BENTONITE SEALS

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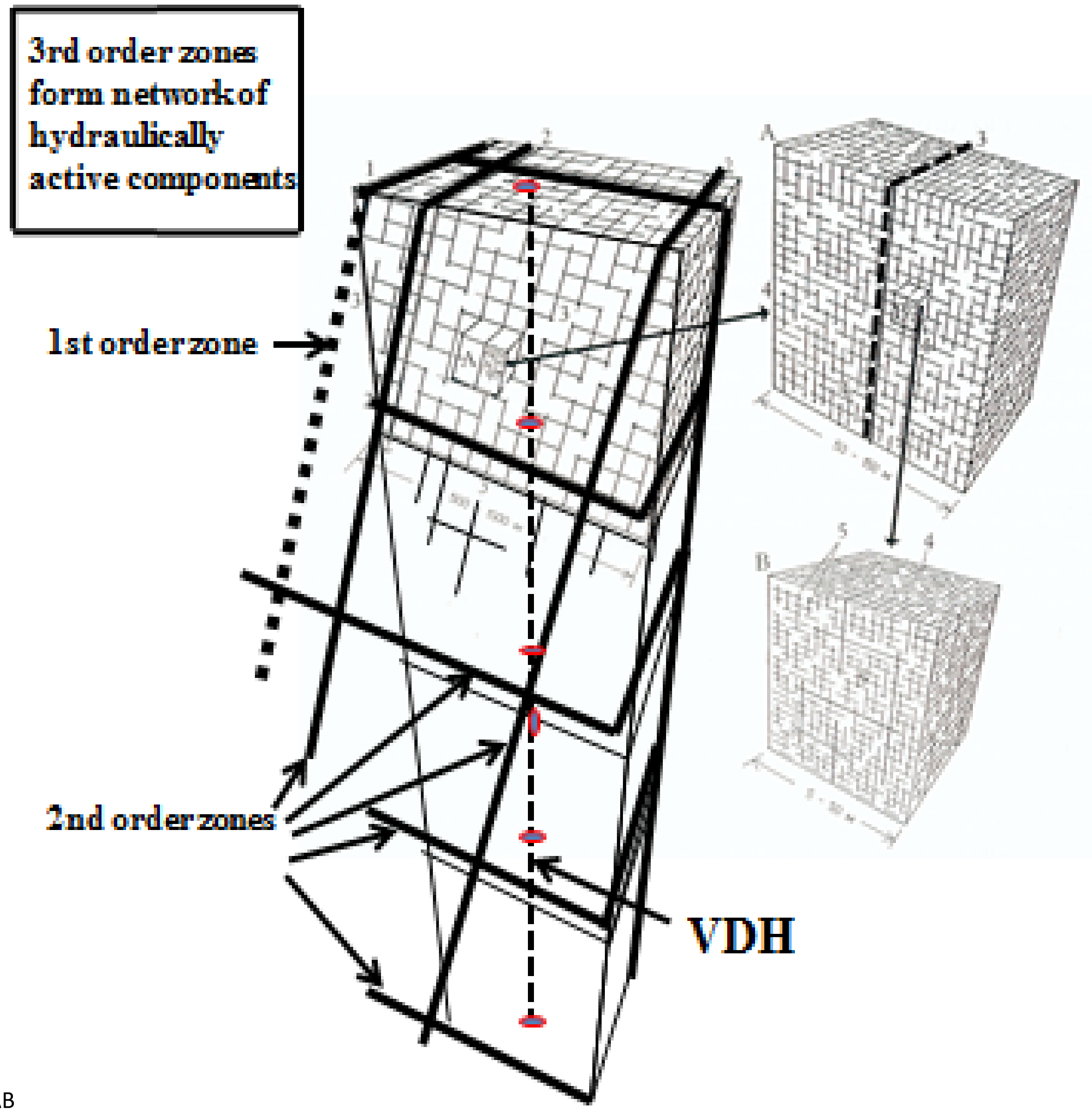
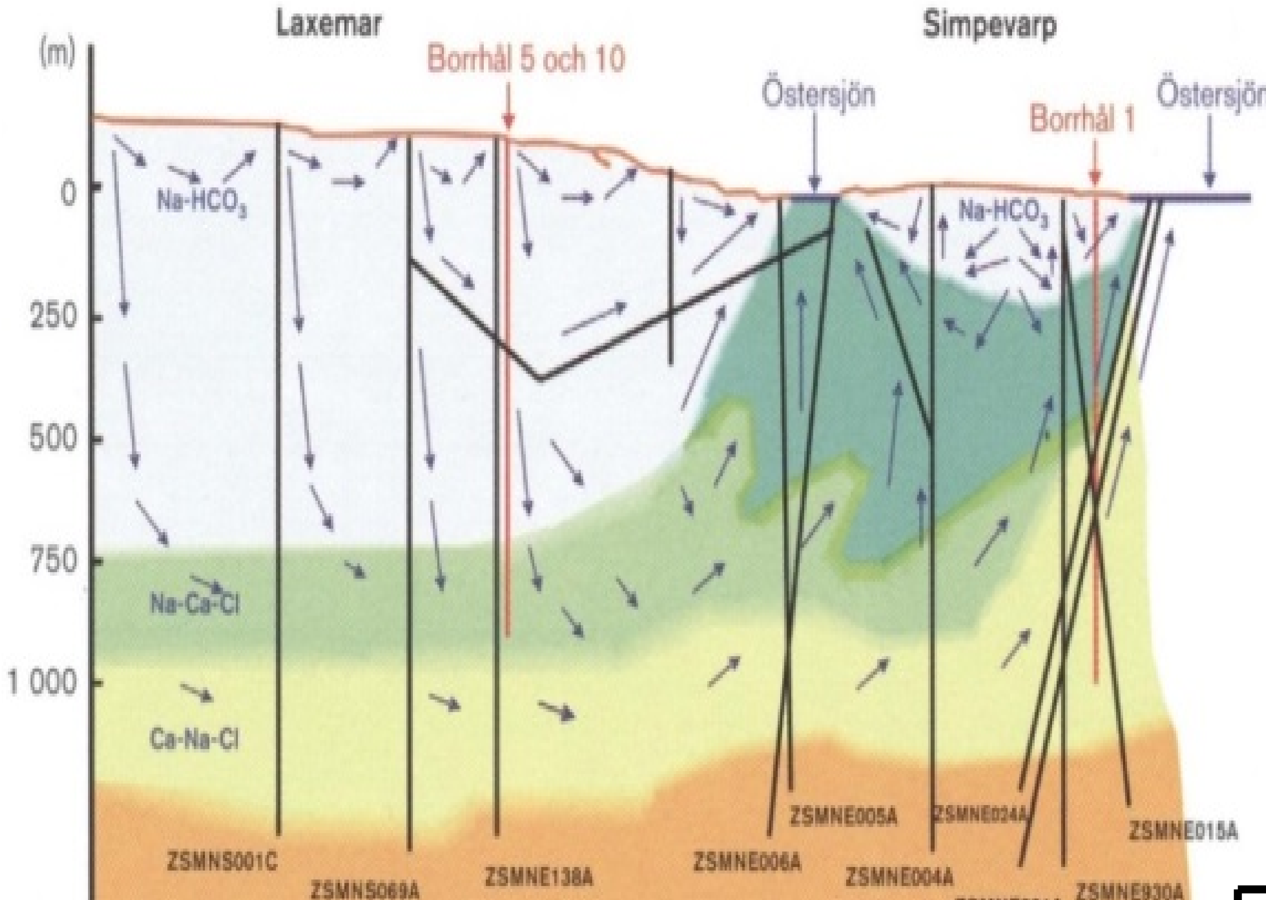
BENTONITE SEALS IN ROCK



