CLAYS IN NATURAL AND ENGINEERED BARRIERS FOR RADIOACTIVE WASTE CONFINEMENT

CLAYS IN GEOLOGICAL DISPOSAL SYSTEMS

A brochure edited by ONDRAF/NIRAS (Belgium) and Andra (France), in collaboration with COVRA (The Netherlands), Nagra (Switzerland), NWMO (Canada), POSIVA (Finland) and SKB (Sweden), and published on the occasion of the 6th International conference 'Clays in Natural and Engineered Barriers for Radioactive Waste Confinement', Brussels, Belgium, March 23-26, 2015.

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nwmo
NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

SKB
Svensk Kärnbränslehantering AB

ANDRA
French national radioactive waste management agency

COVRA NV

nagra.

POSIVA

Many countries have chosen to dispose of all or part of their radioactive waste in facilities constructed in stable geological formations. Geological disposal as a safe solution for the long-term management of radioactive waste is in line with international recommendations and practices. The development of a geological disposal facility on a specific site requires a systematic and integrated approach taking into account the characteristics of the waste to be emplaced, of the enclosing engineered barriers and host rock (the three together being called the 'geological disposal system') and of the geological setting of the host rock. Three main rock types are usually considered for geological disposal: crystalline rocks, salt and clays. Each type includes bedrock formations with a relatively broad spectrum of geological properties. The engineered barriers contain different types of materials, such as metals, concrete and natural materials like clay. This brochure highlights the importance of clays and clayey material in the development of almost all geological disposal systems.

Figure 1 *– Different types of clay.* ***Top****: Boom Clay (Belgium) (source: EURIDICE).* ***Bottom****: Opalinus Clay, survey during excavation of a drift for the Full Scale Emplacement Experiment (Mont Terri Underground Rock Laboratory, Switzerland) (© Comet Photoshopping).*

Figure 2 *– Opalinus Clay of the Benken borehole in Northern Switzerland (core diameter: 10 cm; depth: from 591.6 to 592.0 meters) (source: Nagra).*

INTRODUCTION

Clays exhibit many interesting properties, which are exploited in the development of most geological disposal systems. Clays are used both as host rock and as material for engineered barriers. Whatever their use, clays present various characteristics that make them high-quality barriers to the migration of radionuclides and chemical contaminants towards the surface environment. As host rocks, clays are in addition hydrogeologically, geochemically and mechanically stable over geological timescales, i.e., millions of years **(Figures 1 and 2)**.

THE DISPOSAL SYSTEM AS A WHOLE

The disposal system consists of the waste, the engineered barriers and the host rock **(Figures 3 and 4)**. Each of these elements fulfils, separately or in complementary fashion, multiple safety functions. The 'defence-in-depth' principle requires multiple levels of protection, which are designed to enhance safety through their diversity and redundancy. It is the whole system that must be taken into account in safety assessments and not each system component separately.

