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8-2023

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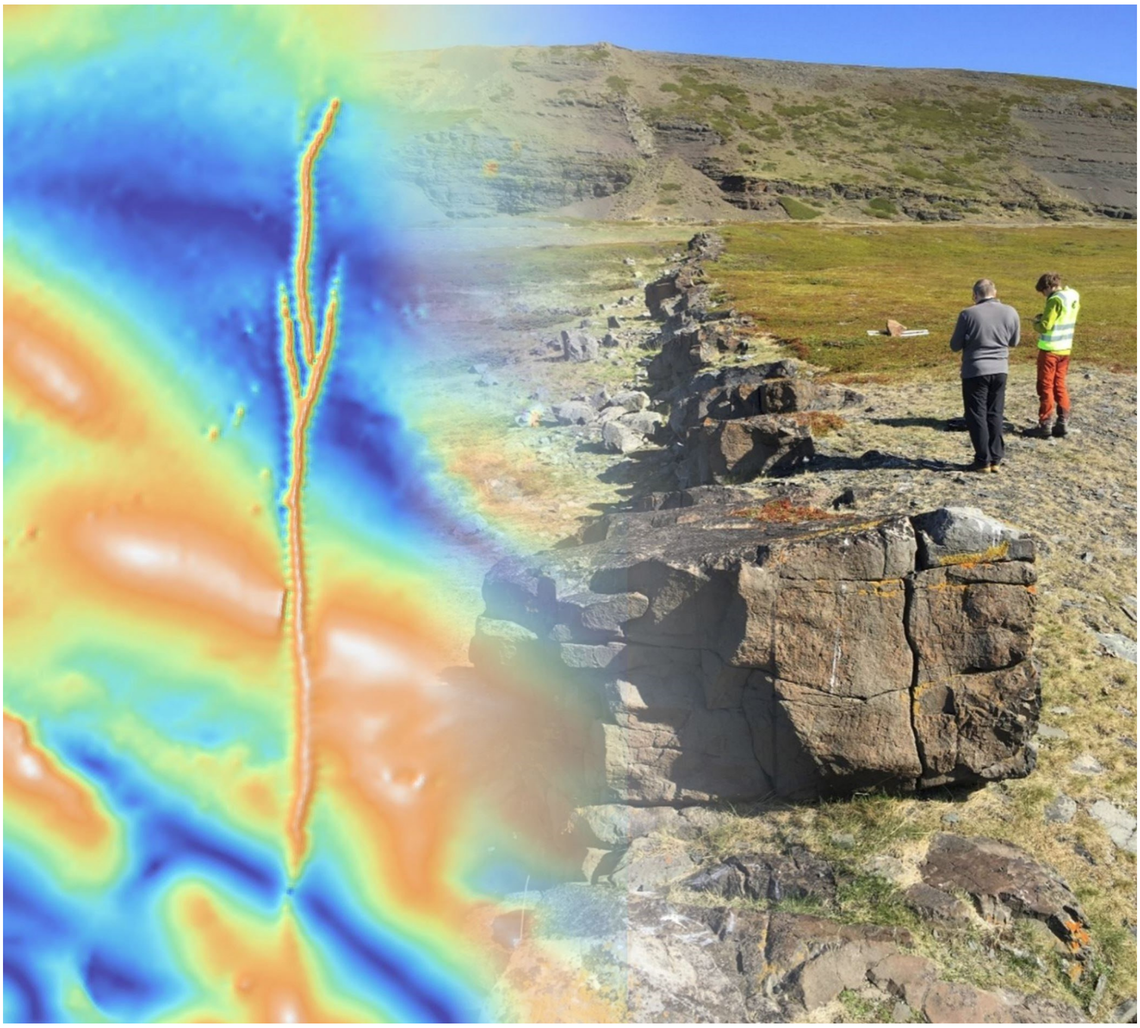

Geological Excursion to the Varanger Area, eastern Finnmark, Norway

Prepared by
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The dolerite dykes on Ekkerøy as mapped by aeromagnetic data and as seen in the field.

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Trondheim, 2023

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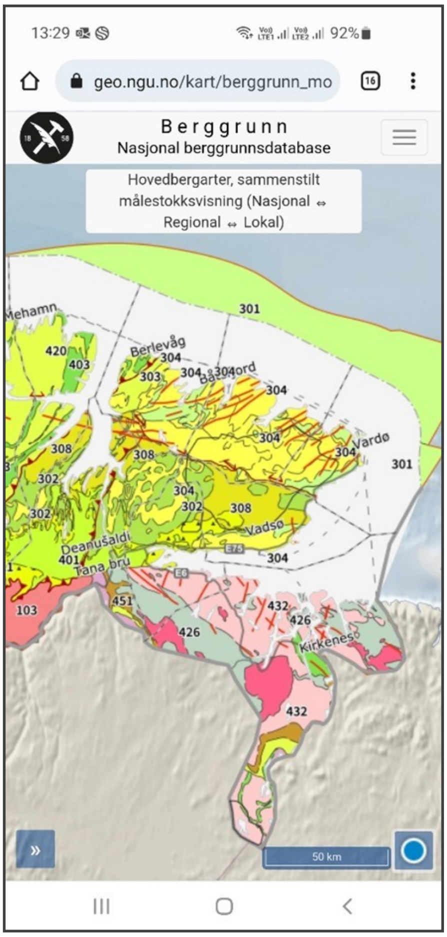
Preface

This guide has been compiled for an excursion conducted in connection with the project end meeting of the industry-financed BOOST project (Barents Onshore-Offshore Structure and Tectonic Modelling), conducted at NGU. The results of the project are compiled in the NGU report 2022.011. While the project focused on the southwestern Barents Sea, the rocks and geological development of eastern Finnmark (Figures 1 and 2) provide a good basis for discussing onshore-offshore relationships and the evolution of the offshore domains.

This excursion guide gives a broad overview of the geological history of the Varanger area and describes and illustrates individual key sites. Naturally, there is much more to say about the geology of the area and many more interesting field sites can be visited. One way to dive into this is with the digital maps of NGU. When displaying them on your smartphone, you can mark your current position (press the blue GPS button in the lower right corner). We recommend the bedrock map https://geo.ngu.no/kart/berggrunn_mobil/ and the digital map for geological heritage https://geo.ngu.no/kart/geologiskarv_mobil/. Here, you can interactively get information about the formations we are driving through and interesting geological sites we are passing but don't have time to look at in detail.



Geological Background

The background material for this field excursion is compiled from previous bedrock maps and diverse studies by NGU and others. Important references for putting all of this together have been: the NGU Special publication by Siedlecka and Roberts (1992); NGU report 92.217 by Roberts and Siedlecka (1992) and the guide 'Gråsteinen 3' by Siedlecka et al. (1998). Most locations are those described in this literature. In addition, information gathered for this field excursion is also inspired from various papers and books: Walker (2004); Nordgulen and Andresen (2008); Nystuen (2008); Herrevold et al. (2009); Roberts et al. (2011); Rice et al. (2012); Zhang et al. (2015, 2016); Nasuti et al. (2015a, 2015b); Müller (2014); Roberts and Siedlecka (2002); Roberts and Siedlecka (2022) and references therein. Last but not least, the whole of Varanger Peninsula is now covered by 1:50 000 bedrock maps and a new 1:250 000 map is in the planning stage. Coordinates of the locations presented in this guide can be found in the appendix.

The geological record of eastern Finnmark extends from Archean to Early Carboniferous time (Figure 3). In addition, very well-preserved sediments and structures inherited from the last ice age and the post-glacial sea-level changes are visible in many places. The county of Finnmark and the Varanger Peninsula seem to have been an important provenance area for the sedimentary rocks encountered farther north and west in the offshore platform areas.

In the southern Varanger region, the Precambrian basement rocks can be observed all along the road from Kirkenes to Karlebotn (Figure 4). The Archean rocks are generally represented by characteristic granitic gneisses and migmatites. The Bjørnevatn iron ore deposits (Sydvaranger mine), first discovered in 1866 by Tellef Dahll, started to develop when oxygen became sufficiently available to bind the free iron in the oceans during late Archean time.

In Late Neoproterozoic time, rifting and passive margin extension along the northwestern and northeastern margins of Baltica led to the Ediacaran-Cambrian opening of the Iapetus Ocean before the onset of the Timanian and subsequent Caledonian orogenies (Gee and Pease, 2004; Gee, 2021; and references therein). On the Varanger Peninsula, the sedimentary rocks from Neoproterozoic to lower Paleozoic time, (900 to 480 Ma) are well exposed (Figures 4 and 5). The Neoproterozoic metasedimentary rocks exposed above the Archean basement include sediments of fluvial, shallow-marine, deep-marine, carbonate and glacial origins. In the Varangerbotn area, there are two intervals of Neoproterozoic diamictites (interpreted as tillites) from 650-635 and 580 Ma; the latter age recently debated. The Caledonian orogeny has affected the pre-existing Neoproterozoic successions to various degrees showing deformation and metamorphism gradually increasing from east to west. Along the excursion route, several places show excellent examples of sediments and structures from the last ice age.

The onshore geology has certain implications for offshore exploration. On the Finnmark Platform, several exploration wells and shallow boreholes have been drilled. Only a few wells have drilled into the metamorphic basement which may exhibit a tectonostratigraphic and magmatic development similar to the rocks exposed in the western Varanger region. In Varanger, the thick Neoproterozoic, tectonised successions could represent provenance areas for potential reservoir sands offshore. Furthermore, aeromagnetic data show that the basement structures and metasedimentary rocks observed in the northern parts of Finnmark county clearly continue into offshore areas, also supported by bathymetric and seismic data.

A general presentation of the geological development of the Varanger area will be given as a basis for discussion during the trip and will work as background for the different field localities. Some of the fantastic outcrops in the Varanger area are considered to be world class.

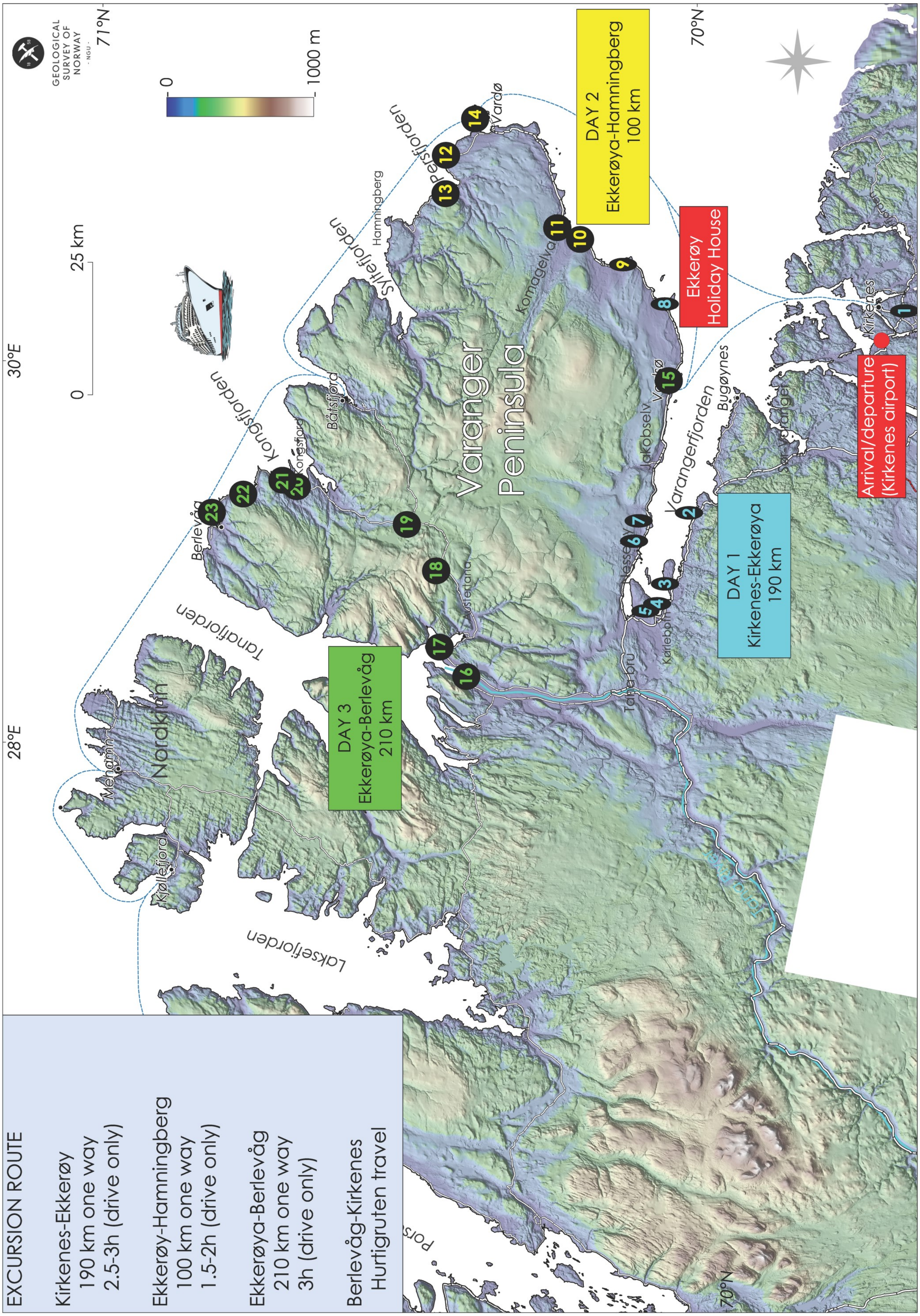


Figure 1: Overview map showing the field stops of the three-day excursion in the Varanger area.

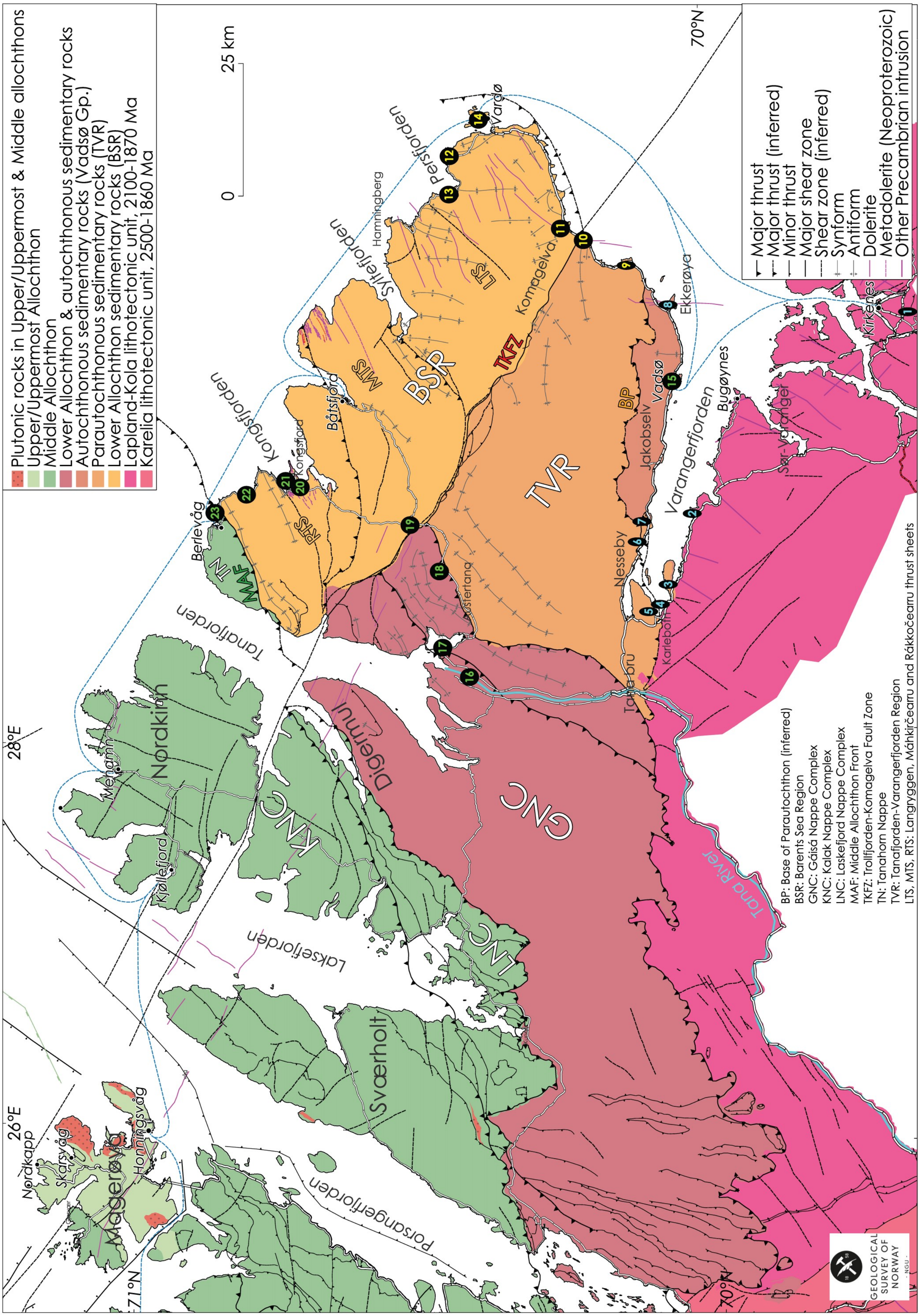


Figure 2: Main structural provinces of the Varanger Peninsula and its surroundings.