Red spots show where a VDH intersects major fracture zones:

NO WASTE HERE, AND NEED FOR CONCRETE SEALS! CLAY WOULD BE ERODED AND LOST!

THE ROLE OF HEAVY GROUNDWATER



General groundwater flow and distribution of dissolved salt in the host rock of a HLW repository.

Grey: Fresh to low-brackish

Dark-green =medium brackish.

Light-green= strongly brackish

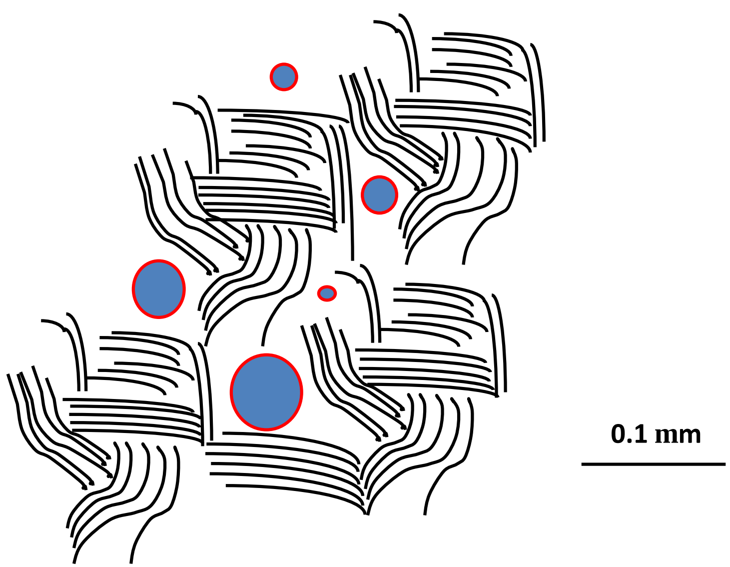
Yellow=salt water (Ocean type with Ca major cation)

