

EVAPORITES AND WASTE DISPOSAL - CRITERIA FOR LONG-TERM SAFETY

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ABSTRACT

In the Federal Republic of Germany salt deposits have mainly been used for the subsurface storage of anthropogenic wastes. This method of disposal will probably continue to be used in the future (in addition to other rock types). The Gorleben salt stock (Lower Saxony) is currently being investigated regarding its suitability as a repository for all kinds of nuclear wastes. The basis of geoscientific conclusions on the long term safety of disposing waste in salt stocks is the quantitative interpretation of processes which have altered the composition of the salt rocks in the past. Prognoses on the future geological development of a repository system could be made based on these investigations.

INTRODUCTION

There are no long-term alternatives for avoiding, reducing, or processing anthropogenic wastes. Safe repositories for great quantities of wastes are not to be found especially in small, densely populated countries like the Federal Republic of Germany. About 14000 m³ of radioactive waste with negligible heat emission is being predicted for the year 2000 assuming the FRG will generate about 25 GW of nuclear power (1). This will also be several hundred cubic metres of radioactive waste with higher heat emission. The quantity of nonradioactive, highly toxic solid waste will be 100 to 1000 times greater over many years (2).

However, at the moment we are still just beginning to develop and apply technologies for avoiding, reducing, and processing wastes. This means that in decades to come even greater quantities of anthropogenic wastes will have to be disposed of.

The geological history of a body of rock must first be investigated to determine geological criteria for the long-term safety of underground repositories. Only the quantitative interpretation of observations in nature can aid a prognosis of future developments. The basis of our concept of study which is schematically shown in Fig. 1, will be explained and the initial results presented here following a short description of the state of the projects on the underground repositories for radioactive wastes in the FRG.

REPOSITORIES FOR RADIOACTIVE WASTES IN THE FRG

In the Federal Republic of Germany the final storage of radioactive wastes, i.e., for the construction and operation of repositories, falls under the jurisdiction of the Federal Office for Radiation Protection (BfS) in Salzgitter

(Lower Saxony) founded on Nov. 01, 1989. This is a federal authority and is subordinate to the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU). In the field of radioactive waste disposal the BfS assumed the duties of the Federal Institute of Physics and Metrology (PTB), which was responsible for these tasks from July 1977 to Oct. 31, 1989. In fulfilling its responsibilities in the field of radioactive waste disposal the BfS can involve third parties according to the German Atomic Energy Act.

In the course of the suitability studies for the site the Federal Institute for Geosciences and Natural Resources (BGR) was active. Institutes from different universities also make important contributions (e.g., Institute of Mineralogy and Mineral Resources, Department of Evaporite Deposits and Underground Repositories, Technical University of Clausthal). Repositories for different types of radioactive wastes have been planned at two different sites in the FRG, only low-level wastes are to be stored in the planned Konrad repository, and all types of radioactive wastes are to be disposed of in the planned Gorleben repository.

An abandoned iron ore mine near Salzgitter (in southeast Lower Saxony) is to be used for the Konrad repository. This repository is situated in iron bearing, calcareous to argillaceous rocks of the Upper Jurassic at depths of 800 - 1300 m. These rocks are discordantly overlain by several hundred meters of argillaceous Cretaceous rocks. After storage is completed, formation water will slowly enter the filled repository chambers and radionuclides will spread out at very slow rates.

The planned Gorleben repository is located near the Elbe River southeast of Hamburg in northeast Lower Saxony. The repository is to be situated in a salt stock which is about 14 km long and about 3 km wide. The base of the

