GEOSIGMA

Review of topics related to structural geology

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SSM's Workshop on
the Review of SKB's License Application for a Spent Nuclear Fuel Repository
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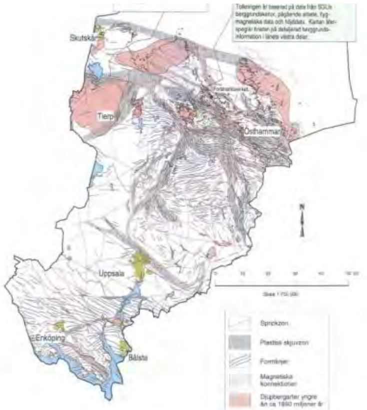
Complimentary information from SKB in bold letters

Geologic evolution – Regional geologic setting of the Forsmark Site

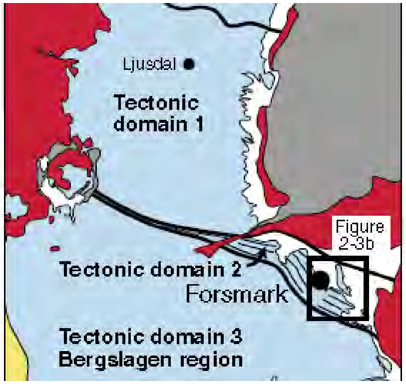
The description of the geological evolution (R-08-09) reflects the current understanding of the site.

1. Scales considered in text; from global to local site scale.
2. Focused on Precambrian events, **the late geological evolution should be emphasised.**
3. **Map describing interferences between regional structures** missing - regards both ductile to brittle deformation.
4. Systematic rotation of rock blocks outlined by Singö, Eckarfjärden and Forsmark deformation zones – indication of curved faults.
5. **Is the size of the regional Forsmark area appropriate?**

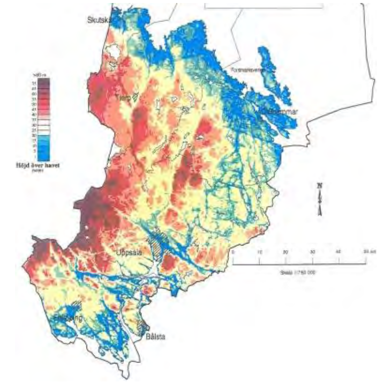
Geologic evolution – Regional geologic setting of the Forsmark Site



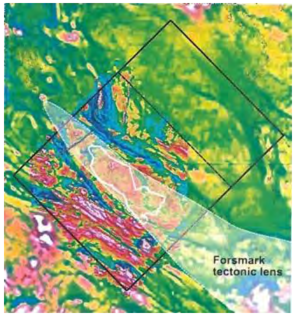
Inter. of airborne magnetic measurements, Uppsala län
R-98-32 Fig. 13



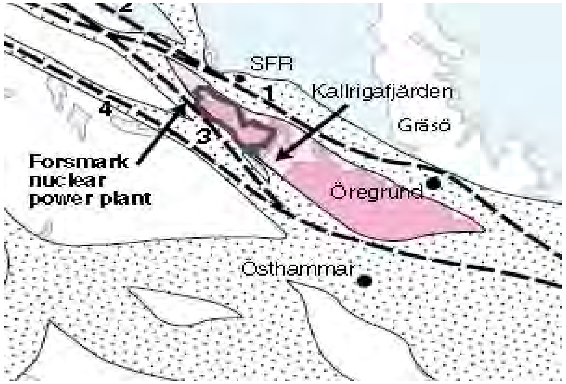
Tectonic domains
R-08-19 Fig. 2-3



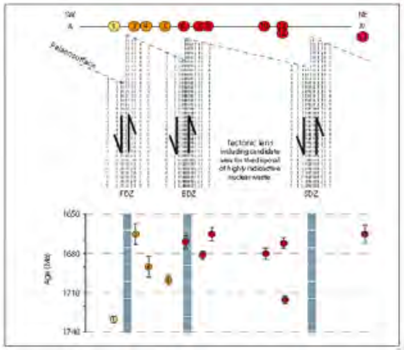
Topographical map,
Uppsala län
R-98-32 Fig. 12