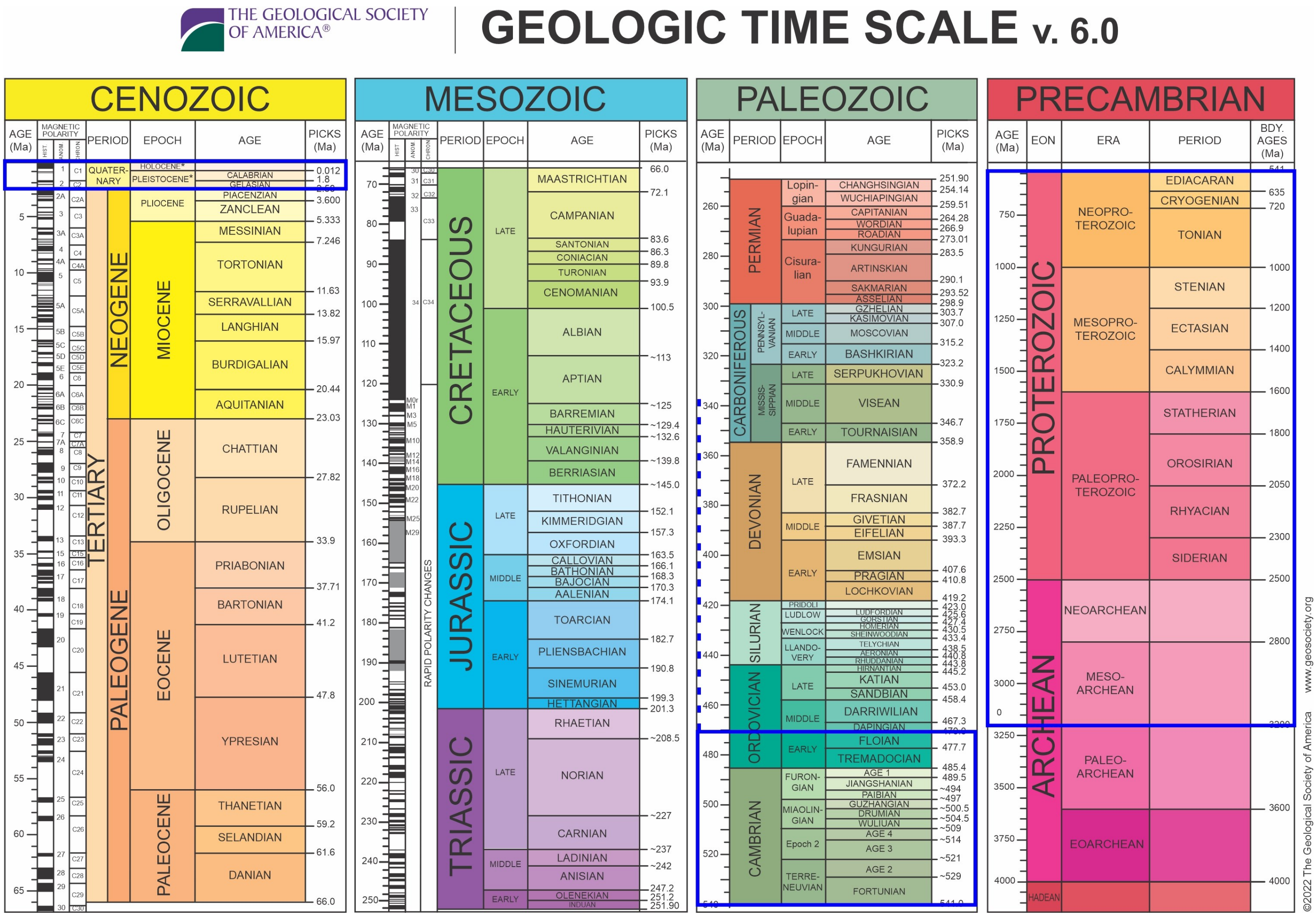


Figure 3: The geological time scale. Ages of outcrops visited in the field are marked with blue boxes or dashed line.

Regional and tectonic context

The oldest tectonic and basement history of the northern Fennoscandian Shield adjacent to the southern Barents Sea is represented by Archean granitoid and greenstone belts of the Kola and Karelian cratons, to the southwest of which lie various provinces which were involved in the Paleoproterozoic Svecofennian orogeny (Daly et al., 2006; Bogdanova et al., 2008; Janik et al., 2009; Lahtinen et al., 2009; Mints, 2011).

In the Late Neoproterozoic, rifting and passive-margin extension led to the Ediacaran-Cambrian opening of the Iapetus Ocean. However, Baltica's relationship to the Iapetus Ocean has recently been questioned (Trond Slagstad, pers. comm.). Simultaneously, the latest Neoproterozoic-Early Cambrian Timanian orogeny developed as a fold-and-thrust belt that accreted along the northeastern passive margin of Baltica during Vendian (Ediacaran) time, around 610-560 Ma ago (Roberts and Siedlecka, 2002; Kostyuchenko et al., 2006; Pease, 2001). The extent of the Timanide basement is still enigmatic in most of the greater Barents Sea but is commonly associated with the NW-SE structural, gravity and magnetic trends identified all the way to the western Barents Sea (Fichler et al., 1997; Gernigon et al., 2014, 2018; Shulgin et al., 2018; Hassaan et al., 2021; Henriksen et al, 2021; Gabrielsen et al., 2022). In the southwestern Barents Sea, the Timanide basement is progressively affected by the overprint of the Caledonian orogeny, as identified from the previous regional aeromagnetic data (Gernigon and Brönner, 2012; Gernigon et al., 2014, 2018). In addition, several generations of plutonic intrusions of Neoproterozoic (580-560 Ma: Seiland Igneous Province) and Paleozoic age (370 and 340 Ma) are recorded onshore (Lippard and Prestvik, 1997). Dolerite dykes of Neoproterozoic and Paleozoic age are observed on the Varanger Peninsula and on Magerøya (Guise and Roberts, 2002; Corfu et al., 2006; Nasuti et al., 2015b) (Figure 4).

The subsequent, protracted, Caledonian orogeny culminated approximately 400 Ma ago. It resulted in collision of the Laurentian and Baltican plates into the Laurasia continent and domains with Timanian signature locally cropping out on the sea floor in the Barents Sea (Roberts, 2003; Gasser et al., 2014). The lower thrust sheets and nappes of the Scandi-navian Caledonides overlying the autochthonous crystalline rocks of the Fennoscandian Shield began to be emplaced during the latest Cambrian to Early Ordovician but most were transported during the later Scandian phase of the Caledonian orogeny in Silurian to Early Devonian time (Roberts, 2003; Gee et al., 2010). Some of the nappes were translated up to hundreds of kilometres from their original settings onto the foreland and major allochthons extend over a distance of nearly 2000 km from SW Norway to the south-western Barents Sea (Gernigon et al., 2014), Svalbard (Gasser et al., 2014) and other high Arctic regions (Higgins et al., 2008; Pease, 2011; Lorenz et al., 2013; Schiffer et al., 2015). A conventional tectonostratigraphic subdivision of the Scandinavian Caledonides (i.e., Lower, Middle, Upper and Uppermost allochthons) has been proposed and is further described in the literature (Roberts and Gee, 1985; Roberts, 2003; Rice, 2014). It involves thrust sheets originally sourced from the Neoproterozoic and proximal Baltoscandian continental margin (Lower and Middle allochthons) to out-board nappes with ophiolites and island-arc complexes derived from the Early Paleozoic Iapetus Ocean (Upper Allochthon) or late, marginal, oceanic basins (Dunning and Petersen, 1988) and an even more exotic Uppermost Allochthon derived from Laurentia (Roberts et al., 2007). In the county of Finnmark, the exposed Caledonide and Timanide fold belt structures just at the southern edge of the Barents Sea sedimentary basins are much better constrained and understood than their offshore counterparts. The Varanger Peninsula represents the external part of this compressive system. Comprehensive overviews of the geology, sedimentology, regional structures and petrophysical properties of the onshore formations can be found in several publications (Rice et al., 1989; Karpuz et al., 1995; Siedlecka and Roberts, 1996; Roberts and Siedlecka, 2002; Roberts, 2003; Kirkland et al., 2008; Rice, 2014; Nasuti et al., 2015a; Roberts and Siedlecka, 2022 and references therein).

East of the Middle Allochthon Front, the northern Varanger terrane is also an important relic of an old Neoproterozoic basin and adjacent margin also affected by the Timanian orogeny (Roberts and Siedlecka, 2002; Zhang et al., 2015). The Trollfjorden-Komagelva Fault Zone (TKFZ) separates two main geological provinces (Figures 2, 4 and 5), namely the Barents Sea Region (BSR) to the northeast and the Tanafjorden-Varangerfjorden Region (TVR) to the southwest. The NW-SE-trending fault zone is considered to have been active extensionally in the Neoproterozoic Era (1000-540 Ma) as a major rift border fault and later reactivated. Presently, it represents a continuation of a major thrust in the Timan Range in western Russia (Roberts, 1996). During the Caledonian orogeny in Ordovician-Silurian time, it functioned mainly as a dextral strike-slip fault (Rice et al., 1989; Herrevold et al., 2009; Gabrielsen et al., 2022).

To the west of Varanger Peninsula, Finnmark is dominated by the Caledonian thrust-and-fold belt. Three major nappe complexes and a higher nappe overlie the parautochthonous successions. These are, in ascending order: (1) Gáisá Nappe Complex; (2) Laksefjord Nappe Complex; (3) Kalak Nappe Complex; and (4) Magerøy Nappe. Note that the name Gáisá is a revised Sami spelling of the former name Gaissa.

Stratigraphy and tectonostratigraphic evolution

Below the base of the Neoproterozoic successions, the Arche-an-Mesoproterozoic crystalline and metamorphic basement rocks south of the Varangerfjord are represented by tonalitic gneiss of various metamorphic grades. These rocks are overlain by a thick metasedimentary succession of Neo-proterozoic to Cambrian age (approximately 900-530 Ma) (Figures 4 and 5).

The Neoproterozoic successions preserved in the Tana-fjorden-Varangerfjorden and Barents Sea regions are fossilif-erous. One of the oldest microfossils ever found in Norway is the starshaped *Podolina minuta,* from marine calcareous shales in the lower part of the Båtsfjord Formation near Persfjorden. This fossil is used to correlate Neoproterozoic sedimentary successions worldwide. The sedimentary cover of the Varanger Peninsula also represents examples of shal-low-marine to deep-water depositional environments. The suc-cessions comprise diverse, fluvial and shallow-marine sandstone, shale and mudstone, deltaic successions, platform carbonate and deep-sea submarine-fan greywacke and shale beds.

The Neoproterozoic successions on the Varanger Peninsula have been subdivided into several groups, formations and members (see details in Figure 5). A recent review paper on the lithostratigraphy and correlations with successions on the nearby Rybachi and Sredni peninsulas in NW Russia is that of Roberts and Siedlecka (2022).

The Tanafjorden-Varangerfjorden Region represents a c. 4 km-thick platformal to shallow-basin succession which is largely autochthonous or parautochthonous. It comprises (from bottom to top) the fluvial to shallow-marine Vadsø Group, Tanafjorden Group and the Vestertana Group (Siedlecka and Roberts, 1992) (Figure 5). The complete suc-cession ranges in age from Tonian to Early Cambrian. This platformal region is also characterised by NW-SE-trending aeromagnetic anomalies representing mafic rocks or structural features in the basement beneath the Vadsø Group (Nasuti and Roberts, 2023). These are extensions of comparable magnetic anomalies occurring in the Archean crystalline basement south of Varangerfjorden and on the Kola Peninsula in Russia (Karpuz et al., 1995).

The Barents Sea Region of northern Varanger exposes sedimentary formations which are subdivided into two main groups inferred to be Tonian to Cryogenian in age: the Barents Sea Group and the Løkvikfjellet Group. The Barents Sea Group is 9 km thick and mostly consists of deep-marine submarine-fan to deltaic sedimentary rocks and is overlain by the 5.7 km-thick fluvial to shallow-marine Løkvikfjellet Group (Figure 5). In the northwestern part of the Peninsula, the Løkvikfjellet Group is overlain by higher-grade metasandstone and phyllites of the Berlevåg Formation which occurs in the Tanahorn Nappe located just to the west of the Middle Allochthon Front (Figures 2 and 4).

The general development of the Neoproterozoic stratigraphic sequences on top of the metamorphic basement before and during the onset of the Timanian and Caledonian orogenies (Figure 6) can be summarised as follows:

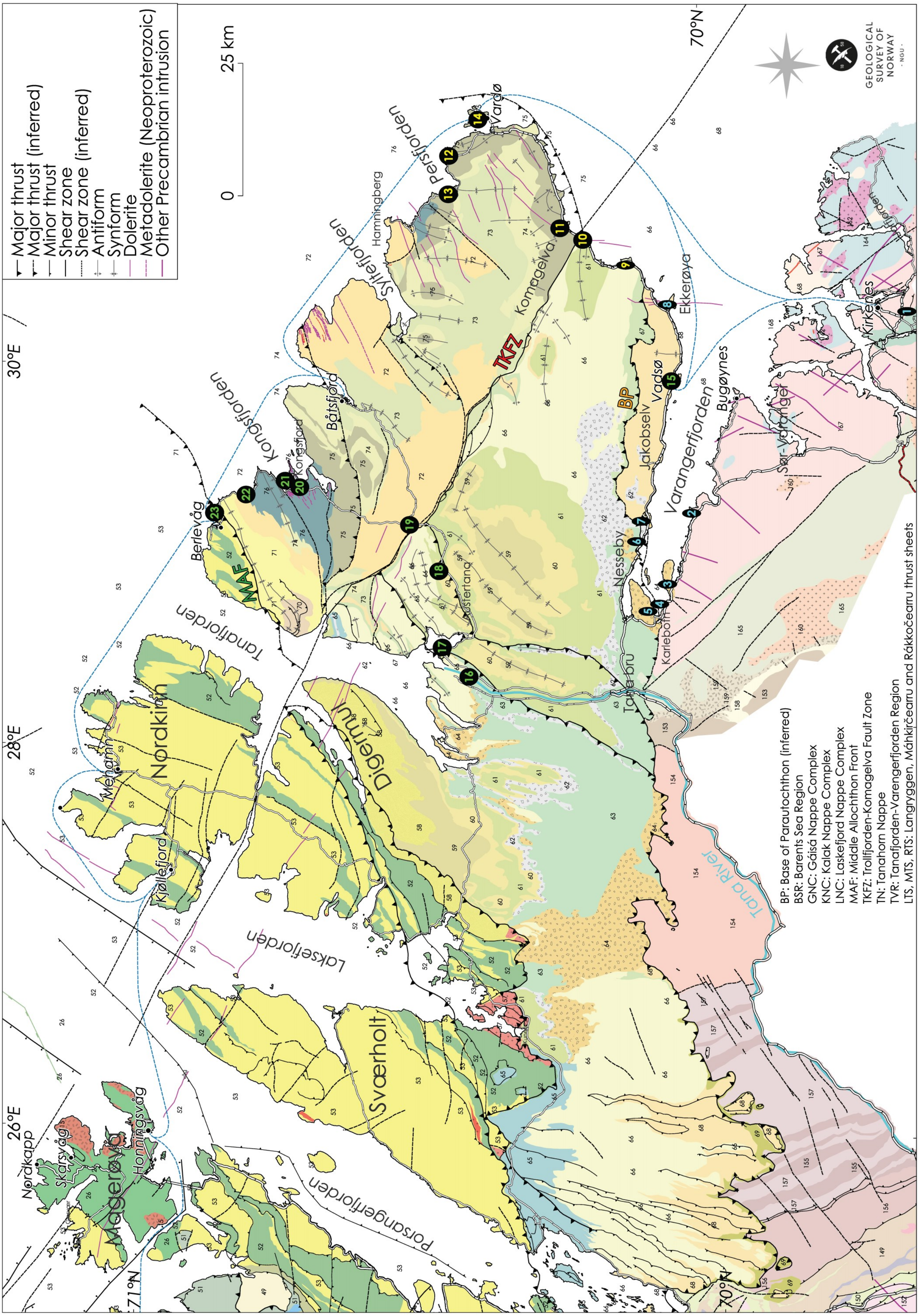


Figure 4: Geological map of the Varanger Peninsula and its surroundings. See Figure 5 for legend and Appendix for A3 version of this figure.

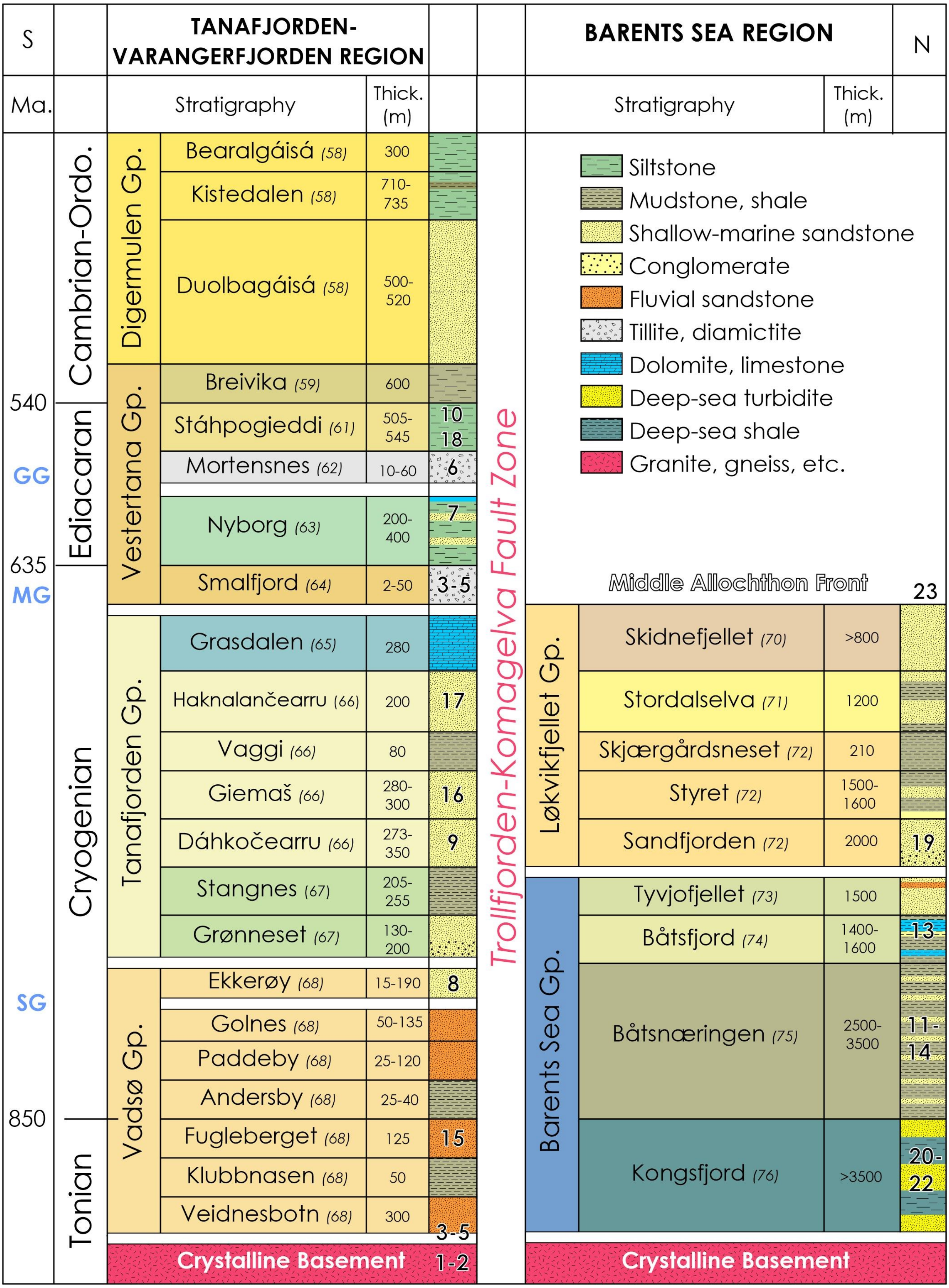


Figure 5: Chronostratigraphy of the Neoproterozoic sediments in East Finnmark, adapted after Roberts and Siedlecka (2022). GG: Gaskiers glaciation (584-583 Ma); MG: Marinoan glaciation (c. 636 Ma), SG: Sturtian glaciation (712-717 Ma). The black numbers indicate the stratigraphic position of each field stop.