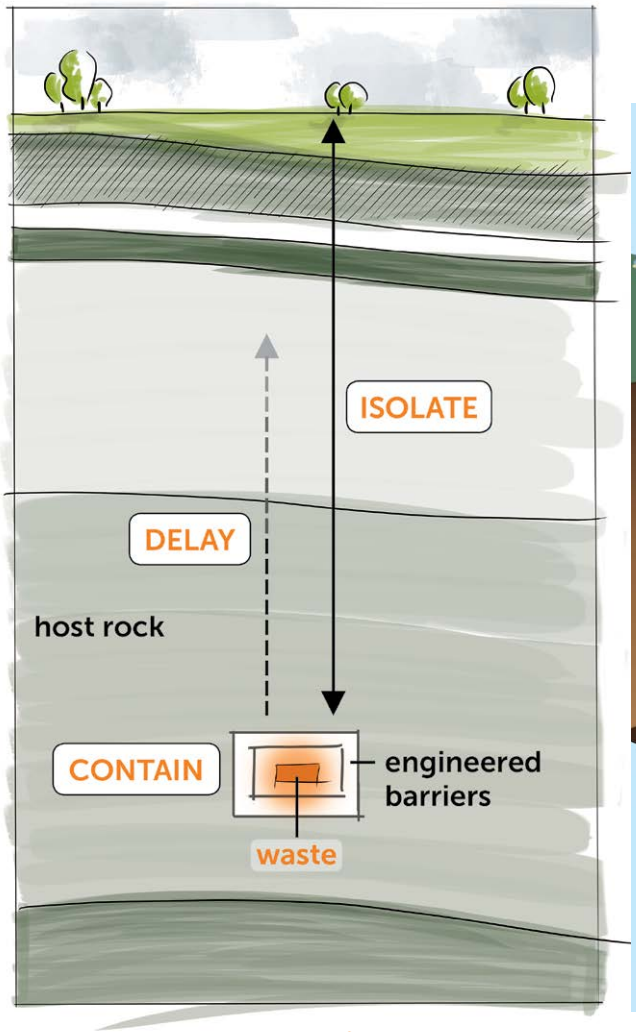


Figure 3 *– Illustrative diagram of geological disposal. Geological disposal provides protection of people and the environment without human intervention being necessary once the facility is closed (source: ONDRAF/NIRAS).*

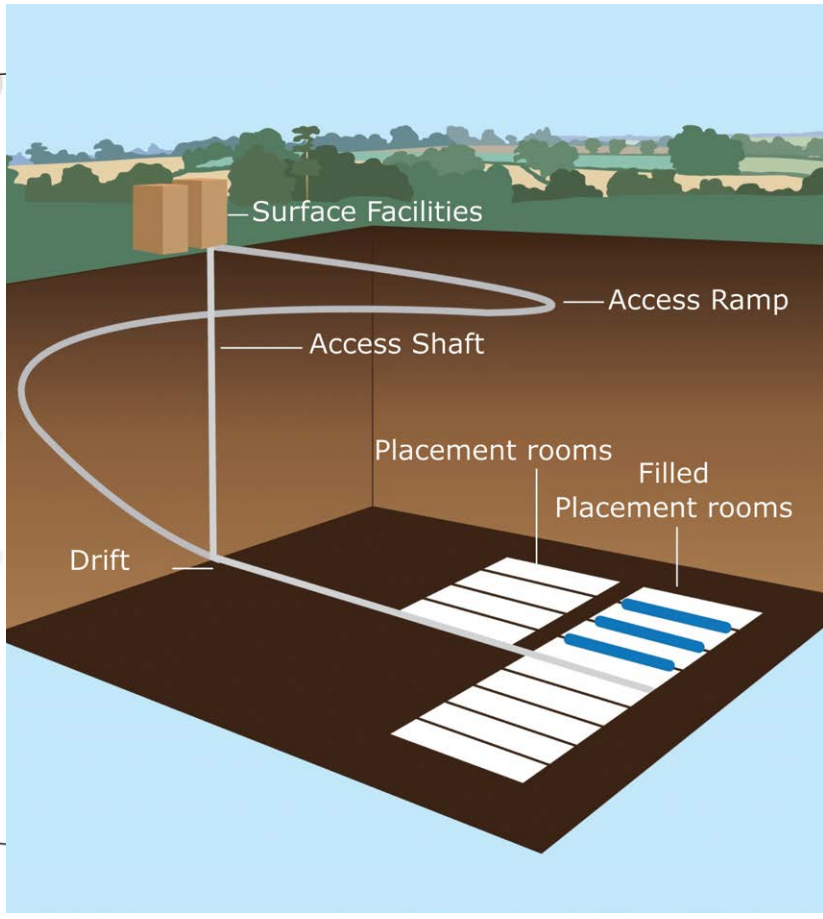


Figure 4 *– Schematic overview of an operational geological disposal facility (contains Environment Agency information © Environment Agency and database right).*

CLAYS AS HOST ROCKS

France and Switzerland have chosen to dispose of their high-level and long-lived intermediate-level radioactive waste in indurated clays, respectively in the Callovo-Oxfordian and Opalinus Clay formations; in Switzerland, Opalinus Clay is also the proposed host rock for low- and intermediate-level waste. In Belgium, the technical solution recommended for the long-term management of high-level and long-lived low- and intermediate-level waste is geological disposal in poorly indurated clay (Boom Clay or Ypresian clays). In the Netherlands, clays are considered as a potential host rock for the disposal of all types of radioactive waste. Other countries also plan to use clays as host rock.

