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Geological data requirements and investigation needs relating to SMR site evaluation processes in Møre og Romsdal and Trøndelag, Norway

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Abstract

The Geological Survey of Finland produced a report concerning investigation needs related to site evaluation for SMR (Small Modular Reactor) development processes in Norway, acting as a subcontractor for TVONS (TVO Nuclear Services) for the client, Norsk Kjernekraft. The SMR investigation site, designated as Taftøya, is located on the border of two counties, Møre og Romsdal and Trondelag, near Kjorsvikbugen.

The purpose of this report is to initially evaluate and compile data available from the site area to assess the suitability of the site for small modular reactor site development. As the investigations are preliminary and are related to the siting process, this report will produce the preliminary data needs to evaluate the suitability of the site for SMR nuclear power development.

As the development of specific regulation and legislation for SMRs is currently ongoing in several countries, this report will use relevant IAEA documents related to conventional size nuclear power plants (NPPs) and other data and scientific research articles applicably to develop the investigation data needs and requirements enabling site evaluation processes in the SMR context. Certain IAEA documents, such as SSR-1, SSG-35, SSG-9 and others, present valuable information that can be readily applied within the SMR framework. The results from this report may also be relevant for regulators and legislators for evaluation.

As the report is mostly discussing risks associated with geological features of the site and geology in general, Geological Survey of Finland (GTK) used data and maps available from the Geological Survey of Norway (NGU) website and other available datasets from e.g., the Institute of Seismology in Finland concerning seismological data points.

The report can be described as an initial desktop evaluation of the suitability of the site in question, and at this time and project phase based on the results presented in this report, the site can be considered suitable for further research.

With the results from this report, further geological investigations can be designed, providing more detailed technical descriptions of a site and its suitability for SMR development. The report may serve as a basis for evaluating other sites as well.

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1 INTRODUCTION

In this report, the Geological Survey of Finland will identify preliminary site investigation needs or geological data requirements for a site evaluation process regarding small modular reactor (SMR) site selection in the counties of Trøndelag and Møre og Romsdal, Norway, in the site designated as Taftøya by the client, Norsk Kjernekraft. The specific investigation location in this report is however referred to as Eiteråa at this stage and is used as the site location name throughout the report.

Geological investigation needs or data requirements are based on existing recommendations by the IAEA on siting of nuclear facilities, and in this case related to SMRs, specifically related to site vicinity scale investigations. The purpose of these investigations is to perform a preliminary evaluation of an SMR development site, and to encourage more detailed studies, to ensure the geological suitability of a site with site specific investigations.

In this report, we will first derive and describe the most important geological characteristics relevant to site selection and evaluation processes at a specific site survey stage. This will be done by reviewing the site vicinity area for any existing relevant geological data that is available to initially describe the prevailing geological conditions or characteristics. Second, these characteristics are reviewed with more detail regarding the follow-up investigations within a site vicinity area in their respective separate chapters.

The investigation scale with a focus on the site vicinity scale would also allow evaluation of several areas in different SMR development areas. This would be beneficial to establish boundary conditions for different economic, social, environmental, or geological criteria relevant to the site selection process.

2 DESCRIPTION OF SITE SELECTION PROCESSES FOR EITERÅA

The site selection processes of nuclear facilities are a multi-stage process involving many phases of research and development. In this report, we will use the descriptions derived from IAEA Specific Safety Guide No. SSG-35; Site Survey and Site Selection for Nuclear Installations SSG-35 (IAEA 2015), when referring to the site selection principles. The different stages proposed in the SSG-35 document (Figure 1) are interlinked to certain geological investigation scales, such as regional scale, near-regional scale, site vicinity scale and site area scale. These scales concerning SMRs are also discussed initially in Hietava et al. (2023).

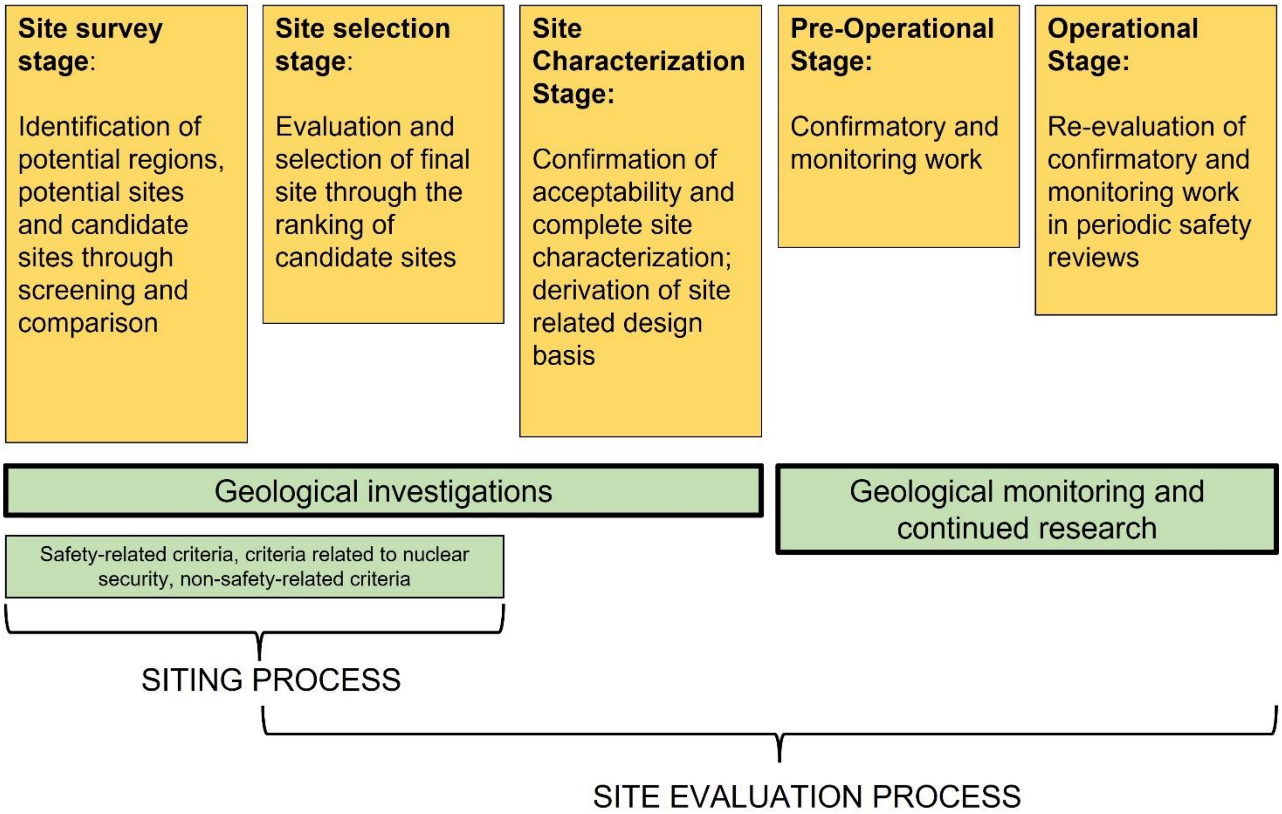

Figure 1. Descriptions for the siting process and site evaluation process, from Hietava et al. 2023 (Modified from SSG-35, IAEA, 2015).

IAEA Specific Safety Guide No. SSG-9; Seismic Hazards in Site Evaluation for Nuclear Installations (IAEA 2022a) states that: "*The geological, geophysical and geotechnical investigations for evaluating the seismic hazards at the site should be conducted on four spatial geographical scales — regional, near regional, site vicinity and site area — leading to progressively more detailed investigations, data and information. The detail and type of these data are determined by the different spatial geographical scales. The first three scales of investigation lead, primarily, to progressively more detailed geological and geophysical data and information. The site area investigations are mainly* *aimed at developing the geophysical and geotechnical database for evaluation of vibratory ground motion and fault displacement*".

It is proposed here that in this site survey stage conducted as a desktop study, the focus should target the site vicinity scale, with an investigation area radius of 5 km. Some data types, such as lineament interpretation data and fault and fracture zone data should extend to larger scales due to their extent in the region. Lithological and seismological data could also be one example of a dataset that should consider larger scales when appropriate, such as regional to near regional investigation scale. The applicability and usability of the site vicinity scale of 5 km radius should however be evaluated wherever and whenever deemed necessary.

SSG-35 states that: "*an in-depth investigation should be made of the capable faults within the area of the site vicinity (5 km radius), that combines the survey of existing reference materials, tectonic geomorphological investigation, investigation of surface geological features, and geophysical and other investigations. Also, the site survey stage investigations should involve the locations, shapes, activity and characteristics of the capable faults, while also considering their distance from the proposed site"*.

This investigation radius concurs with the proposed radius of 5 km for the site survey stage in this report and is thus deemed suitable and appropriate for this desktop study and site survey stage and in applied manners to the actual site vicinity field studies to be performed. While SSG-35 refers to the 5 km radius for the capable faults, the scale is also deemed suitable for other characteristics as well, including lithology, geotechnical data, hydrogeological data and e.g., geophysical data. SSG-35 also states that this radius is to be conducted in an in-depth manner in the site selection stage, which is followed by the site characterization stage (Figure 1).

The use of smaller scales concerning geological data has to do with the fact that small modular reactors have a smaller source term, meaning that their total radioactivity levels are not has high as conventional gigawatt-scale NPPs (Nuclear Power plants). Lower fuel inventory in the core, lower core power density and larger amount of coolant per reactor and generally lower burn-up of the fuel in e.g., LW-SMRs (Light-Water) and HTG-SMRs (High Temperature Gas) affect the safety requirements of the nuclear facility (TECDOC-1936, IAEA 2020b).

This in turn also leads to possibly reduced sizes of emergency planning zones (EPZ), precautionary action zones (PAZ) and urgent protective action planning zones (UPZ), effectively allowing for placement of SMRs closer to population centers. While these scales and attributed zones can be considered as general recommendations for conventional NPPs, research and development are being conducted to adjust these zones to be applicable to SMR concepts (e.g., TECDOC-2003, IAEA 2022b; Hummel, et al. 2020; Carless, et al. 2019; SMRRF, 2018 & 2021). The EPZ, PAZ and UPZ requirements however can be subject to change if there are plans to introduce multiple SMRs to a specific site.

In SSG-35 and SSG-9, the concept of a capable fault and accompanying descriptions of exclusionary criteria can be viewed. A minimum safety distance of 8 km from a capable fault from a nuclear facility site is defined. While similar adjustments to safety distances from capable faults could be expected, as the overall safety requirements concerning reactor facility safety are most likely reduced for SMRs, the capable fault concept in an SMR context requires further research in a larger context and is yet unknown. The concept of fault capability is one of the key features in the initial survey stages, for it has the potential to discard a site if the conditions and characteristics of a fault are deemed not suitable for nuclear or SMR development. The capable fault concept is further explored in chapter 6, along with specific suspected capable faults in the vicinity of Eiteråa.

Ranking criteria with point totals for investigations for different sites and subsequent comparison of sites falls out of the scope of this project, but initial characterization of the SMR related ranking process can be found in Hietava et al. (2023). The development of the ranking process requires further examination to find the best possible criteria for the process, including also other than geological criteria. These could include economic or social criteria or other criteria.

While this report focuses on the site survey stage and related data requirements, it is heavily recommended that further stages, such as the site selection stage and site characterization stage are included in the overall situation analysis to some degree. This is due to the magnitude of research required in the later stages of siting processes and site evaluation processes that overlap each other at many phases during site research. Evaluation of capabilities or capacities of pursuing the next stages would be beneficial, and anticipatory activities would increase the predictability of project planning to multiple stakeholders, such as regulatory and legislative authorities, and the public. These anticipatory activities could include the mapping or listing of specific activities concerning the later stages, which are also mostly listed in the IAEA documents.

3 SITE LOCATION

The site is located on the border of Møre og Romsdal and Trøndelag counties and is designated as Eiteråa, at the Norwegian coast, with the islands of Hitra, Frøya and Smøla to the north and west from the site area (Figure 2). Closest larger cities or towns are Trondheim, Kristiansund and Molde, with smaller population centers such as the administrative centers of Aure and Heim being closest to the Eiteråa site. Industry facilities are located in Tjeldbergodden, ca. 2 km west from the site, and include a fishery and methanol production facilities.

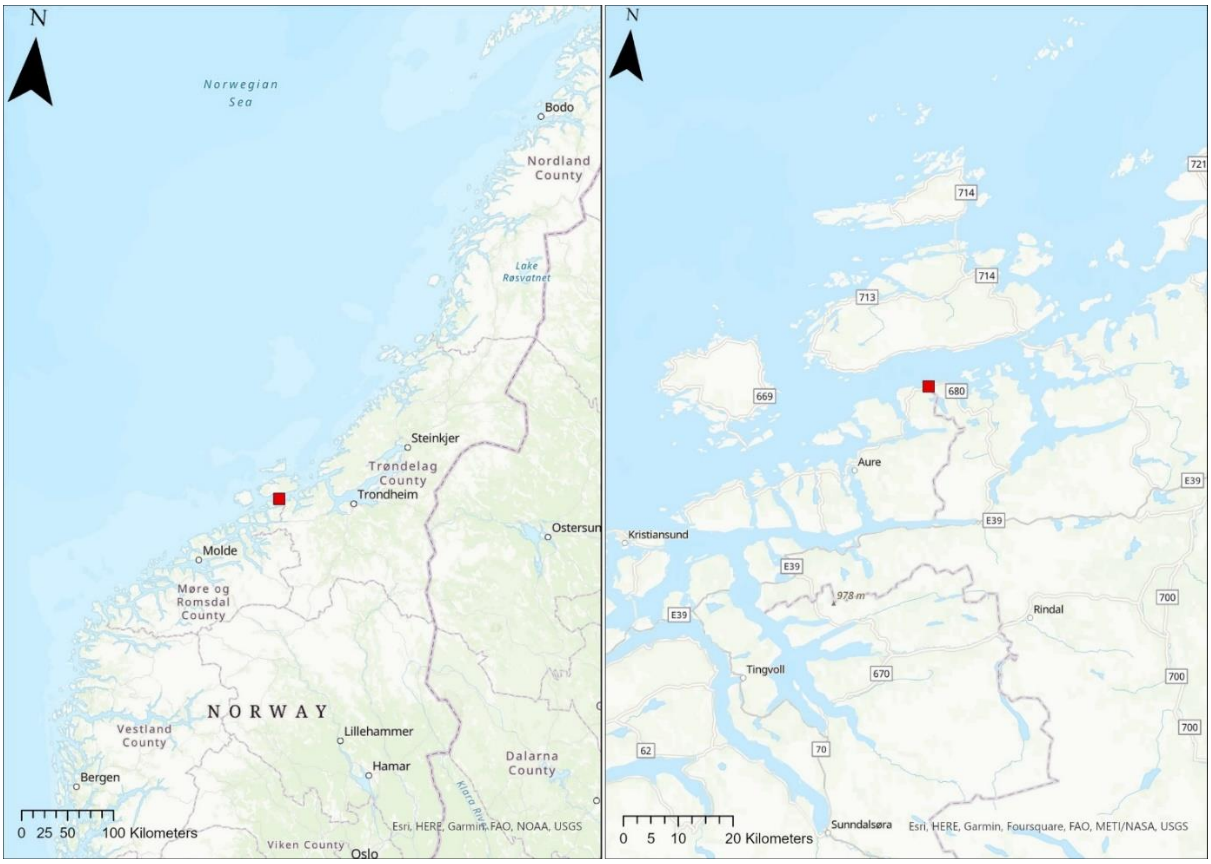

Figure 2. Site location maps, site location marked with red square. Map projection: ETRS 1989 UTM Zone 33N.

4 TOPOGRAPHICAL SETTING AND DATA REQUIREMENTS

The topography near the waterfront is rather subdued but variable and quickly rises to more rugged and elevated heights when proceeding inland. Figure 3 displays the topographical overview of the site area. Site contours indicate an approximately 50 m height from sea level, with some higher elevations in Ytterkammen, before dropping to the approximate site location on the south side of the road. Notable topographical features in the site area include the Eiteråa, a creek or a small river with a flow pattern towards the sea.

Topography data is vital for the project and should be considered a top priority when collecting the overall data package. This can be achieved with either existing LiDAR data or available topography maps. Benefits to LiDAR data would include better resolution of the site topography, resulting in subsequent quality enhancement in any other related data set. LiDAR data should be presented in a GIS format, with possibilities of evaluating and improving the data with multidirectional hillshades or lighting direction in a GIS software platform.

Topography data was available for download from the NVE Atlas website. Figure 4 displays one example of data and its usage in a GIS platform. The level of detail or resolution available from the NVE Atlas website can enable a very detailed analysis of the topography.

LiDAR data and topography data form a baseline data set from where e.g., lineament interpretations, fault and fracture zones, drainage patterns, waterways etc. can be derived, modelled and analyzed. The multitude of usage of this type of data is not thoroughly reported in this study, but the overall importance of topography data and cannot be underestimated.

Establishing a 3D modelling environment of producing topographical models along with detailed geological 3D models would be warranted within the site survey stage. These models could be derived from existing LiDAR data and could be further enhanced with current technology using drones with LiDAR capabilities.

Available bathymetry data should also be used applicably where deemed relevant. Bathymetry data can be readily applied to e.g., seismic hazard assessment processes and lineament interpretations and given the coastal proximity of the site area, the use of bathymetric data should be assessed.

Figure 3. General topography map of the site investigation area. Site location marked with red square is located within the proposed site area. Image from norgeskart.no.

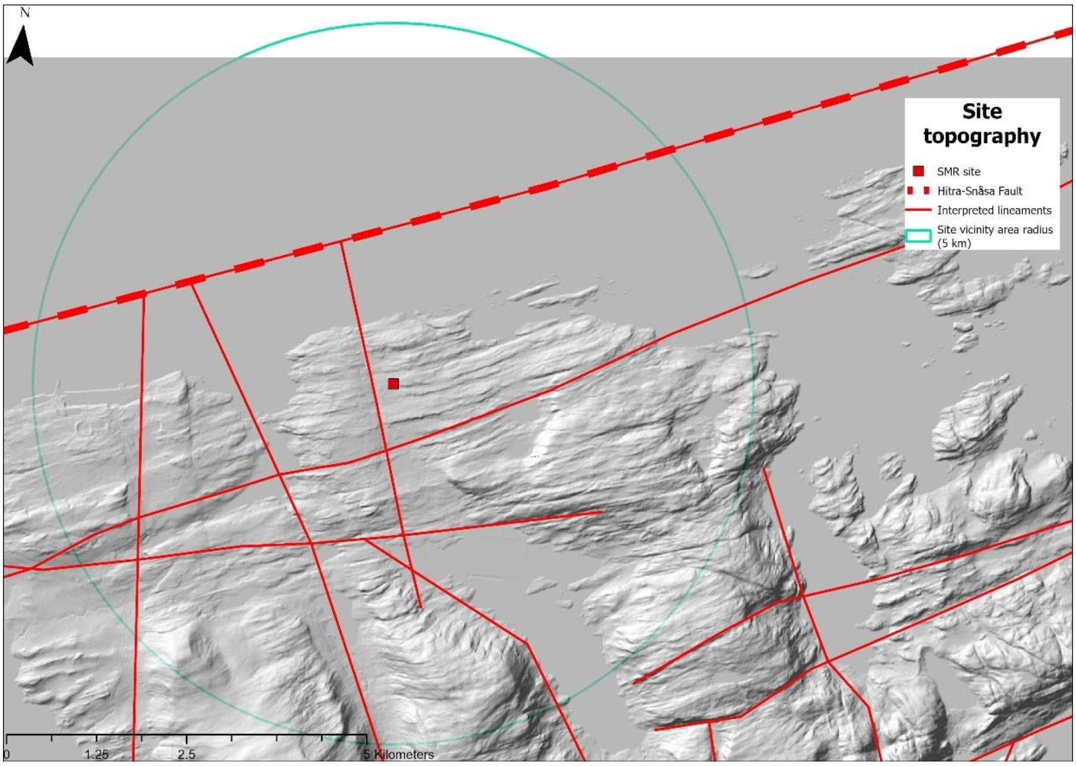

Figure 4. Detailed site topography data at the site vicinity scale with lineament interpretations. Data from NVE Atlas.

5 DATABASE REQUIREMENTS

IAEA documents require establishing a database for any data regarding the geological, geophysical, geochemical, seismological, geotechnical, and rock mechanical data that is to be used in the site evaluation processes. The following list is derived from SSG-35 and includes a site-specific database, containing all relevant site characteristics. These include but may not be limited to:

- Geological data
- Hydrogeological data
- Seismological data
- Data relating to fault displacement
- Volcanological data
- Geotechnical data
- Data on coastal flooding including tsunamis
- Data on river flooding

- Data on meteorological events
- Data on human induced events
- Data on population, land use, water use and environmental impacts

As this report will focus on geological and related issues, coastal and river flooding, meteorology, human induced events with population related data are only briefly discussed in this report. These have to be further discussed in other possible reports as the site evaluation processes proceed. The database should also cover information related to scales of data. This includes regional, near-regional, site vicinity and site area scale investigations (SSG-9, IAEA 2022a).

