NGU REPORT 2019.011

Young Trondhjemites 2019
- Programme and
abstracts

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REPORT

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Young Trondhjemites 2019 - Programme and abstracts

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Summary: The 4th Young Trondhjemites conference for young researchers working in geoscience and geological engineering was held at NGU on 22nd of March 2019.

The young researcher community contributed with 11 oral presentations and 9 posters. The abstracts of these contributions are presented here in the programme order. Two guest speakers were invited. The first guest talk was presented by Evy Glørstad-Clark from AkerBP, who talked about the future of oil prospecting. The second invited talk was given by Lars Harald Blikra, who introduced us to "Veslemannen" rockslope failure and the challenges related to monitoring the site and communication to the society.

Finally, five workshops have been organised to offer the opportunity to the participants to discuss and learn about how to write an article, how to hold a presentation, how to prepare a poster, how to use a drone for 3d modelling and an introduction to digital mapping. A total of 60 researchers participated, contributing with eleven oral and nine poster presentations. The conference has been organised thanks to the support from the Geological Survey of Norway (NGU), AkerBP, Norsk Bergforening, Department of Geoscience and Petroleum (NTNU), Lundin, Norsk Bergindustri, Forskerforbundet and Sintef.

Keywords:

Content

Sponsors
The conference has been organised thanks to generous support of:

Programme YT2019

08.30 – 09.00	**Registration & coffee**
09.00 – 09.10	Opening, May Britt Myhr (Director NGU).
09.10 – 09.25	Rockslide mapping in Sikkim, India – fieldwork and photos – *Odd André Morken*
09.25 – 09.40	Bedrock lineament and landscape mapping using high-resolution topography data at the Sunnmøre coast – *Alvilde Krohn–Nydal*
09.40 – 09.55	Iron and manganese encrustations in groundwater source heat pump systems – *Lars Aaberg Stenvik*
09.55 – 10.10	Sulfide mineralizations in the deep rooted Reinfjord ultramafic complex, Nord-Troms – *Monika Oftedal Voll*
10.10 – 10.25	Utilisation challenges for local large–size aggregates in highway construction – *Marit Fladvad*
10.25 - 10.40	**Break - fruits & coffee**
10.40– 10:55	Zoning in cassiterite: Sectors or twins? – *Kristian Drivenes*
10:55 – 11.10	Machine learning and automatic classification of landscape elements – *Alexandra Jarna*
11.10 - 11:25	The Weddell Sea Expedition 2019: Preliminary scientific findings and a first–hand account of the 'worst sea in the world' – *Christine Batchelor*
11.25 – 12.10	Invited talk: *Evy Glørstad-Clark* (AkerBP) – Framtidens olje–leting
12.10 –12.45	**Lunch**
12.45 – 13.00	The role of sediment composition on element mobility in a CO2 leakage scenario – *Simon Ross Stenger*
13.00 – 13.15	Proglacial lake Nedre Glomsjø and the debacle that swept Southern Norway: From Norway's largest lake to a devastating and landscape –*Fredrik Høgaas*
13.15 – 13.30	Illuminating geologic processes with laser–ablation ICP–MS – *Graham Hagen-Peter*
13.30 – 13.45	Poster pitch (following poster programme order)
13:45 – 14:05	**Poster session w/ cake, fruits & coffee**

14.05 – 14.50	Invited talk: *Lars Harald Blikra* (NVE) – From mapping geologist to landslide expert
14.50 – 15.00	**Break**
15.00 – 16.00	Workshop 1
16.00 – 16.05	**Break**
16.05 – 17.05	Workshop 2
17:05 – 18.00	**Poster session, awards & refreshments**
18:00	**Bus to Habitat (Olav Tryggvassons Gate 30)**
18:30	**Dinner & refreshments**

Poster programme

How significant is inheritance when dating rockslide boulders with terrestrial cosmogenic nuclide dating? - a case study of an historic event – *Paula Hilger, Ivanna Penna, Reginald L. Hermanns, Thierry Oppikofer, John C. Gosse*

Sedimentation in Lake Nordlaguna – a closed basin on Jan Mayen – *Marianne Christoffersen*

A closer look at microstructures related to the intrusion of dykes in the Upper Layered Series in the Reinfjord Ultramafic Complex–*Jørgen Sakariassen, Bjørn Eske Sørensen, Rune B. Larsen, Kristian Drivenes*

Airborne radiometry of North Norway: a useful indicator for radon hazard assessment – *M.A. Dumais, A. Stampolidis, F. Ofstad, A. Rodionov, O. Olesen, J.S. Rønning*

40 years of low–temperature thermochronology in Fennoscandia – where are we now? – *J. Giese, A.K. Ksienzyk, T.F. Redfield, M. Ganerød, B.W.H. Hendriks, J. Jacobs*

