Site characterisation in the Swedish crystalline rock before and after submitting the construction licence

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Where to learn and how to learn about the Swedish granitic rock

From the study site investigations 1977-1985
From the underground test facilities
Stripa Mine Project 1977-1992

• Development of **characterization techniques and integrated characterization and modeling** of site data

• Fracture flow and transport modeling

• Basis for understanding of channeling and its importance for radionuclide transport

• Basic designs of engineered barriers (buffer, backfill and plugs) and basic understanding of their performance

• Successful international cooperation
  • Initiation of **Task Force on groundwater flow and transport**
  • Initiation of Task Force on Sealing materials and techniques
  • Knowledge transfer

• **Experience** essential for later work at Äspö HRL and other underground laboratories
The purpose of Äspö HRL

- Provide input to performance assessments
  - in situ data from a previously non-disturbed rock mass
  - process understanding
  - assessment of model validity
- Develop, test and evaluate methods for investigation, repository construction and waste emplacement
- Provide experience and training of staff
The site investigations performed

- Two site investigations were performed
  - Forsmark
  - Oskarshamn (Simpevarp/Laxemar)
- The investigation programme were similar, and performed in parallel
- Presented examples are mostly from Simpevarp/Laxemar
The main activity "Investigations"
- Characterization of the geosphere and the biosphere

The work at each site was divided in two main groups:

- Investigation; producing primary data
- Site modelling; producing site descriptions
The programme development 1

• An important issue for the site investigation programme development was to specify what information/data is needed

• The information/data users were
  • Safety assessment (long term safety)
  • Design and engineering (layout, stability)
  • Environmental Impact statement
  • "General (geoscientific) understanding”

• Strategies
  • dividing the task in disciplines,
  • performance in a step-wise procedure,
  • integration between disciplines,
  • interaction with the data/model users
The programme development 2

- Investigation methods feasible for collecting data and for testing rock properties were selected, and further developed when needed
- Extensive experiences from earlier site investigations, mainly
  - Study site investigations; 1977-1986
  - Stripa projects; 1977-1991
  - Åspö Hard Rock Laboratory; 1986-, pre-investigation, construction and experiential phase
- An appropriate sequence of activities were compiled to a generic investigation programme (TR-01-29)
- After selection of candidate sites, the programme was adapted to site specific programmes (R-01-42, R-01-44 (in swedish))
Some information of importance for the characterisation

Geology
- Rock type (distribution and properties)
- Major deformation zones, dividing the rock mass into rock blocks (occurrence and character)
- Fracturing within the rock blocks (frequency and character)

Rock mechanics and thermal properties
- Properties of intact rock and fractures
- Rock stress (magnitude and orientation)
- Thermal conductivity

Hydrogeology
- Hydraulic conductivity of rock mass
- Transmissivity of deformation zones
- Interaction between bedrock and soil

Hydrogeochemistry
- Water chemistry
- Fracture minerals

Transport properties
INITIAL SITE INVESTIGATION

PURPOSE
Select priority site within candidate area.

RESULTS
- Homogenous rock area of 5–10 km² selected as priority site.
- Description of surface ecosystems and fundamental geoscientific conditions.

PREREQUISITE
Candidate area of up to 200 km² has been selected on the basis of feasibility study.

CANDIDATE AREA

SCOPE
- Regional area.
- One or more subareas.
- General field investigations, mainly:
  - airborne geophysics and ground geophysics
  - geology and surface groundwaters, and
  - inventory of flora, fauna and cultural environments.
- Limited percussion drilling.
- Initiate long-term monitoring of near-surface groundwaters and ecosystems.
- General studies regarding the execution of a deep repository.

SCOPE
- Seismic reflection and VSP (downhole) for preliminary mapping of fracture zones and depth.
- 2–3 deep (~1000 m) cored boreholes for checking essential conditions within groundwater chemistry (dissolved oxygen, salinity), rock mechanics (stresses, strength), geology and hydrogeology.
- Initiate long-term monitoring of seismic movements and deep groundwater.
- Establish initial site-adapted layout and analyze feasibility.
- Safety assessments based on requirements and criteria and compare with SR 97.

RESULTS
- Preliminary site description (based on in-depth information as well).
- Preliminary facility description.
- Preliminary safety judgement.
COMPLETE SITE INVESTIGATION

PURPOSE
Gather the necessary supporting data for selection of site and application for siting permit.

