Salt dissolution under various Quaternary climate conditions

A.F.B. Wildenborg[a], C.N. Bremmer[a] and J. Gerardi[b]

[a]Netherlands Institute of Applied Geoscience TNO - National Geological Survey,
P.O. Box 80.015, 3508 TA Utrecht, the Netherlands

[b]Bundesanstalt für Geowissenschaften und Rohstoffe,
P.O. Box 510153, 30631 Hannover, Germany

Subsurface dissolution of rock salt by undersaturated groundwater (subrosion) is one of the main processes that may affect the natural integrity of a salt structure. Potential future dissolution effects at the Allertal Salt Structure in Germany, in which a repository for radioactive waste is sited, have been assessed. The future period encompasses an interval of about 150,000 years, during which major climatic changes are expected. Highest dissolution rates occur in systems where groundwater infiltrates right above the salt structure. In the case of the Allertal Salt Structure these conditions are expected to occur during periods with permafrost outside the river valley (Allertal).

Keywords: salt dissolution, groundwater flow, climate

1. SCOPE

For the licence application of the ERA Morsleben radioactive waste repository in Germany, a long-term prediction was made of the behaviour of the geological barrier system. The Morsleben repository is sited in a former salt mine in the Allertal Salt Structure and is presently used for the disposal of radioactive waste.

One of the main processes that may affect the natural integrity of a salt structure is the subsurface dissolution of rock salt by undersaturated groundwater (subrosion). That's why a proper analysis of this process is necessary for the safety assessment of radioactive waste disposal in rock salt (Oostrom et al., 1993).

This process tends to be a very slow process but can significantly affect the integrity of salt domes on a time scale of 10.000 to 100.000 years. At these time intervals major climate variations come into play which force the groundwater system. This is certainly the case for North-western Europe where, in the past 150,000 years, glacial and interglacial periods alternated with large consequences for the groundwater flow systems due to large variations in recharge and groundwater pressures.

The Allertal Salt Structure is an elongated salt-tectonic element in the Subhercynian Basin (figure 1). The geology of the basin is dominated by NW-SE striking salt structures, NW-SE striking fault zones and NW-SE striking antiforms and synforms. It is bordered by two Hercynian structures: the Harz Mountains and the Flechtingen-Rosslau Block.

The salt structure is overlain by Mesozoic sedimentary rocks and unconsolidated Quaternary sediments. Right above the top of the salt structure the river Aller is situated, which drains the local groundwater system. The hydrogeological function of this river is important in relation to the rate of subrosion.

This paper focuses in particular on the potential dissolution effects during various climate conditions of the late Quaternary.

2. METHOD AND PRACTICAL APPROACH

A set of computer models was developed to simulate potential dissolution effects. Since climate driven changes in groundwater flow are dominated by processes on a scale very much larger than the scale at which the actual subrosion takes place, a