Airborne magnetic measurements, reg. area
TR-98-57 Fig.5-1



Tectonic lens and ductile deformation
R-08-19 Fig. 2-3



Faulting along Singö, Eckarfjärden and Forsmark DZ, R-08-19 Fig. 2-22

Homogeneity in base data

The geological base data consists mainly of:

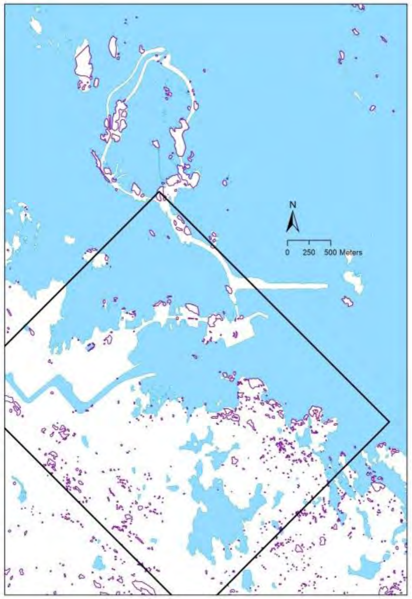
1. Field mapping data; outcrops and rock constructions.
2. Geophysical areal measurements; e.g. helicopter borne and detailed ground geophysics.
3. Reflection seismics; surface based and VSP
4. Borehole investigations.

No cored borehole intersecting the Eckarfjärden DZ – NW trending boundary zone, west of the candidate area.

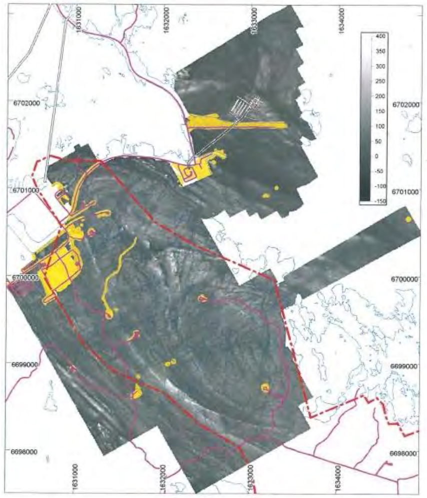
Main uncertainties are related to instrumental limitations, limitations in data processing of data and areal/volume coverage of the preformed investigation.