In the following paragraphs, the listed data is partially tied into the related scales, such as major lineaments and fault zones are related to regional to near-regional data, and site lithology more related to site vicinity and site area scale data. While overlapping of the scales of data is to be expected, a reasonable differentiation between data scales and associated requirements will be inferred in the report discussion and conclusions.

6 GEOLOGICAL AND LITHOLOGICAL DATA

The bedrock in the site belongs to the Western Gneiss Region (WGR), with the deep crustal geology consisting originally of Palaeoproterozoic granites, granodiorites and migmatites, further reworked during Caledonian and Scandian orogenesis into foliated and banded gneisses with local re-migmatization (e.g., Koenemann, 1993; Gordon et al. 2016; Watts et al. 2023).

The Western Gneiss Region is divided by the Møre-Trøndelag Shear Zone (MTSZ) (Figure 5, Gordon et al. 2016), dividing the metamorphosed Caledonian gneissic and granitic rocks into two sections (Northern and Southern). The MTSZ can also be referred as the Møre-Trøndelag Fault Complex (MTFC; Watts et al. 2023), depending on the context. In the near site vicinity, these rock types are also located on the other side of the site on the island of Hitra.

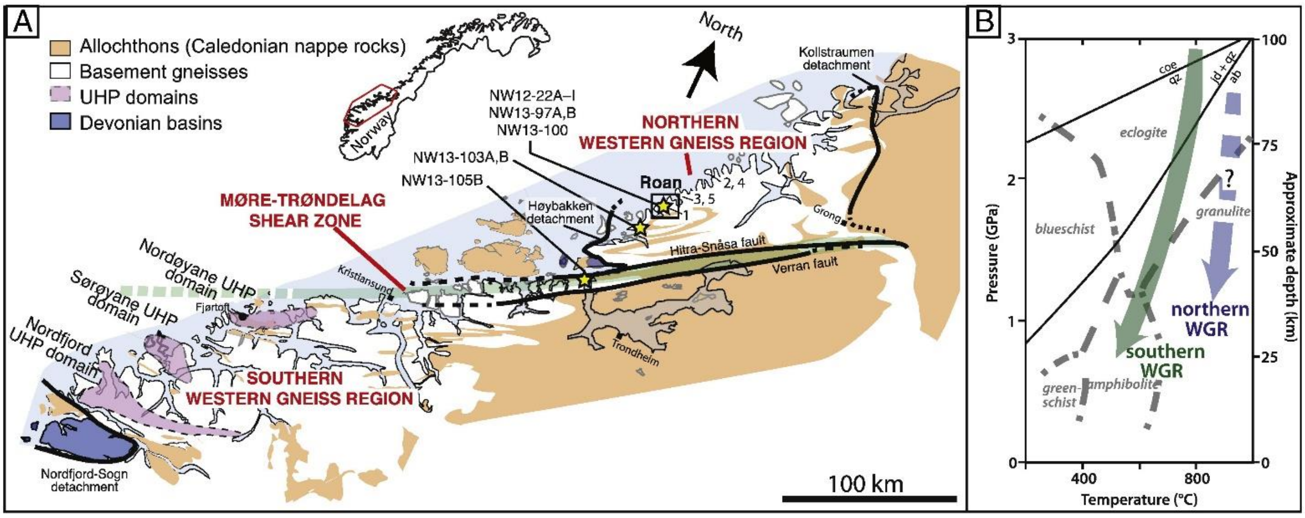

Figure 5. Geological map of the Western Gneiss Region, modified from Gordon et al. 2016.

The age determinations of the Western Gneiss Region range from 1690 Ma to 1620 Ma and the later Sveconorwegian and Caledonian orogenic metamorphism ages range from 1100-950 Ma to 500-405 Ma, respectively (Fossen 2010). These age determinations place the WGR rocks into basement rock complexes, forming a solid foundation for subsequent analysis of the geological characteristics of the site.

The MTSZ is dated to be ca. 488 to 388 Ma years old, with U-Pb age determinations from pegmatites in Selva. The ancient origins of this very large, steep, and complex strike-slip shear zone began within a ductile deformation regime with sinistral transtension (Gordon et al. 2016). The complex is >300 km long and 10–50 km wide, with an ENE-WSW strike trend (Watts et al. 2023).

Reactivation of the complex is thought to occur in multiple phases along the two main fault strands, the Hitra-Snåsa Fault (HSF) and the Verran Fault (VF), first during the early Devonian (ca. 410 Ma), continuing to Permo-Carboniferous (290 Ma), indicated by the formation of cataclasites and pseudotachylites together with the N-S trending faults representing also the present-day brittle deformation regime, relating late Cretaceous to early Cenozoic opening of the Atlantic Ocean, with also the Verran Fault Zone reactivation during the Mesozoic (Watts et al. 2023). Some publications (Nasuti et al. 2011) also include the Bæverdalen Fault (BF) and the Tjellefonna Fault (TF) into the MTSZ, while also using the term Møre-Trøndelag Fault Complex (MTFC). These major fault zones will be further discussed in chapter 7 along with lineament interpretations.

Geological or lithological classification of the facility host rock complex is relevant to validate the basis for further site investigations, such as diamond drilling operations to sample the bedrock at depth. NGU data reveals the geology of the host rock complex of the site (Figure 6), and it is comprised of the five major rock types belonging to WGR rocks. The rock types or geological units within the site vicinity area include diorite and dioritic gneiss rocks, mica gneiss, mica schist, migmatite and a narrow marble horizon directly SE from the site area. The site area is mostly comprised of the diorite or dioritic gneiss rocks. Other rock types in the area are granitic gneisses and conglomerates, but these are not encountered in the site area radius of 5 km.

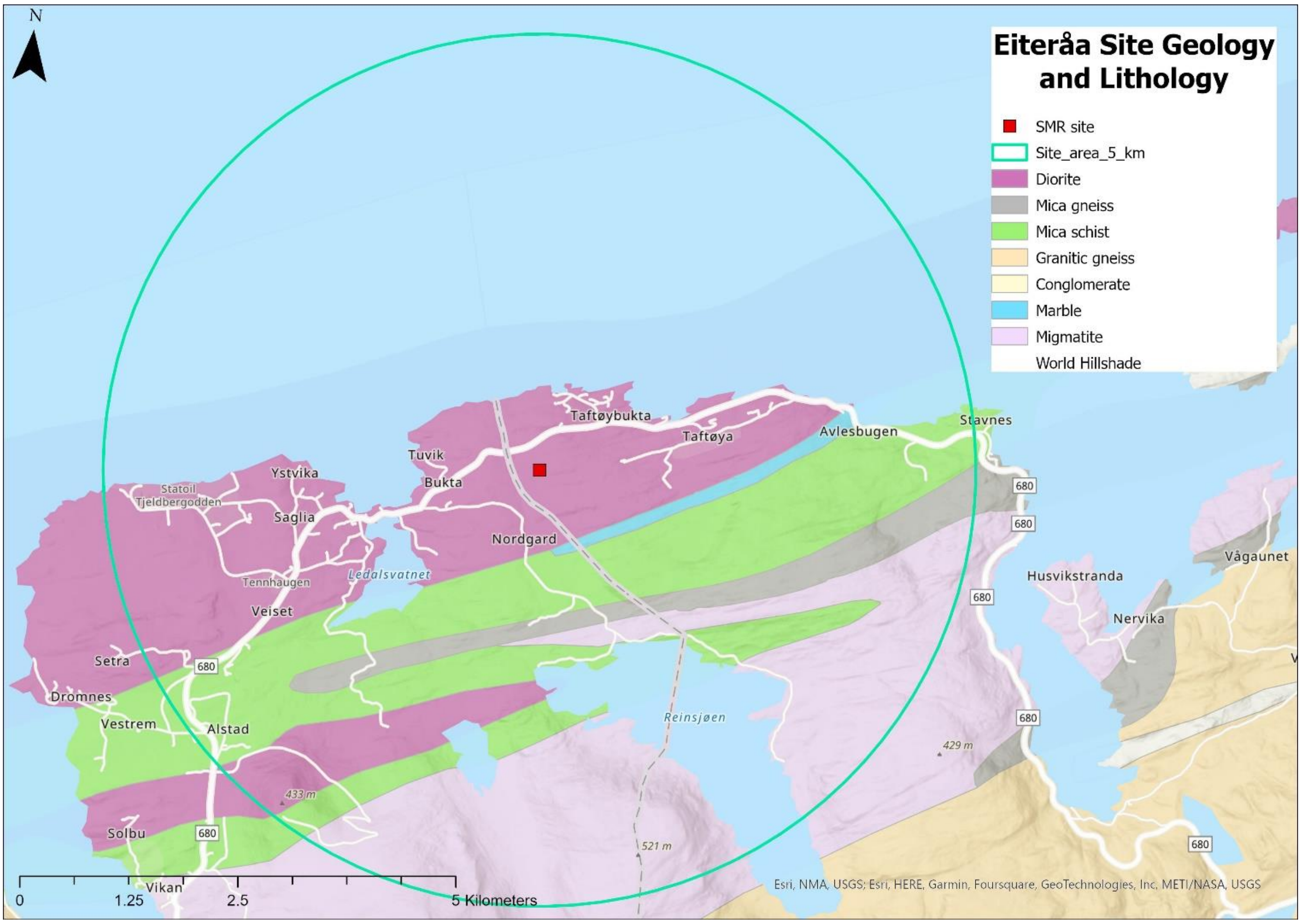

Figure 6. Eiteråa site geological map with main rock types (lithology). Map scale 1:50 000. Data from NGU from NGU.

This type of data would serve as a basis for planning a geological mapping program in a more detailed scale, which would involve geological data collection (bedrock samples, structural observations etc.) and geological profile generation across the investigation site.

Figure 7 displays the available foliation data (structural geology data) from the site and adjacent areas in a near-regional scale. The general strike and dip of the WGR rock packages within the site vicinity area are concurrent with the MTSZ, trending ENE-WSW and dipping towards N-NW with dip angles of 45-60 degrees within the host rock complex dioritic unit (Figure 6). The strike and dip of the rock packages also indicate that the WGR rocks in the site vicinity area are a part of an anticline structure extending in the same ENE-WSW direction.

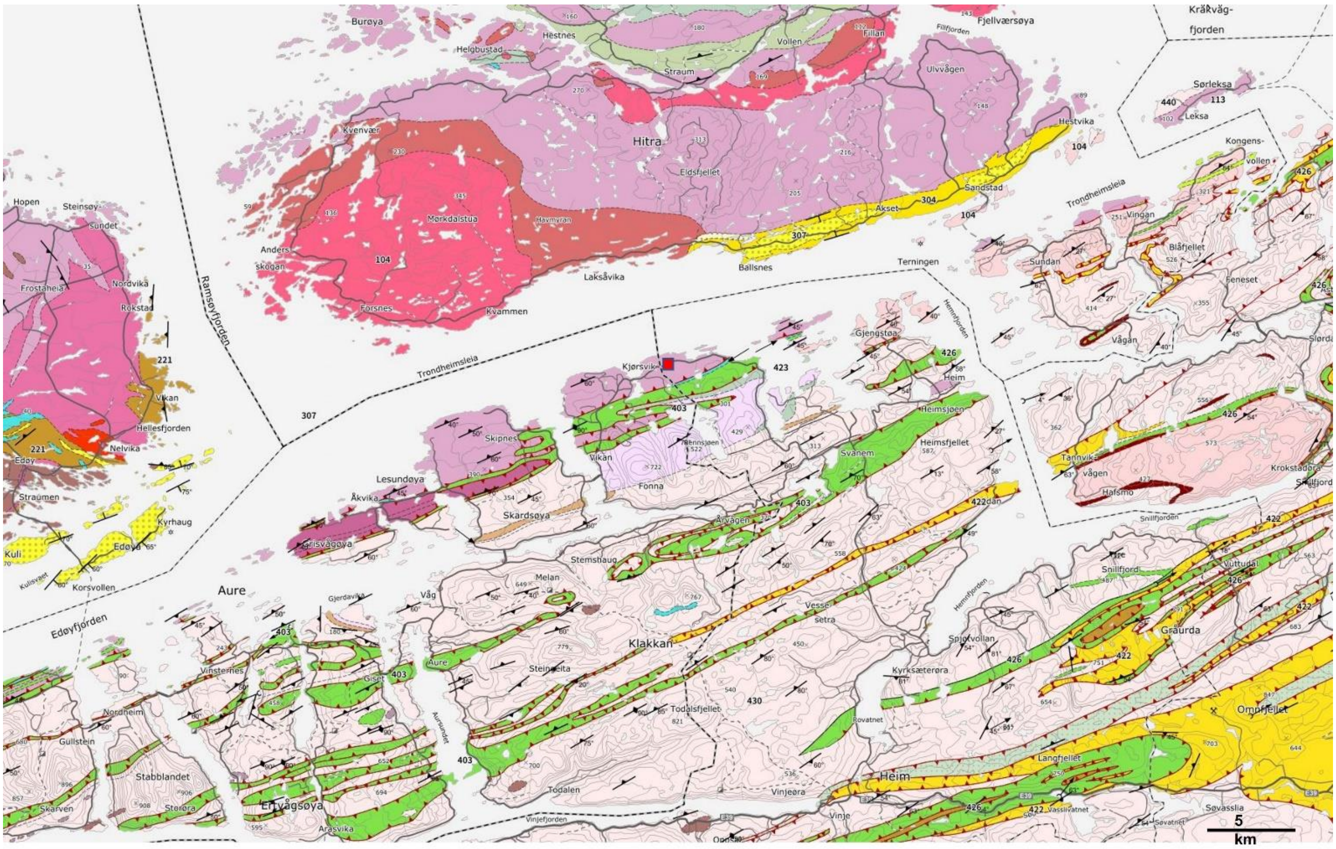

Figure 7. Near-regional geological map of the area including the investigation site (red square) and available simplified structural measurement data . Contains data under Norwegian license for public data (NLOD) made available by the Geological Survey of Norway (NGU website).

Figure 8 displays the host rock complex with lineaments. The most prominent lineaments observed in the area are the HSF and the N-S to NNW trending lineament along the Eiteråa river. Other N-S lineaments are located west from the site. An ENE-WSW trending lineament is observed at the approximate contact between the diorite unit and mica schist unit, with the marble horizon partially in between the two units. Towards the south, a contact between the mica schist and mica gneiss can be observed also with an interpreted lineament at or close to the contact.

Downloaded NGU data also shows inferred shear zones at the contact of each geological unit within the site vicinity area. The occurrence of possible shear zones or fracture zones would need to be investigated with survey profiles preferably perpendicular to the approximation of the geological contacts.

Borehole data from the NGU archives is available, and for example groundwater wells drilled within the site vicinity perimeter could be further studied with e.g., geophysical methods but are of limited use due being mostly concentrated within the diorite unit. A report on groundwater resistivities and indications of bedrock fracturing by Rønning & Elvebakk (2005) was conducted, and lithologies for boreholes closest to the site were referred to as foliated quartz diorite, indicating a rough similarity with the NGU rock type data.

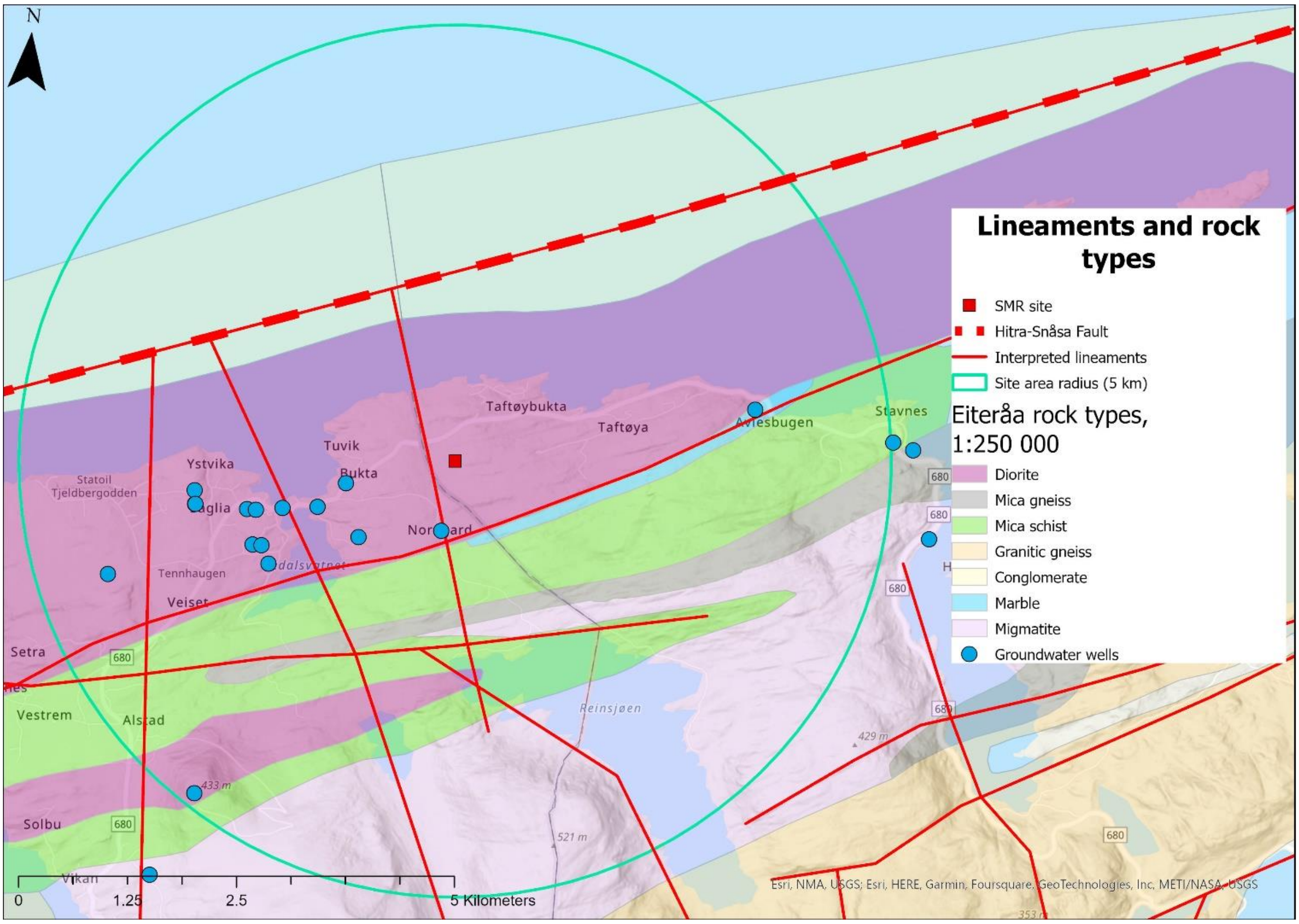

Figure 8. Eiteråa site rock types (lithology) with lineaments. Data from NGU data download website.

6.1 Data requirements for site vicinity investigations on geology and lithology in the site survey stage

Site vicinity scale should be investigated at least in the scale of 1:5000 (SSG-9, IAEA 2022). This scale would be appropriate to get a detailed resolution of the site geology and lithological units and specify the characteristics of different host rock types in the 5 km radius area.

SSG-9 (IAEA 2022a) lists the required investigations. These include but are not necessarily limited to:

- geological map at the site vicinity scale with cross-sections,
- drillholes or boreholes within the subsurface with aims of detailed stratigraphy of the area including lithological determinations from drill core, and

- identification and characterization of potential hazards induced by earthquake in the subsurface. These would include potential for landslides, subsidence, cavities, collapse or water retaining structures.

As the bedrock is comprised of foliated igneous basement rocks, the risk for larger cavities is most likely low. Geological mapping with cross-sections should be coupled with appropriate surface sampling of bedrock. The identification of subsurface hazards essentially warrants drill core samples to be analyzed for lithology, but also for rock mechanical parameters such as Rock Quality Designation (RQD) and the Q-system (Barton et al. 1974) and fracture zone identification and fracture studies from drill cores. Additional rock quality investigations could include geophysical methods for drillholes, such as Optical Borehole Imaging/Acoustic Borehole Imaging (OBI/ABI) measurements that would also infer fracture frequency or fracture density from the bedrock.

The overall foliation and schistosity patterns observed in the host rock complex at Eiteråa from existing NGU data suggest a general geological investigation profile perpendicular to the ENE–WSW orientation.

7 LINEAMENT INTERPRETATION AND CAPABLE FAULTS

Linear features in bedrock reflect the deformation processes occurring across geological time. Geological lineaments can be directly attributed to faults and fracture zones and can be detected or interpreted from aerial imagery, satellite data or photogrammetric data and more currently, LiDAR data. Fracture zones and fault zones by definition are a part of the bedrock and deform during tectonic processes across the geological time scale and are further deformed by weathering and alteration processes.

The use of the lineament data spans across the entire spectrum of research performed on a site and forms a foundation for every category of geological investigations. These include but are not necessarily limited to lithological data, seismic data, geotechnical data, and hydrogeological data. All of these data types are further discussed in their respective chapters.

The aforementioned concept of a capable fault, in direct relation to these lineaments, fracture zones, or fault zones is further discussed here.