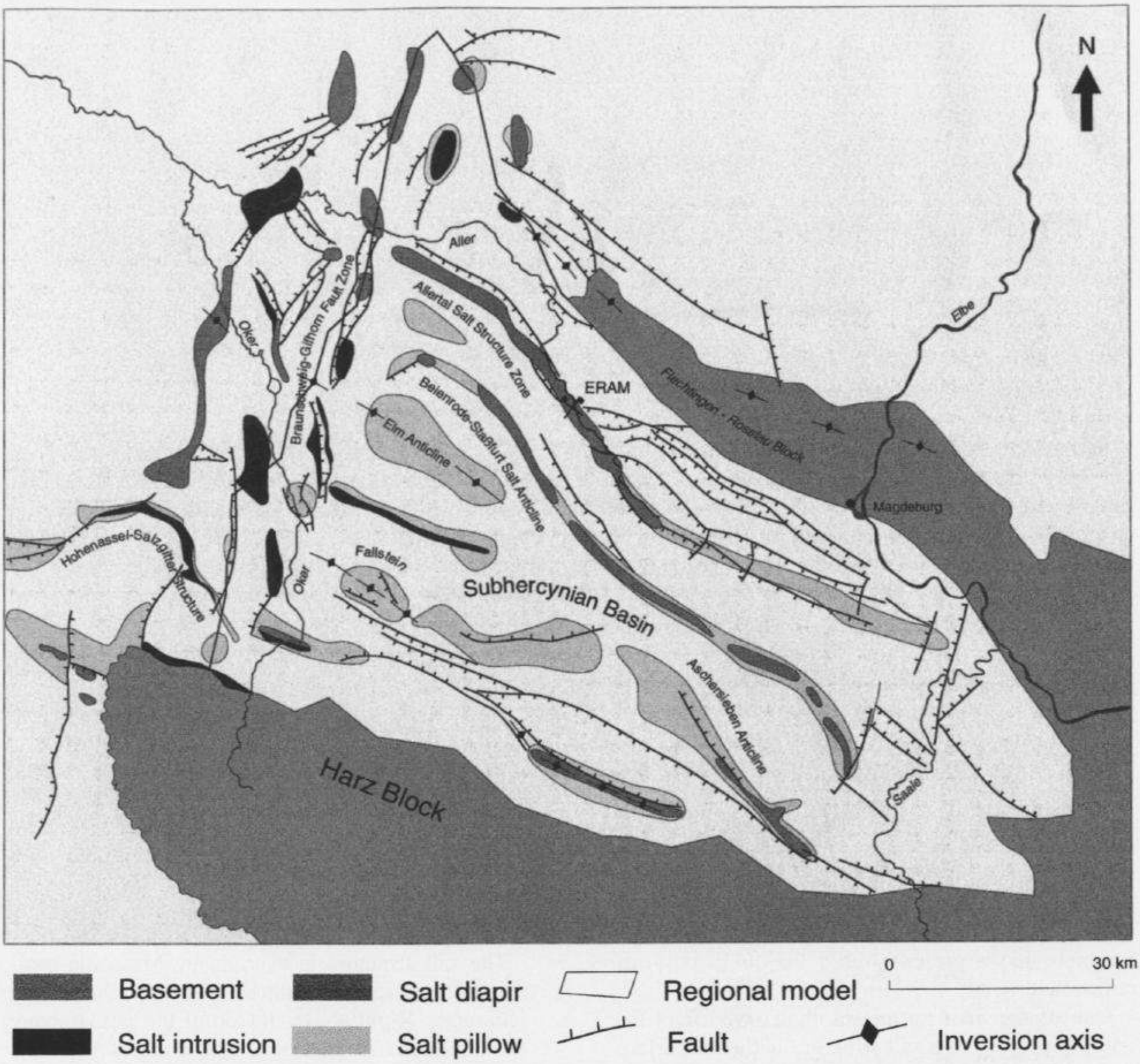


Figure 1 Geological setting of the Subhercynian Basin.

telescopic approach was chosen as a method for estimating the local changes in groundwater flow. The telescopic approach typically starts with computing large-scale (N.W. Europe, ca. 1000x1000 km; Boulton & Curle, 1997; Van Weert et al., 1997) groundwater flow and uses the results as boundary conditions for a refined regional model (Subhercynian Basin, ca. 100x100 km; figure 1). The results of the regional scale model are then used to fix boundary conditions for the local model (repository, 4 km long). The supraregional and regional models were run in quasi-3D and 3D-mode,