Using "petrochronology" to decipher the metamorphic history of a convergent margin: A case–study from the Ross orogen, Antarctica – *Graham Hagen–Peter, John Cottle, Matthijs Smit, Alan Cooper*

Svecofennian tectonomagmatic evolution at the SW margin of Fennoscandia; central West Troms Basement Complex, Troms, Norway – *Kristine G. Nymoen, Bjørn Eske Sørensen, Trond Slagstad, Nolwenn Coint*

Experimental application of underwater hyperspectral imaging on seafloor massive sulphides from the Loki's Castle on the Arctic Mid-Ocean Ridge, Norway – *Øystein Sture, Ben Snook, Sigurd A. Sørum, Kurt Aasly*

Tectonomagmatic Evolution of the Sveconorwegian Orogen Recorded in the Chemical and Isotopic Composition of 1070 – 920 Ma Granitoids – *Anette Granseth, Trond Slagstad, Nolwenn Coint, Nick Roberts, Torkil Røhr & Bjørn Eske Sørensen*

Oral presentations

ROCKSLIDE MAPPING IN SIKKIM, INDIA - FIELDWORK AND PHOTOS

Odd André Morken

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Fieldwork in connection to an ongoing rockslide mapping project in Sikkim, Indian Himalaya, presented through photos and impressions from the field. Rock avalanches! Landslide damming of rivers! And a moving city!

BEDROCK LINEAMENT AND LANDSCAPE MAPPING USING HIGH-RESOLUTION TOPOGRAPHY DATA AT THE SUNNMØRE COAST

Alvilde Krohn-Nydal

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Mapping the seafloor and coastal landscapes in southern Sunnmøre, Møre & Romsdal is central to my graduate studies, with the aim to identify bedrock structures and geomorphologic features. Using Light Detection and Ranging (LiDAR) data, green LiDAR and bathymetry data, a thorough mapping of the topography in shallow marine areas and onshore is possible. The availability of a high-resolution continuous DEM presents new possibilities for research and detailed mapping of the seafloor and the coast.

The strandflat follows most of the coastline along Norway and is characterised as a low relief platform extending from the coastal mountains and islands. Its morphology has been the subject of much discussion. One hypothesis, perhaps the most accepted one at “current” state that Quaternary glaciations removed a deep saprolite layer originating from chemical weathering from pre-glacial times. Crystalline bedrock thought to have been the weathering front, -or etch surface was exhumed and then glacially modified. There are still uncertainties connected to the precise mode of formation and age of the strandflat.

The research question is whether an old, weathered landscape was partially preserved despite extensive glacial erosion. By looking closer at landforms and bedrock structures, a better understanding of the different processes influencing the coastal landscape can be reached. Preliminary results show that the bedrock structures dictate much of the topography along the coast. Some larger systems like the Møre-Trøndelag fault system can be recognized in the mapped lineaments and field measurements. The coastal landscape is complex with local differences emphasized by many influences.

IRON AND MANGANESE ENCRUSTATIONS IN GROUNDWATER SOURCE HEAT PUMP SYSTEMS

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Groundwater in unconsolidated sediments represents a local and renewable energy resource. By use of an open-loop ground source heat pump system (open-loop system), heating costs of buildings can decrease by 70% compared to conventional electrical heating. The system also offers the possibility of cooling in warmer periods. The method is still not much utilized in Norway, probably because of a lack of knowledge. Therefore, the ORMEL project (Optimal utilization of groundwater for heating and cooling in Melhus and Elverum) was initiated in 2015. A sequel, ORMEL 2, followed from autumn 2018.

One of the R&D focuses in ORMEL 2 is the challenging groundwater chemistry of Melhus, mediating iron and manganese encrustations in the open-loop systems. The groundwater environment is often reducing and with a relatively low pH, leading to metal dissolution. When the water enters the system, contact with the atmosphere and CO2 degassing may occur. This will lead to oxygenation and a pH increase respectively, consequently triggering precipitations. The presence of bacteria and mixing of different water qualities will contribute as precipitation catalyzers. With time, these precipitations will encrust and clog parts of the system, e.g. well screens and heat exchangers, leading to a decreased water extraction and heat transfer capacity.

Unfortunately, there is a knowledge gap regarding remedies to the encrustation problems. Therefore, as part of ORMEL 2, the first author's PhD will investigate the processes causing encrustations, and test and evaluate system design, maintenance and operation strategies to avoid the problem.

SULFIDE MINERALIZATIONS IN THE DEEP ROOTED REINFJORD ULTRAMAFIC COMPLEX, NORD-TROMS

Monika Oftedal

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Our work describes certain sulfide mineralizations in the Reinfjord ultramafic complex (RUC) in the Seiland Igneous Province, North Norway. In particular we studied the RF4 drill core that intersects several sulfide reefs.

