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Modern method for sealing deep boreholes

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ABSTRACT

Deep, investigation boreholes for suitable location of radioactive repositories and holes with larger diameter for storing such waste at great depth must be effectively isolated from the biosphere. A method for sealing boreholes by use of dense smectite clay where the rock is low-permeable and has only very fine fractures, and by concrete cast where the holes intersect water-bearing fracture zones, has been used for sealing of up to 500 m deep exploration boreholes in Sweden and Finland. The paper describes the practical conditions for construction of seals, and the processes that lead to the required tightness of the clay and concrete materials. Application of this technique to even deeper boreholes requires use of mud instead of water for stabilization and for moderating the rate of maturation. Placeability requires that the maturation of the initially unsaturated clay is neither too fast nor too slow and means of controlling the rate are described. The proposed concrete material has a very low cement content, and talc as fluidizer, which gives slow but ultimately very significant strengthening and low solubility of the cement reaction products. At a few kilometer depth the temperature can be more than 60 °C, which has to be sustained by the sealing materials, and this makes saponite and mixed-layer smectite/illite clay possible alternatives to pure smectites. The concept is judged to be applicable also to sealing of abandoned boreholes used for fracking.

1. Scope

Deep investigation boreholes in rock considered for hosting a radioactive repository, and large-diameter holes for storing such waste at great depth must be effectively isolated from the biosphere by installation of tight seals. Systematic work for finding practically useful sealing methods and materials was started in Sweden by the Swedish Nuclear Fuel and Waste Management Co (SKB) in the eighties and a method has been worked out and utilized for sealing of cored boreholes of up to 500 m length (Pusch, 1994; Pusch and Ramqvist, 2007; Pusch, 2015). It is proposed for holes reaching down to at least 4000 m as described in the paper, implying that clay seals are installed where the holes are located in low-permeable rock, and that concrete is cast in reamed parts where fracture zones are intersected (Fig. 1). The role of the concrete seals is primarily to provide stable and erosion-resistant support to the clay seals placed over them. If clay is used here instead of concrete it would be dispersed, eroded and lost, which could ruin the overall tightness of the seal system.

2. Conditions

A number of criteria must be fulfilled for successful installation and function of clay and concrete seals for up to 100,000 years in boreholes in the host rock of repositories with highly radioactive waste, and for disposal of such waste:

- the holes must be stable, rinsed and filled with electrolyte-poor water or clay mud, grouting of fracture zones for avoiding loss of clay from clay seals, and for avoiding build-up of hydraulic gradients that can damage placed but not yet matured[1] seals,
- the seals to be placed must not be stuck at installation because of obstacles,
- maturation of the clay seals must neither be too rapid nor too slow. Quick maturation causing too early expansion can make it impossible to bring the seals down in deep holes, while too slow expansion can delay strengthening and their ability to carry concrete that is cast on top of them,
- the hydraulic conductivity of the clay seals must be lower than of the surrounding rock and the swelling pressure must exceed 100 kPa for providing tight contact between seal and rock (Pusch, 2015).

The first condition can be fulfilled by applying techniques that are common in deep drilling for petroleum and gas prospection and exploitation, i.e. use of heavy-duty rigs, bore muds, rinsing techniques, and grouting.

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[1] We will use "mature" for hydration (wetting) and homogenization for reaching a defined, stable state.

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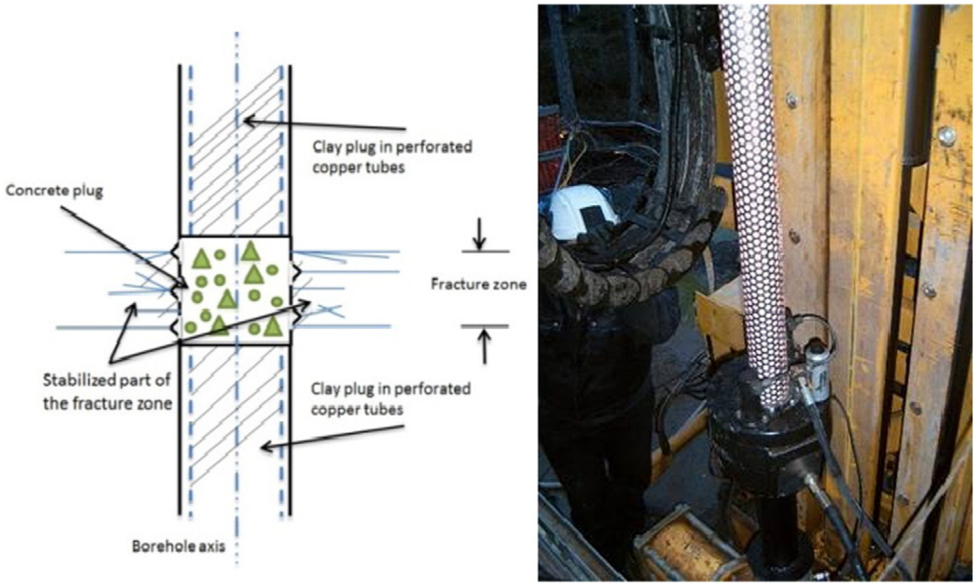

