESTRIAL IN-SITU COSMOGENIC ^{10}Be AND ^{26}Al

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The last several decades have witnessed significant growth in the use of cosmogenic ^{10}Be and ^{26}Al in quartz to quantify Earth surface processes. Sample preparation for ^{10}Be and ^{26}Al determinations requires extensive and careful chemical processing that differs between laboratories, while AMS (accelerator mass spectrometry) groups may use different configurations, analysis schemes and calibration materials. The standard method of analyzing how well the results from different laboratory and measurement facilities agree is by inter-laboratory comparison. However, this requires available common materials, ideally with known, or at least accepted (i.e. nominal), values. Here, we discuss the preparation and initial ^{10}Be and ^{26}Al measurements of a quartz material labelled CoQtz-N. We propose CoQtz-N should be adopted as an in-house, chemistry procedure reference material by the terrestrial *in situ*-produced ^{10}Be and ^{26}Al user community.

The CoQtz-N quartz material was produced from a single boulder of vein quartz that was part of a lag deposit mantling a low relief surface near Hakos in Namibia. Following crushing, sieving and etching in dilute HF/HNO₃, the quartz was homogenized and split. Packaged splits of c. 165 g were distributed to cosmogenic nuclide sample preparation laboratories. Eleven laboratories prepared ^{10}Be AMS targets from CoQtz-N. These targets were then measured at seven different AMS facilities. Five of the preparation laboratories also prepared ^{26}Al targets and these were measured at four different AMS facilities. In total, eighty-nine ^{10}Be measurements and twenty-three ^{26}Al measurements have been reported.

Inductively coupled plasma - optical emission spectrometry (ICP-OES) determinations show CoQtz-N is relatively free of interfering impurities and has a low Al concentration (c. 18 ppm). Additional HF/HNO₃ etching tests show that the cleaning of CoQtz-N performed prior to splitting was sufficient to remove any adsorbed meteoric ^{10}Be . In cases where several results were returned from a single laboratory it was possible to consider the intra-laboratory scatter of ^{10}Be and ^{26}Al concentrations. Reduced Chi-square values from these laboratories show that CoQtz-N is homogeneous with regard to ^{10}Be and ^{26}Al concentrations but also suggests that some laboratories under- or over-estimate their ^{10}Be concentration uncertainties. Inter-laboratory comparison shows statistically significant differences in the average ^{10}Be results from certain laboratories and we briefly discuss possible reasons for the discrepancies. In general, it is not yet clear whether the differences we observe stem from the target preparation or the AMS measurement. The data which passes our outlier criteria tests is used to derive preliminary concentrations for ^{10}Be and ^{26}Al in CoQtz-N as $2.54 \pm 0.02 \times 10^6$ at/g and $15.7 \pm 0.4 \times 10^6$ at/g, respectively, at the estimated 95% confidence limit. Despite observed differences in ^{10}Be concentrations between some groups, it is encouraging that the majority show reasonable agreement. ^{26}Al measurements show less concordance and clearly require focused attention in future. To acquire a split of CoQtz-N contact S. Binnie or T. Dunai.

EXTENSIVE EARLY MOUNTAIN GLACIATION IN CENTRAL PATAGONIA DURING MARINE ISOTOPE STAGE 5

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Resolving the timing and structure of glacial advances throughout the last glacial cycle is essential for understanding the underlying drivers of climate changes in the southern hemisphere. Here we use geomorphological mapping and ¹⁰Be exposure ages from moraine boulders and outwash cobbles to reconstruct glacial advances over the last glacial cycle at Lago Belgrano (47.9°S), central Patagonia. The Belgrano outlet glacier reached its maximum extent near the end of Marine Isotope Stage (MIS) 5, much earlier than other southern hemisphere mountain glaciers. A second advance dated to c. 25 ka, coeval with the global Last Glacial Maximum (gLGM), was substantially less extensive. We suggest that the extensive advance early in the last glacial cycle reflects the high climatic sensitivity of these mountain glaciers leading to fast initial ice build-up and advance. Reduced southern hemisphere isolation towards the end of MIS 5 may have been sufficient to promote an advance at this time. Westward ice divide migration and precipitation starvation led to a substantially smaller ice extent during the gLGM as the Patagonian Ice Sheet united and attained its full elevation.

NEW RECORD OF ICE SURFACE ELEVATION CHANGES FOR TUCKER GLACIER IN VICTORIA LAND, ANTARCTICA

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Antarctic ice sheets represent the largest reservoir of melt water in a warming climate. Yet the most important and dynamic portions of these large systems have only been observed for ~50 years, since the beginning of the satellite era. Using geological dating techniques and focusing on outlet glaciers, the observational record can be extended 100-fold, from decades to millennia. By extending the observational range we can illuminate past changes in coupled ice-climate systems and infer their future response and related sea level change in a warming climate.

To more fully understand the nature of these important coupled ice-climate systems, surface-exposure dating of rocks adjacent to outlet glaciers can provide insight to the style and rate of change for outlet glacier surface-elevation through time. Sampling campaigns in Victoria Land have produced a robust, high-resolution age-elevation transect for Tucker Glacier draining in to the western Ross Sea region of Antarctica.

We present 11 new *in situ* ¹⁰Be ages from Tucker Glacier. This new ice surface elevation chronology directly constrains the style, rate, and magnitude of change for the largest outlet glacier along the Borchgrevink Coast in Victoria Land. This chronology provides critical insight to Holocene ice-load history for the region and show rapid significant thinning of Tucker Glacier during the Holocene. These data are critical analogues for modelling the response of present and future ice-climate systems in a warming world.

CHANGES IN VERTICAL ICE EXTENT ALONG THE EAST ANTARCTIC ICE SHEET MARGIN IN WESTERN DRONNING MAUD LAND – FIRST FIELD AND MODELLING RESULTS OF THE “MAGIC-DML” COLLABORATION

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Constraining numerical ice sheet models by comparison with observational data is crucial to address the interactions between cryosphere and climate at a wide range of temporal and spatial scales. Such models are tested and refined by comparing model predictions of past ice geometries with field-based reconstructions from geological-, geomorphological-, and ice core data. However, for the East Antarctic Ice sheet, there is a critical gap in the empirical data necessary to reconstruct changes in ice sheet geometry in the Dronning Maud Land (DML) region. In addition, there is poor control on the regional climate history of the ice sheet margin, because ice-core locations, where detailed reconstructions of climate history exist, are located on high inland domes. This leaves numerical models of regional glaciation history in this near-coastal area poorly constrained.

MAGIC-DML is an ongoing Swedish-US-Norwegian-German-UK collaboration with a focus on improving ice sheet models of the DML margin by combining advances in modeling with filling critical data gaps regarding the timing and pattern of ice-surface changes. A combination of geomorphological mapping using remote sensing data, field observations, cosmogenic nuclide surface exposure dating, and numerical ice sheet modeling are being used in an iterative manner to produce a comprehensive reconstruction of the glacial history of western DML. Here, we present an overview of the project, field evidence for formerly higher ice surfaces, and *in-situ* cosmogenic nuclide measurements from the 2016/17 expedition. Preliminary field evidence indicates that interior sectors of DML have experienced a general decrease in ice sheet thickness since the late Miocene, with potential episodes of increasing thickness in the late Pleistocene (700-300 ka, 250-75 ka). To aid in interpreting these field data, new high-resolution ice sheet model reconstructions, constraining ice sheet configurations during key episodes, are presented.

THE LOCAL LGM IN THE PATAGONIAN ANDES: INSIGHTS FROM NEW ^{10}Be AND OSL MORaine AND OUTWASH CHRONOLOGIES AT 39-44 $^{\circ}\text{S}$

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The timing, structure and termination of the last mountain glaciation in the southern hemisphere and the broader-scale mechanisms responsible for forcing changes remain unclear. Most studies have focused on the global Last Glacial Maximum (gLGM; 26.5-19 ka) time period, which is just part of the extensive time frame within the last glacial period that also includes Marine Isotope Stages 3 and 4. Robust glacier chronologies throughout the glacial period are a prerequisite for uncovering the climate mechanisms driving southern hemisphere glaciation and potential interhemispheric climate links. In this project, we aim to better understand the timing of the local Last Glacial Maximum (lLGM) in the Patagonian Andes (41-54 $^{\circ}\text{S}$), southern South America. We have identified key sites from where we collected geochronologic data to better constrain the timing of the maximum extent of the former Patagonian mountain Ice Sheet. Here, we present a new ^{10}Be chronology from two outermost moraines at Río Cisnes (44 $^{\circ}\text{S}$), on the eastern side of the Patagonian Andes. We also present ages obtained from outwash sediments making up the uppermost perched glaciofluvial terraces at Cucao, Taiquemo and Panguipulli sites in the Chilean Lake District and Isla Grande de Chiloé (39-41 $^{\circ}\text{S}$), in the northwestern Patagonian Andes. At Cucao, we sampled a ^{10}Be depth profile from sediments deposited during the maximum glacial extent of the Chilotan piedmont glacier in the Isla Grande de Chiloé. From this and other sites we also present OSL data obtained from sandy sediments that make up the outwash terraces. We use this workshop opportunity to discuss the available pre-LGM glacial geochronological evidence obtained by this and previous work at different sites along the Patagonian Andes and elaborate on the structure and possible forcing mechanisms of the maximum glaciation in the area.

ICE MARGINAL FLUCTUATIONS OF THE GREENLAND ICE SHEET AND A LOCAL ICE CAP IN MCCORMICK FJORD, NW GREENLAND

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Knowledge about the glacial history of the Greenland Ice Sheet and its dynamic response to past climate variability is important to put the current changes into context. In southern Greenland, a number of recent studies have documented the ice marginal response to Holocene climate variability (Larsen et al. 2015; Young and Briner 2015), but from northern Greenland very few observations have been made.

In this study, we have used a multiproxy approach including analysis of sediment cores from proglacial lakes, ¹⁴C dating of dead mosses and cosmogenic exposure dating of moraines to constrain the Holocene glacial history in McCormick Fjord, Northwest Greenland. On satellite imageries, we identified a number of recessional moraines outside the Little Ice Age moraines in the McCormick Valley, originating from the Greenland Ice Sheet and a nearby local ice cap. During the field season 2016 and 2017, we retrieved sediment cores from 5 lakes in different elevations, boulder samples for cosmogenic exposure dating from two moraines and shell fragments in the McCormick Valley together with mosses from the margin of a nearby local ice cap to constrain the timing of the ice marginal fluctuations.

Here we present ¹⁴C ages and XRF data for 6 lake sediment cores, ¹⁴C dates of moss samples and ¹⁰Be dates of 5 boulders sampled on two moraines. Our preliminary results show that following the initial deglaciation c. 11 ka a re-advance occurred causing an outlet glacier from the Greenland Ice Sheet to dam the McCormick Valley. This is reflected by the age of the outer moraines and in the lack of marine sediments in the lake cores. The lakes continued to receive meltwater input suggesting that the local ice cap survived the Holocene Thermal Maximum. However, the ¹⁴C ages of dead mosses show that the ice cap was smaller than present from 3.3 ka cal BP to 1.2 ka cal BP. Our results show that the glaciation history in McCormick Fjord is similar to other glacier reconstruction from e.g. Thule in Northwest Greenland (Corbett et al., 2015) and West Greenland (Young et al., 2011; Cronauer et al., 2016) where the Greenland Ice Sheet experienced a marked re-advance during the Early Holocene.