The RUC comprises one of several root systems in the Seiland Igneous Province. Here, at a depth of 25-35 km, thousands of km^3 of ultramafic astenospheric melts passed through on the way towards more shallow levels.

Several Cu-Ni-PGE reefs were previously described from 3 other drill cores, whereas here we study a thick Cu-Ni rich mineralization in the lower parts of RF-4, close to the lower contact of the RUC. The Cu reef is ca 15 meters thick and sub-horizontal, with a maximum of 900 ppm Cu. Ni has a maximum grade of 4000 ppm with an average of ca 2400 ppm, however, some Ni is lattice bound in olivine. The Ni content drops dramatically below the Cu reef. The PGE content peaks at 290 ppb over 5 meters, and drops drastically in the lower part of the Cu reef.

The main ore minerals are pyrrhotite (Fe1-xS), pentlandite ((Fe,Ni)S) and chalcopyrite (FeCuS2). Magnetite (Fe3O4), ilmenite (FeTiO3) and chromium spinels (FeCr2O4) are also common. Most of the ore minerals occur as isolated grains. The main host minerals are olivine (Fo82-85.6) and pyroxene (Mg# 78.8-84.3), with few ore minerals hosted in serpentine and calcareous spots. There is an apparent positive correlation between Cu and Cr in the samples.

Most of the ore minerals are primary magmatic crystals, only a small portion is remobilized through serpentinization. However, as there are 3 distinct generations of olivine, the primary magmatic crystallization of ore minerals could have occurred step-wise as well. Some samples contain small specks of carbonates, possibly originating from carbonate rich magma that mingled through the not yet

solidified dunitic mushes. If so, some of the ore material could originate from these melts. Because of the correlation between Cu and Cr, these two elements were probably concentrated by the same mechanisms in the magma chamber.

UTILISATION CHALLENGES FOR LOCAL LARGE-SIZE AGGREGATES IN HIGHWAY CONSTRUCTION

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A pavement structure is a multi-layered structure consisting of aggregates in several sizes and qualities. The layered structure is designed to distribute traffic loads to the underlying subgrade while withstanding detrimental forces from traffic loads and climatic conditions over the lifetime of the road. A unique challenge in seasonal frost environments is freezing and thawing of the soil, making drainage and frost protection especially important subjects in pavement design. With frost protection, Norwegian highways can be up to 2.4 meters deep, and the amount of aggregates needed is substantial.

In several highway projects, the construction of tunnels creates a surplus of blasted rock. Despite the overall surplus, aggregates for the pavement structure may still be transported in from quarries in order to comply with quality requirements. To increase the utilisation of “short-travelled” aggregates, production and quality assessment methods needs adaption. The most substantial parts of the pavement structure are the subbase and frost protection layers, where aggregates up to 300 mm are used. These large-size aggregates are challenging to sample and test. Suitable test methods are lacking because European standards for aggregates are limited to aggregate sizes up to 90 mm. Larger aggregates are not sievable, so alternative and manual methods are needed. Full-scale testing has shown that production methods affect the quality of aggregates in a way that the traditional quality assessment methods are unable to detect. The lack of suitable quality assessment methods obstructs the utilisation of local aggregate resources in construction projects.

ZONING IN CASSITERITE: SECTORS OR TWINS?

Kristian Drivenes[1], Bjørn Eske Sørensen[1], Sytle Antao[2], William Brownscombe[3], Chris Debuhr[2], Morten Peder Raanes[4], Reimar Seltmann[3], and John Spratt[3].

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Distinct zoning patterns in cassiterite from a quartz-tourmaline rock in SW England can clearly be observed in the optical microscope. They appear in (near-) basal sections and are reminiscent of sector zoning found in other minerals such as zircon, titanite and clinopyroxene. The model for sector zoning in minerals involves contrasting incorporation and diffusion rates of elements between different forms and faces in a crystal. Cassiterite in our samples differs from the well-known examples in that there is no systematic chemical difference between the apparent sectors. The chemical zoning of detected trace elements (Ti, Fe, W, Nb) is either oscillatory or patchy, commonly relating to the color observed in plane polarized transmitted light. In particular, W (up to 1 % m/m WO3) is correlated with dark brown color in transmitted light. The other main trace element, Ti, is typically concentrated in the core and is oscillatory

zoned, and may be up to 2.4 % m/m TiO_2. The cathodoluminescence intensity shows a weak inverse relationship with Ti and W, and a distinct inverse relationship with Nb. The yellow CL is dominated by a broad peak at ca 2.13 eV, a sharp peak at 2.18, and a smaller, broad shoulder at ca 2.75 eV. EBSD analyses of the grains showed no variation in c-axis orientation across the “sectors”, and very minor misorientation throughout grains with the pronounced zoning. Two EBSD patterns taken from two different “sectors” could not be distinguished from each other. Misorientation within a grain relative to a randomly selected point was less than 3°,and can be correlated to fine CL-zoning. This minor variation in orientation may be due to local defect induced lattice strain. Cassiterite commonly develops elbow twins by reflection around [011]. This is also observed in our samples, but is not the cause of the sectors, since the c-axis orientation does not vary.