SCOPE
- Supplementary geological and geophysical ground surveys on the site and in the regional environs.
- Drilling programme (percussion and cored drilling) with measurements including:
  - measurement and sampling during drilling,
  - core mapping, BIP (Borehole Image Processing), geophysical measurements,
  - flow logging, injection tests, pumping tests, cross-hole tests,
  - dilution tests, groundwater sampling/analysis.
- in-situ rock stress measurements and laboratory analyses of rock samples.
- Continued long-term monitoring.
- Activities governed by site-specific conditions and arising questions (cf. red symbols in figure at left, i.e. ○○○).
- Site-specific databases with quality-assured primary information.
- Site models on regional and local scale.
- Site-adapted deep repository facility and analysis of feasibility.
- Complete safety assessment carried out.
- Background information for EIA consultations and EIS document.

LEGEND
- Fracture zones of varying size
- Vertical cored borehole
- Inclined cored borehole

RESULTS
- Site description.
- Facility description.
- Safety report.
Siting factors

- Safety related site characteristics
  - Bedrock composition and structure
  - Future climate
  - Rock mechanical conditions
  - Groundwater flow
  - Groundwater composition
  - Retardation
  - Biosphere conditions
  - Overall site understanding

- Technology for execution
  - Flexibility
  - Technical risks
  - Technology development needs
  - Functionality, operational aspects
  - Synergies
  - Costs

- Health and environment
  - Occupational health and radiation protection
  - Natural environment
  - Cultural environment
  - Residential environment
  - Management of natural resources

- Societal resources
  - Suppliers, human resources
  - Public and private services
  - Communications
Site characterisation and site selection
Site characterisation in Sweden for a repository for spent nuclear fuel

Candidate sites: Forsmark and Laxemar-Simpevarp

Investigations and modelling work: 2002-2008

Site selection: 2009
Sites

- **Forsmark site**
  - flat topography
  - below the highest shoreline at last deglaciation, 6 mm uplift per year
  - metamorphosed medium-grained granite to granodiorite (metagranite) formed between 1,900 and 1,850 million years ago

- **Laxemar site**
  - relatively flat topography
  - below the highest shoreline at last deglaciation, 1 mm uplift per year
  - granite and quartz monzodiorite, some 1,800 million years old
Site investigation data

- **Surface investigations**
  - airborne photography, airborne and surface geophysical investigations
  - lithological mapping and mapping of structural characteristics
  - investigations of Quaternary deposits
  - meteorological and hydrological monitoring, hydrochemical sampling of precipitation, surface waters and shallow groundwater investigations

- **Drilling and borehole measurements**
  - 14 (Forsmark site) and 20 (Laxemar site) deep (800 - 1,000 m) cored drilled boreholes
  - Several more shallow core drilled and percussion drilled boreholes
  - Mapping, testing and monitoring boreholes and bore cores (geology, thermal properties, rock mechanics, hydrogeology, chemistry)
  - Many soil/rock boreholes
Evaluation of field data – Site Descriptive Model

- Synthesis
  - geology, rock mechanics, thermal properties, hydrogeology, hydrogeochemistry and surface system
- Traceability
  - From field investigation to 3D interpretation
- Assessment of uncertainties and confidence
- Used by Design and Safety Assessment
- Usually a new version after each data freeze
Site Descriptive Modelling

Investigations

Database
Primary data (measured data, calculated values and conceptual assumptions)

Interpretation of geometries and properties

Sitedescriptive model
- Geology
- Geometry (Structural geology)
- Rockmechanics
- Thermal properties
- Ecosystem
- Transportation properties
- Hydrogeology
- Hydrogeochemistry

Site description

Method-specific interpretation

“Datawash”, computations

Integrative, discipline specific interpretation

Integration, Cross disciplinary interpretion
QA and Peer Review

- Clearance procedures for entering data into Site database (SICADA)
- Internal Peer Review
  - documented (templates)
  - SKB staff
  - independent expert group
- International review teams set up by the authorities
  - review all published reports
  - Tracking Issue List
- Seminars held about two times every year.