From a geological perspective, the possible occurrence of capable faults adjacent to the site area is of utmost importance. This is due to the overall effect of a capable fault in a nuclear facility context. The definitions for a capable fault, derived from IAEA documents SSR-1 (Site Evaluation for Nuclear Installations No. SSR-1, IAEA 2019) and SSG-9, are as follows:

- "*Where reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation, an alternative site shall be considered" (SSR-1, IAEA 2019).*

- *"Geological faults larger than a certain size and within a certain distance of the site and that are significant to safety shall be evaluated to identify whether these faults are to be* *considered capable faults. For capable faults, potential challenges to the safety of the nuclear installation in terms of ground motion and/or fault displacement hazards shall be evaluated." (SSG-9, IAEA 2022).*

- *"If the fault shows evidence of past movement (e.g., significant deformations and/or dislocations) within such a period that it is reasonable to conclude that further movements at or near the surface might occur over the lifetime of the site or the nuclear installation, the fault should be considered capable." (SSG-9, IAEA 2022).*

The IAEA document SSG-35 indicates a minimum safety distance of 8 km from a capable fault and refers to it being an exclusionary criterion for the site. This safety definition and all other applicable definitions should however be coupled with the following definition from SSR-1:

"*A proposed new site shall be considered unsuitable when reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation, and which cannot be compensated for by means of combination of measures for site protection and design features of the nuclear installation. If a capable fault is identified in the site vicinity of an existing nuclear installation, the site shall be deemed unsuitable if the safety of the nuclear installation cannot be demonstrated.*"

The definitions concerning the lifetime of the facility along with the potential of combination of measures and design features should be relevant in the SMR context. As regulation and legislation of SMR specific topics proceed, review and applicability of the criteria concerning the concept of the capable fault should be reviewed and possibly renewed in the SMR context.

SSG-9 states that: "*The size of the region to be investigated, the type of information and data to be collected, and the scope and detail of the investigations to be performed should be defined at the beginning of the seismic hazard assessment project. The acquired database should be sufficient for characterizing, from a seismotectonic point of view, features relevant to the seismic hazard assessment that are located in other States or in offshore areas*".

Given the uncertainties still present for the regulation and legislation, this statement should be evaluated in accordance with current and possibly upcoming national regulation and legislation and should be evaluated in conjunction with the findings and suggestions made in this report.

The lineament interpretation data and fault zone data can be attributed to near regional investigations. Near regional investigations would include characterization of seismotectonics of the near region, determination of most recent movements of the seismogenic structures and potential capable faults and determination of the amount and nature of displacements, rates of activity and evidence relating to the segmentation of seismogenic structures. Near regional investigations can also be described in the context of tectonic history, meaning that fault capability studies could involve compilation of tectonic information history through the Upper Pleistocene to the Holocene (i.e., the present) high seismic regions, which may be adequate. In low seismic regions, information from the Pliocene to the Holocene may be necessary (SSG-9, IAEA 2022a). The Pliocene would also serve as an appropriate timescale point to investigate possible post-glacial faulting in the regional or near-regional context.

There are multiple lineaments within the site vicinity scale area of 5 km. The most prevalent and dominant feature is the Hitra-Snåsa Fault, a northern section of the More-Trøndelag Fault Zone (Watts et al. 2023). Figure 9 displays the lineament interpretation made from the site vicinity area and with a more regional geology context (50 km radius), due to the major lineaments such as HSF exceeding lengths of hundreds of kilometers. Available topographical data from GTK servers was used to infer the locations of the lineaments, and relevant structural data from NGU was used as supporting data to validate the results.

The lineament interpretations were made combining scales 1:500 000 and 1:200 000 to gain a better resolution of lineament occurrence and frequency. These scales were also appropriate to infer the locations of the major lineaments in the area (MTFZ, HSF and VF) and to infer the location, shapes and lengths of N–S to NNW trending fracture zones, possibly indicative of the more brittle deformation regime. The reference frame of 50 km radius was also used to partially limit the interpretations of the larger scale lineaments.

Figure 9 displays the location of the major fault zones in the 50 km radius area. The Hitra-Snåsa Fault Zone intersects the site area vicinity of 5 km radius. The two other major faults, the Verran Fault Zone and the Bæverdalen Fault (BF) intersect only the 50 km radius used to interpret the lineaments and are not influencing directly of the site vicinity area of 5 km radius.

The possible effects of the Verran and Bæverdalen faults however cannot fully be estimated on the current interpretations neither from the NGU data or lineament interpretations presented in the maps of this report. This is due to the possible limitations of the representative data. The extent and length of the VF and BF cannot be exclusively determined from the current data alone, creating uncertainties in the interpretations. In case of the VF, the data inferred from the topographic maps can result in the interpretation that the Verran Fault continues within a fjord concurrent with the topography. These types of interpretations, while somewhat speculative, give reasonable indications of the total lengths of the major faults or fracture zones within the near-regional scale. Thus, appropriate measures should be conducted in the seismic hazard assessment processes to address these types of uncertainties, if possible.

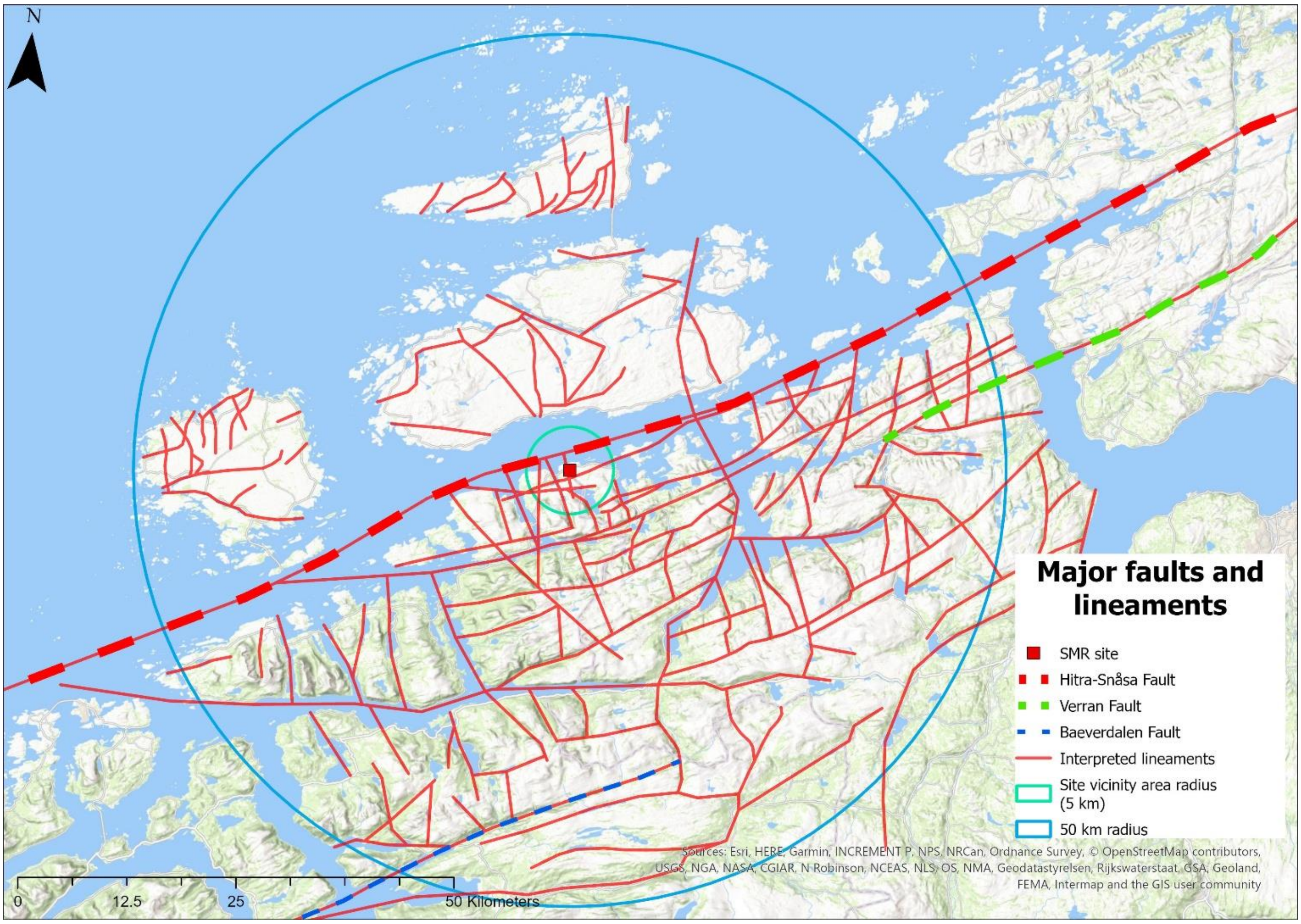

Figure 9. Major faults and lineaments in the site area (near-regional to regional scale).

Defining the most important possible capable faults within the MTFZ could include studies performed outside the site vicinity study radius of 5 km. Lack of outcrop in Eiteråa directly attributed to the MTFZ is possible, so alternative sites outside the perimeter should be considered. This could be necessary to provide geochronological evidence on the ages of the faults and can be done elsewhere if suitable outcrops attributed to the faults in question can be found in other areas.

Figure 10 displays the site vicinity area with the most prevalent lineaments interpreted from scales 1:500 000 and 1:200 000. Two ENE–WSW trending lineaments can be seen (along with the HSF), and these can be further correlated to lithological contacts, possibly being shear type contacts. The N–S to NNW trending lineaments are also visible, with the most prevalent of these being the Eiteråa creek lineament.

The rather orthogonal relationships between these two general lineament directions can be helpful in designing the investigation profiles needed in further site studies. Profiles would be designed being positioned perpendicularly to the general foliation direction, which concurs with the ENE-WSW trending major lineaments. The N–S to NNW trending lineaments such as the Eiteråa creek lineament should be investigated with a profile trend roughly parallel to the ENE–WSW direction. Other possible lineament directions should also be investigated, along with the overall smaller scale fracturing conditions in the host rock complex.

SSG-35 (IAEA 2015) states that: "*Exclusion criteria are used to discard sites that are unacceptable on the basis of attributes relating to issues, events, phenomena or hazards for which there are no practicable engineering solutions*". Also, the implementation of this criteria is to be considered in the site selection phase of the site evaluation process.

The term practicable engineering solutions will have to be examined for possible effects in the SMR facility context. Adding these criteria to the existing exclusionary criteria of minimum distance of 8 km from a capable fault, the scenario regarding the capable fault concept becomes increasingly conservative in relation of indicatively old and ancient fault complexes, such as the MTFC and the HSF.

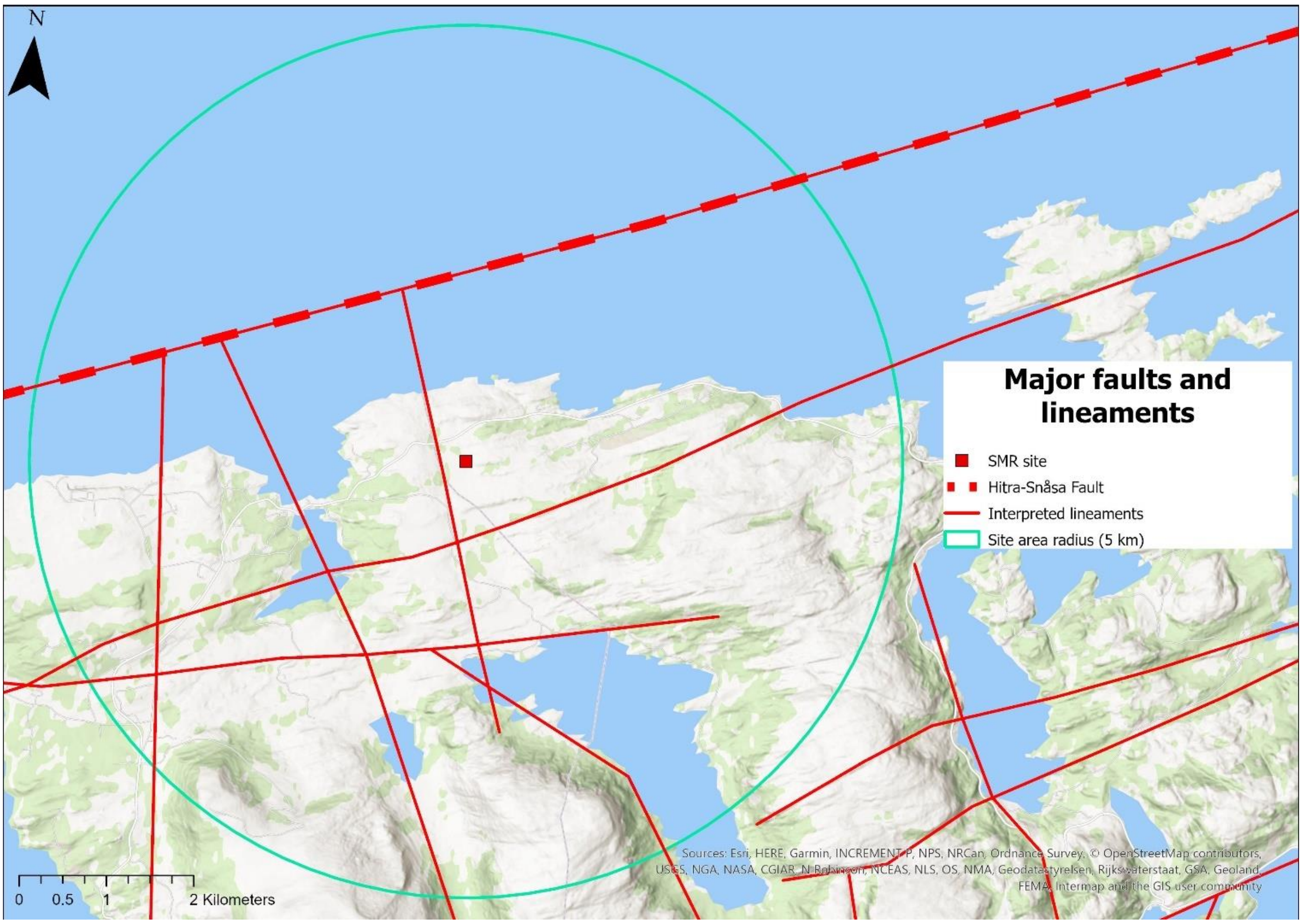

Figure 10. Lineament interpretations in the site vicinity area (5 km radius).

SSG-9 (IAEA 2022) also dictates that secondary faults that can be reliably attributed to being capable, can be considered as a discretionary attribute and: “*If reliable evidence shows that this secondary fault can be traced to or could extend to the site area, and its effects cannot be compensated for by proven design or engineering protective measures, the existence of this secondary fault should be treated as an exclusionary attribute and an alternative site should be considered. If there is insufficient evidence or data to differentiate between primary and secondary faults, a conservative approach should be applied, and such faults should be identified and characterized as capable faults*”.

These secondary faults within the context of the site vicinity area could be attributed to the N–S to NNW trending minor faulting or fracturing occurring in the site vicinity area and the site area, warranting their investigation in sufficient detail.

The secondary N–S to NNW fracturing along with general bedrock fracturing mode can be derived from the available NVE Atlas data, as shown in Figure 4. Depending on the selected resolution and scale of the data, initial reviews of the available topography data indicate possibilities to enhance the lineament interpretations directly from the data available from NVE Atlas. Especially the Eiteråa river lineament indicates typical characteristics of a fracture zone, with a multitude of parallel fracture planes visible in the topography data, with also rather typical orthogonal fracture patterns of igneous rock formations. An example of the Eiteråa lineament topography data is shown in Figure 11.

Figure 11. Detailed site topography data with fracture patterns near the Eiteråa creek lineament.

Post-glacial faulting is one possible phenomenon that can produce earthquakes during and after glaciation periods. Research conducted in Finland (e.g., Ojala et al. 2019) and SW Norway (Helle et al. 2007) indicate the potential of these types of faults that have the capability of producing earthquakes of a considerable magnitude. However, the likelihood of post-glacial activation faults is at its highest directly after the glaciation period, leading to the interpretation that the potential for post-glacial activity would be relatively low in the site vicinity area. The investigation of existing faults and fracture zones within the site vicinity area would lead to better interpretations on the possibilities of post-glacial fault occurrences in the area.

7.1 Data requirements and recommendations for lineaments, capable faults and bedrock fracturing in the site survey stage

Lineament interpretations on the site vicinity scale have to be further enhanced from the current data and interpretations. Geological investigation profiles must be designed and implemented with multiple methods. The general data requirements for lineaments, capable faults, and fracturing would be consisted of but not necessarily limited to:

- structural geological mapping of faults, fracture zones and bedrock fracturing,
- drillhole or borehole investigations with geophysical methods to further infer locations and dimensions of faults and fracture zones and individual fractures at depth (subsurface) and correlation of these subsurface data to surface data. The individual fracture analyses should include fracture orientation data collection and analysis,
- surface geophysical surveys (seismic surveys) along geological and geophysical profiles,
- LiDAR surveys or other existing available high-resolution LiDAR data,
- additional geochronological and geochemical methods on fault gouges (drill core, trenching etc.) in documented fault zones, if applicable and necessary,
- investigations on possible post-glacial faulting and activity.

Enhanced LiDAR data can be acquired with current drone technology, either with rotary or fixed wing configurations with different payloads. Better resolution LiDAR models would enable more accurate estimation or characterizations of different types of faults and fracture zones and fracturing of the bedrock in general and would provide a baseline dataset for 3D geological modelling of the site. Appropriate literature reviews on lineaments should also be conducted, and a general view of regional to national scale in lineaments is available (e.g., Gabrielsen et al. 2002).

8 SEISMIC HAZARD PROCESS EVALUATION, SEISMIC METHODS AND DATA AND INITIAL SEISMOLOGICAL CONDITIONS AT EITERÅA

Seismic hazard assessment (SHA) processes involve a multitude of procedures to ensure the safety of a nuclear facility. The approach for SHA in this report is preliminary in its nature, meaning that applicable and relevant information from the site area is collected to get an initial idea of the seismological conditions within the Eiteråa site. While the applicable measures referred in this report are related mostly to conventional sized NPPs, the principles are still relevant when discussing the issues in an SMR context. While it can be difficult to ascertain a specific moment of when and at which stage the SHA process should begin, it is suggested here that preparatory actions should start at the site survey stage, collecting as much information about the related processes and data for more implementation on the more detailed and rigorous SHA processes.

The examples and figures presented in this paragraph serve mostly as general principles on where and how the SHA processes could be developed in later stages of the site selection processes. The applicability of the seismic hazard processes described in this report are not necessarily directly related to the site vicinity area but are reviewed more in a regional to near-regional scale context. Some details concerning the seismic data on the site vicinity area will however be discussed and presented.

Development of the regulation and legislation in the SMR context may result in modifications in these principles perhaps regarding the magnitude of required research within a site, similar to EPZ, PAZ and UPZ requirements, but at this point in time it is deemed relevant to discuss the issues with current documentation and data requirements.

SSG-9 dictates the following: "*The evaluation of seismic hazards for a nuclear installation site should be done through the implementation of a specific project plan for which clear and detailed objectives are defined, and with a project organization and structure that provides for coherency and consistency in the database and a reasonable basis on which to compare results for all types of seismic hazard. This project plan should include an independent peer review. It should be carried out by a multidisciplinary team of experts, including geologists, seismologists, geophysicists, seismic hazard specialists, engineers and possibly other experts (e.g. historians) as necessary. The members of the team for the seismic hazard assessment project and the independent peer review should demonstrate expertise and experience commensurate with their role in the project*".

SSG-9 calls for a project earthquake catalog or a database, which can be initially derived from different seismic network data available for use. The data used in this project has been collected from the Institute of Seismology in Finland (data as M_w, homogenized moment magnitude), and the data partially covers the Norwegian coastline (Figure 12), including the site vicinity area, extending to a more regional to near-regional scale. The data also includes depth estimations of the earthquakes of each data point.

The data in Figure 12 is however spatially limited in the south and southwest, and thus examples of seismic data are also derived from NORSAR (Figure 13) to review the seismic data point conditions on a larger regional context. Figure 12 data points are comparable to the other seismic data sets presented from NORSAR and also other references in this report, such as relevant scientific literature from the area. The seismic data points from the Finnish Institute of Seismology within 200 km from the Eiteråa site are presented in Appendix 1. An adequate combination of different datasets should be used to assess the general seismicity of a given area. The Eiteråa site can be viewed as an area of relatively low seismic activity, when compared to other areas in Norway such as the continental shelf areas in the SW of Norway, and the areas near the Rana region (e.g., Hicks et al. 2000) in Nordland county (Figure 13).

This type of data should be used in an informed manner to gain a thorough understanding of the challenges posed by seismic risk within a site survey area. Data processing even prior to the project earthquake catalog would include selection of consistent magnitude scale for use in the seismic hazard analysis, determination of the uniform magnitude of each event in the catalogue on the selected magnitude scale, identification of main shocks, estimation of completeness of the catalogue as a function of magnitude (regional location and time period) and quality assessment of the derived data with uncertainty estimates (SSG-9, IAEA 2022a).

