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Welcome to the Winter meeting 2021

The fact that geology is the most interesting and important topic is getting more and more clear. The fast-growing populations and the lack of resources to provide a good way of living for every-one, indicate the need of understanding the earth systems better. The challenges are to improve the supply of food and clean water, secure mineral resources and energy production and avoid environmental problems and climate change.

The geologist has an important role to solve all these challenges. To fill this role, we all need to update our competence, share and discus new ideas, and make new connections, in order to learn and understand more. The Norwegian Winter meeting 2021 is the best place to start a new year, with new knowledge and inspiration.

Thorbjørn Kaland
Chairman

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CONTRIBUTORS

North Atlantic-Arctic tectonics related to the wider Barents Sea paleogeography and basin evolution

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The North Atlantic-Arctic region comprises a wide range of crustal structures and sedimentary basins developed in response to a series of post-Caledonian rift episodes until early Cenozoic time. This complex tectonic history involves a variety of geological processes operating at different temporal and spatial scales and generating a lateral variation on the distribution of the petroleum play elements (reservoirs, source rocks and seals). To understand the evolution and the depositional history of the region, a multidisciplinary approach, including paleogeographic and kinematic reconstructions, should be applied. Paleogeographic maps are compiled for selected time slices spanning the Late Paleozoic, Mesozoic and Cenozoic. Older versions of paleogeographic maps from both sides of the Norwegian-Russian border are combined and updated with more recent data records. These include new data from boreholes, seismic surveys and provenance studies.

For the kinematic reconstructions, the post-Caledonian history of the region has been largely dominated by rifting as well as major extrusive and intrusive magmatic emplacements. Greenland has a key position within the North Atlantic Arctic transition, its evolution is a key piece for understanding the kinematic evolution, and to address the question of how Paleogene breakup in the Arctic and North Atlantic was linked. To reconstruct the basin evolution and construct well-constrained paleogeographic/-tectonic maps we have to quantify the pre-drift extension through time and space. This is done by comparing the observed geometry of crustal thinning to a reference thickness of the crystalline crust close to onshore areas, which have experienced limited or no crustal extension since Late Paleozoic time, in addition to stretching/thinning estimates from numerical tectonic modelling and margin restoration.

The establishment of new and updated paleogeographic maps enable better constraints on the regional basin evolution and sediment provenance (source-to-sink), including the role of structural inheritance and varying regional stress fields of the North Atlantic- Arctic region.

Lime availability in bedrock, soil, and humus: an integration exercise

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Naturally occurring calcium compounds (herein lime) are important sources of nutrients for plants. The availability of Ca (among other nutrients) may determine the occurrence and/or type of vegetation that populates a particular area. Identifying zones of high and low Ca availability may be used as a proxy to categorize areas of higher and lower biodiversity. Combining this with plant species observations leads to elaborate ecological maps.

Calcium concentration (i.e., lime availability) can be quantified in distinct media such as rock, soil, humus and water. Recent work by Heldal and Torgersen (2020) has re-classified bedrock units in Norway according to their Ca content. In addition, regional geochemical mapping of soil and humus carried out by the Geological Survey of Norway covers approximately 50% and 10% of the country, respectively, and provides additional information on the Ca contents present in those media.

The area for this study, the former Northern Trøndelag county (22 412 km^2) was chosen based on its lithological diversity and data availability. We developed a data-driven fuzzy logic and index overlay-based methodology to elaborate an integrated multi-media Ca availability map. Following the same methodology, a targeted survey (372 km^2) was defined in the Steinkjer municipality to evaluate the Ca-budget of areas below and above marine limit, as the former are commonly avoided during regional geochemical mapping.

Our preliminary results show a rough correlation among lithology type, and humus and soil geochemistry suggesting that even though soils are not developed in-situ (e.g., till), they remain relatively close to its source. This further accentuates the role of the local bedrock on the availability of Ca for plants. However, geochemical variations found in soil and humus (relatively to underlying lithology) indicate distinct mechanical and biochemical processes by which Ca (and other nutrients) are brought and absorbed into the biosphere. Future work will involve: i) the use of machine-learning techniques to classify areas according to their geochemical profile and Ca-availability, ii) incorporate pH, LOI and physical properties (magnetic susceptibility and radioactivity) measurements from soils and humus into the integration matrix, and iii) correlate these results with data available for plant species.

Overall, we consider this holistic approach will provide relevant information on the processes governing the interaction between geo- and biosphere, and ultimately lead to the development of more reliable predictive models for the construction of ecological maps.

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Uraninite geochemistry in the Central Mineral Belt, Labrador, Canada

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The Central Mineral Belt (CMB) of Labrador in Canada is host to several enigmatic Proterozoic U±base±precious metal showings, prospects and deposits that have disparate features in terms of their mineralization styles (e.g., vein and breccia-hosted, disseminated) and host rocks (metasedimentary, -volcanic and -intrusive). Through multivariate statistical analysis (principal component and cluster analyses), quantitative trace element maps of uraninite grains were used to understand the origins of U mineralization from selected locations across the CMB.

Chemical signatures of uraninite from the felsic intrusion- and intermediate volcanic-hosted Dandy prospect (negative Eu anomaly, U/Th < 1000 and ∑LREE/∑HREE= 3) and Near Miss prospect (Near Miss 1; U/Th > 1000 and ∑REE > 1 wt.%) and Jacques Lake deposit (U/Th < 1000 and ∑REE ≈ 1 wt.%), respectively, support formation under high temperature magmatic-hydrothermal or metasomatic environments. However, post-crystallization alteration caused LREE enrichment and increased U/Th values in uraninite. Lower temperature (<350 °C) hydrothermal vein-type conditions are inferred for uraninite samples from the Two-Time deposit (Two-Time 1 to 3), and Anomaly No. 7 (Anomaly No. 7 1 to 4) and Near Miss (Near Miss 2) prospects based on high U/Th values (>> 1000), elevated ∑LREE/∑HREE ratios (> 14) and variable ∑REE contents (from < 1 wt.% to >1 wt.%). Trace element mapping of uraninite from the Anomaly No. 7 revealed concentric multi-elemental (e.g., Zr, Bi, V, Hf) zoning representing four uraninite generations that formed under relatively equivalent hydrothermal conditions (analogous ∑LREE/∑HREE and U/Th values). The more ambiguous chemical footprints and complex textural features of the metasedimentary-hosted uraninite from the Moran Lake Upper C Zone, Nash and Anna Lake deposits (U/Th >> 1000), ∑REE << 1 wt.% and ∑LREE/∑HREE < 5) indicate formation by syn- to post-metamorphic, high salinity and low temperature hydrothermal fluids.

Overall, this study reveals the presence of distinct U mineralizing events and fluid sources, driven by syn- to post-mineralization orogenic and magmatic events.

Soil and bedrock geochemistry in Svalbard: Implications for arsenic pollution regulations

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The national pollution regulations limit local re-use of excavated masses in case they have concentrations, of potentially toxic elements (PTE) (arsenic, cadmium, mercury, chromium, copper, nickel, lead and zinc) that exceed the norm values. The study was conducted in cooperation with Longyearbyen local council that administer the growing construction activity in Longyearbyen and thus wish to promote new, local norm values. Both surficial mineral soil and bedrock within the study area of Longyearbyen plan area were analyzed. This study was conducted to determine background concentrations of the elements that are regulated by norm value concentrations according to Norwegian pollution regulations.

The study area lies within the Central Tertiary Basin on Svalbard, which is a young sedimentary basin that has its origin in eroded sediments from the West Spitsbergen Fold-and-Thrust Belt. The flat-lying sedimentary rocks, which originate in stratigraphic units of lower Cretaceous to Paleocene age, consist predominantly of schists and sandstones. The flat-lying sedimentary rock formations, when eroded, give rise to surficial material that derive from many bedrock units, transported by various slope processes and end up on the valley slopes.

The samples were air dried and sieved to <2 mm or milled and analyzed for 51 elements following an aqua regia extraction. The results conclude that arsenic is the only PTE where samples exceed the existing norm values. All sampled surficial material and 44 % of bedrock samples exceed the norm value of 8 mg/kg. Arsenic is thought to be incorporated in pyrite, as no arsenic-minerals were found. The study shows that arsenic generally occurs in higher concentrations in the loose materials than in bedrock in the investigated area. Results from marine sediments encompassing Svalbard (mareano.no) show a correlation between arsenic and the content of clay fraction as well as total organic carbon. This may explain the increased concentrations in surficial material compared to bedrock.

A previous study of overbank sediments and unpublished bedrock data that cover the whole of Spitsbergen show that areas with bedrock of Carboniferous, Permian and Devonian age display lower arsenic concentrations that also display a narrower concentration spread. This study combined with previous studies thus shows that younger sandstones and shales derived from the West Spitsbergen Fold-and-Thrust Belt will probably exhibit higher arsenic values, while older sedimentary rock units, such as the Devonian Old Red Sandstone, display low concentrations.

Arsenic concentrations over norm value pose a challenge during land use planning, excavation work and disposal of masses on Spitsbergen. This study provides the necessary knowledge base to recommend a new, local norm value for arsenic of 20 mg/kg.

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Pilot investigations of acid sulfate soils in Alta, Norway. Is it a national issue?

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Acid sulfate soils (ASS) have been defined as "the nastiest soils in the world". They are naturally occurring soils, sediments and peat that contain sulfides, commonly in the form of the mineral pyrite or metastable iron sulfides. The iron sulfides, which are the compounds causing environmental problems, have been formed under anoxic and reducing conditions, such as in waterlogged soils. In oxygen-free conditions below the groundwater level, sulfidic sediments are harmless to their environment, but if the water level is lowered due to fall of relative sea level or drainage, they become active. It has been shown that human-induced drainage causes a very efficient and deep leaching horizon compared to soils only subjected naturally falling water level, e.g. caused by glacioisostatic uplift. In active ASS, sulfidic material starts to oxidise and produce sulfuric acid, which in turn starts to leach metals from the soil. The release of acidity and metals into ground- and surface waters have severe effects for biotic life.
Known global ASS occurrences cover over 17 million hectares, but the occurrence of ASS in Norway on any scale is unknown. A pilot project has started in Alta to develop a Norwegian methodology that enables predictions and estimates of occurrence of Norwegian ASS. The project is in conjunction with GTK, SGU and Kola Science Centre, where their extensive experience in the subject has proven extremely valuable.
The Alta- and Tverrelva area was chosen as a pilot area for Arctic Norway for several reasons:1) detailed Quaternary mapping is ongoing and soil maps exist for the area, 2) Alta is a regional centre with agricultural activity, 3) the Alta river is recognised as an important salmon river and 4) soil maps shows extensive areas of water-logged soils, such as Gleysols, Histosols or Stagnosols.
Preliminary results show that sulfate soils are present as far north as Finnmark. ASS occur, in Alta, under specific conditions:

- Under thick peat
- In areas less than 10 meters above sea level
- In areas with a low surface gradient
- In lagoonal environments
- In areas where grainsize ranges from fine sand to fine silt

However, the occurrence of ASS is not given, even though an area fulfils these conditions. Future work is aimed towards understanding this heterogeneity as well as dating the affected areas. The knowledge can then hopefully be applied to a more regional scale along the Norwegian coastal landscape.

Esker eller europavei? Hva gir et sted verdi nok?

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Det er viktig å ha et etterprøvbart system for å kunne vurdere om en geologisk lokalitet er så verdifull at den burde ivaretas eller om det er greit at den fjernes i et byggeprosjekt. Denne problemstillingen har vi jobbet med i de interregfinansierte prosjektene GEARS (Geologisk arv i Indre Skandinavia; Lundquist og Dahl, 2020) og videreført inn i GNIST (Geologisk arv i Naturbasert Innovasjon for Skandinavisk Turisme).
Geologiske lokaliteter som har en iboende verdi for noe eller noen, kan defineres som **geosteder**. Slike geosteder har over mange år blitt registrert fra ulike lokaliteter i hele landet og informasjon om disse har blitt samlet sammen i NGUs database for geologisk arv. Problemet er at det ikke har eksistert en formell og etablert metodikk for å utføre en systematisk evaluering. Da kan vurderingene stå i fare for å bli subjektive, personavhengig og i ulikt format. Dårlig rammeverk kan også medføre at resultatene ikke blir tatt hensyn til i en arealplanprosess.
Det er en abstrakt materie å forholde seg til: Hva gjør at noen lokaliteter har mindre verdi enn andre og hvordan kan man etablere robuste kriterier og metoder som er etterprøvbare? Vi har tidligere samarbeidet med kommuner og geoparker om å teste ut ulike varianter for metodikk og gjort viktige erfaringer uten å lyktes helt. Likeledes er metodene for å verdisette geosteder i andre deler av verden fortsatt unge og omdiskuterte fordi det ikke har lyktes å gjøre en metode robust, fullstendig objektiv og etterprøvbar nok (Reynard and Brilha, 2018) Gjennom et samarbeid mellom SGU, NGU og NINA har vi jobbet frem et sett med kriterier som har blitt testet og utprøvd over en periode (Lundquist og Dahl, 2020). Metoden skiller ut tre hovedverdier; Undervisningsverdi, forskningsverdi og opplevelsesverdi. Verdiene er basert på fjorten grunnkriterier som til sammen beskriver lokalitetens relevans for forskning, undervisning, formidling og forvaltning.
Kriteriene er hentet fra litteraturstudier av andre lignende undersøkelser av geosteder i andre land og fra norske vurderinger av biomangfold, landskapsmangfold og Statens vegvesens generelle metodikker for konsekvensanalyser. Metodikken vår har blitt testet og utprøvd ved hjelp av feltarbeid og gjennom analyser av foreslåtte geosteder. Den er styrket, men har fortsatt noen svakheter. Disse tar vi tak i gjennom prosjektet GNIST og geologisk landskapskarakterisering. For eksempel har vi spesielt utfordringer med begrepene sjeldenhet og representativitet.
Utvikling av kriteriene har medført til at retningslinjene for konsekvensutredning av byggesaker i Norge nå skal fornyes og lanseres av Miljødirektoratet i desember. Verdivurderingene vil bli tilgjengelig i NGUs nasjonale database for geologisk arv som et digitalt verdikart med

tilhørende rapporter. Verdien av et geosted skal heretter tas med når en vurderer om en esker skal bevares eller bygges om til europavei.

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Coupling hydrodynamic simulations with field observations to reconstruct the Nedre Glomsjø outburst flood

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Nedre Glomsjø was an ice-dammed glacial lake that drained at least once during the end of the last Ice Age. The glacial lake outburst flood(s) swept down the Glomma valley. Hydrodynamic simulations are used to approximate the peak discharge from the largest outburst flood.

The peak discharge has been previously estimated as 170,000 m^3/s (Berthling and Sollid, 1999) and 350,000 m^3/s (Longva, 1994) using empirical equations. Advances in hydrodynamic simulation algorithms and additional field observations (Høgaas and Longva, 2016) allow for a more precise estimate of the peak discharge.

The hydrodynamic software programs HEC-RAS and RiverFlow2D are used to simulate the flood wave through the first 30 km of the open flood path, starting where the floodwater emerged from the south side of the continental ice sheet. This stretch is selected because geomorphological evidence for the flood is present throughout. The upstream boundary of the model is the estimated location of the continental ice sheet during the outburst flood (ca. 16 km south of Rena). The downstream boundary is ca. 13 km south of Elverum.

Empirical formulas are used to estimate the peak discharge based on the maximum lake volume. The previously estimated peak discharges are also tested. A variety of input hydrographs, Manning's roughness values and model parameters are also simulated. The maximum water elevation level for each hydrodynamic simulation is compared to the elevation of observed erosive ledges along the stretch as described by Høgaas and Longva (2016). The flow patterns from the flood simulations are compared to flood bars attributed to the outburst floods.

Current results indicate a peak discharge of approximately 350,000 m^3/s. The simulations show that the flood bifurcated ca. 9 km south of Elverum, with a small percentage of the discharge draining towards Mjøsa, which is consistent with field observations.

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Instability versus adaptation of the pre-Viking society to the climate variability of the Late Antiquity in Eastern Norway

Bajard, M.[1,2], Ballo, E.[1,2], Bakke, J.[3], Støren, E.[3], Høeg, H.[4], Loftsgarden, K.[4], Iversen, F.[4], Hagopian W.[2], Jahren A.H.[2], Svensen, H.[1,2] & Krüger, K.[1,2]

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Understanding how agricultural societies were impacted and adapted to past climate variations is critical to adapt to contemporary climate change and guaranty the food security. However, linking climate and change in the behaviour of a population are difficult to evidence. Here, we studied the climate variations of the period between 200 and 1300 CE and its impact on the pre-Viking and Viking societies in south Norway. We used a retrospective approach combining a multi-proxy analysis of lake sediments, including geochemical and palynological analyses, to reconstruct past changes in temperature and agricultural practices during the period 200-1300 CE. We associated variations in Ca/Ti ratio as a result of change in lake productivity with the temperature. The periods 200-300 and 800-1300 CE were warmer than the period between 300 and 800 CE, which is known as the "Dark Ages Cold Period" in the Northern Hemisphere. During this colder period, phases dominated by grazing activities (280-420 CE, 480-580 CE, 700-780 CE) alternated with phases dominated by the cultivation of cereals and hemp (before 280 CE, 420 -480 CE, 580-700 CE, and after 800 CE). The alternation of these phases is synchronous of temperature changes. Cold periods are associated to livestock farming, and warmer periods to crop farming. This result suggests that when temperature no longer allowed crop farming, the food production specialized in animal breeding. The development of agriculture seems to have reached a maximum between 400 and 550 CE and a minimum between 680 and 800 CE, in agreement with archaeological findings. The Viking Age (800-1000 CE) started with an increase in temperature and corresponds to the warmest period between 200 and 1300 CE, allowing a larger development of the agriculture practices and society. Our results show that the pre-Viking society adapted their agricultural practices to the climate variability of

the Late Antiquity and that the Vikings expanded with climate warming.

Using CT scans to count varves in lake sediments. Application to Lake Sagtjernet, southeastern Norway

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Annually laminated sediments, also called *varves*, are valuable natural archives to reconstruct past environments and climate. Until now the most common and reliable procedure to count varves has been to produce overlapping thin sections of the entire sediment sequence and counting in the microscope — a process that can take months to complete. We here present a new and faster method to count varves using CT scans. This non-destructive method is not only faster, it also provides a 3D view of the varve boundaries — a significant improvement from the 2D view conventional thin section counting yields. We used the sediments of Lake Sagtjernet to develop and demonstrate this method.

Oxygen and temperature measurements from the water column combined with microfacies analyses of the sediments show that the varves are likely formed by cyclical Fe precipitation during the late fall and early spring mixing of the water column in the lake.

Varve counting on CT scans resulted in a 4300-year chronology, which we compared to an independent radiocarbon chronology (based on 17 ^{14}C dates and radionuclide analyses). Our preliminary results show that more than 80% of the varve ages fall within the confidence interval of the radiocarbon chronology.

Ultimately, the Lake Sagtjernet sediment sequence is the first Norwegian non-glacial varved lake sediment sequence continuously covering the last 4300 years. This annual chronology provides a basis for the reconstruction of past climate variability and environments that will improve our understanding of the interactions between climate and human society in Norway.

Palynology of Early Cretaceous hydrocarbon seep carbonates from Wollaston Forland, Northeast Greenland – preliminary results

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Samples from Early Cretaceous methane-derived carbonate bodies in the Kuhnpasset Beds, Wollaston Forland, Northeast Greenland have been processed for biostratigraphical and palynofacies analyses. These seep bodies are previously reported in Kelly et al. (2000) and Nakrem et al (2020).

A palynostratigraphic zonation for lower Cretaceous in East Greenland was published by Nøhr-Hansen (1993), and later for the entire Cretaceous of Northeast Greenland (Nøhr-Hansen et al., 2019). Neither of these works included the hydrocarbon seep deposits from Wollaston Foreland.

Our preliminary analysis of the palynological slides obtained from the seep carbonate samples and associated mudstone has yielded key biostratigraphic marker dinoflagellate cysts. These include *Pseudoceratium toveae* and *Batioladinum longicornutum,* suggesting a Late Barremian age and a correlation to *P. toveae* subzone as defined by Nøhr-Hansen (1993). Large amounts of pollen, spores, and other terrestrial material (and some freshwater algae) are present in the material. In addition, there seems to be a few reworked palynomorphs of older age. There is little difference in the preservation of the palynomorph from the carbonate samples compared to the samples from the associated mudstones.

Palynofacies analysis: The palynological slides from the carbonate samples show a fairly large diversity of dinoflagellate cysts, with a decent amount of terrestrial input. The slides from the mudstones, however, show a domination of terrestrial material, with a smaller diversity in the dinoflagellate cysts.

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Meltwater sediment transport as the dominating process in mid-latitude trough mouth fan formation

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Trough mouth fans comprise the largest sediment deposits along glaciated margins, and record Pleistocene climate changes on a multi-decadal time scale. Here we present a new model for the formation of turbidite sequences on the North Sea Fan derived from detailed horizon- and attribute-interpretations of high-resolution processed 3D seismic reflection data. The interpretation of the data shows that stacked channel-levee systems are building this up to 400 m thick last-glacial sediment sequence. The frequent channels at different stratigraphic levels and the lack of wedges and scars at the shelf edge show that glacial sediments were not temporarily stored at the uppermost slope. Instead, downslope sediment transport was a continuous process during shelf-edge glaciations of the Norwegian Channel Ice Stream, reaching accumulation rates of 100 m/kyr. The channels are elongated and can be traced from the shelf edge towards the deep basin for distances of >150 km, and document long-distance sediment transport in completely disintegrated water-rich turbidite flows. Our model highlights that exceptional large meltwater discharge to the slope led to erosive turbidite flows, and that freshwater supply is an underestimated factor for sedimentary processes active during glacial cycles.

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Characterization of a Glacial Paleo-outburst Flood Using High-resolution 3D Seismic Data: Bjørnelva River Valley, SW Barents Sea

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Proglacial braided river systems discharge large volumes of meltwater from ice sheets and transport coarse-grained sediments from the glaciated areas to the oceans. Here, we test the hypothesis if high-energy hydrological events can leave distinctive signatures in the sedimentary record of braided river systems. We characterize the morphology and infer a mode of formation of a 25 km long and 1-3 km wide Early Pleistocene incised valley recently imaged in 3D seismic data in the Hoop area, SW Barents Sea. The fluvial system, named Bjørnelva River Valley, carved 20 m deep channels into Lower Cretaceous bedrock at a glacial paleo-surface, and deposited 28 channel bars along a paleo-slope gradient of c. 0.64 m/km. The landform morphologies and position relative to the paleo-surface support that Bjørnelva River Valley formed in the proglacial domain of the Barents Sea Ice Sheet. Based on valley width and valley depth, we suggest that Bjørnelva River Valley represents a braided river system fed by violent outburst floods from a glacial lake, with estimated outburst discharges of c. 160,000 m^3/s. The morphological configuration of Bjørnelva River Valley can inform geohazard assessments in areas at risk of outburst flooding today, and is an analogue for landscapes evolving in areas currently covered by the Greenland and Antarctic ice sheets.

Kartlegging av grunnvannsstrømning og interaksjon mellom ferskt grunnvann, elv og salt grunnvann ved nyetablerte løsmassebrønner i et kystnært grunnvannsmagasin

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Hydrogeologien i et fjorddelta på Trøndelagskysten er undersøkt. Det er utført felt- og laboratoriearbeid i en periode med prøvepumping av grunnvann fra to nyetablerte, skråstilte produksjonsbrønner. Prøvepumpingen startet sept. 2019, og pågikk fortsatt ved innlevering av masteroppgaven i mai 2020. Grunnvannet skal benyttes til landbasert akvakultur.

Interaksjonen mellom følgende tre faktorer er studert: 1. Ferskvannsakviferen i avsetningen. 2. Elva som renner gjennom brønnområdet. 3. Salt grunnvann lenger ut på deltaet. Grunnvannets strømning og prøvepumpingens innvirkning på samspillet mellom de nevnte faktorene, sto sentralt i undersøkelsene.

Sonderboringer, etablering av peilebrønner samt korttids trinntester av produksjonsbrønnene, ble utført før oppstart av langtids-prøvepumpingen. Løsmasseprøver ble hentet ut og laboratorieanalyse av kornfordelingen utført. Det ble i prøvepumpingsperioden foretatt jevnlige feltmålinger av grunnvannsnivået, og tilsvarende for registrering av temperatur, elektrisk ledningsevne og oksygenmetning i grunnvann og overflatevann. Det ble regelmessig innhentet vannprøver fra grunnvann og overflatevann for mikrobiologisk og fysisk-kjemisk analyse. Meteorologiske og hydrologiske data er også innhentet.

Fjorddeltaet er tydelig lagdelt med en nokså heterogen karakter. Avsetningen utgjør et stort sett åpent infiltrasjonsmagasin, og elva er styrende for grunn-

vannsnivået. Den maksimale kapasiteten for de to brønnene til sammen er beregnet til ca. 39 l/s. Selv med forventet filtertap ved høyere pumperater viser resultatene fra prøvepumpingen god brønn- og magasinkapasitet. Det maksimale vannbehovet fra brønnene vil ligge på rundt 12 l/s.
Kvaliteten på det oppumpete grunnvannet er svært god. Ingen bakterier er påvist i grunnvannet, og viktige vannkvalitetskrav mht. fiskehelse er innfridd. Indikasjoner på kortslutning mellom elv og grunnvann er ikke funnet. Kvalitative vurderinger tilsier dermed tilstrekkelig oppholdstid. Flere utslag på ledningsevnemålinger ytterst i brønnområdet ble registrert i en periode med hyppig stormflo og høyvann vinter/vår 2020. Likevel er det ikke sett tegn på saltvannspåvirkning i det oppumpete grunnvannet. Den topografiske gradienten og en antatt fjellterskel, bidrar sannsynligvis til å redusere faren for saltvannsinntrengning.
Resultatene fra langtids-prøvepumpingen taler også for at grunnvannsuttaket vil være bærekraftig på lengre sikt. Ettersom grunnvannsmagasinet er grunt og står i kontakt med en elv, vil det være utsatt ved ev. forurensningsutslipp til elva eller tilsigsområdet. Jevnlig overvåkning av vannkvaliteten og aktiviteten i elvas nedbørfelt er derfor viktig.

Assessment of VMS deposits in the Central Scandinavian Caledonides, introducing the MAP Software

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Mineral Resource Assessment Platform (MAP) is an EIT RawMaterials Upscaling project, which lasted for three years from 2018 until the end of 2020. The project was funded by EIT RawMaterials European Institute of Innovation and Technology, an organ within the EU. There were eight partners in the consortium, including geological surveys (GTK, ISOR, NGU, SGU), universities (Luleå Technical University, NTNU, University of Oulo) and one consultant company (BEAK).
The project has produced an enhanced and upgraded method and software for the quantitative assessment of undiscovered mineral resources, by integrating mineral prospectivity modelling, the three-part method and economic filtering. The new software produces quantitative probabilistic estimates of the total amount of metals in undiscovered mineral deposits of selected types, especially geologically defined areas (permissive areas). The MAP software is free, based on modules, as well as offers an open source code which makes it easier for users.
The MAP software is contained in the MapWizard, which consists of a number of tools to perform an assessment of undiscovered mineral resources in an area. The workflow of the tools in the wizard follows a logical sequence from descriptive model to output of a report of the resource assessment in the given tract.
The MAP software has been tested on several different mineral deposit types, including epithermal gold deposits in Iceland, tin-tungsten skarn mineralisations in Germany, seafloor massive sulphide deposits (SMS) on the Mid-Atlantic Ridge and VMS deposits in Norway and Sweden (in the Caledonides and Skellefte).
In the presentation, the MAP software is demonstrated by applying it in areas prone to VMS deposits in the Central Scandinavian Caledonides, including the Joma, Gjersvik, Stekenjokk and Blåsjö districts, all parts of the Upper Allochthon. The four districts were chosen because they have VMS deposits of different sizes, grades and proportions of metals, as well as different host rocks.

Aeolian sediments, Uranium and the Alum shale.

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After the Varangian glaciation on the Baltoscandian shield at around 590 Ma, chemical weathering started of the Precambrian basement. A peneplain developed and the process continued during a period of 50 to 70 Ma. There was no vegetation on land, and we may assume that wind erosion played an important role in the sediment transport, similar to what we see in the desserts today. Most Ediacaran and Lower Cambrian aeolian deposits have been eroded during the Cambrian marine transgression. One exception is the aeolian deposit in the Lower Cambrian sequence in the Vassbo area, Sweden which is close to the Femund Lake in Norway. The geology of the Vassbo Mine has been described by Wallin (1989) who found aeolian sandstone at the top of the Lower Cambrian sequence. The aeolian sandstone is black and consists of fine-grained, well-rounded quartz with cement of apatite, organic carbon, quartz and sulphides.
The Alum Shale was deposited after the Hawke Bay regression event at the border between Lower and Middle Cambrian deposition in a shallow marine anoxic environment on the western part of the Baltoscandian Shield. The Alum Shale contains high concentration of organic carbon and the base metal content with up to 200 – 400 ppm U and Mo and high V content makes the Alum shale different to many black shales (Andersson et al. 1985). A simple adsorption on the surface of cells of dead algae, which is proposed in the literature, can hardly explain the metal composition of the Alum Shale due to the low concentration of these elements in sea water.
The clastic grains in the Alum shale are mainly illite, quartz and K-feldspar, which occur together with organic carbon and pyrite. The concentration of uranium over large areas in the Alum Shale is interesting because uranium should have been reduced at the redox front close to the margin of the sea. The sedimentation rate in the Upper Cambrian was very low and approximately one meter pr. Ma. The reduction in sedimentation rate from Middle to Upper Cambrian is followed by a strong increase in the content of U, Mo and V.
Several authors points to the supply of nutrients to explain anoxic conditions in shallow marine seas, and aeolian sand coated with Fe (Mn)-oxides and adsorbed

P may have been such a nutrient source. Dependent on the pH and Eh in the regolith surrounding the sea, U, Mo and V may be adsorbed on the Fe-oxides (McQeen 2008). Aeolian sediments in Vassbo show that wind erosion of the regolith took place and there was a transport of nutrient to the epicontinental sea. In sea water Fe-rich oxides become unstable and Fe, P, U V and Mo may be released to the seawater and later adsorbed on dead algae before sedimentation took place under anoxic conditions. Aeolian transport is a slow process, and the extremely low supply of sediments from shores and rivers made the aeolian supply important.

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Application of United Nations Framework Classification for Resources (UNFC) for industrial mineral projects - Case Studies from Finland/ Estland, Sweden and Norway – Nordkalk limestone and Forsand sand and gravel mines[a]

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The case studies demonstrate how the United Nations Framework Classification for Resources (UNFC) is being used to classify industrial mineral extraction projects for limestone in Estland and Sweden, and for a gravel and sand project in Norway. These projects, in particular the Nordkalk limestone projects, demonstrates the usefulness of UNFC in categorizing environmental, social economic conditions and technical feasibility that may facilitate or hamper project development. The gravel and sand project demonstrates the use of UNFC in a case with few complications. This also shows an accounting method based on a standard that is common in national statistics as well as in project management.

[A] United Nations Framework Classification for Resources Case Studies from Finland/Estland, Sweden and Norway – Nordkalk limestone and Forsand sand and gravel mines. UNECE, Geneva 2020, ECE/ ENERGY/GE.3/2020/10

What do small-scale sand injectites look like in 2D seismic data?

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Sand injectites are clastic intrusions formed through post-depositional remobilization. These geological structures have, in recent years, been a topic of interest due to their significance in the hydrocarbon industry. Large-scale sand injectites can constitute high quality reservoirs and form distinct exploration targets. Small-scale, non-resolvable sand injectites can constitute a large part of the net-to-gross volume and also affect fluid flow in the reservoir. However, such small-scale structures can also be troublemakers in oil-field development. The Grane field (central North Sea) hosts numerous small-scale sand injectites above the main reservoir unit. These cause challenges for well placement and seismic interpretation. In order to aid seismic interpreters working with such structures, the present study focuses on the seismic signature and detectability of small-scale sand injectites. In order to investigate this, geological models are made based on seismic and well data from the Grane field, in addition to outcrop analogues from the Panoche Hills (USA). A variety of geological models are made where thickness, geometry and size of the sand injectites are varied. Furthermore, the models are used to generate 2D synthetic seismic images utilizing the Point-Spread Function based convolution method.

The resulting 2D synthetic seismic images generated in this study demonstrate that small-scale sand injectites can be detected in seismic data despite being below seismic resolution. Moreover, it is not possible to infer any geometry based on their seismic expression. The seismic signature and detectability of the sand injectites depend on thickness, dip, interaction with one another and surrounding stratigraphy. Comparison of the synthetic seismic images with real seismic data from the Grane field indicates that the low-amplitude anomalies and irregularities observed above the reservoir may be a result of the overlying sand injectites. Additionally, the comparison strongly suggests that the Grane field hosts sand injectites that are thicker and located further away from the top reservoir than what has yet been indicated by well observations.

Nationwide mapping of unstable rock slopes using the Norwegian Ground Motion Service (InSAR.no)

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In November 2018, the Geological Survey of Norway (NGU) launched the Norwegian ground motion service (InSAR Norway), based on Copernicus Sentinel-1 data. The service provides free and open InSAR-based ground motion data for more than 4 billion measurement points in Norway.
Catastrophic failures of unstable rock slopes in Norway have occurred several times in the last century with fatal consequences. Therefore, NGU, on behalf of the Norwegian Water Resources and Energy Directorate (NVE), systematically maps and classifies all unstable slopes in Norway for their hazard and risk.
InSAR data, based on Radarsat-2 collected from 2009, has played an important role in identifying unstable rock slopes in Norway for many years. Due to practical and financial constraints, Radarsat-2 data were only acquired over parts of Norway, focusing only on areas most prone to unstable rock slopes and catastrophic events, far from the entire country.
InSAR Norway has been a game-changer for mapping unstable rock slopes on a national scale. Within a few weeks after the launch, more than 100 new potential unstable slopes were detected. Once an actively deforming slope is identified, its displacement rate provides a first assessment of the hazard level. This allows us to easier and more precisely define priorities for further and more detailed mapping and field investigations.
InSAR measurements can be challenging to interpret since they are one-dimensional (along the radar line-of-sight). By combining InSAR data from several satellite geometries, both from ascending and descending orbits, two-dimensional displacements can be estimated. An improved hazard and risk assessment of unstable slopes require a good understanding of the kinematics. Field investigations and comparison with in-situ measurements are still important to validate and interpret the results.
We demonstrate how InSAR Norway contributes to a better characterization of the kinematics of unstable slopes and a better understanding of the distribution of unstable rock slopes throughout the country.

Deep Sea Minerals on the Norwegian Continental Shelf – Developments in Exploration

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In 2019, the Parliament adopted the Subsea Minerals Act for the purpose of facilitating activities related to exploration and exploitation of marine mineral resources on the continental shelf. The Government has now initiated a study of the possible impacts of mineral activity in an area in the Norwegian Sea. This is the first step in a process provided in the Act for preparing the opening of any area for such activity. This requires an appropriate knowledgebase of information on the nature, distribution, and volume of these resources. Much of the current database in that regard comes from the scientific research by academia, especially the long-term research program by the University of Bergen. In recent years, the database has been considerably expanded by the Government's dedicated seabed mineral exploration cruises carried out by the Norwegian Petroleum Directorate (NPD). The available data show that the continental shelf comprises possibly economic deposits of seabed massive sulphides (SMS) and Fe-Mn crusts, while Fe-Mn nodules are not recorded. The data also show that the Fe-Mn crusts have clear affinities with the crusts deposited in the Arctic Ocean. Compared to other parts of the world oceans, the crusts show high contents of Li, Sc and V, and variable contents of REE. As for the SMS accumulations, the recent year's data indicate that they may be grouped into at least two different types according to their mineral chemistry and their tectonic setting along the Mohn Ridge. So far, mapping of the resources has been done mainly by acquiring geophysical data and seabed sampling. Therefore, there is a lack of data regarding the thickness (three-dimensional configuration) of both the SMS and crust accumulations. This is an obstacle both to a better scientific understanding of the formation of the accumulations, and to a well-founded estimation of the resources. To meet this problem, the NPD is considering methods for acquiring vertical information on the deposits (thickness), both drilling and acoustic methods. Accordingly, in September 2020 the NPD carried out an exploration cruise especially designed to test the use of coiled tubing technology for core drilling of SMS accumulations. Results from the cruise, including drilling results and preliminary geochemical analyses will be presented.

Marine grunnkart i kystsonen – et hav av muligheter

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Svært mange aktiviteter konkurrerer om arealene i kystsonen. For å unngå konflikter mellom verneinteresser, akvakultur, fiskeri, friluftsliv, industri og andre aktører må forvaltningen av kystsonen foregå med best mulig datagrunnlag. De fysiske forholdene på havbunnen kan kartlegges i stor detalj ved å kombinere høyoppløselige sjømålingsdata fra moderne multistråleekkolodd med observasjoner og prøvetaking i felt.
Kartverket, Norges geologiske undersøkelse (NGU) og Havforskningsinstituttet (HI) samarbeider om å samle inn og dele kunnskap og data om havbunnen langs kysten av Norge. Prosjektet «Marine grunnkart i kystsonen» skal bidra til en bærekraftig utvikling av kystsamfunnene våre, og til styrking av de marine og maritime næringene. For å unngå å utvikle kysten i blinde er vi avhengig av grunnleggende marine data. Vi skal kartlegge sjøbunnen langs norskekysten helt inn til fjæresteinene, der folk lever, jobber og bor.

Regjeringen har bevilget finansiering til oppstart i tre områder langs kysten: Kvænangen og Skjervøy i Troms, Stavanger i Rogaland, og Ålesund og Giske i Møre og Romsdal. «Marine grunnkart i kystsonen» er et spleiselag hvor også samferdsels-, klima- og miljøsektoren bidrar. I tillegg deltar kommuner og fylkeskommuner i pilotområdene til finansieringen. Investeringene i de tre områdene har en total kostnadsramme på til sammen 84,6 millioner kroner over tre år.
Sammen skal de tre statlige etatene bidra med hver sin ekspertise til å samle inn, forvalte og formidle data og kart over havbunnens geologiske, biologiske og kjemiske tilstand. De ugraderte resultatene skal være tilgjengelige for alle, til ethvert formål. Kunnskap om sjøbunnen er nøkkelen til en mer helhetlig og bærekraftig utnyttelse av Norges sjøareal. Marine data gir «blå vekst»; fordeler for marine næringer og offentlig forvaltning, økt sikkerhet, muligheter til maritim nyskapning og teknologiutvikling.
Blant hovedproduktene i maringeologisk kystkartlegging er flatedekkende kart over bunnsedimenter (kornfordeling), bunnsedimenter (dannelse), sedimentasjonsmiljø, landskap og landformer og miljøforhold. Fra detaljerte kart over bunntyper kan vi avlede temakart som viser spesifikke bunnegenskaper som gravbarhet, ankringsforhold og bunnfellingsområder, og i kombinasjon med biologiske observasjoner og oseanografiske data er kartene utgangspunkt for modellering av naturtyper.
Kartverket, NGU og HI har på lengre sikt ambisjon om å kartlegge hele den norske kystsonen. Dette skal dekke hele kystsonen på 100 000 kvadratkilometer. Prosjektteamet i Kartverket, NGU og HI skal levere et beslutningsgrunnlag til Kommunal- og moderniserings-departementet i oktober 2021 for å kunne vurdere og eventuelt starte opp et nasjonalt program fra 2023. «Marine grunnkart i kystsonen» er også et av tiltakene i regjeringens nasjonale geodatastrategi.
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3D modelling and interpretation of channels in the Aspelintoppen Formation, Spitsbergen, Svalbard, a facies analysis

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Aspelintoppen Formation, the youngest formation in the central Tertiary Basin in Central Spitsbergen, comprises an up to 1000 m thick succession of continental (channel and floodplain) to near-coastal deposits. Due to the high altitude and low accessibility of many localities where the formation crops out, field studies have generally been limited. Published studies of the formation mostly deal with the fluvial-marine transition zone exposed at localities in Van Keulenfjorden, whereas development of the fluvial system has received limited attention. In previous work, traditional fieldwork proved unsuitable for proper channel dimensions and orientations to be established, due to poor lateral accessibility along outcrops on mountain tops.
In addition to helicopter and airplane surveys, recent development in the use of drones for mapping otherwise inaccessible outcrops, provides possibilities to improve the mapping of channel systems of the Aspelintoppen Formation and tie the results into already existing sedimentological and palaeobotanical data.
The aim of this project is to map and thoroughly describe the distributions, geometries, orientations and number of channels in the Aspelintoppen Formation, with the purpose of contributing to the knowledge of this Eocene(?) formation. The thick succession of relatively similar deposits (shallow, low energy channels separated by floodplain with peat development) bring up the question of potential long-term climatic stability.
This project will use images obtained from drone and helicopter surveys and logs from two sediment cores from Urdkollbreen and Gustavfjellet, 10 km N and 8 km NE of the former mining town Svea. These data are processed into 3D models and interpreted in relation to earlier work, such as field observations and logs by others. From the virtual outcrops, quantitative measurements of channel widths, thicknesses and orientations will be made and used to discuss development and variation in the fluvial system. The data may be used to discuss discharge variations, sediment supply variations, gradient changes and changes in accommodation space of Aspelintoppen Formation.

Quantifying S in silicate melts from their crystal cargo: data and applications

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Five volatile species, H_2O, CO_2, F, Cl, and S, exert their strong control on magmatic systems, but their quantification remains challenging due to their elusive nature. Partitioning between nominally volatile-free minerals and melts was vastly studied for four out of these five volatiles (H_2O, CO_2, F, and Cl), except sulfur. We here present measurements of sulfur partitioning between clinopyroxene and silicate melts over a range of pressure (0.8-1.2 GPa), temperature (1000-1240°C), and melt composition (49-66 wt% SiO_2; Callegaro et al., 2014; 2020). Experiments were performed at either high or low oxygen fugacities, where sulfur in the melt is dominantly present as an S^{6+} or an S^{2-} species, respectively. The study was designed for clinopyroxene, but few additional measurements of crystal-melt sulfur partitioning were performed for plagioclase, ortho-

pyroxene, amphibole, and olivine in some of the experiments. We measured sulfur in the crystals by synchrotron-light microfluorescence at the Beamline I18 of Diamond Light Source, UK (Mosselmans et al., 2009). Calculated as the total sulfur in the crystal divided by the total sulfur in the melt, the partition coefficient varies from 0.017 to 0.075 for clinopyroxene (negatively correlated with the Mg/(Mg+Fe) ratio of the crystal), from 0.036 to 0.229 for plagioclase, and is a maximum of 0.001 for olivine and of 0.003 for orthopyroxene. Total sulfur partition coefficients correlate positively with cation-oxygen bond lengths in the crystals, increasing in this order: olivine < orthopyroxene < clinopyroxene ≤ amphibole and plagioclase. Hydrous experiments at high oxygen fugacity yielded total sulfur clinopyroxene/melt partition coefficients much lower (ca. one-third) than those from low oxygen fugacity, anhydrous experiments. Partition coefficients calculated as total sulfur in the crystal divided by S^{2-} in the melt cluster into a single mean value of 0.063 ± 0.010 (1ó) for most experiments, and show no clear dependence from the clinopyroxene Mg# or Al^{IV}. Sulfur, in its S^{2-} form, seems to replace oxygen in the crystal structure. Oxygen fugacity shows a greater effect on sulfur partitioning than water. The partition coefficients measured for total sulfur and S^{2-} are lower than those of fluorine, higher than those of carbon, and similar to those of chlorine and hydrogen, for the various mineral phases. These newly measured values complete the toolbox of partition coefficients that can be used to assess the concentration of the five most important magmatic volatiles in equilibrium melts by analyses of their mineral cargo. This approach is particularly useful in studies of extinct volcanic systems and as a potential exploration tool for massive sulfide deposits. Examples on rocks from the Central Atlantic Magmatic Province and the Deccan Traps will be presented. We recommend use of these partition coefficients only for sulfur measurements obtained by the same technique.

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Prospecting a Structurally Complex Marble Occurrence in Vassbygda, Helgeland Nappe Complex, Nordland

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Brønnøy Kalk, which today operates the large Akselberg marble quarry in Velfjord, Nordland, are in the process of developing plans to ensure that future resources of calcite marble are available when the current open-pit quarry reaches the end of its life. Options include going underground or exploring new occurrences. Some of the most promising deposits are found in Vassbygda, about 15km south of the current mine. The Vassbygda area has seen little activity in terms of geological exploration. As a result, there is a lack of maps and publications to indicate the quality, origin and structure of the marble deposits.