The apparent sectors observed in the optical microscope represent the growth traces of the pyramidal {h0l} plane or the {h00} prism plane. The 4-fold symmetry around the c-axis in cassiterite (tetragonal, 4/mmm) indicates that pyramidal and prism faces are symmetrically equivalents. This does not conform with the distinct variation in interference color ($\Delta n \approx 0.05$) between the “sectors”. In addition, a grain cut normal to the c-axis showed a biaxial optical axial figure with 2V of ca 10-15°. We speculate that the “sectors” may be produced by either of the following, both hypothesizing that the observed phenomenon is twinning:

1. The observed mineral is not tetragonal. Very minor difference between the lengths of a and b, or possibly β, making the mineral orthorhombic or monoclinic, respectively. Alternatively, the unit cell is tetragonal, but the symmetry of the crystal is orthorhombic or monoclinic
2. Nanoscale phases of another SnO_2 phase included in the mineral induce strain in certain crystallographic directions.

MACHINE LEARNING AND AUTOMATIC CLASSIFICATION OF LANDSCAPE ELEMENTS

Alexandra Jarna, Nicole J. Baeten, Sigrid Elvenes, Valérie K. Bellec, Terje Thorsnes and Markus Diesing

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The landscape is rapidly changing. In the pan-Artic and Scandinavia regions, the river processes and the cryosphere change the landscape over time. Precise land cover maps are of high importance when defining e.g. natural hazards monitoring, or urban planning use. To enable society to respond faster to the changing environment requires more efficient. Traditionally, maps are produced manually using expert-based mapping with a combination of fieldwork and remote sensing data. There are some disadvantages in relation to the manual mapping approach, such as subjectivity, cost inefficiency and time used to produce map of sufficient quality. There remain a lot of unknows and unmapped places, while the landscape is changing quickly. However, there are methods that can produce high accuracy map products with higher objectivity, efficiency and repeatability. (Semi-)automated classification is a powerful group of tools to recognize similar patterns on high-quality remote sensing data. Commonly used methods based on units of analysis are GEographic-Object-Based Image Analysis (GEOBIA) or pixel-based classifier. Another approaches, based on classification methods, are rule-based or data-driven classification.

THE WEDDELL SEA EXPEDITION 2019: PRELIMINARY SCIENTIFIC FINDINGS AND A FIRST-HAND ACCOUNT OF THE 'WORST SEA IN THE WORLD

Christine Batchelor, Aleksandr Montelli, Dag Ottesen, Jeffrey Evans, Evelyn Dowdeswell, Frazer Christie, Julian Dowdeswell

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The calving of iceberg A68 from Larsen C Ice Shelf in 2017 raised questions about the past behaviour of the Antarctic Peninsula Ice Sheet and concerns about the future stability of its floating ice shelves. However, very little is known about the character of the seafloor in this region as a result of the extensive sea ice that persists even during the austral summer.

Assisted by the most favourable sea ice conditions since 2002, the 2019 Weddell Sea Expedition of the SA Agulhas II conducted an ambitious scientific programme at Larsen C Ice Shelf. The Expedition science team used state-of-the-art technology, including aerial drones, a Remotely Operated Vehicle (ROV) and two Autonomous Underwater Vehicles (AUVs), to collect oceanographic, biological, glaciological, geological and geophysical data from the western Weddell Sea. The team's adventures in this typically inaccessible region of Antarctica included traversing the Weddell Sea, visiting the vast iceberg A68, and attempting to locate the wreck of Sir Ernest Shackleton's Endurance, which sank in 1915 after being crushed by sea ice in what Shackleton called the 'worst portion of the worst sea in the world.'

Here, we provide a first-hand account of this international and multidisciplinary research cruise, and present preliminary interpretations of the geophysical data that were collected by the AUVs. These geophysical data reveal the form and internal structure of glacial landforms in unprecedented detail, furthering our understanding of glacial-sedimentary processes and providing insights into complexities in ice-sheet behaviour.

