NGU REPORT 2017.028

Young Trondhjemites 2017 –
Programme and abstracts

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REPORT

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Summary:

Young Trondhjemites 2017 is the second edition of a conference for young researchers working with geosciences and engineering in Trondheim. The conference was held the 2nd of June at the Geological Survey of Norway (NGU) and at brought together people from NTNU, NGU and other geoscientific institutions. Students working on a master, on a PhD, or recently graduated had the opportunity to present their work as a talk or as a poster. 14 contributions were presented as 8 minutes presentations and 11 as poster. The abstracts of the contributions are presented here in the programme order. In total, around 60 persons participated in the conference. After the presentations, 4 workshops have been held and were an opportunity for the participants to deepen their knowledge on how to write an article, how to hold a presentation, how to prepare a poster and how to work with photogrammetry. The conference has been organized thanks to the support of the Department of Geoscience and Petroleum (NTNU) and the Geological Survey of Norway (NGU).

Keywords:	Geosciences	Trondheim
Marine Geology	Reservoirs	Bedrock

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Programme

2nd of June 2017

0900 – 0930 Registration and coffee

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0930 – 0940: Geology of Arctic Northwest Russia during the Paleozoic and Early Mesozoic: – a literature summary. T.S. Harstad.

0940 – 0950: Numerical modelling to evaluate the impact of paleo-bathymetry and basin-fill processes on the source rock distribution in the hammerfest basin, barents sea. A.S. Baskoro, B.U. Emmel, G. de Jager, S.J. Lippard.

0950 – 1000: Uncertainty modelling of water fluid pressures along well path using a Monte Carlo approach, Hammerfest Basin. R. Karimova, A. Lothe, A. Grøver, S.J. Lippard

1005 – 1015: Introduction to digital core analysis: numerical flow simulations and pore network modelling. R. Mandzhieva.

1015 – 1025: Evaluating the potential of nanoparticle-enriched waterflooding for sandstone reservoirs. K. Aurand.

1025 – 1035: Seepage from an Arctic shallow marine gas hydrate reservoir is insensitive to momentary ocean warming. W.-L. Hong, M.E. Torres, J. Carroll, A. Crémière, G. Panieri, H. Yao, P. Serov

1040 – 1100: 1-min poster pitch (follow abstract order)

1100 – 1130 Break & Poster session + coffee and fruit

1130 – 1210 Session 2

1130 – 1140: Integrated analysis of past, and potential future rock slope failures of various size from Rombakstøtta, Nordland. O.A. Morken, P. Hilger, R. Hermanns

1140 – 1150: Geomechanical issues associated with CO_2 storage reservoirs. S. Gheibi, R.M. Holt

1150 – 1200: Development of a rock mass quality model for an open pit mine. M. Morales, K.K. Panthi, K. Botsialas

1200 – 1210: Process mineralogical parameters affecting magnetic separation of the Storforshei iron formation. M.K. Tøgersen.

1210 – 1300 Lunch

1300 – 1400 Session 3

1300 – 1310: Bedrock databases - Zzzzz or Yay! ?. E. Torgersen and colleagues in the solid earth geology team.

1310 – 1320: Unravelling the glacial history of Jan Mayen with K-Ar geochronology. R.J van der Lelij, A. Lyså, E. Larsen, M. Ganerød.

1320 – 1330: A petrogenetic and petrophysical study of high-grade metamorphic sedimentary rocks from the Modum Complex, South Norway. H. G. Jensen.

1330 – 1340: Petrography and geochemistry of the Umbukta gabbro: Rødingsfjellet Nappe Complex, Nordland, Northern Norway. B.K. Storruste.

1400 – 1500 Break & Poster session + Coffee and waffles

1500 – 1550 Workshop session 1

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Workshops:

Oral Presentation (by Espen Torgersen)

Making a poster (by Cecilie Bjerke & Morgan Ganerød)

Writing a paper (by Ola Fredin)

Photogrammetry (by Pierrick Nicolet)

1700 Dinner, refreshments and quiz!

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Mid Miocene – Early Pliocene depositional environment on the northern part of the Mid-Norwegian Continental Shelf. B.S. Blakstad

Unravelling the seepage history of a pockmark on Vestnesa Ridge (off W'Svalbard) using methane-derived authigenic carbonate U-Th. T. Himmler, D. Sahy, W.-L. Hong, G. Bohrmann, S. Buenz, D. Condon, A. Lepland

StoRM - new software for geological exploration. Application example: western Barents Sea. K.J. Zieba, M. Felix

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A structural and InSAR study of the unstable rock slope in Oksfjellet, Troms. M. Bredal , S.G. Bergh , L.H. Blikra , T.R. Lauknes

A quantitative analysis of transtensional margin rift width. L. Jeanniot, S. Buiter

K-Ar age constraints on chemically weathered granitic basement rocks (saprolites) in Scandinavia. A. Margreth, R. van der Lelij, T. Scheiber, J. Faust, O. Fredin, J. Knies

Graphite deposits in Northern Norway; Geophysical prospecting. B.E. Larsen, H. Elvebakk, F. Ofstad, J. Gellein, J.S. Rønning, J. Knezevic, H. Gautneb, J. Koziel

Relative timing, petrography and geochemistry of the Val Plattas gold mineralization in Graubünden, Switzerland. M. Frøystein, J. Reichlin, C.A. Heinrich, M. Frehner

Mineralogy and texture of the Storforshei iron formation, and their effect on grindability. M.K. Tøgersen, R.A. Kleiv, S. Ellefmo, K. Aasly

Programme committee:

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Frank Jakobsen (NGU)

Alexandra Jarna (NGU)

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Abstracts

GEOLOGY OF ARCTIC NORTHWEST RUSSIA DURING THE PALEOZOIC AND EARLY MESOZOIC: – A LITERATURE SUMMARY

T.S. Harstad

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Understanding Arctic Russian geology is an important component in my PHD project focusing on Late Triassic Barents Sea Sandstone Provenance. This talk describe different proposed source areas of the Upper Triassic in the Barents Sea. A complex geological history influenced by several orogeneses, massive volcanic activity and widespread erosion describes the northwest Russian geology in the Paleozoic and Early Mesozoic. Observations from the remote Russian Arctic archipelagos of Novaya Zemlya, Severnaya Zemlya and Franz Josef Land as well as the northern Urals and the Taimyr Peninsula provide insight to the development of the Barents Sea and the entire globe. In the last years, more geologic research have been published from the region, but advances are complicated by the remote locations and other concerns.