This contribution aims to unravel the structural configuration of the marbles in the Vassbygda area and to provide a new understanding of the marble deposits. The Vassbygda and Akselberg marbles are situated within the Helgeland nappe complex, which formed during west-vergent thrusting and folding, and associated migmatisation and magmatism before the main Scandian phase of the Caledonian orogeny. This resulted in an extensive (and in place, intensive) folding of the units in Vassbygda.

A range of techniques have been used to constrain the structural framework, mineralogical properties and metamorphic conditions of the Vassbygda area, including remote sensing, field mapping, optical microscopy, SEM, geothermobarometry, chemical analyses, core logs, and 3D-modelling.

The Vassbygda area consists primarily of marbles (spotted and banded) and metasandstones (from metagreywacke to metaarkose), the latter in places being garnet- and sillimanite-bearing migmatites. Structurally, the area is characterized by tight to isoclinal recumbent F_1 folds that are refolded by large-scale, open, moderately north-plunging F_2 folds, creating a type 2 interference pattern (Ramsay & Huber, 1987). The contact with the overlying Middle Nappe rocks is a top-to-the WNW oblique reverse-sinistral shear zone that may have been developed contemporaneously with F_2 folding. Garnet-associated geothermobarometers applied on a garnet- and sillimanite-bearing metagreywacke yield a well-defined P-T estimate of 4.5-5.0 Kbar and 630-650°C and a less clear estimate at c. 3 Kbar and c. 540°C. Preliminary, we interpret the higher P-T estimate to constrain conditions during migmatization and F_1 folding, whereas the latter may be associated with F_2 folding and overthrusting of the Middle Nappe.

The results of this study will provide a more detailed understanding of the geology of the Vassbygda area, which is important for Brønnøy Kalk in their planning for their future development.

Referanse:

Ramsay, J. G., & Huber, M. I. (1987). Modern structural geology. Folds and Fractures, 2, 309-700.

Evaluation of four potential apatite resources in Norway, results from the EU GeoERA-FRAME project

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As part of the EU GeoERA project on Forecasting and Assessing Europe's Strategic Raw Materials Needs (FRAME), NGU conducted a study on four of the most promising apatite deposits in the country, all of which are of magmatic origin. The intrusions investigated include the Raftsund intrusion (Lofoten), the Bjerkreim-Sokndal layered intrusion (BKSK, Rogaland), the Fen carbonatite-alkaline complex (Telemark) and the Larvik Plutonic Complex (LPC, Vestfold).
The BKSK is a large, low-grade resource of apatite, associated with ilmenite and V-rich magnetite as potential biproducts. The macrocyclic units MCUIII and MCUIV present the greatest economic potential. Total Rare Earth Element Oxide (TREO) in apatite (0.11-0.29 wt%) and Th concentrations are low (0.35-10.04 ppm).
The Kodal deposit (LPC), the next largest deposit in our study, represents much smaller volumes than the BKSK. The resource is estimated to 49 Mt of ore @ 5 wt% P_2O_5, according to JORC standards. The Kodal ore contains apatite with 0.92-1.29 wt% TREO and 45 ppm Th on average. Other Fe-Ti-P-occurrences in the LPC represent much smaller volumes, although recent field observations suggest that the process that led to Fe-Ti-P enrichment happened in several areas in the intrusion. Apatite from these occurrences contains higher concentrations of both REE (1.51-2.17 wt% TREO) and Th (64-211 ppm) than the apatite from Kodal. Further investigations, including detailed geophysical surveys, will help evaluate the potential for apatite resources in the rest of the LPC.
Apatite resources related to the Fen alkaline-carbonatite complex are not yet well characterized. Whole-rock chemistry suggests high ore grades, however, the distribution of the mineralizations and the volumes potentially available are unknown. Magmatic apatite in calcite carbonatite contains between 0.16 and 0.80 wt% TREO, associated with variable amounts of thorium (5.6 -199 ppm). Microcrystalline apatite, resulting from hydrothermal activity, and mostly found in the Fe-rich dolomite carbonatite, presents more challenging compositions, with high Th (up to 762 ppm), Ba and Sr concentrations, associated with a depletion in LREE. Systematic sampling of the various lithologies is needed to evaluate further the phosphate resource in the complex.
Despite local enrichment in apatite, the Raftsund intrusion is the least promising area. Apatite contains 0.69 wt% TREO on average and low concentrations of Th (13 ppm avg). Only a few Fe-Ti-P-rich rocks contain more than 4 wt% P_2O_5 and the size of the mineralizations is limited. Nevertheless, the process responsible for forming the mineralizations by silica-liquid immiscibility resulted in the formation of an Fe-Ti-P-rich melt which could have ponded somewhere else in the intrusion, forming a larger deposit. The extreme topography of the area makes further detailed investigation complicated.

Database for geologisk arv – et verktøy for å fremme forvaltning og formidling av geologisk naturarv

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Foredraget er knyttet til Interregprosjektet GNIST (Geologisk arv i Naturbasert Innovasjon for Skandinavisk Turisme).
Mange geologer har «jordbærsteder» som enten egner seg for å vise fram til naturinteresserte eller for å forstå geologiske prosesser som har skapt akkurat dette landskapet. Denne kunnskapen er viktig. Til sammen utgjør disse stedene et viktig nettverk av lokaliteter verdt å ta vare på. Men hva skjer dersom det planlegges en ny vei, vindmølle eller hus på en slik lokalitet? I praksis tas det mye hensyn til biologisk mangfold i utbyggingssaker, mens geologisk mangfold vanligvis ikke er på dagsorden. Nå endrer dette seg. I desember 2020 lanserer Miljødirektoratet en ny veileder for konsekvensutredninger, der geologisk mangfold for første gang omhandles eksplisitt.
NGUs database for geologisk arv vil være en kilde til informasjon om geologisk mangfold i konsekvensutredninger. Databasen inneholder data om geologiske objekter i Norge, sammen med informasjon om hva de kan brukes til. Materialet er i hovedsak basert på systematiske registreringer av verneverdige geologiske lokaliteter fra 1970-1990-tallet. Materialet i basen er imidlertid av ulik kvalitet og det er behov for en mer systematisert og kvalitetssikret system for verdivurderinger. Basen har derfor behov for en omfattende «makeover» for å bli det verktøyet forvaltningen trenger for å kunne ta vare på verdifull geologi.
Databasen trenger også gode registreringsløsninger og innsynsløsninger tilpasset tre brukergrupper; forvaltning, skole/universitet og reiseliv. I tillegg vil det være behov for å implementere en nyutviklet metodikk for verdisetting.
Tidligere versjoner av databasen har ikke lykkes med å lage konsekvente verdivurderinger som er forvaltningsrelevante. Gjennom et godt etablert samarbeid mellom SGU, NGU og NINA er det nå utviklet metoder for å kartlegge og verdisette geologisk arv. Registeringene må også struktureres på en slik måte at skoleverk og reiselivsbransje kan bruke dem i undervisning og naturbasert reiseliv.
Nå bygger NGU opp en datamodell som tar hensyn til ny metodikk for verdivurderinger, og implementerer nye registreringsløsninger og såkalte innsynsløsninger for forvaltning, skole og reiseliv.
Datamodellen utarbeides dels igjennom resultater fra metodeutprøvingen, og dels i dialog med brukerne, enten det er skoleverk, forvaltere eller besøksnæringen. Brukertesting av løsninger er en del av denne dialogen.
En oppdatert versjon av NGUs database for geologisk arv vil være et viktig verktøy for flere samfunnsområder. Den vil inneholde informasjon som er direkte anvendbar for forvaltning av vårt naturmangfold på nasjonalt, regionalt og kommunalt nivå. Den vil være en ressursbank for å finne gode lokaliteter som er eksemp-

ler på geologiske prosesser som elever skal lære mer om, i henhold til fastsatte undervisningsmål. Den vil også være en viktig kilde til informasjon for å utvikle et naturbasert reiseliv.

Late Palaeozoic syn-rift deposition at the margin of the Sørkapp-Hornsund High, Southern Spitsbergen

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The Carboniferous – Permian succession outcropping in the inner part of Hornsund, southern Spitsbergen, developed along the flank of the tectonically active Sørkapp-Hornsund High. The Sørkapp-Hornsund High was active during the middle-to-late Palaeozoic and represents an onshore analogue to the contemporaneous Selis Ridge in the SW Barents Sea. Fieldwork during summer 2020 targeted the late Carboniferous – Permian Treskelodden and Kapp Starostin formations around the Treskelen peninsula. 412 m of sedimentary logs at dm scale and 400+ GB of high-resolution drone and ground -based images were collected. From the images ca. 50 georeferenced digital outcrop models (DOM) were created, across a ca. 20 km NW-SE transect, with the majority focussing on the outcrops at Treskelen peninsula. The data will be supplemented with petrographic analysis of 30+ thin sections to support detailed microfacies analysis of the carbonate sections. The combined dataset will provide a better understanding of the depositional evolution along the margin of the Sørkapp-Hornsund High.
The lower part of the Treskelodden Formation consists of conglomerates, sandstones and occasional mudstones representing a paralic setting including sediments belonging to the braidplain, delta, lagoon, tidal dunes, and flats, paleosols (calcretes), shoreline and shallow marine carbonate platform facies associations. The southern part of the studied succession is dominated by coarse to medium-grained sandstone to conglomeratic delta/shoreline deposits, passing northwards to warm-water platform carbonates. This shift is suggested to occur down-flank of the high. The younger Permian Kapp Starostin Formation consists dominantly of silicified cool-water carbonates deposited in a deeper water environment. The succession in Hornsund is extremely thin compared to the succession in central Spitsbergen. Mapped in the field erosive, subaerial exposure (karst) and flooding surfaces are important tools for basin reconstruction, and some of them might represent key regional sequence stratigraphic surfaces with probably offshore seismic reflectors as counterparts.
Rapid base level changes caused abrupt shifts in facies, lithology, and grain size. Deposition took place under global icehouse conditions; however, we suggest that lateral shift in facies and accommodation might also be related to tectonic movements of the high. The Treskelodden Formation was deposited during the extended late Palaeozoic extensional phase in Svalbard and the western Barents shelf and our observations document that tectonic movements persisted for most of the Permian in the Hornsund area. Potential erosion and removal of the majority of the Kapp Starostin Formation might be linked to renewed tectonic activity during the Late Permian/Early Triassic and further elevation of the Sørkapp-Hornsund High.

Tourmaline from Nb-Y-F-pegmatites in south Norway: implications for pegmatite melt origin and evolution

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Tourmaline is the most common borosilicate mineral in the Earth' crust occurring in magmatic, metamorphic, as well as sedimentary rocks. In magmatic settings, tourmaline is a frequent constituent in Li-Cs-Ta (LCT) pegmatites. By contrast, it is very rare in Nb-Y-F (NYF) pegmatites. In the Kragerø area in south Norway, tourmaline is, however, commonly found in Sveconorwegian (Grenvillian) NYF pegmatites. The local enrichment of tourmaline in these pegmatites and the origin of boron in the pegmatite melt are still under debate because the Sveconorwegian metamorphic basement is poor in boron elsewhere.
This study in progress aims to (1) determine the major and trace element chemistry and boron isotope signature of tourmalines of the Kragerø pegmatites; (2) investigate the mineral paragenesis and the zoning of these pegmatites; and (3) utilize the mineral chemical results to better understand the origin of boron and the genesis of the Kragerø pegmatites. SEM, EPMA and SIMS analyses are performed on tourmaline samples collected in the field as well as specimens from the mineral collection of the Natural History Museum of Oslo.
The investigated tourmalines show minor chemical variations and are geochemically classified as dravite and schorl. Our tourmaline $\delta^{11}B$ data from four Kragerø pegmatite localities range from -1.9 to +2.4‰. All samples are homogeneous internally but there are distinct variations among the localities. Pegmatites from the Lindvikskollen area (Lindvikskollen and Tangen) contain tourmaline with -1.9 to -1.0 ‰ $\delta^{11}B$ and those from Dalane and Havredal have 0.6-1.0 ‰ and 1.8-2.4 ‰, respectively. These distinct isotopic compositions

seem to depend on local variations in the mixed metasedimentary and meta-igneous components from which the pegmatite melts were sourced. The Lindvikskollen and Tangen pegmatites are located near the contact between metagabbro and banded paragneisses, which could explain the light isotopic composition compared to the Dalane and Havredal samples, which intruded metasediments. If confirmed, the indication that the pegmatites have different melt sources even though they occur only a few kilometres apart implies that the melts formed more likely by local partial melting rather than derivation from a large, buried parental granite pluton. Further work will focus on comparing these results with data from other Sveconorwegian tourmaline localities and will include geochemical whole rock and mineral data of pegmatites and host rocks.

Measuring landscapes and infrastructure from space, the Norwegian Ground Motion Service (InSAR.no)

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Since November 2018, the Norwegian Ground Motion Service, InSAR.no, has provided free and open ground motion data over all of Norway, based upon data from the Sentinel-1 satellites. Operated by the Geological Survey of Norway (NGU), the service provides data for more than 3.8 billion measurement locations nationwide. A driving force behind the development of the service was the need to map and monitor geological hazards, such as landslides. Other geological processes can also be mapped with unprecedented detail, for example, surficial landscape development processes like rock glaciers and subsidence in various settings. The InSAR technique, however, measures far more than just natural processes. We have observed subsidence due to tunnel construction, deformation of hydropower dams, transport infrastructure, and buildings, both newly constructed and very old. We have also observed slope movements in numerous sites related to the resource extraction industry.

The amount of ground motion data InSAR.no produces is unprecedented. Each measurement is based upon nearly 300 satellite images acquired since 2015 and contains the full deformation history since then. Each year, 60 new satellite images are available for a given location. Thus the current Norwegian database comprises several hundred billion individual data points. The next release will also contain data for all of Sweden, thanks to cooperation with the Swedish Space Agency and the Swedish Transport Administration. By the end of 2021, the European Ground Motion Service (EGMS) will release similar data for all of the Copernicus Cooperating States. Tens of billions of measurements locations, comprising trillions of individual displacement estimates, will be available, free and open to all.

The initial impact of the first avalanche of ground motion data has been huge here in Norway, as many of the displacement phenomena measured were previously unknown or unquantified. For example, the data allowed NGU to identify over 100 new unstable rock slopes within a few weeks of the initial data release. E-mails and telephone enquiries began to pour in after Norwegian homeowners, and public authorities discovered the InSAR service and found possible deformation affecting their local areas. The release of first EGMS data later this year will lead to the inundation of phone lines across Europe. The datasets available now for Norway, and soon for Sweden, provide a good basis for developing analysis techniques and downstream applications that can be used across the rest of Europe.

Finding the needle in a haystack – Extracting cold-water coral carbonate mounds from MAREANO's multibeam bathymetry data

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Cold-water coral reefs are fragile ecosystems that are vulnerable to direct human activities (e.g. bottom-contact fishing) and climate change related pressures (e.g. acidification). They are regarded as biodiversity hotspots and therefore require effective protection against human induced pressures. A prerequisite for protection is a detailed map pinpointing the locations of cold-water coral reefs over large areas. The geological products of cold-water coral reefs are carbonate mounds, which can be readily identified from multibeam bathymetry data of sufficient resolution by a skilled geologist. Given the large number of carbonate mounds that exist in Norwegian waters, a manual approach of delineating mound features is, however, very time consuming and only achievable with generalisation. To address this shortcoming, we developed a new approach that combines geological expert knowledge with robust spatial prediction using machine learning. Initially, local maxima in the seafloor terrain are detected with a focal analysis function. These local maxima will inevitably include the tops of carbonate mounds as well as other geomorphic features. Therefore, a random subsample is taken and manually labelled as to whether the local maxima coincide with carbonate mounds or not. This training dataset is subsequently used to build a Random Forest machine learning model that aims to predict carbonate mound presence or absence using terrain variables extracted from the bathymetry data. The performance of the model is thoroughly tested based on a spatial leave-one-out cross validation scheme that accounts for spatial autocorrelation in the data. The model is then applied to all local maxima, which are classified as carbonate mound presence or absence. The modelling framework

also allows to estimate the confidence in the results. Finally, the accuracy of the resulting map might be estimated with an independent test dataset derived in a similar way as the training data or from seafloor observations gained with underwater video systems. We demonstrate our method based on bathymetry data collected off the Norwegian coast as part of the Marine areal database for Norwegian waters (MAREANO) programme.

Geology as a foundation for seabed habitat mapping

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Seabed habitat mapping includes mapping the spatial distribution of biotopes, species, communities, and nature types. These habitat maps are produced on local, regional, and even global scales providing invaluable information for the sustainable management of seabed resources. Regardless of the spatial and thematic focus of a seabed habitat map it is inherently linked to the physical nature of the seabed, and thus to its geology. The substrate which benthic animals have available to live on is fundamental in determining which animals will live there. For example, we find quite different communities living on rocky seabed to those on in mud. The morphology of seabed terrain and the nature of the water masses (temperature, salinity, current speed) at and near the seabed are additional factors which determine the extent to which living conditions are optimal for a given animal or community in terms of shelter, food supply, comfort etc.

Typically, marine habitat maps are based on seabed observations from a limited number of stations representing only a small fraction of the total mapping area. These observations, generally from video observations or physical samples, when combined with more widely available full coverage environmental data can be used to predict the extent of habitat distribution between observation stations. Environmental data often includes digital terrain models of seabed bathymetry and derived terrain attributes which quantify its (geo) morphometry. Oceanographic data quantifying near-seabed temperature, salinity and bottom currents are also commonly used, where available, along with other data relevant to the mapping area and particular theme of the habitat map. In areas where seabed grain size and geomorphological maps exist e.g. areas mapped by Norway's offshore mapping programme, MAREANO (www.mareano.no) or coastal mapping projects these have become essential inputs to habitat characterization and modelling.

We provide examples of how geological maps produced by the Marine Geology group at the Geological Survey Norway have been increasingly used in seabed habitat mapping related activities at various scales over the past decade or so. This period has seen a rapid expansion in seabed mapping with maps of surficial seabed geology emerging as a central product for many users, and laying the foundation for the production of reliable habitat maps. As well as being directly incorporated in habitat maps from many projects, we discuss how increased knowledge of seabed geology has fed into the development of the Norwegian standard for describing and classifying ecological variation Nature in Norway (https://artsdatabanken.no/NiN).

Applying machine learning on InSAR data for carbon sequestration site monitoring

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With approximately 65 %, CO_2 is the largest contributor to global warming among the greenhouse gases. Carbon capture and storage (CCS) is a promising technology, which is used to filter out CO_2 from gas mixtures, for instance at industrial chimneys or petroleum factories in order to store it permanently, for example in saline aquiferes. To guarantee the permanence and safety of carbon storage, continuous monitoring is essential to observe potential leakage of CO_2 through fractures or horizontal migration.

During the injection of CO_2 into the rock units, we can distinguish between two different injection modes, matrix injection and fracture injection. During matrix injection, the injection pressure does not exceed the fracture pressure of the rock. Matrix injection typically results in a regular surface uplift that is proportional to the injected fluid volume. During fracture injection, the injection pressure does exceed the fracture pressure of the rock, which causes mechanical changes to the rock. Fracture injection can be recognized by missing or irregular surface uplift or subsidance. Satelite observation, especially through InSAR, has been proved to be a reliable and cheap tool for ground surface movement monitoring. However, throughout the year, InSAR satelites generate several terabytes of data, which makes a manual examination very expensive.

Convolutional neural networks (CNN), which belong to the machine learning techniques, are often employed in automatic image classification. CNN uses multiple layers of neural connections with learnable weights and biases that are inspired by the human visual cortex. In geoscience, CNNs are already well established, for instance in volcano monitoring, landscape classification and seismic data processing.

This study we focus on the case study of the In Salah CCS pilot project in Algeria. Automatizing monitoring of carbon sequestration sites with CNNs can help to process large datasets that were acquired over multiple years, within minutes. The aim of this study is it to perform a binary classification that distinguishes between ongoing matrix injection and fracture injection modes from unwrapped interferograms. The findings are compared to other studies that have identified periods of fracture injection at In Salah.

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AlasKA: the Digital Well Log Aliaser

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Geologists working with digital well log files spend lots of their time manually aliasing well-log mnemonics to improve readability. In this study we create a Python package called alaska to automate the process of aliasing well-log mnemonics. The package comprises three parsers: a dictionary with 1,236 mnemonics and labels, a m-ary keyword extractor tree, and a pointer generator recurrent neural network. The dictionary aliases 60% of mnemonics to their labels by looking for exact matches of mnemonics in the dictionary. The m-ary keyword extractor tree takes care of another 20% of the work. It looks for keywords in the description of a mnemonic and traces keywords down from the nodes to find a label. Lastly, the pointer generator utilizes a Seq2Seq model to generate summaries. In this case the model generates the labels, from the mnemonics' descriptions. To do this, the pointer generator first bidirectionally encodes hidden states from the mnemonic's description. Then the decoder RNN calculates the vocabulary distribution using a context vector and decodes the hidden states. The vocabulary distribution is the probability distribution over all the words in a fixed vocabulary. The vocabulary distribution is what generates words outside of the mnemonic's description. Finally, the decoder RNN calculates generation probability that combines the vocabulary distribution and attention distribution. That is, a probability distribution over the words in the source text that points to source words. It then determines the word with the largest probability, and adds it into the generated summary.
Automatic aliasing of mnemonics in AlasKA allows for basin-wide correlations across thousands of wells. This not only permits uniform aliasing standards for all mnemonics, but also offers a sketch of the input data via the heatmap function in the package. The package is important because it standardizes well-log mnemonics so that non-experts can use well logs without time consuming data wrangling and munging.

Sediment transport and upland linkages in an enormous intracratonic basin - Insights from cross-disciplinary source-to-sink studies in the Greater Barents Sea

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The Greater Barents Sea Basin (Svalbard, the Russian and Norwegian Barents Sea, the Kara Sea and Franz Josef Land) was about five times the size of the North Sea and filled with enormous amounts of sediments in the Triassic. This is one of the most well-studied and data-rich basins in the world, ancient geomorphology (fluvial channels, clinoforms) is well-imaged in 3D seismic data, and a high-resolution palynostratigraphic framework gives excellent correlations and time-control. This makes the area an excellent place to study sediment transport and develop models for sediment provenance. Most existing studies have however studied only parts of this basin, but in the ongoing ISBAR project, we study the entire basin using an integrated stratigraphic framework and diverse techniques such as seismic interpretation, fluvial geomorphology, detrital zircon dating, sediment mass balance, palynology and petrology.
In this presentation, we give an overview of the recent advances made in understanding the Greater Barents Sea Basin and summarize our latest research. These results include variations in amount of sediment supplied to the basin throughout the Triassic, the degree and timing of onset of sediment recycling in the basin, the petrographic and detrital zircon-age signatures of the different sediment sources, and the evolution of petrographic- and detrital zircon-age signatures through time. These variations are discussed in terms of source-area evolution, and they indicate that sediment supply was strongly variable and controlled to geodynamic events in the Urals and West Siberia. Sediment supply from minor, marginal sources (Fennoscandia, Loppa High, Greenland) appears to have varied less through time. Our results also indicate significant bypass of sediment to adjacent arctic basins in the Late Triassic. Upcoming research in the project related to autogenic controls on detrital zircon age spectra, and thermochronology and basin modelling in the Barents Sea, will also be presented.

Identifisering av skredhendelser ved hjelp av stratigrafiske og sedimentologiske studier. Et hjelpemiddel i kvartærgeologisk kartlegging og for avgrensning av faresoner

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Vi presenterer her resultater fra stratigrafiske og sedimentologiske undersøkelser av jordskredavsetninger i en vifte ved Breidokk, Gol sentrum, Sør-Norge. Viften ligger i et tettbebygd strøk med mange bolighus og barnehage. Seks 10-15 m lange og 1-3 m dype grøfter ble gravd ut med gravemaskin og undersøkt. Totalt ble 16 forskjellige jordskredavsetninger identifisert og korrelert mellom fem av de seks undersøkte grøftene. De korrelerte stratigrafiske enhetene er tolket til å representere minst åtte individuelle skredhendelser. Dette er dog trolig et underestimat for den reelle jordskredfrekvensen gjennom postglasial tid, da lokaliseringen av grøftene i stor grad ble styrt av infrastruktur i området og dermed ikke optimalt plassert. Sedimentene i snittene består av vekslinger mellom morene-, glasifluviale-, fluviale- og skredavsetninger. Skredavsetningene stammer fra jordskred og består av matriksstøttete, usorterte massive lag fra 1 cm til >1 m tykke, og med klaster i alle størrelser inkludert blokker med diameter opp mot 80 cm. Matriksen består av medium til grov grus, av og til er sand og silt til stede. Det ble ikke registrert noen dominerende klastorientering. Avsetningene er tolket til å stamme fra jordskred som startet i den morenedekkete skråningen ovenfor Breidokk, og skredene fulgte i all hovedsak godt definerte, opptil 10 m dype skredbaner, før de ble avsatt i dalbunnen.
Dateringer av begravete jordsmonn og annet organisk materiale som ligger over og under jordskredavsetninger, har gitt avgrensende min- og maksimumsaldre for skredhendelsene. Totalt ble det foretatt 37 radiokarbondateringer av slikt materiale, som sammen med den sedimentologiske og stratigrafiske tolkningen, viser at det har gått jordskred i området gjennom hele holocen, også innenfor de siste 1000 år. Dette er data som er viktige både for den kvartærgeologiske tolkningen og for avgrensning av skredfaresoner i området.

Preliminary results on the earliest known mixosaurid fossils, ever

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Mixosaurids are a group of small marine reptiles belonging to the Ichthyosaria and are highly adapted to a marine life. The fossil record of Mixosaurids have thus far seen them as a Middle Triassic taxon, with recorded occurrences from China, Svalbard and the USA. Mixosauridae exhibit more advanced adaptions for an aquatic life than Early Triassic taxa such as Grippiidae, Utatsusauridae or Cymbospondylidae. These adaptions include a pronounced dorsal fin, a more pronounced tail bend and flippers, and a body outline more optimized for swimming.
During their 2014 expedition to the Flowerdalen valley on Svalbard, the Spitsbergen Mesozoic Research Group uncovered a large amount of disarticulated fossil material in the Lower Saurian bonebed in the Vikinghøgda Formation (Early Triassic). The material consists of a large number of vertebrae, both fragmentary and complete humeri and skull fragments which are referable to a small-bodied ichthyopterygian. The fossils are compared to both Middle Triassic mixosaurids as well as other Early Triassic ichthyopterygians. Preliminary results show that the material includes a mixosaurid and a cymbospondylid, demonstrating that they were extant during the Early Triassic, which has implications for the evolution of ichthyosaurians after the Permian-Triassic Mass Extinction (PTME).

Global carbon isotope signal found in the Middle Triassic on Svalbard

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Carbon isotope curves are controlled by depositional environment and global fluctuations. While global factors such as the carbon cycle control the long-term carbon isotopic compositions, short-term fluctuations may reflect the origin of organic materials in the sediment (e.g. algal or terrestrial matter), stratification of the water column, and/or surface water productivity. Carbon isotopes are therefore used both to understand the depositional environment and to correlate globally time-equivalent rocks.
Correlating Triassic rocks around the world is interesting for several reasons. Firstly, the Triassic Period was a tumultuous time for life. Life recovered from the End-Permian Mass Extinction event, and the Triassic on Svalbard has shown to be an important locality to understand the early radiation of marine vertebrates. Secondly, and especially in Norway, Triassic rocks are important source rocks. Currently, much effort is put into understanding the Barents Sea through Svalbard's geology.
Several carbon isotope curves were recently published for the Early and Middle Triassic in Tethys. Recent work also focused on the Early Triassic of Svalbard with detailed stratigraphic sampling. This work is the first to measure the ä^{13}C for different Middle Triassic localities on Svalbard. Our aim is to place the carbon isotope curves in a global setting and to correlate them with Tethyan locations (e.g. China and Germany).

Our initial dataset is from the Blanknuten Mountain on Edgeøya and the Botneheia Mountain in Central Spitsbergen. Preliminary results show three strong transitions; 1) on the boundary between the Early and Middle Triassic, 2) in the middle of the formation and 3) at the Middle and Late Triassic boundary. Several Tethyan localities show a similar Early-Middle Triassic signal. Future work will include more Svalbard localities to the study. Sedimentological analysis by thin sections and X-ray fluorescence spectroscopy (XRF) is in progress with the aim to untangle local and global controls on the Svalbard carbon isotope curve.

Fluid-producing mineral reactions and microfabric development during formation of nodular sillimanite-gneiss (Bamble lithotectonic domain, south Norway)

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The Proterozoic gneisses of the Bamble lithotectonic domain (south Norway) underwent intense scapolitisation caused by K- and Mg-rich fluids and extensive albitisation with formation of numerous ore deposits.
By detailed studies of mineral reaction textures we document release of the chemical active Mg, K and Fe-components forming the metasomatic fluid: Breakdown of biotite to muscovite produces K, larger amounts of Mg, Fe, quartz, and H_2O. Fe is present as tiny Fe-oxide needles in the transforming rock. H_2O is used in the mineral reaction with K-feldspar producing additional amounts of white mica, quartz and K. During a subsequent reaction muscovite is replaced to sillimanite again releasing quartz and K. The reactions form the peculiar sillimanite-nodular quartzite, but also well-foliated sillimanite-mica gneiss.
Optical and EBSD microfabric studies reveal a shape preferred orientation for quartz, but despite of a pronounced foliation, quartz does not show a crystallographic preferred orientation. A crystallographic preferred orientation is present for mica and sillimanite. Coarse micas show sutured boundaries to quartz, implying low nucleation rates, no crystallographic or surface-energy control during growth and no obvious crystallographic relationship to quartz.
Our study illustrates the transformation of a quartzofeldspatic lithology into sillimanite-bearing quartzite. The microfabric data indicates reaction at non-isotatic stress condition. The deduced mineral replacement reactions document a source of K- and Mg-metasomatic fluids necessary to cause the pervasive scapolitisation in the area.

Kortreist fyr – en bygningshistorie fra Hustadvika

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Fyrene langs kysten vår ble en revolusjon for sjøfarende etter hvert som de ble etablert på 1800-tallet. En av våre mest beryktede sjøstrekninger, Hustadvika i Møre og Romsdal, fikk sine fyr fra 1840-tallet. Kvitholmen fyr utenfor Vevang ble i 1842, sammen med Stavnes fyr på Averøy, de første som ble tent i området[1]. Fyrtårnet gir oss et innblikk i en tidligere del av norsk anleggshistorie og bergindustri. Bygging av de norske fyrene var krevende, og på Kvitholmen var om lag 100 mann i arbeid.
I eldre bygningshistorie tok man flittig i bruk lokal stein. Motivasjonen hang sammen med enkel tilgjengelighet, kort transport og effektivitet. Gneis som vi har mye av langs norskekysten, har vanligvis en markert båndning som gjør at den enkelt spalter langs flatene og egner seg til muring. På Kvitholmen i Hustadvika ble fyrtårnet bygget i stor grad av kortreist stein. Den migmatittiske gneisen på holmen har en solid båndning, og bruddene for bygningssteinen finner vi både på den østlige delen av den 0,25 km^2 store øya, og i fjellskrenten rett på nordsiden av fyrtårnet. Blokkene ble sirlig banket og brutt ut, antagelig også ved hjelp av små ladninger med mineringskrutt, og kilemerkene fra driften står igjen på bruddstedene i dag. Murersteinen i tårnbygningen er hver og en svakt buet, slik at de til sammen formet det runde fyrtårnet. Bruddflater med kilemerker i steinbruddene viser at avrundingen ble definert allerede ved uthuggingen. Så ble blokkene fraktet opp på høyden hvor tårnet ble satt opp. Gjennom videre bearbeiding med prikkhammer ble de jevne avrundede flatene som vi ser i tårnbygningen formet.
Selv om bruken av den lokale steinen utgjorde hoveddelen av anlegget, ble materiale for etasjeskillene importert fra Østlandet. Massive blokker av homogen rød granitt fra Oslofeltet kom ferdig uthugget, avrundet med kantprofileringer. Et flott steinhuggerarbeid var også her utført av innsatte ved Botsfengselet i Oslo. Sand til oppmuring ble hentet fra Bremsnes på Averøy, og lyktehuset i støpejern laget ved Nes Jernverk[1,2].
På starten av 1900-tallet førte ombygninger av fyret til at tårnet ble kuttet med 8 meter, og dagens lykt står på et 12 meter høyt betongsøyle foran restene av steintårnet[1,2]. Steinblokkene fra rivningen har blitt værende på holmen. Både de avrundede gneisblokkene og den profilerte granitten ligger i små hauger rundt tårnet i dag. I 1978 ble Kvitholmen fyr fredet. Fredningen omfatter begge fyrtårnene, fyrvokterboligene og området rundt fyrtårnet hvor blokkene etter rivningen ligger.
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Geologiske prosesser rommer enorme dimensjoner - det er derfor jeg elsker å være geolog. Å lese landskapet rundt meg gir innblikk i hvordan Norge har blitt formet gjennom 3 milliarder år.
I nettavisen forskning.no skriver jeg bloggen «Bergtatt». Her deler jeg historier om bergarter og mineraler - og om geologiske prosesser som har dannet landskap og fjell.
I bloggen går jeg dypt ned i jordskorpen og langt tilbake i tid. Jeg skriver om hva slags reiser steinen i fjellene har vært med på, om hvordan berggrunnen i landet vårt er dannet. Om mineraler og bergarter, og hvordan dannelsen deres kan fortelle historien til berget vårt.
Til daglig er jeg forsker og geolog ved Norges geologiske undersøkelse. Der arbeider jeg med kartlegging av Norges berggrunn og forskning på mineraler og bergarter. Jeg jobber ute i felt, og vel hjemme etter feltarbeid bruker jeg mikroskop og avanserte laboratorier for å forstå dannelsen til mineralene og bergartene. Gjennom dette ønsker jeg å bidra til å økt kunnskapen om hvordan fjellene og berggrunnen i Norge er dannet. Noen av disse historiene deler jeg i bloggen på forskning.no.
Gjennom bloggen håper jeg også å bidra til at geologi blir en del av naturhistorien vi tar med oss som følgesvenn. Friluftslivet er sentral for oss i Norge og naturkunnskap gir en ekstra dimensjon til naturopplevelsene. Vi reflekterer gjerne rundt planter og dyr, kjenner på vær og vind, og nyter utsikten til flotte fjell eller barskt hav. Men også landskapet kan vitne om en lang historie tilbake til tidenes morgen og berget kan skjule hemmeligheter vi ikke ante var der. Geologi, læren om jordas oppbygning og historie, rommer prosesser med enorme dimensjoner. Å lese landskapet med geologiske briller på gir innblikk i hvordan Norge har blitt formet gjennom milliarder av år.
Men det er ikke bare i naturen vi kan oppleve geologi. I bloggen vil jeg gjerne slå et slag for betydningen av å bruke lokal stein, til bygninger, anlegg og monumenter. Tidligere var bruken av kortreist stein en nødvendighet, nyttet med enkel tilgjengelighet, kort transport og effektivitet. Der råstoffene er hentet lokalt gir menneskenes spor i dag en tilhørighet og historie. Om det er byvandring eller opplevelse av kulturminner gir bruken av lokal stein kunnskap om hvordan menneskene og naturen henger sammen.

Geologisk landskapskarakter – et mulig verktøy innen geoturisme og forvaltning?

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Foredraget er knyttet til Interregprosjektet GNIST (Geologisk arv i Naturbasert Innovasjon for Skandinavisk Turisme). Motivasjonen for å utvikle begrepet geologisk landskapskarakter er å utvikle en metode for å bedre verdivurderinger av geologiske lokaliteter og skape merverdi av geologiske besøksmål for reiseliv, forvaltning og undervisning. Dette kan brukes til å bevisstgjøre om områdes egenart, ta forvaltningsmessige konsekvenser av denne egenarten og gir mulighet til å se hele naturen som et enhetlig landskap med sine forskjellige enkeltegenskaper.
Landskapskarakter er i norsk sammenheng definert som «*et konsentrert uttrykk for samspillet mellom et områdes naturgrunnlag, arealbruk, historiske og kulturelle innhold, samt romlige og andre sansbare forhold som særpreger området og adskiller det fra omkringliggende landskap*» (Riksantikvaren/ Direktoratet for Naturforvaltning 2010). En kanskje mer presis definisjon er: " *the a distinct and recognisable pattern of elements, or characteristics, in the landscape that make one landscape different from another, rather than better or worse*" (Tudor 2014).
"Landskap" betyr et område, slik folk oppfatter det, hvis særpreg er et resultat av påvirkningen fra og samspillet mellom naturlige og/eller menneskelige faktorer (Den Europeiske Landskapskonvensjonen). En vesentlig del av det fysiske landskapet er knyttet til geologi, landformer og geologiske prosesser, d.v.s geologisk mangfold. Det er det geologiske mangfoldets gjenkjennbare mønstre i landskapet vi kan kalle geologisk landskapskarakter. Denne kan hjelpe oss med å beskrive og analysere geologiske fenomener på landskapsnivå, bidra til å formidle geologiske verdier og opplevelser for forvaltning og publikum, utvikle forståelsen av verdikriterier som sjeldenhet og representativitet, øke bevisstheten om geologiens betydning lokalt og nasjonalt og bidra til puslespillet i en helhetlig landskapsanalyse slik landskapskonvensjonen krever.
Gjennom naturkarakteriseringssystemet Natur i Norge (NiN) utviklet i regi av Artsdatabanken er det allerede laget et system for å inndele Norge i landskapstyper (Erikstad m.fl 2019). Dette inkluderer et landskapstypekart. Ved å supplere med informasjon knyttet til berggrunn, jordarter og detaljerte terrengforhold (LIDAR), vil perspektivet utvides og kunne gjøres mer relevant i lokale og regionale studier. Kombinasjonen mellom geologiske kart i ulike målestokker og analyser av terrengforhold vil vi bidra til å kunne identifisere geologiske trekk som er synlige i, og som kan være karakteriserende for landskap. Multivariate analyser og modelleringsteknikker vil kunne bidra med informasjon som til en viss grad kan bøte på problemer knyttet til kartleggingsinformasjon i grove skalaer og manglende kartdata.
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Exploring extensional fault interpretations from seismic reflection data of various resolution substantiated by seismic modelling

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Complex fault geometries are critical to fault risking in relation to subsurface hydrocarbon or CO_2 reservoirs. To increase confidence in the seismic interpretations, it is therefore important to investigate the uncertainties and limitations of interpreting subsurface faults in seismic data. Limitations in seismic illumination and resolution make it challenging to detect and interpret subsurface faults in detail. To explore the challenges and pitfalls in extensional fault interpretations we combine modern 3D conventional (dominant frequency 40 Hz) and high-resolution P-Cable 3D (dominant frequency 150 Hz) seismic data from the Hoop area, SW Barents Sea, and utilize 2(3)D Point-Spread-Function based convolution seismic modelling to investigate the potential of seismic data to image detailed fault architectures. The geological layered models tested by seismic modelling are based on interpretations of the high-resolution seismic data.
The study highlights the importance of taking interpretation uncertainties from individual interpreters into account. Twenty geoscientists with different geological/geophysical background interpreted two seismic sections (conventional and high-resolution data). This resulted in one best-fit geological layered model and nine scenario models that were tested by seismic modelling. By varying input fault geometries (geological models) and elastic parameters (such as Vp, Vs and density), a wide range of dominant frequencies, illumination and incident angles, we analyse a variety of synthetic seismic images corresponding to the two seismic data types. Finally, we compare our modelled outcomes with the original depth-converted seismic data. A synthetically trained neural network is also applied as interpreter #21 to compare automatic with the manual fault picking.
The results show: (1) Closely spaced fault segments are difficult to resolve even when displacement is large, especially in the conventional synthetics; (2) The vertical resolution of closely spaced reflections and small offset faults is 20 m and 5 m in the conventional and high-resolution seismic data respectively; (3) Importance of angle between fault and reflections - lower angle requires larger throw for detection; (4) Statistical analysis shows the uncertainty and variation with manually picked interpretations by several interpreters. The advantage of having high-resolution data with better seismic imaging and resolution is that it contributes to more geological details, hence better geological interpretation and analyses of the study area and can challenge the interpretation on conventional seismic data in the same area. The interpretations can be pushed further by testing it out by seismic modelling.

Comparison of pore pressure estimation from P- and S- wave velocities

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Pore pressure estimation is of considerable importance in drilling prognosis to minimize blow-out and other drilling-related risks, such as shale bridging and stuck pipes. We employed the Eaton method (Eaton and Eaton 1997) that is commonly used for predicting pore pressures from P-wave velocities for being reliable and straightforward, and that estimates pore pressure within acceptable limits. Therefore, it is the most widely used technique in the oil and gas industry. The Eaton method employing P-wave velocity is considered a reference against which other pressure estimation methods are often compared. The usage of P-wave velocity has, however, some limitations. Even a small amount of gas in pore spaces results in a large decrease in velocity. Moreover, the S-wave velocity is insensitive to fluids but more sensitive to effective stress than the P-wave velocity.
We used data from a recently drilled exploration well 31/5-7 planned to inject CO_2 in the Longship CCS facility. The well is located in the west of the Troll East field on the Horda Platform in the northern North Sea. The well dataset contains pressure measurements from Xpress Pressure Tool (XPT), modular formation dynamics tester (MDT), conventional mud weight, and wireline log data. The Eaton calculations using S-wave velocities (Ebrom et al. 2003) compared with that of P-wave velocity showed that the pore pressure estimation using S-wave velocities was as good as P-wave velocities, or even better at places. One can use the P- and S-wave velocities inverted from seismic for the pore pressure estimation; therefore, calculations from both and their comparison are essential, especially in the area where a small percentage of gas is present in the formations.
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Structural and lithological controls on Quaternary rock slope collapses and rockfalls in the interior of Hornelen Devon basin, Western Norway

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Aerial photographs reveal a large concentration of rock-slope failure- and rockfall deposits in the interior of Hornelen Devon basin, on the Hennøy peninsula, Vestland municipality. The interior of the basin consists mainly of green sandstone that forms a characteristic topography of bedding controlled monoclinal ridges up to tens or hundreds of meters tall. Along the northern fringes of the regulated lake of Svelgsvatnet, located east of Svelgen village the interaction between bedding and highly persistent joints creates repeating wedge-shaped slide scars of up to several tens of meters in height with respective deposits along the lake. Remote sensing on ALS and aerial photographs reveals large fractures delimiting several possibly active instabilities. The deposits of previous failures fan out into the lake, indicating a potential hazard of displacement waves and/ or internal damming at narrow parts of the lake in the case of future rock-slope failures. Both could potentially impact the longevity and functionality of the reservoir.
The spatial distribution of landslide deposits and size is not random. Preliminary results from field mapping suggest that the interaction between topographic factors, including slope gradient, aspect and relief, and critical structures are important for the magnitude of rock slope failures. Structural controls include the persistent bedding plane, favorably oriented joint sets and bedding parallel minor faults. To further understand structural and lithological controls, additional investigations are to be conducted. These include: (1) mechanical testing of rock and fault gauge samples collected in field to obtain rock strength parameters that can be used in stability calculations. This will help to better assess past and possible future trigger for rock slope failures. (2) Results of terrestrial cosmogenic nuclide exposure dating on three separate rock-slope failure deposits will give an insight on timing of previous events and thus might help assessing environmental conditions that might have contributed to failure. Lastly, (3) dynamic run-out modelling and empirical displacement wave analysis will help to better define consequences for potential failures.