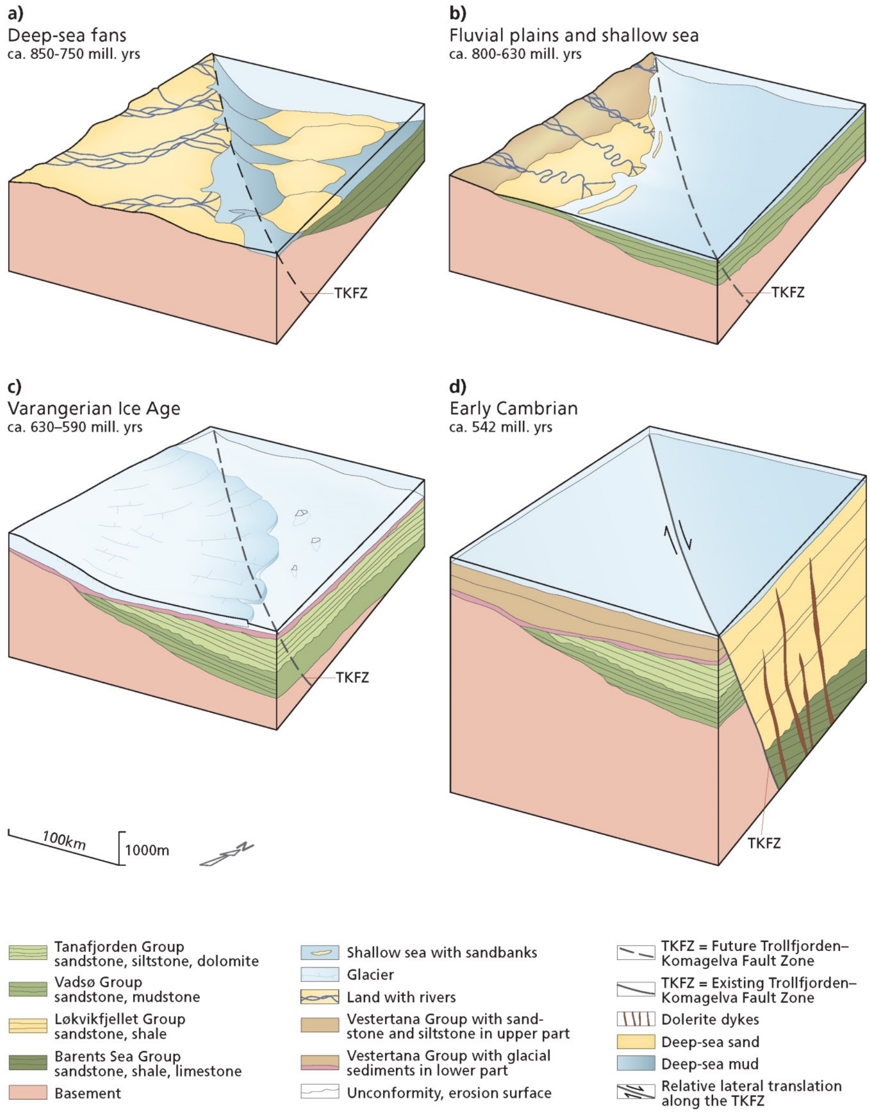


Figure 6: Pre-Caledonian development of the Varanger Peninsula (after Nystuen, 2008).

1. During the Tonian to early Cryogenian period (~850-750 Ma ago, Figure 6a), fluvial to shallow-marine sediments were deposited in the platformal Tanafjorden-Varangerfjorden Region onlapping the Precambrian basement (Karlebotn). Farther offshore, north of the precursor fault to the TKFZ, contemporaneous deep-marine sediments including turbidites were deposited in what is now the Barents Sea Region.

2. In late Cryogenian (~800-630 Ma ago, Figure 6b), a gradual deepening of the Tanafjorden-Varangerfjorden platformal area followed, and shallow-marine sediments and platform carbonates of the Tanafjorden Group were deposited. The presence of carbonate on top of the group (Grasdalen Formation) indicates an episodic warmer climate. Towards the northeastern and distal part of the Barents Sea Region, delta sequences of the Barents Sea Group (e.g., Båtsnæringen, Båtsfjord and Tyvjofjellet formations) were contemporaneously developed indicating a shallower basin paleogeography.

3. Near the transition Cryogenian-Ediacaran (~635-590 Ma ago, Figure 6c), sudden climate changes took place as suggested by the glacial sediments interbedded with carbonate rocks in the lower Vestertana Group (e.g., Smalfjord, Nyborg and Mortensnes formations, together constituting the Varangerian glaciation). During the same period, shallow-marine to fluvial sediments developed in the Barents Sea Region (e.g., the Sandfjorden Formation). In the Tanafjorden-Varangerfjorden Region, tillite and other glacial deposits of the Smalfjord and Mortensnes formations are separated by the interglacial sediments of the Nyborg Formation. The Smalfjord diamictites have commonly been regarded as equivalent to the worldwide Marinoan (650-635 Ma) glacial event and the Mortensnes (c. 580) as a Gaskiers glaciation (Rice et al., 2012; Figure 7). The Neoproterozoic glacial formations in Finnmark and elsewhere worldwide have been looked upon as enigmatic because several of the glacial deposits are overlain by carbonate formations. These commonly form in a CO_2-rich climate associated with tropical climatic conditions. During a global glaciation, the oceanic and atmospheric CO_2 reservoirs are decoupled, leading to raising CO_2 levels in the atmosphere and eventually to a temperature rise that terminates the glaciation. This is the background of the hypothesis

of the 'Snowball Earth' glaciation spanning the entire globe, introduced by the geo-scientist Paul Hoffman (e.g. Hoffman et al., 2017, and references therein).

4. At the end of the Ediacaran (~542 Ma ago, Figure 6d), a fairly flat shelfal area is inferred for the entire region. Shallow-marine sands and mudstones including organic-rich shales (Stáhpogieddi and Breivika formations) were deposited in what is suggested to have been a shallow foreland basin ahead of the rising of the Timanide orogen (Zhang et al., 2015).

5. The Timanian orogeny further developed as a fold-and-thrust belt accreted along the northeastern passive margin of Baltica during Vendian (Ediacaran) time, around 610-560 Ma ago (Roberts & Siedlecka, 2002; Kostyuchenko et al., 2006; Pease, 2021). Although originally assumed to have been solely with Caledonian contraction (Roberts, 1972), later investigations have revealed that the fold complexity in the Varanger region arises from deformation in both the Timanian and the Caledonian orogenies (Roberts, 1995; Roberts & Siedlecka, 2002). The main Timanian orogenic movements involved SW-directed folding and thrusting (Herrevold et al., 2009; Roberts, 1996). Although the Caledonian structural grain predominates in the eastern part of the Varanger Peninsula, there is a significant number of fold axes transverse to the Caledonian trend (Figure 4). Here, there are folds with amplitudes on the scale of tens to hundreds of metres, wavelengths up to several kilometres, and NW-SE to NNW-SSE-striking fold axes with axial planar slaty cleavage, which are of Timanian origin and Ediacaran in age (Roberts, 1996; Gabrielsen et al., 2022).

6. During the Caledonian orogeny, the emplacement of the three principal nappe complexes (Kalak, Laksefjord and Gáisá) affected and mostly deformed the rocks of the western part of the study area. Metamorphic grade reached upper anchizone conditions in the Gáisá Nappe Complex (Townsend et al., 1986) while the Laksefjord Nappe Complex underwent epizone metamorphism (Bevins et al.,1986). The overlying Kalak Nappe Complex displays a progressive westward increase in metamorphic grade in greenshist to amphibolite facies (Gayer et al., 1987; Rice and Roberts, 1988; Figure 4). The higher Kalak Nappe Complex to the west of Porsangerfjord (Figures 2 and 4) reached at least sillimanite grade (Roberts, 1985). Kirkland et al. (2008) have suggested that the Tanahorn Nappe should not be included in the Kalak Nappe Complex. However, two stretching lineation trends developed also in its basal mylonites are parallel to those in the Kalak Nappe Complex mylonites (Rice, 2014) and are suggested to be early ductile structures. The succession of the Tanahorn Nappe underwent epizone-grade metamorphism – a higher grade than in the thrust sheets of the Barents Sea Region allochthon farther east (Rice et al. 1989). Thanks to aeromagnetic data, the Middle Allochthon Front can be extrapolated offshore up to the Nordkapp Basin (Gernigon & Brönner 2012; Gernigon et al., 2014).

Massive erosion of the Precambrian-Cambrian rocks in subsequent periods might have been the source of later petroleum reservoirs in the sandy successions of the Barents Sea. It is suggested that the present Tana River, for example, may have existed over a very long time as an entry point to the Barents Sea (Eide et al., 2018; Henriksen et al., 2021). For instance, the Lower Triassic channel and fan systems mapped by seismic data on the Finnmark Platform might be a response to deposition from the same area.

The offshore continuation of the Quaternary glacial deposits has been thoroughly studied and published in several articles. In the coastal areas off Finnmark, postglacial uplift of several hundreds of metres is evident from erosion of the Paleozoic and Mesozoic successions observed in seismic sections and confirmed by well logs (Vorren et al., 1991; Henriksen et al., 2011; Ktenas et al., 2017, 2019). The Varanger area, as well as the rest of Fennoscandia, has been subject to severe uplift and erosion. In onshore areas sediment thicknesses of several kilometres probably existed in the region before the Mesozoic and Cenozoic tectonic events and the Quaternary glaciations.

In addition to the diamictites of the Cryogenian and Ediacaran glaciations, 'recent' Quaternary glacial deposits can be studied in several places along the excursion route. Several of the Quaternary glacial deposits are used for industrial purposes by several smaller business units in Finnmark.

Magmatism

Mafic dykes of two generations occur on Varanger Peninsula. Metadolerite dykes of Ediacaran age (c. 570 Ma) are common in the northern Barents Sea Region, whereas a few unmetamorphosed Devonian dolerite dykes (c. 370 Ma) are present in eastern areas, also south of the TKFZ.

The metadolerite dykes are most frequent in the Barents Sea Region and continue into the offshore domain as has been mapped with high-resolution magnetic data (Nasuti et al., 2015b). The metadolerites are present as dyke swarms in the Kongsfjord and Båtsfjord areas (Figure 4). The magnetic data also show that the metadoleritic intrusions locally increase the amplitude of the inherited Caledonian NE-SW-trending magnetic anomalies stemming from the deformed, low-magnetic sedimentary layers. This characteristic signal is also observed offshore in the southern Finnmark Platform. The Early Carboniferous dolerite dykes exposed on Magerøya can also be followed east-southeastward on magnetic data and are considered to occur below western Varanger Peninsula (Nasuti et al., 2015b).

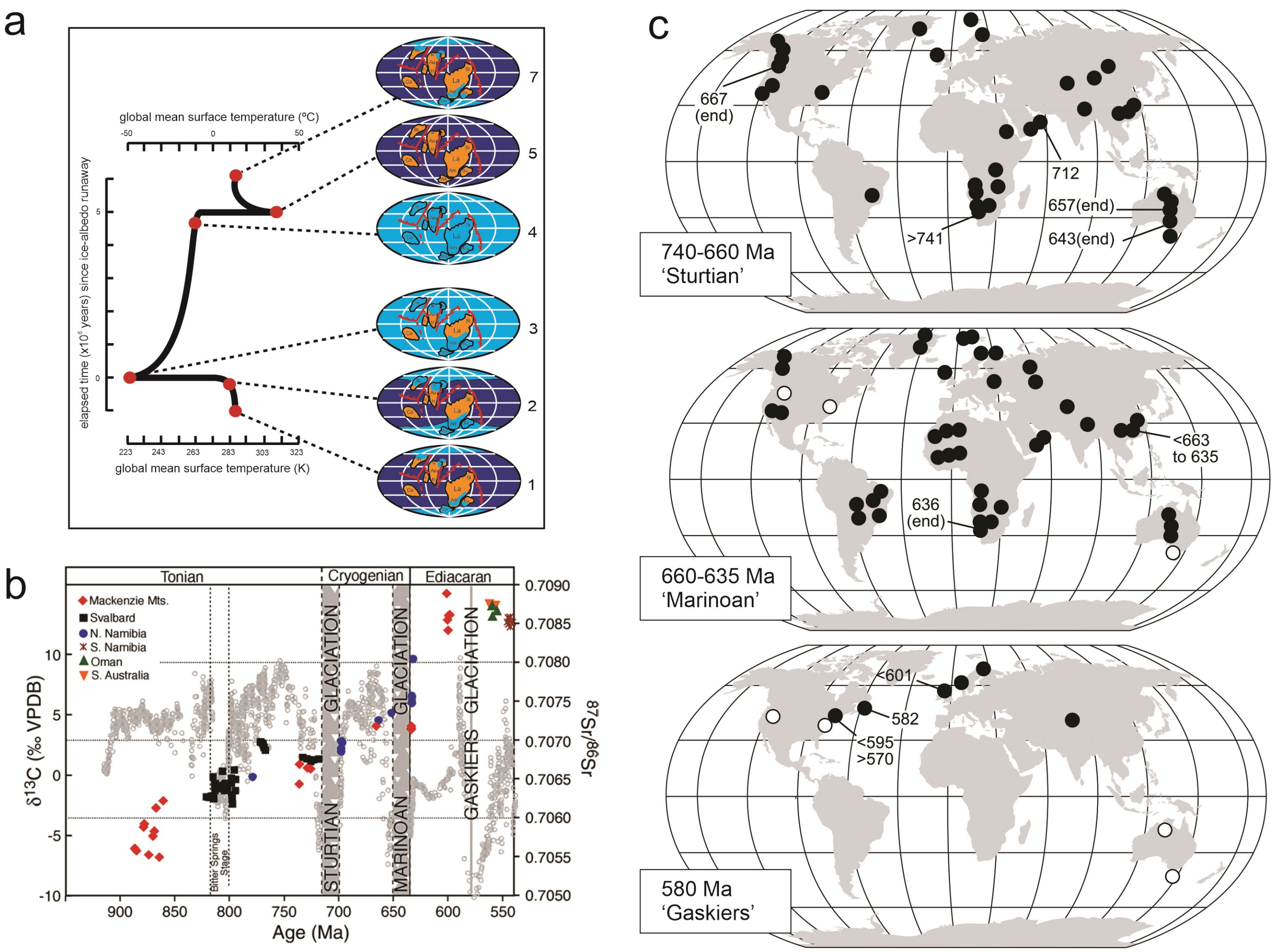


Fig 7: Global Neoproterozoic glaciations. a) Snowball Earth concept. From Hoffmann and Schrag (2002). Global palaeographical model from Powell et al. (2001). b) Composite $^{87}Sr/^{86}Sr$ record, overlain on the composite $\delta^{13}C$ record (shaded circles) for the Neoproterozoic. From Halverson et al. (2007). c) Geographical distribution of Neoproterozoic alleged glacial deposits grouped by age. Open circles indicate uncertain assignments, numbers indicate critical age constraints. From Fairchild and Kennedy (2007), modified from Halverson (2005).

Geological diversities and heritage

Geological diversity describes the variation in solid rocks, minerals, loose sediments, landforms and geological processes of a certain area. Geological heritage represents the part of the diversity with value for the biosphere, science, education and experience. Localities that represent a piece of the Norwegian geological heritage are called geosites (geosteder). These sites get special attention during impact assessments for infrastructure and construction projects. Since 2020 it has been required by law to consider the geology in impact assessments.

Information on geological diversity is compiled on NGU's web page www.ngu.no and in the map database http://geo.ngu.no/kart/geologiskarv_mobil/.

In the Varanger area, the geosites are very well exposed due to little vegetation. The spectacular sedimentary structures related to the last ice age, the Neoproterozoic sedimentary rocks and the Archean basement can be studied in detail.

Preparations

HSE precautions

Currently, there are no regulatory measures against COVID-19 in Norway, which would need to be followed. Nevertheless, effects are seen in that the excursion has been postponed by nearly two years until now, early summer 2022.

There will be a general HSE briefing at our arrival in Kirkenes before the start of the excursion. A separate HSE briefing will be carried out by the local guide when visiting the Sydvaranger iron ore quarry.

There might be possibilities for alternative stops on the way, if the time schedule allows for it and if the HSE regulations can be followed. Please be careful when stepping onto the narrow roads from the minibus. The greatest care should be taken along and crossing the roads; they are narrow, and some cars drive very fast.

Some moderately steep cliffs will be traversed, and care should be taken. Keep your distance from the cliff on the narrow trails.

A follow-up and reminder of HSE rules will be given at all localities.

Equipment for the trip

(1) **Field boots and warm clothes**, there can be rain and cold winds. But you may also spend a day in the sun, in which case **sun screen** is advised.

(2) **Hard-hats** have to be used when inspecting steep cliffs. These will be provided by NGU. Do not step close to cliff walls where loose rocks can be seen.

(3) Use **eye protection** when hammering rocks.

(4) **Yellow warning vests** should always be worn when walking along roads. These will be provided by NGU.

Figure 8: HSE requirements during the trip. We will experience narrow roads and fast-passing cars. Be aware!

Typical view in the early summer on Varanger Peninsula. Bring warm clothes!

Field route description

Day 1 — Kirkenes to Karlebotn to Ekkerøya

The excursion will start with visiting the Sydvaranger iron mine and continues passing various basement exposures and mafic intrusions on the way to Karlebotn. Here, we enter the Neoproterozoic sedimentary cover showing examples of fluvial, ancient glacial and shallow-marine deposits from Karlebotn to Ekkerøya. An evening walk on the island of Ekkerøya is planned.

The excursion starts in Kirkenes, a town in Sør-Varanger community which was founded in 1926 and currently has 3500 inhabitants. Originally, the peninsula was called Piselvnes but changed its name to Kirkenes in 1862. The total population including the nearest surrounding areas is around 7200 people. For many years, the most important industry has been the iron ore mine run by the company A/S Syd-varanger from 1906 until the late 1990s. At its most active time, more than 1500 persons were employed. The company has been through several restructurings in the last decades and undergone bankruptcy, and production has stopped at present. Tourism is now an important business in the Kirkenes area. Approximately 10% of the citizens are of Russian origin. In the centre of Kirkenes the street signs are written in both Russian (Cyrillic) and Norwegian. Kirkenes holds the seat of the Barents secretariat (since 1993) which represents a part of the wider Barents Sea cooperation. Many cooperation projects have been established across the border with Russia. The Russian invasion of Ukraine starting February 2022 has completely changed the cross-border cooperation. In particular, it has affected the local shipyard very hard, which is a cornerstone industry in the town.

SKIPPED STOP: Jarfjorden (previously oldest rock in Norway, not visited)

The drive from Kirkenes to Jarfjorden is estimated to around 40 minutes, and the road passes only a few hundred metres from the Norwegian-Russian border.