Homogeneity in base data

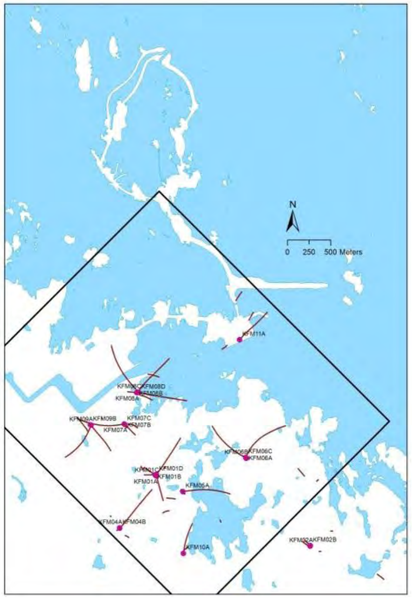
Outcrops



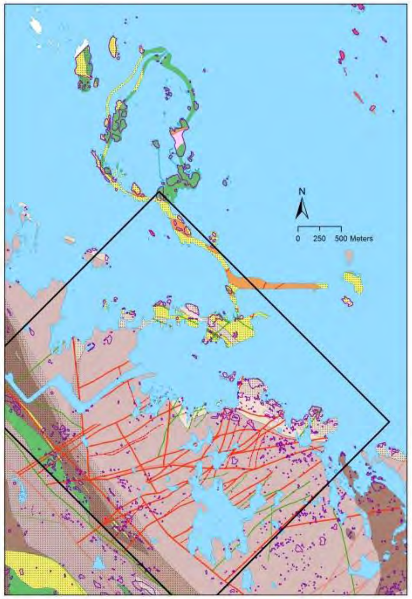
Detailed ground magnetic measurements



No cored borehole intersect the Eckarfjärden DZ



Geological map – areas not covered by water



High quality in the detailed magnetic measurements together with outcrop data gives a good base geological maps. Reflection seismics detect gently inclined structures – no data in the NE part of the local area. **The borehole sampling bias (relative to planar structure elements) should be evaluated.**

Local geological models

The geological models are deterministic models:

1. Regional model (165 km^2 large, depth: -2 200 m a.s.l.); surface trace length of structures ≥ 3 km.
2. Local model (16 km^2 large, depth: -1 100 m a.s.l.); surface trace length of structures ≥ 1 km.
3. (Modelled minor deformation zones, MDZ, in the local area; surface trace length of structures ≤ 1 km. Used in the layout.)

Type of models:

A. Bedrock model – lithologies

B. Model of deformation zones.
   A character synthesis of different sets of zones is for the first time presented and describe:
   a. internal fracture sets
   b. fracture minerals.

C. Fracture domain model (only on local scale).

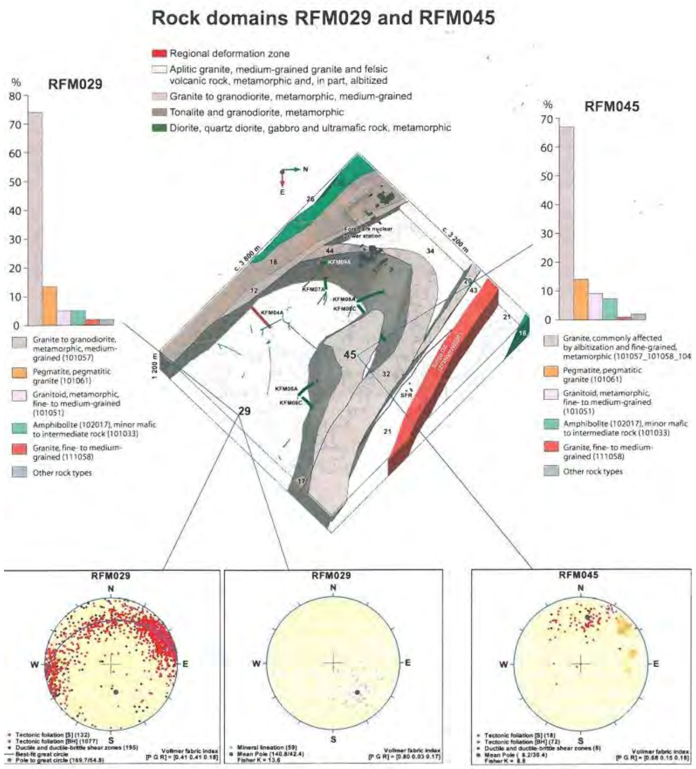
Local bedrock model - Rock domains

The bedrock in the central parts of the Forsmark local model area has a pronounced tectonic fabric (mineral lineation and foliation).

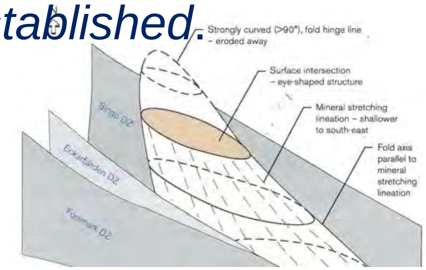
The distribution of rock domains is related to:

- ductile deformation (tube/sheat folding)
- shearing (formation of ductile to ductile-brittle deformation zones).

The geometry is well established.