Geochemical characteristics of the volcanogenic massive sulphide deposits (VMS) on the Bømlo and Stord Islands, Sunnhordland, SW Norway

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Volcanogenic massive sulphide (VMS) deposits represent the most abundant type of ore mineralization in Norway. The VMS deposits are almost exclusively hosted by the Upper Allochthone of the Scandinavian Caledonides. The Caledonian VMS deposits formed during different stages of evolution of the Iapetus Ocean and show distinctive features in terms of their host-rock lithology, mineral characteristics of ore parageneses as well as trace element composition of ore minerals (e.g. Grenne et al., 1999).
The islands of Bømlo and Stord, Sunnhordland, SW Norway, host numerous VMS deposits of various sizes and ore grades (Eilu, 2012). The geological setting of the area is complex and comprise elements of SSZ ophiolite complexes (Lykling Ophiolite Complex), immature island-arc sequences, and overlying mature island-arc magmatic-sedimentary sequences of Ordovician age (Pedersen & Dunning 1997).
The ongoing study has been focused to geochemical characterization of various types of VMS mineralizations in the Bømlo and Stord area, with a particular focus to the Alvsvåg mineralization and the Stord (Litlabø) deposit.
The Alvsvåg mineralization is spatially associated with two W-E trending shear zones hosted by the gabbroic sequence of the Early Ordovician Lykling Ophiolite Complex. The mineralized gabbroic sequence consists of coarse- and micro-gabbro and probably represents a high level gabbro zone. The coarse-grained gabbro mostly hosts dissemination and clusters of chalcopyrite, pyrite and pyrrhotite, while micro-gabbro host lenses predominantly composed of pyrite.
In contrast, the Stord (Litlabø) deposit is hosted by a sequence of graphite-rich sediments associated with bedded radiolarian cherts and basalts of the Langevåg group (Nordås et al., 1985, Granne et al, 1999). The mineralization occurs in a form of very-fine grained pyrite layers intercalated with grey to greenish chert with local jasper occurrences, magnetite and hematite lenses as well as thin layers of Fe-silicates.
This study brings a new set of geochemical data, including lithogeochemical characteristics of host rocks, mineral composition of ore parageneses and associated hydrothermal alteration products, trace element content of sulphides as well as their sulphur isotope composition, with an aim to constrain the metallogenic model of the studied area.
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Soil - Plant Interactions along a 100 km Transect in southern Central-Norway

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A transect was placed over two known mineral deposits in southern Central-Norway, the Nordli molybdenum deposit (one of Europe's largest hitherto untouched deposits) and a lead mineralisation (near Gjøvik) in order to test which sample material will provide the most reliable signal for geochemical exploration under Norwegian conditions. At each sampling site, soil C and O horizon samples were collected, together with several biological media: moss (*Hylocomium splendens*), mushroom (*Lactarius rufus*), birch (*Betula pubescens*) twigs and leaves, spruce (*Picea abies*) needles and twigs, pine (*Pinus sylvestris*) bark, cowberry (*Vaccinium vitis-idaea*) twigs and leaves, blueberry (*Vaccinium myrtillus*) twigs and leaves, fern (*Pteridium aquilinum*) leaves and horsetail (*Equisetum sylvaticum*) leaves and stems. Concentrations of 53 elements were analysed by ICP-MS in an aqua regia extraction of all sample materials.
Plants will take up elements either from soil via the transpiration flow or as microparticular matter via atmospheric deposition, including local dust, on their aboveground parts. Some media (especially moss) will predominantly trap airborne matter on their large surface and are thus often used to detect airborne contamination. Element enrichment from soil via the transpiration flow will be much more selective. It will result in threshold values for individual elements or element groups in the different plants, dependent on the properties of element carriers used to bridge the cellular membrane system. The goal of this study was to find several media accumulating the target elements up to a quantifiable amount, unveiling the location of the known deposits. The majority of sample materials deliver a clear geochemical signal related to the two deposits. Spruce needles and horsetail are the best indicators for available Mo in soil, and the soil O horizon acts as a reservoir for the Mo originating from bedrock Mo. Fern and horsetail, together with the soil C horizon show the largest background/anomaly contrast over the Pb mineralisation. Furthermore, the data show a very individualistic behaviour of each plant species to element uptake control within the plant. Compared to the other plants the mushroom accumulates Ag, Cs, Cu, Rb, Na and Cd and shows exceedingly high concentrations of the major nutrients K, P and S, while uptake of Ca is avoided. Both horsetail and fern enrich rare-earth elements like Ce, La and Y, but to a different degree, and they invert the geochemical La/Ce ratio during uptake. Many elements show a strong decrease in variation in plant materials compared to soil.

New Geochemical data and Maps from Mid- and Northern Norway

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Newly compiled data from four mineral soil surveys covering the mid- and northern part of Norway will be presented.
The Geological Survey of Norway (NGU) has re-analysed stored soil C-horizon samples, which were collected during two low-density soil surveys in the 1980s in Northern Norway (1 sample/36 km2). Recently, two new soil surveys covering all of Trøndelag, the county in the prolonging southern direction, have been carried out using the same sample density. All analyses were carried out in the same laboratory. Compared to the analyses from the 1980s, lower detection limits were obtained and results for many more elements than previously were reported. Quality control demonstrated that the analytical results from Trøndelag are, for most elements, directly comparable with the results from Northern Norway. It was thus possible to produce uniform geochemical maps covering Norway from Mid-Norway to the coast of the Barents Sea and the Russian/Norwegian border for many chemical elements.
Although, the occurrence of base and precious metal and rare earth elements (REE) anomalies indicating mineralized areas are obscured by the low-density sampling, bedrock geology and many mineral districts are generally well reflected in the element maps. Examples include Caledonian and Proterozoic sediments at the coast of the Barents Sea marked by prominent Ag, As, Bi, REE, Cs, Fe, Mn, Pb and Sb anomalies and the two geochemically quite distinctly different greenstone belts in Finnmark (Kautokeino and Karasjok) prominently visible on the Co, Cr, Cu, Mg, Ni and V maps. Especially on the Ag, As, Bi, Co, Cu and Sb maps, many of the known mineralisations and mineral belts like Nussir/Repparfjord copper or the Joma/Skorovas Cu/Zn district and possible extensions thereof are highlighted. Despite the low sampling density, the new geochemical maps provide useful first order criteria to identify areas with potential for mineral exploration in northern Norway.

Geochemical characteristics of the Lykling gold-bearing quartz vein mineralization, Bømlo, Sunnhordland

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The gold mineralization at Lykling on the island of Bømlo, Sunnhordland, is hosted by the Early Ordovician Lykling Ophiolite Complex. The Lykling ophiolite represents the oldest portion of the Upper Allochthones of the Scandinavian Caledonides. The ophiolite is unconformably overlain by the Geitung Unit (494Ma) composed of a mixture of extrusive volcanics and sediments formed as a part of an immature island arc sequence (Brekke et al., 1984; Pedersen and Dunning, 1997).

The mining activity in the area dates back to the 19th Century and the total production is estimated at 140 kg of gold (Grenne et al, 1999). The mineralization occurs in a form of quartz veins that are sitting within ductile and brittle shear zones. The shear zones are frequently spatially associated with mafic dykes and crosscut layered and isotropic gabbro of the Lykling ophiolite and younger tonalite intrusions.

The gold-bearing veins hosted by ductile shear zones consist of massive quartz associated with variable amounts of ankerite and minor amounts of sulfides. The quartz veins are usually embedded within an envelope composed of chlorites, amphiboles, epidote and micas. In contrast, the gold-bearing quartz veins hosted by brittle shear zones contains significant amounts of pyrite and chalcopyrite. Carbonates are absent or occur as a minor mineral phase in this type of quartz veins.

The ongoing study brings new data on mineralogy and mineral chemistry of the gold-bearing veins and associated hydrothermal alteration products, fluid inclusions hosted by quartz and carbonates and stable isotope composition of carbonates with an aim to give a better insight into the gold transport mechanism and physicochemical factors that controlled deposition of gold at the Lykling locality.

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Last glacial cycle ice surface variations in western Dronning Maud Land, East Antarctica

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The East Antarctic Ice Sheet (EAIS) is generally assumed to have been relatively insensitive to Quaternary climate change. However, recent studies have shown potential instabilities in coastal, marine sectors of the EAIS. In addition, long-term climate reconstructions and modelling experiments indicate the potential for significant changes in ice volume and ice sheet configuration since the Pliocene. Hence, more empirical evidence for ice surface and ice volume changes is required to discriminate between contrasting inferences.

MAGIC-DML is an ongoing Swedish-US-Norwegian-German-UK collaboration focused on improving ice sheet models by filling critical data gaps that exist in our knowledge of the timing and pattern of ice surface changes along the western Dronning Maud Land (DML) margin and combining this with advances in numerical techniques. Here, we report cosmogenic multi-nuclide data from bedrock and erratics at 72 sample locations on nunatak ranges from Heimefrontfjella to along Penck-Jutulstraumen ice stream throughs in western Dronning Maud Land. The sample locations span elevations between 741-2437 m above sea level, and record apparent exposure ages between <2 ka and >5 Ma.

The highest bedrock samples, from high on the inland nunatak ranges, indicate continuous exposure since >5 Ma, with a very low erosion rate of 15±3 cm Ma^{-1}. These results indicate that the ice sheet has not extensively buried and eroded these mountain ranges since at least the Pliocene

Moreover, and in contrast to current studies in eastern Dronning Maud Land, we record clear indications of a thicker-than-present ice sheet along the Penck-Jutulstraumen throughs within the last glacial cycle, with a thinning of ~35-120 m towards the present ice surface on several nunataks during the Holocene (~2-11 ka). These results thus indicate ice-surface fluctuations of several hundred meters between the current grounding line and the edge of the polar plateau for the last glacial cycle.

Stress and deformation in the Norwegian Barents Sea caused by Paleogene transpression along the Greenland-Eurasia plate boundary

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Late Cretaceous-Cenozoic contractional structures are widespread in the Barents Sea. While the exact dating of the deformation is unclear, it can only be inferred that the contraction is younger than the early Cretaceous. One likely contractional mechanism is related to Greenland Plate kinematics at Paleogene times. We use a thin sheet finite element modelling approach to compute deformation within the Barents Sea in response to the Greenland-Eurasia relative motions during the Paleogene. The analytical solution for the 3-D folding of sediments above basement faults is used to assess possibilities for folding. Two existing Greenland Plate kinematic models, differing slightly in the timing, magnitude and direction of motion, are tested. Results show that the Greenland Plate's general northward motion promotes growing anticlines in the entire Barents Sea shelf. Our numerical models suggest that the fan-shaped pattern of cylindrical anticlines in the Barents Sea can be associated with the Eurekan deformation concurrent to the initial rifting and early seafloor spreading in the northeast Atlantic. The main contraction phase in the SW Barents Sea coincides with the timing of continental breakup, whereas the peak of deformation predicted for the NW Barents Sea occurred at later times. Svalbard has experienced a prolonged period of compressional deformation. We conclude that Paleogene Greenland Plate kinematics are a likely candidate to explain contractional structures in the Barents Sea.

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Geology and methods for resource estimation of north Norwegian graphite occurrences and their international comparison

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There are provinces of abundant graphite at a number of localities in north Norway: the islands of Senja, Lofotoen and Vesterålen, and the Holandsfjord. In all these provinces the graphite occurrences seem to share a common geological setting. They occur in sequences of meta supracustal rocks, comprising carbonates, iron formations, meta arenites, intermediate to acid gneisses, and graphite schists. As a result of metamorphism to high amphibolite and granulite facies, the graphite schist occurs at most localities together with rocks that can be partly anatectic granulites with little sign of primary sediments. All three areas have been investigated with both airborne and ground geophysics, with electromagnetic and electric methods as the most important. Selected localities have been investigated in detail to quantify the resources. By measurements of the number, width and length of the graphite-rich horizons combined with analysis of total carbon, tonnage and resources, the amount of graphite is estimated. 28 localities show an average carbon content of 11.6% and tonnage of 9.3 Mt. The biggest deposits are the Bukken deposit on Senja and the Vikeid deposit in Vesterålen, with 3.35 and 3.34 Mt of contained graphite respectively. The localities on Senja are significantly larger than the Lofoten-Vesterålen, the latter are believed to be dismembered by younger intrusions. We demonstrate that the deposits have grade and tonnages that are comparable with international deposits. (Gautneb *et al.* 2020) However, since our methods for resource estimation is mainly based on geophysics, with drilling data , limited to a few localities, our results are classified as inferred only resources only. In all provinces the graphite schist is part of a succession presumably of comparable age. On Senja the West Troms Basment Complex (2.89-2.70 Ga) is overlain by the graphite bearing supracrustal successions, which again are intruded by 1.8-1.7 Ga rocks indicating an age of the graphite schist in det order of 2.2-2.0 Ga. Most other graphite occurrences in the Fennoscandian shield seems to be of the same time interval. This is also contemporaneous with the Shungite rocks of Russian Karelia, and interestingly also the same age paleoproterozoic age range as the major graphite occurrences in Ukraine, China, Madagascar and Brazil.

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Plate Tectonics steers Climate Change

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Today´s changing climate is the result of a complex interplay of processes in the Lithosphere, Hydrosphere,

Cryosphere, Biosphere and Atmosphere. The first of these is essential for understanding why we are living in an Icehouse today, after fifty million years of cooling out of a Hothouse in the early Eocene (IODP Cenogrid). During the Cenozoic, plate tectonics dramatically changed the living environment on Earth. Sea-floor spreading dominated equatorial latitudes and farther north, with opening up of the South and North Atlantic oceans and also the Eurasian Basin beneath the North Pole. At the same time, in the higher southern latitudes, Australia separated from Antarctica in the earliest Oligocene and migrated northwards leaving a huge continental "island" isolated beneath the South Pole. The break-off at 34 Ma, resulted in a rapid change of climate from Warmhouse to Coolhouse; during the next thirty years, the encircling southern ocean widened and eventually landed us in the Icehouse at c. 4 Ma. These changes in the climate were also promoted by the progressive opening of the northern oceans, permitting the development of near surface currents carrying warm equatorial waters northwards to beneath the North Pole, where they increased in salinity, cooled, sank and then back-tracked southwards into the cool ocean circulating around Antarctica.

Cenozoic carbon dioxide levels in the atmosphere reached a maximum of a couple of thousand ppm in the Hothouse and dropped to less than a tenth of this in the Icehouse. The timing of peak temperature in the early Eocene (c.54-50 Ma) coincides remarkably with the collision and many hundreds of kilometres of underthrusting of India beneath Eurasia. This correlation in timing suggests that the vast Alpine-Himalayan Orogen, together with North Atlantic mafic magmatism, were responsible for the highest CO_2 levels in the Cenozoic.

Based on the evidence of Cenozoic plate movements, outlined above, it can be concluded that there are very small chances of our planet escaping from the Icehouse during the coming millions of years. Milankovitvh cycles will continue, with migration from dominating long glacial epochs to short interglacials. We may succeed in avoiding the next Little Ice Age by increasing CO_2 levels; but judging by the on-going effects of increasing anthropogenic emissions (mainly from the burning of fossil and bio-fuels) and their remarkably rapid consumption (sequestration) in the Biosphere, it will be difficult to achieve. To test different hypotheses for explaining global warming and cooling, we should hold anthropogenic production of CO_2 at present levels for a few decades, ban commercial Biosphere burning, and see whether planet Earth continues to green. Maybe higher levels of CO_2 productivity will be necessary to improve the living conditions of our world´s expanding population in this incredibly beneficial Holocene interglacial.

Triassic sediment supply reconstructions in the Greater Barents Sea Basin

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Triassic strata in the Greater Barents Sea Basin (GBSB) are critical to understanding the evolution of surrounding hinterlands, including the Urals, Siberia, and Fennoscandia as well as adjoining Arctic basins in the Lower Mesozoic. Previous studies on the Triassic succession in the GBSB have provided information about which source contributed sediments at different stages in the basin history. However, none have focused on the evolution of the source areas throughout time. Here, we use state-of-the-art basin-wide correlation of stratigraphic units in the GBSB and adjacent Timan-Pechora and Kara basins to: i) calculate sediment load for each time-unit and use this information to understand Triassic sediment supply; ii) link changes in sediment supply and catchment parameters to tectonic events in the source area; and iii) investigate whether the Triassic sediment source in GBSB also acted as a source for other sedimentary basins in the Arctic.

Our results, which use seismic data and BQART equation using Monte-Carlo simulations, show that sediment loads were extremely high during the Lower Triassic. This sediment supply matched the biggest modern river systems with sources in the most tectonically active orogens (Himalayas and Andes). Middle Triassic sediment load was significantly lower but still comparable to the top ten biggest modern rivers, as and ancient counterparts (Paleogene Wilcox Formation, Gulf of Mexico). Another peak in sediment supply occurred in the Late Triassic, coinciding with a westward depocenter shift. The Upper Triassic contains four time-units, three of which show a considerable mismatch between observed and modelled sediment load. This mismatch in the sedimentary budget, together with sediment transport direction, is evidence for sediment transport through and beyond GBSB and into other Arctic basins.

These results have important implications: The western Urals have traditionally been regarded as the sediment source for the Triassic deposits in the GBSB, but the sediment volumes are too large to have been supplied only from this catchment. Our results strongly suggest that West Siberia and possibly the Central Asian Orogenic Belt also supplied sediment to the GBSB. Furthermore, the large amounts of sediment supplied to the GBSB during the lower Triassic requires tectonic reactivation of the Urals orogeny, likely caused by onset of the greatest volcanic event during the Phanerozoic, the Siberian Traps Large Igneous Province. The low sediment loads during the middle Triassic indicates sediment storage in proximal basins that lay E and SE of the GBSB, and the renewed high sediment loads and subsequent bypass in the late Triassic suggests an early onset of the final Northern Ural orogeny, possibly combined with climate changes related to the Carnian Pluvial Event. During the late Carnian and Norian, these events led to sediment spilling to the Sverdrup Basin and the tectonically offset Chukotka Basin.

Late Paleozoic Supradetachment Basin Configuration in SW Barents Sea – Intrabasement Seismic Facies of the Fingerdjupet Subbasin

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The importance of late/post-Caledonian, Devonian extension in the SW Barents Sea remains unresolved, contrary to knowledge from onshore Norway, East Greenland and Svalbard. We have performed intrabasement seismic facies analysis on high-resolution 3D and reprocessed 2D data to investigate evidence for Caledonian deformation and post-Caledonian detachment faulting in the central SW Barents Sea. The results from seismic interpretation have been compared to published potential field models and analogue field studies onshore Svalbard and Bjørnøya. Based on our study we propose how structures likely inherited from post-orogenic extension influenced the Late Paleozoic and Mesozoic basin evolution. The Late Paleozoic Fingerdjupet Subbasin is underlain by a NNE-striking, ESE-dipping extensional detachment fault that records a minimum eastwards displacement of 22 km. The detachment fault and associated shear zone(s) separate post-orogenic metamorphic core complexes from the syn-tectonic deposits of a presumed Devonian supradetachment basin. Spatial variability in isostatically induced doming likely governed Devonian basin configurations. Pronounced footwall corrugations and faults splaying from the detachment reveal eastward extensional transport. This ultimately led to two interacting but subsequent, east-stepping detachments. Local rejuvenation of the detachment systems controlled the extents of Carboniferous carbonate and evaporite basins in the Bjarmeland Platform area. Further, the Mesozoic Terningen Fault Complex and Randi Fault Set testifies to how the inherited Devonian structural template continued to control spatial localization and extent of extensional rift structures during subsequent periods of extensional faulting in the Fingerdjupet Subbasin.

Detachment Faulting, Successive Incision and Controls on Supradetachment Basin Formation at the Mid-Norwegian Rifted Margin

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The growth and interaction of km-scale and smaller faults is fairly well understood. Simultaneously, some of the principles of fault growth appear as not applicable to detachment fault systems. These may record displacements in the order of 10 s to 100s of km and bound supradetachment basins – a basin type that is not well understood compared to extensional half-graben basins. The isostatic response to detachment faulting leads to the exhumation of metamorphic core complexes. Numerical and analogue 2D modelling have shed light on mechanisms of footwall back-rotation during progressive extension (rolling hinge model), but the nature of, and effects of lateral development within such detachment systems remain poorly understood. It has been proposed that with increasing amounts of extension, detachment faulting favors formation of isostatically induced, longitudinal and transverse folds and to basin inversion in the area of maximum displacement. The growth and lateral linkage of such faults will thus be critical to the evolution and configuration of associated supradetachment basins. We use interpretation of 3D- and 2D seismic data from the necking domain of the Mid-Norwegian rifted margin to discuss the effects of lateral detachment linkage and interaction. The inner parts of the south Vøring and northeastern Møre basins demonstrate how successive incision may induce a complex structural relief in response to extensional detachment faulting and folding. Isostatic responses are recorded in the form of extension-normal back-warping and synclinal keel formation and in the form of extension-parallel turtlebacks. The overall N-S striking, c. 270 km long Klakk Fault Complex (KFC) bounds the Frøya High to the west and constitutes the margin's necking breakaway complex. Segments of the KFC exhibit sinusoidal geometries and we recognize an extension-parallel turtleback flanked by recess depocenters controlled by isostatic uplift, lateral linkage and successive incision along the Late Jurassic-Early Cretaceous Klakk Fault Complex. Southwest of the Frøya High, the Slørebotn Subbasin forms a synclinal keel basin with rafted blocks, a structural configuration which is recognizable also in the northern structural recess towards the Halten Terrace.

3D-modelling of Subsurface Stratigraphy at Mosvatnet, Stavanger, Norway

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Thousands of birds of more than fifty different species come to Mosvatnet to breed every year. Mosvatnet is a glacial lake located 36 masl in the Stavanger municipality in Rogaland County, Norway, and it is considered a national bird sanctuary. In the eastern side of the lake lies an islet that acts as a bird nesting ground. A forest and a walking trail of ca. 3 km long surround the lake that has an area of ca. 0.45 km² and an average depth of 2 meters.

The municipality wants to extend the islet by one third in order to provide a larger habitat for migrating birds. One of the alternatives considers hauling material by trucks along the eastern segment of the walking trail until the closest discharge point to the islet. Although this solution appears feasible, technical aspects concerning the infill and in-situ materials underlying the walking trail and the bottom of the lake need to be understood. The lake and its surrounding landscape have been altered by the construction of important infrastructure projects since the twentieth century. Aerial imagery has revealed that the eastern shoreline of the lake has artificially prograded about 100 m since the mid-1930s. The type, characteristics, and three-dimensional distribution of the infill material used in the progradation of the shoreline are unknown. This study aims to deliver a model that provides the stratigraphy and structural features underlying the area of interest.

This interdisciplinary study involves remote sensing, geophysics, and geology. It integrates light detection and ranging (LiDAR), on- and off-shore ground penetrating radar (GPR), 2D on-shore seismic, geological data from wells, and compressed high radar pulse (CHIRP). LiDAR, GPR, seismic, and CHIRP were all collected in 2020, and well data dates to 2013. The LiDAR model was instrumental in the generation of a high-resolution digital terrain model (DTM) of the study area and in the detection of important topographic changes in the terrain. The CHIRP model delivered the lake bathymetry. The CHIRP and DTM together represent the lakebed and uppermost terrestrial surface of the model, respectively. Tomography derived from seismic facilitated identification of the basement depth. The position of the basement observed in the seismic lines matched well with those positions observed in well data. The GPR radargrams revealed subsurface geological structures underlying the study area. It is possible to observe the basement and overlying layers which are offset by fractures.

The integration of seismic, GPR, and CHIRP data enabled three-dimensional mapping of the top of the basement, the overlying layers, and the fractures. Future work includes the analysis of very low-velocity anomalies observed in the seismic and volume calculation of the material between the current topography and the basement.

Fluid alteration of Ordovician limestones in the Baltoscandian Basin during Caledonian collision revealed through trace-element mapping and U-Pb dating by LA-ICP-MS

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Combined trace-element mapping and U-Pb geochronology of calcite *in situ* (in thin sections) by LA-ICP-MS provides opportunities to assign absolute ages to calcite crystallization and recrystallization with petrographic and geochemical context. The ability to date multiple, texturally distinct generations of primary, diagenetic, and metamorphic carbonate phases enables deciphering of complex depositional and post-depositional histories sedimentary successions have experienced. We have applied this approach to two samples of Ordovician bioclastic limestones from the Viki drill core (western Estonia), representing the eastern part of the Baltoscandian Basin. The depositional ages of the samples are constrained by biostratigraphic correlation to ca. 460 and 445 Ma (Hints et al., 2014). Several lines of evidence—such as very low organic-matter maturation and properties of clay minerals—indicate that this sequence did not experience temperatures above 100 °C, and likely not above 50°C, since deposition (Kirsimäe et al., 2020). Optical petrography and backscatter-electron ("BSE") imaging reveal low-porosity, "BSE-bright" calcite spar cement in pore spaces between "BSE-dark" microporous calcite bioclasts. Trace-element mapping of several areas (several mm^2 each) in each thin section by LA-quadrupole-ICP-MS reveals variably elevated Mn/Sr, U concentration, and U/Pb in the calcite spar cement. The trace-element maps were subsequently used to guide the placement of laser spots for U-Pb dating by LA-multicollector-ICP-MS. Primary bioclastic calcite in both samples has low U/Pb ($^{238}U/^{206}Pb < 7$) and, thus, does not yield precise Concordia-intercept dates. One sample, however, yields an intercept date of ca. 450 Ma, consistent with the deposition age, albeit with a large uncertainty. Calcite spar cement has higher U/Pb ($^{238}U/^{206}Pb$ up to ~15.7) and including all analyses, yields intercept dates of ca. 420 Ma in each sample. Additionally, several of the domains with the highest U/Pb from each sample yield slightly younger dates of ca. 400–380 Ma. The timing of calcite (re)crystallization and cementation identified here overlaps with the Scandian (collisional) phase of the Caledonian orogeny. We interpret this to be a result of fluid flow in response to the collision at a relatively far-inboard position (i.e., far from the orogenic front).

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Identifying and constraining sedimentary recycling from microscopic fluid inclusions in quartz overgrowths

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Sedimentary basins that contain recycled sediments delivered from older and uplifted basins create important complications for source-to-sink relationships, provenance interpretations, burial history reconstructions and robust reservoir quality predictions in siliciclastic sedimentary basins. In this study, we integrate petrographic and cathodoluminescence microtextures with fluid inclusion thermometry in quartz overgrowths to identify sedimentary recycling and to constrain the potential provenance candidate for recycled grains in Lower Mesozoic sandstones of the western Barents Sea basin.

Four diagenetic imprints were recognized as proof of sediment recycling: i) microtextural surface properties of overgrowths, ii) the presence of overgrowths at sutured grain contacts, iii) reversed diagenetic sequences and iv) fluid inclusions within quartz overgrowths. The widespread distribution of these diagenetic imprints across the basin suggest that the recycled grains derived from a catchment area with regional-scale sediment dispersal potential during the latest part of the Triassic. Furthermore, the drainage basin must have contained consolidated sedimentary rocks. Homogenization temperature measurements from fluid inclusions in rounded quartz overgrowths suggests that the precursor sedimentary basin was subjected to burial temperatures exceeding 130°C, whereby the syntaxial quartz overgrowths precipitated. The recorded temperature indicates an uplift of around 3–4 km, which represents a significant tectonic event.

The geothermal signatures and geographically widespread distribution of recycled quartz exclude spatially restricted intrabasinal highs and higher-temperature crystalline rocks as provenance candidates for the recycled grain portion. Our data support the contemporaneous Novaya Zemlya Fold and Thrust Belt as the most likely provenance candidate in the region.

Recycled quartz grains are recognized globally from several stratigraphic intervals and geographic locations and can provide insight on their provenance as they retain direct temperature records. The integrated approach demonstrated in this study can be used to constrain sediment recycling and partly eroded provenance candidates in sedimentary basins worldwide.

An outburst-flood generated scour along lake Nugguren, SE Norway - not a landslide pit!

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A major glacial-lake outburst flood took place in the Glomma valley, south-eastern Norway, during the final decay of the Scandinavian Ice Sheet. Traces from the flood are commonly identified from giant-scale flood bars, erosional escarpments, and thick, coarse-grained deposits (Høgaas & Longva 2016). Flood basins with landforms in sand and mud also developed locally (Hansen et al. 2020). The entire range of landforms and deposits related to this extreme event is, however, not yet fully understood.

The present study focuses on a sand- and mud-dominated terrace-like area along the north-south trending Nugguren lake, that hosted an arm of the outburst flood. A scar with an outlet toward the lake dissects the terrace just south of a bedrock outcrop. The scar is >400 m wide and has a <10 m high edge no more than 300 m from the lake. The area is located below the marine limit and could potentially contain fjord-marine deposits. The scar-like feature could, at a first glimpse, thus be considered a landslide pit involving buried marine clays, implying a potential landslide hazard in the area. It is the aim of the present study to provide an up-to-date interpretation of the scar and of the terraced area within the framework of the glacial-lake outburst flood.

The area surrounding the scar is studied using LiDAR-derived shaded reliefs models, supplemented by field characterisation of surface materials. Geophysical profiling using ground penetrating radar (GPR) and electric resistivity tomography (ERT) was also carried out. A few GPR profiles were collected from land and onto a frozen lake.

The terrace along Nugguren lake was created during the evolving outburst flood. Buried, large-scale cross-bedded deposits accumulated early from an expanding flow. During rising flood levels, flow strength decreased but turbulence downstream of protruding bedrock hindered sedimentation and caused erosion helping the formation of a scar-like feature. Sediments accumulated primarily in lateral areas and a fine drape developed as the deep flow started to decline. No layers within the scar could with certainty be identified as landslide debris. Instead, well-organised, stratified deposits are present which supports the interpretation of a current-generated feature. Large-scale scours have been identified elsewhere in the area.

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Introducing the concept of detrital zircon age-spectra stratigraphy

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The last few decades, detrital zircon age-spectra distributions have become a conventional method for investigating the source of sediments and sedimentary rocks. Zircon is a proven indicator of provenance although the interpretability of detrital zircon age data have limitations. In our detailed detrital zircon study of the Middle to Late Triassic sandstones over an extensive area in the Barents Shelf, we recognised intra-formational zircon-age spectra variations related to stratigraphic position. Samples covering different stratigraphic levels within the Middle to Late Triassic Snadd and De Geerdalen formations in the Barents Shelf generated systematic differences in the zircon age spectra. Two age peaks at ~ 300 Ma and ~ 540 Ma dominate detrital zircon age spectra from the lowermost deposits, while the uppermost deposits are dominated by a 235 Ma age peak, and two minor age peaks at ~300 Ma and ~425 Ma. Between the stratigraphic lowermost and uppermost deposits, the age peaks change incrementally suggesting a gradual increase in the ~235 Ma and ~425 Ma age peaks, decrease in the ~300 Ma age peak and disappearance of the ~540 Ma age peak. The observed changes in detrital zircon age spectra with stratigraphic age is interpreted in terms of a gradual shift in zircon provenance generating a detrital zircon age-spectra stratigraphy. An implication of this work is a potential for detailed use of detrital zircon spectra as a valuable tool in intra-formational stratigraphic correlation and provenance studies.

Pre-salt Carboniferous basin architecture, structural inheritance and segmentation in the Nordkapp Basin, Barents Sea

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Reprocessed regional 2D seismic reflection profiles, 3D seismic data, available wells, and gravity and magnetic data were used to study the pre-salt rift architecture in the Nordkapp Basin, Barents Sea, and its impact on the evaporite accumulations and distribution of salt structures. The basin is subdivided into three main segments (the northeastern, central, and southwestern sub-basins) and has evolved over the complex interaction between the Timanian and Caledonian structural basement grains. Each segment is characterized by prominent magnetic anomalies related to the Timanian and Caledonian structural inheritance. The rotated magnetic lineations associated with the Caledonian structures beneath the Finnmark Platform pass through the central segment, where the Middle Allochthonous Front creates the major sub-division between the two structural grains. We suggest that the rheological properties, locations, orientations and interaction of the parts of the basement influenced by Timanian and Caledonian structural grains together with two subsequent extensional phases, have strongly influenced the shallower pre-salt rift architecture.

During the late Devonian – early Carboniferous NE-SW -oriented extensional phase, the Nordkapp Basin consisted of a northern and a southern regional half-graben separated by an elevated interbasin ridge. The hinged margins of the northern and southern regional half-grabens were restricted against the NW-SE-striking graben beneath the Veslekari Dome and Troms-Finnmark Fault Complex, respectively. The internal configuration of the regional half-grabens was affected by the NW-SE-striking master faults. During the late Carboniferous to early Permian, a second extension phase took place with a shift in stress orientation to NW -SE and influenced the two regional half-grabens. In particular, a transfer fault with the character of an inter-basin transfer zone (the northern transfer zone) divided the northern regional half-graben by separating its hinged margin (incipient northeastern segment) from the deeper part (incipient central segment). At the same time, the elevated interbasin ridge acted as a southern transfer zone, separating the incipient central and southwestern segments of the Nordkapp Basin. The Thor Iversen, Polstjerna, Måsøy and Nysleppen basin border fault systems were formed during the second extensional phase and reshaped the internal configuration of the two regional half-grabens.

The structural interaction between the spatially variable Timanian and Caledonian structural grains overprinted by two subsequent phases of NE-SW and NW-SE extension caused the development of seven sub-basins in the Nordkapp Basin. Internally within the sub-basins, the evolving structural elements including cross-cutting master faults and structural highs have influenced the deposition and facies of the layered evaporitic sequences and defined the location of subsequent salt structures. We suggest that the relative depth of each sub-basin, the arrangement of structural highs along with the evolving master faults and the depositional paleo-environment all controlled the thickness and facies of the syn-rift layered evaporitic sequences.

Salt tectonics in the Nordkapp Basin, Barents Sea – Interplay between sediment progradation and differential loading, syn-rift layered evaporitic sequences and pre-salt rift architecture

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The study utilised reprocessed regional 2D seismic reflection profiles, 3D seismic data, available wells and basin modelling to reveal the controlling factors for the supra-salt sedimentary evolution of the northeastern, central and southwestern segments of the Nordkapp Basin. The basin offers an excellent environment for the study of diverse supra-salt structural styles, including turtle structures, secondary squeezed and thrusted welds, collided mini-basins, bowl vs wedge geometries, salt wing and megaflap. The observed salt structures show different sizes, shapes, orientations and lateral extent that affect the late Permian to Cenozoic supra-salt sedimentation in the Nordkapp Basin.

Some remnant topography existed in the Nordkapp Basin in the earliest Triassic related to the underlying late Devonian to early Carboniferous (NE-SW) and late Carboniferous to early Permian (NW-SE) extension structures that overprinted on the contrasting Timanian and Caledonian basement structural grains. A regional prograding system arrived from the east causing differential loading and triggering of salt movements, which in turn created significant local topography with mini-basins surrounding the growing salt structures. The resulting basin topography strongly influenced the Triassic progradational sediment routings and dictated both where the initial deposition could take place and the formation of distinct depositional fairways. The depositional fairways primarily formed by differential loading and density-driven subsidence caused by the progradational sedimentation, and have restricted the subsidence in the mini-basins outside the fairways. Once the mobile salt was depleted from the layered evaporitic sequences (LES) beneath the axial zone then the salt structure was sourced from the depocenter opposite to it. The salt was evacuated from the LES diachronically along the strike of the basin as the earliest passive diapirism occurred in the northeastern segment and then progressed to the central segment due to the direction of progradation of the approaching deltaic system. We suggest that the direction and the velocity of the prograding system arriving from the east filled the initial depositional fairways over the syn-rift LES and the pre-salt rift architecture thus defined the sedimentary depositional architecture within the Nordkapp Basin.

The salt structures were slightly rejuvenated due to the reactivation of the Carboniferous structures caused by the far-field stresses propagating during late Triassic in response to the evolving Novaya Zemlya fold-and-thrust belt farther to the east. The salt was depleted from the LES by the early Cretaceous as the prograding shelf platform complex buried the salt structures. The main phase of rejuvenation of the salt structures took place during the early-middle Eocene as a result of the transpressional Eurekan/Spitsbergen orogeny farther to the northwest until the Cenozoic uplift eroded most of the post-middle Cretaceous sediments.

Titanite petrochronology in the Sveconorwegian Nisser detachment zone, Telemark, Norway

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Can titanite be used to constrain the timing of deformation within a crustal scale mylonite zone? We investigate the use of titanite as a petrochronometer to unravel the conditions and geochronology of deformation along the Nisser detachment zone (NDZ) within the Sveconorwegian orogenic domain. The NDZ is situated in Telemark, Norway, and is a >100 m wide, top-to-the SE mylonitic to cataclastic shear zone that juxtaposes the Nissedal supracrustal complex against the underlying Vråvatn granitic gneiss complex to the north.

Titanite is known for a closure temperature for the U-Pb system approaching 700 °C, and it is a reactive mineral at medium to high grade metamorphic conditions. U-Pb ages in Titanite has the potential to yield temporal evolution of deformation and metamorphism. To evaluate the meaning of the obtained age, analysis of the spatial context of titanite, its composition and zoning pattern is required.

Investigations were undertaken on in-situ titanites in thin sections, from four samples representing little, medium and strongly mylonitic rocks, as well as one cataclasite sample. Selected titanite crystals were characterized and analysed by optical microscopy, Backscatter Electron microscopy (BSE), Electron Probe Micro Analyzer (EPMA), Electron Backscatter Diffraction microscopy (EBSD) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

The BSE and EPMA analyses suggest multiple generations of titanite. All grains show a strong BSE zoning correlating with a change in trace element composition (mainly F, Fe and Al). High strain rocks have a wider range in chemical composition than the less deformed rocks, indicating a change in crystallization environment. All titanites have zirconium content below the detection limit of the EPMA (c. 80 ppm), suggesting

crystallization temperatures, according to the Zr-in-titanite geothermometer, below c. 700°C. EBSD analysis reveals deformation twinning in titanites, also in the least deformed sample. LA-ICP-MS analyses are currently underway to constrain the age of the different zones detected in titanite crystals.
Our results show potential for the use of titanite petrochronology in unravelling the temporal evolution of shear zones. At a regional scale, the understanding of the tectonic evolution of the NDZ is important to characterize the ductile extensional evolution and crustal collapse of the Sveconorwegian orogen.

Value assessment of the Iddefjord granite resource

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Throughout Europe, there are large industrial and cultural landscapes originating from the exploitation of ornamental stone through history. Such landscapes may contain a range of potential values; as cultural and industrial heritage, as areas for recreation and tourism, as geological heritage, and as areas for future exploitation of stone. The Iddefjord granite, SE Norway, has been exploited since the middle ages, but the main phase came with the industrial revolution. During the last half of the 19th Century, the granite industry here grew to a considerable size, culminating around the turn of the century when more than 5000 people worked in the quarries, producing paving and building stone. At present time, only one active natural stone quarry remains, but the quality of the granite should encourage further future developments.
The study summarizes the geology and evolution of quarrying and quarry technology and provides a characterization of the quarry landscape: its resources that can provide economic values for the future and the anthropogenic morphology of the landscape created by exploitation through history. From the characterization, we propose a scheme for value assessment of the Iddefjord natural stone resource. In particular, we focus the non-economic values. For instance, the importance of the Iddefjord granite as a historic marker in world architecture may provide significant arguments for future designation of exploitation areas.
This case study is a part of the Eurolithos Project, aimed at harmonizing and visualizing information about natural stone resources in Europe.

Geologi i det økologiske grunnkartet

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Naturmangfoldets viktige rolle for en bærekraftig fremtid er klart og sterkt dokumentert gjennom forskning, likeså at dette mangfoldet står i fare for å bli dramatisk redusert. Derfor er det av stor betydning å introdusere bedre og mer helhetlig forvaltning av naturen, som også inkluderer geologien. «Natur for Livet», norsk handlingsplan for naturmangfold, kom i desember 2015. En viktig del av oppfølgning av denne handlingsplanen var å etablere «Det Økologiske Grunnkartet», administrert av Miljødirektoratet. Økologisk grunnkart er ikke ett kart, men en samling av ulike kartlag som gir kunnskap om hvor naturtyper, arter og landskapstyper finnes. Dette gir oss et viktig kunnskapsgrunnlag for å forvalte arealene i Norge.
Blant kartlagene i det økologiske grunnkartet finnes både «typiske» NGU-kart, slik som berggrunn og løsmasser, men også kart som er skreddersydd til portalen, som for eksempel tematiske maringeologiske kart. I denne presentasjonen vil vi sette søkelys på to kartlag som er avledet fra berggrunnskart, nemlig kalkinnhold i berggrunn og ultramafiske bergarter. Begge disse kartlagene har stor nytteverdi i forhold til kartlegging av biologisk mangfold. Kalkinnhold er en viktig økologisk gradient, og bergarter er gruppert i fem klasser fra svært kalkfattig til kalkmark. Empiriske data fra økologisk kartlegging og geokjemiske analyser er benyttet for å etablere de fem klassene. Ultramafisk berggrunn kan ikke beskrives som en gradient, men som berggrunn med avvikende kjemisk sammensetning (høy Mg og Fe). Dette gir grobunn til særegne naturtyper, som for eksempel «olivinskog».
Kartlagene er publisert som første versjon. De vil bli videreutviklet og forbedret etter hvert i nye versjoner. Samtidig er flere økologiske grunnkart i utvikling på NGU, som for eksempel grotter og karst, landformer og andre, geokjemiske berggrunnstema.

Coastal changes 21st century – a geologist's perspective

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Coasts and coastal lowlands are attractive regions for humans providing settlement, and are of great societal, economical and agriculture value. Nearly 40% of the world's population, 2.4 billion people, live within 100 km of the coast and nearly 1 billion people live below the high tide line including an estimated 250 million people who are at risk to annual projected flood levels. In Europe alone, yearly damages are estimated to 6 billion € and 2 million people could be exposed to coastal flooding each year by the end of this century, given a high emission scenario.
Predicting future coastal changes requires interdisciplinary collaboration between geologists, climate modelers, physical oceanographers, coastal engineers, meteorologists, statisticians, computer scientists, and geomatics and remote sensing expertise. To date, much research is focused on future sea-level changes and extreme sea-level events (storm- and tidal surges) and their socio-economic impact. However, to fully assess future risks along coasts requires not only an understanding of sea

level rise; all factors influential on changing coastline morphology must be considered.
Coastal changes are the response to aggregated earth science processes governed by both anthropogenic and natural drivers, including average sea-level changes and extreme sea-level events, vertical land movements, sediment supply and sediment distribution. The combined expertise in fields like geodynamics, source-to-sink, sedimentology and geomorphology can provide a substantial contribution to our understanding and prediction of future coastal change.
In this talk we will give a few examples of how these interacting processes are fundamental for understanding future coastal changes and risk scenarios and argue for why the contribution from the geoscience community is extremely important and yet under-communicated for one of the largest challenges of our society.

Structural controls on carbonate deposits in Nordland: 3D modelling and visualisation

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Recent regional scale mapping and carbonate dating of the extensive carbonate deposits around Rognan, Nordland (Gjelle et al., 2013) reveals a complex tectonic picture with NS striking tectonic packages with a wide range of carbonate ages (Melezhik et al., 2013). Korneliussen et al. (2019) studied the detailed chemical variation in a grey carbonate interval of the Nestbylia carbonate deposit south of Rognan with the purpose of determining its economic potential. This zones trends NS in a several hundred metre wide band just to the west of the town of Rognan, south of Bodø. We present a detailed and integrated field structural analysis combined with chemical analyses and 3D modelling to determine the geometry and volumes within the carbonate. An area was determined within this carbonate interval which was well suited to possible future mining activity. A polygon was created here in which was defined an Area of Investigation (AOI). With a potential open pit mining depth to 200m, giving a volume of approximately 375 million m^3 and an estimated 1.01 billion tonnes. Detailed structural mapping was carried out in the AOI which reveals that the carbonate is internally complexly and isoclinally folded. The folds were subsequently attenuated, segmented and displaced along axial planar shear zones. Furthermore, low-angle thrust planes displaced the carbonate from west to east. In addition, the carbonate was dissected by east-west striking normal faults. The complex tectonic evolution necessitates a compartmentalisation of the simple volume defined by the AOI and a subsequent complex progression in the geological 3D modelling. Based on the above geological constraints we have created 10 separate volumes from the AOI. Integration of these volumes with the chemical analysis allows the creation of distinct and complex geometric/geochemical volumes and demonstrates that only 4 of these 10 volumes have Fe+Mn less than 250ppm (Korneliussen, 2019) which is a measure of the quality of suitable raw materials for high whiteness industrial carbonate products. In addition, it is observed that the overall quality of these volumes is better in the northern part of the AOI than in the southern part. These high-quality volumes have a combined volume of 234 million m^3 equating to approximately 631 million tonnes of high-quality carbonate. This study demonstrates that determining how the structural geology and tectonics, that both creates and attenuates the deposit geometry, is vital to the understanding of complex carbonate deposits and their management.
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Study of the controlling factors for run-out length of “steinskred” and test existing software packages for usefulness for “steinskred”

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“Steinskred” (rock slope collapses smaller than those resulting in rock avalanches, but larger than individual rock falls) is a known hazard in Norway. There is still a lack of experience and methodology for handling these types of events in hazard zone assessments. The controlling factors for the run-out length are difficult to define as modelling software’s that fit the volumes of “steinskred”, are in contrast to equivalents for rock fall and rock avalanches not yet developed. A “steinskred” can cause high economical and personal losses if it interacts with houses or other infrastructure as showcased by the Modalen event, in 1953. This “steinskred” destroyed a house far beyond the limit where rock fall blocks accumulated earlier. Luckily,

people could just escape the event as it occurred during daytime.
The aim of the study is to find controlling factors for run -out length of "steinskred", by compiling a large data set of historic and prehistoric "steinskred" events in western part of the county Vestland in Norway (earlier called Hordaland) and study the relations between geomorphic environment, substrate in the run-out zone and the relation to volume. Furthermore, individual events will be back analyzed with various software packages for rock avalanches and rock falls to test the usefulness for "steinskred". The inventory mapping of "steinskred" deposits based on hill shade derived from aerial laser scanning, bathymetric data and aerial photos is almost completed and contains so far 140 deposits. The data will be combined with data collected in an earlier master thesis (Velardi et al. 2020) and will become part of a geological landslide data base at NGU.
In particularly, substrate, roughness and tree density of four historic "steinskred" have been mapped in the field. The volume assessments are not yet performed. The Modalen event, 1953, is of special interest. In an early publication (Kolderup, 1954) it was reported that the deposited volume was multiple times larger than the failed volume, and the deposits reached further out of the slope than the frequent rock fall events. Based on field observations a ca. three meter thick layer from the scree deposit covering the lower slope was eroded from the slope and entrained into the flow like landslide.
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The brittle architecture of the Sognefjord-Nordfjord area, Western Norway: fault mineralizations, paleo-stress analysis, K-Ar fault dating, and (U-Th)/He thermochronology

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Regional studies of the brittle bedrock architecture, combined with geochronological methods, can give us important insights into landscape-forming processes. The Sognefjord-Nordfjord area, one of the most iconic landscapes in Norway, is situated between the Nordfjord -Sogn Detachment Zone to the west, the Lærdal-Gjende fault to the south-east, and the Møre-Trøndelag Fault Complex to the north. In this study, we investigate the brittle bedrock architecture between these major faults in more detail by combining field observations, paleo-stress analyses, K-Ar fault gauge dating, thermo-chronology, and paleosurface analysis to understand the major landscape-forming elements. Based on fault- and fracture-trends derived from lineament analysis and structural field measurements, we divided the study area into seven subareas. The faults and fractures were grouped based on the fault rock type and observed fracture mineralization; gouge, cataclasite, epidote/ chlorite/quartz, zeolite, zeolite + epidote/chlorite/quartz, stretched host rock/mica, hematite, calcite, or a combination of several mineralization groups. Field data show that fault- and fracture systems in the region are dominated by epidote/chlorite/quartz and zeolite mineralizations; steep fractures striking from NW-SE to N-S to NE-SW; striations with varying trends but often a shallow plunge; strike-slip, oblique-slip, and normal kinematic indicators. Preliminary paleo-stress analysis of subareas displays a dominating extensional NW-SE trending stress field in the southern part of the area, an E -W transpressional stress field along the Nordfjord, and a NE-SW transpressional stress field north of Nordfjord. Six K-Ar fault gouge samples from NE-SW and N-S trending faults were dated with five grain-size fractions from each sample (6-10 μm, 2-6 μm, 0.4-2 μm, 0.1-0.4 μm, <0.1μm). The single grain size fractions show a spread in ages from the Triassic to the Cretaceous. Preliminary calcite U-Pb analyses show late Cretaceous ages. Samples for thermochronological analysis were collected as horizontal transects from N to S and from E to W, and as a vertical profile at mount Skåla in inner Nordfjord. Eighteen apatite (U-Th)/He samples give single grain ages ranging from ca. 280 Ma to 60 Ma. Apatite fission track analysis on 31 samples is work in progress, and time-temperature modeling of vertical and horizontal transects as well as paleosurface analysis will complement our data set.