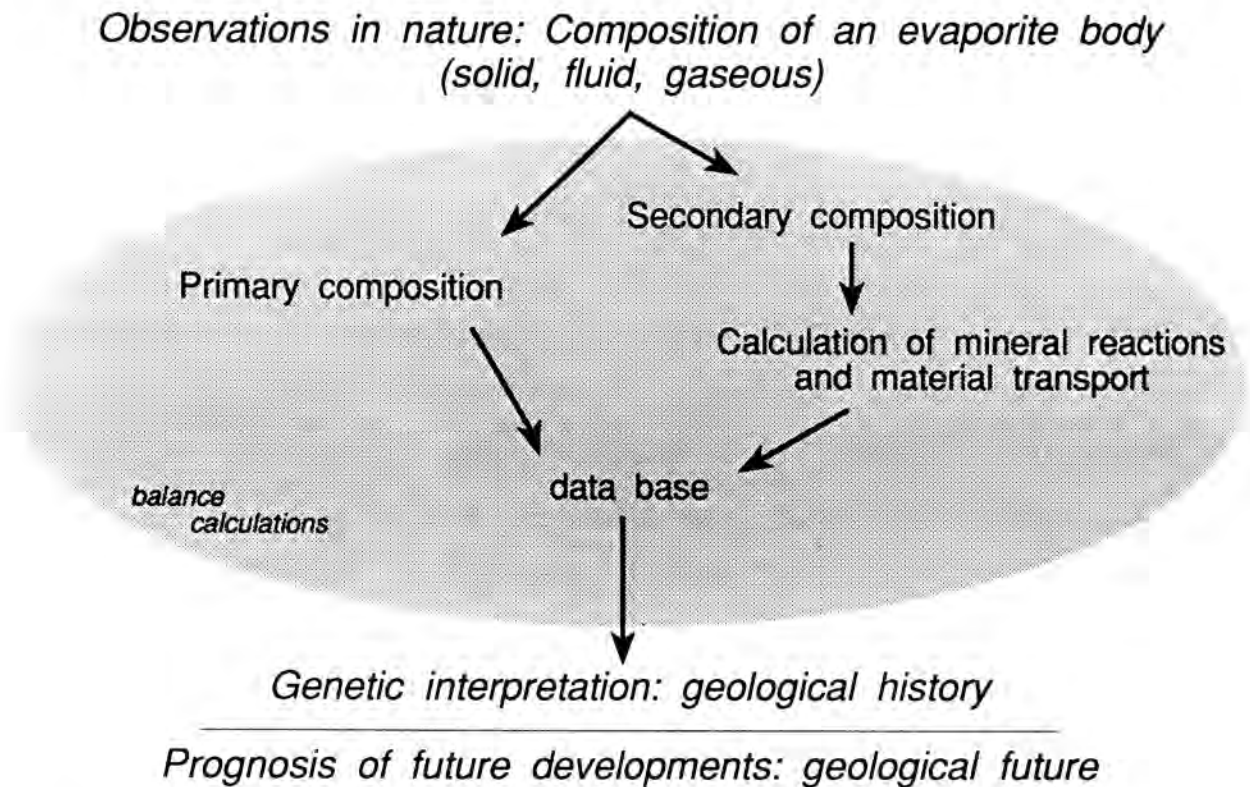


Fig.1. Concept for quantifying mineral reactions and material transport in evaporites to obtain information on the long-term safety of repositories for anthropogenic wastes (from (2)).

repository will be about 870 m deep in salt beds of the Zechstein (Upper Permian). This salt stock was the object of intensive study from the surface between 1979 and 1985. In the course of this reconnaissance 4 deep drillings, 2 shaft predrillings, 44 drillings into the salt wash surface, and over 300 drillings into the overlying rock were done.

The base of the salt beds lies at depths between 3100 and 3300 m. The top of the Gorleben salt stock is situated about 250 m below the surface. The rock overlying the salt stock consists in part of argillaceous Tertiary sediments and predominantly of glacial and interglacial Quaternary sediments. The Gorleben salt stock began to form in the Upper Buntsandstein to Muschelkalk (about 210 mio. years). A large salt pillow formed in the Keuper (about 200 mio. years) and developed further in the Lias and Dogger (ca. 155-190 mio. years). In the Upper Jurassic to Lower Cretaceous (about 140 mio. years) the salt stock penetrated the overlying rock (3). The evaporite sequence was folded intensely during formation of the salt stock. The top of the salt stock was dissolved by subsidence. The evaporite beds are mostly overturned down to depths of 600-700 m (4).

The deep drillings and shaft predrilling studies evidence that the Zechstein deposits had had an original thickness of about 1100 m. In addition to rock salt, there are various layers particularly of anhydrite with a collective thickness of about 80 m, mudstones with a collective thickness of about 40 m, and carnallitites with a collective thickness of about 20-25 m. The carnallitites in the Gorleben salt stock are not of economic significance since the average K_2O contents are below 6 % (mass fraction). The rock salt in the Gorleben salt stock consists, on the average, of up to 96 % halite, the remainder being comprised mainly of anhydrite, polyhalite, kieserite, other evaporite minerals, and clay minerals (5).

