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

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SKB

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

From the study site investigations 1977-1985

From the underground test facilities

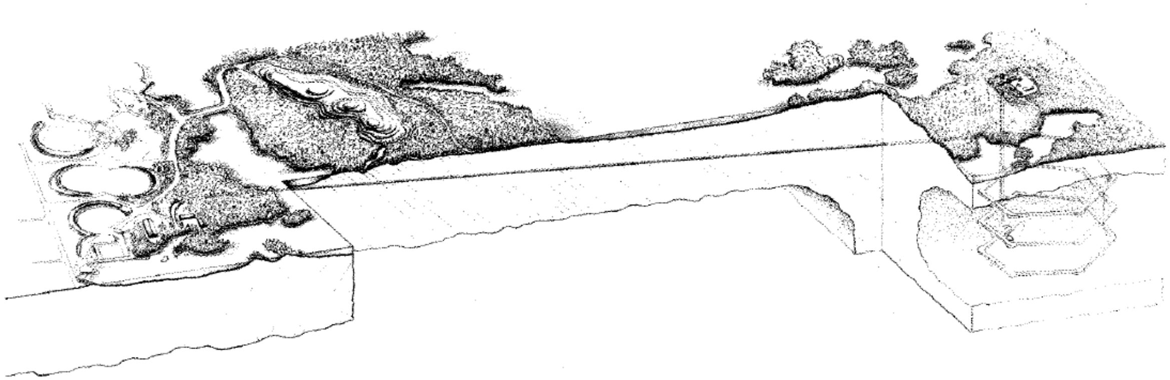
Stripa Mine Project 1977-1992

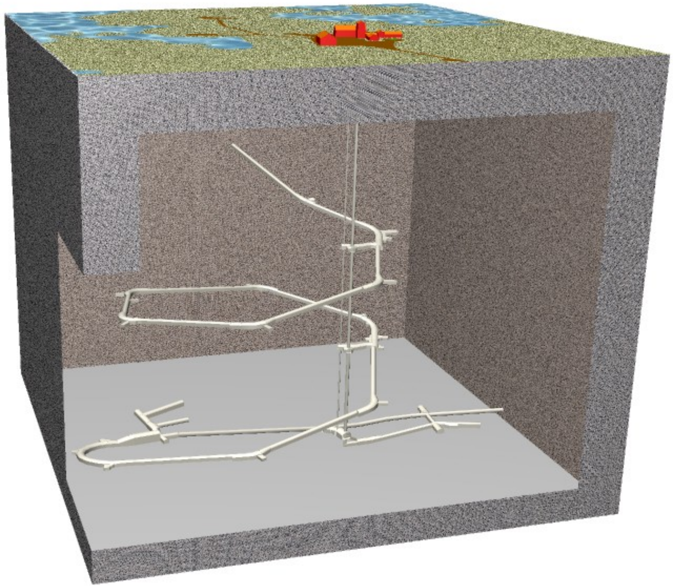
- Development of **characterization techniques and integrated characterizatio**n **and modeling** of site data
- Fracture flow and transport modeling
- Basis for understanding of channeling and its importance for radionuclide transport
- Basic designs of engineered barriers (buffer, backfill and plugs) 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