Collector & field maps for ArcGIS: using web maps for data collection on the field

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In 2020, the department for Construction Material of the Geological Survey of Norway (NGU) started to use the application "Collector" for ArcGIS from ESRI, to collect data in the field. Since all NGU employees can have access to an ESRI ArcGIS license, it was natural to explore the possibility offered by the software which was tested successfully during the field season of summer 2019. Since then, Field Maps for ArcGIS has been released. This new application is similar in design to ArcGIS Collector, but it does have an extended range of functionalities. Both Collector and Field Maps are cloud-based, data collection system with offline and multi-users capabilities. Both applications are available on iOS and Android but only Collector is currently supported on Windows 10.
Collector and Field Maps can be described as "template readers", which function in tandem with ArcGIS Pro and ArcGIS Online servers. Templates are created in ArcGIS Pro and uploaded to ArcGIS Online. Collector and Field Maps interact with the server to read and edit these templates referred to as Web Map. Editing of a Web Map can be done offline, and from several persons

at once. Collected data are synchronized in ArcGIS Online and the resulting dataset can be directly opened in ArcGIS Pro. The result is a seamless workflow between an ArcGIS Pro project, data collection on the field and data export back to ArcGIS.
In this presentation I will go through the process of creating a Web Map. I will present the programs functionalities and propose a workable workflow for post-fieldwork data processing. The presentation will be illustrated by several projects of last year's field season. To conclude the session, I will discuss each software's strengths and limitations.

Structural characterization of the Aurora prospect, a potential CO_2 storage site in the northern North Sea

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Carbon Capture and Storage (CCS) is a key technology to mitigate climate change. Norway, as a forerunner on this technology, is planning full-scale CCS operations by 2024, and the industry-led Northern Lights project (Equinor, Total and Shell) is evaluating the Aurora EL001 license as a potential CO_2 storage site. Contributing to this evaluation, we perform a structural characterization of the Aurora prospect that will help ensure effective storage of CO_2.
In the Aurora prospect, sandstones of the Early Jurassic Johansen and Cook formations are envisaged as potential storage intervals. The Johansen Formation, buried at 2 – 3 km below MSL, is either conformably overlain by Amundsen Formation mudstones or unconformably by the Cook Formation. Thus, both sandstone formations are considered the bulk storage unit, with the overlying Drake Formation mudstones serving as the regional caprock. The Aurora prospect is located between two large-scale structural features, the Tusse Fault Zone to the east and the Svartalv Fault Zone to the west. Segments of these fault zones strike mainly N – S, dip towards the west, have max throw between 125 – 500 ms TWT and displace units from the basement to the Cenozoic. Between these fault zones, a second population of several (n = 50) smaller-scale N – S and NW – SE-striking intra-block faults displace the storage and caprock units. These faults have no preferential dip direction, average trace length of 3 km, max throw between 5 – 58 ms TWT and are largely restricted to the Upper Triassic to Lower Cretaceous successions.
To assess these structural features, seismic interpretation of key horizons and faults are performed to develop a high-resolution 3D geomodel. The geomodel is then utilized to define the structure and thickness of reservoir and caprock formations, as well as to conduct characterizations of the faults displacing them. We find that 1) structural maps of the target units indicate that CO_2 will migrate northwest from the injection well (31/5-7); 2) three triangular shaped two-way closures, where smaller-scale faults intersect the Svartalv Fault Zone, are identified 9.3, 11.3 and 13.7 km northwest of the well potentially trapping CO_2 column heights of 23, 22 and 69 ms TWT respectively; and 3) the northernmost closure juxtaposes parts of the reservoir in the footwall with Brent Group sands in the hanging wall providing possible across-fault migration routes. However, high shale content within the fault zone could prevent this migration. Therefore, further ambitions include thorough juxtaposition analysis of key faults and calculations of Shale Gouge Ratio.

Dental morphological disparity among marine reptiles from the Early Triassic of Svalbard – When Life didn't Bite the Dust

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The Permian–Triassic mass extinction (PTME) resulted in up to 96 % of all marine species to become extinct. Different reptilian groups seized this opportunity to move into the marine realm, occupying empty niches and became the dominant tetrapods in the Mesozoic oceans. The early recovery of the marine ecosystems after the PTME and the accompanying early evolution of marine reptiles is documented in the Lower Triassic rocks of the Vikinghøgda Formation of Svalbard. Extensive research has been made to uncover the ecology in these parts of the Triassic Boreal Sea.
Recent studies have incorporated tooth morphology of marine tetrapods to examine the ecosystems of the Mesozoic oceans. Up until now, this has not been done for the Lower Triassic material found on Svalbard. In this study, reptilian teeth from the Lower Triassic *Grippia* bone bed of the Vikinghøgda Formation are further examined. The study provides information on niche-partitioning among early marine reptiles and gives a better understanding of the complexity of the marine ecosystems in these early recovery stages after the PTME. CT-scanning, morphometry and multivariate analyses of the teeth are used to identify different morphotypes and plot the teeth in a morphospace. This provides an estimate of the dental morphological disparity among early marine reptiles and allows identification of different feeding guilds and possible trophic levels present.
Preliminary results show that the studied tooth assemblage contains multiple morphotypes, representing different feeding guilds. This includes both fish, amphibian, and reptilian teeth, which can be difficult to discern from each other without histological examination of the teeth. The reptilian teeth mainly represent morphotypes belonging to the smash, crunch, and crush feeding guilds. The occurrence of different tooth morphotypes shows that the Early Triassic marine reptiles of the Boreal Sea had already started adapting to multiple feeding strategies. This supports recent studies suggesting that the ecological recovery after the PTME happened relatively quickly and attained a certain level of complexity early on.

Deciphering the structural and metamorphic history of the Balsfjord Series in the Scandinavian Caledonides of northern Norway

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The Balsfjord Series is located in northern Troms–Finnmark, Norway, and is part of the uppermost allochthon of the Norwegian Caledonides. The Balsfjord Series belongs to a nappe stack (from top to bottom: Tromsø Nappe, Nakkedal Nappe, Balsfjord Series and Lyngen Nappe) that resulted from the Caledonian collision between Laurentia and Baltica. The Tromsø Nappe represents an ultra-high pressure unit containing eclogites, and is underlain by the Nakkedal Nappe that appears as a high temperature crustal slice throughout the investigated area. Finally, the Balsfjord Series on top of the Lyngen Magmatic Complex (LMC) exhibits a gradual change in metamorphism, ranging from very low grade in the SE to medium grade in the W.
First results show that the Balsfjord Series typically presents a flat lying metamorphic foliation (<30°) that becomes folded in tight as well as open folds. Going from W to E towards the LMC, these open folds show gradually steeper fold axial planes with vertical fold axial cleavages striking N. The gently plunging stretching lineation (<10°) does not remain in the same orientation throughout the extent of the Balsfjord Series, but continuously changes from a NW–SE direction in the NW to approximately E–W in the SE. The Balsfjord Series features two discernible fold phases. The earlier phase displays tight to isoclinal folds with flat lying axial planes parallel to the respective foliation. Observed fold axes are parallel with the stretching lineation and follow the same trend. These folds are best preserved in the NW–W and syn-metamorphic in certain areas. The later folding phase is represented by mainly open folds with inclined to steep axial surfaces. Their fold axes are again gently plunging with a predominant NE–SW orientation. This younger folding appears at about halfway between the W and E limit of the Balsfjord Series and becomes gradually more dominant towards SE. Fieldwork has frequently shown that these secondary folds are overprinting the earlier phase of folding. In the SE, their axial planes are inclined, whereas in the NE they can become subvertical and accompanied by a well-developed cleavage. The fold axes in the east are approximately parallel to the N–S striking interface between the Balsfjord Series and the LMC.
We interpret these two fold-events to be genetically related but slightly diachronous. The earlier folding phase with flat axial planes was likely generated during nappe thrusting and metamorphism of the Balsfjord Series. The open folding phase with inclined to steep axial surfaces is explained as a result of shortening of the softer, metapelitic Balsfjord Series against the rigid gabbro of the LMC during the late stages of the Caledonian nappe thrusting. The axial plane dip angle of the later folds depends on the orientation of the interface between these two units, which acted as a major rheological boundary.

Palaeolakes and outburst floods in south-central Norway

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Mapping of shoreline features in south-central Norway using high-resolution LiDAR data, has led to the reconstruction of several early Holocene ice-dammed lakes. In this talk we report on the extent and volumes of well-known (e.g. Nedre Glomsjø) and partly undescribed palaeolakes in Østerdalen, in addition to a new mapping of Store Dølasjø in Gudbrandsdalen farther west.
Perched delta-features with topset and foreset units found in connection to the undescribed lower-lying levels in Østerdalen, suggest the palaeolakes existed for a prolonged period and that the lakes spilled across stable, bedrock thresholds. As we find no traces of corresponding levels in the neighbouring valley Rendalen, we propose that the drainage occurred across Jutulhogget and hence infer a multi-phased early Holocene development of the canyon.
We also report traces of an undescribed glacial lake outburst flood in Østerdalen, indicating a sudden southward emptying of the lowermost (510 m asl - Jutulhoggsjøen) palaeolake level. The landform record related to the outburst flood consist of high-water marks, palaeochannels, and flood bars, as well as obstacle mark features considered diagnostic for glacier outburst floods. At the time, the remnant ice sheet was c. 25 km across and we believe this event signals the final demise of a coherent ice sheet in this region, and, thus, the origin of the present-day river Glomma.

The Ersfjord Granite (1.79 Ga) in West Troms: A result of anatexis in a Late-Svecofennian accretionary thrust system

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The Ersfjord Granite is a 1.79 Ga intrusion in the geological region of West Troms Basement Complex in northern Norway. Its genesis and evolution relative to surrounding Neoarchean tonalitic, trondhjemitic and granodioritic (TTG-) gneisses has previously been poorly understood. This work resolves the Ersfjord Granite to represent several sheet-like intrusions, possibly formed by anatexis of Neoarchean TTG-gneisses at high-grade conditions, rather than a single

plutonic body. Ascent and emplacement of the granitic melts occurred during the late stages of the Svecofennian accretionary orogeny. Through study of magmatic and tectonic fabrics within the granite and in the surrounding TTG-gneisses, we propose the following tectono-magmatic model: (i) The granite intruded as sill-like, tabular sheets and/or formed in situ by partial melting of Neoarchean mid-crustal lithosphere at 1.79 Ga. Nonmelted mafic residuum remained in sheet-parallel migmatite zones. (ii) During or shortly after the intrusion of the granite, WNW-directed crustal compression (the D1-event) formed an imbricate thrust stack with internal mylonitic shear zones. New melt formed simultaneously, using the pre-existing foliation in the migmatitic gneisses as melt pathways. (iii) Later, the Ersfjord Granite sheets and associated internal structures were folded into NW-SE trending upright macrofolds (the D2-event). Steep, granitic pegmatite dykes injected parallel to the axial surface of the D2-folds, both in the Ersfjord Granite and the surrounding lithologies. (iv) Transpression (the D3-event) formed steep, ductile shear zones and subvertical folds. During a final melting, the transpression emplaced granite pegmatite dykes at low metamorphic conditions parallel to the subvertical D3-folds and along the associated shear zones. We suggest, then, that the Ersfjord Granite sheets intruded into the Neoarchean crust in an accretionary arc system by anatexis and mixing of crustal components. This interpretation has wide impact for the general understanding of ca. 1.8 Ga plutonism and Late-Svecofennian accretionary tectonism in the Fennoscandian Shield.

Can relict landscapes shine though the glacial hammer? Geomorphology of three half-grabens in Norway and Svalbard

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Tectonic controls on landscape evolution are well documented globally. In actively extending areas, tectonic geomorphology is typically represented by uplifted footwalls, downthrown hanging walls, distinct bounding escarpments, and characteristic drainage patterns.
In onshore parts of the NE Atlantic margin, several studies suggest that some present-day landforms are inherited from rifting and margin formation in the Late Paleozoic, Mesozoic and Early Cenozoic. Such inheritance can be difficult to recognize because much of the pre-existing landscapes are obscured by post-rift Cenozoic uplift and repeated glaciations during the Quaternary. Interpretations of these landscapes vary considerably; from preservation of vast Mesozoic erosion surfaces, to present-day landforms being Quaternary in origin with little pre-Quaternary inheritance. However, some remnants of Late Paleozoic and Mesozoic rifting are preserved directly inboard of the NE Atlantic margin.
In this study we use structural and geomorphological field observations and DTM (Digital Terrain Model) analyses to investigate three half-graben basins. Detailed landscape classification and analysis is used to systematically review present-day landscape distribution and bounding faults in and around the basins, in order to distinguish extensional tectonic landforms from the other geomorphological features. The half-grabens considered in this study are the Billefjorden half-graben of Carboniferous age on Spitsbergen, Svalbard; the Jurassic Sortlandsundet half-graben in Vesterålen, northern Norway; and the Jurassic Beitstadfjorden half-graben in Trøndelag, mainland Norway.
Preliminary results reveal major topographic contrasts between footwall and hanging wall in all three half-grabens, meaning among other things higher topographical elevations and deeper incision in the footwalls compared to the hanging walls. Additionally, the three study areas have very distinct landscape signatures, suggesting a difference in the post-rift landscape evolution. These differences seem to be dependent on a number of factors including unique post-rift erosion events, erosional exploitation of pre-rift structures, possible late-Cretaceous or younger reactivation of normal faults, and degree of glacial incision. This study will provide insight into the relationships between inherited, tectonically controlled landforms, and incising Cenozoic and Quaternary landforms.

Tectonostratigraphy in northern Gudbrandsdalen and implications for the regional tectonostratigraphy and tectonic evolution of the Scandinavian Caledonides, Norway

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In the Scandinavian Caledonides, the tectonic units are commonly correlated along strike of the orogen within four allochthonous levels, i.e., lower, middle, upper, uppermost allochthon. In southern Norway, the middle allochthon is dominated by nappes largely composed of Baltican-type orthogneisses, including the Lindås and Jotun nappe complexes, which in the west and southwest are structurally overlain by ophiolite and volcanic arc assemblages of the upper allochthon. In central Norway, similar ophiolite and volcanic arc assemblages of the upper allochthon have also been mapped, but there the large nappes composed of Baltican-type orthogneisses do not occur.
The Lindås and Jotun nappe complexes in the southern segment as well as the upper allochthon in the central segment are all structurally underlain by Alpine-type metaperidotite-bearing units. Commonly, the tectonostratigraphic level of these metaperidotite-bearing units is inferred from the presumed tectonostratigraphic position of the unit structurally overlying it. For this reason, the metaperidotite bearing

units have been locally included either into the lower, middle or upper allochthon.
In northern Gudbrandsdalen, metaperidotite-bearing unit assigned to the lower and upper allochthon are juxtaposed with each other. The juxtaposition of the upper with the lower allochthon implies complex tectonic movements in the region, e.g. large-scale late to post-Scandian normal displacements of the upper allochthon, for which there is no evidence in the field. Moreover, there is no change along strike of the metaperidotite-bearing units in metamorphic grade, metasomatic history or the whole-rock geochemical composition of the metaperidotite bodies that may indicate a different genetic and tectonic history of the metaperidotite-bearing units in the southern and central segments.
The geochemical data from the metaperidotite-bearing unit together with the structural geology in northern Gudbrandsdalen show that the metaperidotite-bearing unit can be traced from the southern into the central segment of the Scandinavian Caledonides. The revision of the tectonostratigraphy in northern Gudbrandsdalen greatly simplifies the structural interpretations of the region but is difficult to reconcile with the four-fold allochthon scheme. The continuation of the metaperidotite-bearing unit from the southern into the central segment suggests that the metaperidotite-bearing unit and the Baltican-type tectonic units structurally above occupy each an extra tectonostratigraphic level.

Multiscale synchrotron X-ray microtomography imaging of organic material in shales in the context of primary migration

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Norwegian offshore oil and gas exploration has identified two main sedimentary units where hydrocarbons were produced before migrating to reservoirs. The first is the Upper Jurassic organic-rich Draupne shale located in the Norwegian North Sea, while the second is the geologically equivalent Hekkingen shale of the Barents Sea. While, the Hekkingen shale has undergone significant uplift the Draupne formation in the North Sea has seen relatively little. This difference provides for an interesting opportunity to compare two shales similar in deposition with vastly different diagenetic histories.
Using fourteen exploration wells (five in the Barents Sea and nine in the North Sea), geochemical crossplots helped ascertain that kerogen is predominantly Type II. In our study area Hekkingen shale shows a greater range of TOC (2 – 20%) when compared with the Draupne Shale (2 – 10%). Finally, it is clear that due to greater historical depth and subsequent uplift the Hekkingen shale has undergone greater maturation despite being shallower today. We collected shale samples from depth in two boreholes and characterized their microstructure in 2D and 3D. Synchrotron 3D microtomography images at two sampling resolution (0.65 and 6.5 micrometers) were acquired on beamline ID19 at the European Synchrotron Radiation Facility. In addition, scanning electron microscopy images were acquired. These unique data are paramount to understand the fabric of the shale and kerogen within it, as well as to analyze the relationship between fractures and kerogen lenses. Higher levels of TOC are clearly present in the Hekkingen shale samples, mimicking the macro- results. Kerogen lenses are characterized in 3D in terms of volume, shape, and anisotropy. Results show that kerogen lenses, like the fabric it is a part of, shows anisotropy when any one axis is compared to another. Anisotropy, as a result of all three axis, is born out by an analysis of the common kerogen lens shapes. Distribution of kerogen lenses is also variable in the samples, with both a dominant and secondary axis. Finally, by looking at the shale at two different resolutions that crossover in terms of kerogen size, one is able to see two distinct normalized slopes (PDF) relating to the volume of the kerogen lenses.

Analogue modelling of primary migration in shales using organic-rich and organic-poor layered gel

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While only 8% of the total volume of the crust is estimated to be sedimentary, 73% of the Earth's current land surface consists of it. Of that 73% sedimentary rock, a total of 70% is estimated to be shale suggesting 51% of the world's land surface consists of shale. Shale, while not always organic-rich (>2%), predominantly has some organic content (~1 - 5%). Therefore, understanding the nature of how fracture creation is, or in some cases not, driven by kerogen content and its maturation state is critical to a number of energy and construction industries (e.g. geothermal, oil/gas, storage of nuclear waste, and groundwater seals).
Tensile failure (Mode I) within shale is driven by increased temperature and/or pressure applied to the organic content (kerogen). Similar to the fabric of the rock that contains it, distribution of kerogen lenses are anisotropic in nature. This anisotropy of kerogen distribution holds for both the macro- and micro- scale, and mimic one another in said placement. Total amount of organic material within the shale and the degree to which it has undergone higher temperatures and pressures drives the geomechanical state of the rock. Understanding this can be important when considering oil/gas plays with shale as a source rock and/or

reservoir. The degree to which kerogen pushes a section of shale to act as a seal, or not, as a whole regardless of how ductile or brittle an individual layer can be modeled utilizing analogue experiments. Understanding seal competence is critical for geothermal energy, storage of nuclear waste, and groundwater management.
Analogue modelling provides an opportunity to understand how variably emplaced organic material will influence the total competence of a section of rock. Our study utilizes interlayering of gelatin that has been deemed either organic-rich or organic-poor in nature. The organic-rich layers contain a mixture of sugar and yeast, creating CO_2 to create tensile failure in the gelatin. This analogue experimental system models the reaction of hydrocarbon production within kerogen lenses that may lead to fluid expulsion and fracturing of the surrounding shale. The organic-poor layers only contain gelatin. The two mixtures are interlayered in a Hele-Shaw cell representing a 2D plane of shale in-situ. By varying the sugar-to -yeast ratio one can alter the amount of organic material represented within a layer. Taken all together, the amount of organic material required to crack through shale that would otherwise act as a seal can be modelled.

Constraining the climatic impacts of the NAIP magmatism with upcoming ICDP and IODP drilling

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The North Atlantic Igneous Province (NAIP) was a large (5–10 million km^3 magma) large igneous province that coincided with both the opening of the northeast Atlantic Ocean and the greenhouse conditions of the early Paleogene. These close temporal correlations suggest a possible causal relationship between the NAIP and both the climatic and tectonic changes around 56–54 Ma. In particular, the main acme of NAIP activity occurred across the Paleocene–Eocene Thermal Maximum (PETM), an extreme hyperthermal event that represents the warmest conditions of the last 60 million years. The NAIP is among several proposed candidates for driving global warming through CO_2/CH_4 emissions, both by magmatic degassing and through contact metamorphism around shallow intrusions in organic-rich sedimentary basins. What is needed to refine the role of the NAIP during the PETM are key sedimentary sequences that contain abundant volcanic and climatic proxies in the same section, thereby allowing a precise geochronology of events to be attained.
To address this knowledge gap, two scientific drilling programmes have been initiated to core key localities proximal to the NAIP. The primary drilling programme is the International Continental Scientific Drilling Program (ICDP) project PVOLC in Limfjorden, northwest Denmark. The sediments exposed on Fur Island are a key sequence of PETM and post-PETM strata with little thermal overprint and hundreds of well-preserved volcanic ash layers from the NAIP. The effects of Quaternary glaciotectonism have disturbed this key stratigraphic interval at Fur, but seismic surveys indicate that undisturbed strata are found a few km to the south. The ICDP PVOLC project is scheduled for summer 2022, and has the potential to drill to the Cretaceous-Paleocene boundary if additional funds are found. The secondary expedition is the International Ocean Discovery Program (IODP) leg 396 to drill the outer Møre and Vøring Basins (offshore Norway) in August to September 2021. Two of the scientific drilling aims of this cruise are to core Paleogene sequences across the PETM and to drill one of the thousands of hydrothermal vent complexes to attain a proximal record of NAIP activity. This will give vital information on the proximal environmental disturbances during the NAIP emplacement.

Reservoir characterization of Jurassic sandstones in the SW Barents Sea

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This study focuses on the Jurassic Stø Formation sandstone's reservoir characterization by utilizing petrophysical and rock physical analysis. The study area is located in the Hammerfest Basin, SW Barents Sea, and bounded by Loppa High in the north and Bjarmeland Platform in the north-east. The Stø Formation reservoir sandstone was deposited in a prograding coastal regime and primarily consisted of moderately well-sorted sands and thin shale and siltstone units. The area has experienced several uplift, erosion, and subsidence stages, which changed reservoir rock properties. An estimation of exhumation was calculated to evaluate the diagenetic influence based on comparing published Vp-depth trends with the velocity data from wells 7122/2-1 and 7122/6-1 (Fig. 2). Moreover, the velocity versus density rock physics template was used to evaluate the qualitative reservoir properties. The studied wells are approximately 36 km apart, and the present-day top of Stø Formation is 2068 m in well 7122/2-1 and 2015 m in well 7122/6-1. The exhumation study reveals that well 7122/2-1 was uplifted by 1500 meters, and well 7122/6-1 was uplifted by 1000 meters. Hence, Stø formation experienced chemical compaction in both wells. The velocity versus density cross-plots demonstrated that both wells have the same density range but a more significant velocity difference. Gamma ray values for the same plot indicated differences in rock compositions. The data points with higher velocity have been overconsolidated and influenced by chemical compaction.
Stø Formation in well 7122/2-1 is situated between depths 2068-2120m and is 52 meters thick. The

formation possesses good reservoir qualities. The shaliness of the formation varies between 7-61%, with a mean value of 23%. The average porosity is 12.8%, and the net-to-gross ratio equals to 84%. However, the well is dry. In well 7122/6-1, Stø formation is located between depths 2015-2038m and is 23 meters thick. The volume of shale in the formation varies between 0-35%, with a mean value of 6.6%. The average porosity is 16.2%, and the net-to-gross ratio equals to 95.4%. 1.5-meter oil zone is encountered at the top of the formation (NPD), and the rest of the formation is water-bearing. The variation of the reservoir properties of the Stø Formation properties in the studied wells might be due to the depositional environments that influence the grain size and sorting, resulting in the different degrees of compactions in both wells.

Bridge under troubled magma: Field observations from San Rafael Swell, Utah

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Igneous intrusions, such as dikes, sills and laccoliths, are important components of volcanic plumbing systems in extensional tectonic settings, e.g. rifted margins and sedimentary basins (Hutton, 2009; Jerram and Bryan, 2018; Magee et al., 2016; 2019; Spacapan et al., 2016). In contrasts to dikes (i.e. vertical conduits), sills appear as layer parallel, tabular bodies of magma with structural signatures. The majority of sill mechanic models shows that sills are emplaced as continuous igneous sheets and propagates as hydraulic fractures.
Even though sills have been a topic of study in the last decades, questions regarding their architecture, flow conditions, inflation and relationship to sedimentary heterogeneity remains unanswered. This contribution presents a detailed case study of young (c. 3.7-4.6 Ma) basaltic sills from the San Rafael volcanic field in Utah, US. The sills range in thickness from 20-centimeter thin splays to c. 20-meter thick massive intrusions. Our results involve a vast range of data, ranging from large outcrop 3D models (>100m) to thin sections (<1mm).
In this presentation, we report on detailed field observations of exceptional well-exposed sills to show that sills may exhibit multiple propagating points due to complex interaction with the sedimentary host rocks. The sills propagate along weak discontinuities parallel to bedding, and may diffuse splays that follow local sedimentary structures, such as cross bedding. Other strong sedimentary influences include large xenoliths and fluidized sediments close to stepped intrusion geometries (bridges).
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Time-lapse synchrotron X-ray imaging of deformation modes in organic-rich Green River Shale heated under confinement

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Shales are layered sedimentary rocks, which can be almost impermeable for fluids and act as seals and cap-rocks, or if a shale layer hosts a fracture network, it can act as a fluid reservoir and/or conduit. Organic-rich shales contain organic matter - kerogen, which can transform from solid-state to oil and gas during burial and exposure to a suitable temperature. When hydrocarbons are expelled from the organic matter due to maturation, pore-pressure increases, which drives the propagation of hydraulic fractures, a mechanism identified to explain oil and gas primary migration. Density, geometry, extension, and connectivity of the final fracture network depend on the combination of the heating conditions and history of external loading experienced by the shale. Here, we have performed a series of rock physics experiments where organic-rich shale samples were heated, under in situ conditions, and the development of microfractures was imaged through time. We used the high-energy X-ray beam produced at the European Synchrotron Radiation Facility to acquire dynamic microtomography images and monitor different modes of shale deformation in-situ in 3D. We reproduced natural conditions of the shale deformation processes using a combination of axial load, confining pressure, and heating of the shale samples. Shales feature natural sedimentary laminations and hydraulic fractures propagate parallel to these laminae if no

overburden stress is applied. However, if the principal external load becomes vertical, perpendicular to the shale lamination, the fracture propagation direction can deviate from the horizontal one. Together horizontal and vertical fractures form a three-dimensional connected fracture network, which provides escaping pathways for generated hydrocarbons. Our experiments demonstrate that tight shale rocks, which are often considered impermeable, could host transient episodes of micro-fracturing and high permeability during burial history.

The earliest human footprints (Laetoli) occur in lake sediments that have been misinterpreted as datable volcanic ash

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An alternative paradigm of human evolution is the "aquatic-ape hypothesis," in which our ancestors evolved naked skin, long head-hair, large brain, bipedal gait, subcutaneous fat (blubber), descended larynx, hooded nose, and all other human features, during a period of semiaquatic habitat. This unorthodox theory has been ridiculed in paleoanthropology for 60 years, just as the "continental-drift hypothesis" was ridiculed in its time.

The current paradigm is that human ancestors evolved in the eastern African savanna and were bipedal as early as 3.5 Ma ago. I contend that this history is based on errors — falsifications such as Piltdown Man (e.g. Lucy, Turkana Boy, Little-Foot) — and geological misinterpretations (e.g. Laetoli). Humans may instead have evolved from chimpanzees that became isolated on Galapagos-like volcanic islands: proto-Bioko in western Africa, where fossils could not be preserved. No mammal fossils are known in any of the areas where chimpanzees speciated.

The human footprint track at Laetoli is said to be 3.5 Ma old. That age is probably wishful thinking, and the layer less than 200 000 years old. Calcareous sediments have been interpreted to be volcanic ash, in which K-feldspar and biotite dates give meaningful ages.

18 thin calcareous layers with mud cracks, raindrop marks, and footprint trails from hundreds of savanna animals (and even an insect), are interpreted to be fresh ashfall from 18 volcanic eruptions. The geology professor behind this interpretation thought that enough rain fell after each ashfall to dampen the ash so that it could preserve prints. There was not enough rain to wash the ash away from the flat, horizontal and grassless surface where the animals walked. I claim that this is an unreasonable geological interpretation.

The layers are calcaerous, so it was thought that the ash was carbonatite from the Sadiman volcano. But ash of carbonatite is unknown in geology, and no carbonatite is found at Sadiman, or on the Laetoli-Serengeti Plain.

Thin-section photos and chemical analyses of these so-called ash layers have never been published. Mineral grains giving K-Ar dates of 3.5 Ma have been claimed to be the age of the layers and the footprints. Grains giving inappropriate dates were discarded.

To protect the footprints from vandalism, the layer was covered over by soil and blocks of rock, before the exciting results were published. This cover-up kept visiting geologists from suggesting that these were lake sediments that cannot be dated using detrital minerals. A lake-sediment hypothesis has never been mentioned.

I am hoping to publish a paper exposing these errors.

You can read the manuscript, with pdf references, here: *https://www.researchgate.net/publication/344220554_The_story_of_human_evolution_is_based_on_fictional_fossil_evidence* See also http://AquaticApe.net

Geophysical and geological bedrock mapping, eastern Trondheim Nappe Complex, Mid-Norway

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The Trondheim Nappe Complex (TNC) is a collage of magmatic and sedimentary rocks that originated within the Iapetus ocean and includes the main Iapetus suture. Fundamental research in the 1950-1980s (summarized in Gee et al., 1985) established the TNC as one of the key areas to study the opening and closure of the Iapetus ocean and the resulting Caledonian orogeny. Currently available 1:250 000 geological bedrock maps covering the TNC were also produced on the basis of the research from the 1950-1980s.

Recent work in the western TNC (e.g. Grenne & Gasser, 2017; Dalslåen et al., 2020) and initial field work in the eastern TNC indicate that it is time for a thorough re-evaluation of the entire complex. The Geological Survey of Norway has launched an extensive mapping campaign including the collection of airborne geophysical data, field mapping and detailed geochemical and geochronological analyses.

New, high-quality and high-resolution, helicopter-borne geophysical data were collected during 2019-2020, including magnetic, electromagnetic and radiometric datasets (Ofstad et al., 2019). The new data highlight various geological features which were not resolved in such detail before. Field mapping started in 2019 and will be ongoing for several years. The mapping has been guided by the new geophysical data to areas with interesting geological structures. Additionally, the geophysical dataset is used to extrapolate geological boundaries in areas of poor exposure and provides estimates on dip/strike and depth of the observed magnetic features. The combination of detailed geophysical data and field mapping will produce new, high-quality geological and geophysical maps and shed light on the kinematic evolution of the TNC.

As preliminary results, we can highlight that several areas previously mapped as Aursunden Group (Esandsjøen Nappe) should be reassigned to the Hummelfjellet Nappe, that large parts of the Funnsjøen

Group are dominated by metasedimentary rocks rather than the more typical mafic metavolcanic rocks and that extensive ductile and brittle deformation in the eastern part of the Aursunden Group increases towards the east and continues far into the Middle-Lower Allochthon and basement windows.

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Kvantifisering av grunnvasstraum med DTS for betre BTES design

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For å utvikle og betre BTES-system (Borehole Thermal Energy Storage) trengst meir kunnskap om mellom anna korleis grunnvatn påverkar varmelagring og drift. Å finne grunnen sin in-situ eller "effektive" varmeleiingsevne og "effektive" boreholsmotstand er viktig for riktig dimensjonering av BTES, men ikkje alltid like enkelt. Grunnvassfylte borehol vil oppleve ein effektiv varmemotstand som varierer med varmeuttaks-/lagringsraten og temperaturnivået på grunn av naturleg konveksjon. Resultat frå termiske responstestar (TRT) for å finne den effektive termiske leiingsevna til grunnen har i somme tilfelle resultert i ei leiingsevne som aukar med måletida. Lønsam etablering av ein BTES krev truleg at ein kan bruke han både til korttids- og langtidslagring. Kollektorane, varmeoverføring i borehola, konveksjon og temperaturnivået i borehola avgjer om det er råd å få til korttidsdrift eller ikkje, og dermed kor lønsam BTES kan vere.

Regional grunnvasstraum i sprekkar vil fjerne varme fra lageret, men tapet er vrient å kvantifisere ettersom grunnvasstraumane i sprekkane generelt er ukjende. Etablering av høgtemperaturs BTES er ynskjeleg for å unngå dei høge kostnadene knytt til installasjon og vedlikehald av varmepumper, men varmetapet frå lageret aukar også med lageret sitt temperaturnivå. Fleire forsøk på å redusere varmetap fra BTES-ar er teke i bruk, men få data om dei faktiske effektane av tiltaka eksisterer. Tiltaka inkluderer toppisolasjon; lagring av varme hovudsakeleg i botnen istadenfor i toppen av lageret; bruk av gratis, lågtemperatur varme for å skape en termisk barriere rundt lageret og å tette sprekkane for å redusere tap fra regionale grunnvasstraumar.

Dette arbeidet vil bruke DTS til å måle temperaturprofil i ulike BTES og BHE over tid for å undersøke effekten av varmetapsreduserande tiltak, evaluere korleis termisk motstand og effektiv varmeleiingsevne endrast under ulike forhold, estimere forventa varmetap på grunn av grunnvasstraum i sprekkar; korleis ein muleggjer korttidslagring og generelt bidrar til forbetra design og drift av BTES. Nykelfaktorar for arbeidet er kostnadseffektivitet; bruk av in-situ-målingar frå forskjelege BTES og borehol og utvikling av praktiske, billige og enkle tilnærmingar som industrien har råd til å bruke. Arbeidet er ein del av forskningsprosjektet RockStore, der Norges forskningsråd og 26 partnarar foreiner krefter for å «utvikle, demonstrere og overvåke neste generasjons geotermiske BTES.»

Subjective bias in the interpretation of fracture networks

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Geology is an inherently uncertain science, and depending on what a researcher sets out to investigate, the results, interpretation, analysis and/or conclusions may be affected by different types of bias. Subjective bias is the sum of personal preferences, experiences and background that affects one's choice of method, the application of those methods to collect data, and the interpretation and analysis of said data. Although observational science is based on the principle that science should be objective and reproducible, subjective bias is difficult to remove altogether.

In structural geology, the recording and interpretation of structures, such as fractures in a network, may vary between different people due to their respective subjective bias. In this contribution, we systematically and quantitatively investigate the interpretations of 30 students of three identical networks. We hypothesize that subjective bias may be affected by the background and experience level of each students; to test this hypothesis, the participants in the study comprise three different groups: 1) first-year geoscience BSc students, ii) geoscience MSc students, and iii) geoscience PhD students. The 30 participants have manually interpreted the three fracture networks, which subsequently have been digitized in the open source geographic information systems software suite QGIS. To investigate differences and similarities in the interpreted fracture networks, we analyzed the geometry (fracture length, orientation, distribution) and topology (connectivity) of each student's fracture network interpretation, and compared their results.

The results investigation is ongoing, and the results will be presented at the conference. Investigating the effect of subjective bias on fracture network topology and connectivity has a range of implications, since such parameters are crucial to understand fluid flow in fracture networks, with applications i.e. within groundwater management, CO_2 storage, contaminant transport and petroleum production.

A New Relative Sea-Level Database for Norway

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Despite a rich history of research into post-glacial shoreline displacement, Norway lacks a unified collection of national relative sea-level data. A new initiative aims to develop a new post-glacial relative sea -level database, incorporating high-quality data from the entire Norwegian coastline. The database constitutes an integral part of a larger relative sea-level and glacial isostatic adjustment modelling project administered by the Geological Survey of Norway (QUANTSEA) that is ongoing. The database is populated with sea-level index points (SLIPS) and closely follows the international HOLSEA template, allowing future integration into large, global datasets. To date, over 1000 SLIPS have been assembled from previously published studies. They comprise wave-cut platforms, deltas, beach ridges, isolation basins, cave sediments, submerged peat, and salt marshes, which were dated using radiocarbon ages, tephra, pumice, biostratigraphy, inferred ages, and terrestrial cosmogenic nuclide exposure ages. All radiocarbon ages, from both recent and older literature, were recalibrated using the IntCal20 and Marine20 calibration curves. Additional data fields include latitude, longitude, sample elevation, SLIP type, relative sea-level (relative to modern, local Mean Sea Level), and age and elevation uncertainty, among others. Where possible, sample elevations were confirmed using high-resolution digital elevation models derived from LiDAR. New uncertainties were also applied to sites with poor constraints for sample location/elevation. Once completed, the database will comprise an important constraint for future glacial isostatic adjustment modelling of Scandinavia and will thus help improve future relative sea-level projections over the next century and beyond. The database will also be relevant to studies of past ice sheets, Nordic history and archaeology, oceanography, paleoclimatology, and geophysics, among others.

Fish on magma; shaken, not fried. The AD 1732 Eggøya volcanic eruption on Jan Mayen

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We provide the first documentation of tectonic deformation resulting from a volcanic eruption on the island of Jan Mayen. Intrusion of shallow magma caused 13-14 m of vertical uplift of bedrock across the outlet from a coastal lake to the sea. The displacement likely took place within a few weeks to months and led to isolation and adaptation to landlocked environment of the facultative migratory fish species Arctic charr (*Salvelinus alpinus*).

The age of the uplift event is bracketed by radiocarbon dated driftwood covered by material deposited from the developing slope, and by tephra from a volcanic eruption taking place in AD 1732. Radiocarbon ages allow for the possibility that uplift began and was accomplished just prior to the eruption, but overlying tephra indicates that some displacement occurred during the eruption, but that it ended before the eruption ceased. The ages obtained suggest that the uplift and magma intrusion were casually linked with the eruption that surfaced some 5 km away.
Our results complement previous studies of volcanic activity on Jan Mayan by providing precise age constraints for past volcanic activity. More importantly, it raises new hypotheses regarding the nature, timing, and prevalence of precursor tectonic events to Jan Mayan eruptions.

From analog to digital Geology: How to maximize the value of field and drone data in an integrated workflow using next generation algorithms, machine learning and process models in a cloud-based data eco-system for improved Exploration, subsurface characterization and virtual training

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The use of drones represents a unique opportunity to acquire crucial field information in a safe, non-expensive and environmental-friendly manner. Nevertheless, the integration with database and workflows specific to subsurface modelling is a real challenge.
We are presenting a novel workflow aiming at integrating 3D elevation models of geological outcrops built by drone image acquisition, traditional analog field data and subsurface measurements. This new workflow will improve the chance of success in subsurface exploration projects and brings more confidence in field development processes. This is performed by enabling a seamless data flow and the usage of advanced automated and machine learning based technologies for the interpretation of the data. This workflow is orchestrated in a cloud-based live ecosystem, which is a key-enabler.
The presented workflow covers all the steps from drone data acquisition to subsurface seismic data interpretation, characterization and modelling. This integrated solution allows to drastically reduce the time spent on the interpretation tasks and improve the confidence of the interpretation outcomes. More importantly, it unlocks the possibility to directly and seamlessly use the interpretation derived from the exposed analogs to perform an advanced subsurface characterization.

The field datasets, including drone imagery and geological observations and measurements, are contextualized and placed in the same data environment as the subsurface measurement database. This enables a seamless data flow. Expert exploration workflows of the subsurface are then leveraged by the knowledge acquired from the exposed analogs.
The outcomes of this proposed workflow can also be used directly to train geoscientist on their own analog field data through a managed virtual training system, including the use of augmented and virtual reality technologies.
The live laboratory prototype is a collaboration project between AkerBP, Schlumberger and the University of South eastern Norway. It is currently based on three field sessions in the arctic, during which we collected drone images. These imaged have been used to build a 3D digital models of representative Palaeozoic successions exposed along the Svalbard archipelago. This new digital database complements the analog database already compiled by AkerBP through their own R&D program and field work in Svalbard.
The overall integrated workflow can be augmented by existing University driven field databases and ultimately generalized, opening new opportunities and possibilities of transferable value towards Universities, research institutions and industries.

Snow Avalanches on Svalbard: investigating changes in depositional patterns and their palaeoclimatic significance

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Snow avalanches are important geomorphological agents in the High Arctic, producing striking avalanche fans below the mountain plateaus of central Svalbard. Although earlier studies of avalanche fans in the Longyearbyen area have noted light-colored avalanche debris draped over darker, lichen covered, extensive avalanche fans (Eckerstorfer, 2013; De Haas et al., 2015), no explanation for this variance has been put forward. In this study, a comparison of field-based observations and remote sensing mapping of avalanche fans indicates that historical avalanche-runout lengths (indicated by darker lichen covered rocks) were on average 33% longer than more recent avalanche runout lengths (lighter lichen free rocks). Different avalanche runout lengths were reconstructed through computer modelling, using the two-dimensional numerical avalanche model RAMMS. The overall aim of the study is to elucidate which climatic and meteorological conditions are necessary to produce the much larger avalanches of the past. Results from the modelling indicate that the larger historical avalanches were likely caused by an increase in snow precipitation, possibly in a combination with a shift in prevailing wind direction. Today, avalanche release is restricted to the upper part of the snowpack due to internal ice layers, produced during winter warming events. We hypothesise that fewer winter warming events in central Svalbard in the past, would have resulted in situations where the weak snow layer(s) were buried deeper in the snowpack, allowing for larger avalanches when released.
Dating avalanche deposits precisely is difficult, especially on Svalbard, since permafrost limits the search for datable organics that underly the deposits. However, one of the investigated fans is situated close to the sea, and its morphology and surface profile indicate that the old deposits have been affected by wave-erosion. Since the highest post-glacial shoreline is ca 62 m in the area (Lønne, 2005), wave influence on 27 m.a.s.l. indicates at least a mid-Holocene age of deposition for the large old avalanches on this fan.
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Microstructural Constraints and Characterization of Remobilized Sulfides and Associated Alteration at Pahtohavare, Kiruna District, Sweden

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Kiruna, Sweden, is the type locality of Kiruna-type iron oxide-apatite (IOA) deposits, and sits in a region broadly described to be an iron oxide-copper-gold (IOCG) district (cf. Hitzman et al. 1992; Bergman et al. 2001; Barton 2014; Martinsson et al. 2016). However, the nature and timing of introduction of iron oxide versus copper-gold assemblages is at question as regional structural analyses indicate a late brittle Cu overprint is associated with a second deformation event ca. 80 my after iron oxide apatite emplacement (cf. Martinsson 1997; Bergman et al. 2001; Martinsson et al. 2016; Andersson et al. 2019). The source, timing, and possible remobilization of Cu within a regional tectonic framework is critical for exploration in northern Fennoscandia to meet society's demand for a renewable future.