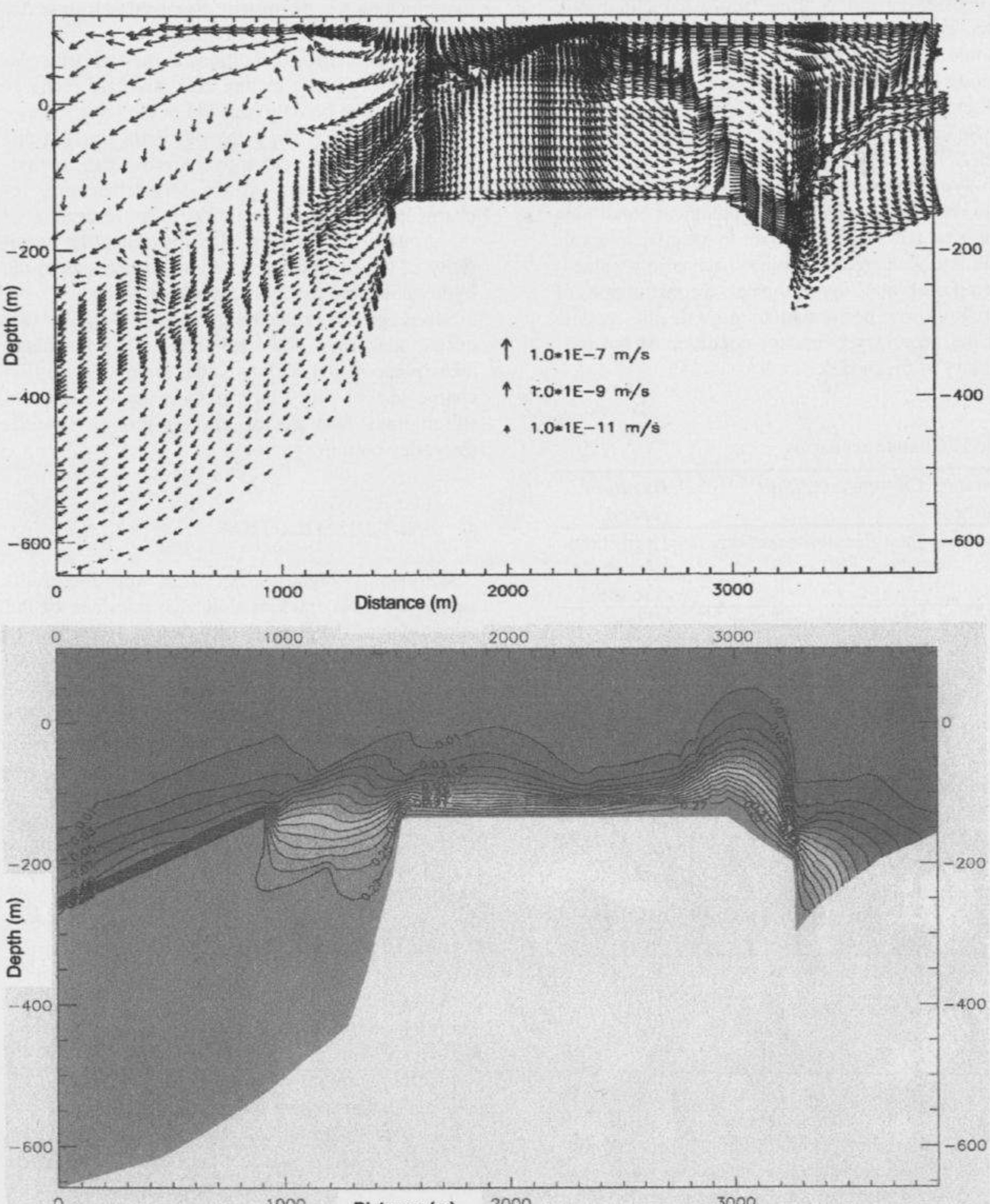


Figure 2 Local groundwater model for climate picture B2 (continuous permafrost); base of the model is formed by the top of the salt; above: groundwater flow vectors; below: salt mass fraction in groundwater.

2D density-dependent code was used (Metropol, Sauter et al. 1990). The latter was also used to compute the dissolution rate at the top of the salt structure. Dissolution of rock salt at the interface between the salt dome and the groundwater flow domain is one of the boundary conditions (Hassanizadeh & Leijnse, 1988).

Six typical climate scenarios (table 1) were chosen to represent distinct hydrogeological conditions at the site. All scenarios relate to specific intervals of the late Quaternary. For each scenario a palaeogeographical and -hydrological reconstruction of the region was performed to provide the models with the necessary boundary condition at the top-boundary of the model.

Table 1 Climate scenarios

Climate picture	*Climate condition*	*Duration (years)*
A	Interglacial/present-day	Until stationary phase is reached
B2	Cold with continuous permafrost outside the river beds	37,000
C2a	Ice-marginal conditions with continuous permafrost and proglacial lakes	5,000
C1	Fully glaciated	5,000
C2b	Ice-marginal conditions with discontinuous permafrost and proglacial lakes	5,000
B1	Cold with discontinuous permafrost	10,000

3. GROUNDWATER FLOW

Regional and local groundwater flow was simulated for all scenarios. The supraregional model was only applied in the glacial scenarios.

As a starting point, flow conditions and salt distribution in the groundwater at the repository are assumed to be stationary for the present time (climate picture A). At present dissolved salt migrates upward towards the valley bottom.

During permafrost conditions at the start of a glacial period (climate picture B2), dis- and recharge are assumed to be only possible in the river valleys. Figures 2A and B show the salt mass fraction distribution and flow velocity vectors for the continuous permafrost case. At the Morsleben site, recharge predominates, resulting in a freshening of the groundwater system. This illustrates the sensitivity of the groundwater system for changes in the hydrogeological function of the river Aller.

Supraregional modellling results suggest that during glaciation (climate picture C1) discharge takes place in the Subhercynian region. Since discharge in the Aller River prevails again, dissolved salt migrates from the top of the salt dome towards the valley bottom.

4. SALT DISSOLUTION

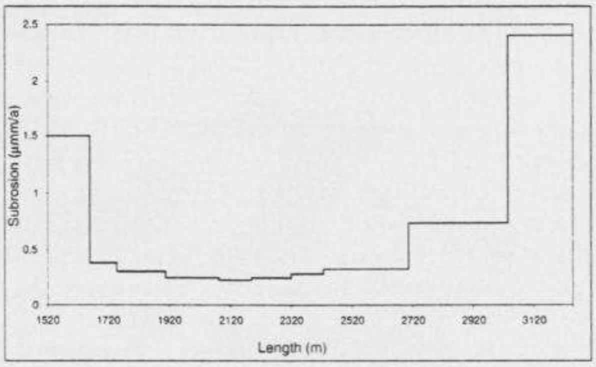
Subrosion is highest at locations were the gradient in salt mass fraction along the interface of the salt dome and the groundwater system, is highest.