Äspö Hard Rock Laboratory 1986-

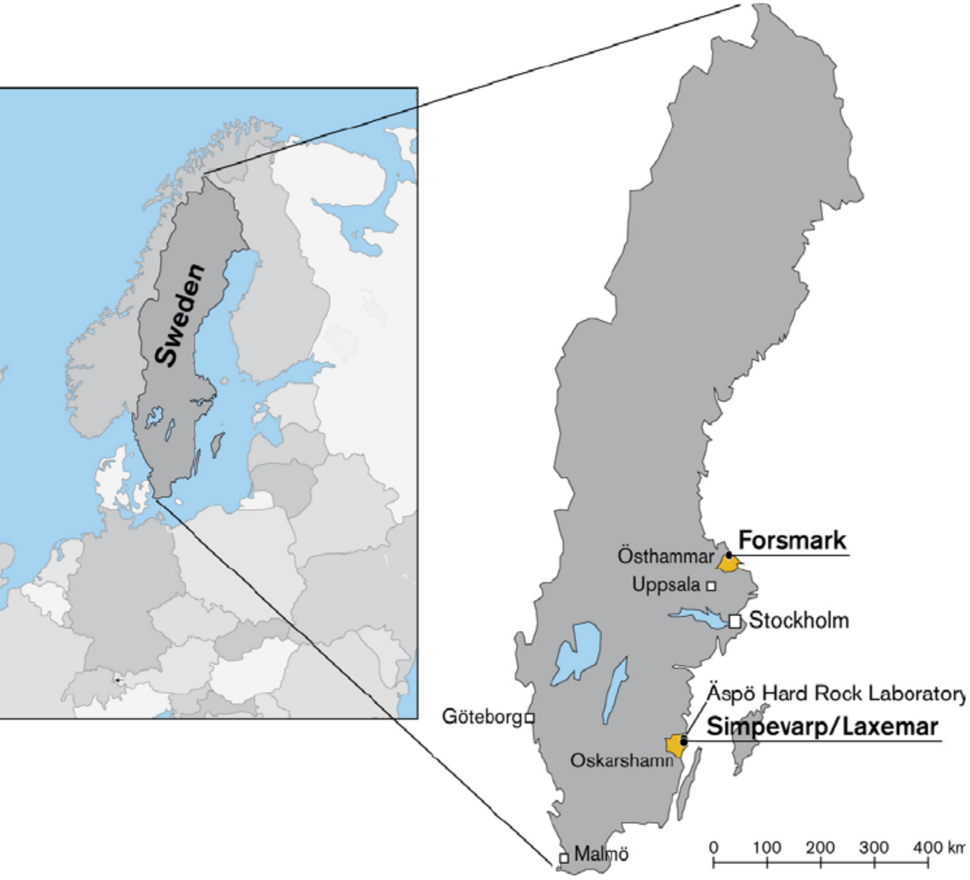
The purpose of Äspö HRL

- 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



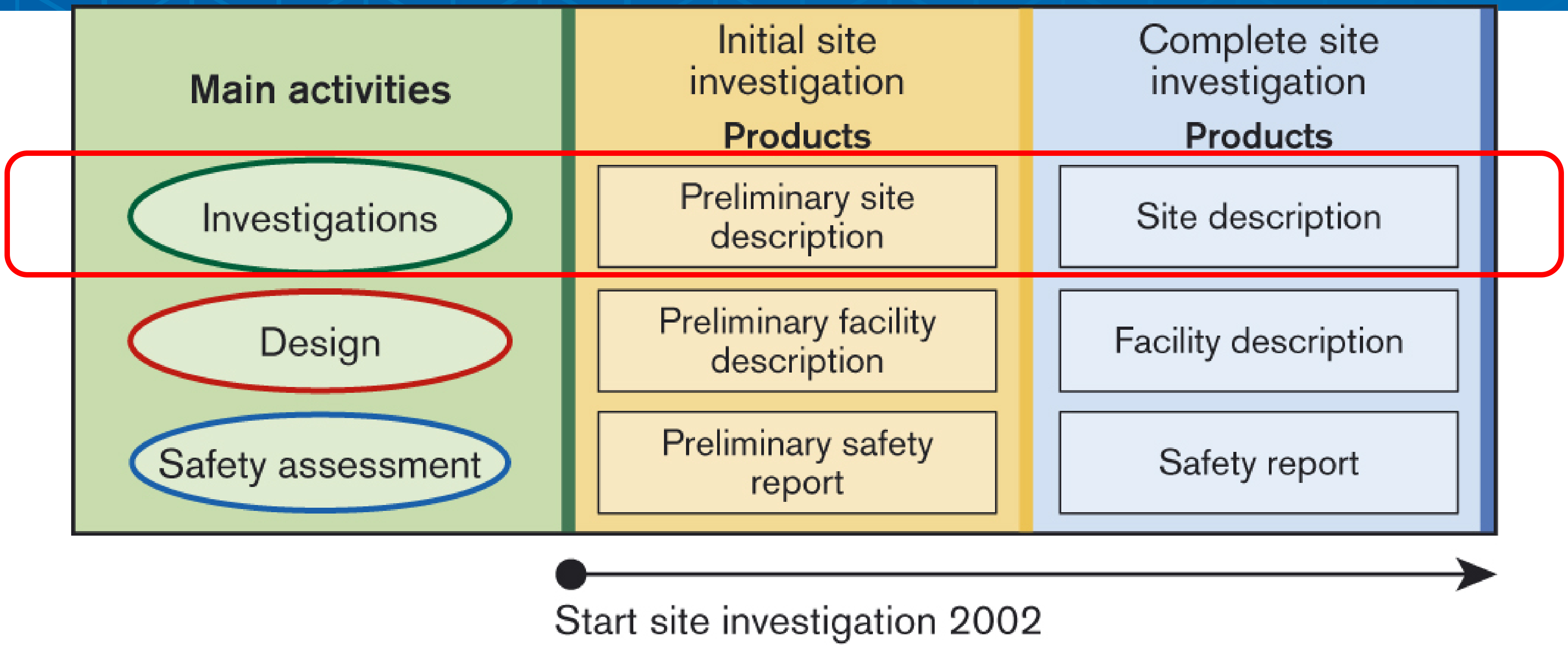


The site investigations performed



- Two site investigations were performed
  - Forsmark
  - Oskarshamn (Simpevarp/Laxemar)
- The investigation programme were similar, and performed in parallell
- Presented examples are mostly from Simpevarp/Laxemar

The main activity "Investigations"
- Characterization of the geosphere and the biosphere

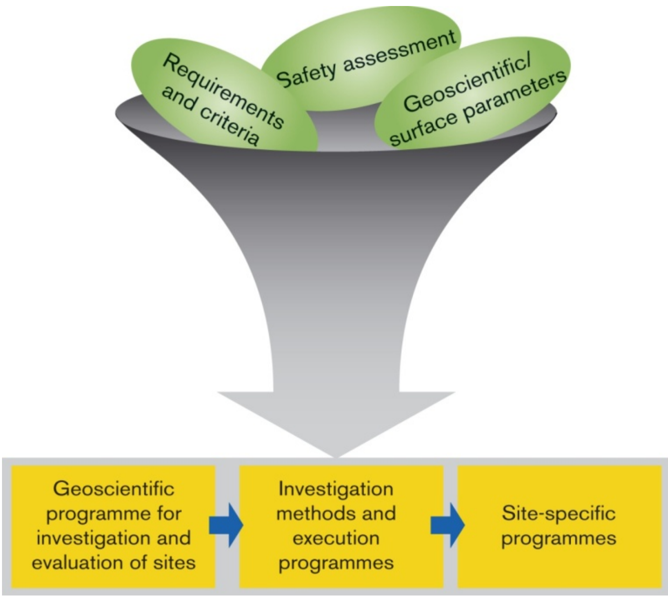


The work at each site was divided in two main groups:

- Investigation; producing primary data
- Site modelling; producing site descriptions

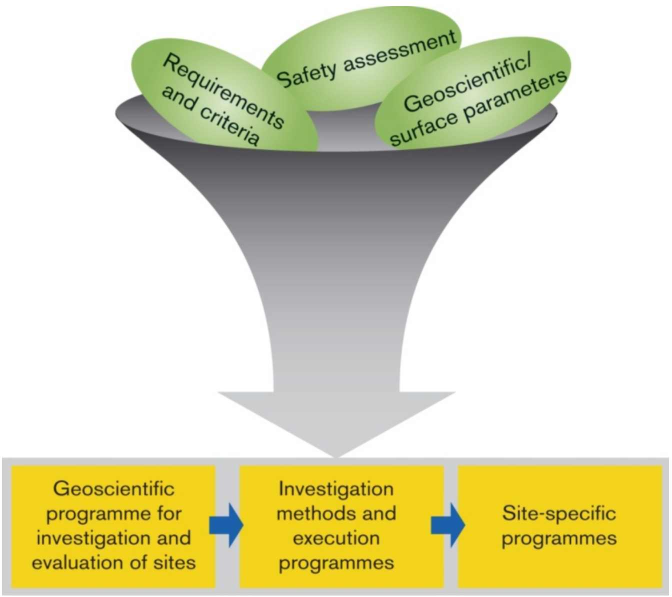
The programme development 1

- 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 enginering (layout , stability)
  - Environmental Impact statement
  - ”General (geoscientific) understanding”
- Strategies
  - dividing the task in diciplines,
  - performance in a step-wise procedure,
  - integration between diciplines,
  - 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
  - Äspö Hard Rock Laboratory; 1986- , pre-investigation, construction and experiental 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 (occurence 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

