Clay rocks as potential protective barriers for radioactive waste

Locked Away Forever?

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Nuclear power plants are playing an increasingly important role in energy production in many European countries. One of the key problems that arise as a result is what to do with the high volume of nuclear waste

The waste generated by nuclear power plants is usually highly radioactive, and as such it must be stored under specific conditions. Currently this is most commonly done in carefully isolated landfills. However, there is growing demand to develop deep subterranean waste storage facilities, in which solid bedrock would provide the barrier segregating toxic waste from the biosphere. Such rock must meet several requirements: it must be located at least 200-300 meters below ground level, be of sufficient thickness (usually at least 100 meters), and exhibit sufficiently low permeability and high sorption (the capacity to capture and absorb certain components). The potential candidate deposits to host such subterranean facilities for storing highly radioactive materials include granite, sedimentary salt rock, and clay sedimentary rock.

Radioactivity in check

Given the current plans to construct nuclear power plants in Poland, the attendant problem of long-term storage of radioactive waste will need to be addressed in the near future. Research conducted around the world indicates that clay sedimentary rocks (which are present in Poland) could provide the best natural barrier for constructing underground storage sites for radioactive waste.

Why clay rocks? The aim of storing radioactive materials is, of course, to lock radioactive atoms away in one place for prolonged periods to prevent them from seeping into the biosphere. Most clay rocks exhibit the very low permeability and high nuclide sorption properties we have noted are crucial for such storage.

Clay rocks mainly comprise minerals such as smectites, illites, and kaolinites. They have a specific internal grain structure, including structural layers with different specific properties. Clay minerals are important sorbents of radionuclides due to the negative charge of these structural layers, their large specific surface area, and the presence of hydroxide groups on the surface; this means that the presence of these minerals reduces the ability of radioactive waste to diffuse within rocks. Particularly useful properties are exhibited by bentonites, which are formed through the transformation of sedimentary rocks of volcanic origin. Bentonite is currently used in the construction of surface landfills for radioactive waste and research is now ongoing into how to best utilize this material to build waste-isolating strata in underground facilities. Since the need to store highly radioactive waste will grow in the future, it is hoped that clay rock deposits will come into their own in this application.

When considering a particular type of clay rock as suitable material for nuclear waste storage, its physical and chemical properties should be taken into consideration. Minerals from the montmorillonite group usually exhibit the highest sorption, and they are capable of numerous substitutions and cation exchange between layers. Rocks containing

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Clay rockbeds accompanying lignite coal deposits at the Turów mine

high levels of these minerals are also very impermeable to aqueous solutions. Kaolinite minerals show significantly lower sorption of metal cations, including radioactive elements, while maintaining relatively low permeability. This is why further research into the mineral and chemical composition of clay rocks is essential. Studies show that montmorillonite rocks found in Poland are highly sorbent to heavy metal cations; it is likely that their sorption properties are similar for radioactive elements.

However, such encouraging results of research into sorption and permeability of clay rock are a necessary but still insufficient reason to regard a given deposit as a potential storage facility for radioactive waste. Other important geological and physicochemical criteria include the presence of cracks, interbedding with porous rocks such as sands, swelling, and the formation of colloidal phases; all these factors can promote migration of solutions over significant distances in short spaces of time, which make the rock unsuitable as a barrier.

The conclusion is, therefore, that if a given type of clay rock is to be classified as suitable for building a radioactive waste storage facility, its sorption capacity and chemical and phase composition need to be assessed; additionally, geophysical and petrographic studies need to be conducted on a regional scale.

Potential threats

As we have noted, the most likely solution for the future will involve building storage sites in subterranean deposits at least 200-300 meters below the surface. Given that surface storage facilities are becoming full, constructing underground repositories appears to be the safest storage method. Although, as we have also noted, clay sediment rock seems to offer one of the best locations for such storage, we still do not have sufficient understanding of the effects of radioactive waste on the surrounding rock. Radioactive waste needs to be stored for a very long time, during which the interactions between clay minerals and radioactive waste could take an unexpected turn. The waste usually takes the form of a glassy matrix with radioactive nuclides diffused within; research shows that its durability is reduced when exposed to layer silicate phases. Sorption of radionuclides is also seen to be reduced in silicate phases. At greater depths, this could be accelerated by the increased temperature and pressure. This process, and in particular its long-term course, are not fully understood. This raises the question of whether significant volumes of radionuclides might be able to diffuse within clay rock.

Essential research

Another important issue concerns the interactions between radioactive isotopes and the layered silicate crystals. This phenomenon is also still poorly understood, even though it is of major importance for the construction of both underground storage sites and surface landfills. It has been documented that the presence of radioactive nuclides causes point defects in the crystalline matrix of certain clay minerals. Alpha radiation can lead to the crystalline structures of clay minerals being rendered amorphous. It has been estimated that in the event of seepage of radioactive substances, the bentonite barrier would become amorphous within 1000 years, although this may only occur on a wide scale at extremely high radiation doses. Significant changes might occur in the physicochemical properties of layered silicates, such as their ability to expand, their ion exchange capacity, and their solubility, but these effects have yet to be studied in depth. Ionizing radiation might also lead to the reduction of iron in the structure of the clay minerals, and thus alter their properties. All of this makes it essential to conduct further experimental studies into the changing properties of layered silicates under the influence of ionizing radiation. It is also important to use computer modeling to develop long-term forecasts of the effects of ionizing radiation over the course of thousands and tens of thousands of years.

Underground is best

Should Poland decide to follow through with current plans to construct nuclear power stations, storing the resulting radioactive waste underground promises to be the best and safest option. However, as we have outlined here, deciding which rocks - granites, evaporites or silts - would provide the best host environment still requires much wide-ranging interdisciplinary research. Poland does have rich clay rock deposits, some of which are located at the optimal depth. Preliminary studies show that certain types of these rocks also have suitable sorption properties. If Poland's power strategy for the coming decades does call for a significant share of nuclear energy, these potentially useful types of clay rock will have to be scrutinized very carefully. The safest geological location will need to be selected, and the properties of rock in the region will have to be assessed. Such research may prove to be extremely costly; the same can be said for constructing the waste storage sites themselves. However, all of this will be essential if the risk of radioactive contamination is to be minimized. ■

Further reading:

Allard Th., Calas G. (2009). Radiation effects on clay mineral properties. *Applied Clay Science, 43*, 143-149.

Deepthi Rani R., Sasidhar P. (2011). Physico-chemical characterization of clays AT Kalpakkam nuclear plant site towards assesment of radionuclide waste disposal. *Nuclear Engineering and Design, 241*, 2353-2358.

Huysmans M., Dassargues A. (2006). Hydrogeological modeling of radionuclide transport In low permeability media: a comparison between Boom Clay and Ypresian Clay. *Environ. Geol., 50*, 122-131.

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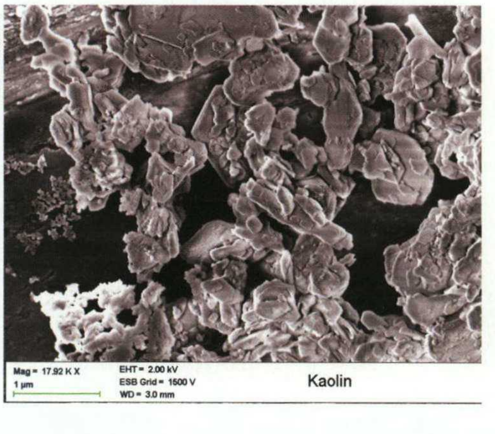

Image of kaolinite grains viewed through a scanning electron microscope