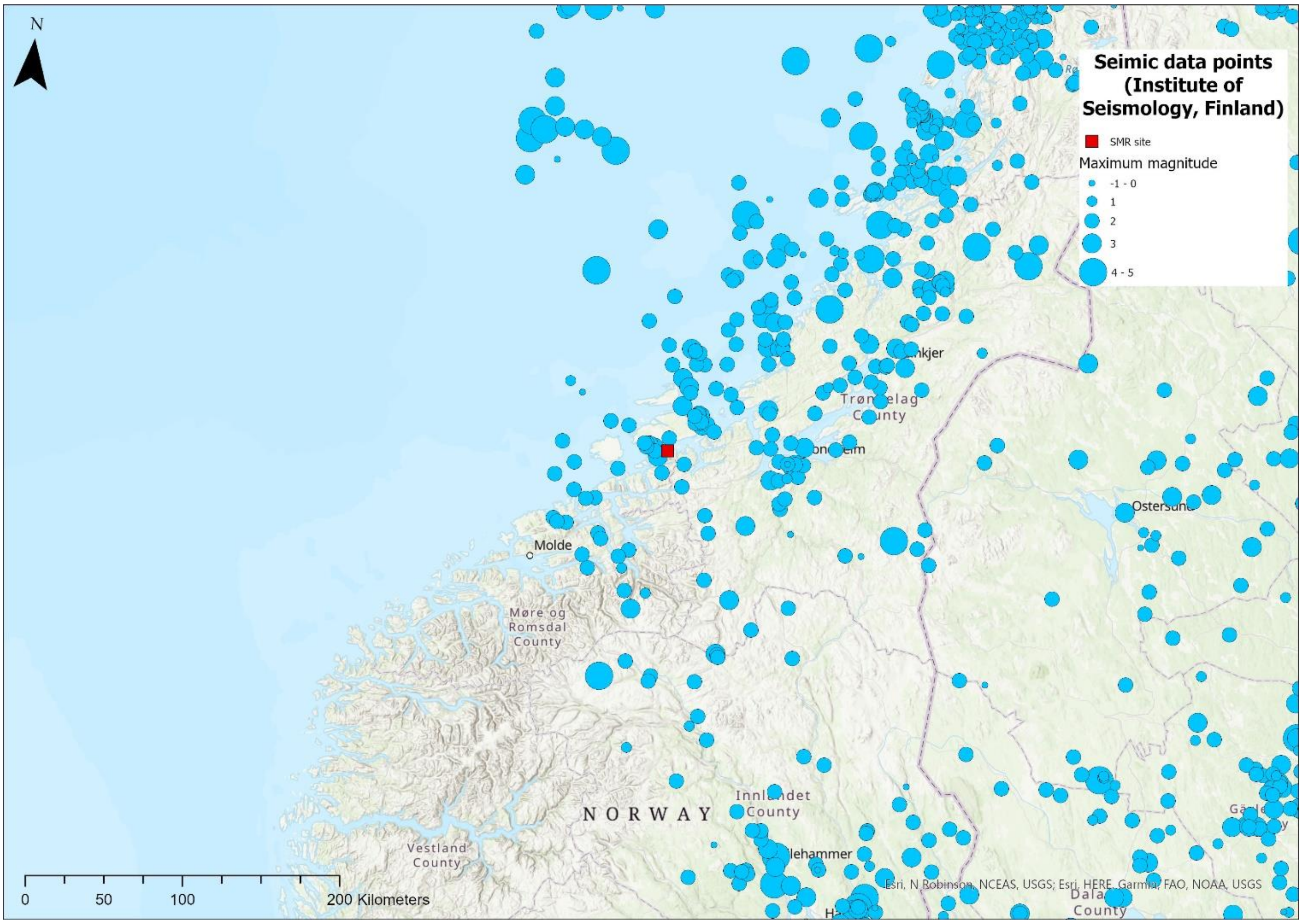

Figure 12. Seismic data points from the Institute of Seismology, Finland. Maximum magnitudes (graduated symbols in blue color). Data from the Institute of Seismology, Finland.

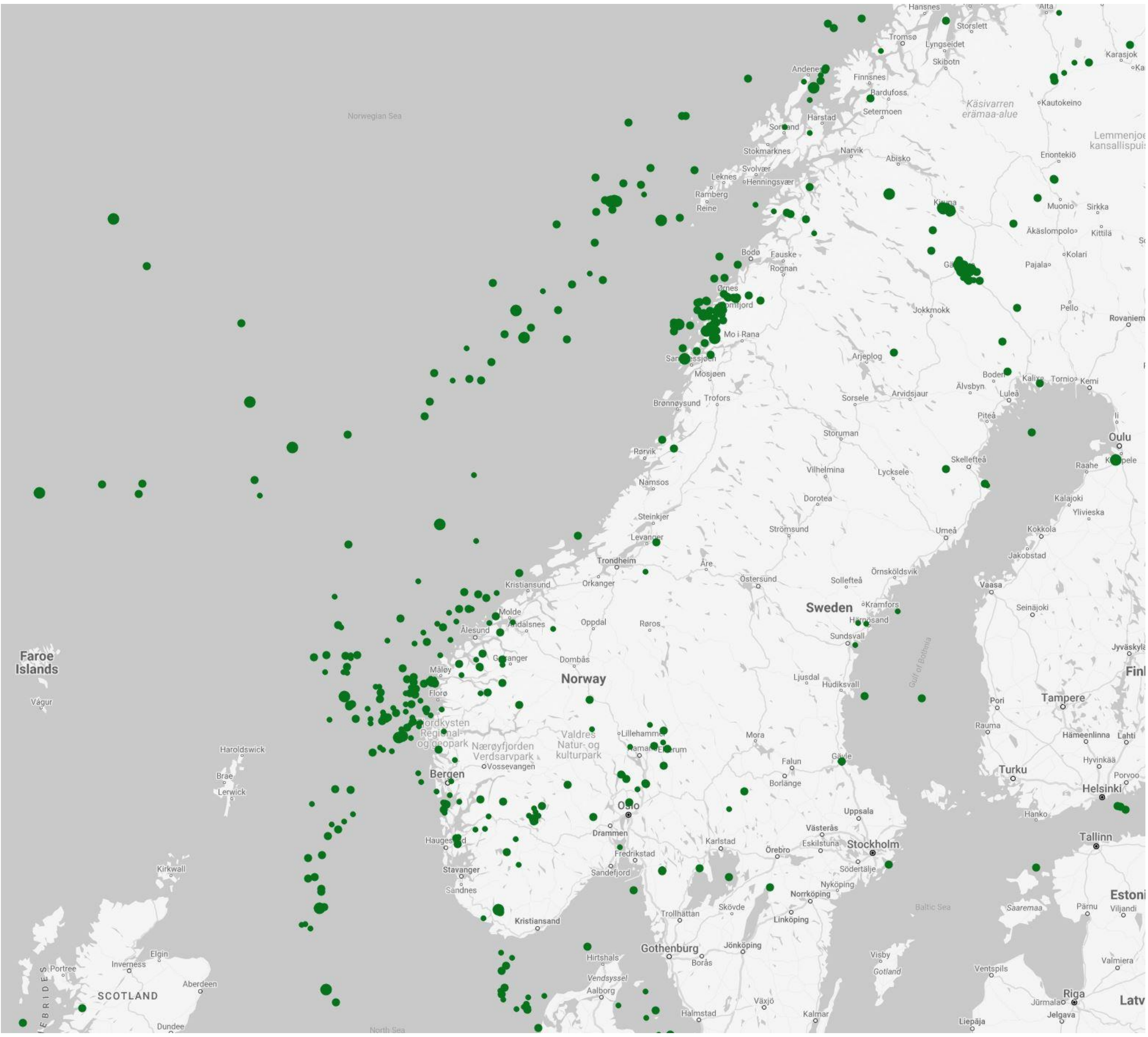

Figure 13. NORSAR seismic data points from the Norwegian coastline and the Norwegian sea, with additional seismic data points from Sweden, Denmark and Finland. Image from NORSAR.

Figure 14 shows a flowchart for the general steps and sequence for the seismic hazard assessment process. Starting from the formation of the general database including the necessary data about geology, geophysics, geotechnical data and seismological data, the process advances in a systematic manner collecting more data and parameters, using varying methods, tools, and modelling principles.

The site vicinity scale along with the collection of data regarding the database would expand to more regional to near-regional scale, further progressing into the site vicinity, where appropriately evaluated procedures and methods displayed in Figure 14 would be performed.

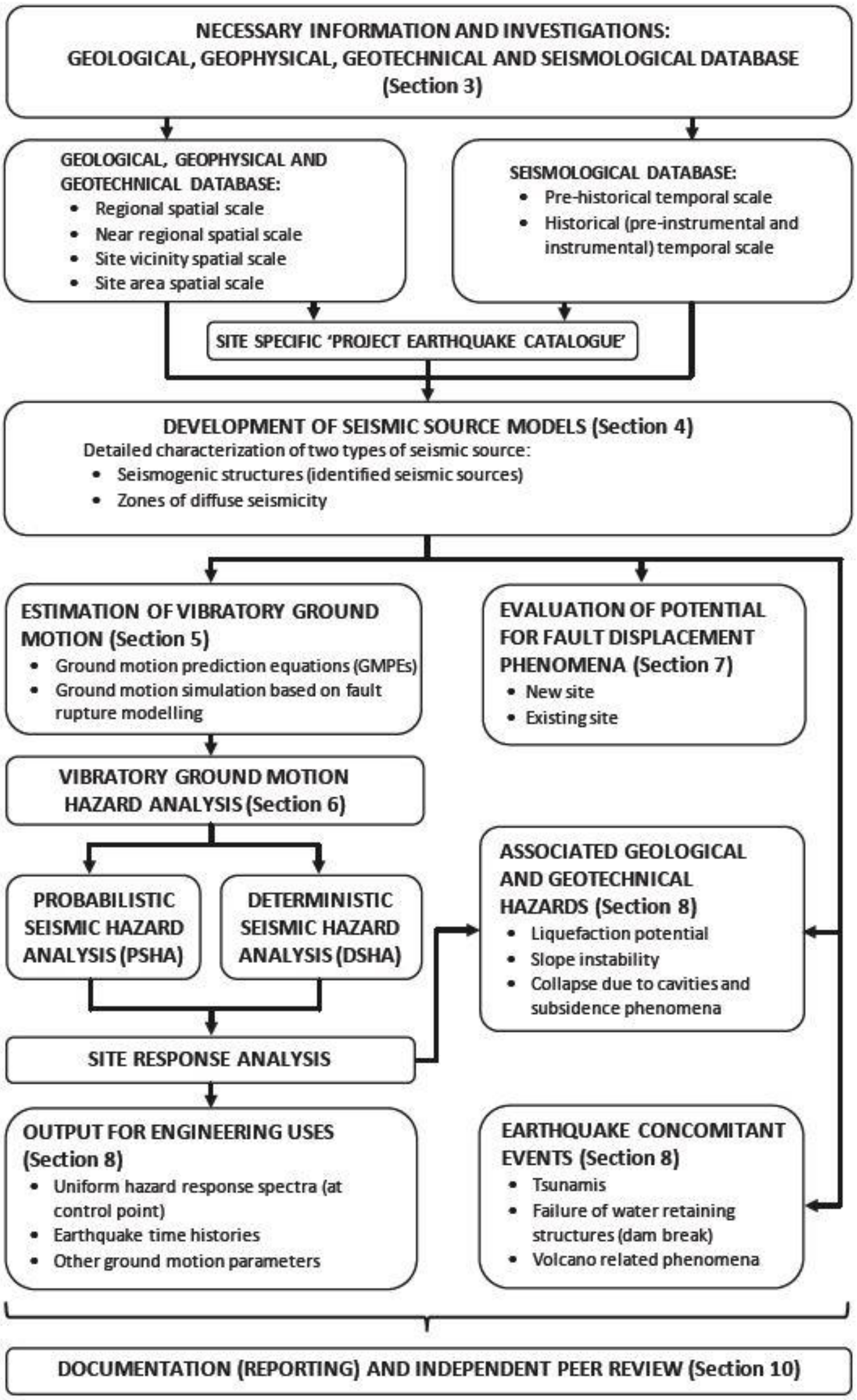

Figure 14. Seismic hazard assessment flowchart. Modified from SSG-9 (IAEA 2022).

Other items necessary for seismic hazard assessment processes would be the inclusion of several important methods and parameters, such as vibratory ground motion analysis and ground motion prediction equations (GMPE) with peak ground acceleration (PGA) values. GMPE is an equation used to predict measures of seismic ground motion caused by an earthquake (TECDOC-1796, IAEA 2016).

Other methods in the SHA processes would include probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA).

Figure 15 displays the basic principles of the probabilistic seismic hazard analysis (PSHA) process. These include the source and ground motion characterization. Fault and areal sources are characterized by their location, subsurface geometry relative to the site, and the size and frequency of occurrence of earthquakes generated by the sources (Ake et al. 2018). PSHA would use parameters such as focal depth, activity rate, b-value, maximum magnitude etc. A PSHA can be performed with apparent results even when seismological knowledge and background analysis is poor (Lindholm & Bungum 2000). Collection of data with the appropriate parameters to complete the different types of SHA processes would have to be identified and verified.

A simplified example of the procedures involved in the DSHA process are seen in Figure 16. The distance of a fault line from the site would be used as a frame of reference and then applied with other data and data handling procedures, such as peak acceleration values and frequency of magnitude curves.

Development of seismic source models would be a priority in the site vicinity scale. Establishing seismic source models would require integration of seismological, geophysical, geological, and other relevant databases to infer a coherent seismotectonic model, with inclusions of related uncertainties. The goal would be to identify in detail all sources that could contribute to the seismic hazard at the site. This source characterization should provide all necessary characteristics, such as location, geometries, potential maximum magnitude, and recurrence of identified seismic sources (SSG-9, IAEA 2022a).

Seismic source model creation would also include analysis of diffuse seismicity, which would consist of small to moderate earthquakes that might not be directly attributable to specific geological or seismogenic structures.

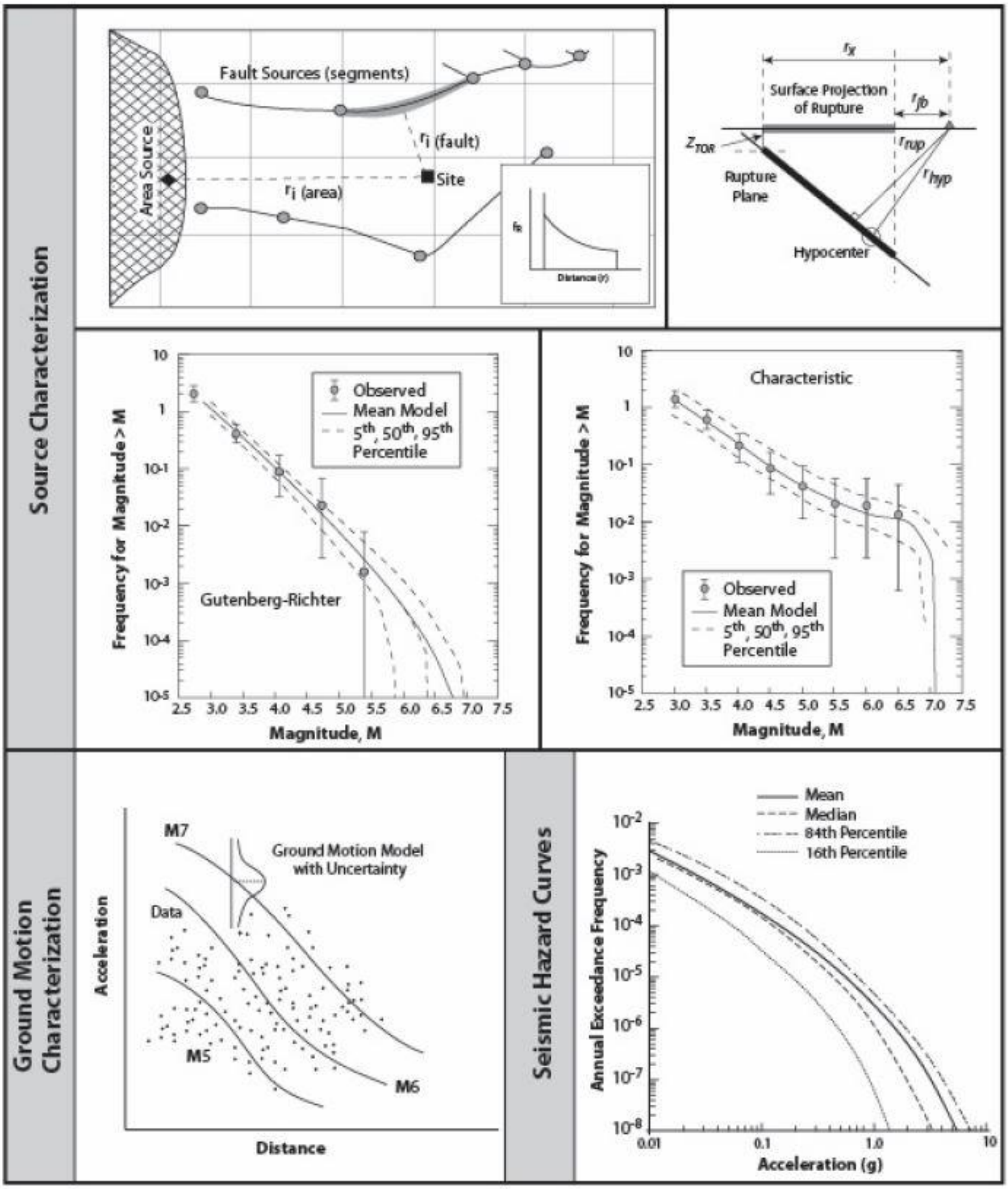

Figure 15. Description of PSHA elements. Modified from Ake et al. 2018 (NUREG-2213).

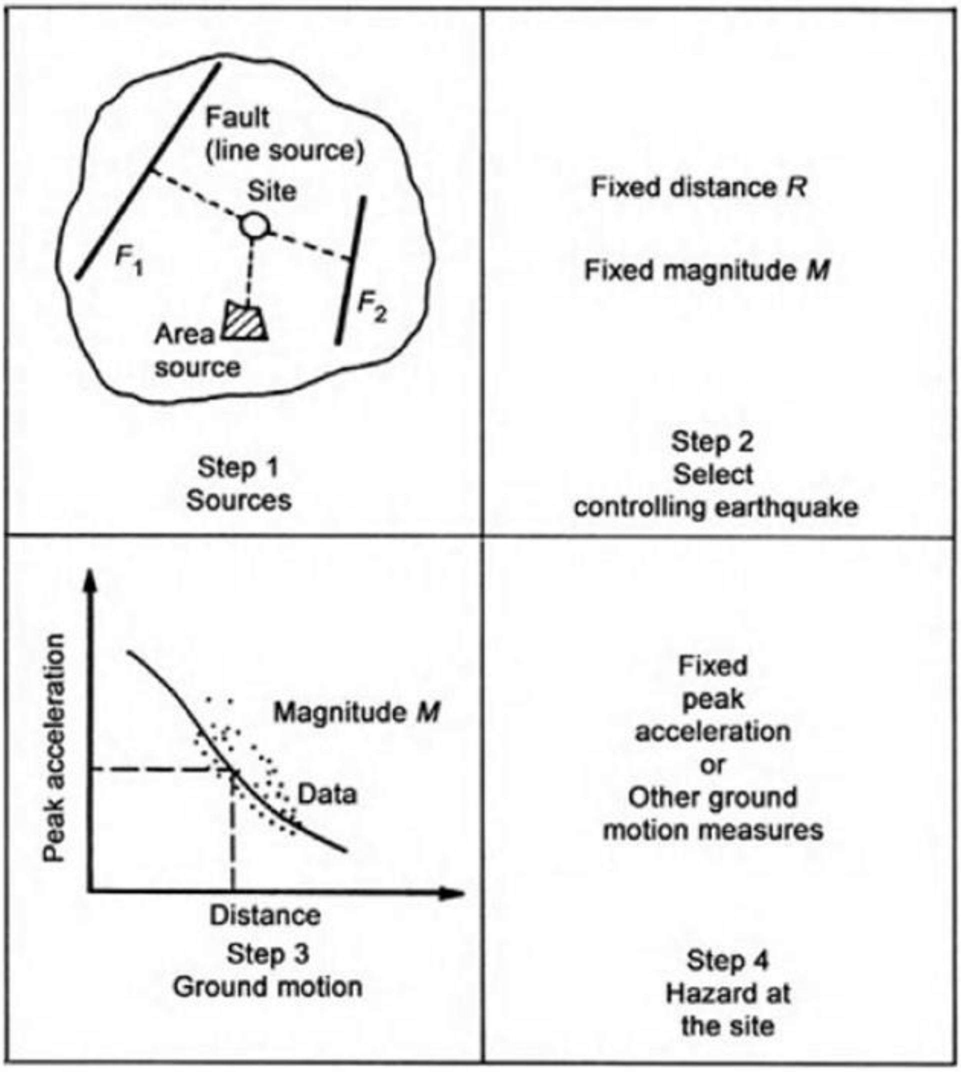

Figure 16. Description of DHSA elements. Modified from Sari & Fakhrurrozi (2018).

Using different regional to near-regional scale seismic data point maps is a useful tool to evaluate the rate and frequency of seismic events further in a specific area. Figure 17 shows the seismic data points from the Institute of Seismology in Finland within a radius of 200 km from the Eiteråa site, also displaying the maximum magnitudes available from the data. Concentrations of seismic data points can be observed in directly west from the site, near Trondheim and on the western portion of the island of Hitra.

