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Hydrodynamics of the Swiss Molasse basin

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In deep sedimentary basins regional groundwater movement may be a very important factor for mass and energy transport. Interpretation of the chemical and isotopic composition of groundwater, understanding of the geothermal conditions (anomalies) and forecasting the possible effects of industrial waste disposals nearly always would require the knowledge of the regional, intermediate and local ground water flow systems.

The available data on the hydraulic parameters being very limited, they generally do not allow an observation-based reconstruction of the deep groundwater flow field. It is a fact, however, that lack of data has never stopped geoscientists from making more or less sound hypotheses on what they do not know. The only way to show the consequences of these hypotheses in a consistent theoretical framework is to use numerical groundwater flow and transport models. The results, even if considered only as qualitative ones, will show what the deep groundwater flow field could look like (see figures 4 A and 4 B which illustrate the sensibility of the flow field to permeability changes in a theoretical sedimentary basin). A few groundwater flow models of the Swiss and German Molasse Basins are presented and briefly discussed.

Requirements for waste disposal in the Molasse

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Marls and clays of the Molasse have been selected for years as the bedrock or host rock for the disposal of non-radioactive waste. The problems concerning the quantities and qualities of waste and of hazardous waste disposal sites (including repositories in the Molasse sediments) influenced the legal requirements for waste disposal, which are outlined in the new technical regulations (TVA) of December 1990. These regulations will have a significant impact on future trends in waste disposal. Although the improved separation of wastes into specified categories and the optimum recycling or disposal of each class of waste is now mandatory, large volumes of waste from industrial and domestic activities will continue to require landfill facilities. The number of potential locations for waste disposal in Switzerland is declining and future site selection will not only be based on scientific criteria, but it will also be constrained by logistical, economic and political considerations. Some of the future sites are planed in the geologic formations of the Molasse.

Prediction of the long-term hydrogeological and geochemical behaviour of the system "Fill-Liner-Bedrock", in particular for waste disposal sites in the Upper- and Lower