Following the Late Neoproterozoic Timanide orogen of northeast Baltica, a passive margin setting was present until the Caledonian orogeny in Silurian – Devonian time. A later oblique Uralide orogeny starts in the south and ends in the polar areas by late Permian. At the Permian – Triassic boundary extensive magmatism associated with massive magmatic activity in the Siberian Traps Large Igneous Province impact global climate as well as regional scale deposition and sedimentation patterns. A later migration of the Siberian Traps mantle plume is suggested to be associated with a mid Triassic phase of magmatism and isostatic upwelling in central Taimyr. The timing of the Novaya Zemlya orogeny is disputed, with varying evidence suggesting shortening sometime between Early Triassic and Early Jurassic.

NUMERICAL MODELLING TO EVALUATE THE IMPACT OF PALEO-BATHYMETRY AND BASIN-FILL PROCESSES ON THE SOURCE ROCK DISTRIBUTION IN THE HAMMERFEST BASIN, BARENTS SEA

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In basin and petroleum system modelling, the paleo-water depth (PWD) and distribution of organic matter within the source rock are important parameters in determining the initial condition of a basin-scale petroleum system. The study aims to produce high-resolution models of PWD and source rock distribution laterally (space) and vertically (time), employing process-based simulations of the three most important source rock intervals in the Hammerfest Basin: Lower-Middle Triassic, Upper Jurassic, and Lower Cretaceous. The models are validated by measurements of sand fraction (SF), total organic carbon (TOC) and hydrogen index (HI) data. Process stratigraphy of the basin-fill as well as organic-matter source type and preservation condition were taken into account. In general, the organic matter in the source rock was modelled according to the basin-fill deposition and basin-architecture. Throughout Early-Middle Triassic, a rift-sequence package was deposited with a coarsening upward trend of shaly-sand. The deposition occurred in the period of shallowing water-depth from ca. 1400 to 880 m and fast-very fast sedimentation rate (SR) (mean SR: ca. 20-48 cm/ka). Basinward prograding, uplift of the Loppa High, and very low primary productivity (PP) (ca. 0.01-7.9 gC/m2/a) were also encountered. These conditions were not favorable for organic matter preservation and thus produced poor source rocks (TOC ca. 0.1-2.3 wt%; HI ca. 23-121 mgHC/gTOC). During Late Jurassic, the Hekkingen Fm was deposited as shaly syn-rift deposit in the rift-climax phase as a result of extensional tectonic period. Slight upward-shallowing water depth from ca. 360 to 320 m, very slow-slow sedimentation rate (mean SR: ca. 1-1.8 cm/ka), and very high PP (ca. 2-175 gC/m2/a) with anoxic indication were encountered in the Late Jurassic. This promoted favorable organic matter preservation and produced very good source rocks (TOC ca. 2-13 wt%; HI ca. 60-340 mgHC/gTOC). The Early Cretaceous was a period of changing sedimentation from carbonate and shaly to sandy deposits. This was controlled by late syn-rift to post-rift deposition, slight deepening of water depth from ca. 300 to 330 m, and intermediate sedimentation rate (mean SR: ca. 7-12 cm/ka). PP was very low (ca. 0.5-4 gC/m2/a) and resulted in poor-good source rocks (TOC ca. 0.7-3.2 wt%; HI ca. 62-198 mgHC/gTOC). Based on the results, the Upper Jurassic Interval is considered as the best source rock in the Hammerfest Basin, promoted by very high PP with anoxic preservation condition and favorable basin-fill process for source rock deposition.

UNCERTAINTY MODELLING OF WATER FLUID PRESSURES ALONG WELL PATH USING A MONTE CARLO APPROACH, HAMMERFEST BASIN

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Hammerfest Basin is a well-known area which has been influenced by uplift and erosion events during the Cenozoic. It is believed that these events has led to the disruption of oil and gas accumulations, with pressure induced cap rock failure and leakage as a plausible explanation for the sparse amount of hydrocarbon occurrence in the traps. Uncertainty in timing and magnitude of these erosion events has led to an increase in exploration risks reflected by the high number of dry exploration wells. In this study, pressure modelling for reservoir rock – Stø Formation through geological time has been carried out in order to assess the impact of the burial history on the pressure development and cap-rock leakage within the Hammerfest Basin. Pressure simulation was performed using Pressim, which considers a pressure compartment methodology defined by faults and sealing barriers. The criteria used for the failure of the seal formation is a Mohr-Coulomb criteria.

Empirical formula has been adopted to illustrate the change of porosity with depth which is responsible for the overpressure generation. Set of parameters including minimum horizontal stress, seal permeability, different erosion scenarios acquired from literature and burial history have been varied in terms of the study to get a good match between the simulated and measured overpressure for wells drilled within the study area. Monte-Carlo simulation approach has been used to consider the uncertainty range of these parameters. The results of this study suggested: 1) proportion between the mechanical and chemical mechanisms responsible for the pressure generation in the field of study 2) overpressure history expanding from late Jurassic till present day 3) the timing and location of hydraulic leakage. The number of leaking compartment increases as the magnitude of the simulated minimum horizontal stress decreases. Variation of permeability is also affecting the leakage by making the overlying shale formation either too tight causing the hydraulic leakage, or too open causing the early release of the generated overpressure. Besides, the tested different erosion scenarios had a very slight influence on the overpressure generation and dissipation.

INTRODUCTION TO DIGITAL CORE ANALYSIS: NUMERICAL FLOW SIMULATIONS AND PORE NETWORK MODELING

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Digital core analysis can replace using of conventional core samples with decreasing time required for conducting experiments and better understanding of complex reservoir structures due to ability to capture pore geometries and fluid behavior at pore scale level.