UNCERTAINTIES ASSOCIATED WITH THE USE OF COSMOGENIC NUCLIDE EXPOSURE DATING (^{10}Be) FOR RECONSTRUCTING THE TIMING OF ICE SHEET RETREAT IN SOUTHERN NORWAY

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We report and discuss results from cosmogenic nuclide exposure dating that have been achieved through several years of field work in southern Norway aiming at reconstructing the deglaciation history since the Last Glacial Maximum (LGM). The data set consist of a large number of ^{10}Be -dates of rock samples that were taken from glacially transported boulders. We find that all coastal mountains in the studied area in SW Norway were ice covered during the LGM, at which time the Scandinavian Ice Sheet was flowing westward, independent of the underlying topography. Later, the fast flow of the Norwegian Channel Ice Stream led to a lowering of the ice surface. A series of dates from the island Utsira, that was overridden by this northbound ice stream during the LGM, gave ages around 20 ka or slightly older. Our first assumption was that the youngest of these dates gave credible ages of the deglaciation. However, modelling results of the ^{10}Be inventory on bedrock surfaces made us suspicious that the chronology could be afflicted by the deep subsurface accumulation of ^{10}Be during long-lasting ice free periods, and that the dates could overestimate the true exposure ages (Briner *et al.* 2016). Radiocarbon dates that more recently have been obtained from sediment cores that were retrieved from lake basins on the neighbour island Karmøy appears to confirm this assumption. They all suggest that the deglaciation occurred around 18 ka, i.e. about 2 thousand years later than suggested by the ^{10}Be -ages. We therefore conclude that all boulders on Utsira contain a uniform level of inherited muon-produced ^{10}Be in the local bedrock from where the boulders were quarried by the overriding ice sheet. Accordingly, we suspect that muon-produced ^{10}Be may be an important source of error for this dating method when applied for landscapes that have experienced long ice-free periods in between glacial phases that caused minimal or little glacial erosion. However, this does not appear to be a pervasive issue for the whole region along the west coast as there are many places where we have found excellent agreement between the ^{10}Be - and ^{14}C chronologies.

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COSMOGENIC SURFACE EXPOSURE DATING OF THE DEGLACIATION OF FINNMARK AND NORTHERN FINLAND

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The timing of the deglaciation at the outer coast in central Finnmark is poorly constrained which has resulted in a broad range of suggested deglaciation ages, especially for the outer coast. In this project we present 23 cosmogenic surface exposure ages (¹⁰Be) from eight localities in northernmost Norway and Finland and discuss implications for the pattern and timing of ice sheet retreat from this region.

Samples were collected along a 240 km long N-S transect ranging from the outer coast of the Nordkinn peninsula (Norway) to Lake Inarijärvi (Finland). The samples were prepared following standard methodology at the Institute of Geological Sciences, University of Bern and were the first geological ¹⁰Be samples measured at the National Laboratory for Age Determination, Trondheim.

With the exception of two old outliers (at 55 and 36 ka) the new ages are reasonably consistent with previously proposed deglaciation chronologies. For the outer coast our results confirm initial ice sheet retreat at 15-14 ka, during early Bølling as has previously been suggested by Romundset *et al.* (2011). For the southernmost part of the transect three samples from the streamlined terrain around Lake Inarijärvi indicate a deglaciation at 11-10 ka.

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THE GLOBAL LAST GLACIAL MAXIMUM IN CENTRAL ASIA

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The last glacial maximum (LGM) is defined as the period, during the most recent glacial cycle (last ~100 ka), when the global integrated ice volume was the largest. As expressed in the marine oxygen-isotope record, the LGM occurred between 23 and 19 ka. Surface exposure ages from glacial deposits such as ice-marginal moraines, typically provide constraints on minimum ages of glacier culminations. A previous global compilation of ¹⁰Be exposure ages from moraines of both high-latitude ice sheets and mountain glaciers, supported a synchronous global LGM between 26 and 19 ka. However, mounting evidence from the Southern Hemisphere and Central Asian mountain glaciers, highlights a more complex behaviour. The aim of this study is to investigate the LGM glacial record of Central Asia—a climatically diverse region with a rich geological record of past mountain glaciations. Investigating the relative role of climatic and non-climatic forcing mechanisms on patterns of mountain glaciation is crucial, in particular when: 1) providing paleoglacier targets (derived from geological reconstructions) for comparison and validation of numerical glacier models and 2) when analysing and correlating large glacial chronological datasets over extensive regions (inference of global-to-regional climatic teleconnections).

Towards building a paleoglaciological reconstruction for the LGM in Central Asia, we present catchment-specific maps describing glacier extent, with spatial and temporal confidence intervals. We use already published glacial landform data together with available ¹⁰Be glacial records, evaluate the dating control and infer past glacier extents from the moraine record using digital elevation models. This analysis yields information on the regional variability in glacier dimensions and timing. Correlating glacial stages across this region remains a difficult task due to the large observed scatter in surface exposure data for individual moraines. Our results show that glacier culminations between 30 and 20 ka across High Asia overlap with the global LGM, although we do find significant variations in timing and extent. In some regions, such as the central Kyrgyz Tian Shan and the eastern Mongolian Altai Mountains, the local LGM occurred during Marine oxygen-Isotope Stage (MIS) 5 (130–71 ka) and MIS 3 (57–29 ka), respectively, which predate the global ice volume signal. In other regions, such as the Chinese Altai and the eastern Kyrgyz Tian Shan, the local LGM coincides with the global signal. Initial geomorphometric analyses of investigated catchments show that some of the observed variation in glacier extents can be explained by catchment-characteristics (e.g. hypsometry, slope, and aspect).

TOWARDS A BETTER CLEANING OF CHERT SAMPLES FOR BETTER ^{10}Be AND ^{26}Al MEASUREMENTS

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Measurements of in situ produced ^{10}Be and ^{26}Al are routinely performed for determining exposure ages or denudation rates in environments. However, if the purification is relatively easy to isolate pure quartz, in samples with low quartz abundance such as chert, the classical purification processes often fail and yield to too high ^{10}Be or ^{26}Al concentrations (Boaretto et al 2000, Matmon et al., 2003; Guralnik et al., 2010, Zerathe et al. 2013) and are explained by complex geomorphological processes. In an attempt to solve this problem, the ^{10}Be , ^{27}Al and ^{26}Al concentrations of 10 samples from desert pavement surfaces (amalgamated pebbles of chert, quartz, granite) were monitored at each step of a new chemical cleaning protocol involving HF leachings followed by partial dissolutions in 3N KOH. From the HF leaching efficiencies (mass of rock dissolved per volume of solution) ranging in this study from 0.26 g/ml (quartz) up to 0.65 g/ml for chert, it is possible to characterize the major mineral involved in the reaction and if extra cleaning steps are necessary. When efficiency is higher than 0.3 g/ml, extra cleaning within KOH solution at 80°C for 24h will help to gently dissolve the sample. Resulting ^{27}Al , ^{10}Be and ^{26}Al concentrations will be presented.

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QUANTIFYING INCISION RATES SINCE THE EARLY MIOCENE USING TCN INTO CAVES: METHODOLOGICAL ISSUES, SOLUTIONS AND EXPECTATIONS

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The ability of discriminating the various forcing parameters controlling the growth of mountain ranges depends on the knowledge of the deformation, exhumation and sedimentation chronologies and on accurate constraints on the orogen geometry necessary to quantify accretion and erosion fluxes. The Pyrenees, an intraplate collision range, built by the shortening of continental thinned margins during the convergence between Iberia and Eurasia lasting from Late Cretaceous to Early Miocene, are a particularly well-suited study area to examine the coupling and retroactions between climate and tectonics. Indeed, consisting in a doubly vergent asymmetric orogenic wedge, the northeastern foreland basin underwent particular conditions from the Miocene to the Pliocene due to the closure of all oceanic connections resulting from the continuing convergence between Iberia and Eurasia. In addition, the orogenic growth and its sedimentary evolution occurred during the Cenozoic climatic cooling.

To investigate these retroactions, alluvium-filled horizontal epiphreatic passages in limestone karstic networks supposedly recording the transient positions of former local base levels during the process of valley deepening were studied. The results obtained applying various suitable geochronological methods (²⁶Al/¹⁰Be, ¹⁰Be/²¹Ne, ESR and OSL on quartz) on intrakarstic alluvial deposits of 61 caves from three valleys of the central and eastern Pyrenees, as well as on a recent analogue comprising an active branch, will be presented. In the Pyrenean context and under particular conditions, these burial duration methodologies allow deciphering the deepening history of the valleys over the long term (~ 16-14 Ma). However, in this orogenic area, some issues have been identified: the density of sub-horizontal levels on an altimetric range and their vertical connections, the low tectonic activity during the post-orogenic evolution, the Mediterranean eustatic variations, the ancient glaciation phases, or storage in the watershed may lead to networks filling stories more complex than expected. In some cases, it may be difficult to evaluate the ²⁶Al/¹⁰Be ratio associated to the sediments entering the caves or at the time of their deposit (mixing with old deposits). We will show that most of these issues can be solved by conducting small ancillary studies and taking precautions when sampling or treating samples.

Acknowledgments: this work was funded by the BRGM within the framework of the RGF - Pyrénées program.

WHEN TCN MEET HIGH SCHOOL STUDENTS: DECIPHERING WESTERN CÉVENNES LANDSCAPE EVOLUTION (LOZÈRE, FRANCE) USING TCN ON KARSTIC NETWORKS

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The rates and chronologies of valley incision are closely modulated by both the tectonic uplift of active mountain ranges and repeated climate changes during the Quaternary. The Neogene evolution of the Cévennes, the southernmost part of the French Massif Central, is poorly constrained. According to Séranne *et al.* (2002), most of its incision is due to a topographic uplift between the Langhian (16 Ma) and the Messinian (5.32 Ma) due to Mediterranean geodynamics as well as eustatic variations. Studies performed at the Montagne Noire and east of the Massif Central (*e.g.*, Olivetti *et al.*, 2016) suggest in addition a marked Pliocene incision. Finally, the Mediterranean facade (Ardèche) records a marked incision during the Messinian and the Pliocene controlled by eustatic fluctuations (Tassy *et al.*, 2013).

With the aim of quantifying the incision rates in the western Cévennes area since the Miocene, alluvium-filled horizontal epiphreatic passages in limestone karstic networks were studied. Such landforms are used as substitutes of fluvial terraces because they record the transient positions of former local base levels during the process of valley deepening. In the study area, the Jonte, Tarn and Lot valleys contain stepped cavities particularly well-suited for such purpose.