The research and development studies performed in France, Switzerland and Belgium over several decades have highlighted the clays' favourable properties:

- **Very little water movement**: thanks to their low permeability, there is practically no water movement in clays. Radionuclide and chemical contaminant transport via this medium is thus strongly delayed.
- **Diffusive transport**: given the limited water movement, transport in clays is essentially diffusive, which means species migrate primarily under the influence of their concentration gradient, and very little under the influence of the pore-water movement.
- **Retention capacity**: clays have a strong retention capacity for many radionuclides and chemical contaminants. Their migration through clays is thus considerably delayed.
- **Buffer effect**: clays display a significant buffer effect with regard to chemical perturbations. The thickness of the clay that is chemically perturbed by the disposal facility is therefore very limited.
- **Self-sealing capacity**: clays show a high capacity for self-sealing. Any fractures and fissures that occur, in particular those created by excavation activities, close quite rapidly **(Figure 5)**.
- **Stability**: the selected clay host rocks – and therefore their favourable properties – have remained unchanged over millions of years. The migration of natural chemical species through these clay host rocks has remained diffusive during at least the last million years.
- **Vertical homogeneity**: radionuclide and chemical contaminant transport properties are very homogeneous almost throughout the entire thickness of the selected clay host rocks.
- **Lateral continuity**: clays are present within simple geological structures, with a significant lateral continuity, which facilitates their large-scale characterisation.

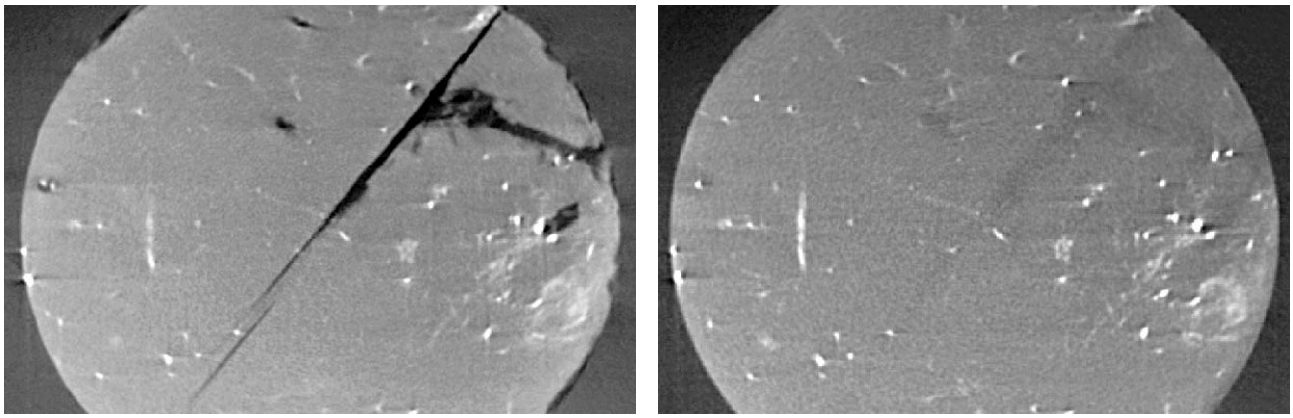


Figure 5 *– Illustration of the self-sealing capacity of Boom Clay. Left: clay sample in which a fracture has been induced; right: the same sample four hours after hydraulic saturation: the fracture has been sealed (source: ONDRAF/NIRAS).*