TR-08-05 Fig. 5-25



TR-08-05 Fig. 5-23

Local bedrock model - Rock domains

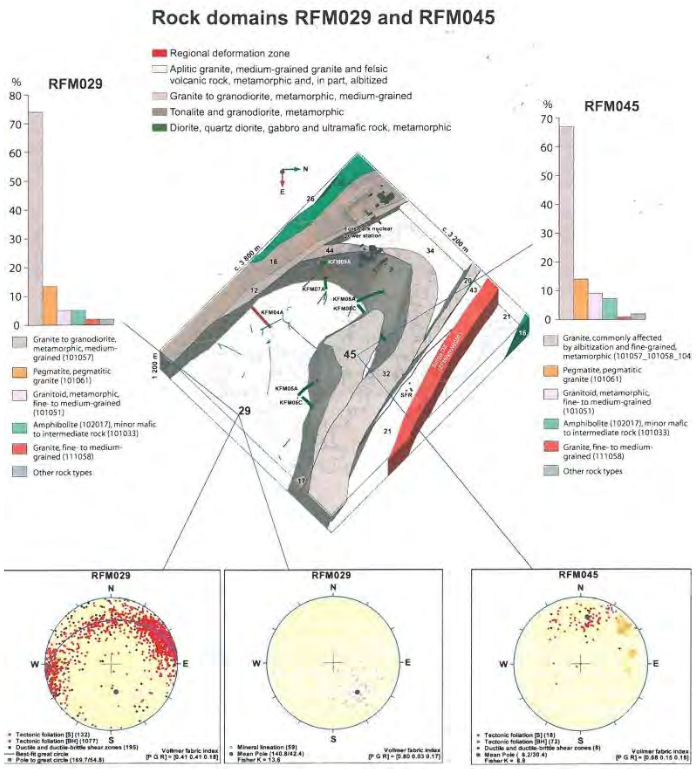
The central part of the fold, containing rock domain 29 and 45, *is large enough to host a repository*.

Amphibolite layers/bodies lying in the foliation may have effect on the layout.

The western limb of the fold is altered by ductile deformation and is sheared off. **The effect of shearing on rock domain 29 should be evaluated**. **Establish the borders of "the lens".**

Rock domain 45 has a rod like appearance. **Other rock domains may occur at depth.**

Dykes of younger granites (NE-ENE trending) cut the foliation.



TR-08-05 Fig. 5-25

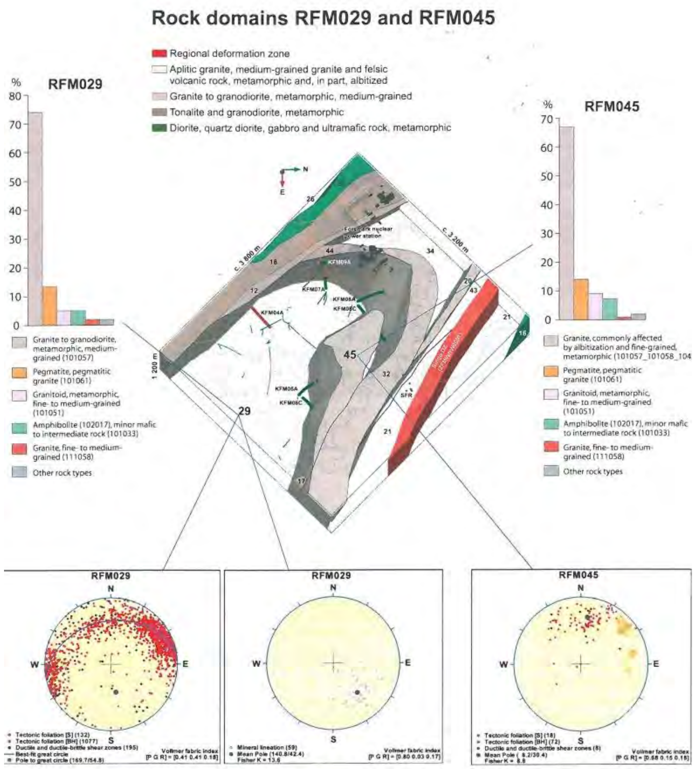
Local bedrock model - Rock alteration

The main types of alterations are:

1. oxidation (related to deformation zones).
2. albitization (related to the occurrence of amphibolites, common in rock domain 45).