Fig. 1. Clay/concrete seals in boreholes. Left: Schematic view of seals in boreholes intersecting a fracture zone. Right: Installation of perforated copper tube with dense clay blocks in the 500 m deep borehole KR-24 at Olkiluoto, Finland.
Photo: Ramqvist.

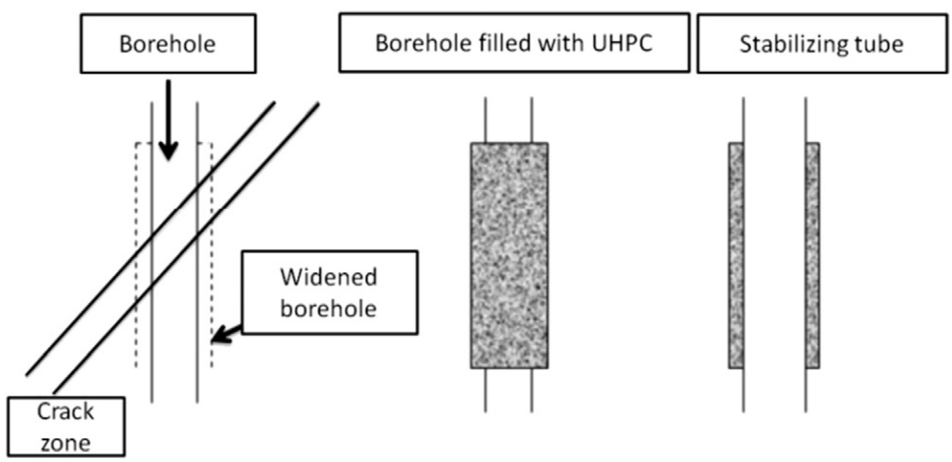

Fig. 2. Technique for stabilizing boreholes. Left: Borehole intersecting fracture zone, Center: Reamed hole filled with concrete (UHCP-type developed by the Swedish Nuclear Fuel and Waste Management Co) between packers, Right: Re-boring creates a stabile concrete tube.
After Torbjörn-Hugo Persson, SKB.

A technique for stabilization that has been tested in Sweden involves reaming, concrete casting and re-boring to the original borehole dimensions (Fig. 2).

The second condition is particularly important for sealing of holes bored from drifts at large depths where the groundwater pressure is high (Fig. 3). They may intersect fracture zones with different water pressures, which can expose clay and concrete seals to high hydraulic gradients that can cause permanent channeling and malfunctioning by piping and erosion.

The third, geometrical, condition means that clay seals and containers for casting concrete must not be longer than the straight parts of the commonly curved holes (Fig. 4). In practice, this means that they must not be longer than 10 to 12 m.

The fourth condition, respecting the maturation rate, is particularly important for sealing very deep holes since slow installation of clay seals can cause significant dispersion, erosion and loss of clay moving out from the clay seals being placed. This important issue is further discussed below.

The fifth condition concerns the geotechnical properties of matured clay seals and implies that their hydraulic conductivity should be lower than

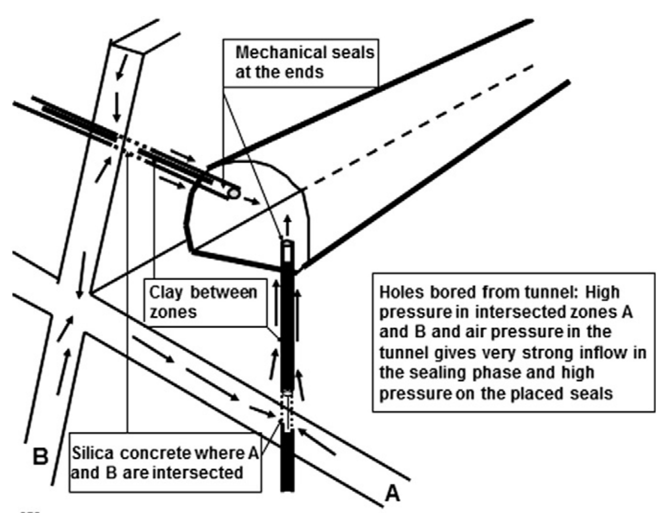

Fig. 3. Cases where high hydraulic gradients can prevail and damage freshly prepared clay and concrete seals. A and B are fracture zones with high water pressure.