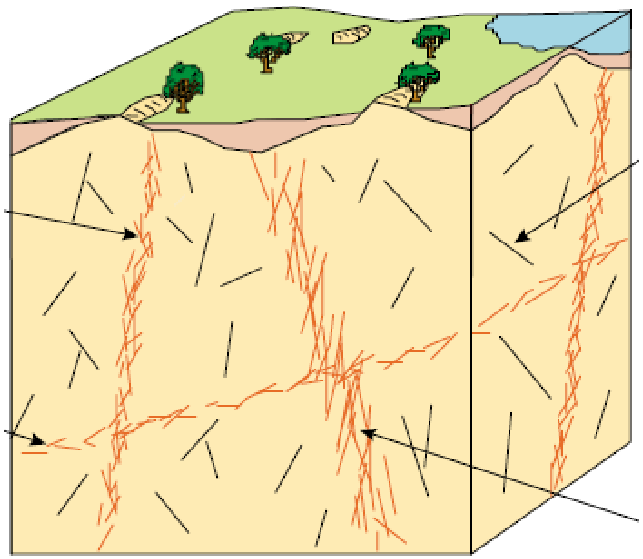
Hydrogeology

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

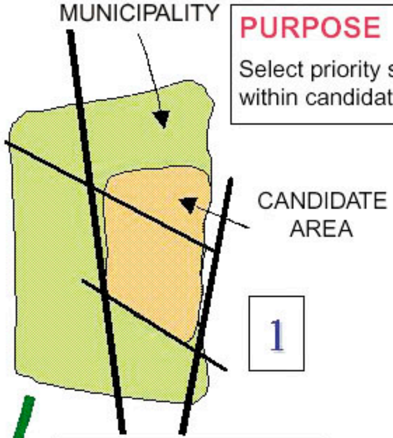
Hydrogeochemistry

- Water chemistry
- Fracture minerals

Transport properties



INITIAL SITE INVESTIGATION



PURPOSE

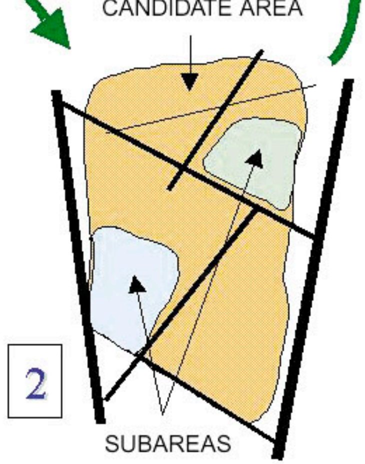
Select priority site within candidate area.

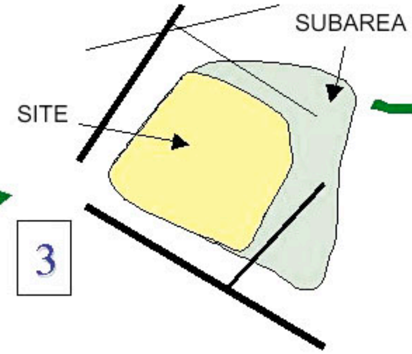
RESULTS

- Homogenous rock area of 5–10 km^2 selected as priority site.
- Description of surface ecosystems and fundamental geoscientific conditions.

PREREQUISITE

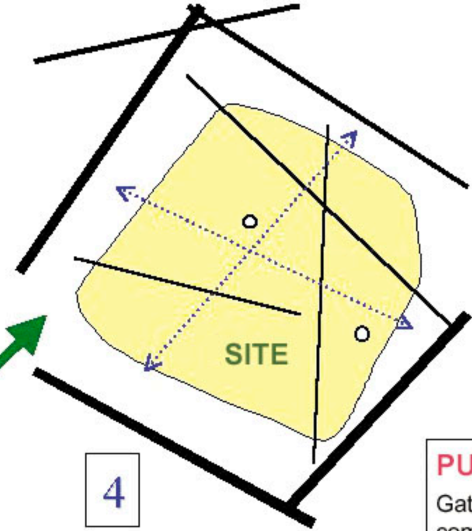
Candidate area of up to 200 km^2 has been selected on the basis of feasibility study.





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.



LEGEND

Interpreted lineaments and fracture zones of varying size

Seismic reflection measurement profile

Deep cored borehole

PURPOSE

Gather data for decision on complete site investigation.

SCOPE

- Seismic reflection and VSP (downhole) for preliminary mapping of fracture zones and depth.
- 2–3 deep (~ 1000 m) cored borehole 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

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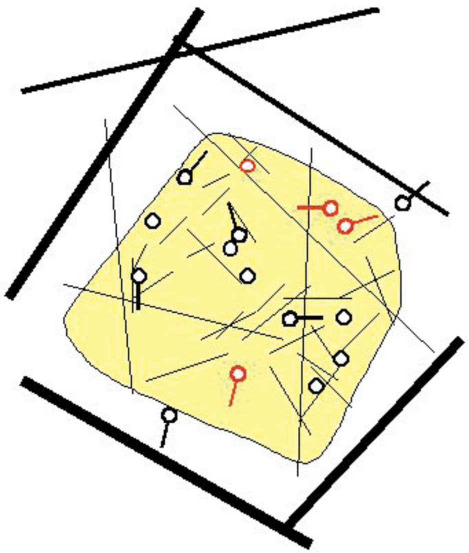


LEGEND

Fracture zones of varying size

Vertical cored borehole

Inclined cored borehole

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.