In this work, the whole workflow of digital core analysis – from image study to creating of simple pore network models – had been performed.

The first step was related to analysis of 2D thin section images. It had been noticed that they might contain significant amount of information about pore microstructure which could be useful in further stages, e.g. average pore radius. Then several 3D micro-CT models (including those from the open database of the Imperial College London) had been analyzed. To calculate the absolute permeability, Lattice Boltzmann method was implemented in PALABOS software. It was noticed that several parameters influenced on the obtained results, for example, the image resolution and the volume of analyzed microstructure. In order to obtain reliable permeability (i.e. close to experimentally measured), the volume should be greater or equal to REV [Representative Elementary Volume] value.

When multiphase flow occurs in porous media, it is difficult to estimate relative permeabilities directly, since in this case REV should be bigger and LBM calculations are very computationally expensive. That why, the importance of pore network modeling was discussed and several simple models were created using the regular lattice patterns.

EVALUATING THE POTENTIAL OF NANOPARTICLE-ENRICHED WATERFLOODING FOR SANDSTONE RESERVOIRS

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The Norwegian Petroleum Directorate estimates that 50% of the oil on the Norwegian Continental Shelf (NCS) will remain in the reservoirs at field end-of-life according to current production plans. Methods that can enhance oil recovery from existing reservoirs will become increasingly important as oil production continues to decline. Priority will be given to technological advancements that require comparatively low capital investment. Patent-pending nanoparticles produced by Evonik Industries and evaluated at NTNU have been developed to increase oil recovery while using existing infrastructure on the oil platforms. The silica nanoparticles are added to synthetic North Sea water at 0.05 wt% (500 ppm).

This presentation provides an overview of the experiments leading to the development of specialized nanoparticles. The targeted application is for sandstone reservoirs on the NCS that currently use waterflooding. The goal was to create a concentrated nanoparticle dispersion that could be easily diluted and applied to existing waterflooding operations. Environmental concerns, energy demand and practical aspects related to the injection procedure are discussed.

Key coreflooding experiments that have led to the development of modified silica nanoparticles are highlighted. Tests have been performed with Berea sandstone cores and crude oil from the NCS at both 20°C and 60°C. Initial coreflooding tests evaluated commercially available silica nanoparticles to screen for the best possible candidate for further surface modification. Two morphologies were considered: spherical nanoparticles and dendritic (nano-structured) particles. The nano-structured particles achieved the highest oil recoveries. These particles were further modified for stability at higher temperatures. Particle size distribution for various nanoparticle concentrations, surface modifications and temperatures was evaluated over time. Prior to surface modification, nanoparticle retention in the core plugs was greater than 95%. After modification, the retention decreased to less than 10%.

SEEPAGE FROM AN ARCTIC SHALLOW MARINE GAS HYDRATE RESERVOIR IS INSENSITIVE TO MOMENTARY OCEAN WARMING

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Arctic gas hydrate reservoirs locate in shallow water and proximal to the sediment-water interface are thought to be sensitive to bottom water warming that may trigger gas hydrate dissociation and the release of methane. Here, we evaluate bottom water temperature as a potential driver for hydrate dissociation and methane release from a recently discovered, gas-hydrate-bearing system south of Spitsbergen (Storfjordrenna, ~380 meters water depth). Modeling of the non-steady-state porewater profiles and the observations of distinct layers of methane-derived authigenic carbonate nodules in the sediments indicate centurial to millennial methane emissions in the region. Results of temperature modeling suggest limited impact of short-term warming on gas hydrates deeper than a few meters in the sediments. We conclude that the ongoing and past methane emission episodes at the investigated sites are likely due to the episodic ventilation of deep reservoirs rather than warming-induced gas hydrate dissociation in this shallow water seep site.

INTEGRATED ANALYSIS OF PAST, AND POTENTIAL FUTURE ROCK SLOPE FAILURES OF VARIOUS SIZE FROM ROMBAKSTØTTA, NORDLAND

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Catastrophic failure of large rock slopes has led to fatalities in Norwegian settlements several times per century. The Geological Survey of Norway (NGU) currently carry out systematic geological mapping of potentially unstable rock slopes in Norway, on assignment from the Norwegian Water Resources and Energy Directorate (NVE). In this context, a hazard analysis and preliminary consequence assessment of the unstable rock slope at Rombakstøtta in Narvik kommune, Nordland fylke has been carried out. In addition, an analysis of rock fall run-out lengths and frequencies since deglaciation has been carried out in the modelling software Rockyfor3D. A fragmentation cycle analysis, used to assess the fragmentation during a failure and to separate rock fall deposits from rock avalanche deposits, has been developed and tested.

The study area is located in a north facing slope along a fjord ca. seven kilometers east of the city Narvik. Based on delimiting lineaments observed in the field, aerial photos, photo panoramas and digital elevation models, eight failure scenarios (1.A-B, 2.A, 3.A and 4.A-D) are defined at Rombakstøtta. Application of NGU´s hazard analysis resulted in one scenario being assigned to the medium/low hazard class, six to the medium hazard class, and one to the high hazard class. Volume estimation and run-out analysis were carried out for all scenarios as a part of the preliminary consequence assessment. Resulting volumes for the scenarios range from 10 000 m3 to 4 650 000 m3, and four of the scenarios have modelled run-out reaching houses, Ofotbanen, the E6 highway, and the fjord. An additional two scenarios have run-out reaching Ofotbanen.

The rock fall analysis show that rock fall blocks larger than ~7.8 m3 have reached coarse rock avalanche deposits with a possible frequency of 5-13 blocks per 1x1 m since deglaciation. This could affect cosmogenic nuclide dating of rock avalanche deposits, carried out within the CryoWALL project to which this thesis has affiliations. The calculation is based on rock fall modelling and an extrapolation of a dataset with ~100 years of rock fall registrations. The fragmentation cycle analysis has been developed and applied inspired by Charrière et al. (2016). Results suggest that rock avalanche deposits at Rombakstøtta underwent 0-3 fragmentation cycles during failure. And that rock fall deposits below Rombakstøtta generally experienced more than 4 fragmentation cycles during failure. Results are discussed and compared to the results of Charrière et al. (2016) from the Frank Slide, Canada.