As part of the Erasmus+ “Live on the karst” project, 4 high school students and the research team firstly performed morphological and petrographic observations. Then, the burial durations of alluvial sediments from 13 caves located in the Jonte and Tarn valleys were determined using cosmogenic ²⁶Al/¹⁰Be and ¹⁰Be/²¹Ne ratios. The results obtained allow us to document the incision processes since the Tortonian (~ 11-8 Ma) in the Tarn gorges, and the Zanclean (~4 Ma) in the Jonte gorges. In both valleys, the estimated incision rates range from 40 to 120 m/Ma, also giving an estimate of the uplift rates. The digging would then be posterior to the Messinian envisioned by Séranne *et al.* (2002) for the Jonte gorges and could result from changes in drainage systems or even closure of the valley. Concerning the Tarn valley, the incision of the Causse de Sauveterre and the Causse Méjean would have started at least 8.39 ± 1.04 Ma ago, in agreement with the scenario envisaged by Séranne *et al.* (2002). This work still in progress provides new and original constraints on incision, paleo-denudation and related uplift rates in the study area. This may help to better understand the late evolution of this area, particularly its relations with the French Massif Central volcanism and the synchronous post-orogenic evolution of the French Alps and the Pyrenees.

Furthermore, the “Live on the karst” project allows high school students, as part of an advanced examination of the French A levels, to study the biodiversity and geodiversity of the Grands Causses karsts (southern Cévennes), and to compare them to other European karsts in interactions with Italian and Slovenian high school students. In this project, most of the cosmogenic nuclide concentrations were acquired by high school students supervised by members of the CEREGE team.

Acknowledgments: this work is funded by the ERASMUS+ “Live on the Karst” project and the CEREGE. We would like to thank the DREAL Occitanie for the sampling authorizations, the PNR des Grands Causses, the Parc National des Cévennes, and the Dargilan and Amélineau caves owners.

Poster presentations

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WHEN DID GLACIERS DISAPPEAR FROM THE HIGH TATRA MOUNTAINS?

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The High Tatra Mountains are the highest massif in the Carpathian arc with no current glaciation. Above 1900 m a.s.l. in the uppermost parts of valleys a wide range of glacial and periglacial landforms can be found which represents the youngest glacial landsystem within this mountain chain. It is spatially limited to the glacial cirques and has attributes typical for marginal glaciation. Some studies suggest that these small glaciers could have survived from late Pleistocene until the mid-Holocene or even developed during the Little Ice Age (LIA). Still remains the question of the age of this glacial activity which has been recorded as a variety of landforms e.g. bouldery moraines, hummocky ground, debris accumulation and relict rock glaciers as well as ice-moulded bedrock can be found. Spatial and temporal extent of the glaciation was investigated using combination of morphostratigraphy and exposure dating with ¹⁰Be cosmogenic nuclide. Field recognition and absolute dating of the landforms allowed to identify two distinct glacial systems (PI and PII) which were formed and stabilised approximately 15 ka and 11 ka as a response to the two Lateglacial cold periods, equivalents of the Oldest Dryas and Younger Dryas, respectively.

Our data show that the cirques became ice-free towards the Bølling-Allerød warming and the latest glacial activity took place in the Youngest Dryas (YD) cold period. The result suggest that the glacial response to the YD cooling was characterised by an inception of small festoon-shaped glaciers and rock glaciers advancing from the cirque backwalls towards the centre of the cirque. Their freshness, geometry, position in the cirque and exposure age suggest that there was no further glacial activity after the YD cold period. It further implies that in this mountain range was no glacial readvance related to the LIA.

This research was funded by the Polish National Science Centre (NCN) grant No. 2015/17/B/ST10/03127. We thank the Ion Beam Physics AMS group for laboratory support and AMS measurements.

EXPOSURE DATING ICE RETREAT AND LANDSCAPE CHANGE ON CANADA'S WESTERN COAST

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The timing of Cordilleran Ice Sheet retreat in western Canada during the last deglaciation determines the viability of different routes for the peopling of the Americas and can be used to constrain rates of postglacial landscape change. A human migration along the western coastal margin has been hypothesised as an alternative to the inland route between the Laurentide and Cordilleran Ice Sheets. However, the viability of a coastal route between 22-16 ka has not been rigorously tested and the timing of coastal exposure remains uncertain. Here we present 32 terrestrial cosmogenic ¹⁰Be nuclide ages of erratic boulders and bedrock from British Columbia (centred on 51.6°N, 128.1°W). Our data show that the central coast of British Columbia was ice free by at least 18.1 ± 0.2 ka. Our geologic data are consistent with the viability of a coastal route used by the first people entering the Americas. We use this exposure data to constrain rates of postglacial landscape change on this part of the coastline. Cosmogenic ¹⁰Be nuclide concentrations from bulk river gravels yield watershed erosion rates, and we compare these data with ¹⁰Be nuclide erosion rates from local bedrock. The new data provides an insight into coastal sediment supply since the last deglaciation.

GLACIAL EROSION AND RELIEF PRODUCTION ON GNEISS-GRANITE PLATEAUS

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The great northern hemisphere Plio-Pleistocene ice sheets repeatedly covered extensive low-relief bedrock terrain composed of hard and relatively resistant gneiss and granite (Krabbendam & Bradwell, 2014). Today, many of these landscapes are high above sea level, forming mountain plateaus separated by deep glacial troughs and fjords (Sugden & John, 1976). Bedrock structure clearly exerts dominant control on the topographic relief of the plateaus. The highest areas typically expose relatively massive, glacially-abraded bedrock, whereas topographic lows correspond to intersecting fractures and rock basins that show signs of glacial quarrying (Krabbendam & Bradwell, 2014). However, the depth of glacial erosion in such terrain has been long debated, and it is difficult to constrain. Given that very similar-looking topography also exists in non-glaciated gneiss terrain, there does not seem to be a unique topographic signature of glacial erosion on mountain plateaus. Indeed, some suggest that the bedrock topography primarily reflects patterns of pre-glacial chemical weathering, and that ice sheets removed no more than the surface mantle of regolith and weathered bedrock (e.g. Lidmar-Bergström, 1997, Krabbendam & Bradwell, 2014).

We combined cosmogenic nuclide measurements with computational modeling to study the patterns and rates of glacial erosion in a typical gneissic plateau landscape south of Lysefjorden, southern Norway. We were particularly interested to see whether topographic highs and lows show a systematic distribution of nuclide inheritance. Measurements of ¹⁰Be and ²⁶Al concentrations in 26 bedrock samples show that nuclide inheritance is limited and almost randomly distributed in the landscape. Markov-chain Monte Carlo modeling of the cosmogenic nuclide concentrations suggests that erosion over the last few glaciations has entailed efficient, but stochastic, quarrying of blocks combined with continuous, but inefficient, surface abrasion.

It is hard to imagine that glacial erosion was largely limited to removal of in-situ weathered regolith, especially when extrapolating the CN results across all Plio-Pleistocene glaciations. In stead, we used computational landscape-evolution experiments to study how glacial erosion might have formed the present bedrock topography. These experiments indicate that heterogeneity of bedrock strength in combination with subglacial hydrology provide the main controls on landscape evolution in these terrains.

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LATEGLACIAL RETREAT CHRONOLOGY OF THE SCANDINAVIAN ICE SHEET IN FINNMARK, NORTHERN NORWAY, RECONSTRUCTED FROM SURFACE EXPOSURE DATING OF MAJOR END MORAINES

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We report results from a comprehensive surface exposure dating campaign in eastern Finnmark, located in the northernmost part of Norway and close to the Norwegian-Russian border. This is a palaeo-glaciologically important region as it sits near the proposed border-zone between the former Scandinavian and Barents Sea Ice Sheets. However, until now the deglaciation history has few direct dates onshore and the chronology of ice front retreat is instead found by correlating ice-marginal deposits with isostatically raised shorelines and marine sediment cores. We measured the content of ¹⁰Be (N = 22) and ³⁶Cl (N = 17) from boulders located at the crest of major moraine ridges at four localities; Kjæs, Kongsfjorden, Vardø and Kirkenes. These are key localities of existing regional reconstructions of ice recession in this area. Despite some spread in age results from each locality due to methodological challenges associated with surface exposure dating, the large numbers of samples from each site except Kjæs still allow for obtaining clusters of similar ages which are used for arriving at a likely chronology of ice front retreat. Our results show that the Kongsfjorden and Vardø moraines were deposited 14.3 ± 1.7 ka and 13.6 ± 1.4 ka, respectively, and thus point to an Older Dryas age of the proposed 'Outer Porsanger' deglaciation sub-stage. Moraine ridges belonging to the 'Main' sub-stage near Kirkenes were dated to 11.9 ± 1.2 ka, corresponding well with the ice retreat chronology farther west in northern Norway and suggesting that the maximum Younger Dryas ice sheet extent was attained in the late Younger Dryas along a more than 500 km long stretch in northernmost Scandinavia.

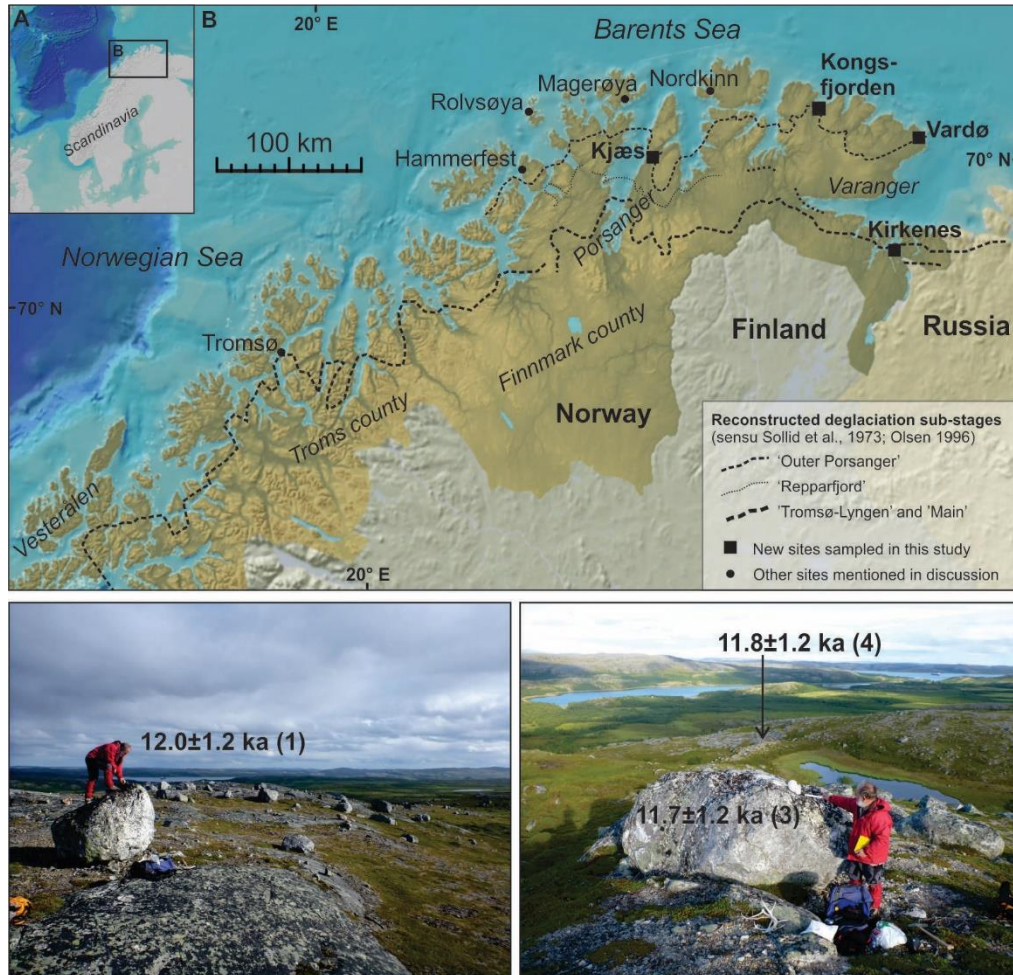


Figure: Map of the field area in northern Norway and two pictures from sampling the Main deglaciation sub-stage at Skogerøya in Finnmark, shown through this study to be of late Younger Dryas age.