THE ROLE OF SEDIMENT COMPOSITION ON ELEMENT MOBILITY IN A CO2 LEAKAGE SCENARIO

Simon Ross Stenger, Ana Borrero, Bjørn Frengstad, Murat Van Ardelan

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Carbon capture and storage is considered central in the effort to reduce net greenhouse gas emissions. Yet, a general concern regarding the application of this technology is reservoir contingency. At offshore storage sites, this is in part because of the potential risk of remobilizing toxic elements from the overlying sediments and the threat this poses to marine biota. It remains unclear, however, in what way the geochemical response to CO2-leakage is related to sediment composition and whether the results demonstrated in previous studies can be reproduced if the experiments are carried out at realistic pressure conditions.

Here we address these issues by carrying out a geochemical and XRD analysis of sediment sampled from two mesocosm CO2-exposure experiments conducted using a pressurized titanium tank. The results demonstrate that CO2-exposure has the potential to affect the mobility of certain toxic elements, including mercury, but also that a majority of the studied elements are merely redistributed amongst the solid species with no significant net release to the water column. Furthermore, we observe that the two sediment types used in the experiments express dissimilar element mobility patterns suggesting a compositional control on the geochemical response to CO2-exposure.

PROGLACIAL LAKE NEDRE GLOMSJØ AND THE DEBACLE THAT SWEPT SOUTHERN NORWAY: FROM NORWAY'S LARGEST LAKE TO A DEVASTATING AND LANDSCAPE

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The late glacial palaeolake Nedre Glomsjø was a 1500 km2, 100 km3 large lake dammed between the main watershed and the receding Scandinavian inland Ice Sheet. When the ice-dam broke a 350 000 m3/s large – or roughly twice the size of the Amazon river – outburst flood swept down Glomdalen. The focus in this talk is to provide the essence of the event: From lake inception to distal traces of the largest flood ever to have taken place in Norway.

The Jökulhlaup drained beneath the ice sheet to Rena, where now-abandoned mega-channels show how the flood spread out into Glomdalen. Distinct and continuous erosional levels cut in till and bedrock – upper flood markers – show that the flood emerged from the ice sheet just north of Elverum. Here, the flood-wave was an 80-90-meter-deep, several km wide, sediment-laden cataclysmic current. Below the upper flood level, large flood bar deposits, some several km long, drape the valley floor. The event lead to the deposition of several meter-thick fine-grained deposits at Romerike (mjele), more than 150 km downstream, where also gigantic flood-rafted icebergs stranded and subsequently created plow marks in the clay plateaus.

ILLUMINATING GEOLOGIC PROCESSES WITH LASER-ABLATION ICP-MS

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Laser-ablation inductively-coupled-plasma mass spectrometry (LA-ICP-MS) provides sensitive, precise, and accurate measurements of elemental concentrations and isotope ratios in a variety of solid materials with high spatial resolution (~1−100's of μm). Since its inception several decades ago, the technique has been extensively employed in geosciences and has seen many advances. In anticipation of the new LA-ICP-MS laboratory at the Geological Survey of Norway, this presentation will provide an overview of the capabilities of the method and will vignette several applications in geology. It will include case studies of magmatic processes elucidated by Sr isotopes in plagioclase, the timing and conditions of metamorphism revealed by combined U-Pb dating and trace element measurements of accessory minerals, and crustal growth and reworking recorded by U-Pb dates and Hf isotopes in zircons, among others.

Posters

HOW SIGNIFICANT IS INHERITANCE WHEN DATING ROCKSLIDE BOULDERS WITH TERRESTRIAL COSMOGENIC NUCLIDE DATING? - A CASE STUDY OF AN HISTORIC EVENT

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After a swarm of shallow earthquakes related to the activity of the Liquiñi Ofqui fault, a Mw 6.2 earthquake (D < 10 km) struck the Aysén Fjord region, south Chile, on April 21, 2007. Around five hundred landslides were triggered by the events, including two large-volume rock avalanches that entered the fjord generating displacement waves which impacted coastal morphology, the regional economy, and the population.

One of the largest mass movements, located around 5 km to the east of the epicenter, is the Punta Cola rock avalanche. Detailed morphologic analyses, a high resolution DEM derived from Terrestrial Laser Scanning (TLS), and further topographic reconstructions allowed to estimate that ca. 20.9 Mm^3 of granitic rock detached from a NW-dipping slope of a small valley tributary of the Aysén fjord. The displaced rock mass produced a maximum run-up height of 150 m on the opposite slope.

Six samples for terrestrial cosmogenic nuclide dating were collected from the nine-year-old deposit in January 2016. A goal of the sampling strategy was to exclude clasts from older rock-slope failure deposits. After subtraction of the ^{10}Be process blank concentration of 9.53 kat/g and negligible (9 years) post-depositional exposure (ca. 35 at/g, ignoring temporal production rate variations in that decade), ^{10}Be concentrations in boulders averaged 0.9±0.3 kat/g (1 σ) and 1.3±0.3 kat/g, respectively and overlap within 2 σ uncertainties (mean of all 5 boulders is 1.2±0.3 kat/g). The outlier clast yielded 7.0±1.7 kat/g. This clast was sampled within a secondary failure of the valley slope along the debris avalanche run-out track.