GEOMECHANICAL ISSUES ASSOCIATED WITH CO_2 STORAGE RESERVOIRS

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Carbon dioxide (CO2) emissions to the atmosphere should significantly be reduced to mitigate climate change and its consequences. This crucial necessity has recently led to an international agreement in Paris, December 2015. The objective is to limit the temperature increase caused by anthropogenic CO2 emissions to 2 ºC. To achieve this objective, CO2 emissions should drop by a factor of 2 by 2050 with respect to the current emissions. According to the International Energy Agency, geologic carbon storage has the potential to contribute to one fifth of the total CO2 emissions reduction.

However, there are some geomechanical issues associated with the storage of CO2 in deep geological formations. Inflation of a reservoir rock leads to total and effective stresses changes inside the reservoir and the caprock. These changes can lead to reactivation of faults and pre-existing fracture causing felt earthquakes and leakage problems.

Stress paths are coefficients by which the stress changes can be quantified as change of stress per unit pore pressure change inside the reservoir.

This presentation will briefly discuss the effect of faults presence and inelasticity on the stress path and the stability of reservoir-caprock system during one-way injection or injection-post-depletion. Also, a developed methodology based on Linear Elastic Fracture Mechanics will be introduced to assess the likelihood of faults rupture growth after depletion or inflation of reservoirs.

DEVELOPMENT OF A ROCK MASS QUALITY MODEL FOR AN OPEN PIT MINE

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In open pit mining, a rock mass model can provide important input for the optimization of production in relation to stability challenges and a safe workplace. In this sense, rock mass classification systems are useful for defining rock mass domains which identifies areas of poorer ground conditions that may require more detailed investigation or modifications to mine designs. These methods are widespread among geotechnical engineers as one practical way to assess quality of the rock mass. In open pit mines bench faces with no clear discontinuities one single joint may dominate on the pit slope plane failure mechanism. To address this, the analysis of low rock mass quality zones combined with the jointing orientation may provide an improvement in the instabilities assessment. The aim of this paper is to develop a rock mass model of an open pit mine under active operation based on extensive field mapping. Through this process, surface maps based on different rock mass classification (RMR89, GSI and Q-system) systems will be established for this mine. The mine was classified and assessed using RMR89. Finally, a 3-dimensional rock mass model was developed based on the values coming from surface and underground mapping. It was hoped that such model allowed evaluating which areas of the mine are prone to have poorer ground conditions and may require more attention during the design and operational phases of the mine life.

PROCESS MINERALOGICAL PARAMETERS AFFECTING MAGNETIC SEPARATION OF THE STORFORSHEI IRON FORMATION

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The Storforshei iron formation in the uppermost allochthon of the north-central Norwegian Caledonides, consists of magnetite-hematite iron ores. Rana Gruber mines and processes the iron ore. The comminution consists of primary crushing and autogenous milling. After that the material goes on to separation processes, the primary being magnetic separation. Magnetic separation utilises the iron oxides magnetic properties to separate them from the non-magnetic minerals. Magnetite is ferromagnetic, while hematite is antiferromagnetic, this means that magnetite has a higher magnetic susceptibility than hematite. Thus, magnetite is removed first from the raw ore with a low intensity magnet, while hematite is separated from the non-magnetic minerals with a high intensity magnet. The magnetic separation process is highly dependent on mineral liberation and mineral content. Iron oxides are not the only minerals with magnetic susceptibility. Minerals containing paramagnetic elements (Fe, Mn, Ti, Cr etc.) may be susceptible enough to attach to the high intensity magnet and go into the concentrate. The separation process concerning the high intensity magnetic separator is the main focus of this study. To which extent these minerals are present in Storforshei iron formation, and will follow the hematite in the high intensity magnetic separator, will be investigated in this paper. Mineralogical characterisation will be conducted with a focus on the effect of mineral liberation on the magnetic separation. How much hematite does a particle need to contain for it to become part of the hematite concentrate? The tailings from the high intensity magnet will also be part of this research, in terms of investigating how much hematite it contains, thus how much hematite particles the high intensity magnet failed to pick up.

BEDROCK DATABASES - ZZZZZ OR YAY! ?

E. Torgersen and colleagues in the solid earth geology team

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Spoiler alert: Bedrock databases are 'Yay!', and extremely useful. This is because databases allow us to efficiently analyze and compare large datasets from potentially many different sources. By doing so, we may discover patterns within the data that are unless hidden. With the amount of data available to us growing by the day, the value of geological databases will continue to increase in the future.

Bedrock databases are particularly useful if they include geographic coordinates. The reason for this is that we can then study how rocks and structures are distributed in space (and time), which forms one of the central components of almost all geological research. For instance, when you want to investigate the geometry of a certain rock sequence, the areal extent of high-grade metamorphism or the distribution of granites of a specific age, you have to study how these properties vary in space – in other words, on a map. Databases are much like classic paper maps, only that they may contain much more information, stored systemically in a table. This makes it possible for the user to freely change how the data is symbolized (by rock type, age, metamorphism etc.). By doing so, new patterns may emerge.

At NGU, several powerful bedrock databases are currently being developed. Some of them are already available, whereas others will be launched in the near future.

UNRAVELLING THE GLACIAL HISTORY OF JAN MAYEN WITH K-AR GEOCHRONOLOGY

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The remote Norwegian volcanic island of Jan Mayen lies at the crossroads of several oceanic current systems in the heart of the North Atlantic Ocean. We present new K-Ar data from Pleistocene volcanic rocks relative to their stratigraphic intercalations with glacial features, to provide unique constraints on Quaternary glaciations and climatic variations in the polar regions.

A PETROGENETIC AND PETROPHYSICAL STUDY OF HIGH-GRADE METAMORPHIC SEDIMENTARY ROCKS FROM THE MODUM COMPLEX, SOUTH NORWAY

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The Modum Complex is a part of the Kongsberg Sector, located west of the Oslo Graben in southern Norway. It is made up of arenaceous, argillaceous and calcareous rocks, in addition to vulcanites and intrusives. Regionally, the rocks have been exposed to amphibolite facies metamorphism, and aeromagnetic surveys have shown numerous negative anomalies in the area. The investigated rocks are a part of the Høgås anticline, and are of a chemical composition that has not been investigated commonly in the past.