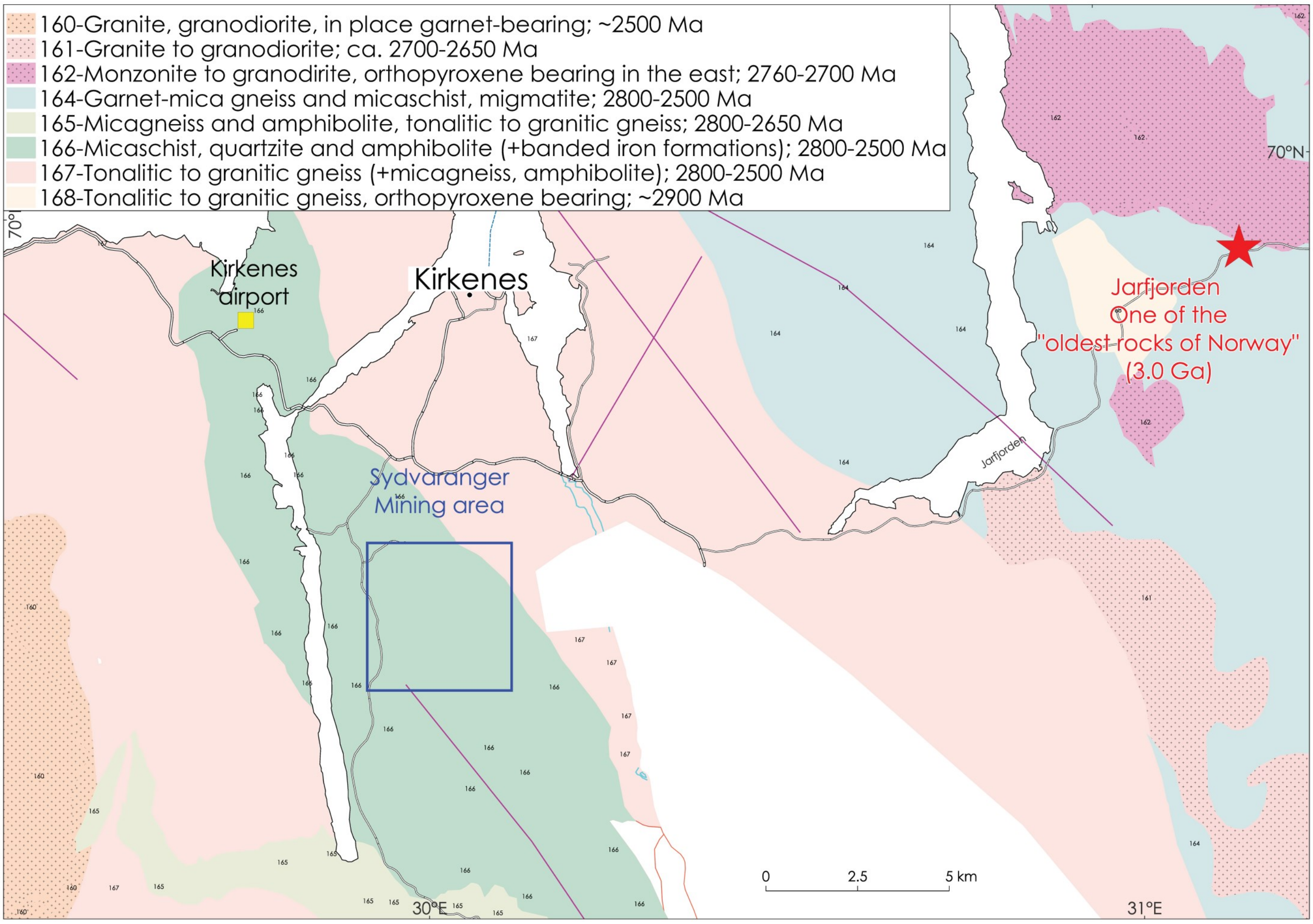


Figure 9: Overview of the Kirkenes area with airport, Kirkenes centrum, the Sydvaranger mine and the Jarfjorden locality of the (previously) oldest rock of Norway.

Jarfjorden is a location advertised as the 'oldest rock in Norway' and has been dated to 2903 Ma (Levchenkov et al., 1995). The basement rock at Jarfjorden is characterised by granitic gneisses and migmatites and represents the western part of a larger area of exposed Archean basement. It is assumed to have formed under high-temperature granulite facies and consists of hypersthene-bearing tonalite and granodiorite. This rock is considered older than the rest of the typical Archean tonalitic and granodioritic gneisses that can be observed elsewhere in the southern Varangerfjord area and have been dated to c. 2800 Ma (Levchenkov et al., 1995). The eastern continuation extends across the Kola Peninsula to Karelia.

The discussion concerning the oldest rock in Norway is an ongoing debate among geoscientists. A recent study reported in 2020 by NGU and the University of Tromsø dated a gneiss (by zircons) from the Lakselv area to be 3002 Ma (Setså, 2019). A paper by Corfu and Andersen (2022) documents Meso-to-Neoarchean crust with a tonalitic vein with a zircon age of 3102 ±15 Ma (the currently oldest rock in Norway). This rock is located c. 200 km to the west in the Skillefjord Nappe area adjacent to the Repparfjord basement window (mostly Paleoproterozoic in age).

Even older minerals (zircons) have been dated in other places in Norway, but these are found in much younger rocks. For example, a single zircon age in the Trøndelag area (c. 3970 Ma) is one of the oldest unpublished single-grain ages in Norway (T. Slagstad, personal communication). Viken (2017) also reported a zircon grain at c. 3980 Ma found in the Ordovician island-arc complex on Bømlo.

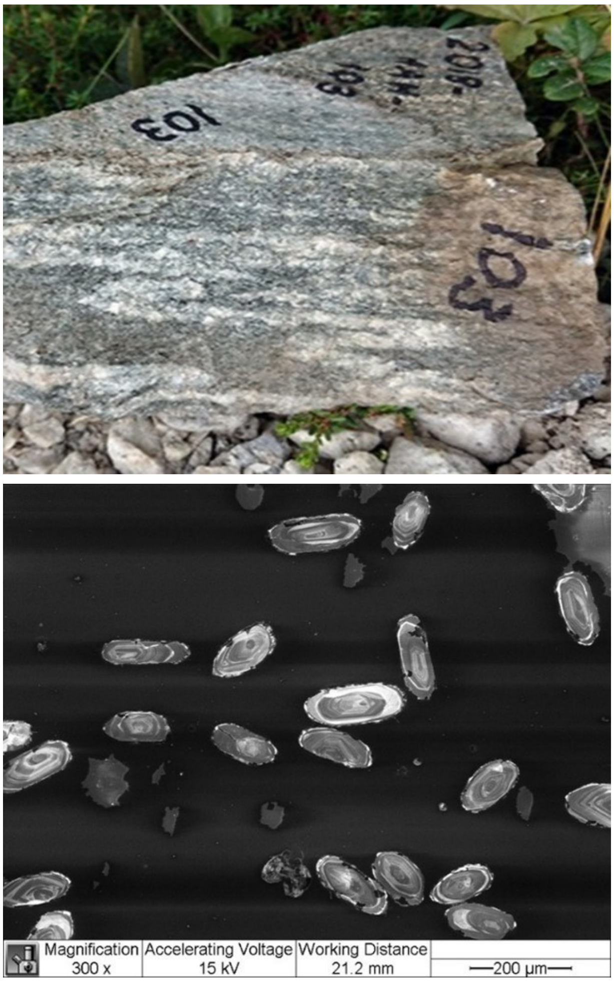


Figure 10: Top: One of the oldest rocks of Norway, the 3000 Ma old gneiss from the Lakselv area in Finnmark. Photo: Harald Hansen, UiT. Bottom: Zircons used for dating of the above gneiss. Photo: NGU.

STOP 1: Sydvaranger iron ore quarry

Presentation of the Sydvaranger iron ore mine will be given by the operation manager on site at the 'Kongetribunen' viewpoint.

The iron ore rock formed in the late Archean when free oxygen started to react with iron. The banded iron formation (BIF) of the Bjørnevatn area shows up as a marked anomaly on the magnetic data. The ore quality of the Sydvaranger mine is very good with a 30% magnetite content that can easily be refined to around 70% in the processing plant. Already in 1866, the mining inspector Tellef Dahll detected the iron deposits in the area. The first transport of iron from the Sydvaranger mine started in 1910. The prices for iron have varied considerably over time and the mine had to close in 1997. Another period of production lasted from 2009-2015, after which the Sydvaranger AS company declared bankruptcy and 400 employees lost their jobs. The assets were soon bought up by the Norwegian Tschudi Group, which in January 2021 merged with the American company Tacora Resources Inc. They plan to start up a limited production again in the coming years.

DRIVE: Archean Basement

On the trip from Kirkenes to Karlebotn we will drive through the tonalitic gneisses of the Archean basement. In some places, spectacular Precambrian mafic intrusions can be seen in the road cuts. Bugøynes is a little fishing community of Sami and Kvensk origin that was not destroyed during the Second World War. The first Sami settlements were established around 1760.
In the period from 1850-1860 a large immigration from Finland took place, and the area was called 'Pikku Suomi' or Little Finland. Many inhabitants speak the Finnish language.

The gneisses of the area are mined as building stones known under the names of Barents Blue and Barents Red. Barents Blue rocks are decorating the Oil Museum in Stavanger.

Figure 11 a) The Sydvaranger iron mine. Picture taken from the 'Kongetribunen' viewpoint. Contact of dark grey iron ore with light grey host rock.
b) The Sydvaranger iron mine. Overview picture taken from the 'Kongetribunen' viewpoint.

Figure 12: Nice example of mafic intrusion in the Archean basement along the road. A very sharp contact is present but may be difficult to see when driving past.

STOP 2: Archean basement I, Bugøynes area

HSE: Along the E6 road. Be careful when crossing the road.

Geology: Here, a flavour of the typical basement structures are shown, with amphibolitic gneisses in combination with tonalitic granitoid rocks and migmatites.

Figure 13: Example of Archean metamorphic basement of granitic-tonalitic composition and migmatites.

STOP 3: Archean basement II, transition to sedimentary cover

HSE: No particular precautions to be made, there is a large parking lot on the northern side of the road. Be aware of traffic along the road when crossing to see the outcrop on the southern side.

Geology: The location is at the contact between Archean basement and the Neoproterozoic sedimentary cover, representing a hiatus of c. 1800 Ma. The sediments of the lower part of the Veidnesbotn Formation in the lower part of the Vadsø Group consist of reddish cross-bedded sandstones deposited in braided-river depositional environments. In places, this unit is interbedded with finer material. A few metres farther to the southeast the Archean basement gneisses are exposed. However, the exact boundary seems to be buried and overgrown at this location.

Figure 14: The first, Neoproterozoic sedimentary strata on top of the Archean basement represented by fluvial deposits of the Veidneset Fm. (lowermost Vadsø Group). The strata are dipping to the NNW.

STOP 4: Archean basement & sedimentary cover, overview

Before driving down to Karlebotn we will make a stop for a panoramic and regional overview of the Archean basement, the overlying sedimentary cover and the geophysical data from the area.

HSE: No particular precautions to be made, there is a good parking place.

Geology: The locality gives an overview of the contact between Archean basement and the Neoproterozoic sedimentary cover, which seems quite distinct from the distance. There is a change of colour of the rocks and the vegetation is typically sparser on the basement rocks as compared with the sedimentary succession towards the northwest in the Varangerbotn area.

STOP 5: The Oaibáhčannjárga (Bigganjarga) tillite — a world class locality

NOTE! The Bigganjarga Tillite is a protected outcrop. (No hammering or removal of rocks.)

We continue on the local road down to Karlebotn and pass the old school towards the end of the road. From there, a trail leads up and across the peninsula, close to the southeastern coastline.

HSE: This will be a 30-40 min walk (one way), that requires good shoes. The walking path mostly follows an old cart track. Remember good clothes and bring something to drink.

Cultural: Karlebotn is a small community located in the Varangerbotn with around 100 residents. Just as we take off from the main E6 road to the very local road, there is an interesting cultural heritage site which shows history dating back to the younger Stone Age. Around 90 remains of houses were found on a beach plain 25 m above present-day sea level (estimated to have been around 7 m above sea level 2000-3000 years ago).

Geology: The Bigganjarga tillite was first identified as such by Hans Reusch in 1891 and has often been referred to as Reusch's Moraine. A tillite is a glacially deposited diamictite, which is the main lithology of the Smalfjord Formation (base of Vestertana Group). It is considered to lie here unconformably upon the lowermost formation of the Tonian to Cryogenian Vadsø Group, indicating a major period of epeirogenic movements and erosion preceding the deposition of the diamictites/tillites. As you walk towards the Bigganjarga type locality, sandstones with excellent examples of large-scale cross-bedding as well as 1-2 m-thick diamictites can be observed. At the Bigganjarga type location, the diamictite/tillite is very well exposed and the very sharp contacts above and below are easily accessible. Scour marks are seen in the quartzite basement below. The Bigganjarga tillite is considered to represent the Marinoan glaciation 650-635 Ma (transition from Cryogenian to Ediacaran period). A younger tillite will be seen at a subsequent stop. A discussion on whether the Smalfjord Formation diamictite of late Cryogenian age represents a glacial or non-glacial deposit (till or mudflow) was presented by Jensen and Wulff-Pedersen (1996). Despite interesting arguments for the mudflow theory, the main consensus seems to be that the unit represents glacial deposits (Edwards, 1984; Rice et al., 2012).

Figure 15: Top: Example of diamictite and cross-bedded sandstone of the Smalfjorden/(Nyborg?) Fm. on the walk towards the Bigganjarga tillite type locality.
Bottom: The famous Oaibáhčannjárga (Bigganjarga) tillite, assumed to have been deposited during the Marinoan glaciation 635 million years ago.

STOP 6: Mortensnes tillite

HSE: Use hard hats when moving close to steep cliffs. Be aware traffic along the road.

Geology: On the northern side of the Varangerfjord, the first stop is the Mortensnes tillite location. The formation represents a typical diamictite, formed of a poorly sorted conglomerate with big clasts and boulders in a finer matrix. The reddish colour is attributed to iron-oxide content.

This unit is younger than the Bigganjarga tillite as it overlies the interglacial deposits of the Nyborg formation, which in turn overlies the Bigganjarga tillite of the Smalfjord Formation (Fig. 5). The Mortensnes tillite has been regarded by many geoscientists as equivalent to the worldwide Gaskiers glacial event (c. 580 Ma; e.g., Gorokhov et al., 2001; Rice et al.,2012). However, this correlation has recently been questioned based on a U-Pb age of c. 596 Ma for a dolerite dyke in the Särv Nappe of Sweden (Kumpulainen et al., 2021). This dyke cuts through tillite formations which have been considered equivalent to the Smalfjord and Mortensnes formations. Thus, accepting the correlation, the two Varangerian tillites may both be part of the same, extensive Marinoan glaciation.

Figure 16: The Mortensnes tillite, Mortensnes Fm. It is younger than the Bigganjarga tillite, but recent studies suggest that it may nevertheless belong to the Marinoan glaciation.

STOP 7: Tectonised Nyborg Formation

HSE: Short walk from minibus. Be aware of traffic, the road is narrow and the outcrop lies on a bend.

Geology: Nice examples of the folded Nyborg Formation. A gradual thickening of silty sandstone layers compared with the shale sequences can be observed. It is considered that most of the Nyborg Formation was deposited by turbidity currents (Edwards, 1984). However, parts of the formation indicate a shallower depositional setting near the coast showing coarsening-upward sequences. Carbonates (including stromatolites) are also recorded (but not at this location), which may indicate a period with warmer climate between the cooler periods. This seems to have been a world-wide phenomenon. The tectonic movements that produced the folds are assumed to be associated with shortening close to the Caledonian deformation front (Rice, 2014; Gabrielsen et al., 2022).

Figure 17: Zig-zag folding in the Nyborg Fm. in the Vestertana Group. The deformation, top to the SE in this case, is attributed to the Caledonian orogeny.

STOP 8: Store Ekkerøya – Accommodation at Ekkerøy and geological evening stroll

NOTE! This is a protected area for bird life (nature reserve), no drone flying or hammering allowed.

HSE: It is generally safe to walk around on Ekkerøya. Precautions should be made whilst walking along the top of the steep cliff on the southern side.

Cultural: Ekkerøy is a small historic fishing settlement located 15 km east of Vadsø centre. Nine-hundred-year-old Viking graves represent the easternmost settlement from that period. The peninsula is famous for its rich bird population along the seaward cliffs. It is a popular area for ornithologists, tourists and photographers. At the local heights you can still see the remains from the German bunkers and fortress positions from the Second World War. Due to Russian break-through in the Kirkenes area the German troops quickly evacuated from the northern Varanger area and Ekkerøy was one of the few places where almost all houses remained intact after the war.
Ekkerøy is the name of the settlement (and of the local geo-logical formation) while *Store Ekkerøya* is the official name of the island. We simply refer to the island as *Ekkerøya* in the text. The island of *Lille Ekkerøya* lies a few kilometres to the northeast.

Accommodation: Ekkerøy is planned as an accommodation for two nights. Here we will stay in different houses organised by Ekkerøy Holiday House. These are local small houses built for tourists and excursions. More information on the history of the island will be given by our local host during dinner or as a welcome introduction.

Geology: The interesting geological history can be outlined from the many local outcrops. Two formations of the lower sedimentary cover, the Vadsø Group (Golnes and Ekkerøy fms.) and from the Tanafjorden Group (Grønneset Formation) are exposed here. These formations represent fluvial to shallow-marine sandstone depositions. It is recommended to start the walk on the cliff side close to the sea and walk up passing the German bunkers. The approximately 40 m-thick Ekkerøy Formation shows a coarsening-upward trend, from mud-dominated sequences at the bottom grading upwards to sandy sediments. The succession is cut by a 16 m-thick N-S-trending dolerite dyke, dated to c. 370 Ma (Guise and Roberts, 2002), which is prominently exposed in the south-facing cliff. The dyke can be traced off the island both to the north and the south for several kilometres based on aero-magnetic data (Figure 20, Nasuti et al., 2015b). Nice examples of sedimentary structures and soft-sediment deformation can be observed when walking from sea level towards the top of the hill. On the way from the 'German bunker' towards the top, examples of shallow-marine cross-bedding can be seen. At the very top of the hill, a thin lens of pebble conglomerate overlain by ripple marks can be observed, which represents

Figure 18: A variety of geological structures can be seen on the Store Ekkerøya peninsula representing the transition between the Vadsø and Tanafjorden groups.
a) Pebble conglomerate of the Grønneset Fm.
b) Cross-bedding of the fluvial Ekkerøy Fm.
c) Ball-and-pillow structure.
(d, e, f on next page)

the lower part of the Grønneset Formation (lower Tanafjorden Group). A deltaic setting influenced by a tidal environment has been suggested as the depositional environment for the deposits, with a potential braided stream deposition for the uppermost section.

Recent erosion features called tafoni (singular, tafone) can be seen in several locations close to the shore. These hollow weathering features are related mainly to salt weathering and are common along the Norwegian coast.