Brown= old, heavy and stationary salt water

Drawrite AB

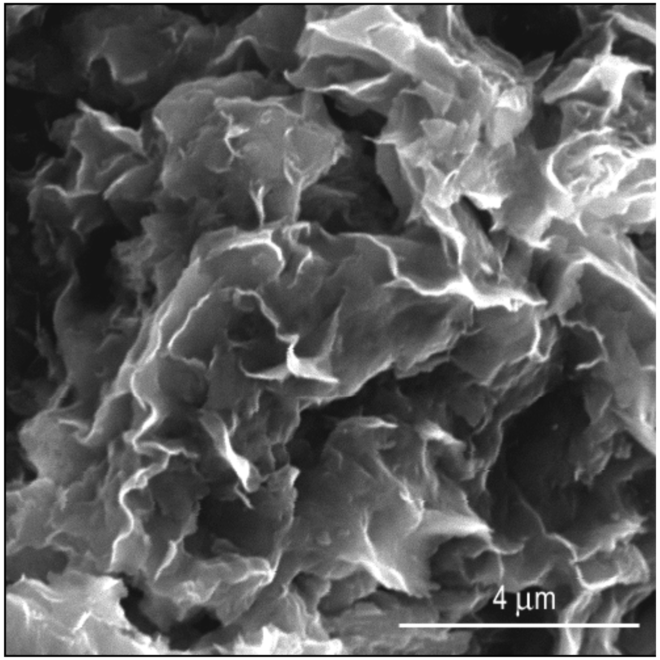
BENTONITE CLAY - Constitution

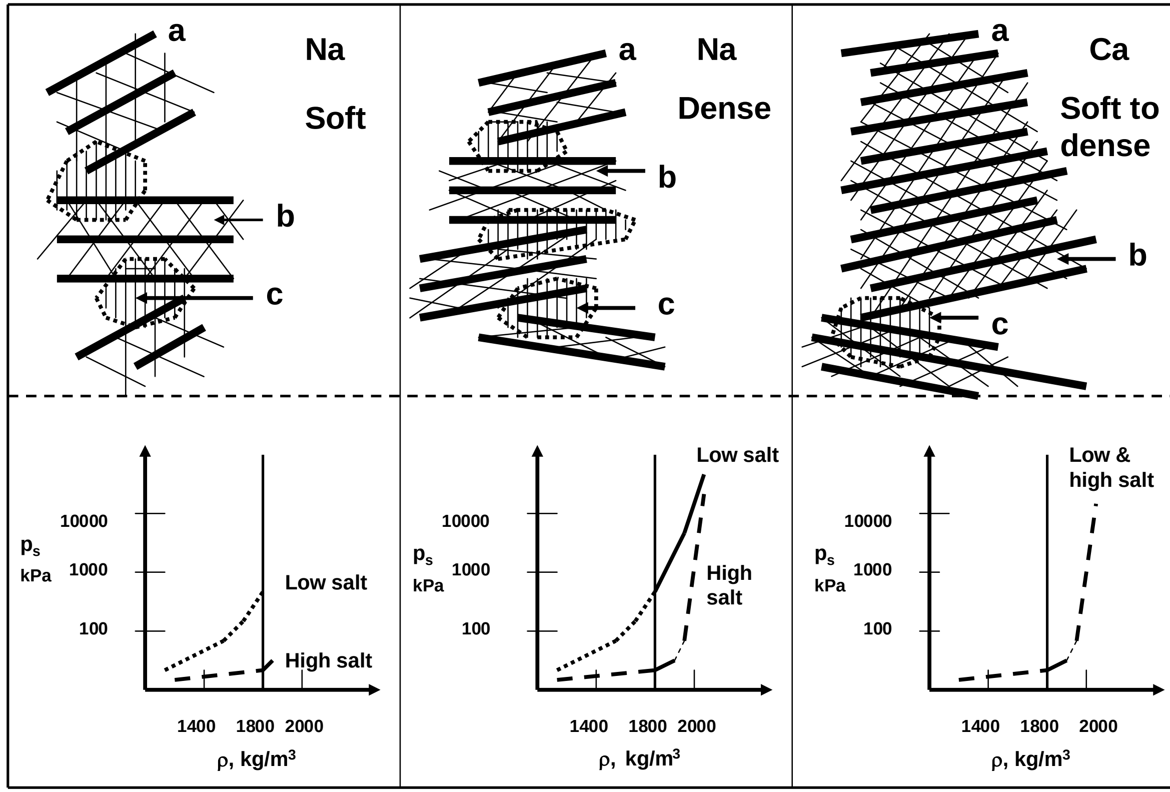
- The dominant clay mineral belongs to the smectite family – similar to micas but is expandable,
- The particles form a continuous system with very small voids, which gives the clay a permeability that is a hundred to ten thousand times lower than of ordinary clays like illite and kaolinite. It is therefore an excellent sealant for isolating radioactive waste placed in deep boreholes.



Schematic cross section of the microstructure of fully matured smectite-rich clay with a bulk density at water saturation of 1800-2000 kg/m^3. For the lower density the bar is 0.1 mm and for the higher 0.01 mm.

BENTONITE – Role of density





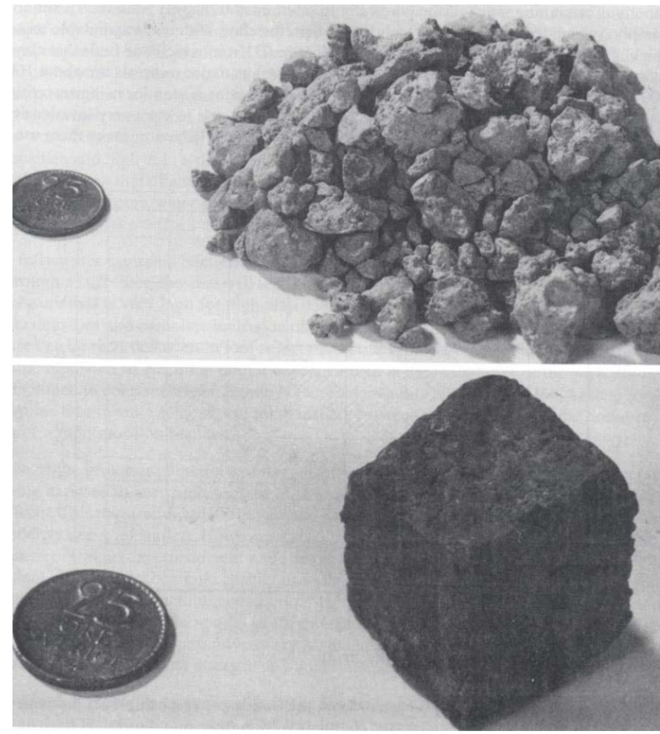
a) lamella, b) interlamellar space, c) contact region with interacting electrical double-layers, exposed hydroxyls and sorbed cations

The mica-like particles contain lamellae separated by water and ions like sodium (Na) or calcium (Ca). Their spacing depends on density and salinity and controls expandability and permeability

BENTONITE – Raw and processed material

Bentonite stems from volcanic ash, transformed to smectite clay in salt sea. Mineral companies dry and grind it. The granules have 7-12 % water content.