More detailed knowledge on the mineralogical composition and on the structure of the salt stock will first be obtained with the subsurface studies. Two shafts are now being sunk in the Gorleben salt stock. At the end of 1989, Gorleben shaft 1 encountered the salt wash surface at the depth of about 260 m. At the same time Gorleben shaft 2 was at about 120 m depth and will reach the salt rock by about the end of 1991. The shafts should attain their final

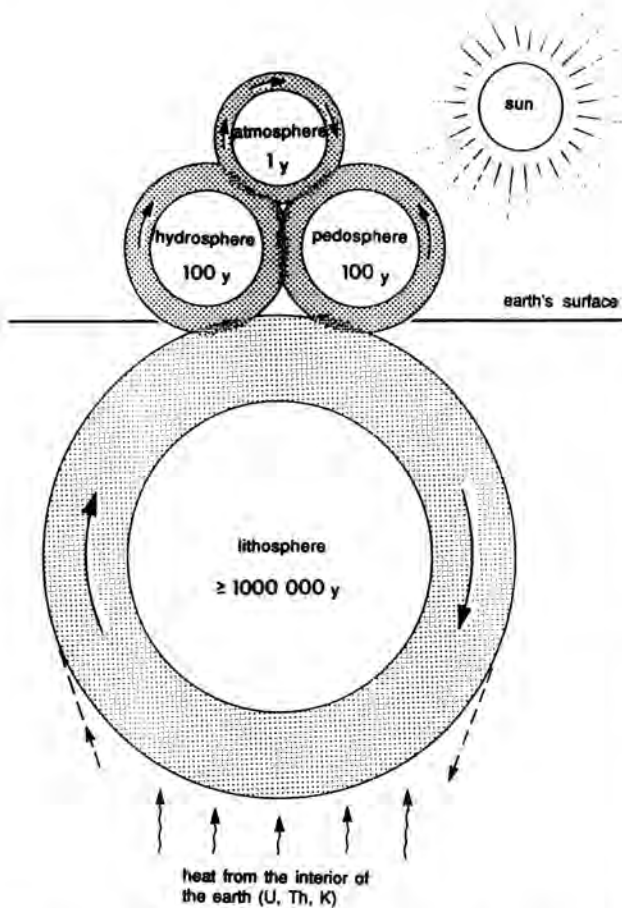


Fig.2: Differing durations of geochemical cycles and the length of residency of elements and compounds in and between atmosphere, hydrosphere, and lithosphere (in approx. orders of magnitude) (from (2)).

depths in 1992 and 1994, respectively. The subsurface study using the shafts and drillings should be concluded by 1998.

General observations and calculations regarding the long-term safety of the planned Gorleben repository were made parallel to these suitability studies of the salt stock on site. Among these the investigations on the composition of the salt stock described in the following will presumably play an important role in proving the long-term safety of the Gorleben repository due to the possible statements regarding the long-term integrity of the salt stock in view of the effect of aqueous solutions.

THE DYNAMIC EARTH

The present geologic and mineralogical-geochemical state of the earth is the result of 4.6 billion years of evolution, which will continue far into the future. Chemical cycles and element redistributions occurring in between the atmo-

sphere, hydrosphere, pedosphere, and lithosphere with varying intensity and velocity are characteristic of this complex evolutionary process (Fig. 2). These natural cycles affect the entire earth and consequently all repositories for anthropogenic wastes. Hence, from the geologic point of view the long-term, safe waste disposal is only possible in suitable rocks at several hundred or thousand meters depth within the lithosphere. This is equally true for both radioactive and nonradioactive toxic wastes.

The entire previous evolution of the rocks from their formation until today must be studied to determine anything about the long-term safety of the repository to be located within them (Table I).

Table I: The dynamic development of evaporites (middle and upper Permian) with surrounding bedrock strata in Lower Saxony over the past 250 mio. years. The changes in the individual salt stock did not always occur simultaneously. The information given in the columns 'Overlying rock' and 'Evaporites' refers primarily to the Gorleben salt stock. Sources: (6), (3), and (2).

Renewed geologic activity of various kinds could make it impossible for people to live near a disposal site. On the other hand, the effects of natural processes also serve as examples of possible processes which could be initiated artificially in a body of rock. The stresses produced in a salt stock caused by the disposal of substances emitting great quantities of heat would be an example. This could give rise to spatially and temporally limited processes similar to those active during salt stock formation 100 - 150 mio. years ago (e.g., the formation of pathways for aqueous solutions or gases, so-called fluid phases, during deformation of evaporite rocks).