In order to investigate the rare chemical space and possible protoliths of these rocks, varied laboratory work has been done. Microscopy, EPMA and XRF were performed to explore mineralogy and geochemistry, presenting Fe-Mg-rich rocks, low in Al, Na, Ca and K. Using rock chemistry and mineral assemblages, two compositional groups were recognized; one kyanite/sillimanite-bearing group including talc with rare NaAl-substitution, and one amphibole-bearing groups, displaying higher amounts of Ca.

The tourmalines in the amphibole-rocks display higher Ca-content than the tourmalines in the kyanite-rocks, and these are interpreted to be formed in early stages of metamorphism. This reflects that the chemical differences in the rocks are due to differences in the original hematite-rich sediments. To find a suitable protolith, the XRF-results are compared to chemical compositions of sedimentary rocks found in various literature. The rocks are possibly derived from a hematite-rich, Al-poor, silty pelite with components of volcanic ash and/or evaporite chemistry. The protoliths are interpreted to be originally oxidized, owing to an oxidizing, alkaline, shallow marine environment with absence of organic carbon.

The magnetic properties were explored by measuring NRM and susceptibility, in addition to temperature dependent susceptibility and demagnetization behavior. These investigations point out titanohematite as the primary remanence carrier. Again, two groups were recognized, displaying higher NRM and susceptibility for the kyanite-bearing rocks, along with higher contents of titanohematite. Demagnetization measurements indicate presence of two oxide phases, possibly owing to nanoscale exsolution lamellae of ilmenite in the titanohematite.

PETROGRAPHY AND GEOCHEMISTRY OF THE UMBUKTA GABBRO: RØDINGSFJELLET NAPPE COMPLEX, NORDLAND, NORTHERN NORWAY

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The Umbukta gabbro, emplaced in Rødingsfjellet nappe complex in the Rana area in Nordland, have been investigated, with focus on the geochemistry, field observations and petrography. This tholeiitic gabbro has an intrusive age of 565 ± 20 Ma, uncommon for igneous rocks in the region. The primary objective of this MSc project is to constrain the petrogenesis of the gabbro and to further investigate the relationship between the Umbukta gabbro and the synchronous Seiland igneous province, emplaced in the Kalak nappe complex in Finnmark.

Whole-rock major and trace elements compositions were obtained from XRF, ICP-AES and ICP-MS analysis, and mineral chemistry was obtained from EPMA and LA-ICP-MS analysis. Fractional crystallization modelling of melt composition was performed using whole-rock trace element concentrations and partition coefficients from literature. In addition, 10 samples were analysed for Sm-Nd isotope composition. Igneous rocks associated with the Umbukta gabbro include olivine gabbro, olivine-free gabbro, monzodiorites, monzonites, diorites, granodiorites and felsic granitoids. A contact zone characterized by mingling between a mafic rock and peraluminous, muscovite-bearing granitoid, with abundant metasedimentary xenoliths, is interpreted as the result of crustal anataxis. Olivine gabbro represent the most primitive rock group and show compositions up to An66 and Fo71, with Mg# up to 73. All rocks except the felsic show an enriched REE pattern, with a decreasing trend from La to Lu and no Eu-anomaly. Mafic rocks display ƐNd values from -2,5 to +5,6, and a strong correlation between ƐNd and trace element signature, which suggest that parts of the pluton experienced crustal contamination.

Petrographic and geochemical studies, as well as field observations and trace element modelling, suggest that the range from ultramafic to intermediate compositions may be explained by fractional crystallization. However, based on the Sm-Nd isotopes there are also implications for assimilation along the margins of the gabbro. To be able to determine the origin of the intermediate and felsic rocks, studies of more Sm-Nd isotopes is required. Similarities between Umbukta and SIP include a wide range of ƐNd values and enriched REE patterns relative to chondrite. This implies that similar processes may have occurred in the formation of the mafic rocks from the two regions; dominantly fractional crystallization with associated assimilation of crustal rocks. In addition, similar ƐNd values (~5,5) and trace element patterns for the less contaminated samples imply they could stem from a similar source.

SEABED SEDIMENT MAPS OF THE NORWEGIAN AND BARENTS SEAS

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The Norwegian seabed mapping programme MAREANO (www.mareano.no) has mapped more than 175 000 km2 of the Norwegian offshore area since 2005. MAREANO has acquired multibeam bathymetry and backscatter, seabed samples, videos and high resolution shallow seismic data which provide the basis for mapping geology, sedimentary processes and habitats on the seafloor.

Seabed sediment grain size maps (scale 1:100 000) of the Norwegian offshore area have been produced between 62°N and 78°30'N. Other derived products show sedimentary environments, genesis of sediments and presence of bioclastic sediments (mainly from coral reefs). All these products are available on www.mareano.no.

The sediment grain size maps have been mostly made from multibeam data of various quality and origins. Olex single beam data have also been used in the Mørebankene area. Multibeam backscatter data, which give information about sediments, were acquired during the same time than bathymetry data, except for some of the old multibeam surveys. Ground-truthing (mainly video lines) helped at interpreting the backscatter in term of sediment classes. Sediment maps have been digitized from the interpreted backscatter.

The seabed sediment grain size maps show finer sediments in glacial trough and coarser sediments on shallow banks. It also shows quite coarse sediments on the upper continental slope (gravelly sand and sandy gravel). Downslope, the sediments become finer and muddy sandy gravel and gravelly sandy mud are the main classes. The deep-sea plain covered in our study area is mainly characterized by slide blocks and slide deposits partly covered by mud.