Figure 18: A variety of geological structures can be seen on the Store Ekkerøya peninsula representing the transition of the Vadsø and Tanafjorden groups.
d) Slump structure.
e) Devonian dyke transecting the Ekkerøy Fm. indicated by dashed lines.
f) Tafoni.
(a,b,c on previous page)

Day 2 — Ekkerøya to Hamingberg

On day 2 we visit localities farther to the northeast on the Varanger Peninsula and reach the fascinating Persfjorden-Hamningberg area. During the trip we will pass a major tectonic boundary, the Trollfjorden-Komagelva Fault Zone (TKFZ), which separates the Tanafjorden-Varangerfjorden Region from the Barents Sea Region.

STOP 9: Skallneset quarry

Skallneset quarry is located around 12 km east of Ekkerøya and can be easily seen from the E75 road. Normally there is a good parking place just off the road. The area is an active quarry where the rock is taken out for industrial purposes.

HSE: Precautions should be taken when going close to the quarry cliff. Be aware of loose blocks (wear helmets). At the southeastern part just outside the quarry, attention should be given to traffic on the road.

Geology: We are now in the Tanafjorden Group, represented by the Dáhkočearru Formation. This is a very sandy unit with several coarsening-upward sequences (10-15 m). The sequences start with thin fine-grained laminae at the base and grading upward into thicker sequences with coarser material. Ripple marks and nice large cross-stratifications or prograding clinoforms are present in the area. The clinoformal nature and the stacked sequences are interpreted as prograding shoreface units, affected by sea-level changes and wave activity in a rather high-energetic environment. This would have been a perfect petroleum or water reservoir deposit if not completely cemented.

Figure 19: Skallneset quarry.
a) Main quarry wall exposing sandstone units of the Dáhkočearru Fm.
b) Example of coarsening-upward sequence.
c) Example of cross-bedding.

STOP 10: Komagnes dolerite dyke

HSE: Grassy area towards the cliff – be aware of some loose rocks as you walk uphill. Parking is at a former resting site about 100 m to the north of the E75 highway.

Geology: At this location we will study the Stáhpogieddi Formation. The formation has a thickness of more than 325 m here and represents the middle part of the Vestertana Group. Missing sections below indicate a major hiatus between the Vestertana and Tanafjorden groups in the area. An immediate impression of the formation (approximately 50 m exposed at the cliff) are the nuances of colour of black, green and red which are associated with the fine-grained material. The formation consists dominantly of mudstones, shales and very fine-grained sandstones and siltstones, indicating a deeper water depositional environment. An open marine shelf has been suggested. The various colours are related to variations in oxygen content in the bottom water. Dark grey to black mudstone and shale represents dysoxic to anoxic bottom water. Red mudstone represents periods with a high oxygen content in the bottom water and very low to no content of organic substances. The greenish-grey and green mudstones indicate a bottom water with an intermediate oxygen content. Depending on the oxygen content, it may have been possible to develop organic-rich sources under such conditions, made by microbiological mats as described by Craig et al. (2013).

Intrusion: In the middle of the dark-coloured cliff we see an almost vertical layer of light, weathered material cutting through the Stáhpogieddi section. This is a dolerite dyke of late Devonian age (c. 370 Ma; Guise and Roberts, 2002). On closer inspection there are, in fact, two parallel dykes. The dykes are also exposed in the foreshore and intertidal zone. On the new NGU aeromagnetic data of the Varanger Peninsula, the dyke appears as a clear N-S-oriented linear feature in the tilt-derivative filter of the magnetic total field (Nasuti et al., 2015b). Like the dyke visible on Ekkerøya, the Komagnes dyke can be followed for more than 8 km offshore and has been indicated on the 1:50 000 bedrock geological map-sheet 'Ekkerøy'.

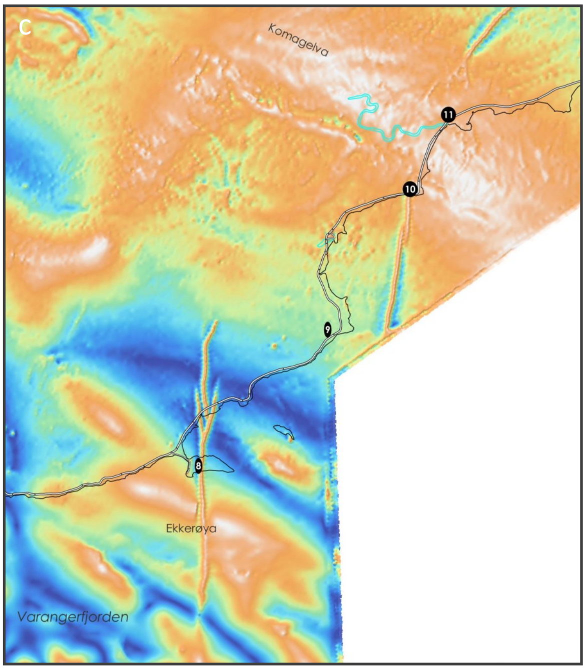


Figure 20: a) Dark shaly unit of the Stáhpogieddi Fm. (Vestertana Group), indicating a deeper marine environment. Strata are dipping to the NNE.
b) Dyke intrusion at Komagneset reaching from the shore (where it can be traced farther offshore with aeromagnetic data) to the cliff inland.
c) The magnetic tilt derivative illustrates the clear signature of the N-S-oriented, 2 m-thick Komagnes dyke as well as the prominent Ekkerøya dyke (see stop 8). See appendix for larger map with colour legend and scale.

STOP 11: Trollfjorden-Komagelva Fault Zone at Komagelv

HSE: Precautions should be taken if crossing the road.

Geology: When continuing the drive 4-5 km northeastwards, we will pass the southeastern limit of the onshore Trollfjorden-Komagelva Fault Zone (TKFZ), which in the field just here does not appear as very distinct. The TKFZ separates the Barents Sea Region (BSR) to the northeast and the Tanafjorden-Varangerfjorden Region (TVR) to the southwest. The NW-SE-trending fault zone is considered as a major Neoproterozoic rift border fault later reactivated (inverted) during the Ediacaran Timanian orogeny. The fault extends southeastwards over a distance of 1800 km into the Timan Range of NW Russia. In Ordovician-Silurian time, it functioned mainly as a dextral strike-slip fault during the Caledonian orogeny (Rice et al. 1989; Karpuz et al., 1993; Gabrielsen et al., 2022). Some deformation of the rocks can be detected south of Komagneset near the previous stop and especially in the intertidal zone (Herrevold et al., 2009). Brecciated, deformed rocks and flower structures are reported from the area which indicate lateral movements in a transpressional-transtensional tectonic regime. When looking at the geological maps and aerial photos, the TKFZ appears very clearly. Also, recent magnetic data help to delimit the fault zone, which seems to appear as a broad deformation zone. It is possible that the magnetic signal does not stem from the fault itself but from a later, thus younger dyke intrusion that utilised the existing weak zone. It is also interesting to note that a half-graben has been detected offshore to the southeast on seismic reflection profiles, in the hanging wall of the TKFZ (Roberts et al., 2011). This extensional event is inferred to be of Early Carboniferous age.

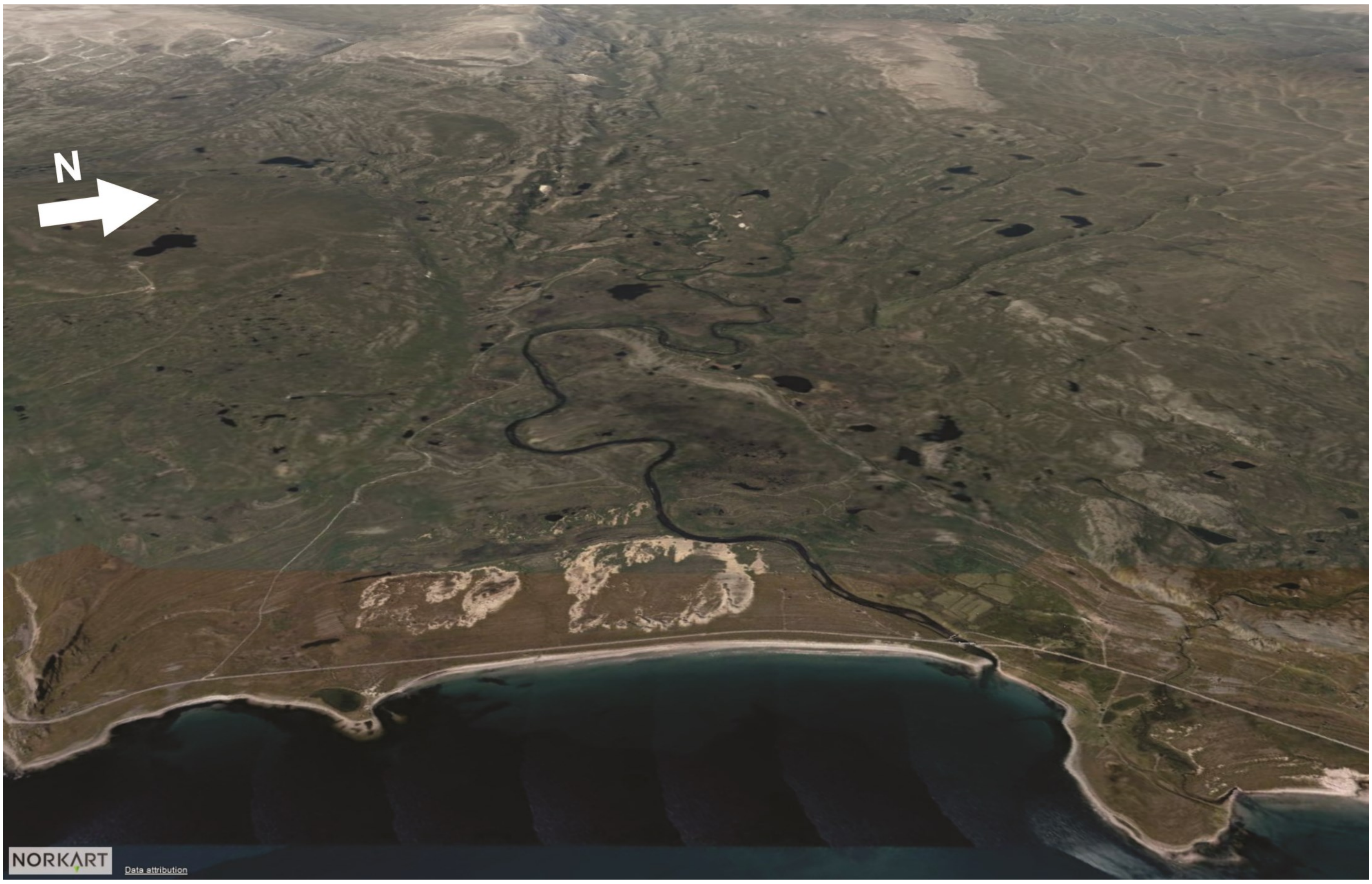


Figure 21: Aerial view to the NW of the TKFZ, which here coincides with the river valley. Note also the aeolian sand dunes in the foreground. Our stop is in the lower left of the picture. Terrain model and screen dump from 3dx.kommunekart.com © Norkart.

DRIVE: TKFZ to Persfjorden (and Hamningberg)

On the way to Persfjorden we pass Kiberg, the witch-mountain Domen, Vardø, Smellror quarry and pass over Mellomfjellet. We are now on the northeastern side of the TKFZ and cross the very thick Båtsnæringen Formation, up to 3500 m thick, interpreted as a delta system (Siedlecka and Edwards, 1980). It is impressive to drive between the spectacular cliffs and beaches on the way to Persfjorden, and farther to Hamningberg, if time allows. There are more turbidites to see, various sedimentary structures, dolerite intrusions, raised beach terraces and ripple marks. However, we should be back in time for dinner and the witch museum in Vardø.

STOP 12: Raised beaches at Blodskytodden

HSE: Parking along the road, watch out for traffic.

Geology: Along the excursion route, moraine material, glacio-marine sediments, weathered basement and reworked sediments like aeolian dunes and beaches can be observed in many places. At this stop we can discuss the marine limit in Finnmark after the last ice retreat in Younger Dryas. More than 30 beach levels can easily be counted along the Barents coast, and the marine limit may vary from place to place (60-100 m) due to uneven ice loading and rebound.

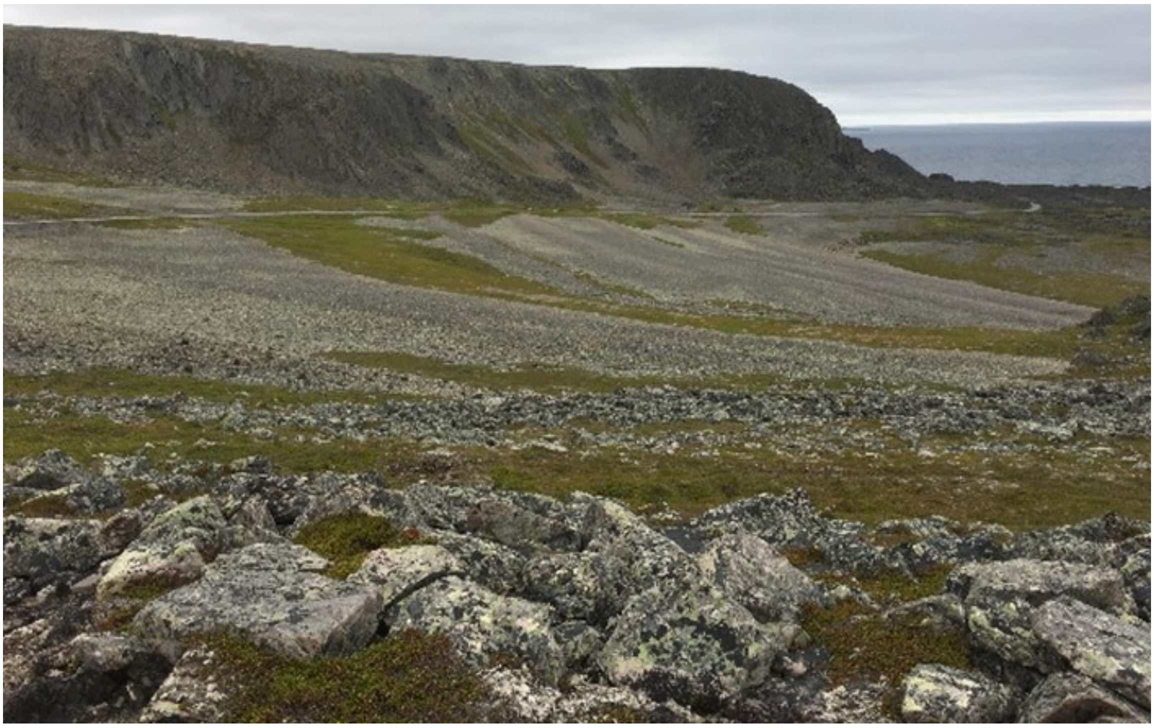


Figure 22: Excellent examples of different beach levels after the last ice age. More than 30 different levels can easily be observed in the field. The marine limit is here estimated to be around 85 m above present sea level.

STOP 13: Persfjorden

HSE: No particular measures or general precautions when walking along low vertical cliffs. Easy parking in Persfjorden. Respect the owner of the cabin in the area.

Geology: The formation present here is the lower member of the Cryogenian Båtsfjord Formation in the upper part of the Barents Sea Group, in the core of a N-S-trending syncline with steeply dipping strata on the fold limbs. The syncline and other folds to the east and on the island Vardøya were initiated during the Timanian orogeny. However, two types of schistosity/cleavage can be observed, which indicate that the area was later significantly deformed by the Caledonian orogeny (Gabrielsen et al., 2022). This deformation sequence, with the NW-SE folds predating the NE-SW folds, has also been reported from a wider area of NE Varanger Peninsula (Roberts, 1996; Herrevold et al., 2009; Gabrielsen et al., 2022). The lithological units consist of carbonaceous red and green mudstones, yellow dolomite, grey limestones and pink fine-grained sandstone. The carbonate beds contain laminated stromatolites which represent the first sign of ancient life in Norway after the time of 'slime bacterial mats' (Siedlecka, 1982). The acritarch *Podolina minuta* (oldest fossil in Norway) has also been recovered from this formation. The depositional environments are interpreted as tidal flats deposited under temperate-warm conditions to start the generation of algae and cyanobacteria. Blue-green algae and the cyanobacteria form sticky mats on the seabed onto which carbonate particles bind together with silt particles and thus built up a bed of wavy internal lamination, called stromatolitic lamination. Stromatolites can have different forms, and some can be columnar in shape. The stromatolites in the Båtsfjord Formation have first been described by Siedlecka (1978, 1982).

At this locality it can be interesting to discuss the 'Snowball Earth theory', and the first signs of ancient life on Earth.

Figure 23: a) The lower member of the Båtsfjord Fm. (Barents Sea Group) in Persfjorden consisting of alternating shale, sandstone and carbonate lithologies.
b) Desiccation cracks indicating subaerial exposure.
c) Ripple marks indicating a shallow/fluvial environment.
d) Example of stromatolites (evidence of life in Earth's early history).

Optional DRIVE: Persfjorden to Hamningberg, passing Seglodden and Sandfjorden

HSE: No particular precautions except traffic.

Geology: Here, the lower part of the Båtsnæringen Formation is present in almost vertical sections. The formation here consists mainly of finely laminated green-grey siltstone layers and red-grey sandstone beds. A braided-river system and delta-plain environment is interpreted as the depositional setting. Farther northwest (Sandfjorden), thick sections of turbiditic sediments of the Kongsfjord Formation (Kongsfjord Submarine Fan) can be observed. Symmetrical ripple marks observed along the road may indicate periods of shallower water conditions. From the inner part of Sandfjorden, fluvial sediments of the Sandfjorden Formation can be observed all the way to Hamningberg, interrupted by a dolerite dyke of late Devonian age (Guise and Roberts, 2002) .

The Kongsfjord Formation in this area exhibits some spectacular double-folding with Timanian folds overprinted by Caledonian folds and cleavages (Gabrielsen et al., 2022). Due to variation in resistance to weathering in sandstones and shales, the erosional form of the Kongsfjord Formation is spectacular, shaping a series of parallel rock ridges. Meta-dolerite dykes penetrate the Kongsfjord Formation in several places. These dykes are of Ediacaran age and are now mostly parallel with the orientation of the late Caledonian schistosity. At several places in Sandfjorden and Hamningberg there are very good examples of postglacial raised beaches. Terraces from the maximum ice advance 14-15000 years ago can also be observed.