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

Societal resources
- Suppliers, human resources
- Public and private services
- Communications

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

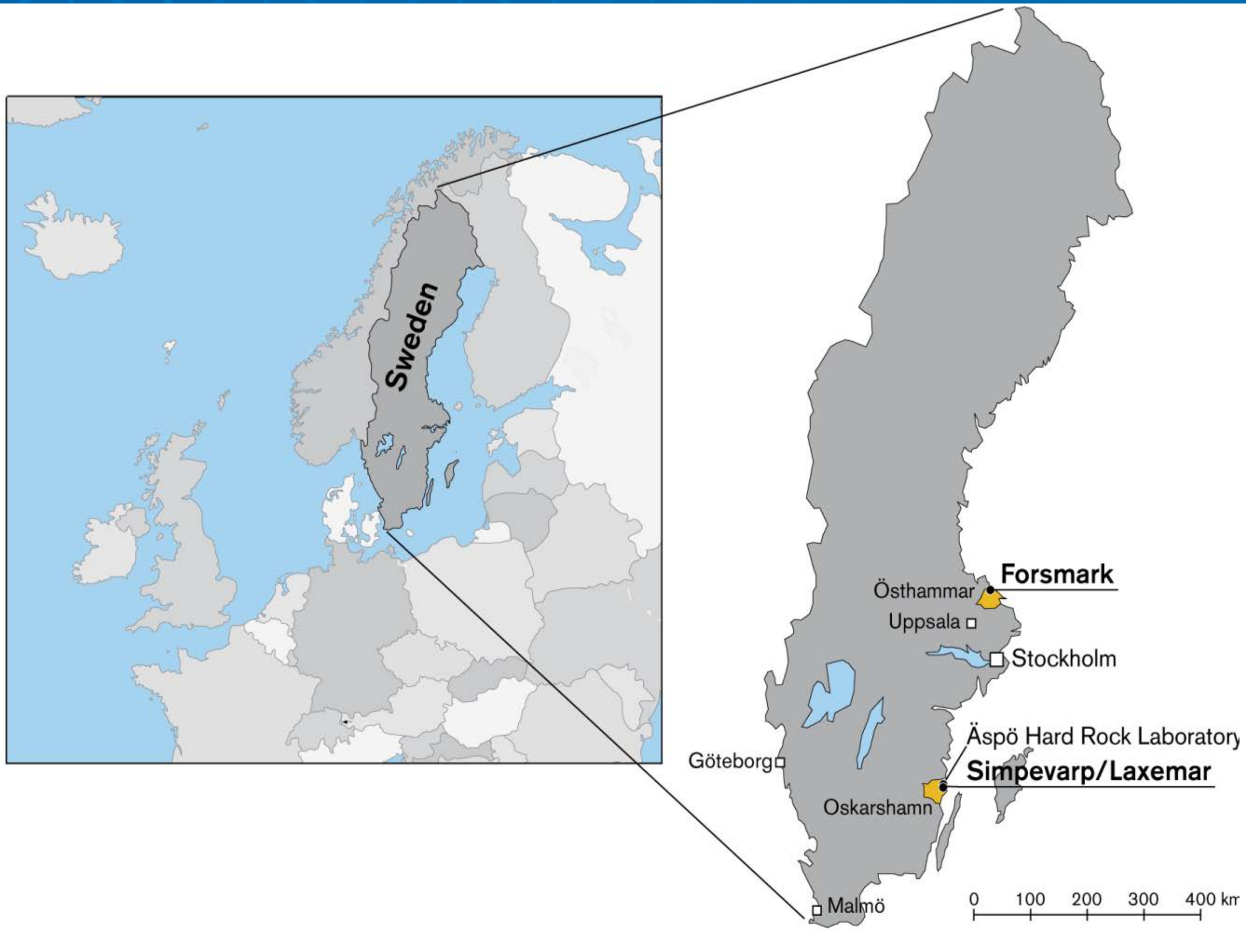
Site characterisation
and
site selection

Site characterisation in Sweden for a repository for spent nuclear fuel

<u>Candidate sites</u>: Forsmark and Laxemar-Simpevarp

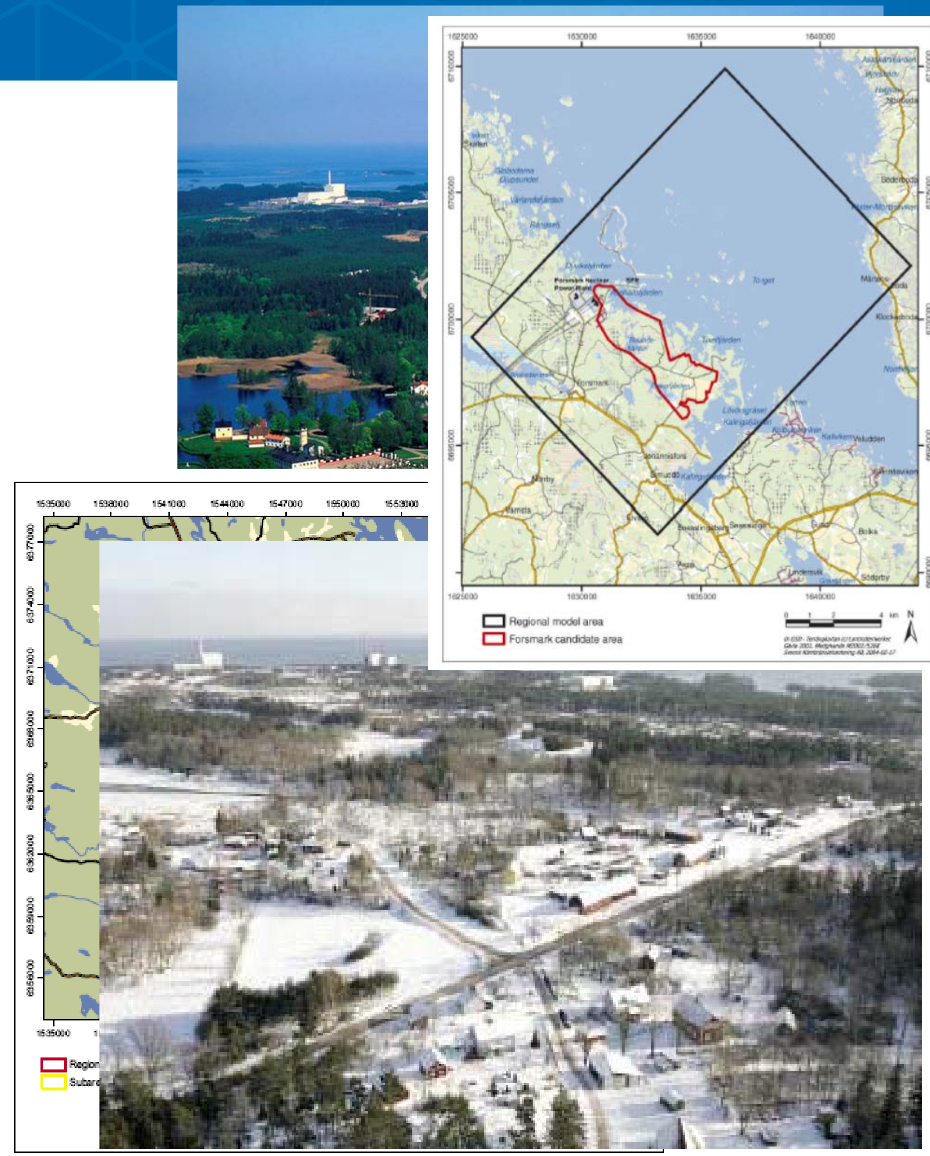
<u>Investigations and modelling work:</u> 2002-2008