Figure 3A shows the variation in subrosion rate at present (climate picture A), considering a stationary system. The gradient in salt mass fraction is highest at the edges of the salt dome. At these places, subrosion will be maximum ca. 2.4 μm/year. The average subrosion rate amounts to 0.28 μm/year.

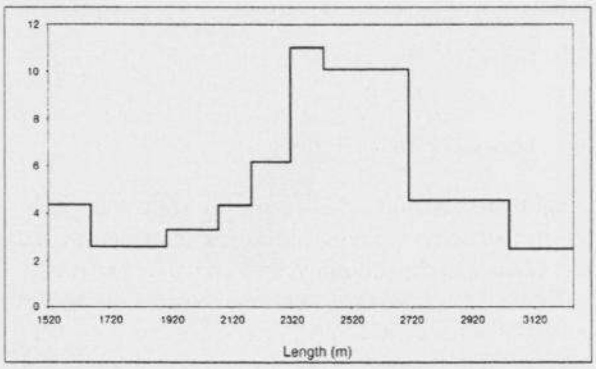
In a situation with infiltration of fresh water atop of the salt dome, as would be the case during a period continuous permafrost (climate picture B2), the subrosion rate increases distinctly because of the overall steepening in the salinity gradient above the dissolving salt front. It is the only period during which subrosion is dominant at the central part of the salt structure instead of at the edges (figure 3B). The highest subrosion rate of 11 μm/year is found to coincide with such conditions during phases with continuous permafrost. The average rate equals 5.3 μm/year in this climate scenario.

The overall subrosion pattern under glaciated conditions (climate picture C1) is surprisingly much alike the present-day situation (figure 3C), due to similar hydrological conditions.

A Climate picture A (warm temperate)



B Climate picture B2 (cont. permafrost)



C Climate pictureC1 (full glaciation)

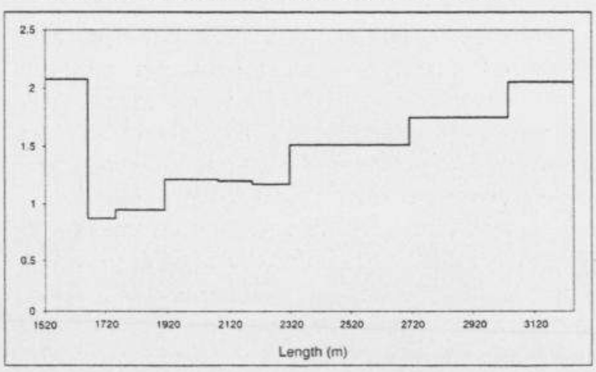


Figure 3 Subrosion rate along top of salt structure. A Climate picture A (warm temperate), B Climate picture B2 (continuous permafrost), C1 (full glaciation).

5. CONCLUSION

Using the local groundwater model it could be derived that subrosion is lowest during interglacial, warm-temperate periods and highest during periods with continuous permafrost. High subrosion rates coincide with a high level of infiltration above the salt structure, resulting in the transport of large quantities of brine. It is therefore concluded that the variation in subrosion rate at this site is mainly influenced by the capability of the groundwater system to discharge the brine at the interface of the salt structure and the flow domain.

In the worst case subrosion at the Morsleben-site will lead to the dissolution of several meters of rock salt during a period of 150,000 years.

REFERENCES

F.H.A.Van Weert, K. van Gijssel, A. Leijnse & G.S. Boulton, The effects of Pleistocene glaciations on the geohydrological system of Northwest Europe. J. of Hydrology, 195, p. 137-159 (1997).

F.J.Sauter, S.M, Hassanizadeh, A. leijnse, P. Glasbergen & A.F.M. Slot, Metropol: A computer code for the simulation of transport of contaminants with groundwater. EC-report Nuclear science and technology, nr. EUR 13073EN (1990).

M. Oostrom, K. van Gijssel & W. Zijl, The SESAM-Project. Modelling Subrosion and Groundwater Flow in the Vicinity of the Zuidwending Diapir on the Basis of Geometrical and (Palaeo)Hydrological Boundary Conditions for the Northeastern Netherlands. RIVM-Report 715205004 (1993).

S.M. Hassanizadeh & A. Leijnse, On the modelling of brine transport in porous media, Water Resour. Res., vol. 24, 321 p. (1988).

G.S. Boulton & F. Curle (eds.), Simulation of the effects of long-term climatic changes on groundwater flow and the safety of geological disposal sites, European Commission, Nuclear Science and Technology, EUR 17793 EN. (1997).