Assuming no unaccounted systematic measurement error, the inheritance provides important information regarding the source of the boulders. Considering the ^{10}Be concentrations, five of the six boulders must have originated from shallower depths than 18 m inside the pre-slide cliff face if a landscape eroded by glacial erosion is considered. This is much less than the maximal depth with 100-111 m based on volume and simple geometry. The secondary rock slide is with 10-50 m depth generally shallower where the outlier clast seems to originate from only a few (2-4) meters depth. With more measurements, it may be possible isotopically to constrain clast position, which can be useful for failure reconstruction and run-out model verification.

SEDIMENTATION IN LAKE NORDLAGUNA - A CLOSED BASIN ON JAN MAYEN

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Nordlaguna is closed basin separated from the ocean by a barrier and surrounded by steep mountains and valleys. The lake has the potential to be a paleoclimatic archive and provide information about the unknown sea-level history of the island. When lake sediments are used in paleoclimatic studies, it is useful to acquire knowledge about the modern sedimentary processes of the lake in order to trace changes in the sedimentary record, as well as obtaining a reliable chronology. A geological map of the sediment distribution and geomorphology of the study area was produced by combining field investigations of the terrestrial environment with bathymetry and Side Scanning Sonar data from the

lake. Two sediment cores from the lake were used to connect the modern sedimentary processes with the sediment record. Five main sedimentary sources were found: temporal and seasonal fluvial activity, deposition by wash-over events on the barrier, mass movement processes from the slopes surrounding the lake, wind-blown sediments, and pyroclastic fallout. The distribution of the sediments is controlled by the proximity to the source as well as processes within the lake. The dating of core NL2 revealed an irregular pattern that may be a result of deposition of old terrestrial material or redistribution of the sediments. In core NL1B, the absence of organic material provided an inadequate chronology. This suggests that the chronology of the cores can be considered unreliable and may complicate their use in studies of past environmental conditions.

A CLOSER LOOK AT MICROSTRUCTURES RELATED TO THE INTRUSION OF DYKES IN THE UPPER LAYERED SERIES IN THE REINFJORD ULTRAMAFIC COMPLEX

Jørgen Sakariassen, Bjørn Eske Sørensen, Rune B. Larsen, Kristian Drivenes

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The Reinfjord Ultramafic Complex (RUC) is part of the lower crustal Seiland Igneous Province which is likely to be a large mantle derived magmatic conduit system. The complex consists of several ultramafic intrusive series hosted by layered gabbros and thought of as the de facto conduits. The Upper Layered Series (ULS) and the Central Series (CS) represents the largest intrusive events of the RUC. The ULS consists of olivine cumulates, as well as wherlites and olivine clinopyroxenites, and the CS is mainly consisting of younger dunites and wherlites. The Southern plateau of the RUC contains both young and old dykes some of the older dykes are cut by the CS dunites, whereas the younger dykes cuts both the ULS and the CS replacive dunites. These relations could provide a unique understanding of the magmatic evolution of the RUC as well as date the intrusion of the ULS and CS relatively and absolutely if dykes contains minerals suitable for dating.

The earliest generation of dykes is believed to have the highest concentration of zirconium, which would be a promising starting point for finding zircon crystals to use in U-Pb dating of the dykes of the ULS. The relationship between the wherlites of the ULS and its youngest generation of gabbroic dykes together with the meter scale dunitic dykes related to the intrusion of the CS can be studied and interpreted in the field. This dyke generation is younger than the wherlites, but older than the replacive dunitic dykes. The mineralogy, geochemistry and structures of these dykes will be studied to get a better understanding of the magmatic evolution and intrusive episodes of this complex. Not least, it may also be possible to better understand the composition of the parental melts

AIRBORNE RADIOMETRY OF NORTH NORWAY: A USEFUL INDICATOR FOR RADON HAZARD ASSESSMENT

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Of geological origin, carcinogenic radon (Rn-222) gas is created from uranium decay series. It then migrates through pores, fractures, and faults and dissolves in groundwater. Therefore, the concentration of uranium present in the bedrock is an important factor for radon hazard assessment.

Airborne radiometric methods are sensitive to naturally occurring and anthropogenic radioactive elements by measuring the gamma radiation spectrum from the ground which is dominated by the emissions products from potassium (K-40), thorium (Th-232) and uranium (U-238).