<u>Site selection</u>: 2009



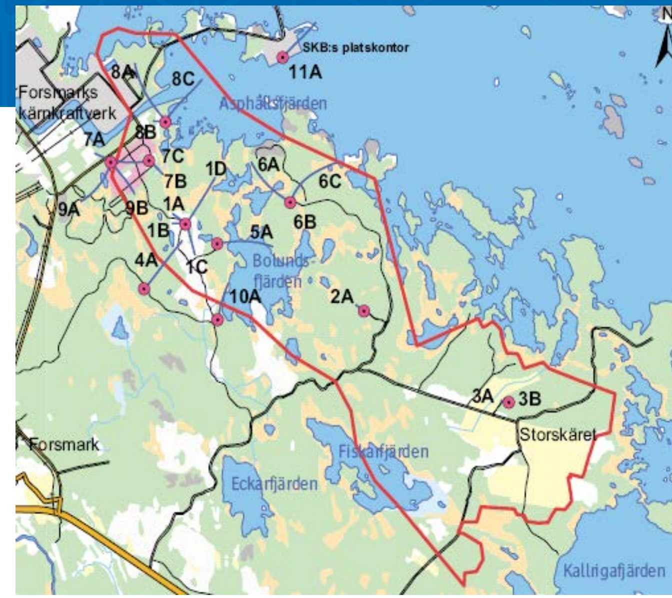
Sites

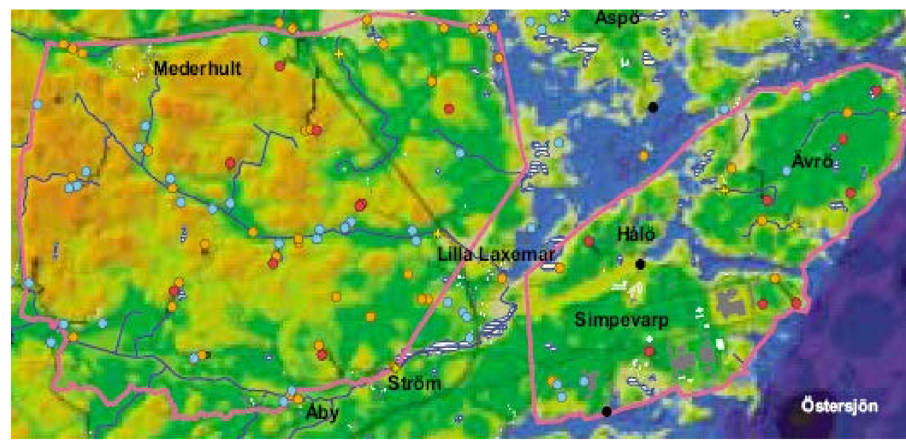
- **Forsmark site**
  - flat topography
  - below the highest shoreline at last deglaciation, 6 mm uplift per year
  - metamorphosed medium-grained granite to granodiorite (metagranite) formed between 1,900 and 1,850 million years ago
- **Laxemar site**
  - relatively flat topography
  - below the highest shoreline at last deglaciation, 1mm uplift per year
  - granite and quartz monzodiorite, some 1,800 million years old



Site investigation data

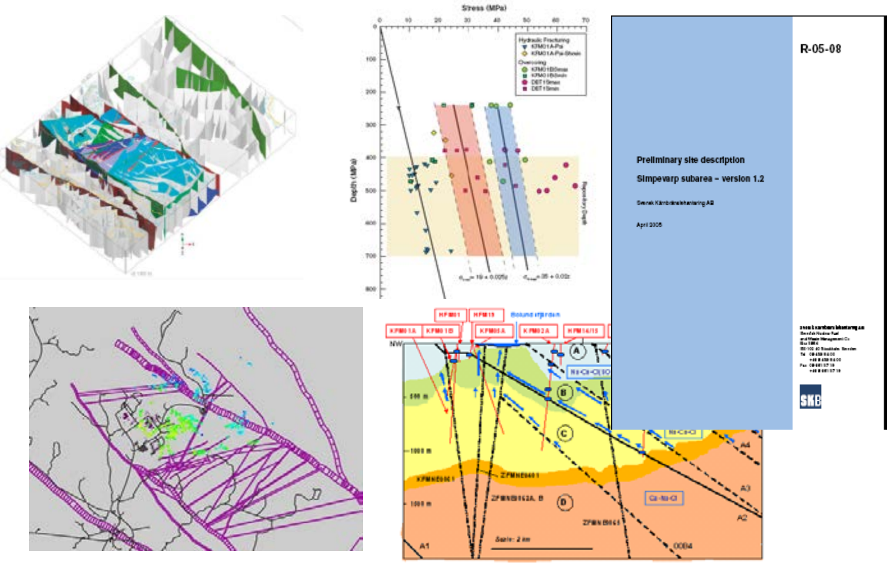
- **Surface investigations**
  - airborne photography, airborne and surface geophysical investigations
  - lithological mapping and mapping of structural characteristics
  - investigations of Quaternary deposits
  - meteorological and hydrological monitoring, hydrochemical sampling of precipitation,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