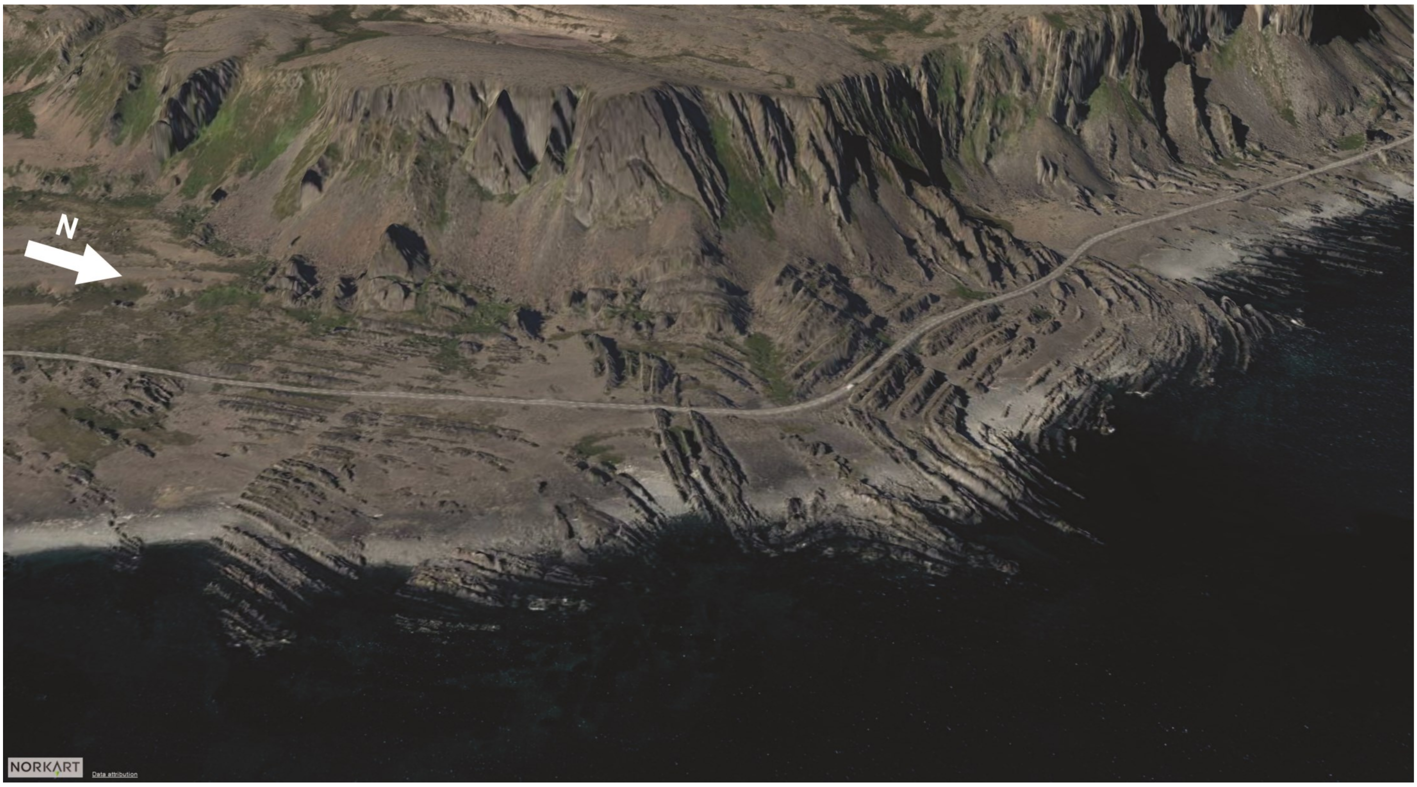


Figure 24: In the area between Persfjorden and Hamningberg the road passes through steeply dipping to vertical strata with several upright folds. Terrain model and screen dump from 3dx.kommunekart.com © Norkart.

Hamningberg

Archeological excavations at the church yard area track the history 5000 years back in time (Stone Age). Several examples of thousand-year-old fishery equipment have been identified. Around the year 1500, the Hamningberg area was an important fishing settlement in eastern Finnmark. Dried cod (tørrfisk) was shipped to Bergen and further to the European market. The place was also very important in the Pomor trade with Russia around 1720. Hamningberg was one of six places where Russian fishermen were allowed to work from. The characteristic long houses (rorbuer from around 1850) are a present proof of the activity. These were not burned during the Second World War, since the Germans were surprised by the Russian troops and had to leave immediately. At around 1900, 250 persons lived in Hamningberg, and during the high season as many as 1200 stayed in the area. Hamningberg has now no permanent inhabitants but has become a tourist place, popular for birdwatchers, photographers and of course some geologists.

Figure 25: Hamningberg is famous for its fishing history which reaches back to the Stone Age. The place has been an important fishery settlement through history. Nowadays, the spectacular scenery attracts tourists, geologists, biologists and archeologists.

STOP 14: Vardø - A cultural stop

A final stop for day 2 will be in Vardø. We will visit the Steilneset Witches' Memorial and learn about the cruel processes that took place from 1598 to 1692, where 91 victims were burned, tortured or thrown into the sea. The Domen Mountain just south of Vardø was central in those processes.

After visiting Steilneset a dinner is planned in Vardø centrum. Thereafter, the bus will drive us back to Ekkerøya.

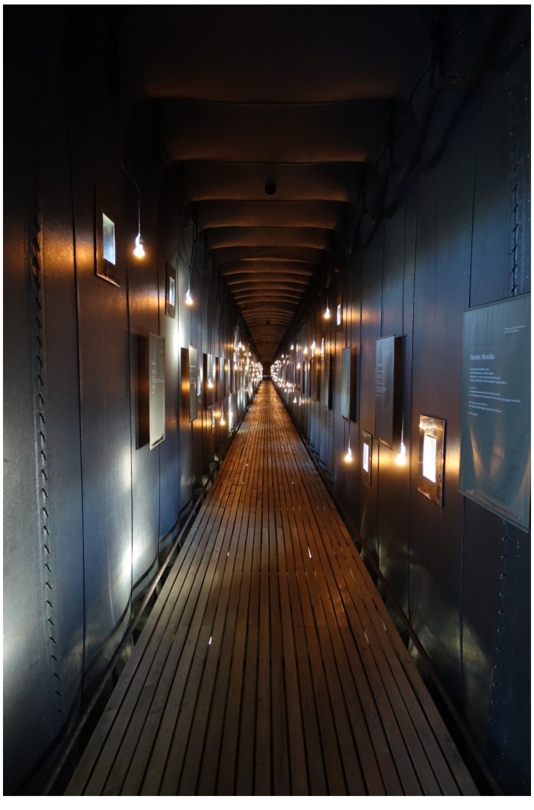


Figure 26: The Witches' Memorial in Vardø, telling the terrible history of the witch burning processes in the 17th century.

Day 3 — Ekkerøya to Berlevåg

Day 3 will be a rather long drive from Ekkerøya to Berlevåg. We will be examining the Tanafjorden and Vestertana groups as well as modern depositional environments during the first part of the day. On the drive north towards Berlevåg we will pass the TKFZ and enter into the Barents Sea Region again represented by the Barents Sea and Løkvikfjellet groups. The geological excursion ends close to the Berlevåg municipal centre. Transport back to Kirkenes will be on a Hurtigruten cruise ship.

STOP 15: Fugleberget Formation at Store Vadsøya

HSE: Locations close to the road and along a coastal cliff.

Geology: The Fugleberget Formation belongs to the Vadsø Group in the Tanafjorden-Varangerfjorden Region. On Store Vadsøya the formation is very well exposed in the cliff section. The horizontal sandstone beds are weathered in the upper part. Trough cross-bedding and planar cross-bedding structures can be observed, commonly with spectacular pene-contemporaneous folding of the foreset beds. Occurrence of mudstone fragments in some sandstone layers is believed to be a result of rip-up processes during floods. Some of these have grown into round concretions, which may look like fossils. Overall, the Fugleberget Formation was deposited in a braided river to fluvial depositional environment. Originally, this unit likely had excellent reservoir quality before the main diagenetic processes took place. The sedimentology of this formation and of other formations in the Vadsø Group has recently been discussed by Grundvåg and Skorgenes (in press).

Figure 27: a) The Fugleberget Fm. in the middle of the Vadsø Group, deposited in a braided river environment.
b) Concretions with mud inclusions that formed as a result of rip-up processes.

DRIVE: Vadsø to Tana River

During this drive, several interesting locations are visible from the bus.

The 'Hitler Teeth' located close to Kiby were built during World War II to hinder German tanks and vehicles from moving for-ward. Besides the cultural stop, there are nice examples of cross-bedded sandstones in the Golnes Formation just below the Ekkerøy Formation.

We pass again the Mortensnes Tillite (poorly sorted, reddish-coloured sediment) and the interglacial unit of the Nyborg Formation, which is exposed in several road-cuts. Farther north, towards the outlet of the Tana River, the Stáhpogieddi Formation (Ediacaran to Early Cambrian) can be observed, containing siltstones of various colours.

Figure 28: The 'Hitler Teeth', remains from the Second World War. These rocks were erected across the old road to hinder German tanks.

STOP 16: Tana River

HSE: Narrow parking place along the river.

Geology: When passing the Tana bridge the landscape opens up and you can see the beauty of the Tana river estuary, where recent sedimentary processes can be studied in detail. From seismic data as much as 300 metres of sediment thickness has been measured in the river close to this stop (Siedlecka et al., 1998). The river system is believed to have been an ancient entry point for sediment in the Paleozoic, Lower Triassic and potentially in Lower Cretaceous time (Eide et al., 2018; Henriksen et al., 2021). The response can be seen from mapping sandy fluvial and submarine fan systems along the offshore Finnmark Platform (Henriksen et al., 2011, 2021; Eide et al. 2018). On the right-hand side (east), shallow-marine pinkish quartzitic rocks of the Tanafjorden Group (Giemaš Formation) can be observed. In places, these rocks are heavily tectonised. We have now moved from the mildly deformed parautochton into the slightly higher-grade tectonised rocks of the Lower Allochthon (Gáisá Nappe) in the western part of the Varanger Peninsula.

Figure 29: Panoramic view of the estuary of the Tana River, where recent fluvial processes can be studied. The area may have been an ancient entry point for sediments deposited on the offshore Finnmark Platform.

STOP 17: Gamasfjellet (*Giemašnjarga)* anticline to Austertana

HSE: No precautions.

Geology: From the western side of Leirpollen there is a nice view of the impressive Gamasfjellet *(Giemašnjarga)* anticline. It formed during Caledonian compression but is oriented oblique to the main shortening direction. The Giemaš Formation is a well-bedded sandstone in the middle part of the Tanafjorden Group. This sandstone is overlain by the Haknalančearru Formation, a light and almost pure quartz arenite, which we will see better at the next stop. Elkem-Tana has a quartz quarry in this formation in Austertana. The quartz arenite (>90% quartz, Størseth and Wanvik, 1992) also contains kaolinite formed presumably during tropical weathering probably in late Cryogenian time (Nystuen, 2008). The area also shows one of the main thrusts of the Caledonian orogeny, the base of the Gáisá Nappe Complex, visible in the NW part of the giant fold and likely present within and under the fjord. The offshore extension of the Caledonian-affected rocks is still being discussed in several scientific papers.

Figure 30: The Gamasfjellet (Giemašnjarga) anticline is evidence of a major compressional structure that formed during the Caledonian orogeny. The pure quartzite used for industrial purposes (right side of figure) belongs to the Haknalančearru Fm. in the Tanafjorden Group.

DRIVE: Stromatolites

On the way from Leirpollen (Austertana) and up to Kongsfjordfjellet we will pass the upper part of the Nyborg Formation, containing excellent examples of stromatolites. This is a small exposure and there is no available parking place nearby.

Figure 31: A small exposure of a dolomite section with stromatolites. This unit belongs to the Nyborg Fm. in the Vestertana Group.

STOP 18: Hanglefjellet

HSE: No particular precautions, except be careful with traffic on the road. There is likely still snow on the ground in early June.

Geology: When arriving on the pass over the Kongsfjordfjellet, the long ridge of the Hanglefjellet mountain appears on the skyline to the northwest. Hanglefjellet mountain contains quarzitic sandstones of the Giemaš and Haknalančearru (Hanglefjellet) formations, representing hard and resistant Neoproterozoic rocks. The different lithologies between the Stáhpogieddi Formation along the road and the Haknalančearru Formation are clearly reflected in the vegetation.

Figure 32: The Hanglefjellet mountain consists of massive quartzitic sandstones of the Giemaš and Haknalančearru fms.

STOP 19: Trollfjorden-Komagelva Fault Zone at Geatnjajavri

HSE: No particular precautions, except be careful with traffic on the road. There is most likely still snow on the ground in early June.

Geology: On the Kongsfjordfjellet, at lake Geatnjajavri, we will discuss the northwestern part of the TKFZ and its impact on the structures going from the Vestertana Group and northward into the Barents Sea and Løkvikfjellet groups. The lake follows the trend of the TKFZ, as a result of more erosion along the fault zone. On the northern side of the lake, yellowish and reddish coarse-grained arkoses represent the lower part of the Løkvikfjellet Group (Sandfjorden Formation).

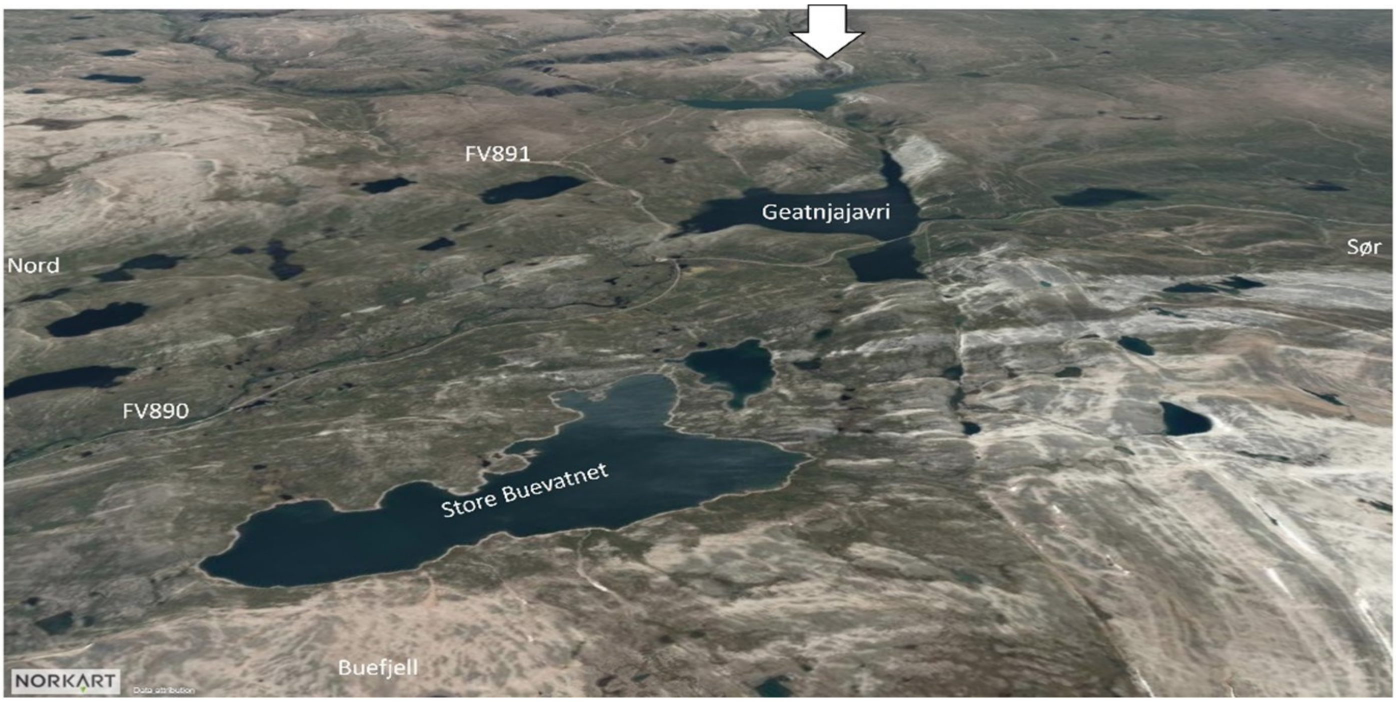


Figure 33: The Trollfjorden-Komagelva Fault Zone (TKFZ) in the hinterland of the Varanger Peninsula, transition from Vestertana group to the south (right) and the Barents Sea and Løkvikfjellet groups to the north (left). The fault itself is hardly detectable along the main road, hence we show the aerial photograph. Terrain model and screen dump from 3dx.kommunekart.com © Norkart.

DRIVE: Kongsfjordfjellet to Berlevåg

After passing across the Trollfjorden-Komagelva Fault Zone we continue towards Berlevåg. We then enter an area popular for the locals with several cabins and possibility for salmon fishing in the summertime. The valley contains excellent examples of moraine deposits in several places. There are examples of unlithified glacial till and glacifluvial/marine material as well as scouring stripes in the underlying lithified bedrock.

STOP 20: Kongsfjord Formation, Inner Kongsfjord

HSE: Easy access. Parking on eastern side of the road. Watch out for traffic when walking along the road. Close to the steep exposures, helmets must be worn.

Geology: The Kongsfjord Formation is exposed in high road-cuts on Highway 890. Repeatedly alternating greywacke-sandstones and shales can be seen in heavily folded and deformed sections. These layers represent deep-water turbidites of the Kongsfjord Formation in the Barents Sea Group (Siedlecka, 1972; Pickering, 1985). Drinkwater and Pickering (2001) interpreted this formation as a submarine-fan system with inner-, middle- and outer-fan environments. The colours vary from blackish-dark grey to yellowish-reddish grey in the sandy intervals.

The outcrops here are part of the oldest formation in the entire Barents Sea Region, of probable Tonian age. Meta-dolerites of Ediacaran age (c. 570 Ma, Rice et al., 2004) cut through the Kongsfjord Formation and are in places present as dyke swarms. Metamorphism was limited to lower greenschist facies. The unit has undergone a major syn-metamorphic fold deformation in Early Ordovician time (Rice and Frank, 2003) and the major tectonic style is that of open, SW-plunging folds. Deformation intensity increases westwards towards the Middle Allochthon Front, the base of the Tanahorn Nappe. The strata are in places almost vertical with a general dip towards the east.

Figure 34: a) Turbidite sequences of the Kongsfjord Fm. (Barents Sea Group) at Rundvannet, inner Kongsfjord area. The strata are heavily folded and faulted.
b) Metadolerite dyke that was emplaced prior to the Caledonian deformation highlighted by dashed lines.

a

STOP 21: Cave and dolerite dyke at Hergevika, Veidnes area

HSE: Next to this locality there is access to a good parking place. Watch out for traffic along the road. Helmets are needed when approaching the exposures.

Geology: In Hergevika, a couple of kilometres NW of Veidnes, a perfect example of a metadolerite dyke of Ediacaran age can be seen just off the road on the landward side. The Pre-cambrian dyke likely formed a buttress to the later Early Ordovician folding of the Kongsfjord Formation, and much later the wave erosion formed the present-day cave. Next to the dyke, a vertical cleavage transecting the bedding of the Kongsfjord Formation can be seen. The cleavage is also axial planar to the folds. The metamorphism of the mafic dykes occurred in Early Ordovician time, concurrently with the wide-spread folding of the Kongsfjord Formation. Several erosional remains of the more resistant dykes can be seen in many places along the coast. Nice examples exist northwest of Hergevika along the western Risfjorden and a few hundred metres west of the road crossing to Veidnes.

The cave next to the intrusion represents an example of marine erosion, now raised by post-glacial rebound.