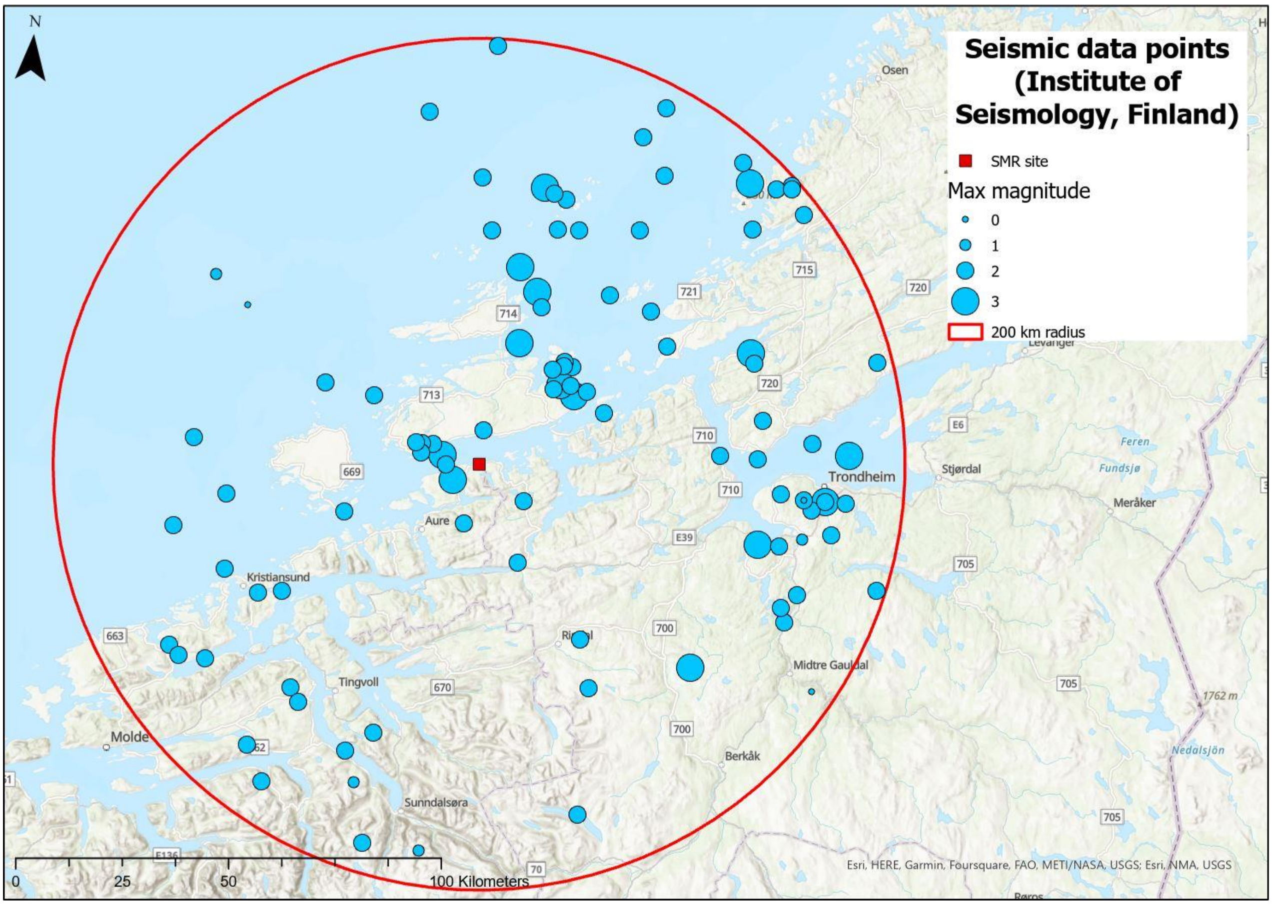

Figure 17. Seismic data points from the Finnish Institute of Seismology within a 200 km radius.

Figure 18 shows the seismic data points together with the lineament interpretations performed on the 50 km radius, also covering the site vicinity area of 5 km. From the combination of these two data sets, interpretations of the effect of the lineaments in conjunction with the seismic data can initially be made. When observing the locations of the seismic data points along with the lineaments, the data points seem to concentrate mostly on the N–S to NNW trending smaller scale lineament than the ENE–WSW trending larger regional scale major lineaments, faults or fracture zones. While this interpretation may be rather crude, it could serve as an example of possible effects of current tectonic activity near the site vicinity area. The N–S to NNW oriented smaller scale lineaments are interpreted here as being representative of the brittle deformation regime in the MTFC (Watts et al. 2023). The inferred tectonic activity is most likely relating to the current major tectonic strain stress direction stemming from the active Mid-Atlantic Ridge spreading zone. The major stress regime condition would also have to be analyzed during the site selection stage at the latest, a part of the total evaluation of seismological and rock mechanical conditions within a site area.

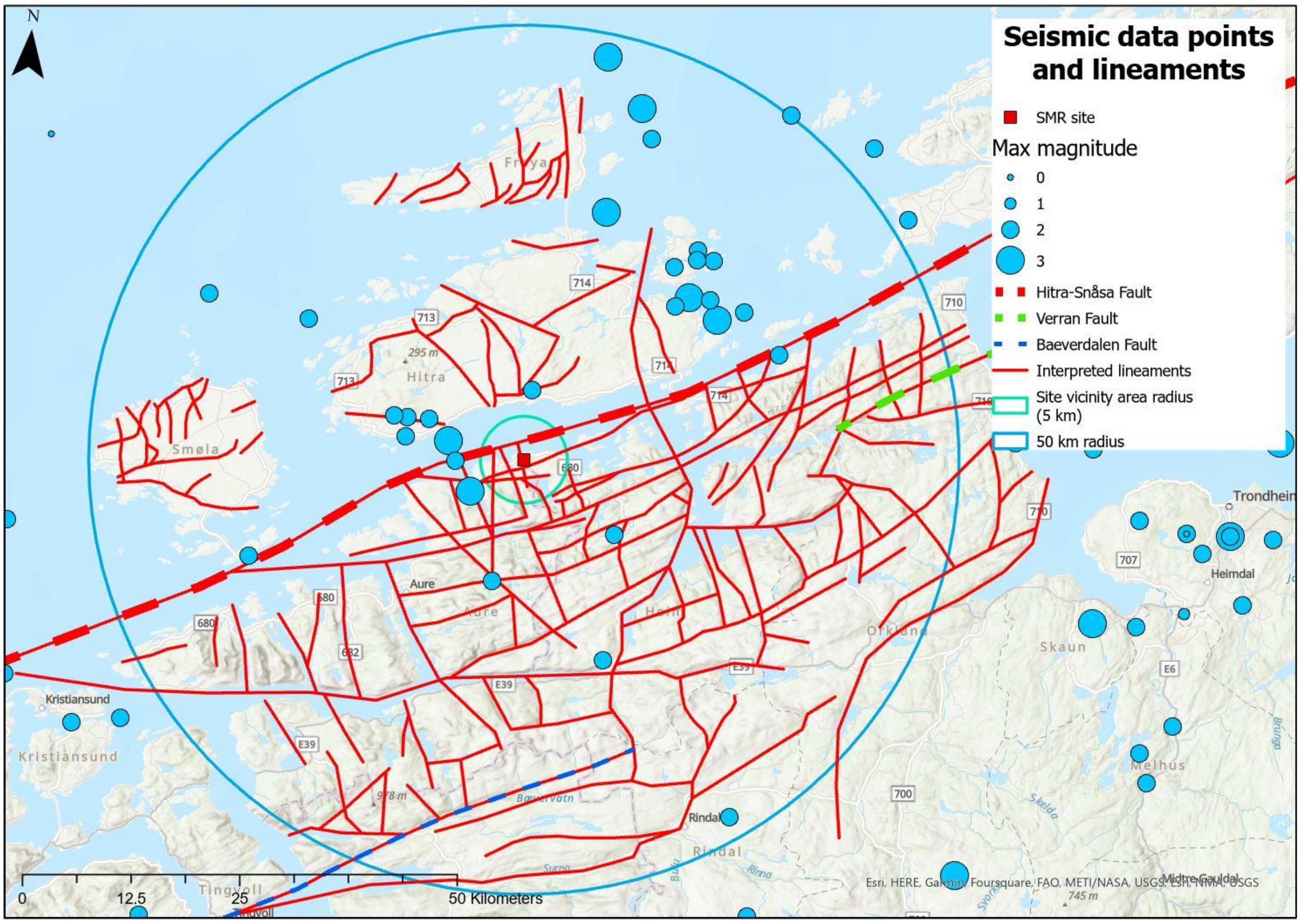

Figure 18. Seismic data points with the site vicinity area (5 km) and a near-regional radius of 50 km with major fault zones and lineament interpretations. Seismic data from Institute of Seismology in Finland.

Figure 19 displays the site vicinity area of 5 km radius with the lineament interpretations. Only a few seismic data points can be seen in the near regional scale (Figure 19 map scale is 1:100 000). Maximum magnitudes are limited to magnitudes of 3 in two seismic data points, roughly correlating with a NNW trending lineament east of the site vicinity area. Other smaller maximum magnitude points represent a magnitude of 2, with a concentration of these data points on a mostly E-W trending lineament on the island of Hitra. The depth of these data points shown in Figure 19 have depth data determinations of 12–15 kilometers, with the data points on the Hitra Island E–W lineament showing no depth readings, leading to an interpretation of minor shallow earthquakes or a non-applicable depth reading.

In addition, Figure 19 shows the distance to the NNW trending lineament with the seismic data, pointing towards the closest possible suspected capable fault if the HSF can be excluded based on its tectonic development history. The distance from the Eiteråa site to this lineament is approximately 6 km, within range of the exclusionary criteria of minimum distance of 8 km from a capable fault. Reminded with the realities concerning the concept of capable faults presented in this report and in

IAEA documents, this lineament exemplifies the most probable risk to the Eiteråa site, but the potential risk seems very low at this point, considering the overall low seismicity of the site vicinity and near-regional area, coupled with risk reduction from possible engineering solutions within the SMR framework. These however have to be verified in further stages, e.g. in the site characterization stage and appropriately configured seismic hazard assessment processes.

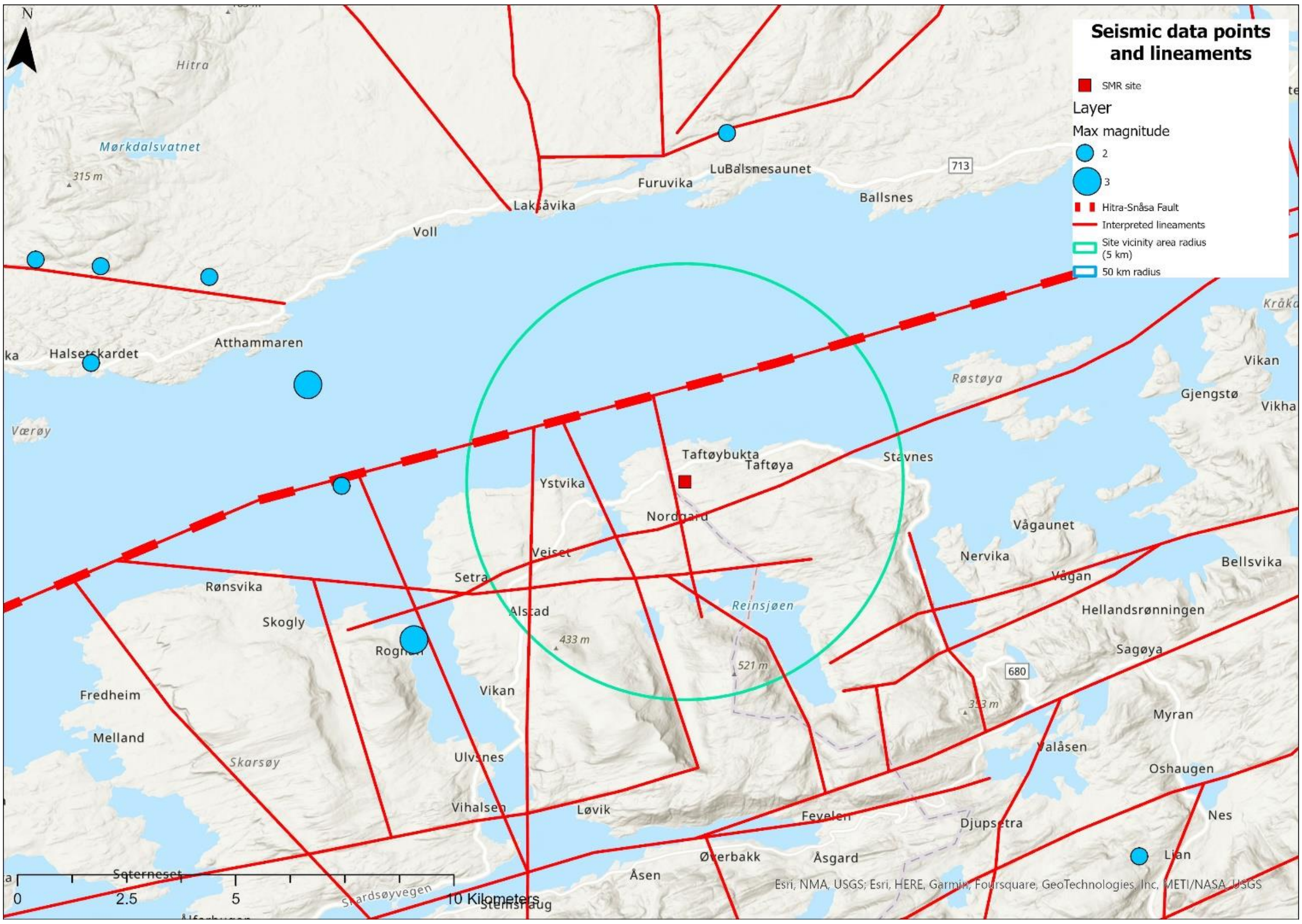

Figure 19. Seismic data points and lineaments within and near the site vicinity area. Seismic data from Institute of Seismology in Finland.

Table 1 shows the compilation of seismic data points within a 200 km radius from the Eiteråa site. Most of the data points (n=112) are located very deep within the 200 km radius, with an average depth of 6920 meters, with maximum depths of 31 000 meters. The seismic data points are further introduced in Appendix 1.

Table 1. Average, minimum and maximum values for earthquake data from the Institute of Seismology in Finland within 200 km radius from the Eiteråa site.

n=112	**Maximum magnitude**	**Depth (m)**
Average	2	6920
Min	0	0
Max	3	31000

Relevant earthquake magnitude data can be used in a variety of ways when interpreting the seismic activity in a given area. In any seismic hazard assessment process, the definition of the lower bound magnitude comes into play along with the lower bound motion filter. The lower bound motion filter is necessary due to the fact that a seismic magnitude alone is not enough to describe damage potential from an earthquake. The lower bound motion filter can be described as consisting of the cumulative absolute velocity, peak ground velocity or the instrumental seismic intensity, resulting in practical computations for engineering uses. The lower bound filter should also cover all events with potential radiological consequences (SSG-9, IAEA 2022a).

In conjunction with the lower bound motion filter, a lower bound magnitude has to be defined. In SSG-9, the selected lower bound magnitude is defined as that it should not exceed $M_W = 5.0$ (M_w = normally moment magnitude).

The use of boreholes and drillholes in seismic investigations would have profound benefits in regard to data collection and site characterization. Existing recommendations included in the IAEA documents concerning subsurface rock conditions could be applied already in the site vicinity scale studies with sufficient number and configuration of boreholes in geological profiles. SSG-9 describes the subsurface rock conditions pertaining to firm rock shear wave velocities as follows:

"The reference subsurface rock site condition: For site response analysis, the output should be specified on the rock conditions at the site (usually to a depth significantly greater than 30 m, corresponding to a specified value of the shear wave velocity consistent with firm rock). The results of site response analysis should correspond to this reference condition".

With enough attention to detail on how these drillholes or boreholes would be designed in terms of depth, more than adequate results pertaining to reference subsurface conditions can be acquired within the dioritic to diorite gneissic bedrock in the site area.

8.1 Data requirements for seismic hazard assessment in the site survey stage

The following descriptions can be described as a minimum requirements or recommendations to produce a reliable seismic hazard assessment and should be reviewed by personnel with appropriate and prerequisite experience for suggestions and improvements. It also has to be noticed that if a SHA process is not required by regulation or legislation in regard to the site vicinity scale in a site survey stage, adaptive measures have to be taken. The necessary procedures for the site vicinity area within a site survey stage could be described as follows:

- choosing a strategy concerning the magnitude and scope of the seismic hazard assessment process due to the relatively low seismic environment in and around the Eiteråa site,
- evaluation on the feasibility of conducting a seismic hazard assessment process for the site vicinity area by an expert or a team of experts with the prerequisite experience,
- collection of seismic data from appropriate existing seismic networks in Norway or abroad,
- evaluation and identification of the necessary seismic data parameters (focal depth, rates of activity, maximum magnitude, date and time etc.) for the implementation of the seismic hazard processes,
- improved and exact seismic data requirements and parameters, classifications and determinations to implement either a probabilistic seismic hazard analysis or a deterministic seismic hazard analysis, or both,
- appropriate geophysical methods and profiles to evaluate the geometries of the dominating fault and fracture zones present in the site vicinity area for seismogenic source characterization,
- use of drillholes and boreholes to investigate seismic conditions in the subsurface using appropriate methods.

Analysis of the current data with the appropriate methods have to be produced at the site selection stage at the latest of a given site and siting process. Further analysis of existing seismic data could provide essential data points for seismic network station planning needed in the geological monitoring processes in the final stages of a site evaluation process (Figure 1).

Seismic surveys using geophones and seismographs can be readily applied by companies with the prerequisite experience. Seismic survey methods can produce interpretations on overburden thicknesses, bedrock topography and bedrock quality. P-wave (primary wave) velocities inferred from seismograph measurements can be used to assess the rock type quality and also to infer fracture zones within the bedrock along measurement profiles. The slower the P-wave, the more fractured the bedrock. These types of data should be used along with topography, lineament and fracture data and hydrological to hydrogeological data.

A useful general principle of the seismic hazard process is stated in SSG-9, reflecting on the possible complexities and uncertainties encountered during the process:

"*The general approach to seismic hazard assessment should be directed towards the realistic identification, quantification, treatment and reduction of uncertainties through all stages of the project. Experience shows that the most effective way of achieving this is to collect sufficient reliable and relevant site-specific data. There is generally a compromise between the time and effort needed* *to compile a detailed, reliable and relevant database and the degree of uncertainty that should be taken into consideration at each step of the process. Thus, applying a lower level of effort in developing the database for characterization of the seismic sources, fault capabilities and ground motions will result in increased uncertainty in the final results obtained*".

Additional data that has not been used in this report can also be derived from e.g., the Norwegian National Seismic Network.

9 GEOTECHNICAL DATA

IAEA document NS-G-3.6 (IAEA 2004) states that investigation of subsurface conditions at a nuclear power plant site is important at all stages of the site evaluation process. The purpose is to provide information or basic data for decisions on the nature and suitability of the subsurface materials. Specific requirements for the subsurface data will vary from stage to stage.

The site vicinity area studies referred to in this report can be applied to the site selection stage referred to in NS-G-3.6 (IAEA 2004). The selection stage is defined as: *"One or more preferred candidate site are selected after investigation of a large region, rejection of unsuitable sites, and screening and comparison of the remaining sites"*. This selection stage can be applicably used in conjunction with the site survey stage to be more compatible with the other stages referred to in this report.

In essence, in this report, which is focusing on the site vicinity scale area, we will collect available data from the NGU website and other applicable to get a preliminary view on the geotechnical properties in the Eiteråa site, and then provide further recommendations on implementing the specific site studies. Geotechnical data or properties are directly attributed to Quaternary geological properties and parameters, and these data include Quaternary geological information with initial characterization of soils and rock materials on the surface at the Eiteråa site.

Geotechnical data is interlinked with the vibratory ground motion analysis conducted in the deterministic seismic hazard analysis process. A site response analysis should be performed taking account of the geophysical and geotechnical information about the soil profiles in the site area. In case of a new site such as the Eiteråa site, the site response analysis is to be performed at: 1) the most likely location on the installation within the site area, 2) a location representative of the general geotechnical characteristics of the site area, 3) A "mean" location, that is, an assumed place with mean values of the geotechnical characteristics of the soil profile (SSG-9, IAEA 2022a).

Existing GMPEs can be applied if suitable references to prevailing site soil and rock types are available, or to apply direct measurements on the soil and rock materials within the designated site area (SSG-9, IAEA 2022). A review of suitable GMPE data sets should be therefore considered from the appropriate sources and should be investigated for bedrock and soil types.

If direct measurements on soil profiles on the site area are to be conducted, the following parameters should be included: low-strain shear wave velocity (V_s), strain-dependent shear modulus reduction and hysteretic damping properties, soil density, layer thickness and for the vertical component, the compressional wave velocity (V_p) (SSG-9, IAEA 2022a).