A conspicuous type of alteration is the selective dissolution of quartz (vuggy granite/episyenite) associated with strong oxidation of the rock and located in connection to deformation zones. **It is not clear why the vuggy granites are still open.**

Three-dimensional modelling of oxidation will contribute to the understanding of paleoflow in the rock – connection of zones.



TR-08-05 Fig. 5-25

Local structural model – Brittle deformation zones, steeply dipping

Four sets are incorporated in the synthesis: WNW, NW, ENE (NE) and NNE.

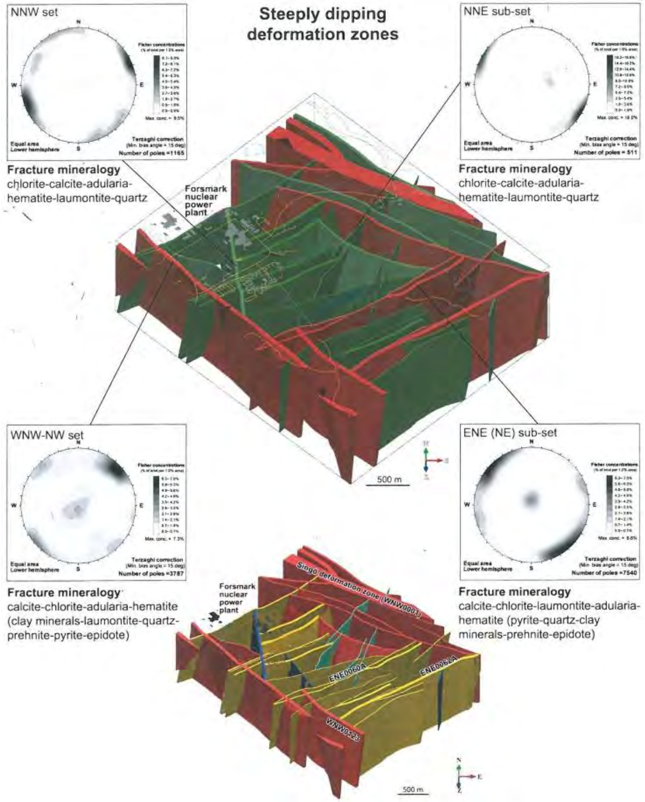
Not included in the synthesis (too few zones):

NNW and E-W.

Missing in the description of zones is the character of termination of zones – especially the blind zones.

Figures describing relations between outcrop scale structures missing – mimic larger scale structures.

Relations between zones displayed on the structural map are in some cases not kept at e.g. 500 m depth – **a**



TR-08-05 Fig. 5-29

Local structural model – Brittle deformation zones, gently dipping

Gently inclined brittle deformation zones dips generally south-eastward.