The tectonic deformation events of relevance in this study occurred during the periods from 1.90-1.86 Ga and 1.81-1.76 Ga, respectively. NE-SW-directed crustal shortening (D_1) resulted in the formation of a S_1 foliation. This was followed by an E-W shortening (D_2) folding S_1 foliation into F_2 folds with related axial-planar parallel spaced S_2 foliation. D_2 is characterized by brittle-plastic conditions that produced many overprinting brittle features observed in the area (Andersson, 2019).

The Kiirunavaara IOA deposit is accepted as early or even pre-D_1 and syn-extensional (1.88 ± 0.06 Ga; (Romer et al., 1994; Andersson, 2019). Located 5 km to the southwest, the Pahtohavare area hosts several low tonnage Cu±Au stratiform epigenetic deposits, where field and microstructural data indicate the mineralization is structurally controlled and often brittle in nature, and evidence points to the deposit forming or being strongly remobilized during D_2, in contrast to the currently suggested D_1 age. Microstructures from Pahtohavare preserve a composite $S_{0/1}$ bedding planar foliation in banded tuffites, which was subsequently folded (F_2), creating a spaced axial planar cleavage. Along these S_2 foliation planes are brittle veinlets of remobilized pyrrhotite-chalcopyrite-sphalerite ± pyrite assemblages. The remobilized sulfides are associated with biotite, chlorite, and titanite, with titanite often entraining pyrrhotite (and chalcopyrite) grains.

LA-ICP-MS results will be presented from generational pyrite within the Pahtohavare area targeting D_1 folded pyrite, porphyroblasts, overgrowth rims, and vein and brittle style pyrite. Pyrite grains have early inclusion-free cores overgrown by porous rims with albite inclusions. Furthermore, D_1 folded pyrite indicate annealed textures which are subsequently cut by brittle fractures that utilize the annealed margins to precipitate chalcopyrite and inclusions of magnetite, ±Au and ±Ag-±Bi- ±Pb- ±Ni-tellurides. This later event is also characterized by weak Mg-Al (probably actinolite) and enrichment of Sb. Co/As/Ni zonation is evident within the grains. These characteristics are used to constrain the geochemical nature and associated alteration of a D_2 -timed remobilization and mineralization event.

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Large scale floods in future climate worsen disproportionally due to sediment transport effect

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Towards the year 2100, rainfall intensity in Norway is projected to increase by up to 50% in the course of flooding events[1]. We investigated, with a 2-D morphological flood model, how this affected the flooding, sediment transport, erosion and sedimentation in catchments and rivers during such extreme events.

We found that a 50% increase in rainfall-intensity yielded a doubling of sediment transport. This means, that not only will a future increase in rainfall-intensity give larger floods by water volume, it will also transport disproportionally more sediment during these events. The additional sediment transport imposes a much greater threat to human life and property. Erosion causes new flood paths to form, and sedimentation expands the flooded area. This has the potential to inflict greater damage. There are numerous examples of this in Norway, for instance in Utvik (2017), Flåm (2014) and Tretten (1995).

In Norway, flood mapping is mandatory for buildings in proximity to rivers. This is to maintain safety against flooding. Flood mapping is normally carried out using hydrodynamic models, neglecting the erosion/ sedimentation effect. Our results demonstrate some of the shortcomings of these hydrodynamic-only simulations. These include the inability of the hydrodynamic model to predict new flood paths caused by erosion and sedimentation, and the static capacity of the river channel. Over the course of a flooding event, the channel capacity may change to adjust the influx of water.

Erosion and sedimentation depend in large part on the flow-velocity. This means that sediment is carried from steep segments (where the velocity is large), to the gentler segments of a river (where the velocity decreases). These differences in slope were identified as a driving factor in sediment transport during a flood, and that makes erosion/sedimentation predictable with this model. The morphological model attempted to straighten out the riverbed to reach a morphological equilibrium. A consequence of this effect is the vulnerability of a town located near a river in a flat area beneath a steep catchment. Such regions are common in Norway, e.g. towns located near a fjord with a steep mountainous catchment. Our simulations showed that such regions may experience large amounts of sediment deposition caused by a flood. Such sedimentation increases the bed of the river, spreading the flood and causing more damage. This effect worsens

disproportionally with a future increase in rainfall-intensity.

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Refining key parameters for long-term carbon cycle models

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CO_2 is the most important greenhouse gas in the Earth's atmosphere and has fluctuated considerably over geological time. However, proxies for past CO_2 concentrations have large uncertainties and are mostly limited to Devonian and younger times. Consequently, CO_2 modeling plays a key role in reconstructing past climate fluctuations. Facing the limitations with the current CO_2 models, we aim to refine two important forcings for CO_2 levels over the Phanerozoic, namely carbon degassing and silicate weathering.

Silicate weathering and carbonate deposition is widely recognized as a primary sink of carbon on geological timescales and is largely influenced by changes in climate, which in turn is linked to changes in paleogeography. The role of paleogeography on silicate weathering fluxes has been the focus of several studies in recent years. Their aims were mostly to constrain climatic parameters such as temperature and precipitation affecting weathering rates through time. However, constraining the availability of exposed land is crucial in assessing the theoretical amount of weathering on geological time scales. Associated with changes in climatic zones, the fluctuation of sea-level is critical for defining the amount of land exposed to weathering. The current reconstructions used in models tend to overestimate the amount of exposed land to weathering at periods with high sea levels. Through the construction of continental flooding maps, we constrain the effective land area undergoing silicate weathering for the past 520 million years. Our maps not only reflect sea-level fluctuations but also contain climate-sensitive indicators such as coal (since the Early Devonian) and evaporites to evaluate climate gradients and potential weatherablity through time. This is particularly important after the Pangea supercontinent formed but also for some time after its break-up.

Whilst silicate weathering is an important CO_2 sink, volcanics carbon degassing is a major source but one of the least constrained climate forcing parameters. There is no clear consensus on the history of degassing through geological times as there are no direct proxies for reconstructing carbon degassing, but various proxy methods have been postulated. We propose new estimates of plate tectonic degassing for the Phanerozoic using both subduction flux from full-plate models and zircon age distribution from arcs (arc-activity) as proxies.

The effect of refined modelling parameters for weathering and degassing was tested in the well-known long-term models GEOCARBSULF and COPSE. They revealed the high influence of degassing on CO_2 levels using those models, highlighting the need for enhanced research in this direction. The use of arc-activity as a proxy for carbon degassing leads to interesting responses in the Mesozoic and brings model estimates closer to CO_2 proxy values. However, from simulations using simultaneously the revised input parameters (i.e weathering and degassing) large model-proxy discrepancies remain and notably for the Triassic and Jurassic.

Global shortage of sand and gravel resources – will there also be a sand crisis in Norway?

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During the past couple of years, reports of a global sand crisis were heading the titles of major newspapers (i.e., Beiser, 2017, Torres, 2017) and books have been published to highlight the problems that lie behind the shortage of sand and gravel resources (Beiser, 2018). The shortcoming of sand and gravel for the building industry (aggregates for concrete and asphalt), shale gas extraction (fracking sand) , the electronic manufacturing (computer chips), and green revolution (solar panel production) gave rise to a global war on remaining sand resources (i.e. Marschke et al., 2020).

Will sand and gravel also soon be a scarcity recourse in Norway? In Norway, most of the active mines exploit submarine glacial delta and terraces that were deposited during the retreat of the last icesheet. Therefore, Norway's sand and gravel resources are not renewable (except if there will be a next ice age) and extraction of the available occurrences may lead to shortage of sand and gravel aggregates in the future. However, it is yet unclear when sand and gravel may become a scarcity resource in Norway.

For the state of Trøndelag in Mid-Norway, an ongoing project is mapping the excavation and usage of sand and gravel aggregates for each municipality. Based on the numbers acquired during this so-called "resource accounting", estimations of how long the current sand and gravel resources with withdrawal-concession will last can easily be calculated. However, estimates of how much of the remaining sand and gravel deposits (without withdrawl-concession) are accessible for future excavation are much more difficult to establish, since many different area conflicts such as buildings, ground-water resources, natural protection areas, cultural monu-ments and last but not least farming purposes have to be considered. In a pilot study for the state of Trøndelag, the volume of remaining sand and gravel resources have been estimated for the areas with highest consumption (i.e., Trondheim municipality) and the lifetime of these resources is calculated based on the average depletion of sand and gravel during the past couple of years.

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«Geopraksis»- internship in geoscience education.

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Lack of perceived working life relevance and experience during the studies is a major challenge in the geosciences. To improve on this, we want to carry out a two-year pilot project, called "GeoPractice" at the geoscientific departments at the University of Bergen (UiB), the University of Oslo (UiO) and UiT in the period 01.2021-01.2023. The term geosciences in this presentation covers the areas of geology, geophysics and natural geography.
The applicant institution is the Department of Geosciences at UiT, and the application partners are the other geoscience institutions at UiO and UiB. We will increase perceived work life relevance by designing and offering a 10-credit internship as part of the bachelor's degree program. This will give students insight into what a relevant geoscientific job entails, increase the opportunities for relevant work, ensure a network in the industry and facilitate the transition from studies to working life.
“GeoPraksis” will also create a new arena for collaboration between the educational institutions and working life where the content and relevance of the educations can be discussed. Employers get students into a real work situation to contribute to coherent problem solving. The students will be actively involved throughout the project, and will contribute both in the planning, introduction and revision phase of the project.
The applicant and partner institutions in this application are all partners in iEarth, Diku Center for Excellence in Education (SFU) which started in 2020. iEarth is a natural link between the institutions, and functions as a national platform. The use and implementation through iEarth will ensure sustainable development, qualified teaching expertise and a national coordination component. iEarth will at the same time be able to offer necessary assistance in the form of professional, didactic and administrative support. When the project period is over, the internship will be introduced as a permanent part of the study program at the various geoscience institutions involved in iEarth.
The conference contribution will provide an input on the importance of the introduction of practice schemes in the geosciences. This is an investment that is largely in demand by both students and employers.

Natural gas seepage from the seafloor above known hydrocarbon discoveries in the southern Barents Sea and the link to the petroleum system

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During summer 2020 a scientific cruise in the Barents Sea (CAGE20-2), documented more than 30 gas flares from the seafloor in areas around the Hammerfest Basin, southern Bjarmeland Platform and the eastern Loppa High in the southern Barents Sea. This was done by using water column data from an EM302 multi-beam echosounder system installed onboard R/V Helmer Hanssen, and by carefully placing the transit lines from/ to Tromsø crossing over as many known hydrocarbon discoveries and other interesting shallow seismic anomalies as possible. All the observed gas flares were either related to these known hydrocarbon discoveries and/or other shallow seismic anomalies. Some of the gas flares, it turned out, were even related to the positions of previously drilled exploration wells.
The gas flares observed in the water column data are the manifestation of natural gas seepage from the seafloor. This is a natural process occurring in all petroleum basins. In this area of the Barents Sea, the gas seems to primarily be leaking out from known hydrocarbon reservoirs by vertical migration along faults where they extend through the stratigraphy all the way up to or close to the seafloor, often ending at base Quaternary level. Most places the flares are related to shallow gas anomalies in and/or at the base of the Quaternary. Some places, like the flank of the Loppa High, flares can also be related to sub-cropping of established petroleum reservoirs due to erosion of the structural high. In these cases, the gas is leaking where the reservoirs are sub-cropping, indicating lateral migration in the reservoirs beneath good cap-rocks.
By combining the information obtained from mapping both natural gas seepage from the seafloor using water column data, shallow gas anomalies observed on seismic data, and seismic anomalies along the migration routes, we can get a better overview of the migration routes for the gas (and potentially also indirectly for oil), and may more easily back-track the hydrocarbons to the reservoirs and ultimately to the source rock. The fact that almost all the investigated proven hydrocarbon discoveries naturally leaks gas at the seafloor (outside where previous exploration wells have been drilled), makes it relevant to consider using information from the water column for prospect evaluation, e.g. in the risking process.

The Scandinavian crust and upper mantle – Insights from a new seismic shear wave model

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We present a new seismic model of the shear wave velocity of the crust and upper mantle in Scandinavia, covering Norway, Sweden and Finland down to a depth of about 250km. The model is based on the analysis of surface waves and ambient noise recorded at 220 seismic stations, most of them belonging to the ScanArray experiment, a temporary network that covered the area from 2013 to 2017.
At crustal depths, the main heterogeneity is situated in the Lofoten peninsula and Nordland province. They are characterised by very low velocities up to -5% respect to the average velocity. A prominent feature is seen at 15 km depth with a low-velocity band striking mainly NNW-NNE from southern Sweden to the Nordland/ Lofoten region. We can relate this structure to the TIB granitoids with their high magnetic susceptibility, low density and high heat flow. While the southern and central Scandes lack a crustal root, we observe a minor root below the northern Scandes. From the larger variation in crustal structure in the North than in the South, we assume distinct uplift mechanisms along the Scandes. The southern Scandes might sustain their topography due to dynamic support from the mantle, while the northern Scandes experience both crustal and lithosphere isostasy.
In the upper mantle, we main lateral heterogeneity is a distinct low-velocity in southern Norway, as found by previous studies. The Lithosphere-Asthenosphere Boundary is deepening from west to east with a sharp step and velocity drop both in the South (120 km depth) and the North (150 km depth), coinciding with the Caledonian belt. The central area shows rather smoothly varying structures from west to east. Additionally, we find low-velocity areas below 150 km depth beneath the Karelia craton in northern Finland and image the Norrbotten craton which separates the Karelia craton and the Caledonides.

The time-dependent thermal trigger for rifting and break-up of continents

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Closure of oceans often leads to refertilization and enrichment of the orogeny-related, lithospheric mantle in radioactive elements, such as uranium and thorium. According to conductive-convective thermal modelling, increased content of radioactive elements within the anomalous mantle block results in a time-dependent rise of temperature, weakening the lithosphere with time and, therefore, providing favourable settings for rifting more than 50-100 million years after the ocean closure. Besides, our results of the numerical modelling show that mantle convection pattern is characterized by a clear tendency of the mantle upwellings to move with time in the direction of the thermally anomalous, upper-mantle block. This movements of the upwellings can cause extensional stresses that can potentially trigger the break-up of the thermally-weakened, continental lithosphere. From our point of view, this time-dependent, thermal mechanism can explain why extensional tectonics and continental break-up within the former suture zones do not occur immediately after orogeny but with a certain time delay which is controlled by the concentration of the heat-producing elements in the anomalous mantle block and size of this block. Therefore, we propose a new, time-dependent process of weakening the continental lithosphere that can be responsible for the intracontinental rifting and the continental break-up controlled by the increased content of radioactive elements within the anomalous lithospheric mantle.
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Norwegian seismicity in relationship to upper-mantle structure and atmospheric precipitation pattern

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Norway is characterized by increased intraplate seismicity in two clearly distinguished clusters: Western Norway and the Nordland area. These two clusters of relatively high Norwegian seismicity spatially correlate with upper-mantle, low-velocity anomalies. Besides, these seismically active areas spatially and also temporally coincide with elevated atmospheric precipitation/snowmelt rates. We suggest that the presence of the low-velocity mantle may have a first-order control on intraplate seismicity in Norway. On the other hand, the gravitational forces due to highly contrasting relief and heterogeneities within the crust may play an additional role. Other tectonic reasons can also contribute to the seismicity in the Nordland area and Western Norway, where intracrustal conditions are favourable for strain and stress localization above the low-velocity mantle. Furthermore, a direct temporal

correlation between the number of upper-crustal earthquakes and intensity of rain and snowmelt at the Earth's surface points to groundwater flow through fractured crystalline bedrock. In this case, the additional initiating mechanism of seismicity is most likely associated with periodic increases in pore-fluid pressure within the fractures and cracks of the upper crystalline crust as a result of groundwater recharge, with gradual pore-fluid pressure diffusion to depth. Consequently, precipitation-related, seasonal pore-fluid pressure increases within the fractured crystalline rocks can be superimposed on the mantle- and gravity-controlled seismicity, causing relatively frequent, but mainly low-intensity earthquakes. Additionally, the precipitation-related water loading/unloading can also be responsible for seismicity in the Nordland area and Western Norway. Moreover, the effect of thermoelastic expansion/contraction within Western Norway and the Nordland area, the deep interior of which is still not in thermal equilibrium, may also be responsible for the crustal/mantle stress changes.

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Natural alteration and fluid migration pathways in basalts with application to permanent CO_2- storage: Examples from the Faroe Islands

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Natural carbonatization occurs during interactions between silicate minerals and atmospheric CO_2 or CO_2 bearing fluids through metamorphism, and silicate weathering. These processes involve the incorporation of CO_2 into the structure of carbonate minerals and represent a significant component in the global carbon cycle. In recent years, engineering approaches to Carbon Capture and Storage (CCS) have been developed in response to the climate crisis. Large scale CCS has been directed towards sedimentary basins with CO_2 injected and stored as a gas, supercritical fluid, or solution. However, this requires long term monitoring due to potential leakage, as CO_2 remains in a mobile phase for extensive time. Alternatively, fast permanent storage can be achieved from the injection of CO_2 into reactive rocks, such as basalt, where it forms carbonate minerals upon reaction with divalent cations such as Ca^{2+} and Mg^{2+}.

This study focuses on basalt sequences from the Faroe Islands Basalt Group (FIBG). These represent surface analogue exposures of the extensive offshore North Atlantic Igneous Province sequences. Located between the Shetland Islands and Iceland, the Faroe Islands comprise a sequence dominated by basaltic lava flows with subsidiary interlava volcaniclastic beds representing the subaerial relics of an extensive lava plateau. Cores of lava flows have significantly lower porosity and permeability than sandstone reservoirs, however, flow tops and sedimentary strata between flows have been proven to comprise good reservoirs globally. This study investigates the potential for fluid migration from permeable strata into less permeable areas of reactive basalt flows.

Field studies on the Faroe Islands reveal primary and secondary pore structures that act as natural case studies for fluid-rock interactions. These structures have enabled mineralization cells and pathways that we ascribe to the evolution of micro-permeability, surface area, and reactivity of various host rock microstructures. We combine detailed analyses of paleo-reaction development with new laboratory experiments on unmineralized examples to explore both the nature and rate of reaction pathways of potential basaltic CO_2 storage sites. Furthermore, petrographic and petro-physical analyses, including micro-CT investigations are carried out to understand fluid migration pathways and mineralization effects on the evolving permeability structures of the basalts through reaction induced cracking and pore clogging.

Late Cenozoic reshaping of the Barents Shelf: Influence of erosion, sedimentation, and glaciation

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Morphology evolution of the Barents Shelf is a key question in understanding how erosion and glaciation reshape the face of the Earth. The Cenozoic history is a subject of a longstanding debate in the Barents realm, in part, due to decades of petroleum exploration in the region. We address here the whole-region study of the influence of a set of mechanisms and factors on the erosion and sedimentation estimations. Several local studies along the edges of the Barents shelf enlighten the relation between sediments accumulated off-shelf and amount of erosion in the adjacent areas. There are only few studies of the entire Barents region but precision of these studies is limited due to uneven distribution of measurements and uncertainties in paleo-conditions. We compare the masses of sediments accumulated along the edges of the Barents shelf with erosion predicted in Henriksen et al. (2011) and estimate that erosion is significantly overestimated. Local corrections to this erosional model do not bring balance close. The major part of the erosional estimate is based on seismic methods and well logs reflecting sedimentary rock's compaction changes caused by (now partly removed) load from above. This load, however, may be

caused not by eroded material alone, but also by ice cap during the glacial cycles. Reduction of erosional estimates by accounting for ice load bring balance between existing erosional model and accumulated sediments close. We also model the glacial erosion using the numerical approach *erosion backward in time* (Medvedev et al., 2018). The method was modified for this study to account for difference in the lateral length scale of on- and off-shore erosion and flexural isostasy. We compare this erosional model with estimated masses of glacial-induced sediments off-shelf the Barents Sea. The results performed for a range of controlling parameters show that the Barents shelf was mainly subaerial at the beginning of glaciation.

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Late Mesozoic-Cenozoic tectono-stratigraphic evolution of the Vesterålen margin, offshore northern Norway

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Available 2D multi-channel seismic profiles and a 3D seismic survey are utilized together with potential field and limited well data to study the Late Mesozoic-Cenozoic tectono-stratigraphic evolution of the Vesterålen margin offshore northern Norway. The analysis resulted in an updated structural and stratigraphic framework, together with new and better refined structural elements for the Vesterålen margin. Distinct along-margin basin segmentation is evident through NW-SE trending curvilinear transfer zones informally named as the Jennegga transfer zone, Vesterålen transfer zone system, and Andøya transfer zone. These divide the study area into three main margin segments, namely the northern Lofoten, Vesterålen, and Andøya segments.

Five main rift phases of varying intensity have been recognised and refined, and they are evidenced by eight mapped fault families: pre-Jurassic, Late Jurassic-earliest Cretaceous, Aptian-Albian, Albian-Cenomanian, three individual fault families within Late Cretaceous, and Paleocene. Furthermore, fault heave and displacement measurements were undertaken within the North Utrøst Ridge Fault Complex (NURFC) that exhibits prominent low-angle detachment faults of Cretaceous strata. The analysis demonstrated a progressively northwards increase of fault heave and displacement intensity from ~3 km in the south to ~7-8 km in the north of the study area, and a maximum stretching factor defined by fault geometry (âf) of ~1.7. These values when compared to the crustal stretching (i.e. >3) and thinning (0.7-0.9) factors required to achieve the observed extension on the >300-km-width extended NE Greenland-Vesterålen conjugate margins reveal an apparent extension discrepancy. Fault population analysis suggests that only ~14% of extension is seen from the faults on seismic profiles in the NURFC.

Finally, a conceptual tectonic multiphase evolution model for lithospheric extension is proposed for the NE Greenland-Vesterålen conjugate margins, consisting of a lower and upper plate configuration. This model elaborates the more ductile mode of deformation evidenced by the Late Cretaceous-Paleocene low-angle detachment fault complexes on both conjugate margins and the asymmetry in crustal structure at the time of continental rupture at the Paleocene-Eocene transition. The study shows that the Vesterålen margin represents an essential area to study the tectono-stratigraphic evolution of the NE Atlantic margins.

Fault Picking Strategies using Seismic Data, and the Effects on Fault Seal Analysis: A Case Study from the Horda Platform, with Implications for CO_2 storage

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Significant uncertainties occur through varying methodologies when interpreting faults using seismic data. These uncertainties are carried through to the interpretation of how faults may act as baffles/barriers or increase fluid flow. How fault segments are picked when interpreting structures, i.e. what seismic line spacing is specified, as well as what surface generation algorithm is used, will dictate how detailed the surface is, and hence will impact any further interpretation such as fault seal or fault growth models. We can observe that an optimum spacing for fault interpretation for this case is set at approximately 100 m. It appears that any additional detail through interpretation with a line spacing of ≤50 m simply adds further complexities, associated with sensitivities by the individual interpreter. Hence, interpreting at a finer scale may not necessarily improve the subsurface model and any related analysis, but in fact lead to the production of very rough surfaces, which impacts any further fault analysis. Interpreting on spacing greater than 100 m often leads to overly smoothed fault surfaces that miss details that could be crucial, both for fault seal as well as for fault growth models.

This contribution is a case example showing how different picking strategies influence analysis of a bounding fault in terms of CO_2 storage assessment. This is an example from the Horda Plaform: the Smeaheia potential storage site, 20 km East of Troll East. This is a fault bound prospect, and hence this bounding

fault is required to have a high seal potential and a low chance of reactivation upon CO_2 injection, increasing the pore pressure.
Uncertainty in the seismic interpretation methodology will follow through to fault seal analysis, specifically for analysis of whether *in situ* stresses combined with increased pressure through CO_2 injection will act to reactivate the faults, leading to up-fault fluid flow / seep. We have shown that changing picking strategies significantly alter the interpreted stability of the fault, where picking with an increased line spacing has shown to increase the overall fault stability. Surprisingly, differences in picking strategy show little influence on the overall fault seal (i.e. shale gouge ratio) of the fault.

Oslo Lufthavn Gardermoen, erfaring med etablering og drift av geotermisk anlegg med 1500 m dype brønner

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Norge har ledet an i utviklingen mot dypere energibrønner for bergvarmeanlegg. I 2018 ble det satt ny dybderekord. Da ble det geotermiske anlegget for oppvarming av rusegropa ved Oslo Lufthavn Gardermoen satt i drift. Anlegget består av 2 brønner til 1500 m dybde. Varmen fra brønnene brukes til å holde rusegropa (del av rullebanen for testing av fly) isfri. Begge brønnen er «lukkede» energibrønner med montert spesialdesignet kollektorslange for sirkulasjon av frostvæske/vann i brønnen.
Brønnene ble boret gjennom ca 80 m løsmasser og ned i prekambriske gneiser. Boringer ble gjennomført med **??** utstyr. Boringen tok **??** dager
NGU logget temperatur, ledningsevne, gammastråling, resistivitet og oppsprekking ved bruk av akustisk televiewer (Elvebakk, 2018). Temperaturen på 1450 m ble målt til 26 °C. Det indikerer en termisk gradient på under 15 °C/km, noe som er lavere enn det som er normalt i Norge, men i bra samsvar med det som tidligere er målt i området.
Anlegget har vært i drift siden høsten 2018, og det har fungert uten store driftsproblem.
Et tilsvarende konsept med 1500 m dype brønner var planlagt for et annet anlegg, men på grunn av utfordringer under boring med forkastningssoner med mye grunnvann, ble det valgt grunnere brønner.
Erfaringer fra Gardermoen anlegget viser at konseptet med 1500 dype energibrønner er et miljøvennlig og økonomisk konkurransedyktig energialternativ. Et slik energialternativ kan brukes i enkelte anvendelser som avising og lav-temperatur oppvarming uten bruk av varmepumpe. Konseptet er spesielt egnet i tettbygde områder med lite tilgjengelige areal for tradisjonelt bergvarmeanlegg og i områder med mektige løsmasse-overdekning.
Det er større risiko og utfordringer for boretekniske problem å bore til 1500 m sammenlignet med tradisjonell energibrønnboring til 2-300m. Dette må det ta hensyn til i planleggingen av slike dype – geotermisk anlegg, slik at man kan få etablert et plan B anlegg med grunnere brønner hvis man mislykkes med å bore til det planlagte dypet.
Referanse:
Elvebakk, H. 2018 Logging av dype energibrønner på Oslo Lufthavn, Gardermoen, NGU rapport 2018.020, 55s

Mantle density structure in the North Atlantic region from 3D inversion of satellite gravity gradient data

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We explore the mantle density structure of the North Atlantic region by performing linear inversion of the satellite gravity gradient tensor data using prior information. The prior model is used to obtain the residual gravity gradient signal and covariance matrix using a crustal model constrained by updated database of seismic reflection and refraction profiles. We construct a 3D reference density distribution in the upper mantle assuming a pure shear model for lithospheric rifting. The mantle reference density model is consistent with mineral phase equilibria assuming a pyrolitic bulk composition. The forward modeling of the gravity gradients in the 3D reference model is performed on a global scale using a spherical harmonics approach. The northeast Atlantic model corresponds to a spherical shell covering the study region down the depth of 410 km. We use tesseroids as mass elements for solving the forward and inverse gravity problem at the regional scale. The relationship between the seismic velocity and density anomalies in the Iceland-Jan Mayen region and the low-density corridor across central Greenland are discussed for understanding the origin of heterogeneities in the upper mantle of the northeast Atlantic region and their possible connections with the Cenozoic Iceland plume activity.

Structural analysis of the Smeaheia fault block, a potential CO_2 storage site, northern Horda Platform.

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Smeaheia, a prominent fault block located on the Horda Platform, northern North Sea is identified as a potential subsurface CO_2 storage site. We utilise the GN1101 3D and regional 2D seismic surveys to generate a high-resolution subsurface geomodel to inform the structural style and evolution of the fault block, to investigate geological controls on proposed CO_2 storage and

provide a geometric framework as a basis for future analyses. Two basement-involved (first-order) north-south trending fault systems, the Vette Fault Zone (VFZ) and the Øygarden Fault Complex (ØFC), bound the 15 km-wide fault block. Apart from activity during the Permo-Triassic (Rift Phase 1) and the Late Jurassic–Early Cretaceous (Rift Phase 2), we present evidence that rifting in this part of the North Sea continued into the Late Cretaceous with minor reactivation in the Palaeocene–Eocene. Two segments of the VFZ interacted and linked at a relay ramp during Rift Phase 2. Second-order (thin-skinned) faults show basement affinity and developed during Rift Phase 2 in two distinct pulses. A population of polygonal faults intersects the overburden and developed during the Eocene to middle Miocene. We have revised the areal extent of two structural closures that define the Smeaheia fault block, Alpha (VFZ footwall) and Beta (ØFC hanging wall) which consist of Upper Jurassic Viking Group target formations. Cross-fault juxtaposition analysis of the VFZ and second-order intra-block faults are presented and inform pressure communication pathways between the Smeaheia and Tusse fault block, as well as reservoir integrity and compartmentalisation. The geomodel further identifies important geological controls on CO_2 storage in the fault block including a thinning caprock above the Alpha structure, and identification of hard-linkage between deep tectonic faults and shallow polygonal faults. Fault reactivation analysis was conducted on depth-converted faults to determine the risk of up-fault CO_2 migration. Hydrostatic and depleted scenarios were modelled. Faults are modelled as classic cohesionless structures but also utilising parameters (cohesion and friction angle) derived from host rock mechanical analysis.

The GREENPEG Horizon2020 project: New exploration tools for European pegmatite green-tech resources

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The GREENPEG project supported by the EU under the Horizon 2020 scheme "Climate action, environment, resource efficiency and raw materials" with 9 million EUR aims the development of multi-method exploration toolsets for the identification of European, buried, small-scale (0.01-5 million m3) and clustered pegmatite ore deposits of the Niobium-Yttrium-Fluorine(NYF) and Lithium-Caesium-Tantalum(LCT) chemical types. The project, coordinated by the Natural History Museum of the University of Oslo, involves 8 industrial and 5 academic partners from 8 European countries and started 1 May 2020. It is the largest innovation project coordinated by the Natural History Museum of the University of Oslo ever and the first Innovation Action project of the university.

The target raw materials of GREENPEG in European pegmatite-type ore deposits are lithium, high-purity silica and metallic silicon, ceramic feldspar, rare earth elements, tantalum, beryllium and caesium, which are naturally concentrated in pegmatite rocks. No exploration and exploitation strategies have so far been developed and tailored to European buried pegmatite ore deposits due to their poor current economic viability. In addition, there has been an extremely low discovery rate for pegmatite ores due to several technical challenges. GREENPEG will overcome these challenges by developing new toolsets tailored to LCT and NYF ores and different settings (wall rocks, vegetation, topography) of European pegmatites to increase exploration success and decrease environmental impact. The developed methods will be adjusted, optimised and tested under Technical-Readiness-Level-7 conditions in three European demonstration sites for commercialisation. The demonstration sites, leased by GREENPEG partners for LCT and NYF pegmatite exploration, include: Wolfsberg, Austria; South Leinster, Ireland; and Tysfjord, Norway.
This contribution focuses on the methodological approach applied in GREENPEG and highlights some preliminary result of the first field season. In addition, experiences from the successful project application are shared.

Neste kapittel i 'Geologi for samfunnet' – NGU mot 2030

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Geologisk kunnskap blir stadig viktigere for utviklingen i samfunnet, og gir nødvendige bidrag til mange av FNs bærekraftsmål. Derfor motiveres også NGUs ansatte av vårt enkle slagord 'Geologi for samfunnet'.
NGU er landets sentrale institusjon for kunnskap om berggrunn, mineralressurser, løsmasser og grunnvann, og er en etat under Nærings- og Fiskeridepartementet. Gjennom målrettet samfunnskontakt formidler NGU forskningsbasert geofaglig kunnskap og kompetanse til næringsliv, forvaltning og publikum. Dette gir viktige beslutningsunderlag som bidrar til bærekraftig næringsutvikling, god forvaltning av landets naturressurser og miljø, og samfunnssikkerhet. NGU har et stort faglig nettverk og deltar aktivt i internasjonalt samarbeid, blant annet gjennom Eurogeosurveys.
Data fra NGU er åpne og gratis tilgjengelige. Våre kart og databaser benyttes av det offentlige innen en rekke områder, blant annet arealforvaltning og planlegging av infrastruktur. Vi bidrar også med data og kompetanse som er viktig for næringsvirksomhet, enten det dreier seg om grunnlag for mineralutvinning eller plassering av oppdrettsanlegg.
Kjerneaktivitetene til NGU er konsentrert om innsamling av data bl.a. ulike målinger fra fly, helikopter og båt; tradisjonell geologisk kartlegging med feltarbeid og prøvetaking; samt bearbeiding, tolkning og formidling. Mye av dette gjøres i tett samarbeid med andre etater, blant andre Kartverket og Havforskningsinstituttet innen marin kartlegging og NVE innen skredfarekartlegging. Vi har også et nært samarbeid med

DMF innen mineralområdet, der DMF og NGU har komplementære oppgaver og virkefelt, og vi har et veletablert samarbeid med universitetene.
NGU har velutstyrte laboratorier og driver sammen med NTNU og Sintef den nasjonale forskningsinfrastrukturen MiMaC (Mineral and Materials Characterisation). Vårt nasjonale prøve- og borekjernelager på Løkken er nettopp blitt oppgradert og utvidet til 2200 m^2. Her ligger over 700 km med norske kjerneprøver tilgjengelig for både forskning og næringsutvikling.
Nyheter fra NGU det siste året er blant annet ny toppledergruppe og ny strategi for perioden 2020-2030. Vi har også utviklet vårt samarbeid med NVE innen kartlegging av skredutsatte områder. Det siste året har NGU også styrket sin internasjonale posisjon innen utvikling og bruk av InSAR (radardata fra satellitt). I de neste årene vil NGU delta i ledelsen av en ny europeisk tjeneste basert på den norske modellen. Alle data fra denne nye tjenesten vil bli distribuert fra webservere i Trondheim. Sist, men ikke minst, NGU har fått midler til et nytt forskningsfartøy som fra sommeren 2022 vil tas i bruk for kartlegging i kystnære områder og i fjordene. Organisasjonsutviklingen som er gjort det siste året svarer også ut evalueringen av NGU i 2019. Vi mener derfor at vi nå er godt skodd, både organisatorisk og faglig, til å bidra med viktige geologiske data og kompetanse til et samfunn med store utviklingsoppgaver fram mot 2030

Petrographic and provenance analyses of Upper Triassic sandstones from shallow stratigraphic cores, offshore Kvitøya, Svalbard

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The northern Barents Sea is currently unopened for petroleum activity and the present knowledge is based on regional studies from 2D seismic and shallow stratigraphic cores acquired by the Norwegian Petroleum Directorate (NPD) as well as from outcrop studies from adjacent land areas. During a drilling campaign offshore Kvitøya (80 °N) by NPD in 2015, shallow stratigraphic cores of late Carboniferous to early Jurassic age were collected. Thick accumulations of Triassic sediments constitute an important part of the petroleum system. The present study focuses on the sandstone- dominated Upper Triassic cores 7934/6-U-1, 7934/6-U-2, 7934/8-U-1, 7934/9-U-1 for petrographic characterization and identification of provenance rock signatures of the De Geerdalen - Snadd Formation in the northeastern part of the shelf.
Preliminary results from the study off Kvitøya show mineralogically immature sandstone compositions with contributions from a large variety of rock types from different sources. In addition to abundant cherts and other fine particulate sedimentary rocks, as well as micaceous metamorphic rocks, erosion of high - temperature igneous rocks are suggested by composite fragments of Ba-rich K-feldspar and albite. Contributions from mafic volcanic sources are shown by presence of chloritized rock fragments rich in albite needles, and from ultramafic sources by frequent appearance of detrital chromite as part of the heavy mineral contents. Preliminary mineralogical and mineral chemical data, in combination with seismic data suggest a major source for the sand deposition off Kvitøya from a northeastern border land, also localizing a possible ophiolitic source area. Further work will focus on mineral chemical analysis and zircon dating of selected samples for comparison with existing published and ongoing research from other areas on the Barents Shelf.

The Reinbenkan coastal cliff and rock slope failures along the eastern shoreline of northernmost Porsangerfjorden

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The recent launch of the Norwegian ground motion service (InSAR Norway) allowed the detection of around hundred unstable rock slopes in Norway. Among them, an unstable part of a coastal cliff in Finnmark county, 1 km wide by 300 m high, was highlighted. The site, called Reinbenkan (Kruvvnut), is facing Honningsvåg city 20 km away on the opposite side of the Porsanger fjord.
Satellite InSAR data shows an average line of sight displacement of 10 mm per year from 2015 to 2019 for the site. As part of the hazard and risk assessment in the country, NGU has conducted field work in 2019 and 2020 aiming to determine the structural controls of the instability and its dimensions. In addition, dGNSS measuring stations where installed for periodic measurements. This would give key information to determine the threat to Honningsvåg and its surrounding areas.
Field work and analysis of high-resolution digital elevation models and bathymetric data showed that the coastal cliff in which Reinbenkan developed has experienced several collapses in the past. These events ranged from 0.05 to 1 Mm^3. The last one (close to 1 Mm^3) has been witnessed in Autumn 1986 or 1987. Alfred Karlsen was fishing in the area and states that his boat was rocked by 7 to 8 m high waves at 2 nautical miles from the impact. He estimated the waves to be about 1 m high when they reached the harbor, but they did not cause any damage because of the low tide at that time.
Our analyses show that the past events in the vicinity share similar structural conditions as Reinbenkan. A persistent joint set dipping around 40° out of the cliff

face in the NNW direction is suspected to play a major role in these instabilities. Seepage coming out of these joints was observed at the scar of the event of 1986-1987. This NNW sliding direction also fits with the horizontal component measured from the first time series of dGNSS measurements. The vertical component measured is however more important, suggesting the implication of steeper structures, breakage of rock bridges, and internal shearing within the sliding mass. This hypothesis is also supported by the irregular morphology of the observed scars, but contrasts with the relatively homogeneous morphology of the top plateau of the sliding mass.
Lastly, the bedding steeply dip inward at about 65° in the SW direction with a strike subparallel to the shoreline. It then acts as a good proxy for displacement since it is mostly perpendicular to the motion. And indeed, an offset is visible on the north lateral flank close to the bottom of the slope, suggesting a relatively low daylighting basal failure surface and a total involved volume beyond 10 Mm^3.

The International Continental Scientific Drilling Program (ICDP) – status and prospects for 2020 – 2030

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Norway is member of the International Continental Scientific Drilling Program (ICDP - https://www.icdp-online.org/home/). Currently the program has 21 member nations, including Finland, Sweden and Norway, while UNESCO serves as a Corporate Affiliate.
ICDP has recently published a Science Plan 2020 – 2030 focusing on four key topics: Geodynamic Processes, Geohazards, Georesources and Environmental Change. Future ICDP drilling projects will engage in fundamental science issues related to the evolution and past climate of planet Earth, the formation and use of resources, and hazards related to volcanos and major fault zones.
In 2021 ICDP will celebrate its 25th anniversary. Over the years, a large number of planning workshops and many successful drilling projects have been supported by ICDP. There is also a clear ambition to increase the number of member countries, as well as forming closer partnerships with other organizations, especially IODP.
Three Nordic projects have currently been approved by ICDP. The COSC-2 drilling project (Collisional Orogeny in the Scandinavian Caledonides) is a follow-up of the COSC-1, immediately east of the Swedish-Norwegian border in Trøndelag. COSC-2 drilling was recently finalized. Complementing the cores from the COSC-1 project, drill core is now available through many key sections of the Caledonian Nappe stack and the underlying basement of the Fennoscandian Shield
ICDP has previously approved a drilling proposal (DAFNE – Drilling Active Faults in Northern Europe), aiming to intersect and investigate the tectonic and structural nature of a postglacial fault near Kiruna, Sweden. Prominent post-glacial faults are widely distributed in northern Fennoscandia, and given their relatively recent movement history, a better understanding of these fault systems has great scientific and societal relevance.
A new drilling proposal with a strong Nordic component, Volcanic Forcing and Paleogene Climate Change (PVOLC), was approved by ICDP in 2020. In this project, two planned boreholes in northwest Denmark will obtain a complete section through Paleocene-Eocene marine strata, including abundant ash layers. The drill cores will provide data that are critical to improve the understanding of potential causal relationships between the emplacement of the North Atlantic Igneous Province and the global Paleocene-Eocene Thermal Maximum (PETM).
Using the ICDP platform, the earth science community in the Nordic countries and beyond has an opportunity to develop drilling projects of global importance. The work on samples and data collected during ICDP projects stimulates international collaboration and commonly results in numerous scientific publications and the promotion of early-career scientists. Importantly, all the cores and samples are registered and stored for future studies.
Video ICDP Science Plan 2020 – 2030:
https://www.icdp-online.org/fileadmin/icdp/media/doc/ICDP_Science_Plan_Video.mp4

The Segele deposit, SW Ethiopia – An unusual example of ultramafic-hosted orogenic gold mineralization

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The Segele gold deposit is located in the Akobo region, approximately 720 km southwest of the Ethiopian capital Addis Ababa. The Segele mineralization was discovered in 2015 and is currently undergoing a pre-feasibility study with resource definition by Akobo Minerals. The deposit occurs within the Precambrian Western Ethiopian Shield, which is composed of a range of supra-crustal and plutonic rocks embedded within the juvenile Neoproterozoic crust of the Arabian Nubian Shield and the older, predominately gneissic Mozambique Belt (Woldemichael et al., 2010). A mafic to ultramafic layered intrusion is the predominant host rock to the gold mineralization at Segele.
The Segele deposit is characterized by a very high gold grade, locally exceeding 10,000 g/t of gold. Gold mineralization is associated with extensive hydrothermal alteration and carbonatization of the mafic -ultramafic host rocks. Hydrothermal fluid flow is currently interpreted to have been controlled by both regional- and local-scale shear zones that primarily affect pyroxenitic sections of the host intrusion. The ore mineralogy at Segele comprises veinlets and disseminations of native gold, which is intergrown with a volumetrically minor sulfide assemblage that includes

cubanite, pyrrhotite, cobaltite, and several yet not fully characterized PGE-minerals. In the broader Akobo region also occur several additional prospects comprising different styles of quartz vein-hosted gold mineralization within mafic and felsic intrusive rocks. The genetic relationship between these geologically dissimilar prospects and Segele remains unclear.

The ongoing study will bring new mineral and geochemical data, including characterization of host rocks and hydrothermal alteration and mineralization products, stable isotope compositions of gangue carbonates, as well as fluid inclusion data, with an aim to provide an insight into ore-forming processes that resulted in the deposition of an unusually high-grade gold mineralization.

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Late Carboniferous deposits in the Oslo Graben – a regional overview.

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Regionally, the continental dominated deposited Asker Group can be subdivided by two major key sequence stratigraphic surfaces. The first is the basal boundary with sandstones or limestones of the Caledonian orogeny, then classified as a first order sequence boundary (cf. Embry, 2007). The second interpreted key surface is the boundary between the red coloured alluvial lacustrine deposits of the Kolsås Formation and the overlying grey or multi coloured deltaic and paralic Tanum and Nærum formations in the central and southern part respectively. The two key sequence stratigraphic surfaces are probably diachronous, but nonetheless vital to interpret the basin dynamics in the early stage of the Oslo Graben.