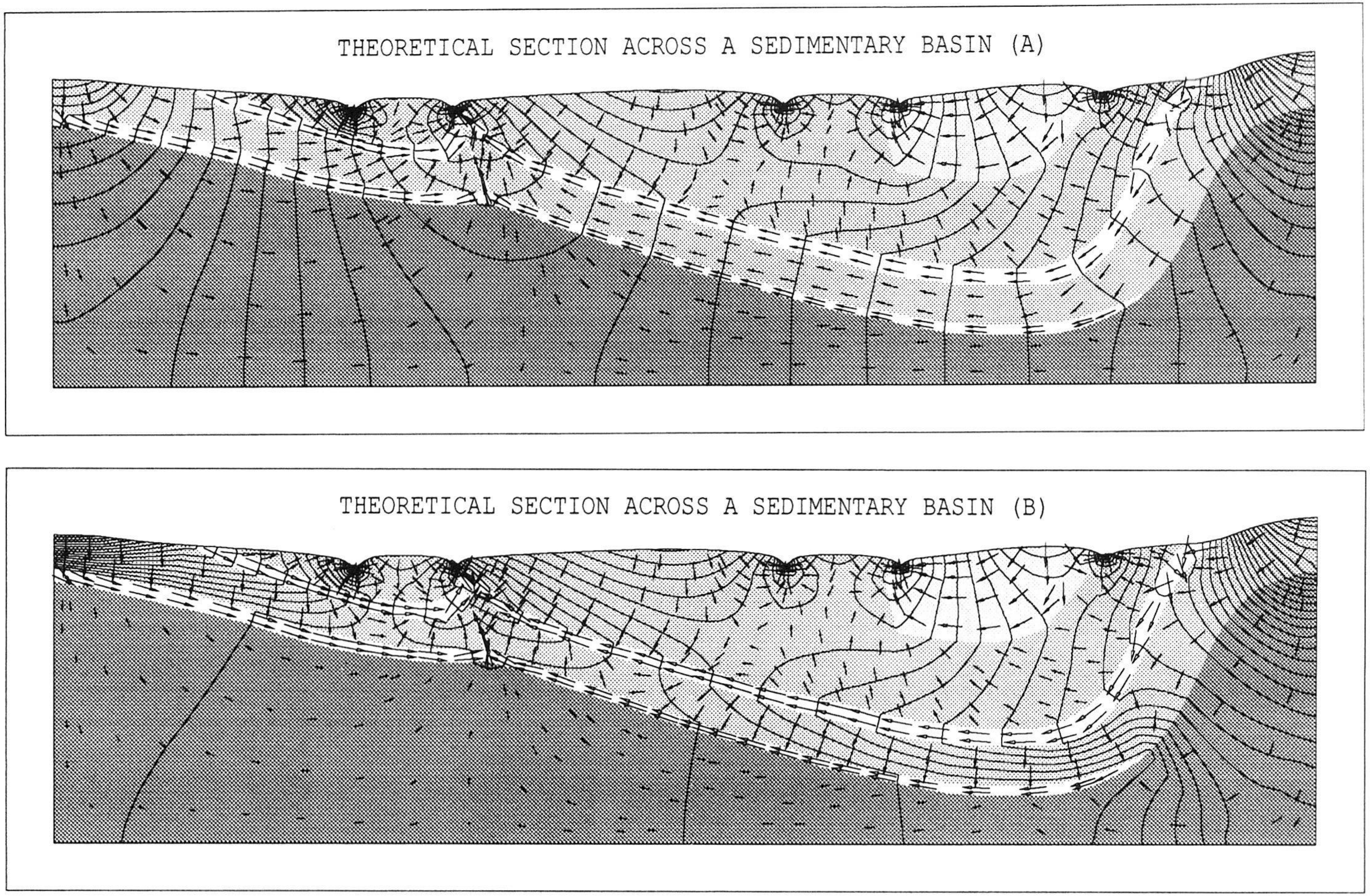

Fig. 4. Sensibility of the flow field to permeability changes in a theoretical sedimentary basin. Fig. 4B represents the same sedimentary basin as fig. 4A, but the permeability of the two main aquifers (white layers) are increased 100 times with respect to fig. 4A. Note the drastic change of gradients in the basement (dark) and between the two main aquifers. Solid lines: equipotentials; arrows: flux vectors in log scale.

Freshwater Molasse is not an easy task. The main elements of uncertainty are the complex geologic/hydrogeologic conditions (1) and the long-term behaviour of the disposed material (2):

1) Complex facies changes, different degrees of cementation of sandbodies and fracture networks are illustrated by two examples from the Upper- and Lower-Freshwater Molasse (Figs. 5 and 6). Knowledge of these inhomogeneities is of major importance for the understanding of transport processes. The characteristics and compositional variability of inhomogeneities at the meter to decimetre scale which determine the variability of the hydraulic properties (Figs. 5 and 6) determine the requirements for the geophysical or geotechnical exploration method to be applied.

2) The methods to asses the long-term chemical behaviour of different types of waste are sparse. Recent laboratory experiments and field assessments of solid waste incinerator bottom ash by Belevi et al. (1992) support the hypotheses that:

"– the non-metal fluxes by leachate (such as chloride, sulphur, DOC fluxes) would adversely impact the environment for years to decade after disposal."