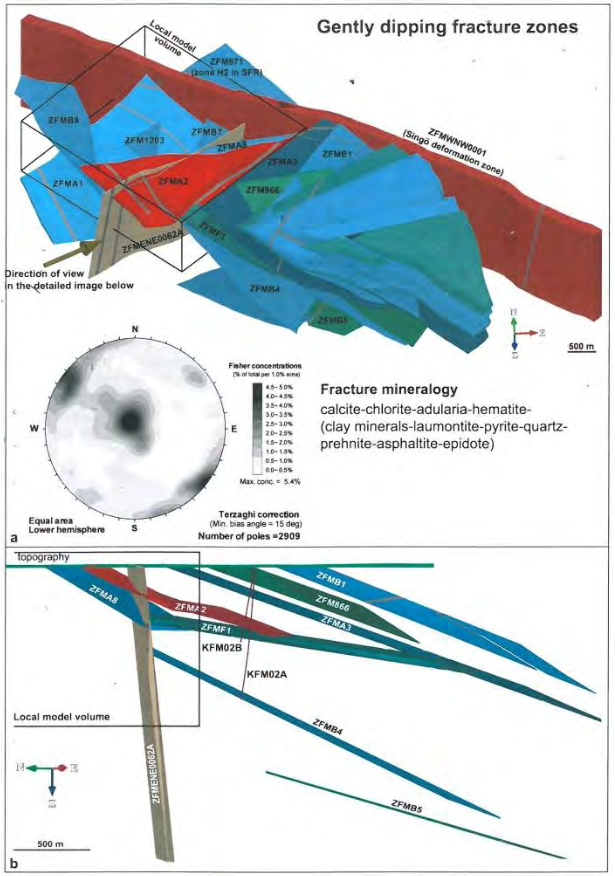
They are preferentially found southeast of the local model area.

The relation to vertical zones are not clear. This holds especially for:

- regional WNW to NW trending steeply dipping regional zones.
- regional ENE trending zones.

No gently inclined zone is detected at the potential location of a repository.

Although zones are detected at greater depths southeast of the local area.



TR-08-05 Fig. 5-30

Local structural model – Brittle deformation zones

There is a need for updating the description of the deformation zone (both the actual description and also data in databases, e.g. ESHI).

The presented synthesis can be used to check the model of brittle deformation zones and reactivation of zones.

There is a need for a database – for parametres describing deformation zones.

Intersections between zones causes traces along the zones with modified character (channels). Intersections between brittle deformation zones are found in a few boreholes. However, orientation and extension of such intersections can be obtained from the structural models.

Local structural model – Brittle deformation zones, Fracture minerals

1. The new synthesis for brittle deformation zones also comprise fracture minerals (6 to 11) associated with different sets of zones.

2. Generations of fracture minerals (4 + fractures without minerals; R-08-102) and fracture minerals related to deformation events (R-07-45) are established .

Together (1+2) they can form

a base for studying the change of character of zones by time (the effects of reactivation of zones). (The core log, SICADA, contain ≤ 4 minerals per fracture.)

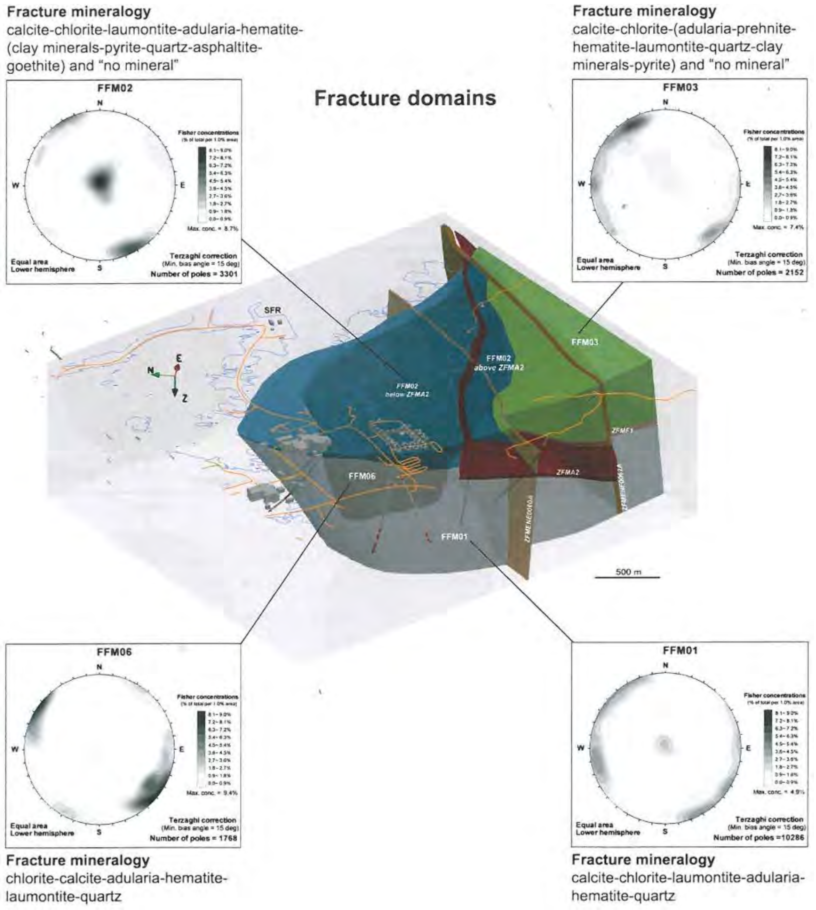
(Three-dimension modelling of the distribution of open fractures without fracture minerals and alteration of wall rock – to test the relation to zones).