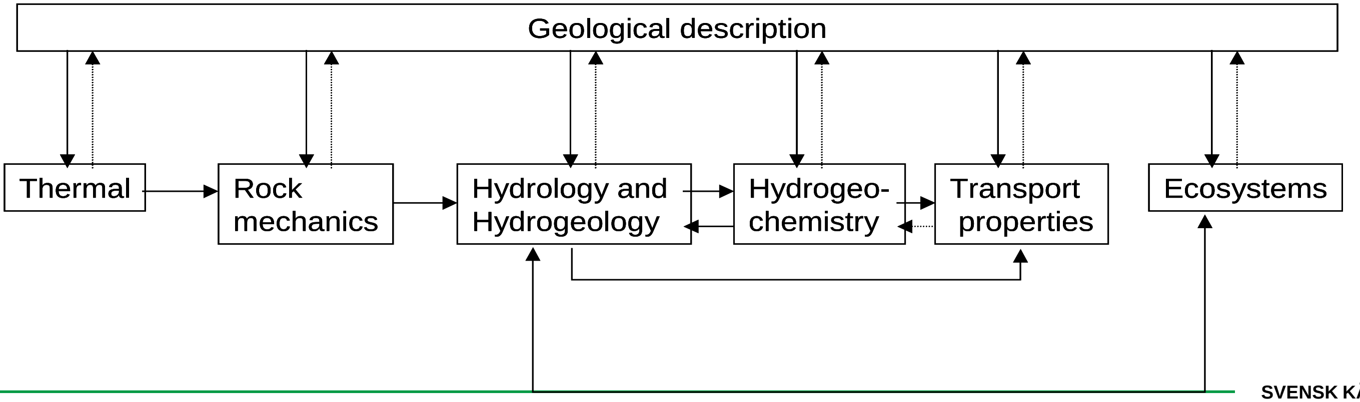




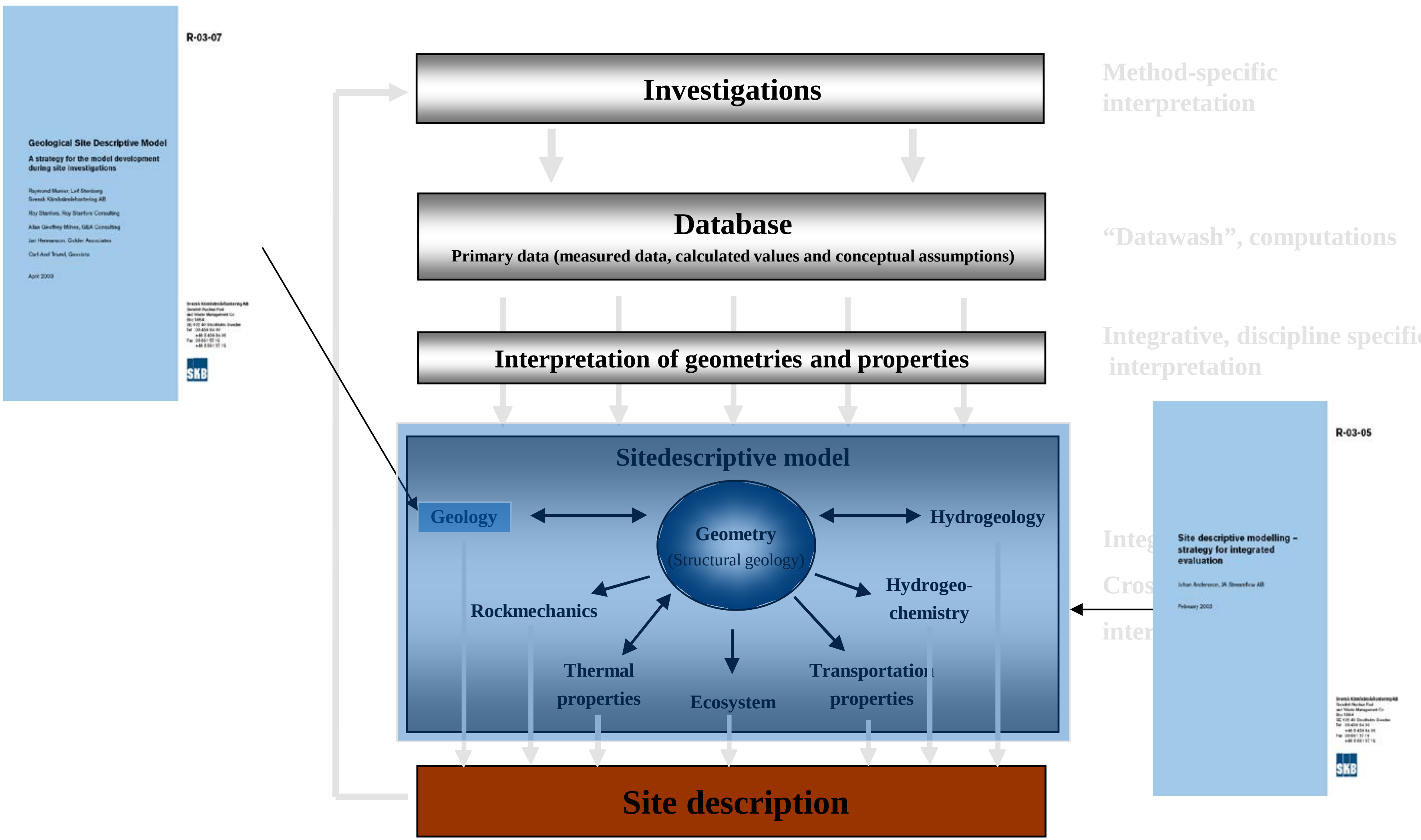
Evaluation of field data – Site Descriptive Model

- 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



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!