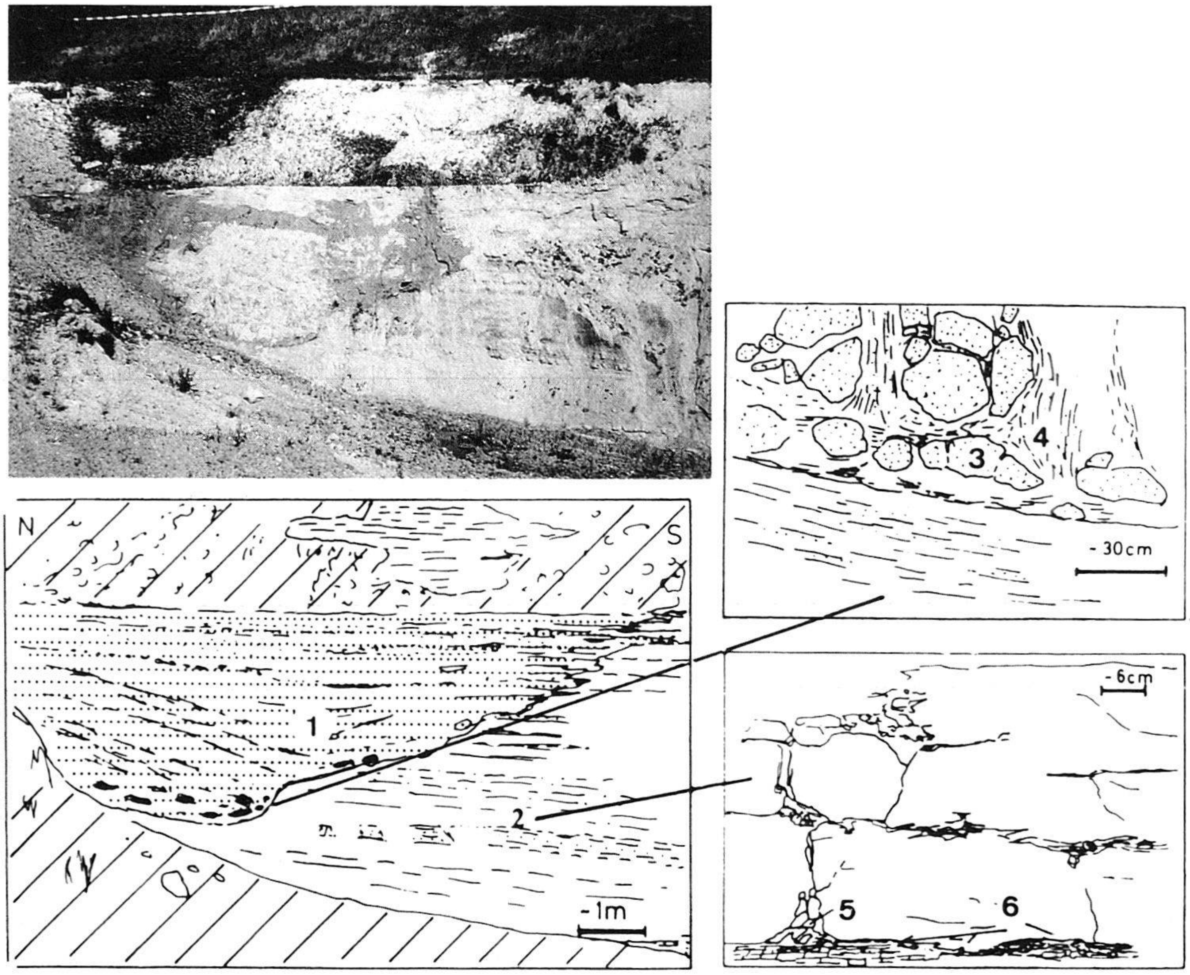

Fig. 5. Lower Freshwater Molasse (Bachs valley, NE-Switzerland): 1) Channel cut into a sequence of alternating marls, clays and silty sands 2) and subsequent fill and abandonment. Sedimentary structures within the sands only barely recognisable. Blocks of cemented sand 3) in a sandy matrix without cohesion at the channel base 4). Fractures and brecciation perpendicular 5) and parallel 6) to bedding. (From Huggenberger 1989).