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GLACIAL GEOCHRONOLOGY OF NORTH-EASTERN PATAGONIA USING ^{10}Be & ^{36}Cl : IMPLICATIONS FOR SOUTHERN HEMISPHERIC PALAEOCLIMATE

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The southern westerly winds (SWW) dominate mid-latitude climate and significantly influence global circulation patterns. Southern South America provides the only continuous landmass to study SWW palaeodynamics across a variety of landscapes. A strong correlation between SWW core (ca. 50-51°S) and precipitation exists ($r=0.8$), hence glacier chronologies distal to the core might provide insights into possible strength or positional changes in the past. This study builds a glacial-deglacial geochronology in north-eastern Patagonia (42°S, 71°W) where a high sensitivity to precipitation availability during the Quaternary existed. Cosmogenic surface exposure ages ($n=38$) have been obtained from three major valleys in north-eastern Patagonia: Puelo, Epuyen & Cholila. Erratic boulder samples were collected from lateral (where available) and frontal moraines with a total of 9 sampled moraine ridges. Results for our study area are compared to chronologies established in north-western Patagonia (Chilean Lake District) to ascertain regional palaeo-glacier & climate dynamics with focus on southern westerly wind forcing.

BURIAL DATING OF FLUVIAL TERRACES USING COSMOGENIC NUCLIDES, ARIEȘ RIVER (ROMANIA)

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Dating of the fluvial terraces and providing a morphochronological picture has always been part of a controversial scientific debate, both locally and globally. The rivers in the Transylvanian Basin were studied between 1960-1980 and mainly focused on the number of terraces, the timing of river incision and how these terraces are represented in a palaeoreconstruction framework. In most cases, these studies were based on sedimentology, palynology, palaeontology, and archeology, but their chronological history has never been established. Surface exposure dating using the ¹⁰Be and ²⁶Al cosmogenic nuclides would be an ideal dating method; however, river terrace deposits are made of individual clasts, each with their unique complex history of an initial exposure during exhumation and fluvial transport and then burial.

This study is based on the numerical dating of the River Arieș terraces in the Cornești – Plăiești area using the cosmogenic burial dating method. The morphological features of the study area were initially mapped in the field using topographical maps (1:25 000), geological maps (1:50 000), and orthophotographs (1:5000). The cosmogenic samples were collected from three different terraces: terrace II (10-12 m relative altitude), terrace III (20-25 m relative altitude), terrace IV (30-35 m relative altitude) from depths down to 12-15 m from newly excavated parts within the study area. The ¹⁰Be and ²⁶Al burial dating of these river terraces yields palaeoincision rates in the upper basin during the terrace deposition, provides age estimates for these deposits and further argues for the role of climate and tectonics in the deposition and subsequent incision of the terraces.

CONSTRAINING FURTHER SWISS DECKENSCHOTTER SITES WITH COSMOGENIC ^{10}Be - ^{26}Al ISOCHRON BURIAL DATING

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The understanding of the landscape evolution during the Quaternary time epoch will be helpful in modelling future landscape evolution scenarios of the northern Alpine Foreland (NAGRA, 2014). In this context, the timing of the deposition and incision of glaciofluvial gravels that form high elevated terraces and plateaus in the northern Swiss Foreland – the so called Swiss Deckenschotter – is of special interest. They signify the onset and persistence of glacial or glacially related landscape forming processes since the Pliocene/Pleistocene boundary. The depositional ages of these spatially extensive paleosurfaces and their subsequent incision is crucial in order to establish incision and erosion scenarios, river drainage patterns and related base-level reconstructions.

Glaciofluvial gravels can be dated with cosmogenic nuclides in an isochron burial dating approach (Balco and Rovey, 2008) also for glaciofluvial gravels with low nuclide inventories (e.g. Akçar et al., 2017) using the differential decay of a nuclide pair in a mineral (here: ^{26}Al and ^{10}Be in quartz). In contrast to the determination of the ^{10}Be content in sediment, the challenge is still given for ^{26}Al . The low inheritance of glaciofluvial sediments and a subsequent long burial time result in low ^{26}Al concentrations and therefore a low ^{27}Al background is required.

In this study, we aim to reconstruct the chronology of the Deckenschotter units along a transect at two locations in northern Switzerland in the Aare: the gravel pit Tromsberg in Kirchdorf which represents the Higher Deckenschotter (HDS) of the Dürn-Gländ region and the nearby gravel pit Bärengraben in Würenlingen being the Lower Deckenschotter of the Iberig region. Previous age estimates for HDS suggest an age range of 1.5 ± 0.2 Myr based on isochron burial dating at the site Siglistorf (Akcar et al. 2017) and 1.8 to 2.5 Myr based on mammalian faunal assemblages (MN17) at site Irchel (Bolliger et al. 1996).

Additionally, a gravel pit in Beringen representative for the Klettgau valley filling (Hochterrasse) was chosen to cross-calibrate with recently established luminescence chronologies (Lowick et al., 2015). Those ages question a previously established age estimate based on the interpretation of sedimentary facies and lithostratigraphy (Graf, 2009). Thus, an independent age estimate is desirable.

With the strategy of sampling diverse lithologies and grain sizes, it is attempted to have samples with different pre-burial histories but the same burial and post-burial histories. Different pre-burial histories should enable us to calculate an isochron burial age for the sampled bed.

We will present some initial field and preliminary analytical data from these studies. In addition to them, modelling the initial production ratios of possible erosion scenarios at the sediment source will further help to constrain the age estimates.

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REGIONAL MID-PLEISTOCENE GLACIATION IN CENTRAL PATAGONIA

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Southern South America contains a rich glacial geomorphological record that spans the past million years and has the potential to provide palaeoclimate information for several glacial periods in Earth's history. In central Patagonia, two major outlet glaciers of the former Patagonian Ice Sheet carved deep basins ~50 km wide and extending over 100 km into the Andean plain east of the mountain front. Here, a succession of nested glacial moraines offers the possibility of determining when the ice lobes advanced and whether such advances occurred synchronously in different valleys. The existing chronology, which was obtained using different methods in each valley, indicates the penultimate moraine sequences in the two valleys differ in age by a full glacial cycle. Here, we test this hypothesis further using a uniform methodology that combines cosmogenic nuclide ages from moraine boulders, moraine cobbles and outwash cobbles. ¹⁰Be concentrations in eighteen outwash cobbles from the Moreno outwash terrace in the Lago Buenos Aires valley yield surface exposure ages of 169-269 ka. The ages are remarkably consistent even though the samples were collected by two separate field parties, and were measured in three different wet chemistry and AMS laboratories. We find ¹⁰Be inheritance is low and therefore use the oldest surface cobbles to date the deposit at 260-270 ka. The age is indistinguishable from the age obtained in the neighbouring Lago Pueyrredon valley further south. This suggests a regionally significant glaciation occurred in central Patagonia during Marine Isotope Stage 8, and broad interhemispheric synchrony of glacial maxima during the mid to late Pleistocene. Finally, we find the dated outwash terrace is 70-100 ka older than ages obtained from the associated moraines. On the basis of geomorphological observations, we suggest this difference can be explained by exhumation of moraine boulders.

HOW GOOD (OR POOR) IS PUBLISHED GLACIAL COSMOGENIC DATA?

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Over the last 15-30 years, the number of published glacial cosmogenic data has increased substantially. This data has helped resolving and investigating multiple glacial issues, including quantification of glacial erosion, burial under non-erosive ice, ice sheet thickness/thinning, and the timing of glacier advance and retreat. While the glacial cosmogenic data has led to great knowledge jumps for glacial geology, the data is commonly hampered by uncertainties and problems that may limit the potential for scientific advances. Here I will present an analysis of glacial cosmogenic data quality based on the expage global glacial ¹⁰Be and ²⁶Al cosmogenic dataset (<http://expage.github.io/>). First, problems related to geological and physical properties of the cosmogenic dating technique, including measurement uncertainties, exposure age calculations, and geological uncertainties, adds uncertainties of varying amount to the output. Second, data reporting, with data inconsistencies, obvious errors, and missing data in published datasets, adds a “human” uncertainty aspect that commonly impairs or hinders successful re-usage of the data and sometimes casts shadows over the outcome from glacial cosmogenic studies. An analysis of exposure age scatter highlights the importance of geological uncertainties over production rate and measurement uncertainties. Regarding data reporting, less than half of all published papers have all necessary data included without data issues or obvious errors. However, the data reporting quality has improved in particular over the last 15 years. With this poster, I hope to encourage everyone to make an effort to ensure that future published cosmogenic data is correct and complete.

GLACIAL EROSION OF FORSMARK, EAST-CENTRAL SWEDEN, BASED ON BEDROCK ^{10}Be AND ^{26}Al

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While the major Northern Hemisphere ice sheets covered extensive regions of low-relief topography, estimates of glacial erosion are mainly derived from mountainous regions. Hence, there is limited knowledge regarding the amount of glacial erosion for vast areas of northern Europe and North America. As part of an investigation at Forsmark, east-central Sweden, to assess the long-term safety of a planned geological repository for spent nuclear fuel, we attempt to determine the depth of glacial erosion during the past 0.1-1 Ma using cosmogenic nuclide techniques (^{10}Be , ^{26}Al). We have sampled convex upper surfaces on roches moutonnées developed in granitic-gneissic basement in the suggested repository region at the Baltic Sea coastline and along a transect which terminates 60 km SSW of Forsmark, at elevations between 0 and 72 m a.s.l.. Local relief varies from only a few meters to tens of meters. Following deglaciation at 10.8 cal ka BP, the area initially experienced submerged conditions beneath the Baltic Sea and eventually emergence, over time, through continued isostatic rebound. The 14 samples that have been analysed so far yield ^{10}Be (^{26}Al) exposure ages that range from 3.9 ± 0.6 to 66.6 ± 5.0 ka (4.8 ± 0.5 to 74.6 ± 5.6 ka). Taking production rate shielding by water during submergence into account, eleven of these samples are well-clustered and yield exposure ages that pre-date deglaciation by 4.4 ± 1.0 ka (4.9 ± 1.5 ka), whereas three yield older exposure ages. Based on subsurface cosmogenic production rates and ice cover histories inferred from ice sheet modelling and oxygen isotope records of global ice volume, the measured cosmogenic nuclide inventory is used to constrain past erosion rates. Assuming that each ice covered period behaved equally with regards to glacial erosion (either constant rate of erosion or equal episodic depth of erosion), we infer an erosion for these low hill tops of about 1-4 m during the last glacial cycle at 11 of our sample sites, with lower rates (down to a minimum of 0.17 m) at the remaining three sites. For the last 1 Ma, the simulated total erosion ranges from 2.5 m to 70 m depending on ice cover duration and mode of erosion (rate of erosion or episodic depth of erosion). Following these initial 14 samples, we will present results from ^{10}Be and ^{26}Al measurements from an additional 39 samples, and simulated erosion histories taking the combined ^{10}Be and ^{26}Al concentrations into account. Our data and analysis will form a benchmark study for the quantification of ice sheet erosion over low-relief Precambrian shields.