Review of document 1(2)

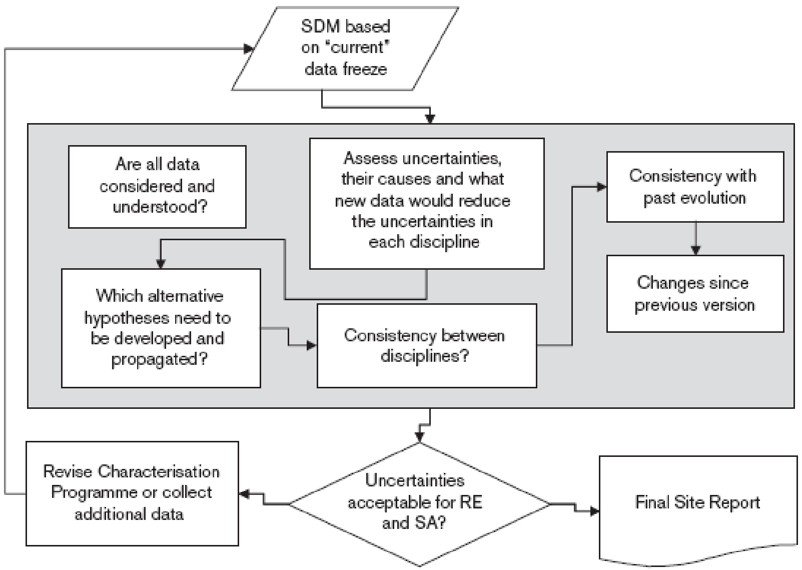
Type: Report	Review date: #Please fill in date#	Revision #:0.1	Revision date: 2007-07-03
Author(s):	Pär-Erik Back1, John Wrafter1, Lars Rosén2 & Jan Sundberg1 1:Geo Innova AB 2:Sweco Viak		
Document:	Thermal properties – Site Descriptive modelling of Forsmark, stage 2.2		
Reviewer(s):	**#Please fill in your name#**		

Space for general comments

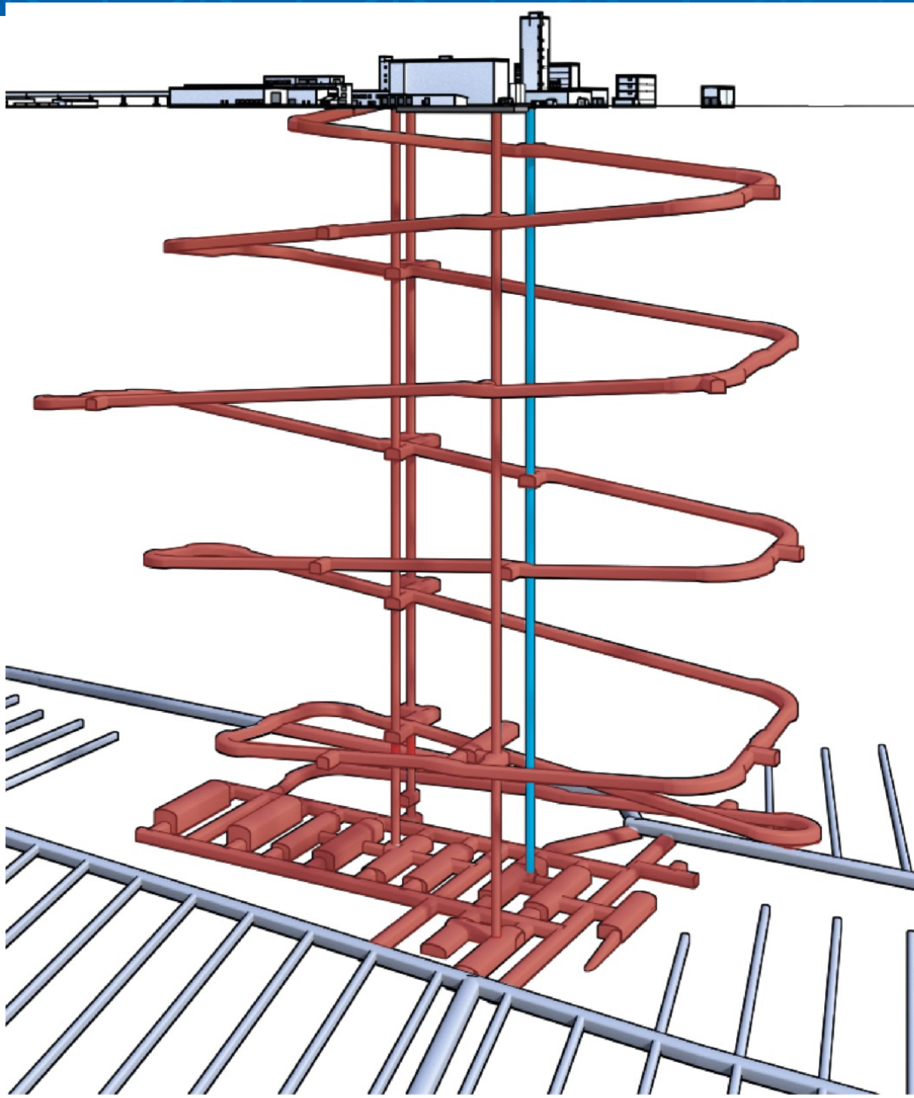
			To be filled in by the Reviewer		*To be filled in by the Author*
ID	**Page**	**Section**	**Content**	**Comment/Question**	**Revision** **Correction/Explanation**
1			Reference is made for example by using cited text, figures, tables, etc.	Advisory comment or question. Proposal for improvements.	What correction is undertaken in respect of the given comments or questions? Explanation in case the comment left without notice.
2					