To assess the long-term safety of an underground repository it is not absolutely necessary to know the time of occurrence of an event. Our current knowledge only allows us to speculate on possible forthcoming geologic events, and this will not change in the future. On the other hand, it is important to know something about the effects such events with their different physical and chemical processes could have on the composition of the rock surrounding a repository, what elements can be transported by fluid phases, and how to quantitatively evaluate their possible influence. This means that the changes in the original composition of the evaporite by cumulative geologic events are of great interest to the evaluation of the long-term safety of an underground repository.

The processes affecting the composition of the salt rocks in the geologic future will essentially be the same as those in the past. Of all the processes that could influence the safety of a repository only the process that cause interaction between aqueous solutions and solid rock come into consideration for the immediate geologic future. Hence the

TABLE I
Dynamic Development

Era	Formation	Mio. years b.p.	Developments and changes			
			Plate tectonics	Earth's surface	Overlying rock	Evaporites
Cenozoic	Quaternary	1,8	Present situation	Continental conditions; ice ages	The overlying rock is stressed by ice ages	Subrosion in the upper part of the salt stock. Alterations and material transport
	Tertiary	65	Decreasing activity of crustal movements	Terrestrial-marine changes. Tropical climate	Younger sediments overlie the salt dome	Further development of the salt stock. Mineral reactions, material transport
Mesozoic	Cretaceous	141	Intense crustal movements	Terrestrial-marine changes	Evaporites penetrate into overlying sediment strata	Formation of the salt stock. Subrosion? Fractal deformation, material transport?
	Jurassic	195	Beginning of crustal movements. Evaporites > 30° N	Terrestrial-marine changes	Continued updoming of overlying rock	Further salt migration into the pillows. Initial state of the salt stock
	Triassic	230	Evaporites < 30° N	Terrestrial-marine changes	Updoming of overlying rock	Initial deformation of salt layers. Formation of salt pillows
Palaeozoic	Permian	280	Pangea. Formation of evaporites south of < 30° N	Marine conditions during middle and upper permian (250 mio. years b.p.)	Overlying rock not yet existent	Crystallization of evaporites during middle and upper Permian (about 250 mio. years b.p.)