Bentonite quarry in Germany



Upper: Dried and ground bentonite,
Lower: Clay granules confined in a form and allowed to sorb water

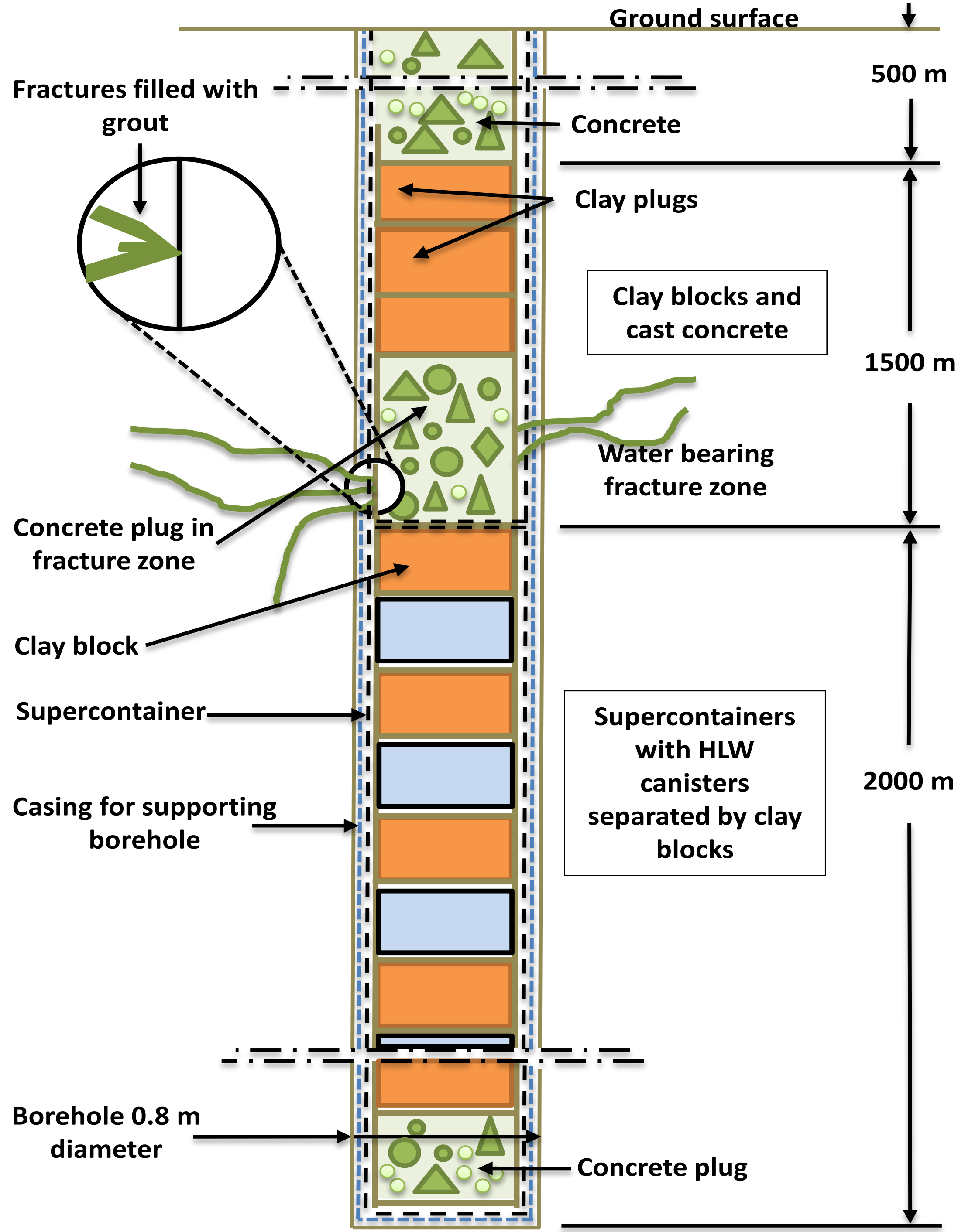
Very dense 0.3 m diam. block of compacted granules, compaction pr. 100 MPa