The dating of the Asker Group is still poor. However, the upper boundary of the group is now well established by current dating of the first rhomb porphyry lava (RP 1) in the Kolsås and Ringerike Lava Plateau which yielded an age of 299,7 +/- 0.4 Ma (Corfu & Larsen, 2020). A minimum age constraint for the deposition is given by the U-Pb ages on perovskite from ultramafic pyroclastic rocks overlying the Asker group sediments in Skien yield an age of 298.7+/-0.7 Ma, and most likely also by the ultramafic pyroclastic surge deposit at Brunlanes which yield an age of 300.2 +/- 0.9Ma, although at the latter locality the sediments of the Asker group is not exposed (Corfu & Dahlgren, 2008). A maximum age of the sediments is given by detrital zircons from the Asker group sediments from Skien and Ringerike, giving U-Pb ages of 329 and 319+/-5 Ma respectively (Dahlgren & Corfu, 2001).These absolute ages show that the group is deposited near or below the Carboniferous Permian boundary according to GSA v.5.0 timescale of 2020. The marine carbonate bed in the Tanum Formation suggest a Moscovian age while freshwater bivalves of an overlying shale units suggest Stephanian age (Olaussen et al., 1994; Eager, 1994).

While the thickness and facies association of the Kolsås Formation is laterally quite similar throughout the Oslo Graben the overlying unit displays a basal erosive surface, abrupt shift in facies association and varies in thickness of a few meter in Ringerike (north) to near 60 meter in the Skien Area (south). Small scale growth faults in the Tanum Formation are observed in Ringerike. In one locality in Skien the Narum Formation rest direct on Silurian sandstone, showing erosion of the Kolsås Formation. The fluvial deposits in the Narum Formation shows drainage towards south east i.e. towards the master fault in the Vestfold Graben. Scarce paleocurrent date in the flipped Akershus half graben indicate drainage towards north west, again towards a master fault.

We suggest that the lower most unit, the Kolsås Formation represent a symmetric basin fill deposited under relative quiet tectonic subsidence. In contrast the overlying Tanum and Nærum formations represent dip slope deposits during minor faulting related to the initiation of the Oslo Graben during the late Pennsylvanian. Furthermore, these early stages of the basin fill of the Oslo Graben shows similarity to the early development of the Billefjorden Trough and graben on Bjørnøya in Svalbard and Loppa high in the Barents Sea. The scale of the graben segments and likely timing is also comparable.

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The Trongdalen shear zone, a newly discovered structure of possible Devonian age in the Western Gneiss Region

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The new Coop3 aeromagnetic compilation has revealed major E-W trending linear anomalies extending from the Rondane area to Sunnfjord. The anomalies are most likely caused by major continental shear zones dominating the bedrock geology of central Norway.
The EW-trending Trongdalen shear zone (TSZ) is situated a couple of kilometers to the north of Vågåvatnet. It crosses Ottadalen valley 3-4 km to the west of the Lom municipality center. TSZ is represented by a pronounced linear 10-40 m deep depression in the topography. Parallel smaller depressions occur within a c. 1-2 km wide zone. The shear zone can be followed farther west to Sandåe and Hestflotin and into the Breidalen area along the northern boundary of the Hestbreapiggan granite. The Hestbreapiggan-Jostedalsbreen area within the Breheimen national park is to a large degree covered by glaciers. It is therefore difficult to trace the shear zone through the heavily deformed gneiss area on aerial photographs and digital topography. The structure can, however, be observed and extended on aeromagnetic data. The 1-2 km wide TSZ bears some resemblance to the Breidalen SZ described by Banham (1968) in the Breheimen area.
The TSZ is characterized by blastomylonites and porphyroclast-bearing mylonites with an average dip of c. 80° to the south. The quartzo-feldspatic augen become progressively smaller and disappear in the zone of presumed most intensive shear. The porphyroblasts represent crystals that existed before the onset of the mylonitisation process but have survived during the high-strain damage.
Brittle structures with a few thin (c. 20 mm) epidote-bearing quartz-veins occur within the TSZ. XRD analysis has shown that one of the veins consists of c. 70 weight percent quartz, 17 % epidote, 5 % plagioclase, 5 % potassium-feldspar, 3 % stilbite and 1 % chlorite. The veins most likely formed by hydrothermal fluid circulation at a late brittle stage of the shear zone formation or during later reactivations.
The aeromagnetic map shows that the TSZ delineates the northern boundary of the Hestbreapiggan Granite. The shear zones must consequently be younger than or contemporary with the granite emplacement. Rb-Sr whole rock age dating of the Hestbreapiggan Granite has given an age of 975±35 Ma (Priem et al., 1973). The brittle structure is most likely related to a Late Caledonian deformation or younger events. A K-Ar dating of the vein minerals and mylonite is in progress.
The TSZ is most likely related to a steep strike-slip structure linking the Agdenes and Røragen detachments to the east to the Nordfjord-Sogn Detachment Zone and Standal Fault in the west. Devonian movements along the TSZ may explain the formation of the Hornelen Basin.

A part of the Stuoragurra postglacial fault complex, at Máze in N-Norway, is less than 600 yrs old

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The Stuoragurra fault (SF) complex constitutes the Norwegian part of the larger Lapland province of postglacial faults. The 90 km long SF complex consists of three separate seismic reverse faults; the Fitnajohka fault system in the southwest, the Máze fault system in the central area and the Iešjávri fault system to the northeast. The distance between the faults is 13-20 km. A total of c. 100 earthquakes has been registered along the SF between 1991 and 2019. Most of them occur to the southeast of the fault scarps and less than 10 km from the extrapolated fault at depth. The maximum moment magnitude is 4.0. The formation of postglacial faults in northern Fennoscandia has previously been associated with the deglaciation of the last inland ice. Trenching of different sections of the faults and radiocarbon dating of buried organic material, however, reveal a late Holocene age (younger than 4000 cal yrs BP), and possibly even younger than 600 years for the youngest major fault event at Máze. The stratigraphy and deformation structures in the sediments along the fault scarp indicate at least one distinct major fault event and additionally possibly one weaker, slightly older postglacial fault event showing a less distinct morphological and sedimentological impact.
Trenching transverse to a fault scarp in the Fitnajohka fault system farther south revealed fault breccia injected into and overlying deformed surficial sediments, with fault clay (altered fault gouge) in the contact zone between the up-thrown hanging wall block in bedrock of albite diabase breccia and adjacent Quaternary sediments. Similar trenching in the Máze fault system at Latnetoaivi to the east of the Kautokeino River revealed a thick unit of fault breccia, with angular clasts from the quartzitic bedrock injected into and on top of the surficial sediments, including angular boulders thrown more than 15 m away from the headwall of the fault scarp. The reverse displacement of c. 9 m and fault system lengths of 14 and 21 km of the two southernmost fault systems indicate a moment magnitude of c. 7. The results from this study indicate that the maximum magnitude of future earthquakes in Fennoscandia can be around 7.
Results from new georadar profiling in Máze and Fitnajohka areas will be available in January 2021.

Reservoir characterization of Utsira High, central North Sea

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This study entails reservoir characterization of Jurassic sandstones in block 16/1 by employing petrophysical analysis, rock physics diagnostics, and machine learning techniques to estimate reservoir properties. The study area is located around the Utsira High in the Central North Sea and produces oil from alluvial, aeolian and shallow sand deposits. Eighteen (18) wells in block 16/1 have been studied to characterize the Jurassic

reservoirs in the area. Comparisons between rock physics templates of the machine learning methods and the measured Vs have been conducted to estimate the behavioral interpretation of the Machine Learning methods on the well logs. Additionally, this study explores the usage of cascaded LSTM (Long Short-Term Memory) to estimate missing log intervals for the wells. With the standard Vs prediction equations (Han, et al., 1985, Greenberg and Castagna 1992, Krief et al., 1990), the predicted Vs are mostly assumed to have a linear relation with Vp. This study aims to use Neural Network, SVM (Support Vector Machine), and LSTM, estimating the more subtle details of Vs. Using published Vp-depth trend of 50:50 silt-clay mixtures (Mondol, 2009) reveals a mean uplift in the study area of about 62 m. Well 16/1-13 have found containing an oil-bearing reservoir zone from 1920 to 1966 m depth with a net-to-gross ratio of 0.88, average porosity of 0.25, and mean hydrocarbon saturation of 0.46.

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Top and lateral seal assessment for CCS in Dunlin Group sandstones within the Tusse fault block, Horda Platform

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Demonstration of the full-scale CCS value chain along the Norwegian Continental Shelf is scheduled to begin in 2024 as a result of both Longship and Northern Lights projects. Subsurface geological characterization and results from well 31/5-7 recently confirmed favorable storage conditions at the Aurora storage site (exploration license EL001), which is located roughly 11 km south of the Troll West hydrocarbon field and 8 km east of the Tusse Fault Zone. Supercritical CO_2 will be injected into the Lower Jurassic Dunlin Group storage complex comprised of Johansen and Cook Formation sandstones, which are sealed by overlying Drake Formation mudstones and shales. Confidence is relatively high with respect to the geology controlling successful CCS operations at Aurora, however, little work has been done to extrapolate satellite storage potential of the Dunlin Group throughout the Horda Platform. This is especially true for the envisaged top and lateral seals that are critical for reliable containment of the injected CO_2, as previous contributions instead focused on understanding the Johansen and Cook storage formations. In order to utilize local infrastructure and encourage further development of the Horda Platform as a European CCS hub, we present an assessment of potential top and lateral seals in the neighboring Tusse fault block east of Aurora and underneath the Troll East field. Relevant horizons and faults defining three potential storage traps are mapped using well logs and 3D seismic data, and are used to build a local structural model. Thickness maps indicate that the Drake top seal is present throughout the study area, but thickness decreases from over 125 m at the Aurora site to approximately 65 m along the eastern edge of the Tusse fault block. Log readings from nine wells within the Tusse fault block also suggest adequate seal properties for CO_2 storage, particularly in the lower part of the Drake Formation. All three traps are dependent on lateral fault seals, however, their nature is primarily determined by the amount of displacement occurring along them and the regional stratigraphy. A number of small faults (throw < 50 m) displace the traps, creating local zones where up-thrown Johansen and Cook sandstones are juxtaposed against Drake mudstones. Contrastingly, displacements along larger trap-bounding faults (e.g., the Tusse Fault Zone) exceed 75 m, juxtaposing up-thrown Dunlin Group sandstones with thick Upper Jurassic Viking Group sandstones (Troll reservoir). These larger faults, therefore, must provide continuous membrane seals at sandstone-on-sandstone juxtapositions, and shale gouge ratio (SGR) analysis suggests that their membrane seal potential is favorable for retaining injected CO_2. Assuming good regional reservoir quality within Johansen and Cook formations, these results infer that ample seals are present for leveraging Tusse fault block traps as supplemental CO_2 storage sites in the Horda Platform.

Detachment faulting, successive incision and supradetachment basin evolution in large-magnitude extensional systems – examples from analogue studies and the Mid-Norwegian margin

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In highly extended areas such as Death Valley, northern Oman, western Norway and the Mid-Norwegian rifted margin, metamorphic core complexes, extension-parallel turtlebacks and synclinal supradetachment basins constitute important parts of the tectonic infrastructure. Core complex geometry varies from asymmetric back-warps elongated normal to the extension direction to regional antiforms (´turtlebacks´) with axes parallel to the dominant extension direction. The evolution of accommodation associated with detachment faults involves inversion, dismemberment and erosion of early depocenters in the area of initial maximum displacement which evolves into the area of maximum isostatic uplift. As the detachment fault grows laterally, structural recesses evolve into synclinal depocenters on the sides of the turtleback/core complex. Associated facies assemblages reflect erosion of the evolving core complex and the higher rates of accommodation in the syncline. In continental settings, synclinal recess depocentres involve fluvial, floodbasin or lacustrine deposits, whereas in coastal settings, recesses may become the loci of marine incursions. Coarse debris is shed from the front and flanks of the core complex/turtleback into the greater supradetachment basin from three sides as the synclinal depocenters evolve into subbasins with axis parallel to the overall extension direction. In regions of regional transtension, extension-parallel folding due to fault growth tend to become enhanced by orthogonal shortening, which, in turn, increase fold amplitudes and introduce real shortening structures in the synclinal subbasins. Incision by more deeply rooted faults eventually leads to the termination of detachment faulting and associated folding and warping, but also induces complex 3D-patterns of reactivation that depend on new versus previous strainfield orientations. When new large-magnitude faults interact and link to form the breakaway complexes that define the main domain boundaries in a rift, an infrastructure of deactivated detachment faults and supradetachment basins becomes abandoned in structurally high positions along the rift flank and in the necking domain.

In situ removal of iron, manganese, and other heavy metals from groundwater

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Groundwater is a major potential water resource for human consumption around the world. Its natural or anthropogenic contamination is a source of concern especially when it concerns heavy metals. This MSc study focuses on near well redox processes at Grindalsmoen water works, Elverum Municipality, through geochemical lab experiments.
Iron and Manganese are both present in groundwater, with different concentrations, due to the weathering process of minerals in the soil, bedrock and sediment as well as from rain infiltration through the soil. High level of Iron and Manganese in groundwater is problematic therefore, different removal methods have been developed, and among these techniques, the Vyredox method. The latter is one of the methods used in Norway at the study site: Grindalsmoen water works.
The exact biogeochemical mechanisms involved in the Vyredox method are not clear yet. Thus understanding Iron and Manganese phases and occurrences in groundwater and as precipitates is key to understand the kinetics and mechanism involved in the oxidative removal of Iron, Manganese and other heavy metals in groundwater. In order to quantify and study these processes, aquifer material from Grindalsmoen was collected during a sampling campaign at Elverum in February 2020 and sediments from the B and C soil horizons were sampled. Physical and chemical studies are being performed, such as SEM (Scanning Electron Microscopy), XRD (X-ray Diffraction), and adsorption and oxidation experiments. The results of these experiments will be simulated with PHREEQC. For studying the oxidation kinetics and phase distribution of Manganese and Iron, abiotic catalytic oxidation and biological oxidation of Manganese through column reactor will be realized.
The Grindalsmoen aquifer material was used as a template for Mn (II) sorption under oxic conditions. The initial results showed a homogenous sediment distribution featuring a fine to medium sand, with more or less sorbed metals. The SEM microscopy revealed Iron coating on grain surfaces. The sorption experiments indicate higher sorption of Manganese for the top sediment compared to the deeper sediment. This sorption of Manganese is clearly dependent on Iron oxide available on the grain surfaces and the sorption capacity obtained proved to be more than sufficient for the Manganese level found in groundwater from waterworks in Norway.
A deeper understanding of these mechanisms may improve the heavy metals removal technologies and broaden the applicability of this low-cost methodology.

The Cu mineralization in the Alta-Kvænangen Tectonic Window, northern Norway

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The Alta–Kvænangen Tectonic Window (AKTW) is one of several terrains in northern Norway that represent a north-western continuation of the Precambrian Fennoscandian Shield beneath the Scandinavian Caledonides. The supracrustal complex of AKTW is similar to those of other tectonic windows in northern Norway, including Repparfjord Tectonic Window and Alteneset Tectonic Window, and it is predominantly composed of mafic lavas and mafic tuffs, intrusive gabbro-dolerite sills, minor ultramafic rocks and carbonate-rich metasedimentary rocks. In contrast to other tectonic windows in northern Norway, AKTW has not been a subject of intensive deformation processes

(Bergh & Torske, 1988; Melezhik et al., 2015). Therefore, AKTW represents an ideal area to study lithostratigraphic features of Precambrian metavolcano-sedimentary complexes in the Fennoscandian Shield as well as associated ore-forming processes.

The Cu mineralization in AKTW occurs mostly in form of quartz-carbonate-sulphide veins hosted by both magmatic and sedimentary lithologies. The mineralizati-on hosted by gabbro-dolerite and mafic volcanic rocks is characterized by a predomination of chalcopyrite and pyrite over other sulphide minerals. In addition to quartz -carbonate-sulphide veins, sulphides also occur as dis-seminations in gabbro. The sediment hosted Cu miner-alization consists mostly of bornite and digenite, with covelite and chalcopyrite as minor phases. This type of the mineralization is enriched in Pb, Se, Te, Bi and Ag.

The ongoing study brings new mineralogical, geochemical and stable isotope data from 1) gabbro-dolerite hosted Cu mineralization (e.g., Kåfjord); 2) mafic volcanites hosted Cu mineralization (e.g., Carl Johan gruve, Wilson gruve) and 3) sediment hosted Cu mineralization (e.g., Anna gruve, Lundstrøm) with an aim to get a better insight into ore-forming processes that controlled transport and deposition of Cu in northern Norwegian tectonic windows. The study is accompanied with mineralogical and geochemical analyses of stream sediments and heavy minerals sampled from streams that drain selected Cu occurrences in AKTW. The obtained results will contribute to the efficient targeting of Cu occurrences in the Fennoscandian Shield.

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Ore-forming processes at the Loki's Castle Hydrothermal Vent Field, the Arctic Mid-Ocean Ridges

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The Loki's Castle hydrothermal vent field, located in the Mohns-Knipovich bend (73.6°N, 8.2°E, ~2400 m depth) of the ultraslow spreading Arctic Mid-Ocean Ridge (AMOR), represents as a basalt-hosted and sediment-influenced type of submarine hydrothermal systems (Pedersen et al., 2010). Venting of ~320° C black smoker fluids occurs at the top of two approximately 20-30 m high sulphide-rich mounds (Baumberger et al., 2016). Low-temperature venting at the flank of the mounds is associated with a field of barite chimneys (Eickmann et al. 2014).

The sulphide mineralization is characterized by predomination of pyrite and marcasite. Isocubanite, chalcopyrite, pyrrhotite, sphalerite and galena are common but their amounts significantly vary between analyzed samples. Amorphous silica, anhydrite and barite are the major gangue minerals. The bulk Cu, Zn and Pb content varies between 300 ppm and 2.4 wt.%, 140 ppm and 9.15 wt.%, and 45 ppm and 2.17 wt.%, respectively. The mineralization is enriched in Ag, Au, Sb, As, Cd, Se, Hg and Tl. The barite chimneys are composed of barite and variable amounts of amorphous silica.

Amorphous silica associated with the sulphide mounds hosts two-phase fluid inclusion assemblages that preserve characteristics of hydrothermal ore-bearing fluids. Eutectic temperatures around -52ºC indicates NaCl and $CaCl_2$ as the main dissolved salts, and the final ice melting temperatures at -3.5°C corresponds to the bulk salinity of 5.6 wt.% NaCl eq. Homogenization by vapor disappearance occurred between 230 and 235° C. The calculated density of the entrapped fluids ranges between 0.872 and 0.879 g/cm^{-3}. In contrast, fluid inclusions entrapped in the barite chimneys show composition close to heated seawater. Homogenization temperatures were recorded in the interval between 100 and 110°C.

Themodynamic modelling, based on fluid inclusion and mineral chemistry data, reveals that base metals and Tl were transported in forms of metal-chloride complexes. Gold was transported as Au-bisulphide complex, and hydroxide complexes were responsible for hydrothermal transport of As and Sb.

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Re-Os geochronology of black shale from Central Spitsbergen, Svalbard: a stepping stone toward establishing the age of the J/K boundary

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Stage boundaries are determined by integrating bio-, magneto-, and chrono-stratigraphic units. Numerical ages of stage boundaries ideally should be constrained or verified by reliable radiometric ages of sedimentary strata – a challenging task in the absence of ash layers suitable for U-Pb zircon dating. For example, the numerical age of the Jurassic – Cretaceous (J/K) boundary is still uncertain. Recent efforts provided some ammonite biostratigraphy across the J/K boundary in the Slottsmøya Member of the Agardhfjellet Formation on Spitsbergen. However, the age and duration of the uppermost Jurassic (Volgian stage) and the lowermost Cretaceous (Ryazanian stage) in the Boreal realm remain loosely defined. Our study adds new radiometric ages for this controversial stage boundary and presents geochemical data to evaluate paleoenvironmental settings. Three black shale intervals from two drill cores (DH2 and DH5) located ~7 km apart in Central Spitsbergen provide three Re-Os ages. In DH2, shales from the Slottsmøya Member previously provided conflicting biostratigraphic results (Volgian to Ryazanian)[1]. An isochron derived from samples at 497 m depth yields an imprecise 146.8 ± 6.8 Ma age, nominally suggesting deposition in the Upper Volgian rather than Ryazanian; the age uncertainty, however, precludes confirmation. Large uncertainties near the J/K boundary are typical for this region[2, 3]. Two Re-Os isochron ages from the Oppdalen Member (DH2 at 724 m and DH5 at 658 m) yield similar ages of 157.6 ± 3.3 Ma and 157.9 ± 2.9 Ma, respectively. These ages are close to the GTS Oxfordian – Kimmeridgian stage boundary and, even within their uncertainties, suggest Oxfordian – Kimmeridgian deposition. The agreement between these correlative intervals in the two cores[4] lends credence to the accuracy of the Re-Os age. Biostratigraphic data, however, suggest a somewhat older age. Seafloor erosion, reworking and redeposition, could create this discrepancy between geochronologic and biostratigraphic age determinations. Given that biostratigraphy between the Boreal and Tethyan realms is poorly correlated, the radiometric ages provided by this study could be a stepping stone toward better connecting the Boreal with the Tethyan realm. But further work, on all fronts, is needed.

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Properties and diagenesis of Palaeozoic sandstones, Bjørnøya

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Outcrops of the Hambergfjellet Fm. were logged and sampled in Ymerdalen, and at Hambergfjellet and Alfredfjellet. Preliminary results on the sandstone samples show both very porous and tightly quartz cemented, mineralogical mature sublith- and quartz-arenite sandstones – as well as mixed, fossiliferous sandy packstones in a framework of quartz, calcite and skeletal allochems. Variations in diagenesis appear related to the depositional environment with substantial carbonate cementation that is likely sourced from intraformational skeletal debris. The Devonian and Permian sandstones, belonging to the Røedvika and Miseryfjellet formations, respectively, are texturally mature sublitharenites, strongly influenced by quartz cementation. The data collected will be further examined as the basis for the 1st author's master thesis with emphasis on sandstone diagenesis and provenance.

Frost cracking intensities in Scandinavian blockfields and implications for long-term landform evolution and weathering (and glaciation history)

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The blockfield landform remains enigmatic regarding genesis and origin, internal structure and movement/ mixing processes and glaciological implications. They are found in Scandinavia across the Arctic and Subarctic in high elevation, low relief mountain terrain (plateaus) and exhibit an atypical stratigraphy of boulders and blocks with large air-filled pore spaces in the top layer, followed by a sandy, silty and gravelly matrix with some blocks below, before the bedrock layer enqueues.
We present a 1D numerical model that uses near-surface temperatures and snow depths measured between summer 2018 and summer 2020 to calculate frost-cracking windows and frost-cracking intensities (FCI) within the ground column and across ~1 km^2 large study areas in three different blockfield locations. About 100 miniature temperature loggers have been distributed in various settings across blockfields on Tron mountain in the Alvdal region and Gamlemsveten near Ålesund in

Southern Norway and the blockfield on Plateaufjellet near Longyearbyen, Svalbard. For the model, the frost cracking window is defined at -3 to -8 °C and frost cracking intensities are calculated from a combination of temperature gradient and water availability, with a penalty function for gradient direction and distance to water across cells.
Firstly, in the cases of Tron and Gamlemsveten, the frost cracking window is never reached at some temperature sensors throughout the year (about 1/3 of sensors). This is mostly due to thick snow cover that occurs in the hollows and depressions of the blockfields and on lee-sides of plateaus and summits. All sensors on Plataufjellet reached the frost-cracking window during the yearly cycle.
Secondly, the time averaged, depth-integrated FCI's for the two Southern Norway sites show some zero-values (because of the frost cracking window not reached) and otherwise relatively high values (30 to 100), if the stratigraphy is a matrix of fine to medium fine sediment (sand, silt, gravel) and boulders or stones. Very low FCI's (0.5 to 0.8) were modelled for a blocky layer with large air-filled pores because of the low water availability there. The Plateaufjellet site shows entirely non-zero, but extremely low FCI values (0.0004 to 0.001), because of water availability due to permafrost occurrence and because surface and near-surface temperatures stay below the frost-cracking window for 3/4 of the year.
Those values do not yet give any rates of weathering or erosion but give a relative view of the differences of ground material for frost cracking sensibility and can partly explain the persistence of the blockfield landform throughout long time scales and multiple glacial cycles. Additionally, implications for glaciation patterns, erosion and the internal thermal regime of former ice sheets can be inferred.

An integrated geological characterisation of marine ground conditions for offshore wind foundations in the North Sea

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The North Sea is set to become an important player in the burgeoning offshore wind industry. A better understanding of how marine ground conditions influence the foundations of offshore wind installations is required in order to bring down project development costs and achieve the renewable energy goals of the EU's Green Deal. This study investigates two recently announced offshore wind sites in the Norwegian sector of the North Sea; Utsira Nord and Sørlige Nordsjø II. The sites are extensive, covering c. 1000 Km^2 and 2600 Km^2 respectively. The increasing size of offshore wind sites represents a significant challenge with regards to characterising geological heterogeneity, particularly within the Late Quaternary glacial-marine deposits of the North Sea. The main aims of this study are to 1) Investigate how the geological conditions at and below the seabed influence the location and design of offshore wind foundations and anchors, 2) Acquire high-resolution acoustic data and cores to investigate the key geotechnical risks to offshore wind developments and provide recommendations for the scope of site surveys in geologically heterogeneous areas and 3) Investigate the potential for integrated geological-geotechnical modelling to predict geotechnical risks across geologically heterogeneous sites to facilitate safe and lower-cost foundation design. The sub-objectives of the study are to analyse and interpret the geophysical, marine and geotechnical data at the two sites, to identify and classify key "geotechnical facies" and their distribution, and to establish work flows and test modelling techniques for acquiring and integrating geological and geotechnical data at offshore wind sites in the North Sea. As a relatively new and rapidly growing industry, an integrated overview of site survey planning and ground modelling techniques for offshore wind is currently lacking. This study aims to fill that gap and contribute towards a more consistent method of characterising marine ground conditions at offshore wind sites in the North Sea.

Understanding breakup magmatism and climate by IODP drilling offshore mid-Norway in 2021

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The NE Atlantic conjugate volcanic rifted margins are characterized by extensive break-up magmatism recorded by basalt flows, volcanogenic sediments, magmatic underplates, and intrusive complexes in sedimentary basins and the crust. This voluminous magmatism is concomitant with the global hot-house climate in the Paleogene. Massive injection of magma into organic-rich sedimentary basins is a likely mechanism for triggering short-term global warming during the Paleocene-Eocene Thermal Maximum (PETM). The aim of IODP Proposal 944 ("*The Nature, Cause and Climate Implications of Excess Magmatism During the Northeast Atlantic Continental Breakup*" by Huismans et al.) is to obtain new borehole and wireline data to better understand the origin and consequences of the North Atlantic Large Igneous Province by scientific drilling of the outer Møre and Vøring basins. This proposal has now been scheduled for drilling during a 60-day expedition (Exp 396) in August and September 2021. A key objective of this expedition is to document the nature and explain the causes and consequences of excess magmatism during break-up as the large amount

of magmatism cannot be easily be explained by passive decompressional melting of sub-lithospheric mantle with a normal potential temperature. New constraints on 1) melting conditions, 2) timing of magmatism, 3) spatial and temporal variations, 4) eruption environment, 5) sedimentary proxy data, 6) temporal resolution of magmatism and climate change events are required to resolve current controversies. Systematic IODP drilling is a way to provide these constraints and will allow the development of a quantitatively testable framework for volcanic rifted margin formation and consequences for global climate change. The proposed drilling strategy is a series of shallow boreholes along and across the Mid-Norwegian margin. New 3D seismic data collected by the industry and academia during the past few years have provided unique imaging of the basalt and sub-basalt sequences and allowed for optimal planning of the drill sites for scientific purposes. Additional holes are located along and outboard of the continent-ocean boundary to constrain the temporal evolution of the breakup magmatism.

Characterization of reservoir compartmentalization using strontium Isotopes

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Routine measurements of formation pressure while drilling reservoirs can indicate the presence of internal barriers to vertical fluid movement when there is a sudden shift in the pressure data. However, pinpointing the location of a barrier is often not possible since the density of pressure measurements is low and irregular. The aim of this contribution is to show how geochemistry can help to pinpoint the precise location of a barrier. As an example, we use a 25 m thick interval within the Middle Jurassic Hugin reservoir unit of the Langfjellet oil discovery on the Norwegian Continental Shelf. The location of the barrier is constrained by the upper and lower pressure measurements and could correspond to any of the several layers of silt, shale or coal layers in this interval. In this study, we collected every 2-4 m a total of 39 samples from a 110 m long cored section of a technical side-track well over the available. Each sample was prepared and analyzed using the SrRSA method (Strontium Residual Salt Analysis), which measures the $^{87}Sr/^{86}Sr$ ratio in salt residue that precipitated in the pore space after the core dried out. The $^{87}Sr/^{86}Sr$ is a natural tracer because the ratio is not affected by mass fractionation. The $^{87}Sr/^{86}Sr$ in rocks is mostly acquired by water-rock interactions during diagenesis and evolves through mixing and equilibration of different water bodies, unless low-permeability barriers prevent equilibration. Therefore, the SrRSA patterns observed in the well represent a 1D snapshot of the fluid dynamics at the time of oil filling, which is a frozen image of competing equilibrium vs disequilibrium conditions. The SrRSA data follow a smooth trend of content values at 0.713 and display a sudden jump to lighter 0.709 values near the top of the 25 m thick interval that suggests the presence of a potential barrier. The lithological core log shows that the SrRSA step change corresponds to a coal-shale unit, which is interpreted to represent the barrier. The SrRSA data further demonstrate the reservoir unit at Langfjellet does not contain any other barriers to fluid flow, since pressure equilibration could have masked a possible compartmentalization. This study shows that the SrRSA method is a powerful tool that helps to locate the precise location of a barrier causing pressure differences between adjacent or superposed compartments. Finally, the RsRSA can also be used to confirm communication since homogeneous pressure may either indicate fluid connectivity or pressure equilibration across barriers.

Multi-scale influence of topography on shallow-marine successions associated with long-term transgressions: from Argentinean outcrops to the Norwegian shelf subsurface

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Thick shallow-marine successions associated with long-term transgressions are less well known than their thin, well-sorted counterparts, more widely studied due to their potential to form good reservoirs. In these successions, particularly in storm-dominated examples, bioturbation can obliterate primary sedimentary characteristics, making stacking patterns and sequences difficult to define, and challenging our understanding of the main controls in their resulting depositional architecture. This study presents an example from the Jurassic of the Neuquén Basin (Argentina), with the aim to: a) refine the depositional model of a thick, shallow-marine succession associated with a long-term, early post-rift transgression, b) constrain multi-scale controls on stratigraphic architecture and lateral facies variability, and c) discuss their preservation and response to post-depositional processes. To do this, a <300 m-thick succession has been studied along a >10 km continuous exposure, with geological mapping, sedimentary logging and correlation of stratigraphic units, integrated with subsurface, biostratigraphic and ichnological data. The succession shows an overall retrogradational-aggradational-retrogradational stacking pattern, with several higher frequency regressive units (parasequences and parasequence sets, PSS). The lower part (PSS I) comprises laterally-discontinuous (10's of m) mouth-bars and distributary channel fills, dominated

by several m-thick coarsening- and fining-up sandstone packages and m-scale erosive conglomeratic lenses. Above these, the succession (PSS II-IV) is composed by laterally-continuous (>100's of m) storm-dominated lower-shoreface to upper-offshore deposits, dominated by <1m-thick fine-grained and highly bioturbated tabular muddy sandstones and sandy mudstones, with rarely-preserved HCS and bioclastic-rich limestones; their internal characteristics and bed boundaries are diffuse due to pervasive bioturbation, suggesting overall low sedimentation rates and recurrent periods of colonization. The coarse-grained nature and lithology of the mouth bars and channel fills in the lower succession (PSS I) are consistent with a proximal sediment source, associated with erosion of intra-basinal highs. Its variable thickness, lateral distribution and onlap against underlying syn-rift deposits demonstrates partial infill of localized higher-accommodation areas. The well-sorted and finer-grained nature of the shoreface-offshore strata the middle and upper succession (PSS II-IV) indicates a more mature, distal source, with sediment redistributed by longshore currents, and then intensely bioturbated. These deposits display well-defined parasequences internally composed of laterally-continuous bedsets (<5 m-thick). They extend along the entire study area, but show a significant vertical thickness variability. The integration of outcrop and subsurface data (well and seismic) reveals the long-term transgression occurred over a complex, regional-scale ramp-step and underfilled rift topography, which controlled the location of main thickness and facies changes, and promoted areas of favored biogenic reworking. This study offers new insights in how to interpret thick transgressive successions based on primary depositional mechanisms and postdepositional processes, and provides useful tools to understand and predict the nature and potential preservation of these deposits in limited subsurface datasets.

First results from the Skutshorn rock slope instability, Vang municipality, Innlandet

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The Skutshorn rock slope instability is located along the NE shore of Vangsmjøse. A thrust fault divides the Vangsdekket (phyllite) in the footwall with the Valdres-sparagmite (arkose, quartzite, and mica schists) of the hanging wall. The instability was discovered during reconnaissance from aerial photos and verified to be an active instability during the first field campaign in 2018. InSAR analysis using data from the Sentinel-1 satellites (https://insar.ngu.no) indicate that velocities vary significantly over the instability with an average of 2 cm/yr in the upper part and 0.5 cm/yr in the scree deposits along the shore of Vangsmjøse. The highest velocities have been documented in the middle part, where the instability is strongly fractured into individual blocks of several tens of meters diameter. Periodic dGNSS surveys (using points installed by NGU), as well as ground based InSAR campaigns by NVE in 2019, agree with the satellite data. The road authorities recorded several small rockfalls between February 2019 and June 2020. On October 12th, 2019, a rockfall came down the slope from approximately 550 meters above the lake level. The material reached the lake, covered, and blocked the road over a stretch of 100 meters and left it closed for almost three days.

Our preliminary data suggest that the instability comprises at least four different failure scenarios, with two self-standing scenarios in the front and one scenario in the central part. We also consider the possibility that the entire slope can also be combined into a single large scenario that even might continue below the waterline.

The volume of the frontal scenarios, as determined by SLBL and PLANOS, is in the range of 100 000 to 1 million cubic meters. The model of the potential runout of both were calculated using DAN3D with frictional rheology using a low pore pressure and friction angle ranging from 25º to 32º for basal friction. The results indicate that both scenarios would reach the lake. Data processing in the next weeks will help to define the other scenarios. This will be complemented by bathymetric mapping of Vangsmjøse to delimit the entire instability and to map out events of potential earlier catastrophic failures.

Groundwater flow patterns predicti-on using unsupervised machine learning

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A database of more than 3000 water samples taken along the Somali territory has been stored for more than 30 years without making further use of it. The water chemical composition database built by C. Faillace in 1986, is a compilation of more than 100 technical reports and unpublished documents from the 1983 and 1986 period.

FAO SWALIM and other organizations have conducted more recent and detailed surveys but are limited to certain areas for security reasons. This database has about 300 samples, which overlap with some water sources that were previously reported and analyzed by Faillace in 1986.

The main objective of this study was to understand whether these databases were useful to predict ground-water flow patterns. The initial approach using piper diagrams showed that it was possible to classify water types and quality from the main six ions, but it was not conclusive for flow patterns predictions; the samples are too many but not enough per square kilometer.

Since lithology plays an important role on water composition, a second approach was to run an unsupervised model to find similarities and to group water samples from the main six ions to infer its provenance. The first run provided four different groups that were analyzed in connection with the surface geology. The model was refined and lead to re-

classifying the water samples into 13 groups of well-defined types of water.
The 13 groups were analyzed individually following Chevotarev sequence identifying two main cycles in most of the catchments. The first cycle begins with low ions concentration and continues with an increment of HCO3-, SO42, and Cl- respectively. The second cycle starts building geographically around the first cycle with an initial ion content resulting from the first one and continues with an increment of HCO3-, SO42, and Cl- respectively. The observed geometry contrasted with water levels, suggests the preferred flow directions taken by the water.
These results are supported by a difference of 60 m. on average on the topographic altitude of occurrence; the first cycle occurs higher up in the mountains closest to the recharge points where lower ion content is expected. Furthermore, the higher strontium content measured in the second cycle suggests a longer time in the aquifer.
Highly sulfated water exceptions to the Chevotarev sequence were identified in shallow aquifers in a large area where some wells drilled by the oil industry showed formations with low salinity water at depths deeper than one kilometer. The high sulfate content on the shallow aquifer, related to a thick outcropping evaporites formation, suggests a vertical disconnection between the shallow and the deep aquifers. This opens the discussion for further investigations on the provenance of the freshwater found in the deeper formations.

Caprock characterization of Longship CCS project

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The CO_2 storage site of the Longship CCS project is located in the Horda Platform (south of Troll Field) in the northern North Sea. The potential CO_2 injection area is bounded by Svartalv and Tusse faults. The Early Jurassic Johansen and Cook Formation sandstones are the main reservoirs in the area capped by the Drake Formation Shale. Failure of the caprock during injection and post-operation is the major risk of the site besides other factors such as reactivation of faults and flexural effect because of production from the overlying Troll reservoirs (i.e., Middle Jurassic Sognefjord sandstone). Therefore, a careful investigation of caprock is needed to evaluate any CO_2 leakage risk. The Drake Formation shale caprock was part of the mega sequence 6 and deposited in a prodelta to delta front environment and divided into two-part based on the lithological variations. The upper part consists of dark grey to black, fissile, micaceous shales containing calcareous nodules, while the lower part consists of medium grey, slightly sandy calcareous claystone. However, white to grey, fine to coarse-grained, often hard, and calcite cemented sandstones are found in the upper part of the formation.
Gamma-ray logs from 23 wells were analyzed to evaluate the qualitative lithological variation of the Drake Formation. The caprock geomechanical parameters such as Young Modulus (E) and Poisson's Ratio (ν) were calculated using the machine learning technique predicted synthetic Vs (shear wave velocity), and assessed using rock physics templates with the data from three selected wells 31/3-3, 31/4-4, and 31/5-2. Moreover, the rock brittleness Indices (BI) were computed using empirical relation based on elastic parameters. The wells 31/3-3 and 31/5-2 are located in the Horda Platform area, where the Drake Formation is located in shallow depth compared with the basinal well 31/4-4, even after exhumation correction. The well correlations reveal that most of the eastern wells do not have the shaly lower part and contain more sandy upper-parts than the western wells. These lithological variations in Drake Formation affect the mechanical properties. The eastern well 31/3-3 (sand-dominated Drake Formation) has higher Young's modulus (E), and lower Poisson's ratio (ν) values (higher brittleness) than well 31/5-2 but has similar properties compared to western well 31/4-4. Although the Drake Formation in the study area was deposited in post-rift time, local sub-basins formed due to the differential subsidence across major faults. This Paleo-depositional phenomenon influences sedimentation that is manifested by the local lithological variations within the Drake Formation. The lithological variation, in turn, influenced the compaction processes (i.e., mechanical and chemical), and so, the sandy eastern wells compacted more and showed higher brittleness.

Geologiske undersøkelser av det ustabile fjellpartiet Åsvedkammen

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Norges landskap med sine karakteristiske dype fjorder og daler er veldig utsatt for ustabile fjellpartier som kan rase ut som fjellskred. Norges geologiske undersøkelse (NGU) har så langt kartlagt mer enn 580 ustabile fjellpartier som klassifiseres systematisk etter potensiell fare og risiko. Åsvedkammen (sørvestsiden av Gloppenfjorden i Gloppen kommune) er en ustabil fjellside som viser tegn på gravitativ deformasjon. Skråningen faller mot øst og det høyeste punktet på toppen av den 20-50m høye bakskrenten ligger på ca. 530 moh. Nedenfor bakskrenten er terrenget ulendt med store sprekker, tett skog, bratte skrenter, motskrenter og løse blokker. Berggrunnen i området består i hovedsak av gneis og kvartsitt, men det finnes også noen små områder med ultramafiske bergarter (blant annet er det funnet serpentinitt i et område rett ved baksrenten). En hypotese er at glideplanet er listrisk. For å få svar på dette skal det gjøres en strukturgeologisk detalj-kartlegging av området med måling av forskjellige diskontinuiteter (sprekker, åpne sprekker, foliasjoner og forkastninger) og dokumentasjon av andre felt-observasjoner. Ut ifra strukturmålingene skal det lages en geologisk modell, volumet til det ustabile område skal estimeres og ved hjelp av kinematisk analyse skal det anslås hvordan skrenten blir påvirket. Siden en

kollaps av fjellpartiet vil forplante seg i fjorden, er det viktig å karakterisere området i detalj for å kunne vurdere farenivået. Derfor er det viktig å forstå både strukturgeologien, volumet og bevegelsen til området og faktorene som driver ustabiliteten.

Possible remnants of ancient weathering and landforms in Røysjømarka, south-eastern Norway

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Røysjømarka is a lens shaped, undulating hilly terrain in south-eastern Norway (approximately 18 x 9 km), bounded by Drammensfjorden to the East and Kobbervikdalen to the West. Røysjømarka reaches elevations up to 400 m.a.s.l, i..e. most of the hills above marine limit of the postglacial transgression.
Located within the Permo-Carboniferous Oslo paleorift, Røysjømarka forms part of the Drammen batholith segment, consisting of a series of early Permian intrusions, known as the Drammen granite.
In the northern part of Røysjømarka, sections of Drammen granite are exposed along a c. 4 km path that follows a north-south trending fault line. Here, two main types of protolith texture and composition have been identified: 1) a fine – medium grained, two-mica granite and 2) a porphyritic type, showing quartz and alkali feldspar phenocrysts dispersed in a fine-grained (aplitic) matrix.
Remnants of weathered rock (regolith), not consistent with being formed in present-day climatic conditions, were observed at several places along the exposed trajectory: 1) blocks, separated by intersecting facture planes, displayed rounded corners that had developed into spheroidal shapes (typical features of lower levels of the regolith profiles in Mediterranean and sub-tropical to tropical regions). 2) Clay-filled fractures, observed extending from top to base of the exposed sections, contained a mixture of kaolinite and illite-smectite, clay minerals that are typically formed in temperate – hot and humid areas.
In addition, a possibly younger episode of arenization (grusification) was indicated by the presence of rocks that easily disintegrated by the force of hand, characterized by reduced mechanical strength, but with very low degree of chemical transformation to secondary clays.
Earlier studies (e.g. Olesen et al., 2006; Japsen et al., 2018) have hypothesized that an ancient weathering surface from mid Triassic to mid Jurassic was partly preserved below a sedimentary cover, which was later removed during early Pliocene uplift and erosion. If this is the case, the Røysjømarka regolith and landforms may represent a re-exposed Mesozoic weathering surface.

Use of pore pressure data from the Norwegian Continental Shelf to characterize fluid-flow processes and barriers

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Jurassic reservoirs in the Norwegian shelf can be divided into four virgin pressure regimes according to their depth and position. At great depths (below 3500-4000 m) one usually encounters the strongly overpressured regime, where the pressure is determined by the fracture pressure of the overburden. Closer to the coast at shallower depth (typically less than 2500-3000 m) one usually finds the hydrostatic pressure regime, where water pressure is very close to the theoretical water pressure which depends on depth and density determined by salinity, temperature and pressure. Between these two regimes at depths of 3000-4500 m one will usually observe the transitional regime, where pressure decreases from high overpressure towards hydrostatic. In the recently strongly eroded regions in the coastal areas and the Barents Sea, one can find underpressured and hydrostatically pressured aquifers, where underpressured aquifers (pressure less than hydrostatic) tend to have small size and/or low permeability.
Production and injection of petroleum has caused depletion of many reservoirs and aquifers, and in some areas recent wells often find a depleted, underpressured regime caused by human activity.
These general pressure regimes can set up subtle pressure steps between segments in petroleum fields and aquifers. Investigation of these pressures is very useful and can help to explain fluid contact differences and make predictions for non-drilled segments. Such pressure steps can be set up in all pressure regimes, but the different pressure regimes behave differently, and steps are produced in different ways.
The Skarv Field is an example from the transitional regime which is characterized by gradual pressure decrease from higher to lower pressure. In this area large Pleistocene movements of the Nordland Ridge may have caused poor equilibration of fluid contacts.
The Goliat Field is an example from an eroded area, where subtle pressure differences are set up by fluid density differences and gas leakage. The lowest pressure is found in the Snadd reservoir, which is less permeable and has a smaller connected aquifer than the Kobbe and the Realgrunnen aquifers. Realgrunnen aquifer has the highest salinity and the highest pressure.
On the Utsira High, in the area of the Johan Sverdrup and Balder-Grane fields, pressure has initially been hydrostatic, but it has been depleted by gas and oil production, first from the Frigg Field, later on by the Heimdal, Sleipner East, Balder and Grane fields. Careful study of oil composition, fluid contacts and pressures can unravel some of the history of oil migration, spill and mixing of the oils in these reservoirs. The Pleistocene depositional history is another important piece in this puzzle.
Reference:

Riis, F. & Wolff, A., 2020: Use of pore pressure data from the Norwegian Continental Shelf to characterize fluid-flow processes in geological timescales.