Figure 35: Cave next to the Hergevika metadolerite dyke (highlighted by dashed lines) in the folded and cleaved Kongsfjord Fm.

EXTRA STOP: Turbidites and Reinoksen

At the Meresjokka river, on the way from Risfjorden to the stop 22 at Sandfjorden, we will pass an excellent location to study deep-water turbidite deposits with well-developed Bouma sequences. The deposition represents the Risfjorden Member of the Kongsfjord Formation. Later, between stops 22 and 23, we will cross the 'Nålneset section' which is an archetype of a sheet-like turbidite system formed at a major channel-lobe transition zone (cf. Drinkwater and Pickering, 2001).

Nearby is also an impressive example of a wave-shaped rock formation, which lies today at 11 metres above sea level. Like the famous Kannesteinen near Vågsøy in western Norway, this sculptured rock formation was likely created by marine scouring, an erosion residue between perhaps two marine potholes or eroded sea caves. When the sea level was about as high as here, the waves had to work with loose materials and abrade the rock over time. Today, this 'reindeer ox' remains as a 1.5 metre-high formation with a narrow foot; the rest has been scoured down to the surrounding platform.

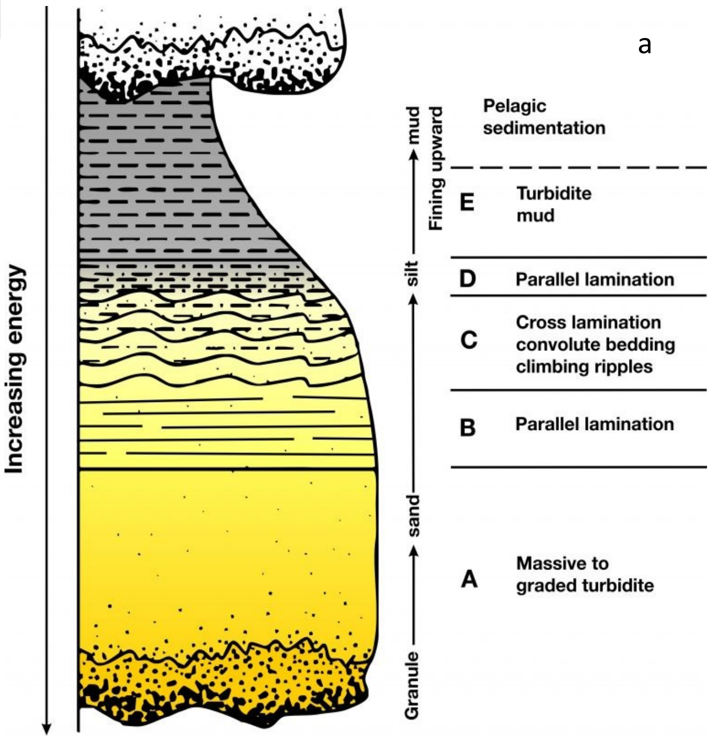


Figure 36: a) Conceptual sedimentary log of a turbidity current showing the classic Bouma sequence (from https://geologyistheway.com/ redrawn after Bouma, 1962).
b) Example of Bouma sequences in the Risfjorden member of the Kongsfjord Fm.
c) Wave-sculptured rock.

STOP 22: Sandfjorden – overview of main groups of the Barents Sea Region

HSE: No particular precautions except traffic.

Geology: In a protected area at Sandfjorden, a nice overview of the main groups of the Barents Sea Region can be seen. We are here standing on the basal Kongsfjord Formation and will have a nice view towards the contacts between Kongsfjord, Båtsnæringen and Sandfjorden formations. Recent geology like large talus fans and aeolian dunes as well as the fantastic beaches can be seen at this location.

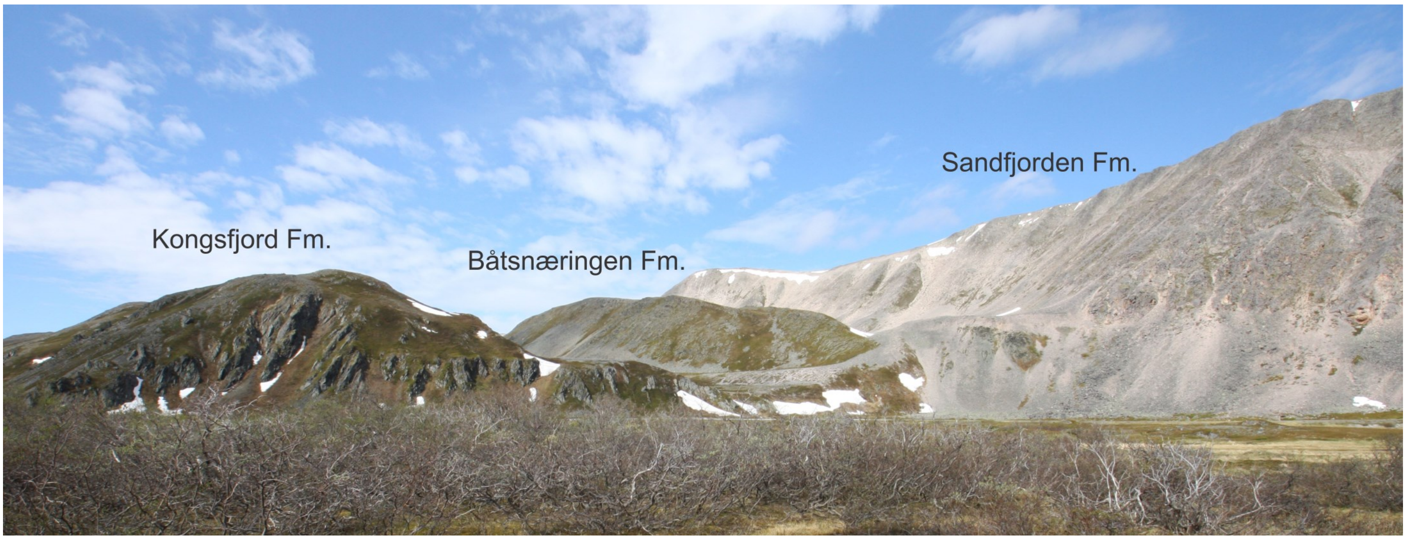


Figure 37: Sandfjorden area showing the Kongsfjord Fm. (lower half and left of the picture), Båtsnæringen Fm. (middle part) and Sandfjorden Fm. (right side). View is to the SSW.

STOP 23: The Middle Allochthon Front (MAF) at Vargvika

HSE: Parking place on the right side of the road. Precaution to be made when crossing the road.

Geology: In Vargvika, located 3 km east of Berlevåg, a NNE-SSW-oriented escarpment extends to the SSW from the road and also NNE-ward into the sea. This sharp thrust boundary marks the base of the Tanahorn Nappe and is considered to represent the Middle Allochthon Front (MAF). The thrust is dipping comparatively steeply here but shallows out farther to the southwest. Mylonites can be observed in the thrust zone.

On the seaward side of the road, nice potholes (jettegryter) can be seen, that are still forming at the present day.

The MAF separates the Berlevåg Formation (Tanahorn Nappe) from the thick terrigenous sandstone sequence of the Løkvikfjellet Group (Barents Sea Region), which in turn unconformably overlies the turbidites of the Barents Sea Group. To the west, graded metasandstones of the Berlevåg Formation indicate a deeper water turbiditic depositional environment. The MAF is a major tectonic/metamorphic contact and coincides with a drop in metamorphic grade (Levell and Roberts, 1977) from low greenschist facies (moderate metamorphism, 300-500°C and pressures of 3-20 kbar) to the west to low P/T epizone metamorphism to the east. The higher nappes of the Kalak Nappe Complex (KNC) west of Porsangerfjord, reached at least sillimanite grade recognised in metamorphic rocks of upper amphibolite/lower granulite facies. The metamorphic zonal variation in the KNC has traditionally been ascribed to the Scandian phase of the Caledonian Orogeny but is now thought to have occurred in the Finnmarkian phase in the latest Cambrian to early Ordovician time (Rice and Frank, 2003; Kirkland et al., 2008).

Modern aeromagnetic data (Gernigon and Brönner, 2012) show that the units on either side of the MAF have different, but characteristic magnetic patterns (Figure 39). The offshore aeromagnetic data show that the contact between the Tanahorn Nappe and the Løkvikfjellet Group extends north-eastward into the inner Finnmark Platform, and then swings into a NNW-SSE trend towards the Nordkapp Basin and the Bjarmeland Platform (Gernigon and Brönner, 2012; Gabrielsen et al., 2022).

The field excursion ends at this locality. The participants will be driven to Berlevåg, where we will wait for the Hurtigruten to take us back to Kirkenes.

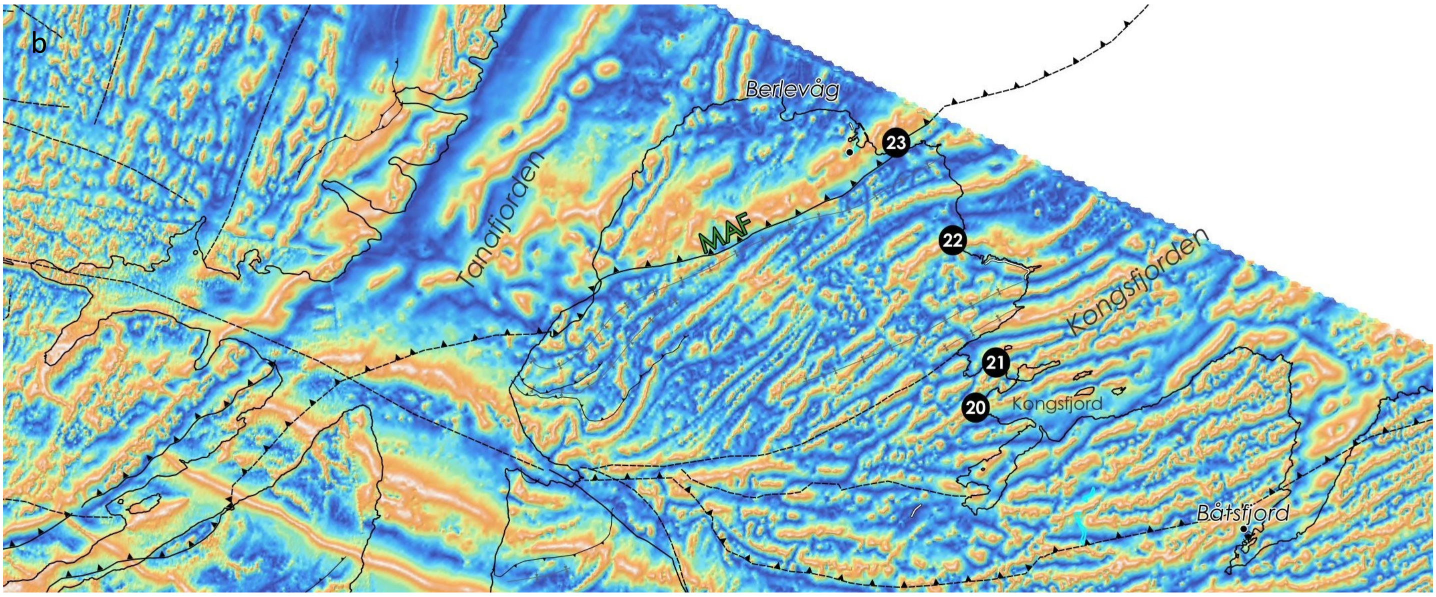


Figure 38: a) The thrust at the Middle Allochthon Front at Vargvika near Berlevåg, indicated by blue arrows. The Styret Fm. (Løkvikfjellet Group) is on the left-hand side, the Berlevåg Fm. of the Tanahorn Nappe to the right-hand side.
b) Tilt derivative of the magnetic field and contrasting pattern on both sides of the Middle Allochthon Front. See appendix for larger map with colour legend and scale.
c) Potholes (jettegryter) on the seaward side of the road, sculptured by present-day wave action.

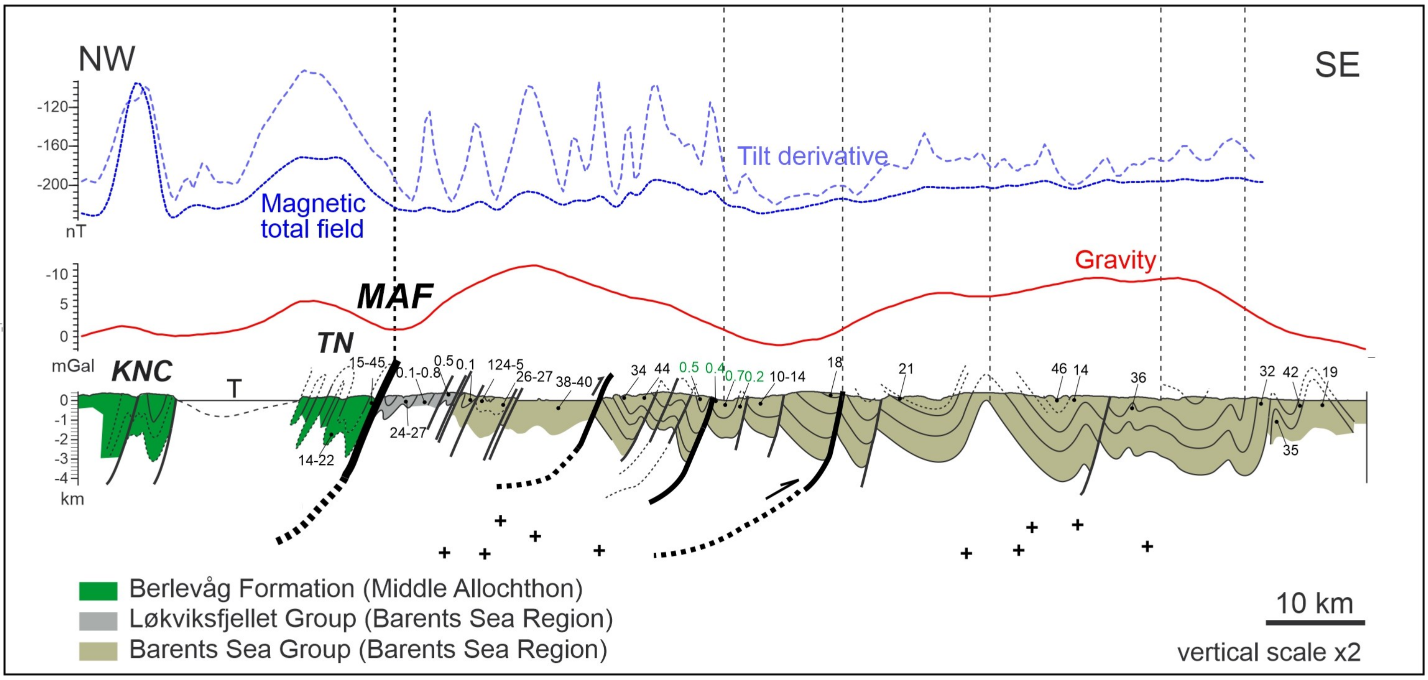


Figure 39: Geological cross-section across the Kalak Nappe Complex and the Barents Sea Region of the Varanger Peninsula. Numbers indicate the susceptibility measurements (× 1000 SI) measured along the profile. KNC: Kalak Nappe Complex; MAF: Middle Allochthon front; T: Tanafjorden; TN: Tanahorn Nappe. After Gernigon and Brönner (2012).

Figure 40: a) View over the town of Berlevåg. b) Old fishing boats illustrating the towns history.

Short summary

The trip has taken you through a geological record from the oldest dated rocks in Norway around 3000 million years old to the youngest intrusive mafic dykes of around 370 Ma. Examples of the diamictites of the Varangerian glaciation at Bigganjarga and Mortensnes, as well as the remains and effects of the last ice age have been seen in several places. Tectonic structures that reflect the major tectonometamorphic events to have affected the area, like the Timanian and the Caledonian orogenies, are well exposed in the nappe complexes in the region.

Another very interesting theme is the presence of stromatolites at several places in the area which indicate the transition from the earliest track of life on Earth (the bacterial 'slime mats'), to multicellular life on Earth.

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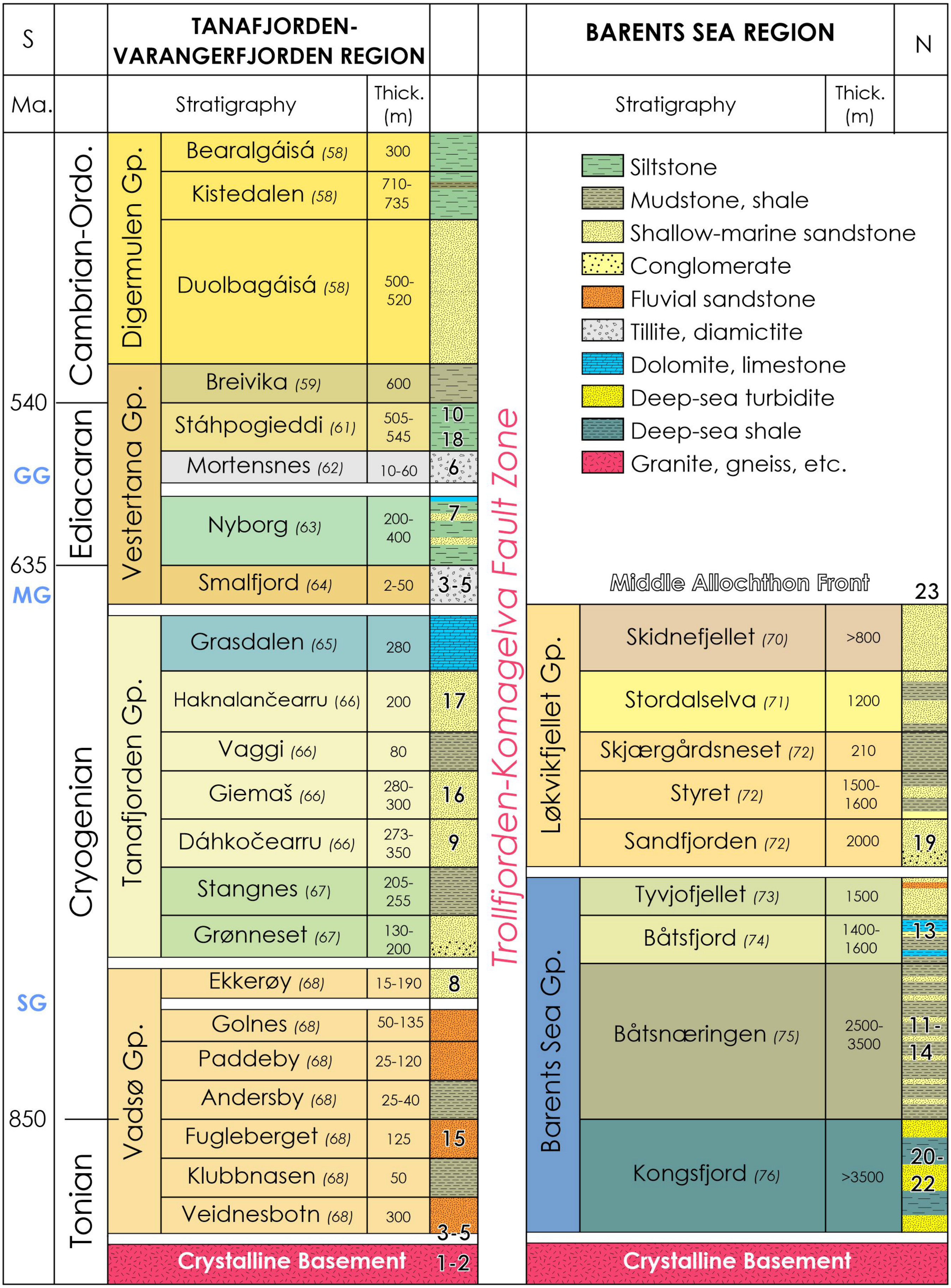
Companies that supported the BOOST project