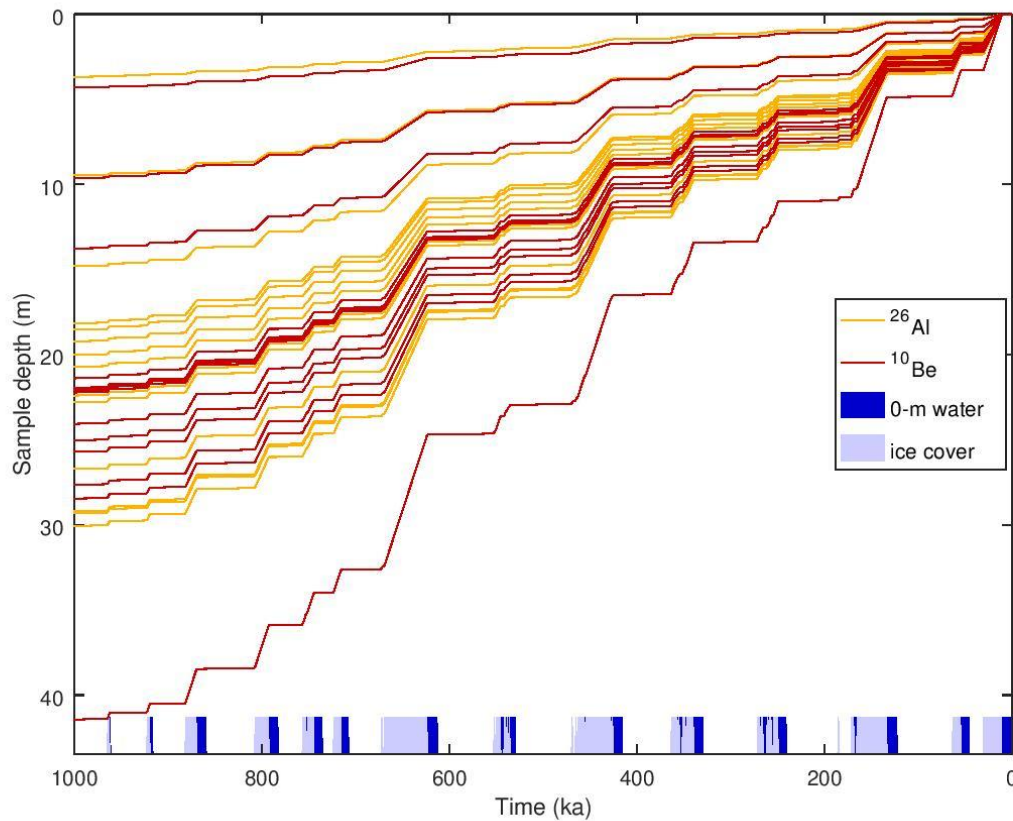


Figure: Simulated erosion history over the last 1 Ma for the initial 14 bedrock ^{10}Be and ^{26}Al measurements. This simulation is run with an assumed non-glacial erosion rate of 1 mm/ka, an estimate of the last glacial cycle ice cover history (SKB, 2010), and a reconstructed last deglaciation age of 10.8 cal ka BP (Stroeven et al., 2016).

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DETECTING AND MONITORING PAST AND PRESENT MOVEMENT RATES OF SLOPE DEFORMATIONS IN LIENZ (TYROL, AUSTRIA)

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Slope deformations cause a considerable threat to settlements and infrastructure in mountainous environments. Analysing slope behaviour retrospective covering time spans beyond some years back is crucial input for sound stability prognoses as slope deformations might reactivate under different conditions as at present.

In Eastern Tyrol, northwest of Lienz, two examples of deep-seated gravitational slope deformations (DSGSDs) within mica schists and gneiss of the Schober Gruppe ranging between 700 and 2900 m a.s.l. were chosen as study sites for combining different methods for assessment of movement rates. The advantage of this area is a modern geological map (Linner et al. 2013) and an already existing reconstruction of the glacial chronology (Reitner et al 2016) as a time constraint for the onset of DSGSDs.

The slope between Thörl (2507 m a.s.l.) the village of Oberalkus (1284 m a.s.l.) is characterised by a saw-tooth slope profile due to a series of antislope scarps as a result of deep-seated toppling (Reitner & Linner 2009). This was enabled by joints and faults steeply dipping into the slope. The uppermost part reveals a 300 wide graben structure where now fossil rock glaciers have their root zone. The activity state of the slope deformation is unknown.

The other case is the slope SE' of Schleinitz (2904 m a.s.l.) and S' of Neuralpscheid, showing a sagging-like slope deformation in crystalline bedrock. This is characterised by big scarps in the upper part, partly dissecting relict rock glaciers and a bulging toe with total disintegration due to rock creep. This toe has been the source area for devastating debris flows throughout history, which resulted in the build up of a huge hyper-trophic alluvial fan NW of the city of Lienz.

For the long-term detection of deformation rates and defining the historic baseline to tie reactivation periods to conditioning factors, we sampled the antislope scarps and (normal) scarps for cosmogenic nuclide dating with in total 14 samples. For age constraints of the mass movement features we took in addition 8 samples of periglacial and glacial deposits linked to the DSGSDS.

The last decades and present movement rates are processed with satellite InSAR (Interferometric synthetic aperture radar) acquired from ERS, ENVISAT and Sentinel-1. The combination of movement rates derived from these two methods should enable a better assessment of the current status of slope deformation since their onset as well as its potential future development.

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CONSTRAINING THE EVOLUTION OF THE EURASIAN ICE SHEETS; HOW USEFUL ARE MORE COSMOGENIC NUCLIDE DATES?

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In 2016 we published results of 10-year effort to compile and archive all published dates relating to the build-up and retreat of the British-Irish, Scandinavian and Svalbard-Barents-Kara Seas ice sheets. The resulting empirical reconstruction of the evolution of the extent of the last Eurasian ice sheets is fully documented, specified in time, and includes uncertainty estimates (DATED-1; Hughes et al. 2016). We assessed over 5000 dates from different dating methods for reliability and used the resulting database, together with published ice-sheet margin positions derived from geomorphological evidence, to reconstruct time-slice maps of ice extent for every 1000-years 25-10 ka and for four periods between 40-27 ka. All uncertainties (both quantitative and qualitative e.g. precision and accuracy of numerical dates, correlation of moraines, stratigraphic interpretations) were combined based on our best glaciological-geological assessment and expressed in terms of distance as a 'fuzzy' margin; separation of the maximum and minimum limits indicates the degree of uncertainty for each time-slice at each location along the ice margin. This approach provides a straightforward means to compare results from numerical modelling of former ice sheet extent with geological data. The reconstructions and chronological database are available to download as GIS shapefiles (.shp) and Google Earth compatible (kmz) formats.

Since the DATED-1 census (1 January 2013), the volume of new information (from both dates and mapped glacial geomorphology) has grown significantly (e.g. 32% increase in the number of dates to 1 January 2017). Despite addition of 933 new locations, the overall spatial distribution of chronological information remains similar. Radiocarbon dating remains the dominant method, but the largest proportional increase (90%) has been from terrestrial cosmogenic nuclide dating methods (¹⁰Be, ²⁶Al, ³⁶Cl), which now represent 22% of the dataset. Here we explore the implications of these new dates and present work towards an updated reconstruction of the evolution of the last Eurasian ice sheets, DATED-2.

Poster presentations

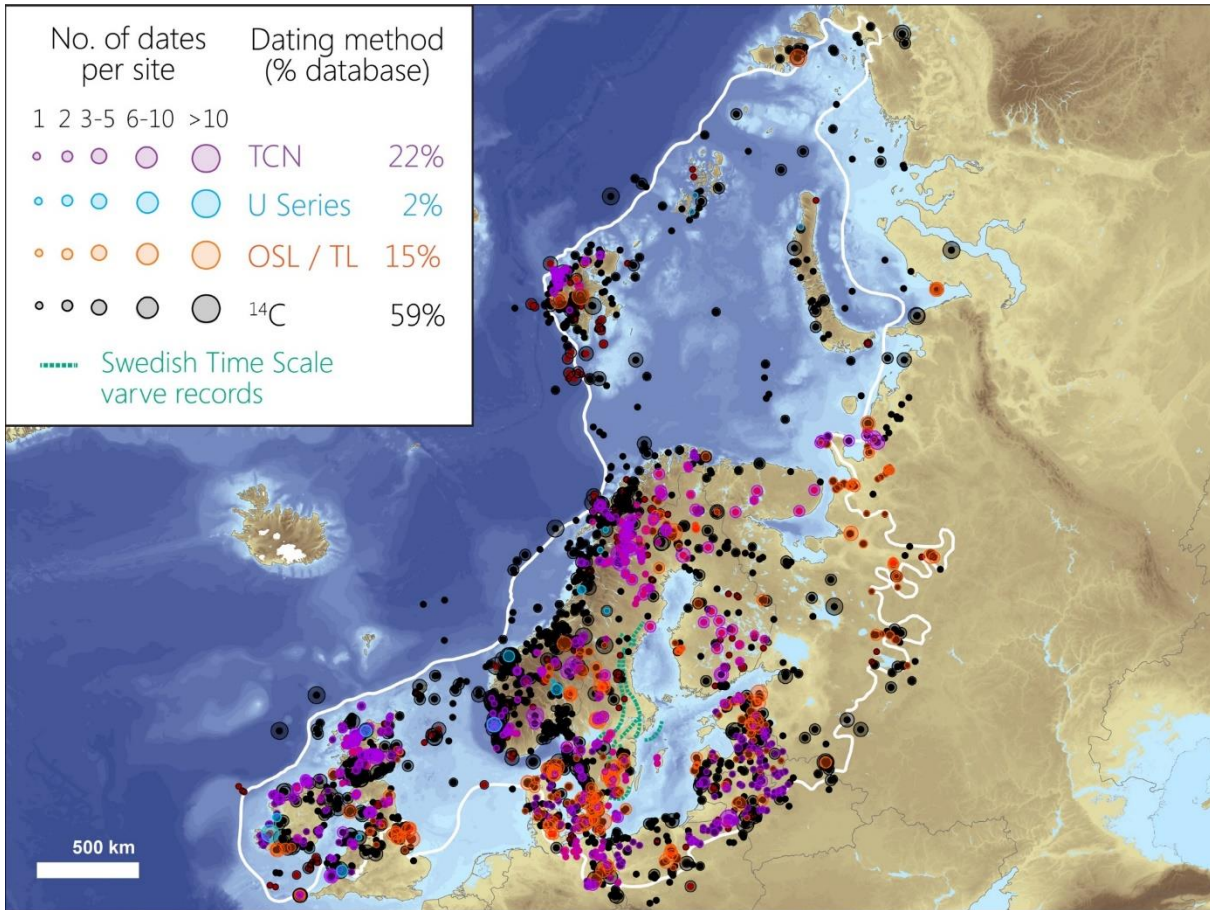


Figure: Spatial distribution of dates within DATED-2 by dating method (to 1 January 2017).