During the site selection stage (NS-G-3.6, IAEA 2004), subsurface information is usually obtained from current and historical documents and by means of field reconnaissance, including geological and geomorphological analysis, and used to assess unacceptable subsurface conditions, the classification of sites based on rock or soil stiffness or cohesion, groundwater regime and foundation conditions.

Unacceptable subsurface conditions refer to conditions that could affect the safety of the nuclear plant. This encompasses geological hazards such as surface faulting, volcanic activity, landslides, permafrost, erosion processes, subsidence and collapse due to underground activities (natural and human induced) or other causes. Classification of sites refers to classification of a site to different categories, such as: a rock site, a soft rock site, stiff rock site, stiff soil site, soft soil site or a combination of these. It must be noted that this simplistic classification may not apply to all sites, as Quaternary formations can be complex. The groundwater regime refers to the estimation of the location of groundwater within a designated space or area. This may include the analysis of groundwater table depth and other associated parameters. Foundation conditions refer to the type of soil and the depth of bedrock and the properties of deposits in question within the area. This in turn allows for the preliminary selection of acceptable foundation types.

Available NGU data from the area reveals several types of different soil and Quaternary geology conditions within the site vicinity area and are depicted in Figure 20. The descriptions for Quaternary geology were freely translated from the NGU website data to English. The origin of these data is unknown to a degree, as NGU metadata does not appear to include the data collection methods.

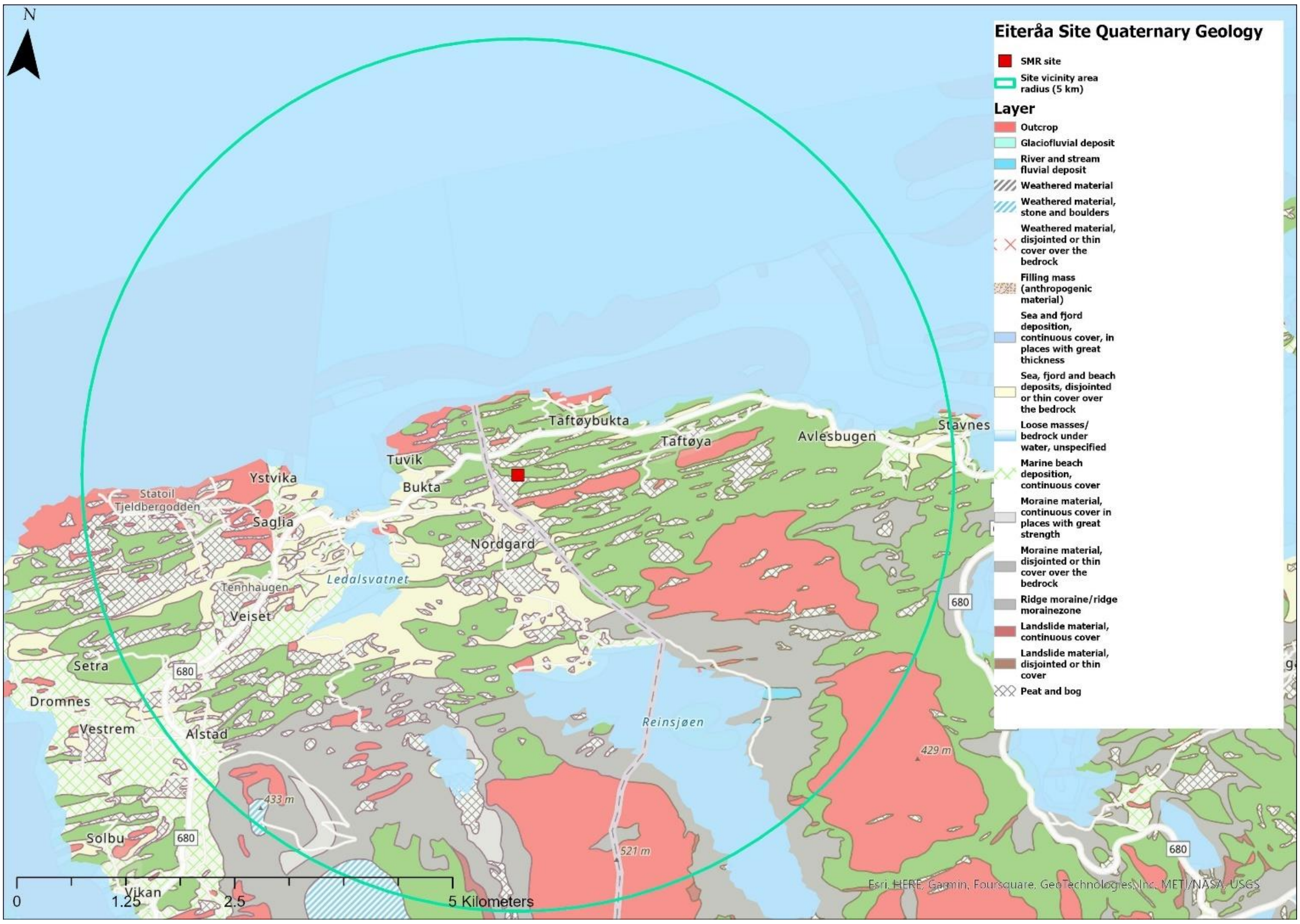

Figure 20. Quaternary geology data available from the site. Data from NGU data download website (https://geo.ngu.no/download/index.jsp).

Outcrops are fairly common, offering plenty of available geological mapping sites to initially confirm the findings in this report. The most common soil type is a thin cover of organic material over bedrock. It can be assumed that this green-colored feature in Figure 20 can also provide material for bedrock measurements and sampling due to the cover being thin.

Peat and bog are very common in the site vicinity area, as are non-classified material deposition from sea, fjords, and beaches, with thin cover over the bedrock. Marine beach deposits are located in Ledalsvatnet and in larger concentrations within the next larger unnamed fjord west from Kjørsvikbugen.

Moraine or till material is concentrated to higher elevations further south in the site vicinity area in conjunction with bedrock occurrences and is classified either as disjointed or thin cover over the bedrock, or a more continuous cover in places. Material related to landslides and weathered material are also limited to higher elevations in the southern portions of the site vicinity area.

Figure 21 displays the Quaternary geology data closer to the site area, representing a more likely scenario of the area where geotechnical investigations on Quaternary materials would occur.

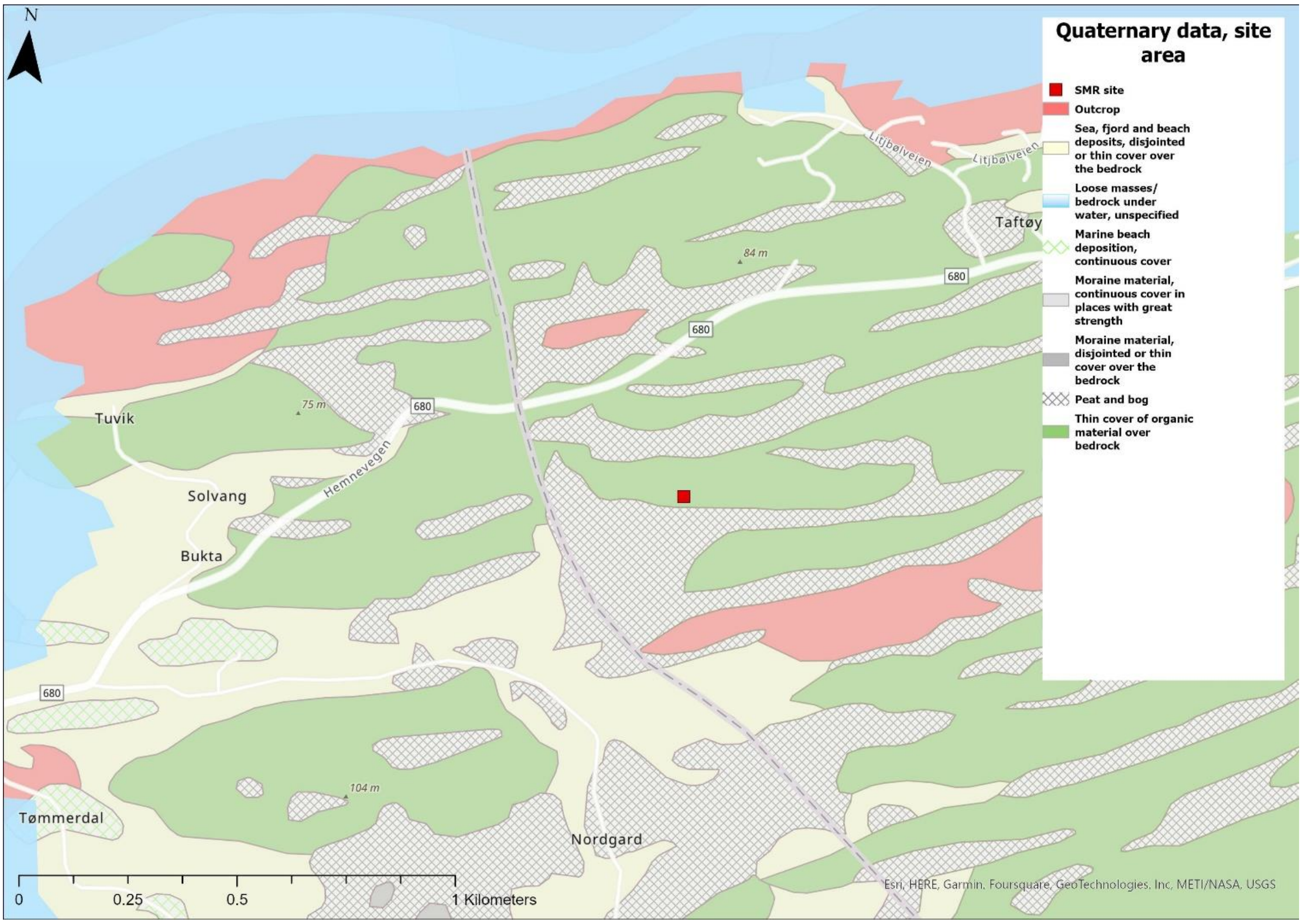

Figure 21. Close-up Quaternary geology data of the site area. Data from NGU data download website.

The peat and bog areas represent a significant soil type component within the site area, and the depth dimensions of peat-bearing areas would need to be established. These locations may also be representative of fracture or fault zones or weathered material underneath the peat or bog.

9.1 Data requirements for geotechnical data in the site survey stage

Selection of the data gathering methods requires a careful design process to determine which methods and procedures would be used. The recommendations for data collection methods or procedures cannot however be conclusively stated here, as there are most likely multiple uncertainty factors in the geotechnical survey planning process that should be addressed appropriately when more detailed planning is to be started. An operator or a company with sufficient capabilities and experience in geotechnical issues should be tasked with the design and data collection processes.

For the site survey stage, the following procedures and methods are initially suggested here as follows:

- creation of site vicinity or site area scale Quaternary geological maps and profiles with descriptions and measuring of the Quaternary geology parameters such as different soil layers with soil type and grain size distribution,
- seismic refraction and reflection survey profiles with the goal of producing initial models for the actual bedrock surface and different soil types,
- a geotechnical boring grid with appropriate grid spacing or an alternative boring grid acknowledging the preliminary NGU data on soil characteristics and conditions at the site to confirm soil characteristics and induce parameters.

Measuring specific parameters from the geotechnical profiles would be important to distinguish the site with measured parameters from general geotechnical data with initial descriptions of Quaternary geology. The measurement of parameters should be conducted with the idea that pre-emptive or anticipatory activities can also be pursued when necessary or possible with regards to future research stages such as site characterization stage, with more detailed measurements and parameter definitions.

Possible parameters from the site survey stage to more advanced stages could include geotechnical investigation parameters such as deformation time propagation and dynamic elastic properties from seismic refraction studies and cross-hole seismic testing to infer soil-structure interaction. Shear wave velocity measurements and S and P wave velocities in each soil layer could be measured to estimate the foundation conditions for the site. Geometrical descriptions and relative density of each soil layer should be considered.

Stress-strain relationships, static and dynamic strength properties, consolidation, and permeability could be included in the measured parameters. These parameters would be collected to assess the site-specific response spectrum, liquefaction potential, foundation stability and different types of stresses in the foundation ground (NS-G-3.6, IAEA 2004).

Physical and chemical properties of soil and rock samples should be studied, with sampling along the profiles. For soil samples such as clay, sand and gravel, laboratory measured parameters could include reaction modulus and elastic modulus for compaction control and settlement and cone resistance for liquefaction and bearing capacity. For rock samples, measured parameters would include in situ normal stress, in situ stress state and shear strength to analyze rock strength and stability (NS-G-3.6, IAEA 2004).

Establishing a geochemical baseline from e.g., the soil samples is not a specific requirement on the site selection processes and in the site survey stage, but it could be one dataset to consider when future stages are planned.

Designing the profiles and grids require some planning to infer the most cost-effective solution and data quality considerations. Existing drillholes or boreholes from the previously implemented procedures can be used in geotechnical data gathering. Rock samples and soil samples require different test types, with specific laboratory tests would most likely be warranted in different site selection stages. These would measure more precise parameters such as Young's modulus, Poisson's ratio, and biaxial to triaxial compression tests to enhance site data resolution (NS-G-3.6, IAEA 2004).

Methods for evaluating the bedrock surface and soil layers could also include methods such as ground penetrating radar (GPR) along with other possible methods. GPR would be a cost-effective method in an initial site survey concerning geotechnical characterization. Further geotechnical testing and measurements in later stages of the site selection process can be reviewed from the IAEA Safety Guide NS-G-3.6 (IAEA 2004). Further evaluation of applicable methods should be reviewed as appropriate.

Due to the possible arising complexities on geotechnical issues, some tailoring of the procedures in terms of scope would be recommended as needed within the site survey stage.

Geotechnical investigation trenches to infer Quaternary geology characteristics could also be used to determine the possibilities for locating post-glacial faulting.

At first glance the varying topography with outcrop and possibly a thin veneer over bedrock in the Eiteråa site suggest reasonably good conditions to investigate geotechnical characteristics of the site. The thin cover over the bedrock also suggests reasonable costs for the geotechnical survey overall as confirmation of the bedrock surface can be attained and tailored with more than one method.

10 HYDROGEOLOGICAL DATA

IAEA document SSR-1 (IAEA 2019) states that a hydrogeological programme is to be launched to assess the potential movement of radionuclides through surface water and groundwater and the subsequent assessment of the radiological impact in operational states and accident conditions. This includes the analysis of hydrological and hydrogeological data and parameters at a specific site in terms of possible dispersion of radioactive materials.

Descriptions on surface water should include the main physical and chemical characteristics of the water bodies in the area. These include natural and artificial water bodies, and major structures for water control, water intake structures and information on water use in the region. Estimations on the dilution and dispersion characteristics of the water bodies should be pursued. The migration and retention characteristics of radionuclides in groundwater should also be investigated.

Figure 22 displays a map of the Eiteråa site with topography, lakes and main waterbodies including waterways such as rivers and creeks. The primary drainage areas and secondary drainage areas are also included in the map (data from NVE Atlas). The site vicinity area is located mostly on a secondary drainage area (purple dotted area), with many small lakes and water bodies present. One larger lake (Rennsjøen) is located on the southern side of the site area, approximately 2 km from the site. Smaller lakes (Yttervatnet, Innervatnet and Flyddtjørna are located closer to the east from site area, and Småvatna directly south from the area. There is also a seemingly dammed or regulated waterbody in Kjørsvikbugen, designated as Ledalsvatnet.

The larger river systems are comprised of Reinsjøelva, draining from Rennsjøen and subsequently to Ledalsvatnet. Smaller rivers and creeks are very common in the area, with Eiteråa draining from Småvatna into the sea, with two smaller flow pathways from Eiteråsmyran discharging water into Eiteråa (Figure 23) and one from higher topography near Småvatna.

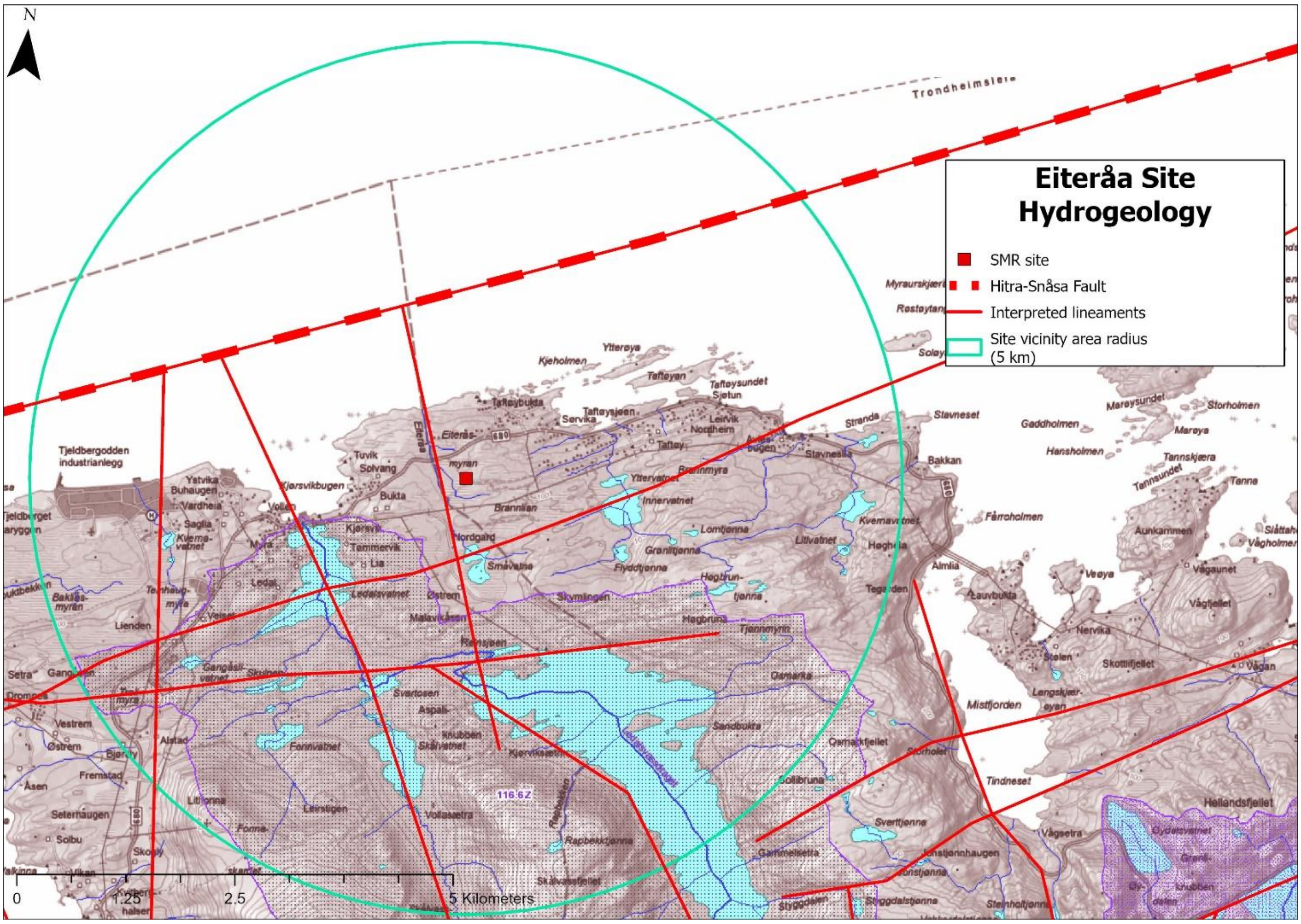

Figure 22. Hydrogeological map with topography of the Eiteråa site. Interpreted lineaments and major faults are included for comparison. Lake, waterway and drainage area data from NVE Atlas (https://atlas.nve.no/Html5Viewer/index.html?viewer=nveatlas). Map scale is 1:50 000.

Possible interactions between bogs, marsh or swamp areas and hydrology should be regarded as an important parameter. This is also in conjunction with the interpreted lineaments or fracture zones in the area, establishing a necessary link with the bedrock and fracture zones, and subsequently surface water and groundwater migration and flow. The fracture zones provide a possible pathway for radionuclide migration in the surface and in the subsurface. This migration might also include the fracture zones not yet defined in the preliminary lineament interpretation. Figure 11 displayed a more detailed view of the bedrock fracturing near Eiteråa, and possible pathways for radionuclide migration in the surface waterbodies and in the possible subsurface waterbodies.

Given the complex waterbody catalogue within the site vicinity area and in smaller scale near the site area, it is reasonable to assume that the hydrological characterization process will have to go through a more rigorous process to ensure the validity of any hydrogeological models that are produced for the site evaluation.