Appendix 1 – Field stop coordinates (parking places)

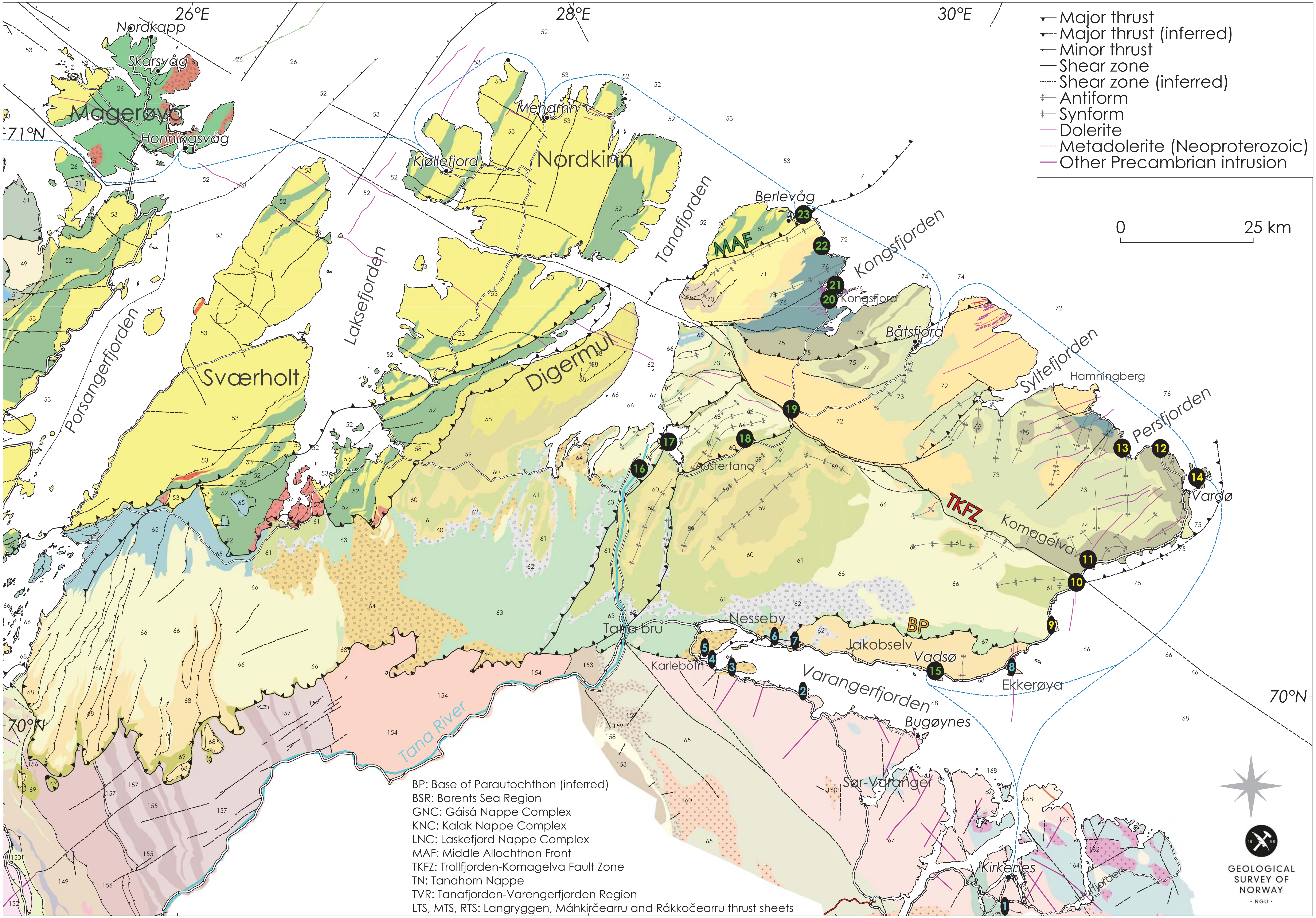
Stop Number	Day Trip	Longitude (WGS84)	Latitude (WGS84)	Easting (UTM35)	Northing (UTM35)
1	DAY 1	30.013144	69.661049	616841	7730957
2	DAY 1	29.084610	70.042227	579398	7771940
3	DAY 1	28.728558	70.090525	565687	7776900
4	DAY 1	28.630802	70.102280	561938	7778108
5	DAY 1	28.597332	70.122755	560607	7780357
6	DAY 1	28.946039	70.138614	573778	7782510
7	DAY 1	28.979713	70.134928	575068	7782140
8	DAY 1	30.103514	70.069928	618024	7776677
9	DAY 2	30.327529	70.137047	626127	7784602
10	DAY 2	30.464387	70.207382	630864	7792724
11	DAY 2	30.474389	70.214931	631193	7793586
12	DAY 2	30.883409	70.437965	645033	7819349
13	DAY 2	30.725629	70.426810	639224	7817738
14	DAY 2	31.094009	70.368364	653411	7812118
15	DAY 3	29.732456	70.068211	603930	7775810
16	DAY 3	28.331907	70.441416	549760	7815645
17	DAY 3	28.455858	70.486185	554271	7820743
EXTRA	DAY 3	28.444113	70.469442	553877	7818865
18	DAY 3	28.830493	70.474055	568274	7819768
19	DAY 3	29.067451	70.524449	576918	7825669
20	DAY 3	29.277610	70.703500	583985	7845905
21	DAY 3	29.315514	70.728615	585275	7848757
EXTRA	DAY 3	29.291319	70.749047	584298	7851000
22	DAY 3	29.247289	70.796388	582484	7856216
23	DAY 3	29.160149	70.849315	579076	7861999

Appendix 2 – Fold-out maps

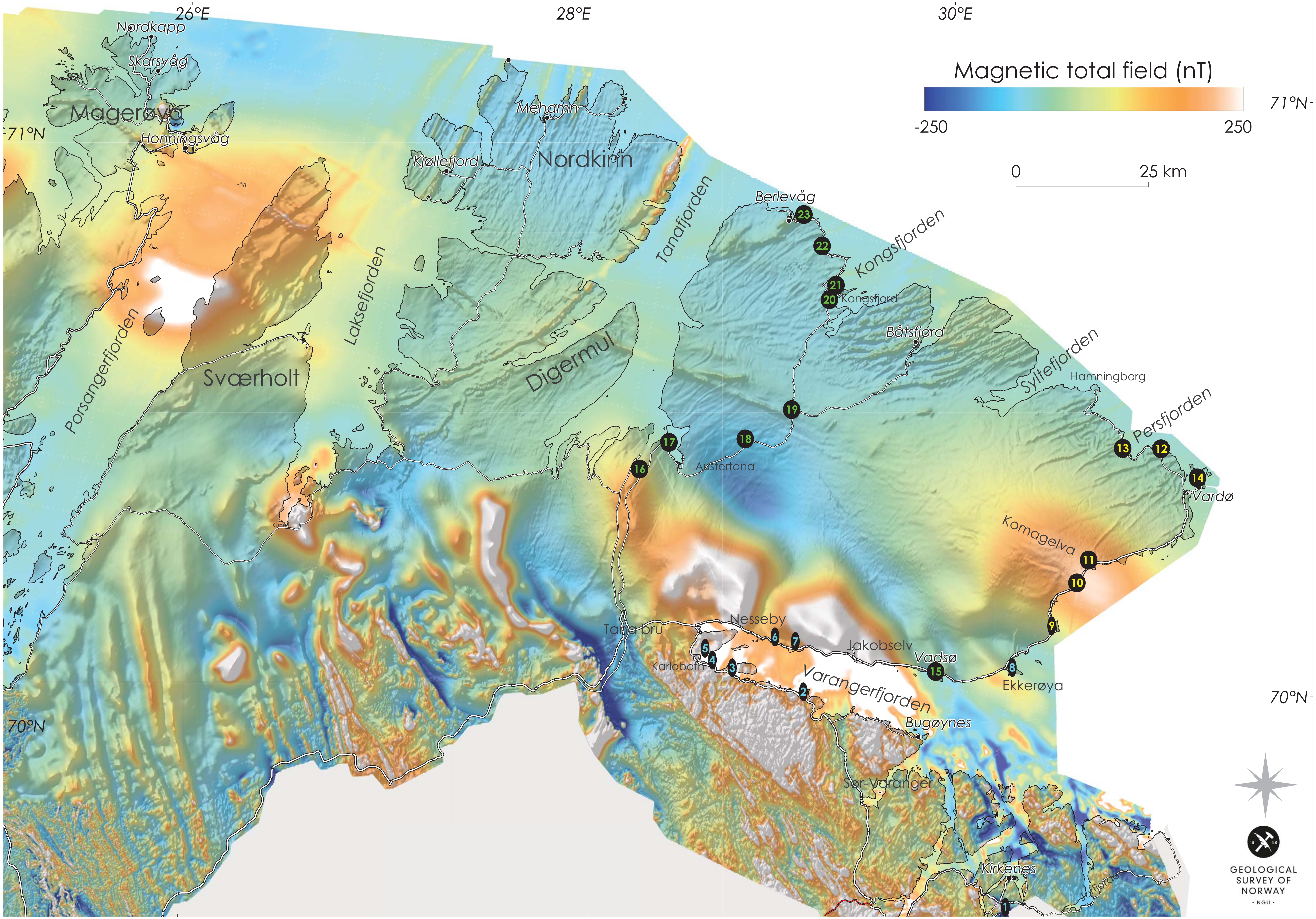
1. Chronostratigraphy of the Neoproterozoic sediments in East Finnmark, adapted after Roberts and Siedlecka (2022)
2. Geological map of the Varanger Peninsula and its surroundings
3. Magnetic total field of the Varanger area (NGU data; Nasuti et al., 2015b)
4. Magnetic tilt derivative of the Varanger area (NGU data; Nasuti et al., 2015b)



S
TANAFJORDEN-VARANGERFJORDEN REGION
BARENTS SEA REGION
N
Ma.
Stratigraphy
Thick. (m)
Cambrian-Ordo.
Ediacaran
Cryogenian
Tonian
540
635
850
GG
MG
SG
Digermulen Gp.
Vestertana Gp.
Tanafjorden Gp.
Vadsø Gp.
Bearalgáisá (58) 300
Kistedalen (58) 710-735
Duolbagáisá (58) 500-520
Breivika (59) 600
Stáhpogieddi (61) 505-545
Mortensnes (62) 10-60
Nyborg (63) 200-400
Smalfjord (64) 2-50
Grasdalen (65) 280
Haknalančearru (66) 200
Vaggi (66) 80
Giemaš (66) 280-300
Dáhkočearru (66) 273-350
Stangnes (67) 205-255
Grønneset (67) 130-200
Ekkerøy (68) 15-190
Golnes (68) 50-135
Paddeby (68) 25-120
Andersby (68) 25-40
Fugleberget (68) 125
Klubbnasen (68) 50
Veidnesbotn (68) 300
Crystalline Basement
10
18
6
7
3-5
17
16
9
8
15
3-5
1-2
Trollfjorden-Komagelva Fault Zone
Siltstone
Mudstone, shale
Shallow-marine sandstone
Conglomerate
Fluvial sandstone
Tillite, diamictite
Dolomite, limestone
Deep-sea turbidite
Deep-sea shale
Granite, gneiss, etc.
Middle Allochthon Front
23
Løkvikfjellet Gp.
Barents Sea Gp.
Skidnefjellet (70) >800
Stordalselva (71) 1200
Skjærgårdsneset (72) 210
Styret (72) 1500-1600
Sandfjorden (72) 2000
Tyvjofjellet (73) 1500
Båtsfjord (74) 1400-1600
Båtsnæringen (75) 2500-3500
Kongsfjord (76) >3500
19
13
11-14
20-22
Crystalline Basement



Major thrust
Major thrust (inferred)
Minor thrust
Shear zone
Shear zone (inferred)
Antiform
Synform
Dolerite
Metadolerite (Neoproterozoic)
Other Precambrian intrusion
0 25 km
26°E
28°E
30°E
71°N
70°N
Nordkapp
Skarsvåg
Magerøya
Honningsvåg
Mehamn
Kjøllefjord
Nordkinn
Berlevåg
MAF
Tanafjorden
Kongsfjorden
Kongsfjord
Båtsfjord
Syltefjorden
Hamningberg
Persfjorden
Vardø
TKFZ
Komagelva
Sværholt
Digermul
Laksefjorden
Porsangerfjorden
Austertana
Tana bru
Nesseby
BP
Jakobselv
Vadsø
Karlebotn
Varangerfjorden
Ekkerøya
Bugøynes
Sør-Varanger
Kirkenes
Tana River
BP: Base of Parautochthon (inferred)
BSR: Barents Sea Region
GNC: Gáisá Nappe Complex
KNC: Kalak Nappe Complex
LNC: Laskefjord Nappe Complex
MAF: Middle Allochthon Front
TKFZ: Trollfjorden-Komagelva Fault Zone
TN: Tanahorn Nappe
TVR: Tanafjorden-Varengerfjorden Region
LTS, MTS, RTS: Langryggen, Máhkirčearru and Rákkočearru thrust sheets
GEOLOGICAL SURVEY OF NORWAY


Magnetic total field (nT)
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28°E
30°E
71°N
70°N
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Skarsvåg
Magerøya
Honningsvåg
Kjøllefjord
Mehamn
Nordkinn
Tanafjorden
Laksefjorden
Porsangerfjorden
Sværholt
Digermul
Berlevåg
Kongsfjorden
Kongsfjord
Båtsfjord
Syltefjorden
Hamningberg
Persfjorden
Vardø
Komagelva
Austertana
Tana bru
Nesseby
Jakobselv
Vadsø
Karlebotn
Varangerfjorden
Ekkerøya
Bugøynes
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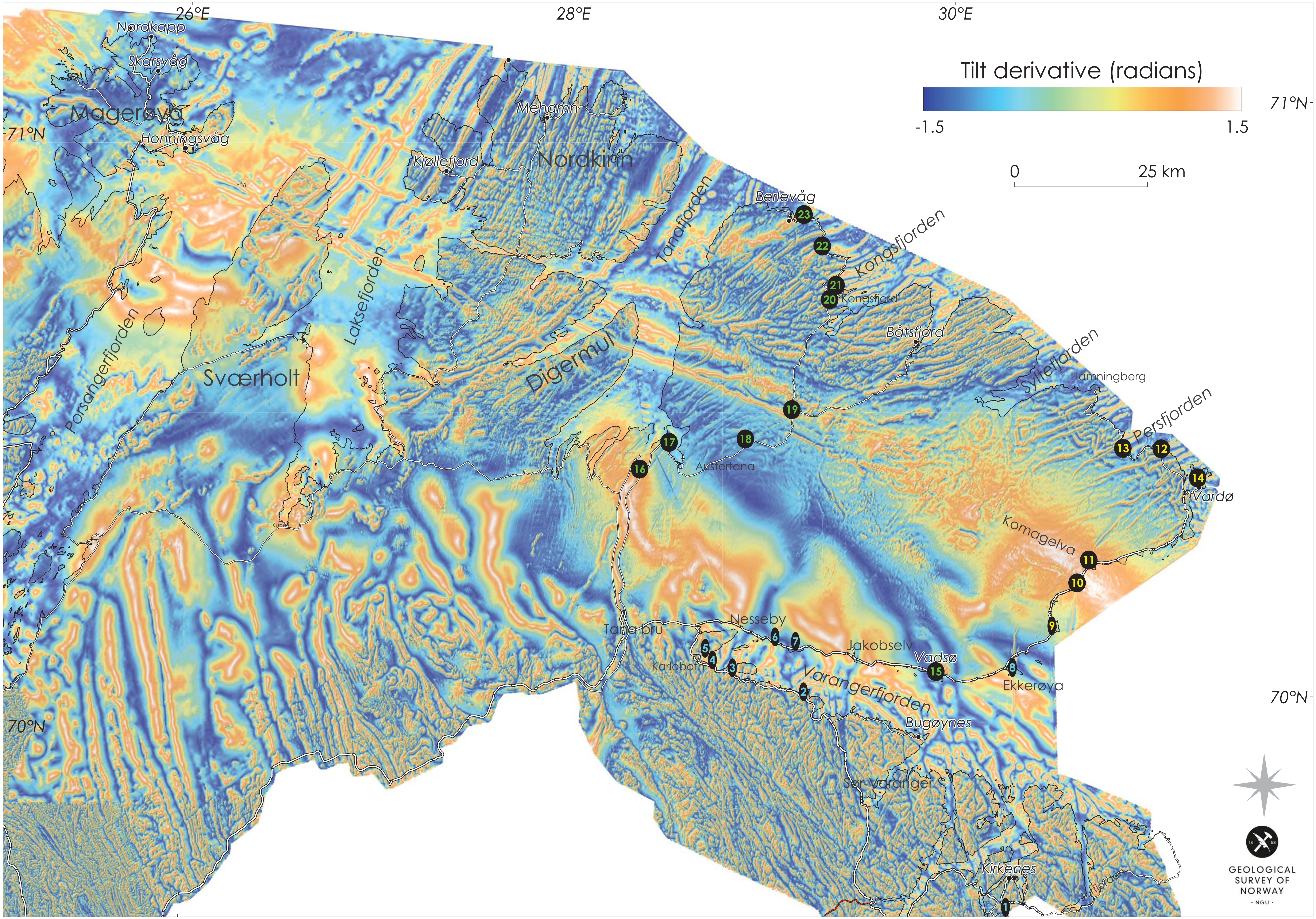
GEOLOGICAL SURVEY OF NORWAY
- NGU -



26°E
28°E
30°E
71°N
70°N
Tilt derivative (radians)
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1.5
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25 km
Nordkapp
Skarsvåg
Magerøya
Honningsvåg
Mehamn
Kjøllefjord
Nordkinn
Tanafjorden
Berlevåg
Kongsfjorden
Kongsfjord
Båtsfjord
Laksefjorden
Porsangerfjorden
Sværholt
Digermul
Syltefjorden
Hamningberg
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GEOLOGICAL
SURVEY OF
NORWAY
NGU

Geological Excursion to the Varanger Area, eastern Finnmark, Norway

Prepared by
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