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SPATIAL AND TEMPORAL DISTRIBUTION OF LARGE LANDSLIDES IN THE ALPS: TRENTINO

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Since deglaciation, innumerable rock slope failures have occurred in the Alps. Understanding inherent bedrock structural predisposition and instantaneous triggers requires in depth study at individual sites. Methodologies include detailed field mapping, remote imagery analysis (GIS-based), runout modelling and surface exposure dating of landslide boulders. This multi-disciplinary approach is used to address the question: Are there clusters in time and space of enhanced rock slope instability or is the data set still too small to draw conclusions?

Landslides in Trentino present a particularly compelling challenge. Steep slopes, highly fractured rock, dipslope limestone conditions, and relatively dense population and infrastructure in areas near prehistoric landslides make knowledge of the timing of past events imperative. In Trentino, we study numerous rock avalanche deposits, including Lavini di Marco, Marocche di Dro, Molveno, Tovel, and Castelpietra (Fig. 1). Dating is with cosmogenic ³⁶Cl.

The Marocche di Dro in the lower Sarca Valley are some of the most distinctive and beautiful rock avalanche deposits of the Alps. Based on morphological relationships and exposure dating of boulders we divide the Marocche di Dro deposits into two rock avalanche bodies: the Marocca Principale to the north at 5300 ± 860 yr (vol. 1000 Mm^3) and the Kas to the south at 1080 ± 160 yr (vol. 300 Mm^3). For Marocca Principale and perhaps Lavini di Marco at 3000 ± 400 yr (vol. 200 Mm^3) failure may have been related to the shift to wetter, colder climate around the transition from the middle to the late Holocene. Nevertheless, a seismic trigger cannot be ruled out.

Castelpietra encompasses a main blocky deposit, with an area of 1.2 km^2 , dated to 1060 ± 270 AD (950 ± 270 yr) with ³⁶Cl. The close coincidence in time of the Castelpietra event with several events that lie within a maximum distance of 20 km, including Kas at Marroche di Dro, Prà da Lago and Varini (at Lavini di Marco) landslides, strongly suggests a seismic trigger. Based on historical seismicity compilations, we have identified the "Middle Adige Earthquake" at 1046 AD as the most likely candidate. Its epicenter lies right in the middle of the spatial distribution of the discussed landslides and is much closer to the Sarca Valley in comparison to the Verona earthquake (1117 AD).

By combining the diverse methodologies, failure factors, emplacement dynamics and resulting landforms can be well reconstructed. We found that in some cases landslides mapped as numerous events are revealed as single events. Presumed Lateglacial events are shown to be late Holocene. Most importantly, scatter in ages is often difficult to interpret without in depth understanding of field relationships.

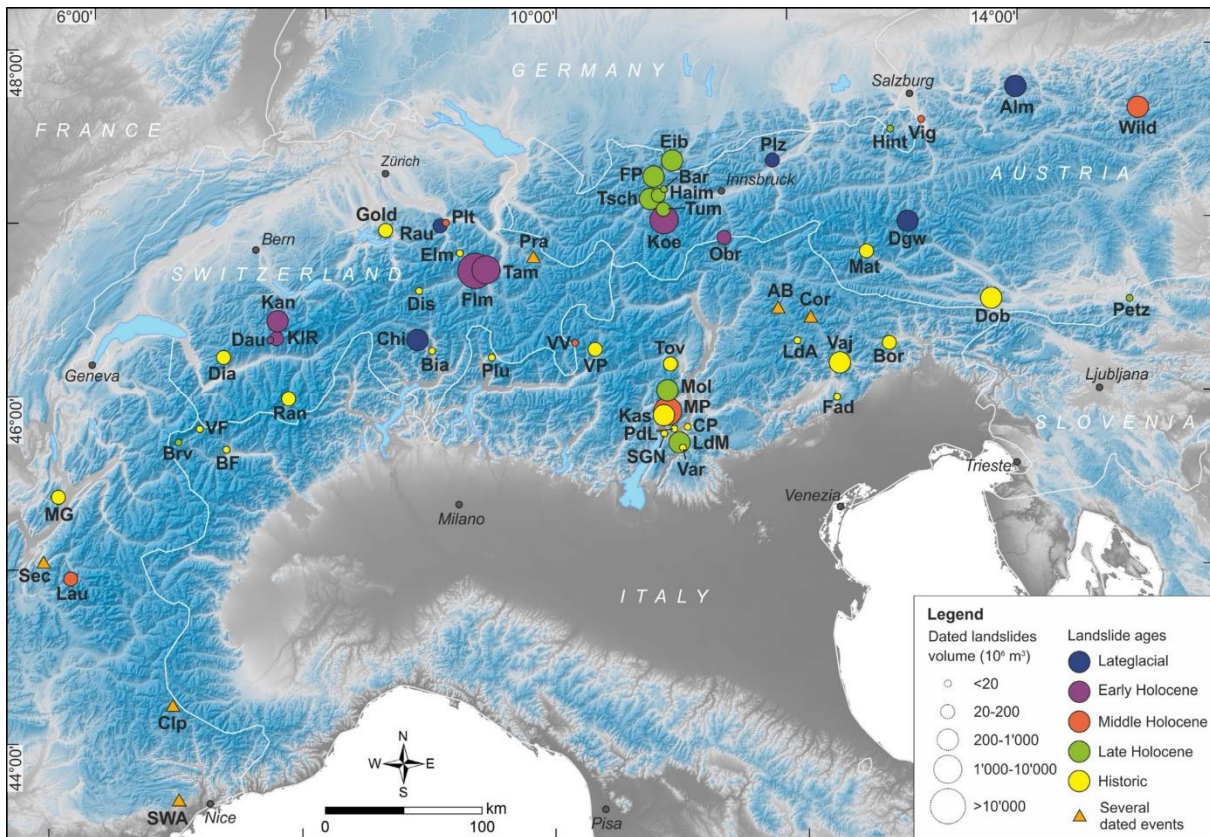


Fig. 1. Locations of isotopically dated (¹⁰Be, ¹⁴C, ³⁶Cl) and historical large rock slope failure events (volume > Mm³) in the Alps (for references see Ivy-Ochs et al., 2017).

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EXPLORING THE SECRETS OF THE BANANA – THE NEW LANDSCAPE HISTORIES ARISING FROM LINKING PAIRED ^{10}Be AND ^{26}Al TO VARIABLE EROSION RATES

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Paired cosmogenic nuclides are often used to constrain the exposure/burial history of landforms repeatedly covered by ice during the Quaternary, including tors, high-elevation surfaces, and steep alpine summits in the circum-Arctic regions. The approach generally exploits the different production rates and half-lives of ^{10}Be and ^{26}Al to infer past exposure/burial histories. However, the two-stage minimum-limiting exposure and burial model regularly used to interpret the nuclides ignores the effect of variable erosion rates, which potentially may bias the interpretation. In this study, we use a Monte Carlo model approach to investigate how the exposure/burial and erosion history, including variable erosion and the timing of erosion events, influence concentrations of ^{10}Be and ^{26}Al . The results show that low $^{26}\text{Al}/^{10}\text{Be}$ ratios are not uniquely associated with prolonged burial under ice, but may as well reflect ice covers that were limited to the coldest part of the late Pleistocene combined with recent exhumation of the sample, e.g. due to glacial plucking during the last glacial period. As an example, we simulate published $^{26}\text{Al}/^{10}\text{Be}$ data from Svalbard and show that it is possible that the steep alpine summits experienced ice-free conditions during large parts of the late Pleistocene and varying amounts of glacial erosion. This scenario, which contrasts with the original interpretation of more-or-less continuous burial under non-erosive ice over the last ~1 Myr, thus challenge the conventional interpretation of such data. On the other hand, high $^{26}\text{Al}/^{10}\text{Be}$ ratios do not necessarily reflect limited burial under ice, which is the common interpretation of high ratios. In fact, high $^{26}\text{Al}/^{10}\text{Be}$ ratios may also reflect extensive burial under ice, combined with a change from burial under erosive ice, which brought the sample close to the surface, to burial under non-erosive ice at some point during the mid-Pleistocene. Importantly, by allowing for variable erosion rates, the model results may reconcile spatially varying $^{26}\text{Al}/^{10}\text{Be}$ data from bedrock surfaces preserved over multiple glacial cycles, suggesting that samples from the same high-elevation surface or neighbouring alpine summits may have experienced similar long-term burial under ice, but varying amounts of glacial erosion.

SUBGLACIAL EROSION IN LIMESTONE BED AT TSANFLEURON GLACIER, SWITZERLAND

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The Tsanfleuron glacier is a rather small glacier (ca. 3 km², 2015) on a gentle slope in the western Swiss Alps. Since the Little Ice Age, ongoing glacier retreat revealed more and more of the polished limestone bed. Besides the glacial polish, the glacier forefield is characterised by a karst landscape including N-channels, R-channels, swallow holes and other features. In a first field campaign, 14 carbonate samples (Tsan1-14) equally distributed inside and outside of the prominent LIA moraine were taken for ³⁶Cl analysis. The aim is to quantify the rates and the patterns of subglacial erosion in limestone, which is anticipated to be significantly different from crystalline bedrock. In particular, it is unclear to which extent the presence of subglacial karst affects the hydrological drainage system and influences glacial erosion patterns and rates. To produce a detailed map of the karst features in the glacial forefield, a drone was used to capture a high-resolution digital elevation model (8 cm) (E-Bee; <https://www.sensefly.com/drones/ebee.html>). These preliminary results will be complemented in summer 2018 with additional samples very close to the current glacier position. Multi-decimetres drill cores of the limestone will be used to look at the ³⁶Cl production depth profile to provide additional information about erosion patterns in the former glacier bed.