Fracture domain model

Fracture domains and deterministically modelled deformation zones are mutually exclusive volumes, whereas rock domains contain both fracture domains and deterministically modelled deformation zones (TR-08-05 P 404).

Four fracture domains are defined:

- Two domains at shallow levels (FFM02 and 03), in shallow parts of rock domains 29 and 45.
- Two domains at deeper levels (FFM01 in rock domain 29 and FFM06 in rock domain 45).



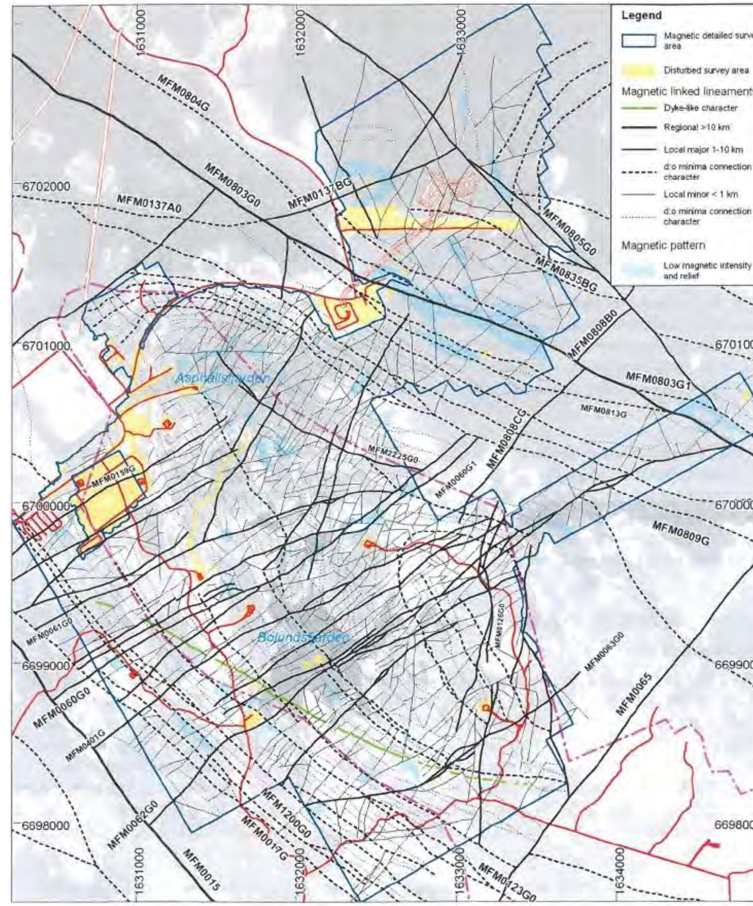
TR-08-05 Fig. 5-29

Local structural model – Fracture domains

The orientation of fractures in the fracture domains is similar to that in the adjacent fracture zones (TR-08-05 P 404)

Further subdivision fracture domains may be tested due to:

1. A structural break along zone ZFM0060A; NNE trending lineaments and MDZ northwest of the zone and ENE structure dominance southeast of the zone.
2. NW structural grain (ductile deformation and brittle deformation zones) in a “belt” along the western boundary of rock domain 29.