Small and large-bodied ichthyopterygians from the Early Triassic of Svalbard

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Ichthyosaurs are a major group of Mesozoic marine reptiles ranging from the Triassic to the mid-Cretaceous. The earliest representatives (Ichthyopterygians) of this group appear in the Early Triassic of Svalbard, China and North America, demonstrating a near global marine distribution. Recent excavations in the Early Triassic "Grippia bonebed" from the Vendomdalen Member of the Vikinghøgda Formation of early to middle Spathian age (Svalbard) revealed a large amount of ichthyopterygian remains. These elements are disarticulated, largely uncompressed and represent at least two different taxa and ontogenetic stages. Here we present the evidence that these remains include a large-bodied ichthyosaur (*Cymbospondylus*), a grippidian ichthyopterygian (*Grippia longirostris*) as well as possibilities for additional taxa. This material is important, as there is limited amount of fossil material referred to *G. longirostris*, with the holotype lost in WWII. As such, the disarticulated cranial material described from the Grippia bonebed helps understand, the poorly preserved skull morphology of this taxon. The shear amount of material, as well as the diversity in size and palaeoecology, demonstrate a larger biodiversity of ichthyopterygians than previously suggested at such an early stage of their evolutionary history.

Late- and postglacial relative sea level changes at Kristiansand, S Norway

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We present work in progress on a reconstruction of relative sea level changes at Kristiansand since deglaciation until today. Through several field trips during 2018–2020 we cored and investigated the stratigraphy of a suite of 20 isolation basins in the areas of Randesund and Høvåg. A total of 35 new sea level index points have been identified and radiocarbon dated. The isolation basins are mostly 10-15 m deep bedrock depressions, presently occupied by lakes and bogs. Isolation and ingression events were identified using biostratigraphy (macrofossils) and radiocarbon dated from series of 3-6 samples of terrestrial plant macrofossils picked at, below and above the stratigraphical transitions. The new relative sea level curve delineates the precise timing and course of the early-mid-Holocene Tapes transgression in this area, as well as documenting an intriguing late Holocene (2-1 ka) acceleration in relative sea level fall. Several basin records extend back to deglaciation of the Kristiandsand area which is dated to 14.000 years ago. The stratigraphy of the Lateglacial records document that a marine transgression of 4-5 m took place during the late Allerød and Younger Dryas. A transgression during this period is well-known from studies in western Norway but has not previously been documented from this southern coastline. Our results provide new constraints for numerical modelling planned in the QUANTSEA-project.

CO_2 reservoir characteristics and storage potential in volcanic rifted margin basalt sequences: an analogue from the Faroe Islands Basalt Group

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Storing CO_2 in basalt reservoir sequences represents a permanent, safe, and large-scale potential worldwide. Injected CO_2 may react with the minerals in basalt to form carbonate-bearing mineral assemblages. Experiments indicate nearly complete mineralization of injected CO_2 within as little as two years, reducing the risks of leakage compared to sandstone reservoirs where CO_2 remain in liquid form for thousands of years.
The Early Cenozoic opening of the NE Atlantic led to extensive volcanism and the formation of the North Atlantic Igneous Province (NAIP). The Faroe Islands represent an uplifted part of the NAIP, providing an opportunity to study volcanic margin basalt sequences in the field. Well data, core samples, outcrop data and photogrammetry models from the Faroe Islands have been used to characterize the reservoir properties and geometry of the lava flows. The Enni Formation comprises the upper part of the Faroe Islands Basalt Group and was chosen for this study as it is least affected by hydrothermal fluid circulation and associated secondary mineralization. The Enni Formation contain both simple and compound lava flows with interbedded volcaniclastic units. Each simple lava flow consists of a thin (c. 0.5-2.0 m), porous flow base that transitions into a massive low porosity flow core (c. 5-25 m) which in turn transitions into a thick (c. 2-10 m), porous and often fractured or brecciated flow

top. The flow tops and flow cores represent potential sequences of vertically stacked reservoir-seal couplets.
Results from this study include 1) wireline logs from the Glyvursnes-1 borehole indicate high porosities (c. 25-35%) for flow tops within the Enni Formation; 2) unmineralized, brecciated flow tops have high preserved porosity and high inferred permeability; 3) tabular lava flows can be traced for several kilometers and contain flow tops up to 10 meters thick. The net-to-gross ratio (of suitable reservoir units to total formation thickness) for the studied Enni Formation examples is up to c. 0.26. Applying these numbers to an offshore scenario with an extent of c. 12.5 km^2 and thickness of 500 m, we predict storage sites with potential net pore volumes of at least 0.6 km^3. In conclusion, the flow tops of simple lava flows have the largest potential for CO_2 injection and will be our main target for future appraisal.

Post-Eocene sandy systems in the northern North Sea

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Sands are ubiquitously present in the post-Eocene section of the northern North Sea. In the upper part of the Hordaland Group, many sands have been encountered in wells but are difficult to map due to chaotic seismic facies. In the Nordland Group, the Utsira sands have been the focus of several workers and different depositional models have been proposed. Based on a study of 2D and 3D seismic and well data, we present an overview of the major post-Eocene sandy deposits together with an improved model of Utsira sand deposition.
Oligocene sands are seismically difficult to map. A large system of sands, commonly hidden in seismic chaotic facies, occur in Quadrants 33, 34 in the Tampen Spur area. These sands are shed from the East Shetland Platform and reach gross thickness in excess of 200 m pinching out to the northeast. The sands overlie Eocene claystones and were most likely deposited as turbidites during Rupelian.
In the upper part of the Oligocene, sands are less frequently observed but, locally, have been encountered below mounded features on the mid-Miocene unconformity. On high-resolution seismic, these sands are locally well imaged and commonly associated with injection sand features. We interpret these as in-situ remobilized turbiditic channel sands.
The Skade sands represent a thick sandy system stretching from Southern Viking Graben (SVG) to the Gullfaks area. The sands were deposited during early Miocene forming a massive pile of turbiditic sheet sands in the basin center. The recent Liatårnet oil discovery was made in thinner sandstone beds below the massive Skade sands.
Overlying Skade in the basin center (Q30), the Utsira sands were deposited in a shelfal environment as lobate deposits reaching gross thickness in the order of 200 m. The sands can be subdivided into five units (U1-U5) separated by thin mudstones. The units form individual lobes that migrate in a northerly direction switching east and west as accommodation space is being filled up. Units U1-U3 were deposited during middle Miocene, whereas the upper units (U4-U5) were deposited during late Miocene. The Utsira sand in SVG differ from its northern counterpart by being sheet sand deposits. These were mainly deposited during late Miocene/early Pliocene, most likely as turbidites.
Overlying the Utsira, turbiditic sands occur within the Naust Formation, in the Oseberg and Snorre field areas. Early Pleistocene deltaic Gilbert-type progradation near the Frigg area records the final input from west before drowning of the large Cenozoic Shetland landmass.
In summary, most of the Oligocene-Miocene sands occurring in the northern North Sea were shed from the East Shetland Platform as erosional products in response to uplift. Sandy input from east was to a much lower extent, as the oblique Fennoscandian uplift resulted in mainly eastward-directed draining systems with sand deposition in Denmark.

Slide model revisited: Giant collapse of Oligocene-lower Miocene strata in Northern North Sea and Møre Basin

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We present an updated version of a previous model, in which chaotic seismic pattern of Oligocene strata in the northern North Sea and Møre Basin was ascribed to a giant collapse of the Oligocene sediment succession, due to uplift of the basin margin (Rundberg & Nystuen, 1999). Recent mapping of 3D and 2 D seismic data supports this interpretation and adds further information on structural character of the slide complex and timing of deformation.
In the northern North Sea, the Oligocene and lower Miocene sedimentary succession is locally characterized by large-scale folding, mounding and intense faulting. Such features are present particularly on the Horda Platform to the west of the Troll Field. The folded strata have amplitudes up to 150 m. In the Stord Basin, mounds at the mid-Miocene unconformity reach heights up to 100 m. Locally, the mounds comprise smaller structural segments with highly inclined strata and faulting patterns.
In the area at about 61° N, the Oligocene-lower Miocene succession is particularly chaotic. Large, mounded structures are located between compressional deformed successions in an area supposed to represent

the collision front between an eastern slide complex, having moved westward, and a western slide complex, having moved eastward. The eastern slide complex comprises the entire Oligocene-lower Miocene sedimentary succession, whereas the western slide complex carries the heavy load of the thick Skade Formation sand deposits. Overlying the folded successions, middle Miocene Utsira sands occur in structural lows and onlap mounds on the mid-Miocene unconformity surface.

In the Møre Basin, chaotic deformation structures also occur within the Oligocene succession. The deformed sediments define an elongate northwesterly trending body ending in a large curve-shaped front, mapped from northernmost North Sea to about 63° N. Locally, behind the front, the top Oligocene is heavily folded with amplitudes exceeding 100 m. Anticlinal ridges are chaotic in internal organization, in contrast to the lows which are less deformed.

We here propose a revised model of the strongly contorted Oligocene-lower Miocene succession in the northern North Sea-Møre Basin, as originated by gravitational tectonics, forming slide complexes, in response to uplift of southern Fennoscandia and the East Shetland Platform. During late Oligocene-early Miocene, this uplift gradually led to shallower conditions, as the flanks of the northern North Sea-Møre Basin gradually were brought into submerged and unstable positions. At the end of early Miocene, the uplift and tilting of the unconsolidated sediments resulted in collapse and sliding of the entire Oligocene-lower Miocene sediment pile. The sliding probably took place in steps, thus giving rise to a complex of individual slides. The smectitic top Eocene interval with high pore-pressure build-up probably acted as a perfect glide zone. The gravitational deformation represents an important stage in the Cenozoic uplift history of the Scandes in southern Scandinavia.

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Strike-slip faults in the Oslo Region - Caledonian compression or Permian transtension?

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The Oslo Region provides the opportunity to study both the development of the late Silurian Caledonian fold-and-thrust belt and the formation of the Permo-Carboniferous continental Oslo Rift. The Oslo Rift is possibly connected to the Variscan orogenic front and the Sorgenfrei-Tornquist Zone through the Permo-Carboniferous Skagerrak and Horn grabens. The complex structural evolution of the region is reflected in the Lower Palaeozoic sediments that have been downfaulted in the Precambrian crystalline basement in the Oslo Rift. This study investigates, through detailed mapping and the construction of balanced cross-sections, the characteristics and origin of sub-vertical strike-slip faults found within the Oslo Region. Previous papers that have explored the tectonic evolution of the region have regarded these faults as representative of a Permo-Carboniferous strike-slip regime related to the formation of the Oslo Rift rather than as a part of the Caledonian structural style. Specifically, the steep faults have been assigned to a strike-slip regime induced by the Sorgenfrei-Tornquist Zone.

Approximately 3 months of fieldwork at selected study areas, Huk and Slemmestad, that were thought representative of the geology of the region resulted in new findings regarding the NNE-SSW striking sub-vertical strike-slip faults. Detailed mapping revealed adjacent domains of differing compressional structures where the lateral break in geology can only be explained by Caledonian tear faults. Additionally, tear faults at smaller scales were observed to terminate in overlying and underlying Caledonian thrust faults, implying that the group of steep faults were formed alongside the thrusting rather than post-dating it. The prevalence and impact on surrounding geology of Caledonian tear faults indicate that they are an integral part of the Caledonian structural style. This study therefore suggests that sub-vertical strike-slip faults in the Oslo Region should be individually mapped and checked against a set of criteria proposed in this thesis to distinguish between Caledonian tear faults and strike-slip faults of a Permo-Carboniferous age.

This study suggests that Caledonian tear faults in previous studies may have been misinterpreted and included in the database for the analyses of some of the tectonic phases relating to the Oslo Rift. Therefore, the faults ascribed to these phases should be checked against the new, proposed criteria for Caledonian tear faults. Furthermore, investigation of the sills in the study areas suggest, in contrast to earlier studies, that a late Carboniferous compressional phase is not required as a controlling factor behind sill emplacement. Consequently, the Sorgenfrei-Tornquist Zone probably had less of an impact on the initiation of rifting than previously assumed, which in turn would have implications for the model of passive rifting in the Oslo Rift.

A Cambrian–Ordovician boundary section in the Rafnes–Herøya sub-marine tunnel, Skien–Langesund District, southern Norway

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Rock specimens and contained fossils collected in 1976 from a submarine tunnel driven between Herøya and Rafnes in the Skien–Langesund area of southern Norway, have been restudied. The contained fossils include olenid and agnostoid trilobites, graptolites and brachiopods, groups described in detail for the first time from the area and documenting a Cambrian–Ordovician boundary section unique in the district where the upper Cambrian Alum Shale Formation is elsewhere overlain by the Middle Ordovician Rognstranda Member of the Huk Formation (Kundan in terms of Baltoscandian chronostratigraphy). The hiatus at the base of the Huk Formation is thus smaller in the section described herein, beginning at a level within rather than below the Tremadocian. Estimated thickness of the Alum Shale includes 10–12 m of Miaolingian and 20–22m of Furongian strata with trilobite zones identified, and a Tremadocian section of 8.1 m identified by species of the graptolite *Rhabdinopora* in the basal 2.6 m and *Bryograptus ramosus* at the top.
The Tremadocian section is preserved in a postulated zone of synsedimentary subsidence along the Porsgrunn –Kristiansand Fault Zone, while at the same time there was extensive erosion across an emergent, level platform elsewhere in the Skien–Langesund District and the southern part of the Eiker–Sandsvær District to the north.

Preliminary results of the Carbonates in Trøndelag project

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The carbonate rocks of Trøndelag are important raw materials both locally and in a national context. Different ore-qualities in the seven mines and quarries in operation (DMF, 2020) provide raw materials for a large spectrum of industrial applications. Carbonates of industrial interest on the Norwegian mainland have formed in a variety of geological situations from the Paleoproterozoic to the Silurian, and because of their complex geological history they show considerable differences in chemical and mineral characteristics.
The carbonate rocks of Trøndelag show a wide variety of characteristics, ranging from low metamorphic, fossil rich limestones to high-metamorphic coarse-grained calcite marble. Because of the large geological variations, the active mines and quarries covers a wide range of end-use products. This includes impure, graphite and silicate rich limestone for agricultural use, aggregates for construction and infrastructure, pure calcite marble of high whiteness used for ground calcium carbonate (GCC) in the paper industry, and burnt lime for production precipitated calcium carbonate (PCC).
So far during the project period of 2019-2021, new samples and data have been collected from carbonate deposits and occurrences all over Trøndelag. Along with previously reanalysed samples stored at NGU's National Drill Core and Sample Centre (NBPS) in Løkken, we aim to give a preliminary overview of the variation of carbonate rocks of Trøndelag. We aim to identify new areas and deposits with a potential for future developments.
A particular focus has been calcium carbonates with low contents of crystal-bound iron and manganese within the carbonate mineral. Such high purity carbonates are suitable as a raw-material for production of high-whiteness carbonate products. On the other side, we also aim for impure carbonates that are suitable for making burnt lime for use in restoration projects of old buildings. So far, a new deposit in Ålen (Holtålen municipality, close to Røros) have been identified for restoration purposes, but further results of chemical and mineralogical analyses need to confirm the field observations.
The Carbonates in the Trøndelag project is part of the "Trøndelagsprogrammet", run by NGU in cooperation with Trøndelag County Council.

Extensive instrumentation of an unstable slope – monitoring active deformation of a rock column and scree deposits at Stampa (Aurland)

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The unstable mountain slope at Stampa above Aurlandsfjorden (Vestland) has been sporadically monitored since 2005 (Blikra et al., 2013). A section that has been classified as a high-risk object (Scenario 3) at Joasetbergi has been continuously monitored since 2016 (Kristensen & Bergeng, 2018). Ground-based InSAR data covering large parts of the unstable slope detected a smaller, strongly deforming object called «Scenario 4a» which is situated southwest of Joasetbergi. This scenario refers to an approx. 5,000 m^3 rock column that rests on a highly fractured base, adding to a total volume of up to 40,000 m^3. The slope below this instability is characterized by coarse scree deposits containing up to ca. 500 m^3-sized boulders. The scree deposits result from previous rock-slope failures show also signs of active deformation.
During several field campaigns between autumn 2019 and autumn 2020, we installed several instruments to obtain a comprehensive overview of the active deformation of the entire slope, from «Scenario 4a» (800 m a.s.l.) down to the fjord. Two extensometers

across the ca. 5 m wide back fracture monitor the displacement and velocity of the rock column of «Scenario 4a». A tiltmeter registers the rotational components of the movement and a time-lapse camera monitors the installations on a daily basis. In addition, we have installed three geophones, which register seismic signals from the slip behaviour of the rock column and any motion in the mountainside. In order to quantify superficial deformation, a total station situated at the bottom of the slope continuously measures the position of 22 prisms. The prisms are installed on large boulders across the scree deposits, on several elements of the unstable rock face of «Scenario 4a», and on supposedly stable bedrock as reference points. Finally, a inclinometer system and three pore pressure sensors in a 27-metre deep borehole in the lower part of the scree deposits provide control over subsurface motion.
Preliminary results based on field observations, structure from motion analysis and instrumental data indicate that «Scenario 4a» is composed of several individual unstable elements which have different velocities and deformation vectors. The element showing most active deformation is the central base below the unstable rock column. The rock column has an average velocity of ca. 7 cm a^-1 and counterrotates slightly around a subhorizontal axis. Data from our newly-installed instruments will, together with other available data (ground-based and satellite-based InSAR), provide a holistic picture of active deformation in this mountain slope.
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Rock surface temperatures in steep high Arctic rock walls on Svalbard

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Warming permafrost temperatures and the effect on slope stability have been studied intensely in recent years, especially in mountainous areas and sub-Arctic regions. However, the thermal regime of steep rock walls in the high Arctic is still poorly understood and a better understanding of the occurring processes is needed. We present measurements of rock surface temperatures (RST) in steep rock walls on Svalbard, comparing coastal and non-coastal settings. The surface energy balance model CryoGrid 3 is used for evaluation, taking into account the modified radiative forcing in vertical rock walls.
Our results indicate that monthly RST in coastal cliffs are increased up to 1.5 °C compared to non-coastal rock walls, which can be traced back to higher air temperatures at the coast compared to inland locations, as well as long-wave emission by relatively warm seawater. Ice coverage on the fjord counteracts this effect. Consequently, sea ice loss might lead to higher RST in coastal cliffs during winter.
We calculated a surface energy balance of both coastal and non-coastal settings. The fluxes in summer and fall show just slight differences, while they differ significantly in winter and spring, when the water body of the fjord acts as an additional energy source for the coastal settings.
Future climate conditions might lead to a further warming of RST and a deepening of active layer thickness as simulations for different pathways indicate. RCP2.6 and RCP4.5 result in a stabilization of mean annual RST (MARST) between -4 °C and 0 °C, while RCP8.5 lead to positive MARST at the end of the century.
Here, we present a unique data set of RST measurements in steep rock walls in the high Arctic. With the thermal model CryoGrid 3, we can analyze the influencing factors in coastal and non-coastal settings and the associated fluxes of the surface energy balance.

Hvordan står det til med Norges grunnvann? Kartlegging av belastede grunnvannsforekomster

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Vanndirektivet trådte i kraft i EU i 2000 og er et av EUs mest omfattende og ambisiøse miljødirektiv. Direktivet skal legge grunnlaget for en mer helhetlig og samordnet europeisk vannforvaltning, der hovedmålet er å sikre beskyttelse og bærekraftig bruk av overflatevann, grunnvann og kystvann i alle medlemsland. Alle vannforekomstene skal opprettholde eller oppnå «god tilstand», basert på faglig anerkjente kjemiske, fysiske og biologiske parametere innen gitte tidsfrister. I 2006 ble direktivet utvidet med grunnvannsdirektivet, som gir kriterier for tilstandsvurderinger av grunnvann. Høsten 2010 ble grunnvannsdirektivet implementert i norsk lovverk som en del av vannforskriften. Norge er dermed pålagt å rapportere til EU om tilstanden til grunnvannsforekomstene ut fra en foregående karakterisering, klassifisering og overvåking.
Det finnes anslagsvis 8.000-10.000 akviferer i Norge, noe som er svært mange sammenlignet med de fleste andre europeiske land. Av praktiske og forvaltningsmessige årsaker er mange små grunnvannsforekomster slått sammen til større administrative enheter, noe som reduserer det offisielle antallet til cirka 1400 grunnvannsforekomster.
Norge har store mengder overflatevann med i all hovedsak god vannkvalitet og det brukes overflatevann til å forsyne omtrent 80% av Norges innbyggere med drikkevann. Det har derfor vært mindre fokus på å kartlegge, utnytte og overvåke grunnvann. I 1977 ble det etablert et landsdekkende overvåkingsnett for mark- og grunnvann (LGN) for å fremskaffe vannkjemiske data om den naturlige variasjonen i grunnvannets nivå, temperatur og kjemiske kvalitet. Ubetydelig menneskeskapt påvirkning fra lokale kilder var et viktig kriteria under utvelgelse av overvåkingslokalitetene. Det har

også vært gjennomført nasjonale kartleggingsprogrammer for å finne egnete grunnvannsforekomster til sikrere drikkevannsforsyning. For grunnvannsforekomster med forurensingsbelastning finnes det imidlertid svært lite data. Det er forventet at de fleste forekomstene har god kvalitativ og kvantitativ tilstand i henhold til vannforskriftens mål. Utfordringen er imidlertid å kunne dokumentere dette med faktabasert kunnskap.
Gitt det store antallet grunnvannsforekomster i Norge er det hverken hensiktsmessig eller økonomisk mulig å fremskaffe tilstrekkelig detaljerte data fra samtlige grunnvannsforekomster. På bakgrunn av dette er det igangsatt et samarbeid mellom Miljødirektoratet, NGU og NIBIO for å kartlegge, karakterisere og overvåke 14 utvalgte grunnvannsforekomster. Disse skal representere typiske hydrogeologiske forhold i Norge med belastning fra urbanisering og industriell virksomhet eller jordbruksaktivitet. Det er forventet at kunnskap og erfaring fra denne overvåkingen vil gjøre det mulig å anslå tilstand til de fleste grunnvannsforekomster uten omfattende og kostbar kartlegging og undersøkelser.
Resultatet fra kartlegging av vannkjemi i urbane områder viser så langt at grunnvannet har gjennomgående god kjemisk tilstand. For jordbrukslokalitetene viser undersøkelsene varierende grad av jordbrukspåvirkning, med forhøyde verdier av nitrat, kobber, sink samt funn av plantevernmidler.

Digital Festningen: a dark season journey through 300 million years of geological evolution

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The renowned Festningen section in the outer part of Isfjorden, western Spitsbergen, offers a c. 7 km long nearly continuous stratigraphic section of Lower Carboniferous to Cenozoic strata. Tectonic deformation associated with the Paleogene West-Spitsbergen-Fold-and-Thrust belt tilted the strata to near-vertical, allowing easy access to the section along the shoreline. The Festningen section is a regionally important stratigraphic reference profile, and thus a key locality for any geologist visiting Svalbard. The lithology variations, dinosaur footprints, as well as the many fossil groups, record more than 300 million years of continental drift, climate change, and sea level variations. As such, the Festningen section is the only protected geotope in Svalbard, covering an area of c. 17 km^2. The first detailed geological cross-section of the Festningen profile was published by Hoel & Orvin (1937), while a revised open-access field guide was compiled by Mørk & Grundvåg (2020).
In this contribution, we focus on presenting a digital outcrop model of this stratigraphic key section, acquired using a UAV (Mavic 2 Pro, 20MP Hasselblad camera). The main objective of this field campaign was to digitize the entire Festningen section, using structure-from-motion photogrammetry. During acquisition, the maximum drone speed was set to 1 meter/second (i.e., "tripod mode"), and photographs were taken automatically at set time intervals (e.g. 1 photo every 5 seconds ≈ meters). In total, 3757 photographs were aligned using photogrammetric processing steps, including sparse and dense cloud generation, point confidence calculations and confidence-based trimming (3% confidence), meshing and texturing, that resulted in a 7 km long digital outcrop model. Georeferencing relied on the drone-mounted GPS, and the resulting digital outcrop model is well aligned with the regional terrain model (estimated total camera error: 4.12 m). The digital outcrop model offers a pixel resolution of 7.27 mm/pixel and covers 0.67 km^2. The Festningen model will be presented for the first time at the Winter Meeting, and subsequently available online for anyone through the Svalbox.no geoscience data platform.
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Filling the Svalbard Rock Vault: Opportunities for deep-time paleo-climate studies

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Svalbard offers an insight into the sedimentary record of paleo-climate change from the Snowball Earth conditions around 650 million years ago through Late Paleozoic tropical and sub-tropical climates, Mesozoic climate fluctuations, Paleogene warming and Quaternary to Holocene glaciations. Vegetation-free outcrops provide excellent opportunities for relatively cheap sampling, as evidenced for instance by the renowned Festningen section in western Spitsbergen. High-resolution mm-to-cm scale sampling and non-destructive analyses are, however, only viable when fully-cored boreholes are available. The Deltadalen research boreholes were drilled in 2014 specifically to constrain the paleoclimatic evolution across the end-Permian mass extinction and provide an excellent role model for targeted future research campaigns to penetrate other geological intervals of interest. The helicopter-based operation was conducted with minimal environmental impact, and two ca. 100 m deep boreholes were drilled and fully cored within one week. In addition to the Deltadalen boreholes, significant material borehole material already exists in Svalbard. The Longyearbyen CO_2 lab boreholes penetrate most of the Mesozoic section near Longyearbyen (ca. 4.5 km of cores), including the Upper Jurassic 'black' shales and the Lower Cretaceous succession recording climate fluctuations of global extent. Store Norske's coal exploration boreholes cover the Lower Cretaceous and Paleogene (ca. 60 km of cores) and were used to infer high-resolution environmental shifts and age constraints across the Paleocene-Eocene Thermal Maximum. Finally, a research borehole was drilled and fully cored (1.1 km) through the Paleogene at Sysselmannbreen in 2008. Many more relevant boreholes were drilled, for instance for petroleum and coal exploration, but unfortunately many have been lost due to lack of a central core storage repository.

The Svalbard Rock Vault initiative aims to safeguard existing material and facilitate its scientific usage. The idea is not only to make existing core material more accessible, but also to provide facilities to conduct non-destructive high-resolution analyses on the drill cores in Longyearbyen (MSCL, XRF, digital photography and FAIR data archiving). Large numbers of samples have been collected by scientists from universities and research institutions. Many of these collections are "tied" to the project responsible and will be lost if the person changes job or retires. Such sample and thin section collections will also be included in the Svalbard Rock Vault. Our ambition is that the Svalbard Rock Vault will not only take care of existing data, but also facilitate the collection of more research drilling across key intervals in the future. In this context, we review the deep-time paleoclimatic studies conducted on Svalbard outcrops and boreholes, and summarize what material is presently available. We also solicit contributions from the international community interested in utilizing Svalbard's geological record for paleoclimatic studies, in anticipating of forming an international continental drilling consortium in the near future.

Characterization of HTHP Reservoir in the northern North Sea, Offshore Norway

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This study focuses on characterizing the high temperature high-pressure (HTHP) Tarbert Formation reservoir sandstones in the northern North Sea. A suite of well log data from two gas discovery wells [34/10-23 (Valemon) and 34/11-1 (Kvitebjørn)] from the Viking Graben was utilized to evaluate the reservoir quality. Middle Jurassic Tarbert formation's depth is 4084 and 4045m, in wells 34/10-23 and 31/11-1, respectively. In the study area, the depositional environment of the Tarbert Formation is marginal marine. It comprises moderately massive fine to medium-grained, gray to brown sandstone, with a minor amount of thin siltstone, coal beds and shale, and few calcareous bands (NPD, 2020). We carried out petrophysical analyses to calculate the clay volume (V_{clay}), total porosity (ϕ_t), and gas saturation (S_g). Moreover, rock physics diagnostics was performed to evaluate the target reservoir sandstones. A comparison of Gamma Ray Log responses of the Tarbert Formation in both wells indicates that well 34/10-23 has cleaner sand than well 34/11-1.

The cross plot of density (RhoB) and P-wave velocity (Vp) shows that the Tarbert Formation in well 34/10-23 exhibits relatively high P-wave velocity and increases with increasing density. However, there is not that much P-wave velocity variation with the increase in density in the other well (34/11-1). The cross plot color-coded with V_{clay} shows that the Tarbert Formation in both wells generally consists of low clays; however, the clay percentage is relatively high in well 34/10-23. The RhoB-Vp cross plots color-coded with total porosity (ϕ_t) and gas saturation (S_g) demonstrates that porosity in well 34/10-23 is relatively high (about 25%), compared to the well 34/11-1 (about 15%). The gas saturation (S_g) is relatively high (about 70%) in well 34/11-1, whereas the gas saturation in well 34/10-23 varies from 20% to 70%.

The comparison of Tarbert Formation in both wells shows a similar physical behavior as the formation depths are approximately the same, and the temperature variation is not significant, assuming no exhumation in the study area. Well 34/10-23 documented high velocity and high density compared to the other well due to calcite's presence. In well 34/11-1, the P-wave velocity in Tarbert Formation does not change with the increase of density values, possibly due to the presence of mica and preservation of porosity by chlorite coatings, which warrant further investigations.

Mechanical parameters of synthetic Draupne gouge using Direct Shear Testing

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CO_2 storage is an important strategy to reduce global emissions and help mitigate the effects of climate change. A key part of risk assessment in fault-bonded prospective CO_2 storage reservoirs, such as Smeaheia, is the estimation of fault rock properties. In this study, an experimental direct shear testing (DST) methodology was developed to evaluate friction and cohesion variation for homogeneous mixes analogous to fault gouge. The mixes consist of varying contents (dry mass %) of a clay-mineral fraction and a sand fraction, respectively: (1) crushed Draupne shale from the Ling depression, North Sea, analogous to the Draupne Fm. in Smeaheia; (2) Cuxhaven sand from offshore Germany, a fine to medium quartzitic sand, with less than 3% fines content (Quinteros et al., 2018), analogous to the Sognefjord Fm. in Smeaheia. The methodology was based on a range of Shale Gouge Ratio (SGR) values considered to be critical for seal capacity: 20 - 40% (Bretan et al., Yielding et al., 2010). Direct shear tests were performed in batches with 0, 10, 20 and 40% Draupne gouge content, and additional tests are planned for 60 and 100%. The samples were pre-consolidated to 1.75 MPa, with water used as the pore fluid. Three samples per batch were respectively sheared under constant normal stress of 0.5, 1 and 1.5 MPa, giving different overconsolidation ratio (OCR). A shear rate of 0.3 mm/min was used. Preliminary consolidation data was taken into consideration when choosing the shear rate. This same data revealed that up to at least 40% Draupne gouge content, the sample still shows a very fast consolidation, indicating a sand-dominated behavior. Pure Draupne gouge consolidated at a very slow rate, as more typical of clay.

Comparing the shearing test results for the batches containing 0 – 40% Draupne gouge, we observe that samples with higher Draupne content and those under higher normal stress (lower OCR) have a general strengthening behavior where the peak values become increasingly less defined. Residual stresses show insignificant variation for 0.5 and 1 MPa, but the difference becomes more pronounced for the highest normal stress (lowest OCR). Overall, for residual stresses, cohesion increases with clay content (6.5 to 88.2 kPa), while the friction angle decreases (31.0º to 25.9º). In sum, the preliminary results indicate that the properties of the synthetic gouge vary systematically with the content of Draupne gouge material. While the mechanical data shows a smooth transition from sand to clay behavior, the consolidation is very sand dominated up to 40% Draupne content, and clearly clay dominated with respect to drainage time (hydraulic properties) for the pure Draupne gouge. Further testing will help define this transition more clearly.

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Provenance of the Middle Triassic Kobbe Formation in the SW Barents Sea – constraining the Fennoscandian sand and locating the mixing zone

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Decades of research and hydrocarbon exploration in the intra-cratonic Greater Barents Sea Basin has resulted in an abundance of well-, core- and seismic data, making this one of the best understood basins in the world. This makes it an ideal region to investigate controls on provenance and sediment mixing processes in intra-cratonic basins. So far, more than 2000 U-Pb detrital zircon analyses have been published from most of the Triassic stratigraphy of the Barents Sea. However, as the data are not from time-equivalent formations, it is difficult to attribute variations to either temporal or spatial effects. Here, we target the A4 (uppermost) sequence of the Anisian Kobbe Formation (Glørstad-Clark *et al.*, 2011). By analyzing time-equivalent sediments from a large area, we eliminate the possible temporal effect in the provenance, and document the spatial variations in the sediment influx.

Traditionally, the Triassic sediments of the Barents Sea have been appointed to two main sources: a southern source related to the Fennoscandian Shield and the Caledonides, and an eastern source from the Urals and West Siberia. By combining more than 2000 new U-Pb analyses on detrital zircons from eight wells with previously published provenance data (Fleming *et al.*, 2016; Flowerdew *et al.*, 2019), we document three distinct age signatures in the Kobbe Formation. The northernmost samples (north of 72°N) are dominated by Triassic to Neoproterozoic zircons. Most of the ages are Triassic to Devonian, and minor amounts of Mesoproterozoic – Archean zircons are also present. This age signature is typical for an eastern source (e.g. Soloviev *et al.*, 2015). Samples from the western Hammerfest Basin and the western Finnmark Platform consist of Cambrian – middle Paleoproterozoic zircons, as well as a small Neo- to Meso-Archean component.

This age distribution is typical for a Fennoscandian source. The samples from the Bjarmeland Platform and the southernmost Nordkapp Basin show strong similarities to the samples from Hammerfest Basin and the Finnmark Platform. However, these samples lack the Timanide-aged component, clearly indicating two different Fennoscandian sources. Additionally, the presence of Permian – Carboniferous zircons on the Bjarmeland Platform indicate that this area was a mixing zone for the eastern and Fennoscandian sediments, thus constraining distribution of the southerly sands which yields better reservoir properties. By documenting regional variations in provenance, as well as pin-pointing the mixing zone for sediments from the different sources, this study helps constrain the distribution of reservoir sand types in the basin, constrains amount of sediment produced from the Fennoscandian source, and provides insight into sediment mixing processes.

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Verdens beste detaljerte kvartærgeologiske kart i Norge – gratis fra NGU

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Norges geologiske undersøkelse (NGU) har tradisjonelt kartlagt Norges kvartærgeologi i målestokk 1:250:000 (M250, fylkeskart) og 1:50:000 (M50). Siden 2012 har NGU i tillegg hatt en stor produksjon av detaljerte kvartærgeologiske kart i målestokk 1:10:000 (M10) i områder som skredfarevurderes gjennom NVEs program for «Faresonekartlegging i bratt terreng». Det er til nå laget ca. 70 slike detaljerte kart i 19 kommuner over hele landet. Kartene har så langt vært brukt av NVE, men blir nå tilgjengelige for alle gjennom NGUs karttjenester.

Kart i små målestokker er veldig nyttige for en regional forståelse av geologien og de landskapsformende prosessene. For å dekke lokale behov er det i mange sammenhenger helt nødvendig med en mer detaljert kartlegging enn M50 eller M250. Lurer man på om huset man vil kjøpe står på marin leire, eller om løsmassene på hyttetomta egner seg til å bore etter vann vil ikke et kvartærgeologisk fylkeskart være presist nok i kvalitet eller romslig presisjon til å gi et fullgodt svar. Det er kanskje drøyt å si at de nye kvartærgeologiske M10-kartene er de beste i verden, men de er i hvert fall de mest detaljerte vi har i Norge og holder et presisjonsnivå som gjør det mulig å bruke dem direkte i arbeid med reguleringsplaner og som ett av grunnlagene for skredfarevurderinger. NGU ønsker med dette å presentere disse nye kartene, fortelle litt om hvordan de lages, hva de kan brukes til, og ikke minst hvordan brukere kan få tak i dem, som pdf, ved wms-link og som data for nedlastning.

How digital outcrop analysis enhances understanding of rift basin architecture (Billefjorden Trough, Svalbard)?

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The Billefjorden Trough is a well-studied half-graben located in Spitsbergen, visited, and explored by generations of geologist and geo-tourists. The spectacular outcrops are quite accessible, and the post-glacial topography provides nearly three-dimensional intersections of the rift-basin. Over the last years, traditional field investigations have been supplemented with analysis of digital outcrop models to further advance our understanding of the basin evolution. The digital dataset consists of LIDAR and Photogrammetric digital outcrops models that enable detailed mapping and correlation at bed level across large areas. Further, the models facilitate easy construction of isopach maps, along with structural and thickness measurements in inaccessible areas. The main benefit of the digital models is, however, their similarity to offshore datasets

promoting easier linkage between onshore and offshore data to the benefit of both.
In Billefjorden, the onset of rifting during the Serpukhovian corresponds to a climatic shift from humid, tropical- to subtropical to semi-arid to arid paleoclimate as recorded in the transition from widespread occurrence of coal in the pre-rift sandstones and mudstones to precipitation of gypsum in the mixed siliciclastic-evaporite-carbonate paralic syn-rift successions. The gradual transition, expressed as interbedding of humid- and dry-climate deposits in the central parts of the rift-basin (outcrop and borehole data), indicates fluctuating climate conditions. On the uplifted basin margins the transition is sharp likely due to erosion or non-deposition.
The Billefjorden Trough fill thickens westwards to up to 2000 m in the vicinity of the Billefjorden fault zone (BFZ). The BFZ consist of eastward dipping master faults with associated smaller-scale faults, relay-breaching faults, and fault-tip monoclines. East of the trough, a system of antithetic faults is segmenting the hanging wall dipslope of the BFZ into isolated fault block-depocenters. Their growth impacted the location of depositional depocenters, drainage footwall catchments, fluvial drainage patterns, and the position of evaporites dissolution. Combined activity of BFZ and antithetic faults influenced the evolution and configuration of the basin, seen as (1) symmetrical fill of early syn-rift phase, (2) asymmetrical deposits of rift-climax phase and (3) fill focused in the central part of the basin during rift-reorganisation phase.
Finally, the digital outcrop models have been used to re-assess the Neogene reactivation along the BFZ, which is seen as reverse displacement along some older extensional faults with a maximum vertical offset of less than 200 m.

Expanding fossil and trace fossil localities in central Norway

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A new survey and compilation of historical roofing plate quarries within the Ordovician metasediments of the Stjørdal region, central Norway, reveals the likely locality of earlier described marine trace fossil-rich roofing slates of a then unknown origin (Uchman *et al.*, 2005, Smelror *et al.*, 2020). *In-situ* trace fossils are earlier reported from a dozen localities (Uchman et al., 2005 and references therein). In addition, we found several other new trace fossil-rich localities.
Further, this investigation also reveals hitherto unknown fossil occurrences. So far, the identified fossils include brachiopods, crinoids and possibly endoceras?. Such fossils are to our knowledge only reported occasionally in the larger surrounding area (Henriksen *et al.*, 2018 and references therein, Smelror *et al.*, 2020 and references therein).
This new survey compilation of roofing plate quarries in the Stjørdalen area have quadrupled the amount of known roofing slate quarries in the area, exposing excellent localities for further work on the paleofauna in this area. This was achieved by field campaigns, conducting interviews, and utilizing new high-resolution mapping data sets (Lidar).
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The potential for seismicity during slip of fractured Draupne shale – an experimental study in the direct shear box

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Carbon capture and subsequent storage in the subsurface is considered by the Intergovernmental Panel on Climate Change as one of the main mitigation methods to limit global warming. After carbon dioxide is captured from large point sources, it is transported to the storage site and injected into deep geological formations consisting of storage formation and caprock. Most potential storage sites will contain pre-existing weakness zones and the increase in pore pressure following injection could potentially compromise the seal integrity and create possible migration pathways for the injected CO2. It is therefore vital with detailed knowledge about the pressure change a system can undertake without becoming critically stressed and a monitoring plan for early warning if failure occurs.
In this study, we perform direct shear box tests on fractures samples of the main caprock in the North Sea; the Draupne shale. Both samples with natural and induced fractures are tested under normal stress levels representative of stresses acting on fractures in the field. In addition to measuring the strength variation with normal stress, the shear velocity-dependence of friction is investigated by including phases of velocity stepping in the test protocol. In the rate and state friction framework, relative changes in friction in response to changes in shear velocity can characterize either velocity-strengthening or velocity-weakening type of behaviour. In the former, friction increases with shear velocity and no seismicity is expected to be generated from movement along the fracture, whereas velocity-

weakening implies unstable slip along fracture and the potential for seismicity to nucleate. We also examine how frictional relaxation develops when shearing is stopped and how frictional weakening between different velocity steps varies with normal stress and shear velocity.
The results indicate a relatively low friction angle and close to zero cohesion for the fractured samples. Friction is seen to increases when the shear velocity is increased, suggesting velocity-strengthening and aseismic slip. Due to creep effects, frictional relaxation, measured as the magnitude of friction reduction when shearing is stopped between the velocity steps, is found to be positively correlated with normal stress and negatively correlated with shear velocity before the stop. The post-peak frictional weakening is the difference between the maximum shear stress and the residual shear stress for each velocity step and is also be found to be positively correlated with shear velocity and negatively correlated with normal stress. The strength of fractured Draupne shale measured under realistic stress levels and the suggested aseismic behaviour, should both be considered when deciding on operational parameters and on monitoring design during CO2 injection.

Identifying the transition between the Gula Complex and the Fundsjø Group in thev Tverråtjønnan area, Trøndelag, central Norwegian Caledonides

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The Gula Complex and the Fundsjø Group are two major geological units dominating the bedrock geology of central and eastern Trøndelag (e.g. Gee et al., 1985). However, locating the exact boundary between them is not straightforward (e.g. Lagerblad, 1984). The Tverråtjønnan area north of Haltdalen includes both the Gula-Fundsjø boundary and the map-sheet boundary between the existing 1:250 000 bedrock maps of the area (Røros & Sveg, Wolff & Nilsen, 1989 and Trondheim, Wolff, 1989). The Røros & Sveg map in the south shows complex folding of the Gula and Fundsjø units, a pattern also visible in recently acquired airborne geophysical data. The Trondheim map to the north, on the other hand, does not reflect this complexity, and instead includes the entire area between the Fongen-Hyllingen intrusion and Bukkhåmmåren mountain into the Fundsjø Group.
In this contribution, we present an updated detailed bedrock map covering the Gula-Fundsjø transition in the Tverråtjønnan area. Field work was conducted using the digital mapping tool FieldMove, and magnetic susceptibility measurements were undertaken to compare with the results form airborne geophysics.
Our results show that the Gula Complex consists of the following units: micaschist (locally kyanite- and staurolite-bearing), marble, metasandstone and a conglomerate dominated by quartzite clasts within an amphibole-bearing matrix.
The Fundsjø Group consists of the following units: amphibole-biotite-schist, gabbro, amphibolite and dolerite. Porphyritic dolerite dykes are a distinct feature of the Fundsjø Group. The contact between the two units within the field area is obscured by an elongated tonalite intrusion. A penetrative ductile foliation is developed in all units and dips steeply towards west, whereas a strong stretching lineation is developed plunging moderately to the south-east.
Airborne magnetic measurements show two anomalies in the Tverråtjønnan area. A NNE-SSW trending, high-magnetic linear anomaly is located west of Bukhåmmåren. Field measurements of magnetic susceptibility in this zone are up to 500 (10^{-3} SI units), and a peculiar rock with magnetite and garnet was found. An ellipsoid pattern in the airborne magnetic data occurs in the Fundsjø Group, which correlates with a larger tonalite intrusion and a fold structure in Fundsjø metasedimentary and metavolcanic rocks.
Our field mapping will be followed up by thin section petrography of the mapped lithologies, as well as age dating of the tonalite and detrital zircons in the metasedimentary units. It will result in a bachelor thesis in geology and geohazards at HVL Sogndal.
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Incrustation monitoring and rehabilitation in Norwegian groundwater works

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Incrustations impede the longevity of groundwater wells e.g. by clogging the well filters. Iron and manganese incrustations are from experience the most common incrustation problem worldwide (Houben & Treskatis, 2007), while the incrustation problems of Norwegian groundwater works remain not well reviewed. An online survey was thus sent out to Norwegian groundwater works experiencing elevated iron and manganese concentrations to investigate to what extent they have experienced and how they handle incrustation problems.
Incrustations lead to increased frictional resistance, evinced by increasing pressure drawdown *s* (m) to the

well to maintain the same pumping rate *Q* (l/s). Incrustation build-up can thus be detected by monitoring the *specific yield*, *Q/s*, with time, e.g. by performing step -discharge tests regularly. Decreasing specific yield by incrustations will first lead to increased pumping costs, and later the risk of completely clogging the well, meaning the well must be abandoned. This can be avoided by performing an appropriate well rehabilitation in time. From experience, (1) "appropriate" means combining mechanical and chemical rehabilitation techniques, while (2) "in time" means rehabilitating when the specific yield has dropped 10-25 % from the original (Houben & Treskatis, 2007).