MID MIOCENE – EARLY PLIOCENE DEPOSITIONAL ENVIRONMENT ON THE NORTHERN PART OF THE MID-NORWEGIAN CONTINENTAL SHELF

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By using 2D seismic data, this thesis have focused on the depositional environment during the deposition of the Kai formation (Mid-Miocene – Early Pliocene) in order to increase the knowledge of the evolution of paleo-environment in the time-period right before the development of the large ice sheets in the Northern Hemisphere. Based on seismic stratigraphic analysis, the deposits comprising the Kai formation were divided into seismic sub-units. The stratigraphy of the formation and the sub-units, as well as the geometry of multiple surfaces have been described and discussed in relation to the development of the ocean circulation pattern in the Norwegian Sea during this time. The seismic interpretation were correlated to previous studies in the area, as well as to available well logs.

The study area can be split into the inner- and outer part of the shelf. The Kai formation is dominated ooze sediments in the deeper basins, general clayey sediments on the inner shelf. Multiple anticlinal highs and structures can be observed within the study area. Based on observations near the flanks of these highs, it is clear that the highs have played a large role in the distribution of currents under the deposition of the Kai formation. The largest high is the Helland-Hansen Arch, which separates the Kai formation on the inner and outer shelf by have non-deposition on top of the arch.

Contourite deposits, interpreted to be mounded elongated contourite drifts with associating moat structures, have been found on both the inner and outer part of the shelf, suggesting ocean current activity in the Vøring basin, as well on the Trøndelag Platform. The contourite drifts suggest a general north/northeast flowing current pattern, entering the study area in the south, and exiting in the north/northeast part of the study area. Multiple generations of contourite deposits have been found, suggesting changes in current strength and –pattern, as well as sea-level oscillation during the Miocene and Pliocene.

The relation between the Kai formation and the Molo formation have been included in the study, with multiple interpretations of an undecided sediment package located between the Brygge and Molo formations.

UNRAVELLING THE SEEPAGE HISTORY OF A POCKMARK ON VESTNESA RIDGE (OFF W'SVALBARD) USING METHANE-DERIVED AUTHIGENIC CARBONATE U-TH

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Significant amounts of methane are stored within continental margin sediments as free gas and methane clathrates. The stability of methane clathrates depends on pressure and temperature conditions. Hence methane clathrate deposits are sensitive to environmental changes including hydrostatic pressure change and subsurface fluid circulation.

Pockmarks, circular depressions on the seabed, form often above methane clathrates bearing sediments along continental margins but their ages remain elusive. In general, pockmark formation is ascribed to methane seepage from the seabed into the water column resulting from relatively rapid gas hydrate dissociation. Most of the released methane is intercepted within the sediment by microbial mediated sulphate-driven anaerobic oxidation of methane (AOM: CH4 + SO42−→ HCO3− + HS− + H2O). One consequence of AOM is increased carbonate alkalinity in pore waters, inducing formation of methane-derived authigenic carbonate (MDAC) rocks (2HCO3− + Ca2+ →CaCO3 + CO2 + H2O). Uranium-thorium geochronology of clear radial-fibrous aragonite cement contained in MDAC rocks thus provides useful means to assess past seepage activity and associated pockmark formation.

Here we show U-Th ages of MDAC rocks sampled from drill cores up to ~23 m below seabed within a pockmark on Vestnesa Ridge off W' Svalbard. Constraining the age of MDAC formation will improve our knowledge about the longevity and environmental changes controlling methane seepage on Vestnesa Ridge.

STORM - NEW SOFTWARE FOR GEOLOGICAL EXPLORATION. APPLICATION EXAMPLE: WESTERN BARENTS SEA

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Geological exploration involve building various types of geomodels. The geomodels are used as a base for further exploration and are decisive for location of expensive wells. Reliable input data used in geomodels are therefore crucial for success in geological exploration. Availability of reliable input data in underexplored areas is however often poor. The main uncertainties include present-day thicknesses and depths of different rock units, lithologies, rock properties as well as burial depth variations of the rocks in the geological past.

The uncertainties in geomodels can be meaningfully reduced if interrelations between sedimentological parameters are analysed. This can be achieved by using StoRM software. StoRM (Stochastic Rock Modelling) is a stand-alone tool supporting geologists in building geomodels. It limits key uncertainties and assumptions in input data. It is Monte Carlo-based software where millions of modelling runs are performed in order to test different combinations of possible parameter values. The modelling runs that fit to available measurements/observations (e.g. seismic depths, outcrop info) are filtered and considered as 'likely' ones.

The presentation will show examples of a StoRM application from the Upper Cretaceous – Cenozoic sequence of the western Barents Sea (Bjørnøyrena Fault Complex). The highest uncertainties in this case are sedimentation/erosion rates, palaeo-water depths and deposition/erosion ages. The data cannot be obtained by core analysis because a large part of the Cenozoic sequence is absent due to erosion. The presentation will demonstrate how these data can be constrained by using the stochastic approach in StoRM software

COVERAGE AND QUALITY OF SEAFLOOR PHOTOGRAPHY: A COMPARISON BETWEEN TOWED VIDEO PLATFORMS AND AUV BORNE STILL IMAGES

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The MAREANO programme has mapped c. 175 000 km^2 of the Norwegian continental shelf and slope since 2005. In this programme, geological seafloor mapping is usually based on a combination of ship-mounted multibeam echosounders, sub-bottom profiler, grab samples and towed video platforms (Campod) for visual inspection. From a geological perspective we wanted to compare this technology with data collected from an Autonomous Underwater Vehicle (AUV) in terms of area coverage and image quality.

Here we present a pilot project where we tested the use of an AUV as a platform to collect both acoustic and visual data. An AUV borne TFish colour photo system was used to collect high quality still images of the seafloor in high spatial resolution. The average Campod video transects used in MAREANO are about 700 m long and takes c. 30 minutes. During this time interval the AUV can travel a distance between 1850 - 3700 m, and cover an average area of c. 11 – 22.000 m^2. In comparison the Campod video data only covers an area of c. 1500 m^2.

The image quality from data acquired by towed video platforms and AUVs depends on a number of factors such as flight height, water turbidity, terrain roughness (particularly for AUVs), optical quality of the imaging system and wave movements (for towed systems).

We will discuss the suitability of the platforms and their pro's and con's in terms of area coverage and image quality.