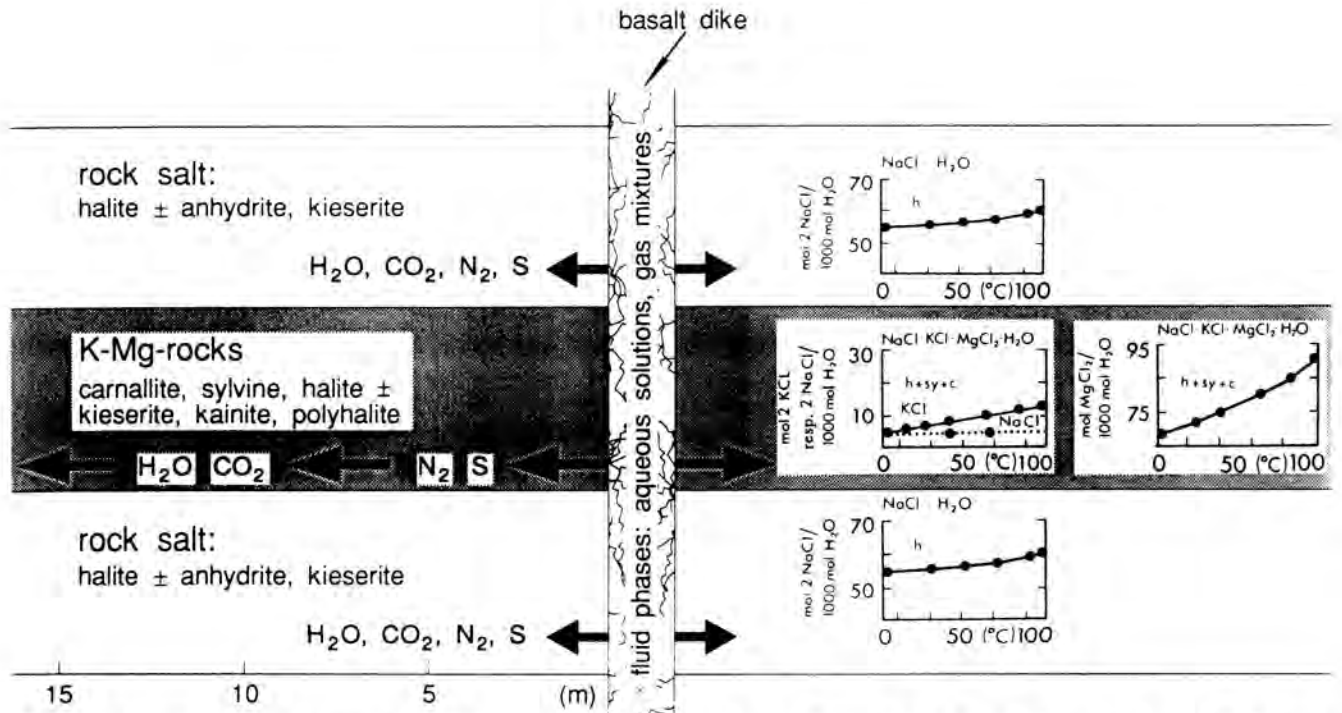


Fig.3. Various reactions between the fluid components of the basaltic magma and the adjacent salt rocks of varying composition. Example of nearly horizontal salt beds (Werra-Fulda minig district, Zechstein 1, Werra series; Hessia, FRG).

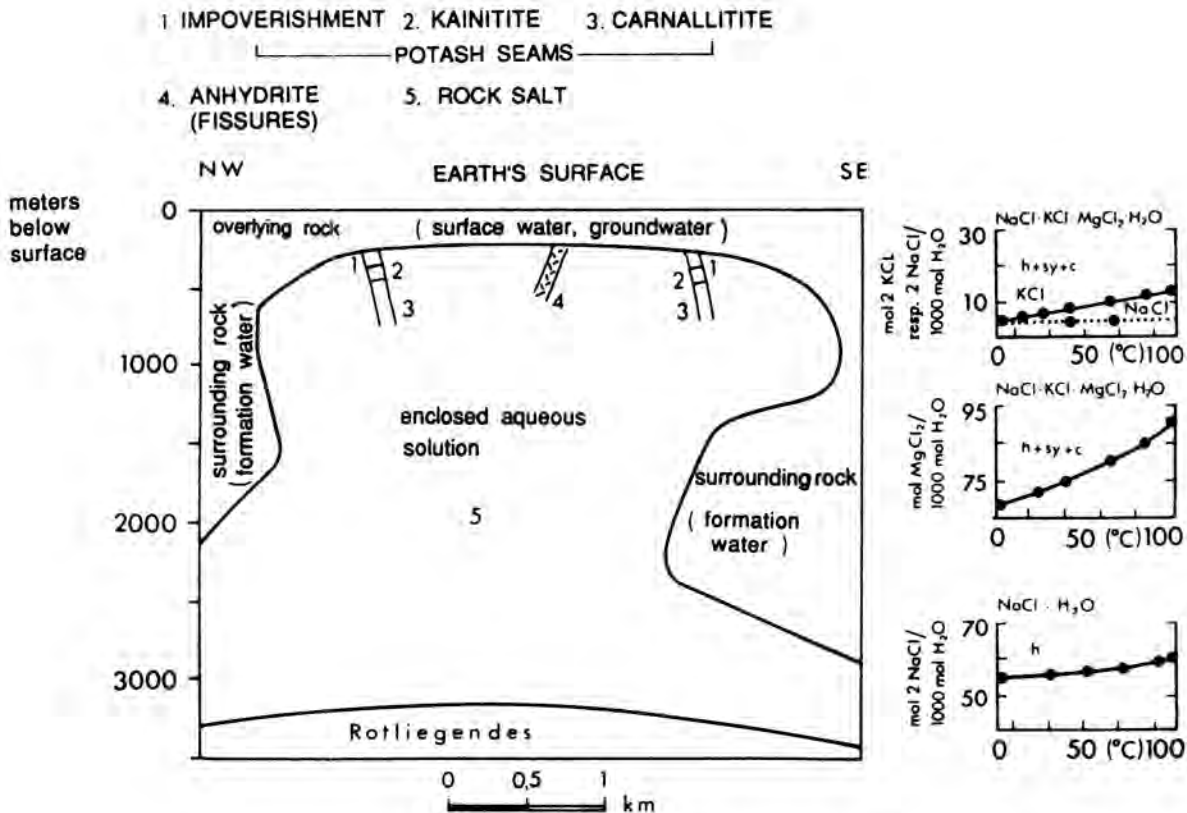


Fig.4: Various reactions between aqueous solutions from the rock overlying a salt stock (example Gorleben) with the rock salt and K-Mg-rocks (Stassfurt potash seam, K2). The mineral reactions and material transport obviously penetrate deeper into the potash seams in the salt stock than into the rock salt. Example of steep to vertical salt beds.

quantitative study of natural processes is by far more important than experiments in the lab which are more or less in the present (cf. (7), p. 1). Therefore, it is necessary to conduct on-site comparative studies of different evaporite occurrences.