INSTABILITY OF THE NORTHEAST GREENLAND ICE STREAM OVER THE LAST 45,000 YEARS

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The sensitivity of Northeast Greenland Ice Stream (NEGIS) to prolonged warm periods is largely unknown and geological records documenting the long-term changes are needed to place current observations in perspective. We use cosmogenic surface exposure ages and radiocarbon dates to determine the magnitude of NEGIS margin fluctuations over the last 45 ka (thousand years). We find that the NEGIS experienced a slow early Holocene ice retreat of 30-40 m a⁻¹, as a result of the buttressing effect of sea- or shelf ice. The NEGIS was c. 20-70 km behind its present ice-extent c. 41-26 ka and c. 7.8-1.2 ka during periods of high orbital precession index and/or summer temperatures within the projected warming for the end of this century. Our results demonstrate that the NEGIS was smaller than present for approximately half of the last ~45 ka and is susceptible to even subtle changes in climate, which has implications for future stability of this ice stream.

UiB COSMOGENIC NUCLIDE PREPARATION FACILITY

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The University of Bergen (UiB) is a medium-sized, internationally recognised research university, consisting of seven faculties and more than 50 departments. UiB has about 3.600 employees, and nearly 17.000 students. In Norway, PhD candidates are paid employees of staff, making a doctoral degree particularly attractive. The Department of Earth Science (GEO) is a medium-sized earth science department with about 160 employees (incl. PhD candidates), about 300 BSc and MSc students, and four research groups: geodynamics, basin and reservoir studies, geochemistry and geobiology, and Quaternary earth systems.

GEO has access to electron microscopes and research vessels, and runs several research laboratories, such as the UiB Cosmogenic Nuclide Preparation Facility. Here, we perform mineral separation, quartz isolation and purification, following procedures modified from Kohl and Nishiizumi (1992). We have experience with tailoring mineral separation procedures, and sequence of procedures, according to lithology (Grant, 2016; Grønnevik, 2017). Quartz purity is assessed, at GEO's ICP laboratory, by ICP-OES analysis of Al, Be, Ca, Cr, Fe, Mg, and Ti. The extraction of Be and Al from clean quartz and production of AMS targets follow procedures described by Child et al. (2000). We can make targets for various AMS facilities, such as the Aarhus AMS Centre (Heinemeier et al., 2015), the National Laboratory for Age Determination at NTNU (Nadeau et al., 2015), and the SUERC AMS Laboratory (Xu et al., 2010). Clean quartz can also be shipped to other laboratories for extraction and analysis of *in-situ* C-14 or Ne-21.

We welcome researchers to visit and process their own rock samples at the UiB Cosmogenic Nuclide Preparation Facility, regardless of prior experience. Research stays must, however, be planned well ahead, to ensure laboratory capacity, as well as to allow the administration to sort out practical issues, such as access to facilities, office space, IT, etc. The number of samples, laboratory costs, and AMS laboratory must also be agreed upon prior to any research stay.

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¹⁰Be-DERIVED PRESENT-DAY AND PALEO DENUDATION RATES OF THE VAR CATCHMENT, SOUTHERN FRENCH ALPS

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The development of a mountain range is the result of complex interactions between denudation, tectonics and climate. Quantifying denudation rates is thus key to understand and characterize these interactions, especially to forecast the future modifications of the landscape under a changing environment and climate.

The denudation rates of the Southern French Alps are yet poorly known. In this mountainous region, the Var catchment (drainage area of 2 800 km², mean elevation of 1 250 m, max elevation of 3 200 m and mean slope of 23°) is relatively small with a short transfer zone.

Indeed, the Var outlet is located on a very narrow continental shelf, ensuring a quick and direct transfer of sediments from the source to a submarine turbidic system composed of a canyon and a levee.

The geology of the northeast part of the Var catchment consists of Paleozoic crystalline quartz-bearing rocks while the southwest part is composed of Mesozoic and Cenozoic sedimentary rocks with variable quartz contents.

This setting is particularly suitable to quantify the basin average denudation rates using in situ ¹⁰Be concentrations in quartz sediments because we can expect a direct link between the measured concentrations and the denudation rates throughout the basin.

Nevertheless, this has been first tested by analyzing several subcatchments of the Var river. We collected 23 sediment samples from active riverbeds at 11 sites along the Var River and its main tributaries. In order to test the impact of grain size on ¹⁰Be concentrations, samples have been sieved in two fractions: 50-100 μm and 100-250 μm and their respective quartz contents isolated. Their in-situ ¹⁰Be concentrations have been measured to determine basin-averaged denudation rates and both grain-size fraction present similar results at the river outlet. We also compare the relative fluxes of each sub-catchment with respect to the whole catchment area and found that fluxes are in average balanced. This suggests that the present concentration measured in the river sediments is not biased neither by reworking of transitory stored deposits nor by landslides. The spatially average present-day denudation rate of the Var catchment is 0.23 (±0.05) mm/year.

Assuming that the in situ cosmogenic concentrations were also not biased during the past we analyzed the sediments from two sedimentary cores drilled by IFREMER (ESSK08-CS01 / CS13) on the submarine levee of the turbiditic system. These two cores are well dated providing a high resolution and continuous stratigraphic record over the last 70 ka. This permits to address ¹⁰Be-derived paleodenudation rates with an unprecedented time resolution over large (glacial vs Holocene conditions) and high frequency (D/O-Heinrich oscillation) climatic variations.

A few samples from these cores have been processed, providing a first insight on the variability of denudation rates in the Var basin over the last glacial period. The paleodenudation rates ranges from 0.16 (±0.05) mm/year (≈12 ka) to 0.37(±0.08) mm/year (≈19 ka).

DEGLACIATION AND ISOSTATIC UPLIFT IN FINNMARK

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Poster presentations

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Fennoscandia was repeatedly glaciated during the Quaternary. During the Weichselian Last Glacial Maximum (LGM, c. 20 ka BP), the Scandinavian Ice Sheet (SIS) coalesced with the Svalbard-Barents-Kara (SBKIS) and the British-Irish ice sheets. The immense load of the ice sheet depressed the crust into the mantle. After the LGM, as the ice sheet waned, the glacial loading was reduced and the crust experienced isostatic uplift. The distribution of ice-marginal deposits as well as the elevation of raised shoreline features have been used for reconstructing sub-stages during deglaciation, i.e. periods when the ice front halted or re-advanced during the general retreat. Sollid et al. (1973) defined seven deglaciation substages, spanning from c. 15 – 17 ka, when the ice sheet margin migrated from the Barents Sea onto Norway's coast (Finnmark) to the Younger Dryas. The purpose of this study is; (1) to refine the deglaciation chronology of northernmost Scandinavia and (2) to study how, and at what rates the crust responded to the unloading. It should be stressed that the deglaciation chronology is poorly constrained, based on few radiocarbon dates (Sollid et al., 1973), radiocarbon dates from basal marine sediments in raised isolation lake basins from the outermost coastline (Romundset et al., 2011) and from a recent study's dates using Surface Exposure Dating (SED) with cosmogenic ¹⁰Be and ³⁶Cl on boulders from crests of major moraine ridges in eastern Finnmark (Romundset et al., 2017). To overcome this issue, we apply SED on erratic boulders from ice marginal deposits and raised shoreline features and Depth-Profile dating on sediments from raised beaches and a delta. For both dating methods in-situ produced cosmogenic ¹⁰Be is used. The application of SED on raised shorelines represents a novel approach to date isostatic uplift. The study and first results will be presented.

NEOGENE BASIN INFILLING FROM COSMOGENIC NUCLIDES (^{10}Be AND ^{21}Ne) IN ATACAMA, CHILE: IMPLICATIONS FOR PALEOCLIMATE AND COPPER SUPERGENE ENRICHMENT

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In the hyperarid Atacama Desert, northern Chile, Neogene sediments host copper rich layers (exotic supergene mineralization). Current mines are excavated into relatively thin (<200-300 m) Neogene basins whose infilling chronology is poorly constrained. We took advantage of two of these mining pits, and sampled for ^{10}Be and ^{21}Ne cosmogenic nuclide dosing. These cosmogenic nuclides help constraining the infilling chronology. Indeed, basin sediments were deposited with a cosmogenic nuclide content acquired on hillslopes. Then within the basin, cosmogenic nuclide concentrations evolved through the competing production (quickly decreasing with depth) and disintegration (not for ^{21}Ne). Sampling depths are up to 110 m below the desert surface. We analysed the cosmogenic nuclide content analytically and by using an house-made inversion model. This analysis revealed meaningful for the period 15-7 Myrs ago. The basin infilling (100 m of sedimentation) occurs during a short period around 10-13 Myrs ago with sedimentation rates of the order of 100 m/Myr (high for the Atacama). It implies a surprisingly high source erosion rate (>400m/My). Moreover, this work proved the $^{10}\text{Be}/^{21}\text{Ne}$ useful to constrain the copper layer age (between 10.5 and 13 Myr-old), probably emplaced during a hiatus of sedimentation or a period of slower sedimentation. In turn, this unique site and the cosmogenic data has strong implications for muon production, which must not be too high (or the attenuation length must not be too long) to fit our data.

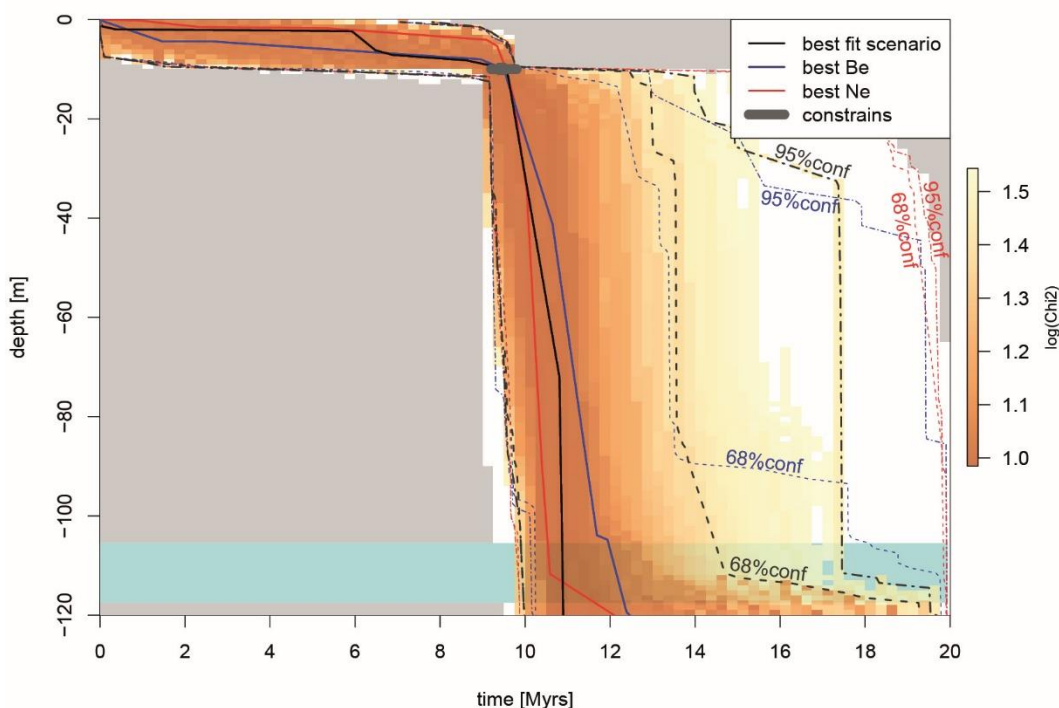


Figure: Inversion model with Heisinger exponential production scheme, source erosion rate of 500m/Myr. Color corresponds to Chi2 value (darker is better). Sample positions correspond to ticks to the left; copper layer is highlighted in light blue color. The inversion is constrained at three positions: arbitrary initial ($t=20\text{Ma}$, $z=-160\text{m}$), ignimbrite layer ($t=9.5\pm 0.3\text{Ma}$, $z=-10\text{m}$) and surface ($t=0$, $z=0$). The best fit scenario (and 68 and 95% confidence envelopes) for the entire data, for Be-10 only and for Ne-21 only are, respectively, in black, blue and red.