A STRUCTURAL AND INSAR STUDY OF THE UNSTABLE ROCK SLOPE IN OKSFJELLET, TROMS

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Oksfjellet is one of many unstable rock slopes clustered east of Lyngen fjord in Troms in northern Norway. Due to the hazard and risk posed by potential unstable slopes, it is important to obtain precise deformation measurements. The main focus of this study has been to combine field observations and InSAR data to better understand the geological structures susceptible for sliding in Oksfjellet. The bedrock comprises mainly mica schists and the area displays a ductile shear zone/thrust, which is interpreted to have formed during Caledonian nappe emplacement. The mapped fractures and faults trend NE-SW and NW-SE, and coincide with regional Mesozoic brittle structures. Structural and kinematic analyses reveal toppling and wedge failures as the main failure mechanisms in Oksfjellet. The analyses show that sliding along the thrust parallel foliation surfaces is another viable failure mechanism. A deep-seated sliding surface is indicated along the intersection between foliation/thrust and fractures. The slope is classified as a complex field with similarities to deep-seated gravitational slope deformations. It is interpreted that the location and evolution of the unstable slope in Oksfjellet is controlled by both ductile and brittle structures. Deformation measurements with satellite- and ground-based InSAR revealed a distinct displacement pattern of subsidence of the unstable slope, well defined by the mapped structures. Satellite InSAR data showed subsidence of the unstable slope at a rate of 4-5 mm/year. Additionally, satellite InSAR data detected subsidence of a larger area, at a rate of less than 1 mm/year, which is thought to reflect real on-going geological processes. GB-InSAR proved especially valuable to reveal seasonal variations of the deformation, at rates of mm/day. It is concluded that the combination of satellite- and ground-based InSAR provided additional and important information that complemented field observations. Deformation measurements proved valuable to assess displacements patterns at different temporal and spatial scales, that contributed to an improved understanding of the evolution of the unstable rock slope.

A QUANTITATIVE ANALYSIS OF TRANSTENSIONAL MARGIN RIFT WIDTH

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Rifted continental margins show variations between a few hundred to almost 1000 km in their conjugated widths from the relatively undisturbed continent to the oceanic crust. Analogue and numerical modelling results suggest that the deformation width of rifted margins may have a relationship to their obliquity of divergence with narrower margins occurring for higher obliquity. We here test this prediction by analysing the obliquity and rift width for 26 transtensional conjugate rifted margin segments in the Atlantic and Indian Oceans. We use the plate reconstruction software GPlates (www.gplates.org) for different plate rotation models to estimate the direction and magnitude of rifting from the initial phases of continental rifting until breakup. Our rifted margin width corresponds to the distance between the onshore maximum topography and the last identified continental crust (Continent-Ocean Boundary – COB). We find a weak positive correlation between the obliquity of rifting and deformation width. Highly oblique margins are narrower than orthogonal margins, as expected from analogue and numerical models. This correlation may imply that the required force for breakup is less for oblique margins, which has been argued for on the basis of numerical and analytical models.

K-AR AGE CONSTRAINTS ON CHEMICALLY WEATHERED GRANITIC BASEMENT ROCKS (SAPROLITES) IN SCANDINAVIA

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Remnants of in-situ weathered bedrock, saprolite, are found in several locations in Scandinavia. Saprolites contain important information about past climate conditions and landscape evolution, although their age and genesis are commonly difficult to constrain. It is generally thought that clay-poor, coarse-grained (arêne) saprolites, mostly occurring as thin regolith blankets or in larger outcrops, formed in temperate climate during the Cenozoic, whereas clay-rich (argillic) saprolites, commonly restricted to small, fracture-bounded outcrops, formed in (sub-)tropical climate during the Mesozoic.

Recent methodological and conceptual advances in K-Ar dating of illite-bearing fault rocks have been applied to date clay-rich saprolites. To test the K-Ar dating technique for saprolites, we first selected an offshore site on the Utsira High of the North Sea, where weathered and fractured granitic basement has been drilled during petroleum exploration, and an abandoned kaolin mine in Southern Sweden. Both targets provide independent age control through the presence of overlying Mesozoic sedimentary rocks. Clay-rich saprolites occurring in fractured basement rocks were additionally sampled in a joint valley landscape on the southwestern coast of Norway, which can be regarded as the possible onshore correlative to the offshore basement high. In order to offer a sound interpretation of the obtained K-Ar ages, the mineralogical and chemical composition of the saprolites requires a thorough characterization. Scanning electron microscopy of thin sections, integrated with XRD and XRF analysis, reveals the progressive transformation of primary granitic rock minerals into secondary clay minerals. The authigenesis of illite is particularly important to understand, since it is the only K-bearing clay mineral that can be dated by the K-Ar method. Individual illite minerals are difficult to identify, but low-K contents in smectite point to small amounts of illite-interlayers.

In agreement with previous models of diminishing contamination of protolithic K-bearing phases in the finest grain size fractions, K-Ar ages invariably decrease with grain size suggesting that the finest grain-size is predominantly composed of authigenic, syn-weathering illite, whose age can thus be used to constrain the timing of saprolitization. We obtained K-Ar ages ranging from Permian to Cretaceous, with a prominent Triassic cluster. While the Early Permian ages can be related to hydrothermal activity, the Late Triassic age cluster bears witness to intense chemical weathering in the Mesozoic. The K-Ar dating of illite-bearing weathered bedrock thus provides new insights into the evolution of the Scandinavian landscape prior to the major, and often obliterating, Quaternary glaciations.

GRAPHITE DEPOSITS IN NORTHERN NORWAY; GEOPHYSICAL PROSPECTING

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The graphite deposits of the Lofoten, Vesterålen and Senja areas have been known for some time for its quality and high grade. For the last few years NGU has been investigating selected areas based on recently acquired helicopterborne geophysical data. The first step of ground follow up work was performed using a one man operated Electromagnetic system called EM-31. To map the size of individual deposits, the Charged Potential (CP) or Mise a la Masse (MALM) method is used. At the Geological Survey of Norway (NGU) we have newly developed an instrument that measures CP together with Self Potential (SP) which means that both known and unknown graphite deposits may be mapped at the same time. To evaluate the size of the individual deposits, it is necessary to know the electric conductivity (resistivity) of the host rock, which is measured using a 2D resistivity system (Electric Resistivity Tomography, ERT). All these methods utilizes the high electrical conductivity of graphite ore.