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

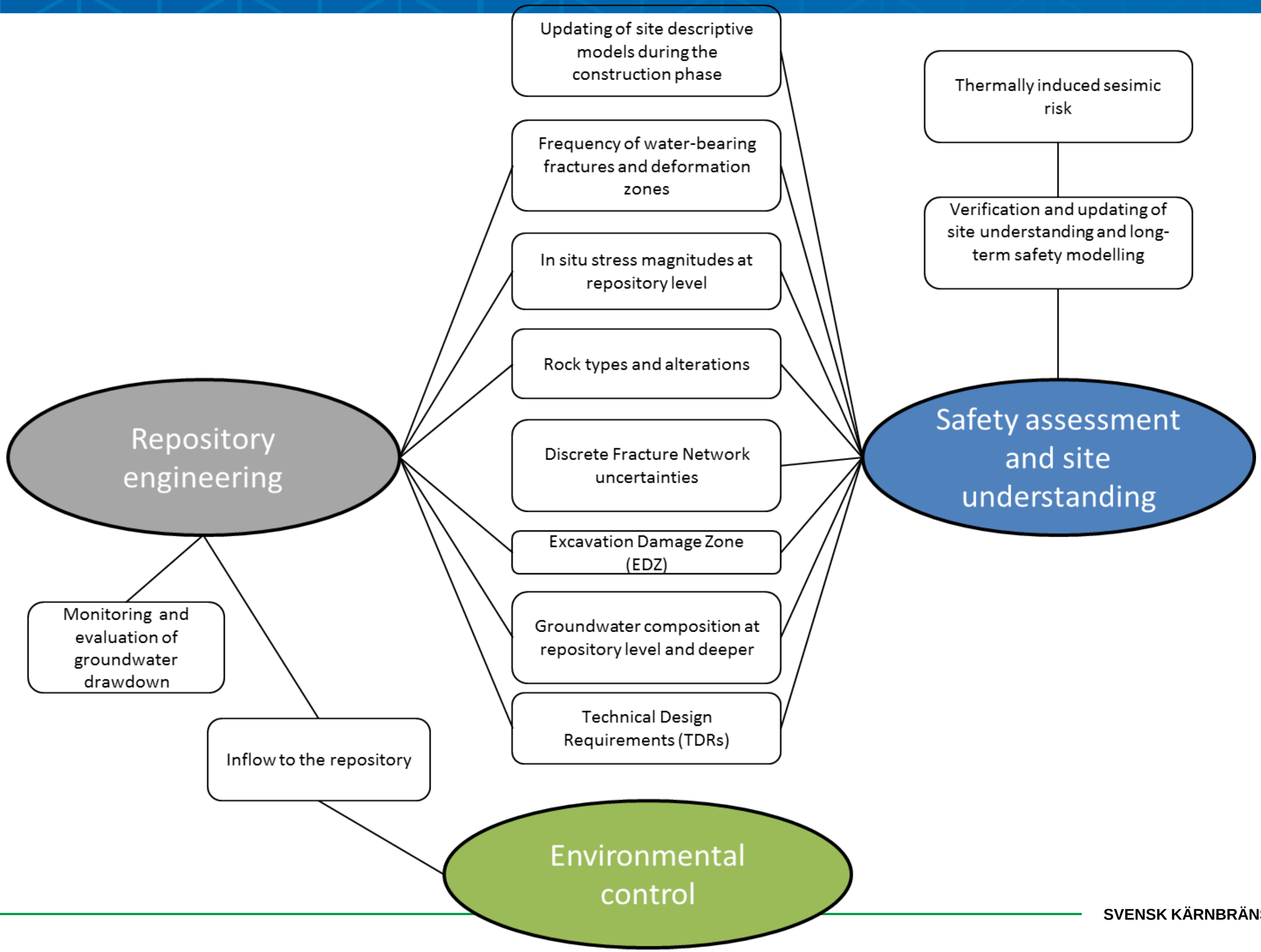
Niches connecting to shafts and for vehicles/equipment

Estimated development time: 6 years

Ramp: 4.5 years
Skip shaft: 2.5 years

Central area: 1-1.5 years

Data needs and requirements



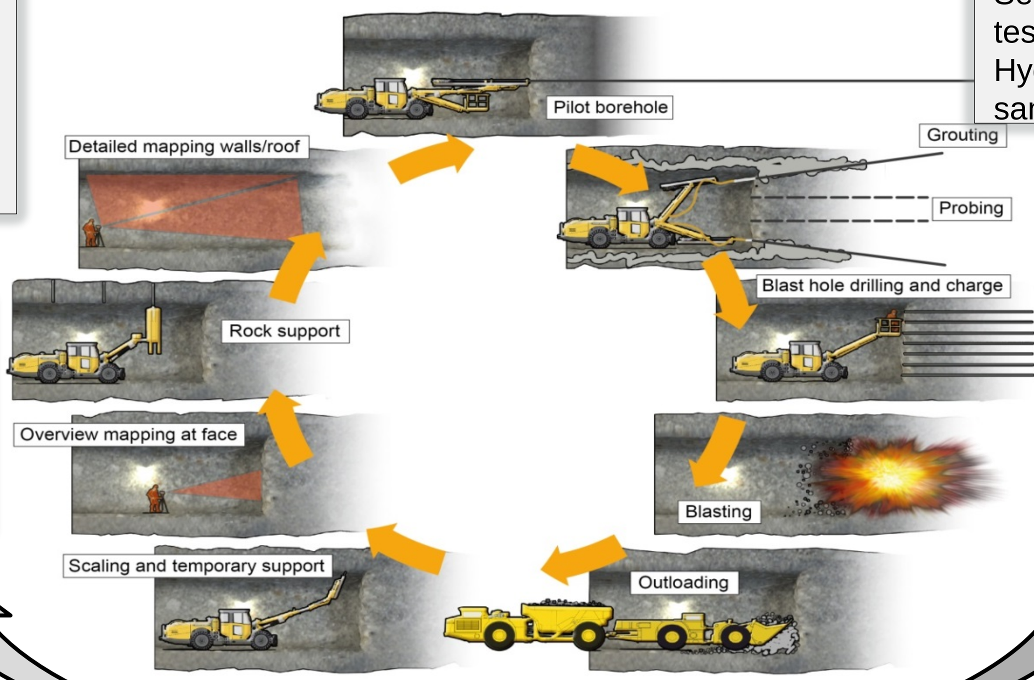
Key investigations

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

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

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

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



Probe hole investigations
MWD
Hydraulic characterisation
FLS→ grouting input

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!