*All these actions essential!*
Confidence Assessment

- Confidence assessment protocols
- Aim at identifying and quantifying uncertainty
  - including alternatives
- Explore various origins of uncertainty
- Procedure
  - experts first answer
  - assessed and revised in a workshop with all experts
- Feedback to continued investigations
- Documented
Accesses and Central area

Accesses & Central area

- Ramp: 4800 m
- Skip shaft: 535 m
- Elevator shaft: 490 m
- Ventilation shafts (x2): 450 m
- Central area halls (x7): 40-65 m
- Central area transport tunnels: 500 m

Niches connecting to shafts and for vehicles/equipment

Estimated development time: 6 years

- Ramp: 4.5 years
- Skip shaft: 2.5 years
- Central area: 1-1.5 years
Data needs and requirements

- Updating of site descriptive models during the construction phase
- Frequency of water-bearing fractures and deformation zones
- In situ stress magnitudes at repository level
- Rock types and alterations
- Discrete Fracture Network uncertainties
- Excavation Damage Zone (EDZ)
- Groundwater composition at repository level and deeper
- Technical Design Requirements (TDRs)

Safety assessment and site understanding

- Thermally induced seismic risk
- Verification and updating of site understanding and long-term safety modelling

Repository engineering

- Monitoring and evaluation of groundwater drawdown
- Inflow to the repository

Environmental control
Key investigations

**Pilot hole investigations**
- MWD
- Core logging (tentative)
- Borehole deviation
- OPTV + geophysics
- Boremap
- Flow logging
- Selective hydraulic tests
- Hydrochemical sampling

**Probe hole investigations**
- MWD
- Hydraulic characterisation
- FLS → grouting input

**Geologic mapping**
- In situ and remote mapping, using different cut-off fracture lengths

**Test of rock strength**
- LHT test
- Rock stress measurements
- LVDT/convergence
- HF

**Hydrogeochemical and microbial sampling**
- Water inflow
- Monitoring of gw levels, flow and chemistry in boreholes from surface and underground
Investigations and monitoring

• Enhance the existing database for the bedrock with new data from underground investigations and monitoring.

• Identify responses in monitoring boreholes from rock excavations and hydraulic tests.

• Input to key issues and requirements.

• Evaluate the validity of and confidence in SDM-Site
Key issues and requirements

• Investigations carried out throughout the excavation of the accesses and Central area – and in conjunction with rock excavation cycle.

• Investigations and measurements related to Post closure safety will be given a high priority during construction.

• Sufficient time for investigations is an important prerequisite for planning the rock excavation cycle and production.
Validity of and confidence in SDM-Site

• **Compare data sets** – check if data/models from surface based boreholes match those from underground pilot holes.

• **Compare model prediction and outcome** – check whether modelled geometries and properties from SDM-Site are correct:
  • Stratigraphy and thickness of Quaternary deposits.
  • Location and geometry of deterministically modelled DZ where these can be expected to intersect the accesses and Central area
  • Statistics of fracture transmissivity of flowing fractures in underground pilot holes in relation to statistics used in SDM-Site for DFN modelling of flowing fractures
  • Rock stress orientation and magnitude vs. depth
  • Spatial distribution of groundwater composition vs. depth.

• Ongoing monitoring of groundwater levels in boreholes important for baseline and the evaluation of pressure responses.
Investigations in the ramp

- Spiral shaped ramp with 4.5 revolutions, → opportunity to investigate anisotropy and statistical geoinformation.
- Test, update and fine-tune investigation strategies and methods.
- Provide input to rock excavation (reinforcement measures) and design (stress orientation and magnitude).
- Prove that the excavation technique fulfils the Technical Design Requirements related to EDZ before ramp reaches -370 m (in a separate niche).
  - Probe hole drilling and associated investigations (e.g. FLS)
  - Pilot hole drilling and assoc. investigations (20% of the ramp).
  - In situ stress measurements in connection to niches.
  - Measurement of water inflow to the ramp every 150-200 m in weirs.
  - Hydrogeochemical and microbial sampling and monitoring (in niches)
Strategy for pilot hole drilling in the ramp

- Understanding of expected rock conditions where the ramp will pass

- Rock excavation requires information regarding: water-bearing fractures when passing through DZ judged to require reinforcement.

- Pilot hole drilling ~20% of the total ramp length~1000 m:
  - Confirm and investigate boundary between fracture domains
  - Characterise intercepts with deterministically modelled DZ
  - Provides data for DFN-modelling
  - Provide input to construction and design
  - Hydraulic tests, geophysical logging and (hydrogeochemical sampling)
Thank you for your attention!

The Forsmark site