The 2D resistivity method produces a vertical section of inverted ground resistivity. Since the hostrock is significantly more resistive, zones of highly conductive graphite can easily be distinguished. This is however a time-consuming method if very large areas are to be covered. So the CP and SP method has been used to constrain the dimensions of ore bodies. A current is injected directly into the ore body and the potential between two non-polarizable electrodes is measured on the surface around the conductive body in a sequence of connected measurement-points. This produces a dataset with high potential values over the charged body is measured simultaneously, and graphite has proved to give very good response on this method as well. However it cannot distinguish between one large body and several smaller bodies. Therefore a combination of these methods will give the best estimate of ore body sizes.

RELATIVE TIMING, PETROGRAPHY AND GEOCHEMISTRY OF THE VAL PLATTAS GOLD MINERALIZATION IN GRAUBÜNDEN, SWITZERLAND

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Metamorphic terranes are one of the most important sources of gold worldwide, associated with orogenic belts from Archean to Cenozoic time. Gold occurrences are found in association with sulfides in sericite and muscovite schists in the Surselva district of Graubünden, Switzerland (Jaffe, 2010 and references therein). They lie within the Gotthard Massif, a tectonic unit consisting of pre-Variscan, poly-metamorphic basement rocks with granitic cores that was deformed during the Alpine orogeny (Labhart 1977; Schmid et al. 2004). Additionally, native gold is found in the adjacent and highly sheared Tavetscher Zwischenmassif (Labhart, 1977). Gold occur as either disseminated, in veinlets of quartz aligned or cross-cutting foliation and as layers of semi-massive sulfides. Alterations include sericicitization, carbonatization and, the understanding of the deposit is still in an early stage. In particular, the timing of the fluid leading to gold enrichment and precipitation remains debated. Some have argued for a pre-Alpine timing of mineralization related to magmatic bodies with an Alpine remobilization, whereas others have suggested an Alpine timing of mineralization.

Here, we present evidence for an Alpine timing of gold precipitation in a ductile-to-brittle environment, based on clear-cut field evidence and detailed petrographic evolution of alteration. We identified and mapped out cross-cutting veins of five generations on a scoured exposure of a pre-Alpine orthogneiss (4 by 9 meters) in Val Plattas, northern Gotthard Massif. The chlorite-biotite-muscovite-alkali feldspar-plagioclase-quartz augengneiss has a penetrative foliation in E-W direction of pre-Alpine age, as visible by its degree of deformation and mineral assemblage (amphibolite facies conditions). Discontinuous muscovite-alkali feldspar-plagioclase-quartz pegmatites are oriented parallel to foliation, and occasionally boudinaged. Quartz veins with rounded holes (< 1cm; often filled with carbonate and pyrite) are generally cross-cutting the pegmatite and foliation, indicative of a syn-Alpine timing. Contrastingly, they are also found parallel to foliation. The quartz bodies are deformed in a ductile-to-brittle regime by sulfide (pyrite-chalcopyrite-pyrrhotite) veinlets oriented in a conjugate-like manner in NE-SW and NW-SE. Additionally, isoclinal quartz veinlets associated with the sulfide veinlets are found. The sulfide veinlets displace pre-existing features in a predominantly sinistral manner, and is associated with discrete zones of limonitic alteration halo (rich in disseminated pyrite, chalcopyrite and pyrrhotite). Carbonate veinlets composed of calcite and ankerite is associated with the sulfide veinlets, and may indicate a CO2-rich fluid.

We studied the petrographic evolution using unpolished and polished thin sections, and alterations were identified – including a progressive evolution from biotite to chlorite, extensive sericitization of feldspars, sulfidation and carbonatization. Despite that the exposure is located several hundred meters from known gold occurrences in Val Plattas, anomalous gold up to 0.131 ppm was identified from the sulfide veins. Whole-rock geochemistry using several XRF methods, LA-ICP-MS and external metallurgical assay and trace element analyses was carried out. Mass balance calculations of least altered versus most altered host gneiss was performed, and geochemical anomalies of Ag, As, S, Sb, Se and Bi were distinguished. Comparison to highly altered and mineralized zones in Val Plattas was performed, and the geochemical anomalies coincide with regards to S, Sb, Se, W and Bi, but less consistent signals are observed by U, V and Cu. This can indicate that the low-grade mineralization from the exposure is a weak but otherwise similar version to the ore-grade mineralization documented elsewhere in Val Plattas, which is also supported by the structural control of mineralization from the study area. Furthermore, it may indicate a large-scale process leading to gold mineralization across both the Gotthard and Tavetsch Massif.

MINERALOGY AND TEXTURE OF THE STORFORSHEI IRON FORMATION, AND THEIR EFFECT ON GRINDABILITY

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Storforshei iron formation (Storforshei IF) is located in the Uppermost Allochthon of the Norwegian Caledonides. It consists of several iron ore bodies that have been separated geographically due to deformation. These iron ore bodies have different process mineralogical properties affecting the yield from the magnetic separation. For this paper, three ore bodies were sampled and important mineralogical properties were tested. They included mineralogical studies, surface hardness measurements and milling. The aim of this was to investigate how these properties affected the mill product. Based on studying mineralogy and texture on hand specimens and in the microscope, samples were classified and divided into six ore types. Surface hardness was measured on each of the ore types using two different approaches; Schmidt hammer and Equotip 3. Samples from three deposits in the Storforshei IF were collected and milled autogenously. The relative distribution of the ore types was linked to the deposits by using drill core log data. From these analyses, it was concluded that mineralogy and texture has a huge effect on both surface hardness and grindability. More specifically grain size, shape and structure of the grain boundaries. There is a clear relationship between surface hardness and grindability, where high surface hardness indicates low grindability. Thus, grindability can be predicted by identifying ore types, and measuring the surface hardness.

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