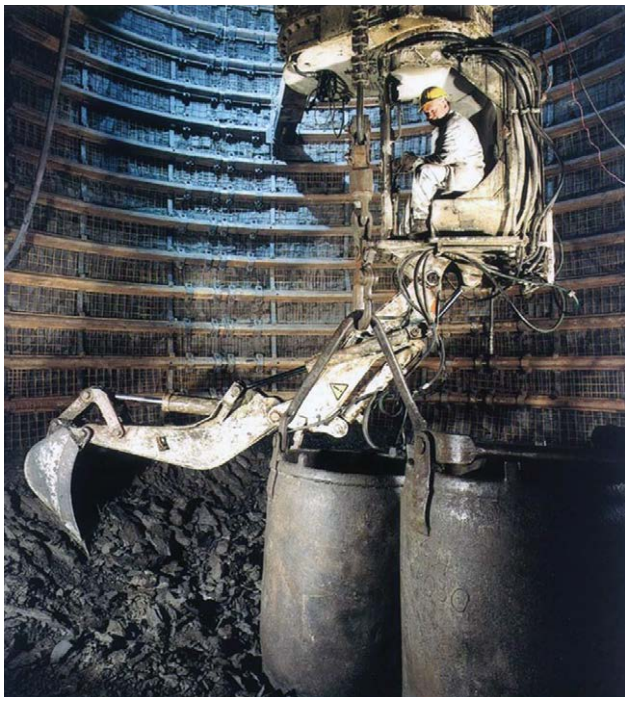
Clays may also contribute to the safety of disposal systems whose host rock is not clay, by being present in their geological environment:

- In Germany, the disposal facility for low- and intermediate-level waste is under construction in an old iron mine (limestone) located under a clay formation.
- In Canada, the host rock proposed for the disposal of low- and intermediate-level waste is limestone situated beneath a sequence of clay formations.

Underground research laboratories help to build knowledge and to carry out demonstration experiments.

Excavation of a drift in Opalinus Clay for the Full Scale Emplacement Experiment (Mont Terri Underground Rock Laboratory, Switzerland) (© Comet Photoshopping).

Excavation of a drift in Callovo-Oxfordian clay (Bure, France) (source: Andra).



Construction of a shaft (left) and excavation of a drift (right) in Boom Clay (Belgium) (source: EURIDICE).

CLAY AS MATERIAL FOR ENGINEERED BARRIERS

The favourable properties of clay (low permeability, self-sealing, stability) make it a material of choice for engineered barriers. Clay is mainly used as:

- **Buffer material**: the empty space between the disposal package and the host rock is filled with clay. For instance, bentonite, a swelling clay, is used as buffer material filling the voidage between the disposal packages and the host rock in the disposal facility designs selected in Canada, Finland, Sweden and Switzerland **(Figures 6 and 7)**.

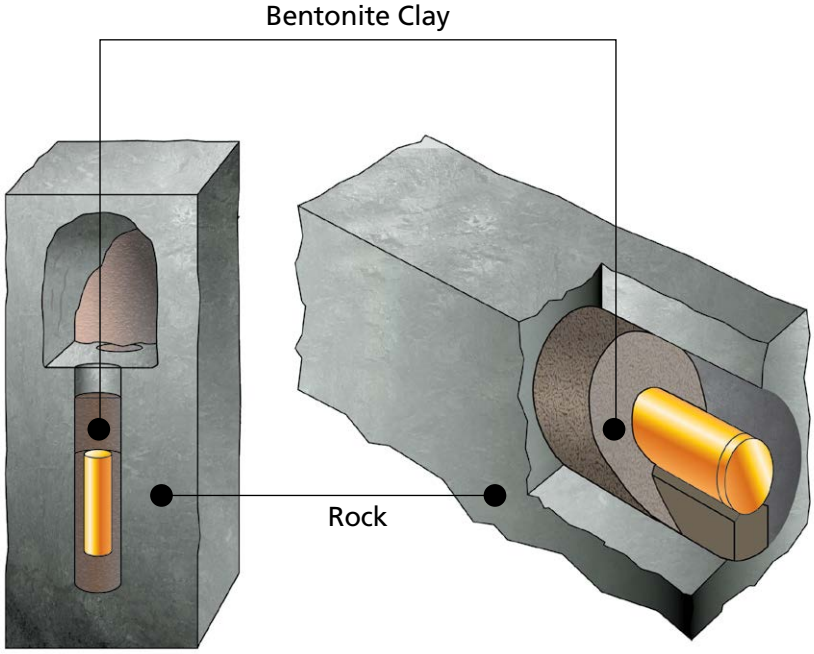


Figure 6 *– Examples of placement of disposal packages in a geological disposal facility. Voidage is filled with bentonite (source: NWMO).*