TR-08-05 Fig. 5-18

Fracture domain model

The greatest uncertainty in the fracture domain model is data on length distribution of structures (can surface data be used?).

Is the maximum size of 1 km for fractures/brittle deformation zones in the fracture domains verified?

What is the relation between ESHI's (DZ in ESHI) included in the geological DFN (R-07-46) and the hydrogeological DFN models (R-07-15)?

The relative proportion of ESHI in boreholes above and below – 300 m. a.s.l., are similar 24 % (SICADA data).
If borehole sections "affected by DZ" (cf. R-07-15 Ap. 4) are included the ESHI+sections "affected by DZ" will increase by c. 5 %.

Mineralizations – Economic geology

The Forsmark area is located within an ore province – Bergslagen.

The selected area for a potential repository is located within plutonic rocks, mainly granites and granodiorites, lacking minerals of economic interest.

However, a potential for iron oxide mineralisation and possibly base metals is recognised to felsic to intermediate meta-volcanic rocks outside the host rock for the repository (R-04-18), i.e. north and south of the repository.

Relative to the plutonic rocks, planned to host the repository, meta-volcanic rocks occur both to the south (minor mineralizations of no economic value) and the north (covered by the sea – no information about mineralizations).

The radioactive waste in a deep geological disposal will form as a physical anomaly. How will such anomaly differ from ordinary mineralizations in the Bergslagen ore province? **Geophysical modelling needed.**

Repository layout criteria

Definitions of, e.g. geological terms to uniformly locate geological features that may affect the layout, e.g.,

Long fractures (discriminating fracture) – length of the structure (single plane, trace of fractures or a part of a network of fractures).

Brittle deformation zones (c.f. now three characters of deformed rock associated: core zone, transition zone and rock “affected by deformation zones”) – to locate borders of zones and lengths of zones (as single structures or as connected to other zones).

Ductile deformation zones (cf. previous items) – to locate the border or the “lens”.

Foliation/banding.

Define scale of observation.

Repository layout criteria

Restrictions for:

Location of transport tunnels/rock excavations at repository level, e.g. what is the acceptable angle of intersection between transport tunnels and deformation zones (0° - i.e. coincide?). **Transport tunnels as extended deposition tunnel.**

Align orientation of deposition tunnels and the maximum principal stress (±30°).

Any restrictions related to the orientation of **foliation/banding** and deposition tunnels?

Occurrence of rock types with deviating (lower) thermal properties.

When should a deposition tunnel be **relocated/abandoned**?

Locating deposition tunnels in the vicinity of long zones (≥ 3 km, respect distance):
How long could ENE trending zones be in the Forsmark area?
Zone with terminating just outside the repository area and pointing towards deposition tunnels?

Brittle deformation zones (< 3 km) and deposition holes.

Long fractures and deposition holes (**FPC/EFPC criterion**).

The instructions should be detailed and well illustrated.

Framework program for detailed site investigations (R-10-08)

Aims: support planning and construction, update SDM and support layout – related to long time safety.

Observation method – prediction and outcome.

Stepwise performance: 1. Ramp and shafts, 2. central area and 3. repository area.

Adopt investigations in relation to items1-3 (3 differentiated – transport tunnels and deposition tunnels/holes). Character of investigations, e.g. tunnel mapping borehole investigations (pilot, probe and injection holes – all located inside the perimeter of tunnels). Monitoring – e.g. seismicity, hydrogeology etc.

Development of strategy, methods and instruments, e.g. tunnel mapping, identification of long fractures, borehole seismics, borehole radar (too saline ground-water?), excavation, codes .

Modelling scales to be used: Regional, via scale of reference layout to tunnel scale.

Data storage – data freeze - QA.

Decision process - Presentation of results.

Missing information on organisation and infrastructure.