BENTONITE SEALS in VDH

Concept proposed in Sweden by Drawrite AB and Luleå University of Technology

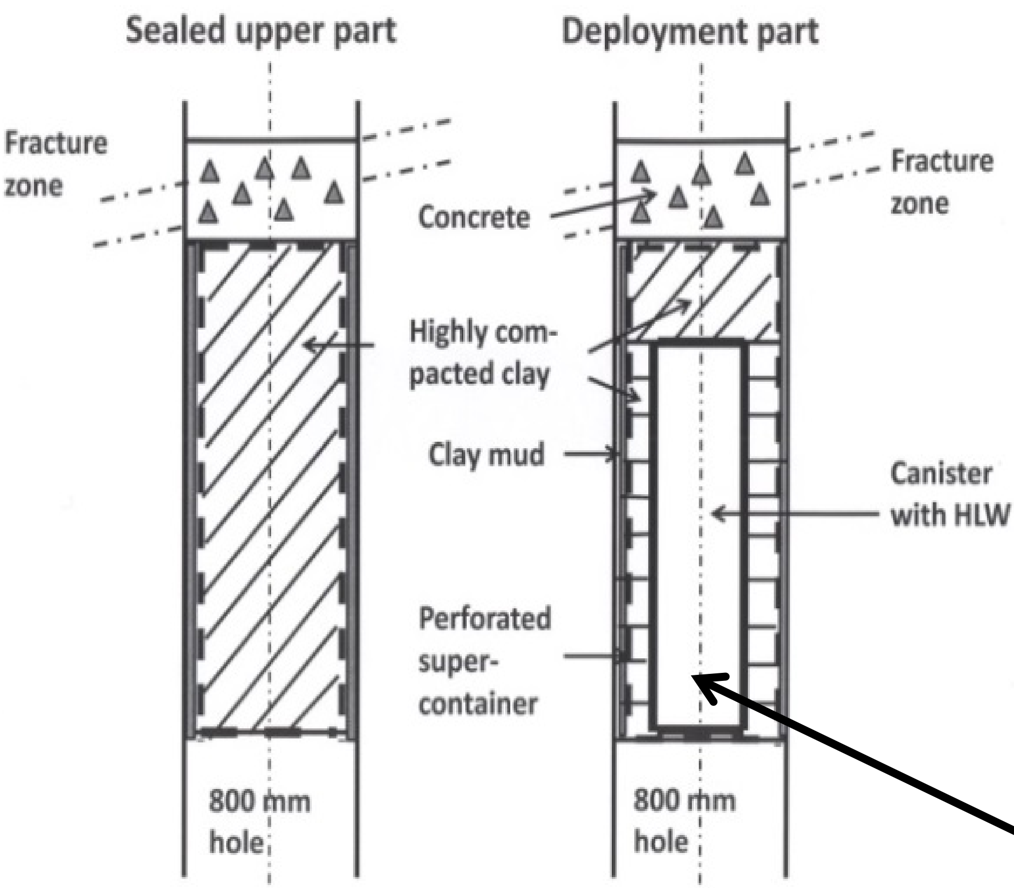
Bearing ideas:

1. By connecting the supercontainers one knows exactly where each unit is located!
1. Casing below 500 m may not be required



Drawrite AB

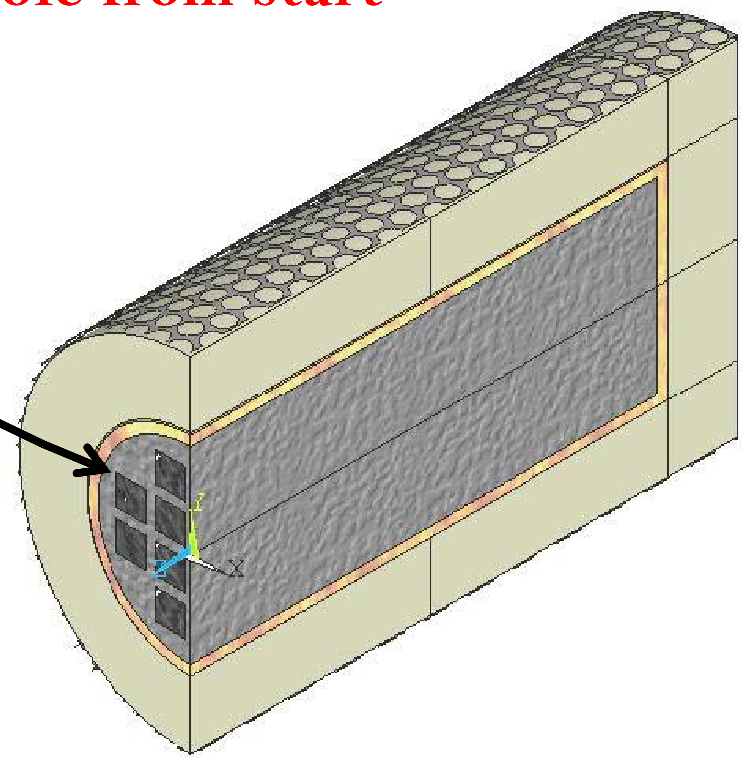
BENTONITE SEALS IN VDH



Note!