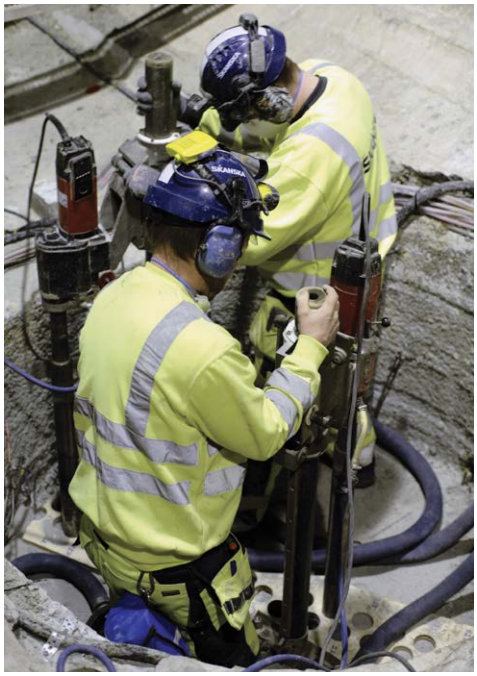


Figure 7 *– Sampling of bentonite in the Swedish Prototype Repository project (source: SKB).*

- **Backfill material**: clay (for instance in the form of blocks or pellets) is used to fill excavated spaces (placement rooms, access ways) **(Figure 8)**, sometimes in combination with other materials.

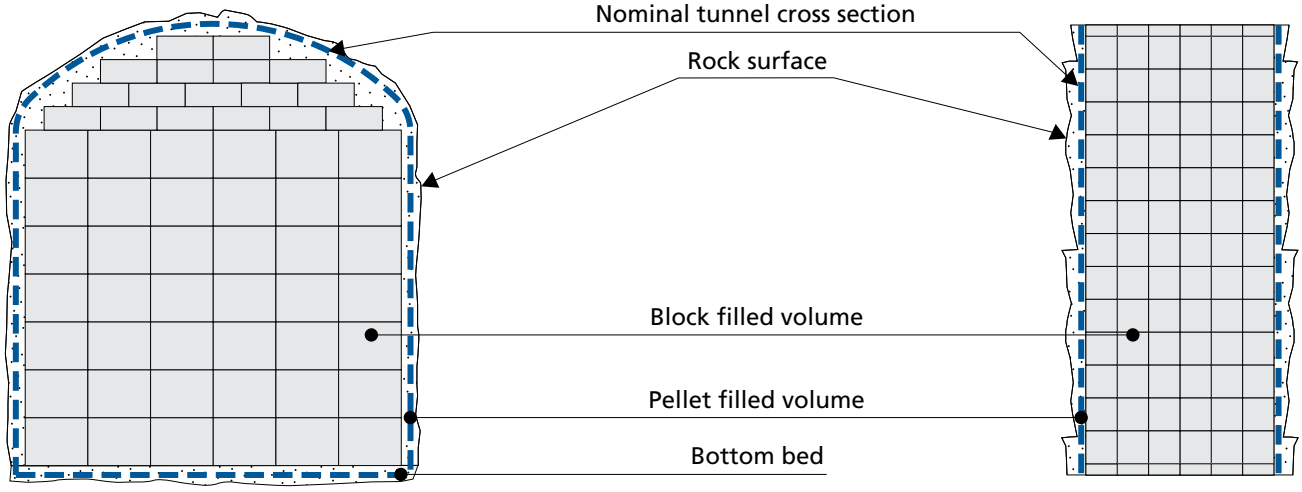


Figure 8 *– Cross section of a drift backfilled with clay blocks and pellets (Sweden) (source: SKB).*

- **Sealing material**: clay, sometimes in combination with other materials, is used to isolate parts of the disposal facility. Seals are works of limited dimensions with specific purpose placed at key locations of the disposal facility. For instance, in France, the seals aim to limit water flow within the underground facilities **(Figures 9 and 10)**.