QUANTIFYING THE GEOLOGICAL HISTORY

Studies of the horizontal evaporite rocks in the Werra-Fulda mining district have shown that 1150°C basaltic melts and accompanying fluid phases affected the adjacent salt rocks (Fig. 3, (8)).

Aqueous solutions reacted more intensely with the K-Mg-rocks of the potash salt seams than with the rock salt due to the differing temperature-dependent solubilities. This means that solutions are able to spread much farther through potash seams than rock salt. In rock salt the effect of high temperatures and solutions in the vicinity of basaltic

dikes is limited to a few centimeters. In potash salt seams, however, they are observed over several meters.

Similar observations have been made in the evaporites of Lower Saxony as well. These salt rocks were not affected by basaltic melts accompanied by aqueous solutions. However, the potash salt seams in the upper part of the Gorleben salt stock were more extensively and intensely altered by aqueous solutions migrating downward (solution metamorphism) than the directly adjacent rock salt (Fig. 4).

For assessing long-term safety it is important to quantify such processes using the stable solution equilibria of marine evaporites (9,10) to quantify such processes. In this way the quantity of solutions can be determined which are necessary to dissolve certain quantities of salt rocks and alter their mineralogical composition. With the help of a computer program we developed, the following results were obtained, for example, for the impoverishment of a car-

nallitite from the upper part of the Gorleben salt stock (Fig. 4).

To alter 1000 m³ of carnallitite (impoverishment), 2680 m³ of saturated NaCl solution must have penetrated the potash salt seam; in this process about 670 m³ of rock salt formed (11,2). Joints, cracks, and fissures serve as pathways for fluids and gases. They occur primarily in anhydrite and saliferous clay, as well as in rock salt and potash layers. Thus, another important aspect is the existence of joints in anhydrite, rock salt, and other evaporite rocks, and above all the study of neogenic minerals found in them. Such studies can serve as basis for calculating the quantity of solutions which were once active at these sites. This is demonstrated using a rock-salt-filled joint from the Gorleben salt stock as example. Rock salt can crystallize by cooling of an aqueous solution or by isothermal or polythermal mixture of NaCl and MgCl₂ solutions. The calculations from these cases yield very different solution quantities. For example, whereas the cooling of 100-300 m³ saturated NaCl solution would be necessary to form 1 m³ of halite, depending on temperature conditions, only 30-70 m³ of mixed NaCl and MgCl₂ solutions (at 25°C) would be required (11,2). We still know little about this miscibility model. We just recently started applying this model to our observations of evaporite deposits of the Werra region.

In summary, there can be no doubt that it is possible to determine whether solutions were active or not at certain sites and depths of a salt stock in the geologic past. For example, during investigation of a salt stock should it be found that the chemical and mineralogical composition of a potash salt seam at 800 or 1000 m depth has not changed since its formation 250 mio. years ago, important conclusions could be drawn regarding the long-term safety of an underground repository.

CONCLUSIONS

It is possible to obtain the following information with the concept presented:

- quantification of the compositional changes and material transport in a salt body caused by aqueous solutions at certain geologic times,
- identification of zones in a salt body where such material transport was intense, less intense, or nonexistent,
- whether material transport occurred primarily at shallow depths or at greater depths as well,
- whether the composition at 1000 m depth has remained essentially unaltered over the last 250 mio. years in spite of glaciation, marine transgressions, subsidence, and deformation of the rock.

The value of such information to determining the long-term safety of underground repositories for anthropogenic wastes in salt bodies is evident.

Information on long-term safety can be obtained with the concept presented here, which would not be possible with other concepts. The prerequisite is of course the most knowledge possible of the composition and its spatial changes within the salt stock. The conducted studies are not only of significance of the disposal of radioactive wastes in salt stocks. They are just as important to the greater problem of disposing of nonradioactive high-toxic wastes in underground repositories.

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