In 2011, the Geological Survey of Norway has launched an airborne geophysical acquisition campaign as part of the MINN (Mineral in North Norway) programme in order to refine the geological knowledge and mineral potential of the area. Flown at low altitude (60m), our instruments are sensitive to the radioactive elements present within the upper 30-50 cm of the ground. Maps showing the ground concentrations of U, Th and K are available to the general public and are effective to indicate higher concentration of radioactive sources. The information from these data are used for geological mapping, mineral investigations and for radon hazard assessment.

We present the radiometric maps of North Norway and delineate the extent and the strength of potential hazardous zones.

40 YEARS OF LOW-TEMPERATURE THERMOCHRONOLOGY IN FENNOSCANDIA – WHERE ARE WE NOW?

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More than 40 years after the first low-temperature thermochronological data were published from Norway, Sweden and Finland, and over a decade since Hendriks at al. (2007) presented the so far only compilation of Fennoscandian thermochronology, it is time to take stock again and review the presently available dataset. We have updated this compilation with data that have become available since then and have at the same time broadened its scope to include thermochronological information from the conjugate margin in Svalbard and Greenland. This new low-temperature thermochronological database of Fennoscandia/Norden collects fission track and (U-Th)/He data and will eventually be accessible through NGU's online services. With close to 1500 entries so far, the new database shows a very heterogeneous picture in both geographical distribution of data and data quality. It allows us to identify areas that deserve future attention, highlights potential problems (e.g. the lack of reliable track length data for large parts of Fennoscandia), and provides a road map for future public-domain archiving of thermochronological data. The database is considered to be a working compilation and is open for contributions and ideas from all interested public and private parties.

Hendriks, B., et al., 2007. Norw. J. Geol. 87, 143-155.

USING "PETROCHRONOLOGY" TO DECIPHER THE METAMORPHIC HISTORY OF A CONVERGENT MARGIN: A CASE-STUDY FROM THE ROSS OROGEN, ANTARCTICA

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Metamorphic rocks retain important records of the conditions, timing, and rates of tectonism in ancient convergent margins. However, it is challenging to link geochronologic data for metamorphic rocks (for example U-Pb dates of accessory minerals) to larger-scale processes that operated during an orogeny. The approach of linking absolute dates to broader tectonic processes has become known as "petrochronology". We provide an example combining garnet Lu-Hf and monazite U-Pb dates with trace element compositions, petrography, and phase equilibria modeling to elucidate a protracted tectonometamorphic history of the Ross orogen, an ancient accretionary orogen active along the margin of Antarctica in the Neoproterozoic-early Paleozoic. Mineral assemblages and compositions along with

phase equilibria modeling indicate a clockwise “Barrovian-style” pressure-temperature path with peak temperatures of ~610-680 °C and pressures of ~7-8 kbar. Concordant monazite dates span ca. 110 Myr (610-500 Ma) with Y- and heavy rare-earth element-depleted cores overlapping the garnet Lu-Hf dates (ca. 616-572 Ma). Voluminous magmatism along the margin predominately occurred ca. 565-490 Ma. The garnet and early monazite dates, along with relatively high-pressure mineral assemblages and compositions, are interpreted to record a period of contraction and thickening of the margin before the onset of steady-state subduction and arc magmatism. The subsequent magmatism resulted in relatively low-pressure high-temperature “contact metamorphism” overprinting. Taken together, the metamorphic “petrochronology” reveals an early period of tectonism not recorded by the magmatic or sedimentary rocks associated with the orogen.

SVECOFENNIAN TECTONOMAGMATIC EVOLUTION AT THE SW MARGIN OF FENNOSCANDIA; CENTRAL WEST TROMS BASEMENT COMPLEX, TROMS, NORWAY

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Grytøya, Bjarkøya, Sandsøya, Meløyvær and Krøttøy are located in the central portion of the West Troms Basement Complex (WTBC) in Troms, Norway. They comprise Precambrian rocks that record Svecofennian (ca. 2.0-1.8 Ga) magmatic and metamorphic events at the SW margin of the Fennoscandian Shield, and later events during Caledonian orogenesis. The purpose of this study is to improve our understanding of these events and place them in a regional tectonic framework. To this end, the project includes geological mapping, petrographic study, whole-rock geochemical and isotopic (Sm/Nd, Lu/Hf) analysis and U-Pb zircon geochronology. The preliminary results show that the basement rocks can be divided into two granitic/granodioritic units, a meta gabbro and a supracrustal unit associated with varying proportions of amphibolite. The basement rocks are overthrusted by Caledonian nappes from the west. Granite is ubiquitous in the study area, with large variation in texture and grain size (medium- to coarse-grained). On Grytøya the granite has a porphyritic texture, with up to 5 cm prismatic to equidimensional Kfs phenocrysts in a fine-grained, feldspar, hornblende, biotite and quartz matrix. The quartz content of this granite increases from Grytøya north/northeastwards to Bjarkøya and Sandsøya. The meta-gabbro also varies in grain size (medium to coarse grained) and is composed of pyroxene, plagioclase and hornblende. The gabbro could be correlated with gabbro on Andøya and contains a skarn-deposit on Meløyvær. The supracrustal unit is found on Bjarkøya, Sandsøya and Meløyvær and consists of several lithologies: quartzite, amphibolite, carbonate, calc-silicate, mica-schist and meta-arkose. The supracrustal unit is intruded by granite. Similar supracrustal rocks may exist elsewhere in the WTBC, whereas the granitic rocks in the study area seem to have a different chemical composition from magmatic rocks in Lofoten-Vesterålen, south in the WTBC. The significance of this observation is as yet unknown.