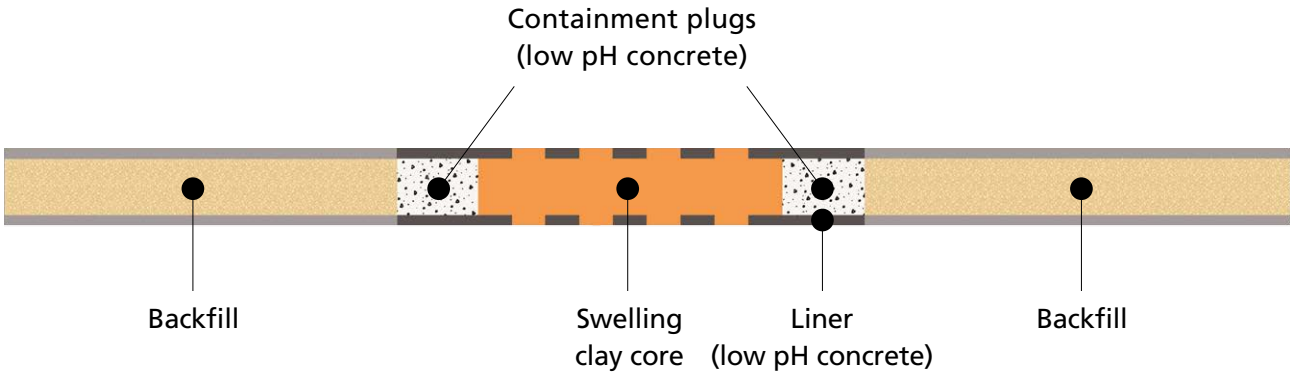


Figure 9 *– Reference drift sealing and backfilling concept (France). The seal is composed of a swelling clay core (bentonite) with two low pH concrete containment plugs, one at each end. The remaining part of the drift is backfilled with the original excavated material (argillites) (source: Andra, C.IM.AETI.11.0152.B-Ref).*

Figure 10 *– Full-scale seal experiment (France). This experiment is a technological demonstration performed above surface by Andra with the scientific support of Nagra, within the DOPAS European project. The test box is 36.1 meters long, with an inside diameter of 7.6 meters. A seal has been installed inside the test box (after the picture was taken), according to the sealing concept presented in Figure 9. The containment plugs are 5 meters long and the swelling clay core is 13.5 meters long (B.TINOCO©Andra).*

The geological disposal facilities in operation or under development in many countries thus contain clay, whatever the selected host rock. The table hereafter lists some of these facilities, sorted according to the progress of the geological disposal programmes.

USES OF CLAY AS MATERIAL FOR ENGINEERED BARRIERS

	Buffer	Backfill	Sealing
OPERATIONAL DISPOSAL FACILITIES			
United States of America			
Waste types: long-lived low- and intermediate-level military waste Host rock: salt			●
Hungary			
Waste types: short-lived low- and intermediate-level waste Host rock: crystalline rock (granite)			●
APPLICATIONS SUBMITTED FOR DISPOSAL FACILITY CONSTRUCTION LICENCE			
Canada			
Waste types: low- and intermediate-level waste Host rock: limestone overlain by clay			●
Sweden			
Waste type: irradiated fuel Host rock: crystalline rock (granite)	●	●	●
Finland			
Waste type: irradiated fuel Host rock: crystalline rock (granite)	●	●	●
HOST ROCK SELECTED			
France			
Waste types: long-lived intermediate-level and high-level waste **Host rock: clay**		●	●
Switzerland			
Waste types: irradiated fuel and long-lived low- and intermediate-level waste **Host rock: clay**	●	●	●
HOST ROCK NOT SELECTED YET			
Canada			
Waste type: irradiated fuel	●	●	●

Cette brochure est également disponible en français.
Deze brochure is eveneens beschikbaar in het Nederlands.

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Cover: Boom Clay from the HADES underground research laboratory, Belgium BIB SEM (source: Desbois et al., 2009)