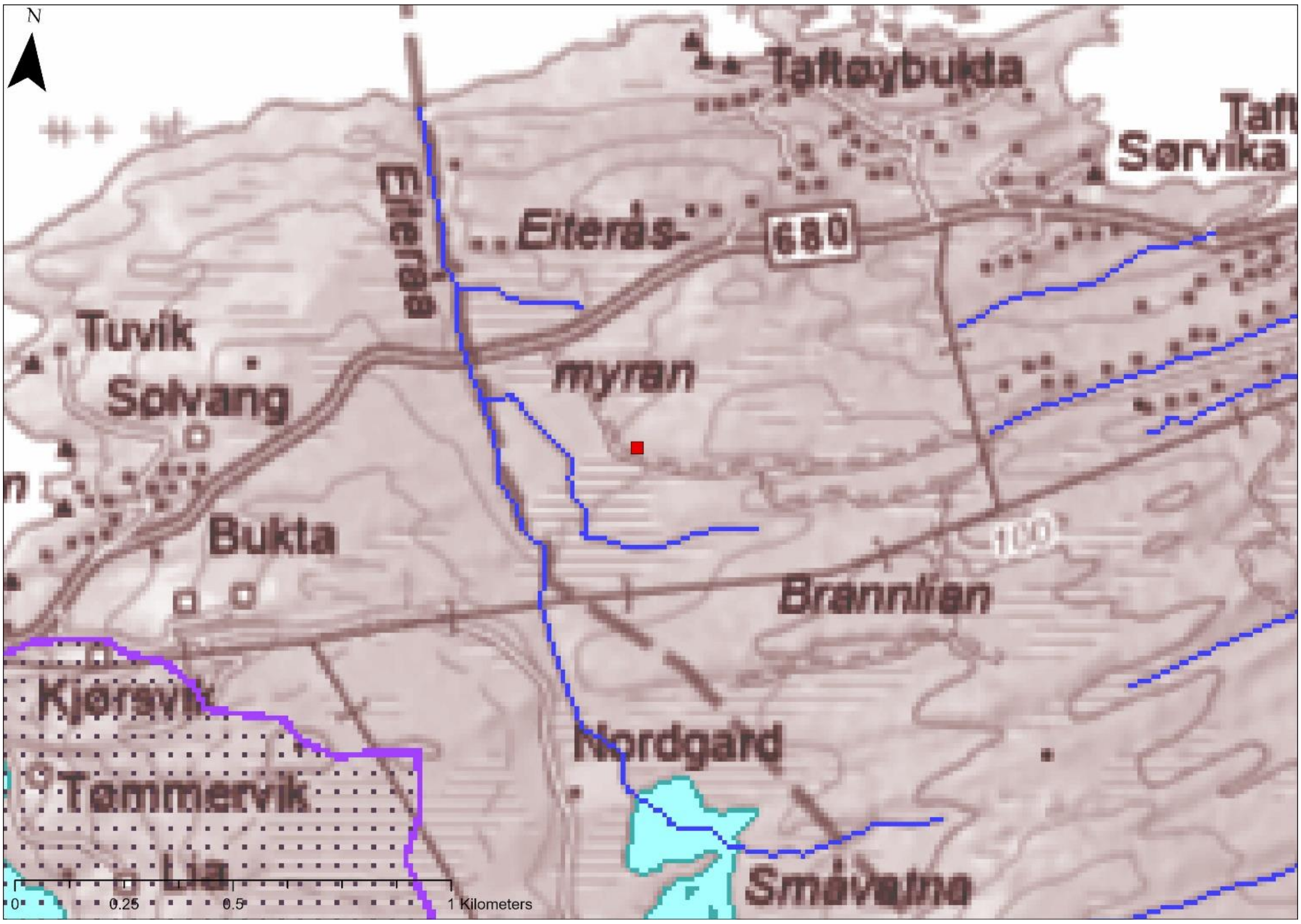

Figure 23. Close-up topography map of the Eiteråa site area with possible drainage pathways (small rivers or ditches). Data from NVE Atlas. SMR site marked with red square.

10.1 Data requirements for hydrogeological data in the site survey stage

The site survey stage should focus on gathering enough information on the most important features and characteristics, given that the site survey stage is not the most complete evaluation of hydrogeological characteristics or data collection.

Hydrogeological data analysis would include the overall impact of subsurface features within the soil and subsequently bedrock, essentially warranting investigations on the interaction with surface waters and groundwaters. Soil contamination with radiological and non-radiological contaminants from accidental release of radionuclides should be accounted for. The following list is a preliminary estimation of the procedures that could be implemented in the site survey stage:

- initial measurements on surface water chemical and physical characteristics from the prevailing water bodies to produce a baseline dataset for hydrological characteristics,
- delineation of the spatial locations of all waterbodies near the site vicinity area and designation of nomenclature on the waterbodies, whether natural or artificial,
- characteristics of the groundwater table from existing boreholes or drillholes such as maximum water level.

Drillholes or boreholes should be used to assess hydrogeological conditions found in the bedrock, with special purposes of defining the potential for hydrogeological zones. These types of data can be acquired with suitable drillhole measurement methods with hydrological measurement capabilities. Transmissivity profiles from drillholes would be essential to establish the subsurface hydrogeological zone definitions and should be correlated to structural geology observations focusing of fracture zones. Initial measurements on hydrogeochemical conditions could also be performed. These procedures however may not apply to the site survey stage but are more likely to be performed later during site selection and site characterization stages.

The extent of hydrogeological data requirements in the site survey stage in terms of scale should be discussed with the appropriate authorities and experts. While the interpretations presented in this report are preliminary, the scope presented for the site survey stage is reasonable.

11 GEOPHYSICAL DATA

Relevant geophysical data sets such as magnetic, electromagnetic and gravity data would be beneficial for evaluation of geophysical characteristics, which would be linked to e.g., lithological and structural geology data.

SSG-35 (IAEA 2015) states that regional geophysical maps with gravity and magnetic anomalies should be used in site selection processes. Aeromagnetic data is available from NGU (Figure 24), with the levelled and corrected total magnetic field data (data unit = nT, nanotesla) inferred from the measurements flown from an altitude of 200 m with a traverse line spacing of 1000 meters (STAS-13, 2014). The resolution for the Eiteråa site is too low to ascertain any relevant interpretations on geophysical characteristics or correlation to lithological data within the site vicinity area scale. Some interpretations can be made that are compatible with the general ENE-WSW strike trend of the WGR rock package.

However, when an appropriate scale is selected and correlated initially to e.g., the lineament interpretations, some correlation of the values representing the middle spectrum of the corrected total magnetic field can be observed (Figure 25). This kind of interpretation, if applied with a better resolution and the appropriate scale, could be most beneficial for the site vicinity scale or near-regional scale geological and geophysical studies in site survey stages.

Gravimetric data points from NGU are also available for analysis, with Bouguer values and corrected Bouguer values present in the data tables and could be analyzed more thoroughly in the actual site vicinity scale studies. This kind of data could be used to infer near-regional to regional geological or lithological and possibly structural characteristics, and this approach could be used in with respect to other sites than Eiteråa, if equivalent data sets are available.

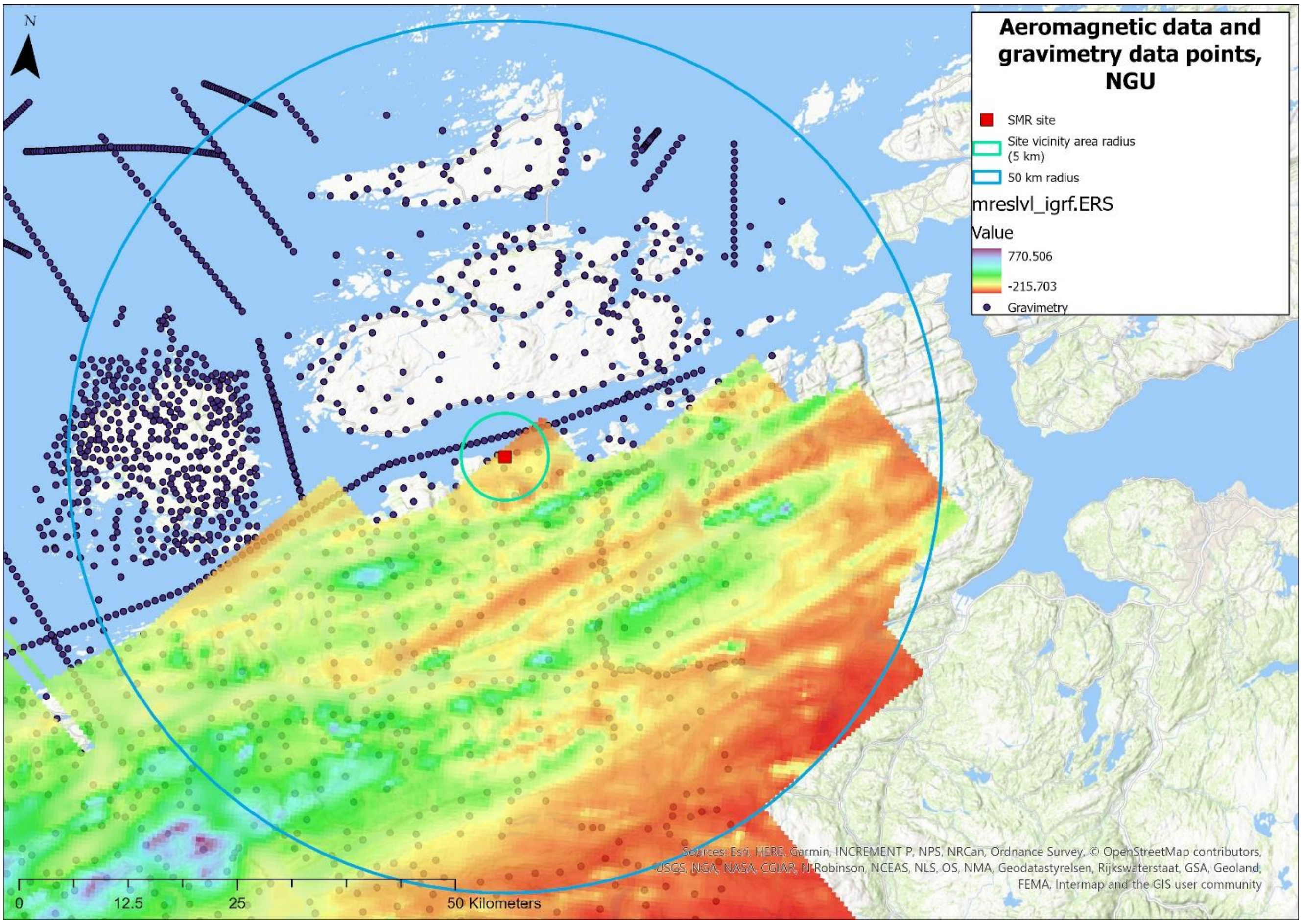

Figure 24. Aeromagnetic (corrected total magnetic field) and gravimetry data points from NGU Geoscience Data Service (https://geo.ngu.no/geoscienceportalopen/Search).

Petrophysical data is also available (Figure 26), with initial values for magnetic susceptibility and density. The petrophysical data points presented in Figure 26 would not however benefit the site vicinity area characterization, due to the points being located mostly on areas near larger waterbodies, and no points are located near the site vicinity area.

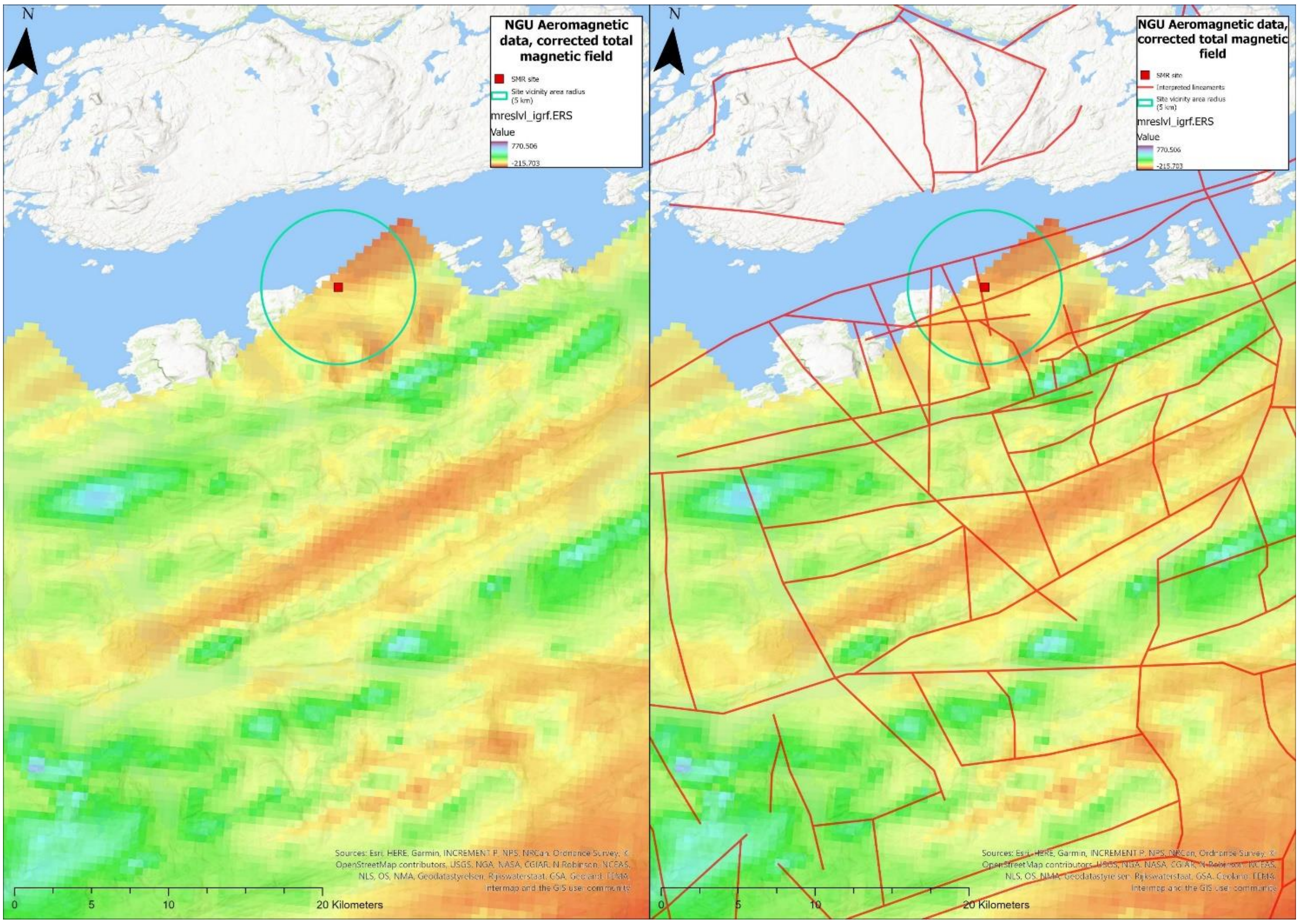

Figure 25. NGU aeromagnetic data (corrected total magnetic field) with superimposed lineament interpretations on the right. Data from NGU Geoscience Data Service.

Sampling for petrophysical characteristics could be done in conjunction with lithological sampling and assign appropriate laboratories to perform petrophysical tests on samples. Measured petrophysical parameters could include properties such as specific heat capacity, density and heat conductivity. Density values could be used to assess construction and land extraction/mining/quarrying costs, and specific heat capacity and heat conductivity values could be used to assess characteristics and requirements for possible interim storage facilities within the site area for low and intermediate-level waste (LILW) and low-level waste (LLW) waste from the reactor, if warranted by regulators and legislators. These values would however be more valuable in the later stages of the project, such as the site characterization stage.

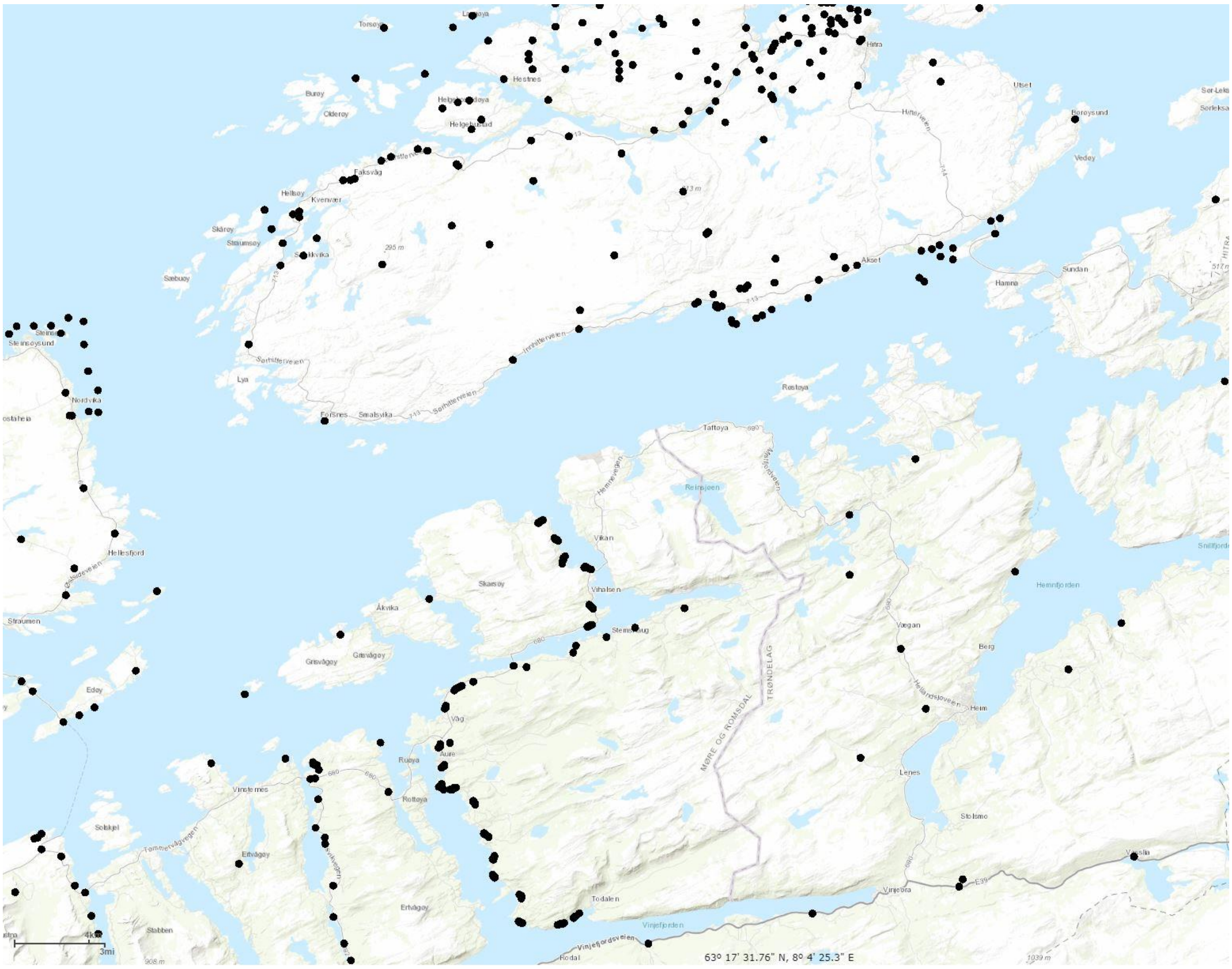

Figure 26. NGU petrophysical data points including magnetic susceptibility and density values in the near site vicinity area. Data points from NGU Geoscience Data Service.

11.1 Data requirements for geophysical data in the site survey stage

The following is a list of geophysical techniques that could be appropriate for use in the site survey stage to initially collect geophysical data. Some of these are also included in the seismic data chapter, but are reviewed here again for more geophysical context and clarity:

- collection and more detailed analysis of existing geophysical data sets, that may include aeromagnetic, magnetic, electromagnetic, gravity and radiometric data sets,
- surface geophysical surveys using electrical resistivity methods. If applied correctly and in the right scale and across different investigation profiles, can be used to infer linear features in bedrock, such as bedrock fractures and fault zones and possibly bedrock fracturing,

- surface seismic surveys using rock speed as a parameter will also enable interpretation of fracture zones if other methods prove to be not applicable.

The national coverage for NGU aeromagnetic data seems to vary considerably, and for this reason, initial investigations on drone-based geophysical measurements would be warranted. Drone-based surveying provides a low-cost method to gather initial survey data. Magnetometers can be readily attached to either fixed-wing or rotary-wing drones as a payload in current drone technology. Other methods such as electromagnetic methods also can be applied within a drone-based survey scenario with the drone capable of bearing heavier payloads. The drone geophysical survey approach could prove to be especially valuable in the SMR context and site selection processes, where the required investigation surface areas may not be as large as conventional NPP sites.

Investigations into different geophysical methods especially related to geological structures would be beneficial to develop cost-effective strategies for initial site survey stage processes within the SMR context. Options between airborne (drone or other) geophysical surveys and ground-based surveys should be studied or use a combination of both.

Geophysical measurements can also be applied to drillholes to obtain geophysical data from the subsurface, but these investigations could be more focused on later stages of the siting process.

12 METEOROLOGICAL, TSUNAMI, ENVIRONMENTAL AND OTHER RELATED DATA

A magnitude of other data such as meteorological data and other relevant data related to risks would also have to be reviewed, but these fall out of scope of this report but are briefly discussed in this chapter.

Due to the proximity of the coastline and related weather phenomena, an analysis on prevailing weather patterns should be compiled. Analysis should include wind, precipitation, snow and ice, air and water temperature, humidity, storm surges and sand and dust storms, as well as their credible combinations, shall be evaluated for extreme values. These require statistical analysis on each measured weather parameter. In addition, potential of rare meteorological events such as lightning, tornadoes and cyclones with severity and frequency analysis should be conducted (SSR-1, IAEA 2019).