Data on iron and manganese concentrations in groundwater works were obtained from the Norwegian Food Safety Authority (Mattilsynet) and the Geological Survey of Norway (NGU). The online survey then sent to 55 municipalities with groundwater works which had experienced concentrations above the drinking water regulations; 0,2 mg/l for iron and 0,05 mg/l for manganese. The survey included questions on the specific yield (monitoring and trends), camera inspections, incrustation types, rehabilitations and abandonments. 28 municipalities have responded so far. The preliminary results indicate that the systems lack monitoring, and that chemical rehabilitation techniques are seldomly applied. Groundwater works are thus encouraged to monitor their wells more systematically, while drilling companies are encouraged to include chemicals in their well rehabilitations, to secure the longevity of the critical infrastructure which municipal drinking wells constitute.

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A large undescribed plesiosaur from Svalbard

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The Plesiosauria is a group of aquatic reptiles that dominated the marine environment during the Mesozoic. Multiple specimens of long neck plesiosaurs have been excavated by the Spitsbergen Mesozoic Research Group (SMRG) on Svalbard from 2004 to 2012. The specimens are found in the Slottsmøya Member and belong to the plesiosaur clade Cryptocleidid. One of the specimens excavated in 2004/2010 is a well-preserved plesiosaur (PMO 212.662). The skeleton is semi-articulated. Phalanges, cervical and dorsal vertebrae with associated ribs and the posterior part of the skull is preserved. This is interesting because fossils of plesiosaurs often lack the skull. As the skull is quite small and rarely preserved. Cranial morphology is important in order to refer Cryptocleidid fossils to specific genera and to provide information about the relationship between the taxa. We have used computer tomography (μCT) to identify the different bones in the braincase. The specimen is described and possible affinities to time-equivalent taxa are discussed. Which Cryptocleidid taxa PMO 212.662 belongs to, or whether the plesiosaur is a new species will be investigated.

Platform carbonates of the Hambergfjellet Formation on Bjørnøya; a field and microfacies study

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The Permian Hambergfjellet Fm. (60 m thick) on Bjørnøya is the only formation within the Bjarmeland Group which is present onshore. During this summer's fieldwork on Bjørnøya, we studied and sampled the formation in detail. Several outcrops were logged, 3D models from photogrammetry of outcrops were made, and samples were taken for a microfacies study. The study combine understanding from big-scale mountain-side tectonics, to microscopy details put together in a microfacies study of the Hambergfjellet Fm.

Our study also shows that the map and a cross-section made by Horn and Orwin in 1928 is more correct than the new edition of the geological map of Bjørnøya from Norsk Polarinstitutt. Our emended map will be presented.

Two overlapping sedimentological logs are correlated by a distinctive coral layer. The lower part of the formation is dominated by mixed carbonate clastic with an abundancy of micrite but some layers consisting of quartzite is also present. Further up, it transits into more brachiopod rich layers, interpreted as brachiopod banks. These layers are distinctive and abundant in the upper part of each log. The logs show the transition from the Hambergfjellet to Miseryfjellet formations and a distinctive change in fauna to noticeable more bryozoans above a basal conglomerate on the angular unconformity separating the two formations.

Pore pressure evolution and related risks at Gaustad, Norway

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With the city of Oslo being subject to increasing urbanization, the available areas for further development is decreasing. As a result, construction and groundwork of new buildings and infrastructure happens close to existing structures. Two M.Sc. students at the University of Oslo are studying the catchment area of Gaustad where UiO´s Life Science Building is being built. One objective is to evaluate the potential risk of settling at the construction site and in surrounding areas, by studying temporal pore pressure changes in clay

deposits and assessing the hydraulic properties of an underlying fractured aquifer. Hydraulic head and groundwater flow will be modelled in 3D (Modflow), while differential compaction may be estimated using Plaxis or Geoslope. Models are applied to evaluate the potential risk of settling at the site and in surrounding areas.

Changes in the water balance due to urbanization and climate changes could also be a factor affecting long term pore pressure evolution, as the recharge of the aquifer may be affected. The water balance and surface water management in the area will be studied in the two master projects, as the surface water - groundwater interaction is central in understanding the effect of urbanization on the hydrogeological water cycle in the catchment. The increase of impermeable surfaces is preventing infiltration, subsequently causing more surface runoff and less recharge of the groundwater. The stormwater in Oslo is dealt with in three stages by catching and infiltrating, delaying and detaining and ensuring safe flood paths. However, with the increase of precipitation due to climate changes the stormwater management strategies implemented are not always sufficient, causing the possibility of leakage and pollution of water.

A 2D, transient groundwater model has been developed to evaluate the effect of having an open vs. sealed construction pit (Tuttle, 2020), and to estimate long term and regional effects, the same initial conditions will be applied in constructing a 3D model. Reduction of hydraulic head in the underlying fractured bedrock is the major factor affecting the pore pressure in the overlying clay aquitard. In addition, there is concern if there is groundwater leaking along steel pylons anchored in bedrock (constructional support), as this would reduce pore pressures considerably. Infiltration wells located at the site will be used during the construction period to prevent further pressure reduction. Model scenarios are defined to quantify effects of groundwater leakage and identifying thresholds for acceptance pressure reduction (i.e. not causing problematic compaction or stability issues). The study will provide knowledge of risk related to differential compaction as a long-term consequence of lowering pore pressures during construction work.

Thank you to Statsbygg for sharing relevant data and giving access to the construction area.

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Recognising tectonic and climatic signals in the Paleogene stratigraphy offshore Norway

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Landscapes and their sediment routing systems can be exposed to various tectonic and climatic perturbations that affect sediment production, transport and delivery to nearby sedimentary basins. Here we investigate a Paleogene depositional system offshore western Norway that was subjected to long-term (~10 myrs) tectonic perturbation and significant hinterland erosion. Superimposed on this long-term uplift, the system was also subjected to a short-lived climatic perturbation during the Paleocene-Eocene Thermal Maximum (PETM), which lasted ~200 kyrs. Regional 3D seismic reflection data is integrated with high resolution well data to map the stratigraphic response to these different scales of perturbations on the depositional system. The initiation of the tectonic perturbation is marked by an angular unconformity in seismic data. A rapid increase in sediment flux followed, causing initial progradation of a shelf-slope wedge. Sediment supply estimates indicate that the tectonic uplift caused an order of magnitude increase in sediment flux to the basin, which peaked in the latest Paleocene. This period coincided with the PETM, which is documented by biostratigraphic data as a discrete event within the overall regressive system. Although the PETM often is characterised by increased continental runoff, no increase in sediment supply is evident from seismic data. This work shows that the system response to tectonic and climatic perturbations may vary along strike, depending on the size of the routing systems and the antecedent topography prior to hinterland uplift. A low supply system may produce a tectonically-linked shelf-slope wedge that is of similar thickness as a climatically-linked wedge in a high supply system. This study documents how the same routing system responded to perturbations operating at different spatial and temporal scales and may help recognise similar process-response relationships in other areas.

Deep-sea mapping down to 6000 metres in the Norwegian Sea – challenges and achievements

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The Norwegian Sea is located between Greenland in the west and Norway in the east. The Norwegian part occupies c. 1,200,000 km^2 and constitutes one of three ocean management regions in the Norwegian waters.

The area covers the deep sea, the continental slopes of Norway, the shallow areas around Jan Mayen, and the Molloy Deep, situated close to 80° N and forming the deepest part of the Norwegian sea area (5569 metres). Potential mineral resources associated with the northern part of the Mid-Atlantic Ridge (Mohn's Ridge and the Knipovich Ridge) have led to increased interest in the deep ocean. Scientific research by university groups has been supplemented with resource potential mapping performed by the Norwegian Petroleum Directorate, who has the main legal responsibility for future exploration and exploitation. The Norwegian government has requested more knowledge on the environmental conditions and ecosystems (government white paper on the ocean management plan for the Norwegian Sea, last revised in 2016). This is the background for a large seabed mapping campaign in the Norwegian Sea started in 2019 under the government funded MAREANO programme (www.mareano.no).

The remit for MAREANO under this initiative is to provide a broad knowledge base of biodiversity and geodiversity, thereby adding to the scientific knowledge basis for ecosystem-based management. This includes identifying (special) areas that management authorities may wish to define as particularly valuable and vulnerable areas. The survey area includes a depth range from a few hundred metres to 5,569 metres; latitudes between 64° 30' and 80° N; different biogeographic regions; landscapes from continental shelves to continental slopes to abyssal plains and, not least, an active mid-ocean ridge where black smokers and vivid chemotrophic communities have already been documented. Importantly, it was attempted to cover the entire environmental space, using available data in designing the mapping strategy.

The presentation will focus on the challenges and achievements related to surface-based multibeam echosounder data collected from about 65,000 km^2 in 2019. Data were acquired by DOF Subsea under contract to the Norwegian Mapping Authority/ MAREANO using the multibeam echosounder EM304 from Kongsberg Maritime for bathymetry, backscatter, water column and sub-bottom profiler data (SBP29). The goal was to collect all data sets simultaneously in a synchronized mode. Several challenges have been encountered, e.g. ship noise, new data formats, synchronization issues, software problems and depth-related issues. A close dialogue and step-by-step quality control between DOF Subsea, the Norwegian Mapping Authority and the Geological Survey of Norway has helped overcoming the challenges, and the result is a unique data set that will provide an excellent basis for the mapping of geology, biology and chemistry which will start in 2021.

Nytt kart over Norges berggrunn 1:1,350,000 - forhåndsvisning

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Det eksisterende kartet over Norges berggrunn i målestokk 1:1 million ble publisert i 1984 (Sigmond m.fl.) og er fortsatt et av de mest etterspurte kartproduktene fra NGU. Kartet er av høy geologisk og kartografisk kvalitet, selv i dag, snart 40 år etter at det ble utgitt. Et slikt norgeskart gir en oversikt over berggrunnsgeologien i hele landet, og lar brukerne raskt sammenligne bergartene på tvers av geografiske regioner. Kartet blir mest brukt i opplæring og utforsking av geologi, men er også ettertraktet av mange profesjonelle geologer og geologiske institusjoner og bedrifter.

Dessverre begynner beholdningen å gå tom og kartet er kun tilgjengelig i et eldre format som er vanskelig å oppdatere og trykke på ny. Samtidig har nyere kartlegging blitt tilgjengelig og nye analyser (geokronologi, geokjemi, strukturanalyser etc.) har ført til en bedre geologisk forståelse i mange områder. Basert på en ny harmonisert utgave av det landsdekkende 1:250 000 berggrunnsdatasettet har NGU nå laget et nytt kart over Norges berggrunn. Kartet har målestokk 1:1,350,000 for å få plass til hele Norge i et A0-format. Geologien er gruppert etter tektonisk hoved- og underenheter, og et tilhørende oversiktskart knytter de mange tegnforklaringene opp mot disse grove geologiske trekkene. Kartet inneholder også et oversiktskart over berggrunnens dannelsesalder, og angir viktige strukturer, bergartslinjer, eklogitt-forekomster mm.. Datasettet vil også bli tilgjengelig i digital form via NGUs kartinnsyn og karttjenester.

Det nye kartet «Norges berggrunn 1:1,350,000» vil bli ferdigstilt i løpet av vinteren 2021. På vinterkonferansen vil vi vise frem en foreløpig utgave som alle kan kommentere og komme med innspill til, før arbeidet blir ferdigstilt.

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Caledonian Orogeny : Possible origin of the Møre-Trøndelag Fault Complex; Observations and analogues suggesting that these faults originated in a fold-thrust belt, implying an initial NNW-SSE collision direction between Laurentia and Baltica)

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Hikers in the central coastal region of Norway may have noticed that hills and mountains are more easily climbed when hiking in a direction parallel to the main coastline. Within an approximately 50km wide belt, most hills, islands, islets, isthmuses, valleys, and many fjords follow this WSW-ENE trend. Roadbuilding has also

been affected, making it faster to travel parallel to this trend than across it.
The basement WSW-ENE strike direction in parts of Mid-Norway is clearly visible at a range of different scales, ranging from region-scale satellite images to basement exposed at ground level. The Møre-Trøndelag Fault Complex (MTFC) is a set of faults parallel to this trend.
The Laurentia-Baltica plate collision is believed to have taken place more than 400 million years ago. More recent, similar type plate-collisions create large-scale fold-thrust belt in the process. By assuming an analogue setting, combined with dip directions of the faults, shifts in topography south of the MTFC and other geological observations, it is suggested that the MTFC originated as a thrust zone in an early phase of the Laurentia-Baltica collision. The impact direction would have been NNW-SSE.
At least some of the faults belonging to the MTFC have been re-activated in different geological periods, further strengthening the case that they originated as deep, basement-involved thrust faults. Better knowledge of the initial origin of the MTFC may lead to improved understanding of the sequence of events during later phases of the Caledonian orogeny.

Microcontinents and continental fragments associated with subduction systems

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Microcontinents and continental fragments are small pieces of continental crust that are surrounded by oceanic lithosphere. Although classically associated with passive margin formation, here we present several preserved microcontinents and continental fragments associated with subduction systems. They are located in the Coral Sea, South China Sea, central Mediterranean and Scotia Sea regions and a 'proto-microcontinent', in the Gulf of California. Reviewing the tectonic history of each region and interpreting a variety of geophysical data allows us to identify parameters controlling the formation of microcontinents and continental fragments in subduction settings. All these tectonic blocks experienced long, complex tectonic histories with an important role for developing inherited structures. They tend to form in back-arc locations and separate from their parent continent by oblique or rotational kinematics. The separated continental pieces and associated marginal basins are generally small and formation is quick (<50 Myr). Microcontinents and continental fragments formed close to large continental masses tend to form faster than those created in systems bordered by large oceanic plates. A common triggering mechanism for formation is difficult to identify, but seems to be linked with rapid changes of complex subduction dynamics. We will present few examples of numerical models that simulate the microcontinent formation.

Diachronous key stratigraphic surfaces in low-accommodation fluvio-deltaic settings: from the Dakota Group (USA) to the Cretaceous on Svalbard/Barents Sea

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The adequate documentation and interpretation of regional-scale stratigraphic surfaces is paramount to establish correlations between continental and shallow marine strata. In active depositional systems however, these surfaces are often composite and hence diachronous, which contradicts their original appreciation. This is particularly true in low-accommodation settings due to their amalgamated nature. This study utilizes the ~400 km transect of the Cenomanian Mesa Rica Sandstone (Dakota Group, USA), which offers an outstanding example of an exhumed full-transect depositional profile across a river-to-delta system. The near-continuous outcrop exposure allows mapping of down-dip changes in facies, thickness distribution, fluvial architecture and spatial extent of stratigraphic surfaces. The two sandstone units of the Mesa Rica Sandstone represent contemporaneous fluvio-deltaic deposition in the Tucumcari sub-basin (Western Interior Basin) during two regressive phases. Multivalley deposits pass down-dip into single-story channel sandstones and eventually into contemporaneous distributary channel deposits and delta-front strata. Additionally, multi-storey channel deposits bound by erosional composite scours incise into underlying deltaic deposits. These represent incised-valley fill deposits, based on their regional occurrence, estimated channel tops below the surrounding topographic surface and coeval downstepping delta-front geometries. The erosional composite surface below fluvial strata in the continental realm represents a sequence boundary/regional composite scour (RCS) and can be mapped for >300 km. Basal distributary composite scours, composite surfaces bounding incised valleys, and basal surfaces below dispersed trunk channels incising into deltaic deposits occur at sub-regional scale. The RCS' diachronous nature demonstrates that its down-dip equivalent disperses into several surfaces in the marine part of the depositional system, which challenges the idea of a single, correlatable surface.
This work is important to understand other low-accommodation systems elsewhere, such as Lower Cretaceous strata on Svalbard and in the Barents Sea. Here, correlation between onshore and offshore depositional systems has been hampered due to – amongst others – the lack of preserved Lower Cretaceous strata in parts of the northern Barents Sea. Acknowledgment of the diachronous nature of key stratigraphic surfaces holds potential to improve the

understanding of fluvio-marine correlations and sandstone distribution.
In general, formation of a regional composite scour in the fluvial realm throughout a relative sea-level cycle highlights that erosion and deposition occur virtually contemporaneously at any point along the depositional profile. This contradicts stratigraphic models that interpret low-accommodation settings to dominantly promote bypass, especially during forced regressions. Source-to-sink analyses should account for this in order to adequately resolve timing and volume of sediment storage in the system throughout a complete relative sea -level cycle.

The urban water cycle – challenges and knowledge gaps

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The urban water cycle is challenging because it is in a built environment where several of the natural conditions have been altered by mankind. Water, both surface and groundwater, is the driver for processes, such as flooding, stabilizing the ground and safeguard ecosystem services.
Water is, in the Norwegian setting, delt with by several disciplines from hydrology for surface processes to hydrogeology for subsurface processes. More or less all other (geoscience) disciplines are connected to water, such as geotechnics, engineering geology, rock- and landslides, genesis, planning, water and sewage, etc. In an urban setting the problems are complex and the challenges plenty. Projects such as "Begrens skade" / Risk Reduction of Groundwork Damage I &II (Holmøy et al., 2019; Baardvik et al., 2016), major construction sites such as The Barcode in Bjørvika, Oslo, The Bryggen Project in Bergen, and the InterCity Fredrikstad all show that there are knowledge gaps in the intersection of disciplines, and water is the common factor.
Damages caused by flooding is at a cost of 1.5 billion NOK each year, based on insurance settlement (NRK Rogaland). These are the damages and cost caused by the visible water. Groundwater get far less attention, but when not thought of can cause costly damages, such as subsidence and ground instability, Bryggen in Bergen and Bjørvika as examples.
Water has no boundary. It is a transport media for particle bound pollutions (Venvik & Boogaard, 2020). Sustainable urban Drainage Systems (SuDS) is a remediation for both excess surface water and a possibility to infiltrate and recharge the groundwater *if* SuDS are located and implemented correctly. More geological understanding and data should be required (Venvik et al., 2019). Measures to stabilize the urban water cycle as well as climate change adaptation needs more attention in urban development. Planners in municipalities are left with the responsibility to plan for and find sustainable solutions for water, surplus water or scarcity. To make good decisions for cities, both data and knowledge must be accessible. How can we as a geoscience community with above average interest for water help and supply the stakeholders to make the right decision?
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From vertical muds to flat sands – where standard sedimentological workflows do not work. Thunder Horse Field, GOM

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The Thunder Horse Field in the Gulf of Mexico is a prolific Middle Miocene deepwater turbiditic reservoir, currently producing 120 000 barrels of oil per day. The several, partly amalgamated reservoir levels are more than 200 meters thick, but their structural and sedimentological characterisation is challenging. Salt diapirs and an extensive salt canopy significantly reduce the seismic quality. In addition, high formation pressures require the use of heavy, oil-based mud, which limits the resolution of borehole image logs (BHI).
The deep marine basin floor depositional setting shows a surprisingly high variability of depositional agents, ranging from low- and high-density gravity flows, debris flows and hemipelagic fines to mass-transport complexes (MTC) induced by post-depositional halokinetic deformation. The MTCs are characterised by genetically related processes, where sediment slides and stacked slumps disintegrate during ongoing transport, and are subsequently transformed into muddy and sandy

debrites.
A combination of cores and several generations of BHI, ranging from dipmeters to the latest high-resolution micro-resistivity imagers, was used to evaluate the depositional environments and to shed light on palaeo-transport directions and fairway trends. The first step of the sedimentological interpretation is to understand and remove structural tilt, which is normally best reflected by mud-prone sediments deemed to be deposited palaeo -horizontally. In the Thunder Horse Field, however, the reservoir beds drape against an E–W oriented salt wall. Most shale units were redeposited as MTCs, comprising slumps and imbricated slide blocks with variable orientations and erosive potential. The MTCs were periodically covered by sandy gravity flows, which in the case of the Thunder Horse Field proved to be the best proxy for palaeo-horizontal reference.
A unique data set comprising 40 000 m of BHI logs from 22 wells was available and calibrated by core. The complex architecture of these deposits was characterised by measuring the axial symmetry of both depositional and deformational features. Together with palaeo-current measurements from core ripples, an overall sediment transport towards the S/SSE is interpreted. No evidence for syn-depositional salt movement at the time of deposition was found, which would have deflected the sandy and muddy gravity flows. MTCs were partly capable of removing reservoir sections, but also deflecting and ponding sandy turbidites and debris flows. The complex interplay of sandy gravity flows and mud-prone MTCs pose a challenge for production due to common compartmentalisation.
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Modelling channelized fluid flow with viscoplastic/ductile deformation in porous media

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Seismic chimneys/pipes are among the most important expressions for the localized fluid flow in the subsurface. Yet, its formation mechanism is not well understood. Hydraulic fracturing and porous wave are the two main mechanisms that have been proposed. Here we study how fluid channels can developed as porous wave under the viscoplastic deformation of the reservoir rock. Previous study shows that the asymmetric bulk viscosity for decompaction and compaction are essential to produce fluid channels. However, negative effective pressure (P_t-P_f) are inevitable due to the simplified rheology formulation. Here, we develop a viscoplastic rheology that takes into account effects of shear stress and plastic failure on the volumetric deformation, consistent with experimental data. A dilation pressure is naturally introduced through viscoplastic strain-rate when plastic failure occurs under high fluid pressure and shear stress condition. Our model results show that this new rheology can produce channelized fluid flow without negative effective pressure in the model. Besides, the solid deformation in our models also show similar structure with the up-bending reflections of seismic chimneys.
In order to apply our models into real geological setting, we test the effects of reservoir properties, geological layering, transport properties of the layers and faults. Our results show that fluid channel initiates at local topography highs in the reservoir and a high-permeability fault can also trigger the initiation of fluid channels. Fluid channels can have different length and time scales in different layers, depending on bulk viscosity and permeability of the layers.

Multi-geophysical data integration using cluster analysis: Assisting geological mapping in Trøndelag, Mid-Norway

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Modern geophysical data acquisition technology makes it possible to measure multiple geophysical properties with high spatial density over large areas with great efficiency. Instead of presenting these co-located multi-geophysical datasets in separate maps, we take advantage of cluster analysis and its pattern exploration power to generate a cluster map with objectively integrated information. Each cluster in the resulting cluster map is characterized by multi-geophysical properties and can be associated with certain petrophysical attributes and therefore with specific classes of rock types based on existing geological maps, field data and rock sample analysis. Such a cluster map is usually high in resolution and proven to be helpful in addition to single-attribute maps in terms of assisting geological mapping and interpretation.
We will present the workflow and technical details of applying the fuzzy c-means clustering algorithm to multi-geophysical data of a study area. Running the algorithm on a set of available datasets is straightforward, providing all datasets are gridded the same way into co-located datapoints. But how to evaluate whether these datasets are appropriate for being used as direct input to the algorithm? If not, can they be fixed? How to choose which datasets should be used as input or is it wise to lump all available data in? How to decide how many clusters are appropriate for the given input choices? And how good is the final clustering result? – These are the questions we aim to answer, and we will present a general guideline of utilizing mathematical criteria to assist such decision-making.
Our study area is located in the Trøndelag region, Mid-Norway. The multi-geophysical data include helicopter-borne magnetic, frequency electromagnetic and radiometric measurements, together with ground gravity measurements. The resulting cluster map broadly shows

a good correlation with the existing 1:250 000 bedrock map (Geological Survey of Norway, June 2020), but on a more detailed level, a number of misfits between clusters and geological units invite further investigation. Specifically addressing such misfits with observable surface geology may lead to more targeted and efficient geological field mapping in the future.

Multivariate elemental chemostratigraphy of Triassic shales, Eastern Svalbard

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The Spathian Vendomdalen Member of the Vikinghøgda Formation (Lower Triassic), the Anisian Muen Member and the Ladinian Blanknuten Member (both assigned to the Middle Triassic Botneheia Formation), and the Early Carnian Tschermakfjellet Formation (Upper Triassic) in Svalbard consist of dominantly siliciclastic shales. Previous studies report <1 to 12 wt. % total organic carbon as well as kerogen types III to II/I in these shales. This implies that they were deposited in a range of palaeodepositional environments, including ventilated (oxic) to restricted (euxinic–anoxic–dysoxic) settings. This study investigates the stratigraphic development of the elemental composition in these lithostratigraphic units, and apply proxies based on these elements to assess the relative changes in palaeo-redox, palaeo-productivity, and detrital content of these shales. Multivariate analyses are used to investigate the relationship between these elemental proxies, and provide an unsupervised, data-driven approach to geochemically distinguish these shales.

Results show that the Spathian Vendomdalen Member is enriched in redox-sensitive and sulphide-related elements, while the bulk Ladinian Blanknuten Member is enriched in redox-sensitive and productivity/ phosphorite related elements. The bulk Anisian Muen Member and Tschermakfjellet Formation show mostly no or low enrichments in elements relates to these processes. Proxies concerned with detrital composition are mostly similar between all of these lithostratigraphic units, however certain elements show compositional excursions correlating with established lithostratigraphic boundaries.

These results indicate that the Spathian Vendomdalen Member was deposited under euxinic conditions in moderately restricted water masses, while high primary production was an important factor towards oxygen depletion during accumulation of the Ladinian Blanknuten Member. The Anisian Muen Member and Early Carnian Tschermakfjellet Formation appears to be deposited during prevailing oxic conditions. Changes in detrital content is mainly observed at formation boundaries, and may reflect changes in e.g. grain size, mineral assemblage or diagenesis. These correlations are recognized in the multivariate analysis, which provide new insights towards recognizing paleo-depositional settings of principally different Triassic shales in Svalbard and possibly in the northern Norwegian Barents Sea.

Mid – and Late Weichselian chrono-stratigraphy of the Kongsfjorden Trough Mouth Fan, W-Spitsbergen

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The high-latitude Kongsfjorden Trough Mouth Fan (TMF), situated on the continental margin west of Svalbard, was developed by the activity from the Kongsfjorden paleo-ice stream through several glaciations. Due to their origin, sediments from the trough mouth fan are ideal for recording the timing of the maximum extent of the Svalbard-Barents Sea Ice Sheet in this area. During a marine geological survey in 2010, a number of high-resolution parametric echosounder TOPAS profiles were acquired between the Kongsfjorden and Isfjorden TMF systems. In addition, a 12.65 meter long sediment core was retrieved from the southern part of the Kongsfjorden TMF, at 846 m water depth.

Three different sedimentary sequences consisting of glasigenic debris flows (GDF) have been identified separated by acoustically laminar layers. Each GDF sequence is inferred to represent an advance to the shelf break. The sediment core GS10-164-09PC penetrate the stratigraphic level of the youngest GDF sequence and terminates into the upper part of the second youngest GDF sequence, and thus allowing us to study the last two advances in greater detail than previously available.

The interval between 2 – 5 m depth in the core has been dated with AMS 14C. An anomalous layer (at 270-335 cm), which can be correlated with the youngest GDF sequence, have been estimated to have an age between 23.3 – 25 ka, and is interpreted to comprise sediments from the Last Glacial Maximum (LGM). To establish the age of the sediments outside of this interval a different approach had to be made.

A clearer view of the Kveithola Slide and neighbouring slides, Norwegian Sea

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As the smallest of the palaeo-ice stream systems along the northeastern Atlantic Margin, The Kveithola Palaeo-Ice Stream and its related remnants gives a unique opportunity for mapping the entirety of the system. Both due to its size and history, as a small ice stream nestled between its two major counterparts, the Bear Island and Storfjorden Ice Stream, has put the Kveithola System in the focus for several studies during the last decade. Following three recent cruises, the MAREANO-programme has collected new datasets, where this study is focusing on data retrieved from the end member of the Kveithola Palaeo-Ice Stream, the Kveithola Trough-Mouth Fan (TMF). The dataset contains new bathymetry data from the Kveithola TMF, with a higher resolution than previous studies (10 m cell size), and is covering an area of more than 2000 km^2, from the shelf edge towards the deep ocean. The surface revealed by the new data display a morphology that is highly influenced by mass movement processes, where the majority are interpreted as either sliding events or glacigenic debris flows. Based on the bathymetry, the slides appear to differentiate in age, where both older and younger events are present (possibly pre- and post-Last Glacial Maximum), and to have occurred both as single or sequenced events. The Kveithola Slide display features that indicates a retrogressive development, and within the new data there have also been observed three minor retrogressive cracks that foreshadows the potential for the occurrence of new events in the future.

S heterogeneities in barite, aragonite, and pyrite record geochemical evolution of cold seeps

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The anaerobic oxidation of methane by sulfate reduction (AOM-SR) produces steep geochemical gradients in active cold seep environments and may foster the precipitation of pyrite (FeS_2), barite ($BaSO_4$), and methane-derived authigenic carbonates (MDAC). These minerals preferentially precipitate near the sulfate-methane transition zone (SMTZ) where AOM-SR activity is high and record the $\delta^{34}S$ composition of porewater sulfide (pyrite) and sulfate (barite, carbonate-associated sulfate (CAS) in MDAC) during precipitation. In active seep environments, SMTZ depth and porewater $\delta^{34}S_{sulfate,\ sulfide}$ compositions depend on the relative rates of sulfate diffusion and AOM-SR. The interconnectedness of methane flux, AOM-SR activity, and porewater chemistry allows for mineral precipitation under non-steady state conditions. In this study, we use a combination of X-ray absorption near edge structure (XANES), secondary ion mass spectrometry (SIMS), and micro-drilled isotopic analyses to evaluate the microscale compositional variability of MDAC, barite, and pyrite precipitated in active cold seep environments. The assessed barites were collected from two recently discovered cold seep sites on the Lofoten-Vesterålen (LV) continental slope, and MDAC and pyrite samples are from gas hydrate pingos (Eurasian Arctic Shelf) and Storbanken craters (north-central Barents Sea). Within cm-scale samples, SIMS $\delta^{34}S_{Py}$ values can range more than 30‰ among framboids, and there appears to be a relationship between framboid diameter, $\delta^{34}S_{Py}$ composition, and adjacent MDAC mineral phase, aragonite or Mg-calcite. Many samples have a multimodal distribution of $\delta^{34}S_{Py}$ values and suggest pyrites precipitated under discrete environmental regimes. The assessed LV barite are highly enriched in ^{34}S, and the mean $\delta^{34}S_{BaSO4}$ value from SIMS spot analyses is 70.3‰. Within individual barite aggregates (< 250 μm), $\delta^{34}S_{BaSO4}$ values can span more than 40‰, and $\delta^{34}S_{BaSO4}$ values are most variable along barite growth axes and among successive layers. We suggest this $\delta^{34}S_{BaSO4}$ variability reflects changes in methane advection rates during barite precipitation. Similarly, μ-XANES redox maps reveal fluctuations in CAS concentrations along MDAC-aragonite growth axes and between successive layers. CAS concentrations appear consistent among contemporaneous MDAC precipitates and over large lateral distances (> 5 mm). These microscale changes in $\delta^{34}S_{Py,\ BaSO4}$ values and fluctuations in CAS concentrations indicate precipitation was prolonged and proceeded under non-steady state conditions. We suggest much of this compositional variability is due to changes in methane flux during precipitation, and that successive microscale changes in CAS concentrations and $\delta^{34}S$ values can be used to reconstruct paleo cold seep conditions.

Facies variability of the continental Lower Carboniferous Billefjorden Group in Central Spitsbergen, Svalbard

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A high spatiotemporal facies variability is common for continental successions, which complicates stratigraphic correlation. Further, sequence stratigraphic concepts are difficult to apply in fluvial deposits due to lack of marine floodings, but relative sea-level variations can be reflected by abundance of coal intervals as lateral expression to marine floodings and unconformities.

The Famennian-Viséan fluvial Billefjorden Group in Central Spitsbergen represents a less understood stratigraphic interval in Svalbard's geological record, due to heterogeneous facies belts that are, in addition, segmented by younger, Serpukhovian-Moscovian faults, later reactivated in Neogene. Traditionally, the succession is divided into the Hørbybreen and Mumien formations. The Hørbybreen Formation is confined to a depocenter in the western part of study area. The lower Triungen Member exposes coarse conglomeratic facies with a sharp transition towards the shale-dominated Hoelbreen Member. This transition represents a change in type of fluvial depositional system as well as a significant hiatus with the Tournaisian strata missing. Higher in the stratigraphy is a sharp transition towards the overlying Mumien Formation with a multi-storey channel sandstone belt at the base (Sporehøgda Member). The channel belt is confined to the central and eastern part of the study area where it oversteps the metamorphic basement, which during Hørbybreen Formation acted as the eastern basin margin. The subdivision into stratigraphic members is based on lithological similarities, correlated across great distances. We would like to challenge this division as it is rarely sustainable to draw time-lines along fluvial facies belts; Interfingering of the different facies belts seems to be more likely.

In this study we contribute with recently collected datasets that cover sedimentological logging, fault mapping and acquisition of drone-based photogrammetry, allowing to create digital outcrop models (DOM's) using structure-from motion-algorithms. The DOM's allow for (1) mapping of sedimentary facies sequences and their thickness variations across faulted blocks, (2) mapping of structural features, such as faults and truncation surfaces, and (3) construction of detailed geological- and thickness-maps. Detailed stratigraphic models, inferred from the collected data, are used to discuss the auto- and allogenic controls on distribution of the continental system. Preliminary analyses show a highly varying distributional facies pattern in the established stratigraphic members. This either suggests that the members were restricted due to syn-tectonic factors or that the members are of highly varying character and thickness across the basin and thereby up for revision of their original definition. Improved constraints on depositional dynamics of continental deposits in Billefjorden will also shed light on the equivalent sub-cropping strata of Lower Carboniferous age in the Barents Sea and on Svalbard's depositional and structural history, with significant consequences to current models for distribution of reservoir zones.

Curtis Wars, episode IV: Return of the (Je)tide: Tidal dynamics in palaeo-seas in response to long-term changes in bathymetry, tidal forcing, and bottom shear stress

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Tidal dynamics in shoreline–shelf systems are principally a function of latitude and the physiography (geometry and bathymetry) of the depositional basin. By studying the influence of changing physiography on tides enables 1) better understating of historical sedimentary processes in shallow marine basins, and 2) potential changes in shoreline tidal dynamics in response to anthropogenically-driven changes in relative sea level.

During the Middle and Upper Jurassic, the 2500 km-long Sundance Sea, also known as the proto-Western Interior Seaway, developed in a retroarc foreland basin that covered an area spanning from today's British Columbia, where it was connected to the Pacific Ocean at ~55-60°N/63-65°W, to today's Wyoming to the SE. During the Callovian and Oxfordian, between 165 and 160 Ma, the Sundance Sea periodically extended ca. 1500 km south-westwards, flooding the SSW–NNE-oriented retroarc foreland basin known as the Utah–Idaho Trough. One of these marine transgressions led to the deposition of the siliciclastic-rich Curtis Formation, which preserves abundant evidence of strong tidal currents during deposition.

Here, we present an analysis of numerical modelling of tidal propagation in the Sundance and Curtis Seas to show that:

- Changes in palaeobathymetry control both the magnitude and the location of tidal amplification. Some palaeobathymetries resulted in a general increase in tidal amplitude across the basin (with various degrees of amplification), whereas other palaeobathymetries led to an overall dampening of the tidal amplitude.
- The impact of change in palaeobathymetries on the flow speed and bottom shear stress is also significant. However, they are very sensitive to local variations, and their responses to palaeobathymetric changes are much more spatially heterogeneous than the response of the change in tidal amplitude.
- Variations in initial tidal forcing and bottom drag coefficient impact the location of tidal amplification, as well as flow speed and bottom shear stress variations in the basin, but to a much lesser degree than changes in palaeobathymetry and with much more spatial variations.
- Despite basin-wide trends associated with relative sea -level rise or fall, the spatial distribution of the tidal amplification across the basin is heterogeneous. This results in the resurgence of tidal amplification or dampening with different periods at different locations, with increasing spatial variations the deeper the basin is. Consequently, the stacking pattern of the various architectural elements would strongly vary from one side of the basin to the other, despite a similar relative sea-level (RSL) history. The interpretation of the RSL history across an entire basin therefore requires caution if tides are one of the major process active at the time of deposition, particularly when data points are sparse.

On CO_2 monitoring techniques and the importance of collaborating during times of crisis

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Our current understanding of sub-surface CO_2 storage feasibility derives mainly from valuable small-scale projects, which have mostly been working at injection or human time scales. These projects, however, have not been operational long enough to fully assess flow and/or seepage at longer time scales relevant for subsurface CO_2 sequestration (e.g. > 10 kY). Many examples of fluid escape have been documented in the offshore subsurface environment (e.g. seismic chimneys), and active or relict natural seeps on land offer informative analogues to subsurface fluid migration.

Of note are the natural seeps located along the Little Grand Wash normal fault in east-central Utah, USA, which are easily accessible and represent suitable on-shore counterparts to the offshore fluid escape features. This system of normal faults, which has total throw of 300 m, intersect a complex succession of aeolian reservoirs naturally-charged with CO_2 and associated paralic to shallow-marine seal units of Jurassic age, and has served as conduit for CO_2 to escape along for the last 113.9 ky. Several natural seeps occur along the fault, but the most active CO_2 leak in the area occurs at the Cystal Geyser, where the CO_2 brines periodically erupt from an old exploration well. However, the detailed study of the outcropping stratigraphy shows a much more complex link between depositional environment, sub-facies variations, and reservoir quality than the oversimplification used in regional and sub-regional reservoir studies.

In January 2020, three cores were recovered within the fault and its damage zone: One 9-m-long, hangingwall (Cretaceous Cedar Mountain Fm.) to footwall (Upper Jurassic Salt Wash Mbr. of the Morrison Fm.) core, and two composite core covering 15 m from hangingwall (Upper Jurassic Brushy Basin Mbr. of the Morrison Fm.) damage zone into the footwall (Upper Jurassic Summerville Fm.). These cores recorded a history of fluid rock interactions through fractures and the alteration of the host-rock. During core-drilling operations oil and CO_2 charged waters were encountered, with active degassing of CO_2 at surface. All core samples show evidence of fluid-rock interaction with re-cementation in the host rock lithologies and multiple generations of carbonate vein development (aragonite/calcite). In the hangingwall damage zone consisting of Brushy Basin material, we observe live oil and oil stained fractures.

An additional, 2-km long Vp and Vs seismic profile will be acquired across the Little Grand Wash fault, and data will be collected during a 72-hours survey, which aims at imaging changes in the subsurface before, during, and after several eruption cycles. Recordings of the ambient seismic noise across the area will complement this dataset.

Transforming the role of the digital geoscientist into the next decade: Enhancing seismic interpretation and 3D modeling using novel machine learning tools to automate, speed up and improve accuracy of subsurface characterization and reservoir development

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Digital transformation of the oil and gas industry holds promises, which may be hard to quantify in terms of overall value for a company, as well as demonstrating everyday benefits in the work of Geoscientists; Will it lead to just another toolset they have to learn, and more importantly, will geoscientists lose their job as machine leaning (ML) in many cases claim to replicate human work, boast automation and improve accuracy? Here we demonstrate that a combination of new ML methods will in fact assist our new Digital Geoscientists to become even better in their day-to-day work and enable them to work more productively across traditional disciplines.

For ML assisted seismic fault interpretation, two novel ML methods were built based on Deep Convolution Neural Networks (CNN). A Pretrained model, to predict fault likelihood across unseen seismic data, was built using a wide variety of seismic datasets with diverse geological settings and high-quality labels from expert interpreters. A supervised model was also built, to let users provide their own fault labels, typically improving the quality of the prediction directly on dataset of interest. A significant time reduction is seen as only a handful of lines (<1% of the seismic volume) is enough to train the machine.

Once the fault prediction cube is generated, automated fault extraction can be used to feed a semi-automated 3D sealed framework model and a 3D Geocellular grid. The same Digital Geoscientist can now turn to '1-click' property modeling to predict e.g. high porosity sweet spot locations.

For ML assisted property modeling, a new algorithm based on adapted Decision trees integrated with geostatistics, was built. This will accelerate and simplify property modeling, alleviating the Digital Geoscientist from days of work trying to learn the intricacies of Geostatistical algorithm behavior, as it removes the need to calculate variograms and asses stationarity. It is

more robust than classic algorithms, can consume many input variables and ultimately provide a prediction of the target with a realistic model of uncertainty.
The new Digital Geoscientist can now take advantage of a set of new ML solutions, enriched in an existing market leading Geoscience software, simplifying and automating some tasks while allowing them to now work seamlessly across disciplines. This allows focusing on real value generation such as building geological scenarios or fast-tracking partner interpretation and model QC. The ML enriched workflows are transferable to University, -and Energy transition work.

Ecological implications of changing sources and accumulation rates of organic carbon during the last 300 years in Hvaler, ytre Oslofjorden – A geochemical and micropalaeontological study

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Hvaler is an estuary in SE Norway, and is influenced by the largest river in Norway. The geochemistry and foraminiferal assemblages of two overlapping sediment cores from the area were analysed. The cores were dated, and analysed for grain size distribution, heavy metal concentrations, TC, TN, TOC, $\delta^{13}C$, $\delta^{15}N$, and changes in foraminiferal assemblages.
Based on extrapolations of ^{210}Pb-dating, the sediment cores span >300 years. The heavy metal pollution in the cores reflects the emissions of the industry in the area, reaching concentration maxima in sediments from the 1970s. Based on heavy metal concentrations, the reference conditions in the sediments are interpreted to be before ca. 1800. After the concentration maxima in the 1970s, the heavy metal concentrations are declining towards the present, following the implementation of environmental regulations.
The organic matter in the sediments is of mainly marine origin, but becomes slightly more terrestrially influenced over time. The proportion of marine vs. terrestrial influence was based on C/N-ratios, isotopic ratios, and a mixing equation. The mixing equation compares the values of the estuarine sampling location to terrestrial and marine end-members found in literature of the research area.
Chronologically, the foraminiferal assemblages were initially characterized by an alternating pattern of *Hyalinea balthica* and *Adercotryma glomerata/wrighti*. This pattern is likely due to climate fluctuations during the time period. In the last ~100 years, the accumulation rates of TOC have increased, accompanied by an increase in *Stainforthia fusiformis* and *Textularia earlandi,* which are species tolerant to organic carbon enrichment. The benthic foraminiferal accumulation rates have also increased towards the present. Possible causes of these changes can be climate change, increased river discharge, eutrophication and land use changes.
The invasion of *Nonionella* sp. T1 was first observed in the cores in 2016. The species seems to replace *Stainforthia fusiformis*, which went from dominating, to comprising only a small fraction of the assemblage in the surface sediments.
Reference:
Aasgaard. S.M., 2020. Ecological implications of changing sources and accumulation rates of organic carbon during the last 300 years in Hvaler, ytre Oslofjorden – A geochemical and micropalaeontological study. Master's Thesis, University of Oslo. Available from: http://urn.nb.no/URN:NBN:no-82786

UNFC: Towards a harmonised inventory for European mineral resources

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With the global increase in raw material demand comes the need for harmonized support tools for sustainable resource management in Europe. Europe needs to assess their resource potential, but the European countries do not have a common tool to aggregate information for continent-wide resource inventories. The United Nations Framework Classification for Resources (UNFC) is a system that may be used for this purpose.
Mintell4EU is a project financed by the ERA-NET research programme GeoERA (www.geoera.eu). The overall aim of the project is to improve the European knowledge base on raw materials. This will be done by updating the European Minerals Yearbook (http://minerals4eu.brgm-rec.fr/m4eu-yearbook/) and to extend the spatial data and quality of data in the current European Geological Data Infrastructure (http://www.europe-geology.eu). One specific task in the project is to test if the European geological surveys will be able to use UNFC as a tool to evaluate a country's resources and potential resources across variable levels of knowledge. The project will also show if the application of UNFC can provide better harmonization of mineral resource data nationally, and across Europe.
To gain the necessary experience, the UNFC work in Mintell4EU is based on case studies. Nine geological surveys are performing 30 case studies that cover the range of different resource types. Studies are conducted at both local, regional and national scale. The case studies will demonstrate that the geological surveys across Europe are able to use UNFC,and develop guidelines on how UNFC should be applied in aggregation of national resource data. The project is also aiming at presenting a pan-European UNFC aggregation on selected resource types.
In Norway, NGU will perform case studies on metals, industrial minerals, dimension stones and aggregates. In this presentation, an example a UNFC classification of Larvikite will be presented.

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