EVALUATING THE ROLE OF COSEISMIC LANDSLIDING ON COSMOGENIC NUCLIDES, EROSION RATES, AND TOPOGRAPHIC EVOLUTION IN MOUNTAINOUS LANDSCAPES. A CASE STUDY OF THE M_w 7.8 GORKHA EARTHQUAKE, NEPAL

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The M_w 7.8 Gorkha earthquake, which struck central Nepal in 2015 presents a unique opportunity to study the effects of coseismic landsliding on long- and short-term sediment transport and landscape response in active orogens. In the years immediately following the earthquake (2015-2017), we repeatedly sample river sands and pebbles for cosmogenic ¹⁰Be, in order to evaluate the effects of such events on cosmogenic nuclide signals. Assuming that wide-spread landsliding during the Gorkha earthquake mobilized deeper material with lower TCN concentrations, we expect our data set to track the potential “earthquake signal” as sediment is excavated from hillslopes and moves downstream. Comparison with pre-earthquake data from the literature should provide some insight into the timing and mechanisms of post-earthquake sediment evacuation. Initial measurements from 2015-2016 show ¹⁰Be concentrations decreasing at the sampling points furthest upstream and increasing at sampling points furthest downstream in both the Bhote Koshi and Trishuli River valleys. Our preliminary data also show consistently lower ¹⁰Be concentrations in pebbles than in sand at the same location, with the same overall trends in both grain sizes. On-going measurements will better resolve this data set and help us further investigate the effects of coseismic landsliding on TCN in riverine sediments.

GEOCHRONOLOGY OF QUATERNARY GLACIATIONS IN PURUOGANGRI, THE LARGEST ICECAP IN THE TIBETAN PLATEAU

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The Puruogangri is the largest Icefield (icecap) in the Tibetan Plateau (TP) with an area of 423 km². Low precipitation, gentle relief of the landscape and stable massif make this place possible to preserve relatively complete records of Quaternary glaciations. However, investigation of Quaternary glaciations have not been undertaken because of extremely remote, hard climate and harsh traffic area (Fig. 1). Using geomorphostratigraphic strategies in field, the cosmogenic nuclide ¹⁰Be surface exposure dating and optically stimulated luminescence dating, we establish glacial advances in LIA, 5 ka, YD MIS 2, MIS 3, MIS 4, MIS 6, MIS 8, MIS8 and MIS10, etc (Fig.2).

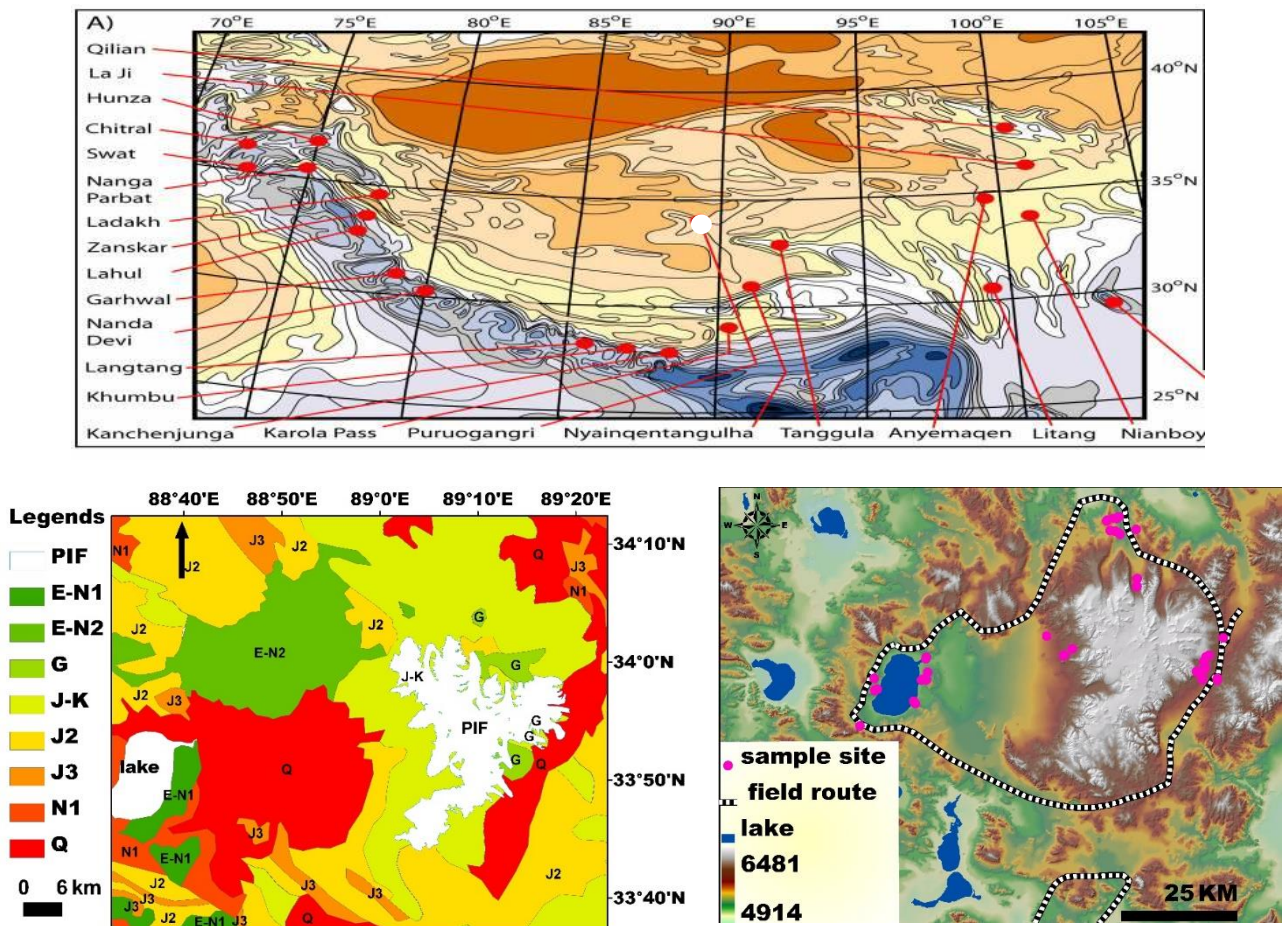


Fig. 1 Location, geological map and investigation routes of the Puruogangri ice field. The upper panel is after Owen et al.

Poster presentations

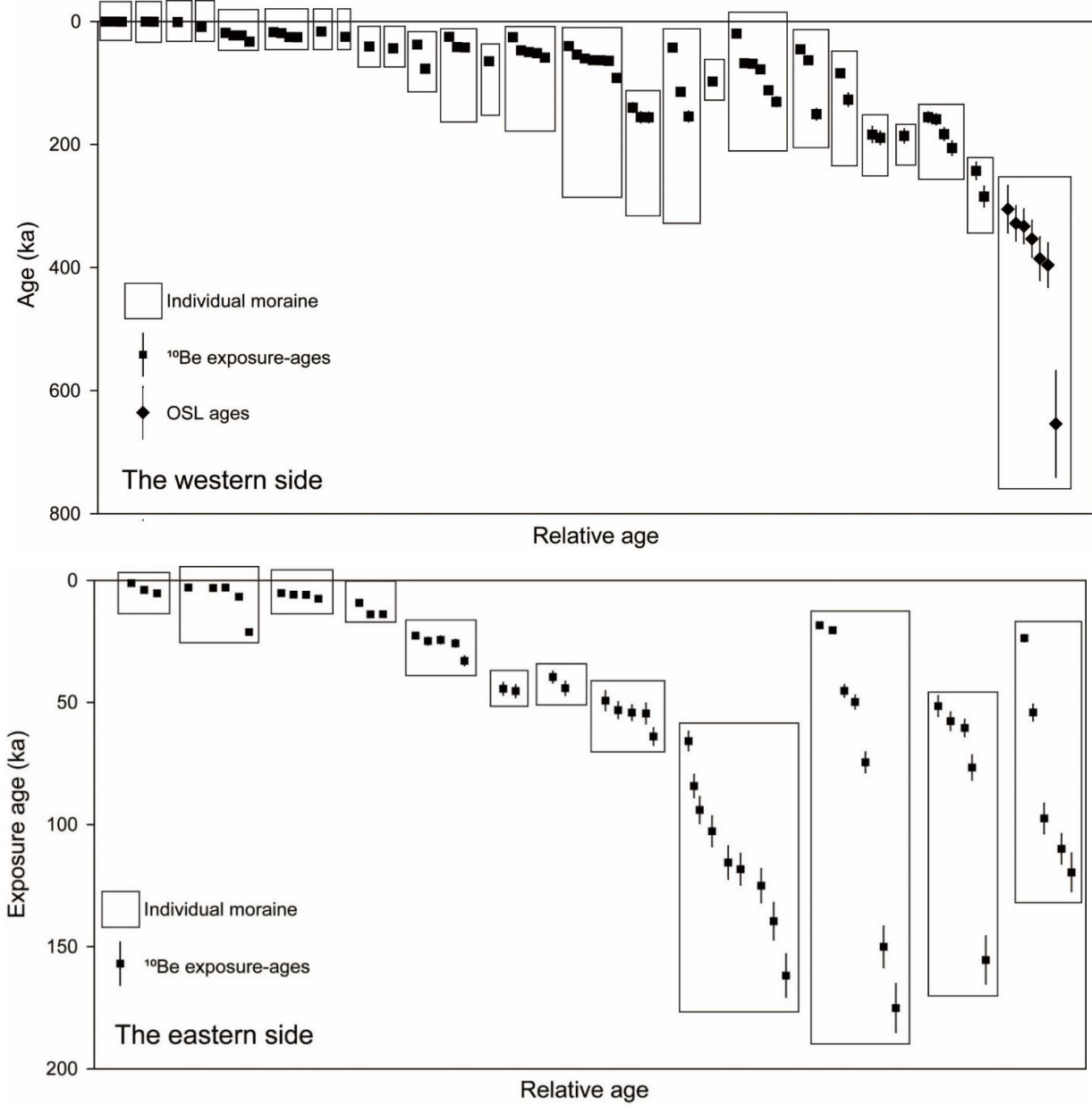


Fig. 2 Geochronology of glacial relicts on the western (upper) and eastern (down) parts of the Puruogangri icefield.

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