Tsunami hazards are a realistic scenario in the Norwegian coastline due to high topography directly near deep water. Landslides or rockslides are known to occur, and rockslides with subsequent tsunamis have been documented e.g., in Langfjorden in 1756, recording three separate tsunami waves with wave heights of ca. 40 meters (Redfield & Osmundsen 2009).

For coastal sites, the potential for tsunamis should be carefully evaluated in the framework of hydrological hazards. Tsunami potential for tectonically induced submarine landslides should also be considered, and the investigation range would have to be very large, ranging possibly to several thousands of kilometers (SSG-9, IAEA 2022).

In investigations to evaluate the potential for earthquake generated tsunamis, the geological and seismological investigations should also include the study of seismic sources located at very great distances from the site. Thus, the sources of earthquakes that can generate relevant seismic hazards and relevant tsunami hazards at the site might not be the same. For tsunamis generated by earthquake induced submarine landslides, the models used to calculate the ground motion inducing the landslide should be consistent with those models used in the seismic hazard assessment for the nuclear installation (SSG-9, IAEA 2022a). Subaqeuous slide potential should be investigated near a coastal area. Indicated major subaqueous landslides are known to have occurred e.g., in the Storegga slide (e.g., Bryn et al. 2004).

For evaluation of fault related tsunami hazard, coastal subsidence and uplift should be estimated. A study of palaeo-tsunamis should be conducted in the near-region to understand the history of tsunamis on the coast. This assessment may be a part of the seismic hazard assessment process (SSG-9, IAEA 2022a). These assessments would also concur with the possible post-glacial fault studies that may be warranted.

Data related to volcanoes would also need to be assessed, although a direct threat of volcanoes is mainly due to possible eruption from the nearest volcanoes. These might include active volcanoes in Iceland and Italy, for example. Thus, volcanic ash fall hazards should be accounted for (SSR-1, IAEA 2019). Evaluations of a tsunami of volcanic origin would have to be assessed due to the proximity of Icelandic volcanoes. The issues related to volcanological data would be more emphasized during the site selection stage (SSG-35, IAEA 2015).

Flooding hazards should be addressed already during the site survey stage, with a focus on storm surges (with extreme sea levels), seiches, tides, flood plains and wind waves, and should be analyzed together with the topography of the site (SSG-35, IAEA 2015). Given the current knowledge on water bodies in the site vicinity and near-regional area, the potential for river flooding should also be considered, with discharge rates, precipitation, ice hazard and snowmelt upstream from the rivers documented.

Other safety related factors such as human-induced events should be analyzed and can be reviewed in SSG-35. These include the possible release of radioactive material from a nuclear installation, with implications of atmospheric dispersion, dispersion of radioactive material in surface water and groundwater. Population density and distribution factors should also be discussed.

Environmental data and related topics are important also for the site selection processes. These include but may not be limited to baseline conditions of the existing environment, descriptions of potential adverse impacts during construction, operation and decommissioning, atmospheric environment, soil quality, aquatic environment, geology and hydrogeology, aquatic wildlife and habitat, terrestrial wildlife and habitat, human health, landscape, and cultural environment (TECDOC-1915, IAEA 2020a).

Evaluations for mineral exploration potential are usually discussed in context of site selection processes of spent nuclear fuel repository siting. Similar processes should be initially performed in the SMR site selection processes to exclude possible conflicts of interest in terms of land use. The existing NGU data does not show any significant mineral potential in the site vicinity area either in the form of mineral occurrences, closed or active mining areas.

12.1 Data requirements for meteorological, environmental, and other risk related data in the site survey stage

Due to the scope of this report and the extent of the aforementioned data in this chapter and their related requirements, the data types referred to in this chapter cannot be feasibly analyzed. It is suggested here that these very broad and relevant topics are managed carefully in separate reports or work packages. The descriptions in the preceding chapter should be used accordingly.

Geotechnical risk maps associated with the tsunami hazards could be produced with NGU geotechnical risk maps with landslide potential, with the appropriate personnel with prerequisite experience performing the tasks.

13 DISCUSSION

A line between site vicinity area investigations and site area investigations can be difficult to differentiate. Several overlapping elements are present with the presented investigation methods included in this report. Geological, structural geological, geochemical, geotechnical, and geophysical methods all overlap each other in the site survey stage and subsequent phases, so it is sometimes challenging to consider the order and the appropriate magnitude of research methods in each stage with each investigation approach.

Drillhole or borehole design in the site vicinity area or the site area should be planned with the goal of producing lithological, geochemical, rock mechanical and hydrogeological data sets from the same drillholes. The configuration of the drillhole grid or drillhole profiles should allow measurements from drillhole to drillhole with different methods. A thorough geological surface mapping program of the site vicinity scale is recommended to be performed before drilling. This would enable better planning procedures for the drilling process in the site vicinity scale investigation phase and subsequent phases with complementary drilling.

The execution of these types of geological investigations would also yield necessary information about the possibilities for interim storage of high-level waste (HLW) and operational nuclear waste storage for LLW and LILW, but these waste storage strategies are also dependent on possible national strategies concerning nuclear waste storage and final disposal.

The documented activation history of the HSF and the MTFC (Watts et al. 2023, and references therein) allows for the interpretations on current fault capability of the HSF. Geochronological data has been presented that suggest that while the MTFC is a major fault complex with a length of over several hundred kilometers, the origin and character of the geological history of the fault and adjacent rock types do not suggest for it to be classified as a high-risk fault or a capable fault at this point of the investigations. The youngest reactivation is thought to have possibly occurred during the early Cenozoic (Watts et al. 2023), starting from 66 Ma, relating to the opening of the North Atlantic Ocean. However, these interpretations will have to be verified to a very high degree during the site selection stage.

Possible seismic source models were initially established in the form of lineaments and associated seismic data, and one lineament, in particular, west from the site can be interpreted as a preliminary seismic source area but with rather limited seismic data attributed to the fault. The seismic data points used in this report (radius of 200 km) in general are confined to an upper limit maximum magnitude of 3 (moment magnitude M_w), and these magnitudes are also below the lower bound magnitude limit of 5.0 M_w. The selected seismic hazard process concerning the site survey stage and subsequent stages is to be thoroughly reviewed and analyzed, even if the seismic activity is seemingly low in the site vicinity area and is occurring in rock types representing deeper basement rocks, that in general represent low seismic activity in the Fennoscandian Shield.

The Norwegian coastal area is subject to tectonic forces coming from the Mid-Atlantic ridge and also from local stress sources. Some areas such as the Rana area experience a higher frequency and magnitudes of earthquakes, and some of this seismic activity has been interpreted to be related to post-glacial activity (Hicks et al. 2000). While the seismic activity in the Eiteråa site and surrounding areas can be considered low, research into post-glacial activity in the area is warranted to some degree and scope.

The Norwegian coastal area is also subject to a tsunami risk as evidenced by historical tsunamis. However, there are possibilities for placing the facility in an elevation or higher topography within the site vicinity area or the approximate site area that is advantageous for minimizing the risk concerning tsunamis.

Lineament interpretation and related documentation for the site area can be used for several purposes. Hydrogeological capability of lineaments or fracture zones would need to be established for the site to assess possible radionuclide migration in subsurface conditions.

14 CONCLUSIONS

Based on the review of available data and material in this report, the site and its geology can initially be considered as a suitable candidate site and host rock complex and could be considered for further investigation for SMR development. Detailed research and data collection within the planned site perimeter and the proposed site vicinity area of 5 km has to be performed and the research program would have to adhere to existing Norwegian national legislation and regulation concerning possible site selection and site evaluation processes at some point, although the state of regulation is unclear at this point in time. Risks involving the major fault lines and lineaments need to be quantitatively and qualitatively assessed to minimize the possible risks involved.

Recommendations for site area investigations should include assessment on the appropriate radius for site area investigations, and these recommendations should come after peer reviews on this report and other possible related reports and scientific reports and work.

The most important exclusionary criteria pertaining to site selection can be viewed in the IAEA document SSG-35 (IAEA 2015), and some of these can initially be directly attributed to the Eiteråa site. Primary exclusionary criteria include earthquakes with ground vibration and surface rupture; geotechnical issues related to slope instability, subsidence, and liquefaction. Other primary exclusionary criteria related to volcanism with lava flow, pyroclastic flow, ground deformation, volcanic gases and massive lahars cannot be directly attributed to Eiteråa, and tephra fall (volcanic ash) can only indirectly be attributed to Eiteråa. However, initial analysis conducted in this report indicate that the risks are relatively minor pertaining to the primary exclusionary risks presented in SSG-35 (IAEA 2015). These risks nevertheless require further study to minimize the possible effects on the site selection processes.

The IAEA safety guides and TECDOC documents related to nuclear reactor site selection referred to in this report are numerous and should be studied and reviewed at a regular basis or time schedule to gain a better understanding of the processes involved. Safety guides and recommendations regarding SMRs are increasingly being produced, and these developments should be monitored by potential SMR license applicants.

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16 APPENDICES

Appendix 1. Seismic data points from the Institute of Seismology (Helsinki University, Finland) within a 200 km radius from the site.

Latitude	Longitude	X_EUREFIN	Y_EUREFIN	Max_magni	Depth	Depth_m	Year_	Month_	Day_	Hour_	Minute_	Second_
63.4	10.3	-327127.2542	7139019.289	0	0	0	1690	1	5	0	0	0
63.4	10.3	-327127.2542	7139019.289	2	7	7000	1799	4	20	17	15	0
63.5	10.5	-314515.3196	7147283.043	3	7	7000	1872	8	13	2	15	0
64.2	9.5	-341516.9121	7236257.01	2	7	7000	1878	8	5	16	21	0
63.4	10.4	-322260.7529	7137717.914	2	7	7000	1880	12	8	1	15	0
63.4	10.4	-322260.7529	7137717.914	2	7	7000	1881	4	9	11	15	0
63.4	10.4	-322260.7529	7137717.914	3	4	4000	1885	12	12	22	45	0
63.2	10.3	-332945.2577	7117312.772	2	3	3000	1887	1	22	4	27	0
63.3	7.6	-461268.678	7166376.725	2	7	7000	1888	12	27	22	2	0
63.3	7.6	-461268.678	7166376.725	2	3	3000	1889	1	28	22	0	0
63.3	7.6	-461268.678	7166376.725	2	7	7000	1889	1	21	18	45	0
63.3	7.6	-461268.678	7166376.725	2	3	3000	1889	1	19	18	39	0
63.3	7.6	-461268.678	7166376.725	2	7	7000	1889	1	4	0	45	0
63.4	10.4	-322260.7529	7137717.914	2	3	3000	1890	11	26	0	0	0
63.4	10.4	-322260.7529	7137717.914	2	3	3000	1896	4	13	21	40	0
63.1	7.8	-458280.8744	7141831.477	2	3	3000	1896	1	10	1	35	0
63.4	10.3	-327127.2542	7139019.289	2	7	7000	1896	1	8	0	15	0
63.4	10.3	-327127.2542	7139019.289	2	7	7000	1896	1	7	21	44	0
63.4	10.3	-327127.2542	7139019.289	2	3	3000	1897	2	17	1	0	0
63.7	10.6	-303936.8849	7167721.972	2	3	3000	1898	12	15	21	30	0
63.4	10.4	-322260.7529	7137717.914	2	3	3000	1899	3	10	10	30	0
63.4	10.4	-322260.7529	7137717.914	2	5	5000	1900	3	7	0	0	0
63.3	10.2	-334919.7914	7129479.378	2	2	2000	1900	2	8	21	15	0

Latitude	Longitude	X_EUREFIN	Y_EUREFIN	Max_magni	Depth	Depth_m	Year_	Month_	Day_	Hour_	Minute_	Second_
62.6	8.4	-445150.5406	7078949.049	2	7	7000	1901	12	13	6	40	0
64	9	-371367.1463	7221451.633	2	7	7000	1909	4	18	5	11	0
64	10.2	-314379.3868	7205399.579	2	3	3000	1919	10	21	13	30	0
63.4	10.5	-317392.6674	7136424.388	2	3	3000	1919	9	1	11	30	0
64	10.2	-314379.3868	7205399.579	2	7	7000	1919	3	1	13	30	0
63.7	10	-332815.641	7175489.368	3	7	7000	1927	9	24	20	30	0
63.7	9.6	-352035.7125	7180823.242	2	5	5000	1934	2	10	23	30	0
63.3	10.1	-339800.5973	7130800.037	3	11	11000	1937	2	28	6	50	0
63.7	7.6	-447721.6263	7209360.753	0	0	0	1966	3	8	15	58	49
63	10.4	-333817.7704	7094286.307	0	0	0	1968	1	10	6	57	29
63.22	10.67	-314233.3961	7114684.432	2	0	0	1980	12	8	7	35	49.1
63.17	10.23	-337250.953	7114977.75	2	3	3000	1982	10	10	18	9	2.3
62.97	9.37	-385505.0084	7104968.754	2	0	0	1982	5	7	21	12	5.8
63.14	10.25	-337144.2965	7111458.175	2	0	0	1984	1	25	22	12	14
63.96	9.96	-326989.5908	7204187.897	2	10	10000	1986	8	6	18	37	12
63.52	10.32	-322663.172	7151780.997	2	1	1000	1986	6	16	17	12	54.1
63.38	10.34	-325761.6491	7136327.064	2	0	0	1986	6	16	14	14	31.9
63.41	10.19	-332185.5014	7141544.684	2	0	0	1986	5	30	13	24	56.2
63.68	10.02	-332447.3113	7173058.196	2	15	15000	1986	4	23	18	33	19.3
63.48	10.07	-335952.1993	7150716.988	2	0	0	1986	4	22	15	9	41
63.48	9.89	-344675.966	7153106.51	2	6	6000	1986	4	5	14	16	57.9
63.56	10.08	-333105.4089	7159259.279	2	1	1000	1986	4	2	18	24	26.8
63.33	10.44	-322333.8801	7129599.328	2	0	0	1986	2	26	15	21	34.3

Latitude	Longitude	X_EUREFIN	Y_EUREFIN	Max_magni	Depth	Depth_m	Year_	Month_	Day_	Hour_	Minute_	Second_
62.88	8.04	-453828.8987	7114522.549	2	3	3000	1989	6	7	14	57	7.2
62.95	7.47	-479455.1538	7130749.059	2	1	1000	1989	5	10	16	49	23.2
63.11	7.91	-452584.8642	7141247.311	2	14	14000	1990	12	6	10	42	40.5
62.79	8.28	-444946.5519	7101230.964	2	13	13000	1990	12	5	10	7	18.1
62.91	8	-454805.4425	7118356.229	2	0	0	1990	9	25	7	49	6
63.76	8.99	-379405.5847	7195676.662	2	16	16000	1991	6	27	0	39	38.2
63.64	9.16	-375017.2143	7180350.36	2	23	23000	1991	6	6	2	14	34.3
63.65	9.12	-376626.6249	7181985.76	2	12	12000	1991	5	28	19	2	10.8
63.64	9.12	-376938.9882	7180905.223	2	16	16000	1991	5	28	18	28	32
63.59	9.24	-372723.7888	7173839.188	2	14	14000	1991	4	18	7	22	38.6
63.6	9.16	-376263.629	7176027.464	2	23	23000	1991	3	20	6	39	12.5
63.63	9.07	-379654.0355	7180520.198	2	0	0	1991	3	7	15	18	50.4
63.55	9.33	-369623.7011	7168273.445	2	17	17000	1991	3	5	16	15	47
63.6	9.11	-378669.3109	7176722.01	3	0	0	1991	2	19	16	44	43.1
63.68	8.9	-386238.7758	7188297.908	3	20	20000	1991	2	15	17	4	24.7
62.95	7.59	-473579.5765	7128899.031	2	0	0	1992	11	5	12	38	14
62.97	7.42	-481221.5397	7133672.676	2	0	0	1992	9	23	14	46	26.5
63.59	9.08	-380425.462	7176059.226	2	23	23000	1992	3	25	15	42	24.2
63.03	9.83	-361038.6755	7105142.615	3	31	31000	1992	3	11	12	5	24.1
62.78	7.83	-467482.551	7106932.466	2	0	0	1992	2	28	12	47	4.5
63.58	9.18	-375923.6024	7173588.514	3	22	22000	1992	1	22	12	45	1.8
63.79	8.96	-379893.3239	7199334.493	3	12	12000	1993	7	12	9	2	20.7
63.41	7.42	-466214.8078	7180943.089	2	12	12000	1993	6	7	14	5	57.3

Latitude	Longitude	X_EUREFIN	Y_EUREFIN	Max_magni	Depth	Depth_m	Year_	Month_	Day_	Hour_	Minute_	Second_
63.49	8.77	-398517.4023	7169624.352	2	12	12000	1994	8	5	18	42	39.9
63.29	8.16	-434484.3783	7156902.244	2	0	0	1994	7	22	15	47	18.7
63.29	8.72	-407304.8375	7148749.962	2	0	0	1994	6	2	9	6	38.6
63.38	8.65	-407826.505	7159467.528	3	15	15000	1994	5	27	8	1	10.2
63.45	8.49	-413310.5308	7169323.267	2	0	0	1994	5	20	9	9	15.9
63.41	8.61	-408800.8083	7163279.053	2	15	15000	1994	5	11	20	33	1.9
63.22	8.99	-396376.6564	7137343.904	2	12	12000	1994	5	10	21	17	18.2
63.43	8.59	-409125.6243	7165724.261	3	15	15000	1994	5	5	19	5	35.7
63.43	8.49	-413956.3818	7167166.592	2	0	0	1994	5	2	20	24	44.9
63.45	8.46	-414758.3586	7169757.258	2	0	0	1994	4	26	4	26	16.4
63.07	9.31	-385384.4094	7116627.47	2	0	0	1995	7	6	12	11	47.3
63.35	8.99	-392297.3066	7151390.49	2	12	12000	1995	6	16	10	3	57.1
63.45	8.54	-410897.1274	7168601.518	2	0	0	1995	5	24	7	41	37.9
63.54	8.24	-422423.858	7182656.717	2	0	0	1995	5	15	13	34	26.9
64.1	9.89	-326126.4782	7220269.736	2	0	0	1996	11	27	12	25	43.6
63.84	8.87	-382604.3905	7205990.102	3	12	12000	1996	6	3	1	34	15.1
63.91	8.72	-387509.9614	7215649.924	2	23	23000	1997	11	12	13	6	34.6
64.01	8.95	-373420.1566	7223223.971	3	0	0	1999	3	2	8	28	6.4
63.99	9.06	-368837.769	7219542.806	2	0	0	1999	3	2	7	26	38.6
64.02	8.65	-387299.3772	7228499.053	2	15	15000	1999	1	9	9	32	37.1
63.142	7.636	-464857.6984	7148841.594	2	0	0	2000	4	21	8	43	30.8
64.058	9.519	-344973.3582	7220646.092	2	16	16000	2001	9	16	19	39	1
63.317	10.307	-329201.1982	7129920.073	1	0	0	2001	1	26	15	27	38.3

Latitude	Longitude	X_EUREFIN	Y_EUREFIN	Max_magni	Depth	Depth_m	Year_	Month_	Day_	Hour_	Minute_	Second_
63.555	8.005	-433215.5846	7187726.994	2	15	15000	2002	11	7	14	17	36.5
63.22	7.374	-474930.3295	7161243.474	2	15	15000	2002	10	2	0	46	16.7
62.596	8.66	-432340.7042	7074680.489	1	12	12000	2003	12	3	0	0	9.5
63.928	9.134	-367268.1306	7211826.767	2	2	2000	2003	11	5	10	17	3.9
62.833	8.4	-437630.7334	7104089.984	2	0	0	2003	8	22	0	39	12.1
63.94	9.424	-353105.7337	7209165.25	2	0	0	2003	8	4	5	40	50.8
63.925	9.031	-372257.986	7212924.636	2	12	12000	2003	3	13	8	21	6.9
64.298	8.659	-377931.7894	7258341.481	2	10	10000	2004	11	17	3	18	10.9
62.701	9.371	-393688.9133	7075834.83	2	15	15000	2004	9	26	10	30	45.5
64.145	8.361	-396875.29	7246067.982	2	12	12000	2006	12	9	14	50	19.3
63.797	9.309	-363001.4734	7195268.878	2	0	0	2006	5	11	8	27	13
63.771	9.508	-354281.6368	7189749.204	2	15	15000	2006	5	11	8	20	33.6
64.057	9.93	-325518.0872	7215088.434	3	10	10000	2007	6	20	10	32	16.6
64.136	9.399	-348250.8241	7230693.835	2	0	0	2007	6	19	11	52	51.6
64.059	10.131	-315919.2544	7212687.461	2	15	15000	2007	5	10	11	37	21.7
64.05	10.06	-319556.6203	7212633.29	2	0	0	2007	4	18	18	56	19.1
63.756	7.433	-453762.3678	7217896.338	1	23	23000	2007	3	27	18	57	18.6
64.051	10.133	-316060.7135	7211794.473	2	6	6000	2007	3	8	8	57	1.2
62.706	7.912	-465889.8354	7097714.816	2	0	0	2008	10	17	19	8	5.5
62.725	8.336	-444286.6536	7093387.244	1	0	0	2013	7	12	2	19	28.3