Final density of fluid-saturated clay>1900kg/m³

Smectite mud with density 1100-1200 kg/m3 in the hole from start



Containers with clay only

Containers with waste/clay

Drawrite AB

BENTONITE SEALS - Function in upper VDH

Criteria for the upper 2 km with T<70°C: i) Less permeable than surrounding rock, ii) no erosion, iii) no shrinkage.

i) Na bentonite with 1900 kg/m3 density saturated with Ca-dominant water (TDS=5-10 %) has the conductivity K<E-11 m/s,

ii) Placement where there are no major fracture zones means that no spontaneous dispersion or erosion will take place,

iii) Cation exchange from initial Na to Ca will cause a drop in expandability but no shrinkage: the dry density has to be lower than 950 kg/m3 for shrinkage!

Long-term function of clay seals in the upper 2 km with T<70°C

iv) Dissolving metallic Fe converts to magnetite (aerobic and anaerobic corrosion), and gives free Fe ions and gaseous hydrogen esp. down to 1 km depth. The clay will sorb Fe and become less ductile and expandable but not more permeable. H-gas will pass through and channnels self-seal.

Corrosion of steel components to i.a. magnetite with density 5.2 g/cm3 from 7.8 g/cm3, gives expansion by about 50 % causing very high pressure on the clay that becomes impermeable but brittle claystone.

BENTONITE SEALS - Function in lower VDH

Criteria for the lower 2 (3 km for DOE) km; T up to 150°C:

i) maintained high density; ii) no erosion, iii) maintained coherence. The main waste-isolating effect is due to the dense, salt groundwater.

i): Na bentonite with 1900 kg/m3 density contacting Ca-dominant brine with TDS=15-20 % has K<E-11 m/s or less since salt fills up voids and channels,

ii) No spontaneous dispersion or erosion will take place,

iii) Cation exchange from initial Na to Ca will reduce expandability but is avoided since the density is higher than 1600 kg/m3!

Long-term function of clay seals in the lower 3 km part; T<100°C

Considering steel HLW canisters in contact with Na/Ca bentonite we know:

- Si will be dissolved from the clay and precipitate at the steel canister surface causing cementation and loss of expandability,
- new expandable mixed-layer illite/smectite phases are formed. Thermodynamics and natural analogs predict formation of non-expandable "illite" close to the steel canister and kaolinite far from it.

BENTONITE SEALS - Conclusions

- The VDH concept requires smectite mud (1100-1200 kg/m^3) for supporting the rock, and for delaying expansion of the dense clay in the supercontainers in the placement phase,
- In the upper 2-3 km sealed part the bentonite is not heated to more than about 70^{o}C and matures sufficiently in a few days for carrying concrete cast where fracture zones are intersected. The clay stays largely intact except for cation exchange from Na-to-Ca. The permeability is lower than of the surrounding rock. The very low hydraulic gradients cause no through-flow, axially or transversially,
- In the lower 2-3 km deployment part T is 150^{o}C for a few decades and then drops to 70^{o}C. The high density of the matured clay makes it stay low-permeable, erosion-resistant & without shrinkage despite heat-generated mineral conversion and precipitation of Si and Fe-compounds.

BENTONITE SEALS, pros- and cons

Pros:

- The expandability makes the clay enter fractures in the rock and exert a swelling pressure on the rock, which eliminates leakage along the rock contact. Through-flow of very dense clay seals (>1900 kg/m^3) is virtually none even after exposure to 150°C because of the largely retained content of expandable minerals, that gives low permeability, and of the lack of vertical hydraulic gradients. They remain less permeable than the tightly contacting surrounding rock for at least E5 years as witnessed by natural analogs. They are erosion-resistant by slight precipitation of silica and iron compounds,
- Bentonite seals are ductile and can self-seal after shearing by being expandable.

Cons:

- Relatively expensive,
- Requires use of perforated ”supercontainers” for placement in clay mud,
- Placement of a single clay seal in a hole must be completed in a few days.