EXPERIMENTAL APPLICATION OF UNDERWATER HYPERSPECTRAL IMAGING ON SEAFLOOR MASSIVE SULPHIDES FROM THE LOKI'S CASTLE ON THE ARCTIC MID-OCEAN RIDGE, NORWAY

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Remote sensing with hyper/multispectral technologies has seen wide use in terrestrial prospecting. Iron oxides and sulphides have low blue reflectance and high red reflectance in the visible spectrum; the ratio between these two pairs has been used in exploration for terrestrial deposits of hydrothermal origin. This discrimination typically also includes wavelengths exceeding the visible spectrum (1.5µm – 2.5µm). These wavelengths are typically not utilised underwater because infrared and higher wavelengths rapidly attenuate in water. However, discrimination based on the full shape of the spectral response in the visible light (350nm – 800nm) may still be possible. Resolving the endmembers from the spectral responses requires prior knowledge about the optical properties of the materials, i.e. their reflectances. These can be obtained in a controlled environment, where the spectra of the lamps, wavelength-dependent attenuation in water and light scattering can be accounted for.

During the MarMine cruise non-mineralised host rock, low grade and high grade ore grab samples were collected by ROV from the Loki's Castle seafloor massive sulphide (SMS) deposit on the ultra-slow spreading Arctic Mid-Ocean Ridge (AMOR). This material has been mineralogically characterised and, by imaging compositionally constrained material, the measured hyperspectral responses can be used to generate a library for identification of deposits on the ocean floor.

In this study, we report the methodologies used in tank experiments in order to generate a UHI spectral library of lithologies associated with SMS deposits (i.e. sediments/mudstone, basalt, low grade ore, high grade ore), we discuss the preliminary spectra results and their viability, and we recommend the experimental conditions for acquisition of valid UHI data pertaining to SMS identification.

TECTONOMAGMATIC EVOLUTION OF THE SVECONORWEGIAN OROGEN RECORDED IN THE CHEMICAL AND ISOTOPIC COMPOSITION OF 1070 – 920 MA GRANITOIDS

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The Sveconorwegian Province in Southern Norway and Sweden hosts four granitoid suites, formed during continuous magmatism at the Fennoscandian margin between 1070 and 920 Ma. This study presents a compilation of published and new geochemical and isotopic data for the granitoid suites and demonstrates their ability to record the tectonomagmatic evolution of the province. The 1070–1010 Ma Sirdal Magmatic Belt (SMB) represents the earliest magmatism, followed by two suites of hornblende-biotite granitoids (HBGs) (1000–920 Ma) and the Flå–Iddefjord–Bohus suite (925 Ma), in central and eastern parts of the Sveconorwegian Province, respectively. The SMB and HBG outside of the outcropping SMB (HBGout) are chemically similar, whereas the HBG located in the same region of the SMB (HBGin) is more ferroan and enriched in incompatible elements (A-type like). Isotopically, the SMB and both HBG suites fall on an evolutionary trend from widespread 1.5 Ga crust in the region. The Flå–Iddefjord–Bohus suite is more peraluminous, with isotopic compositions suggesting a more evolved and older source than that of the HBG suites and the SMB. Trace element modelling shows that the SMB and HBGout suites could have formed by 50% partial melting of 1.5 Ga crust, whereas 5–20% remelting of the dry SMB residue accounts for the geochemical composition of the HBGin. The available data

suggest a scenario where the 1.5 Ga lower crust underwent melting due to underplating of basaltic magma, giving rise to the SMB suite. Regional scale extension may have led to more widespread basaltic underplating, causing remelting of the residue left after SMB melt extraction, forming the HBGin suite, and more widespread lower crustal melting farther east, forming the HBGout suite. Deep continental subduction in the east of the orogen led to partial melting of the isotopically evolved crust and formation of the Flå-Iddefjord-Bohus suite. In summary, the data are compatible with long-lived oceanic subduction as a primary cause of magmatism.


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