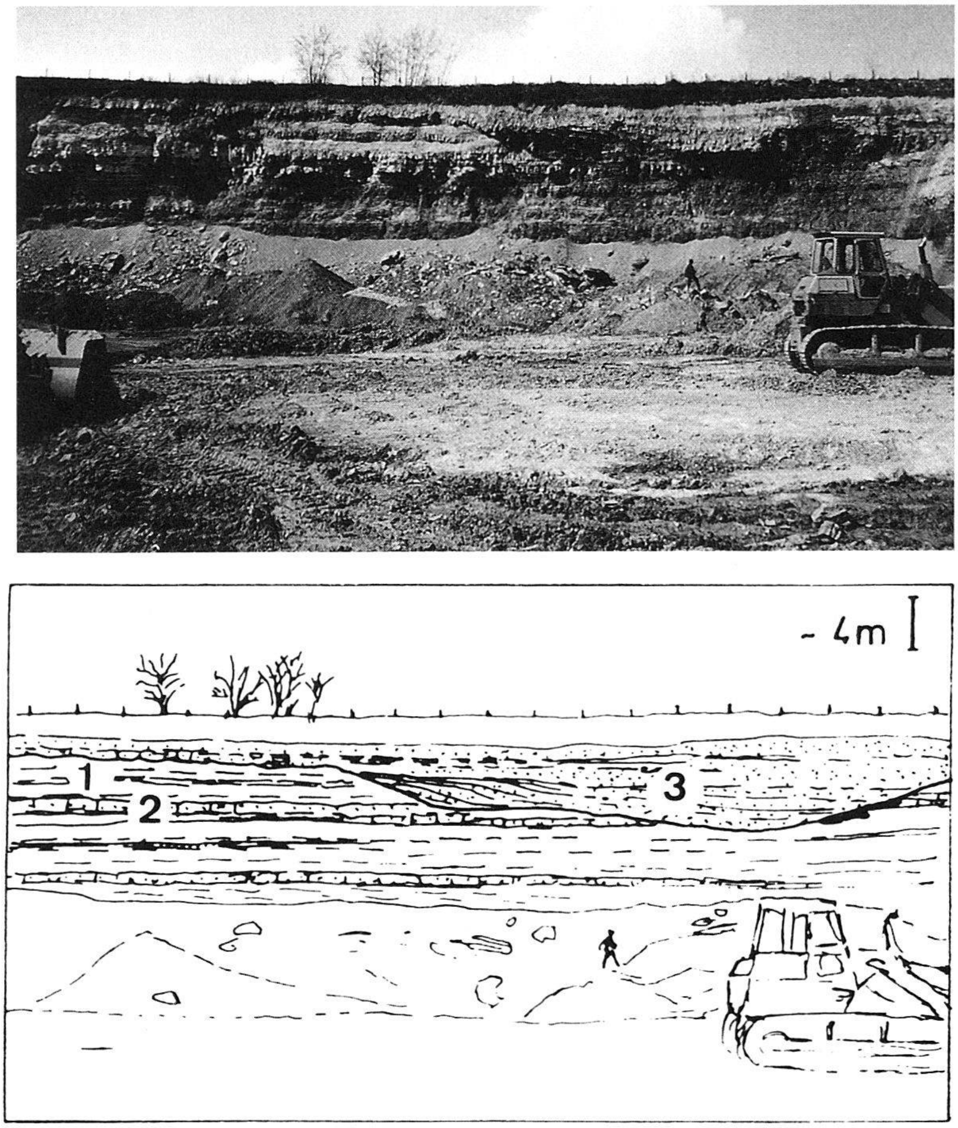

Fig. 6. Outcrop of meandering stream deposits (Upper Freshwater Molasse, Lufingen, NE-Switzerland). 1) Alternation of red and grey shales with varying contents of fine sand. 2) Horizontal sandstone beds alternating with shales and marls 1). 3) Sandy channel fill (notice lateral accretion structure on left side of the channel). (From Huggenberger 1989).

"– heavy metal fluxes by leachate are expected to be compatible with the environment for years to decades after disposal. However, additional laboratory and field studies are necessary to assess their behaviour over longer time periods."

These authors concluded that bottom ash ("inert" type waste according to the TVA) cannot be considered as a material of final storage quality (for which the long-term emissions from a landfill should be compatible with the environment) which means that it should either be disposed of in monofills with leachate collection and treatment systems or be treated prior to disposal to achieve final storage quality. As a consequence, even waste classified according to the new TVA as "inert" could in the long-term present an element of uncertainty and therefore the adsorption capacities of the geological system should be known.

To prevent a repetition of the costly experiences with leaky waste disposal sites in the Molasse, it will be necessary to conduct sound environmental risk assessment studies prior to the construction of new landfill sites (to provide constraints on technical barrier design) and to implement follow-up ground water monitoring. Preconstruction risk assessment should include the provision of reliable geological and hydrogeological information, with emphasis on finding locations with suitable natural barriers. It will also be necessary to identify geological features that could affect the ground water flow if the technical and natural barriers are breached (e.g. major fractures or porous sands). To understand the impact of the system "Fill-Liner-Bedrock" it will be necessary to have base-line information with which to compare the results of the geochemical and hydrogeological monitoring of the landfill. Such reference data should be collected prior to the establishment of the landfill site.

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Waste Disposal in Molasse Sediments: Elements of uncertainty in the safety assessment

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The Kölliken hazardous waste landfill has been operated from 1978 to 1985. During this time, around 300 000 m^3 of waste were dumped into the former clay pit. The geology beneath and adjacent to the landfill was investigated with close to 100 boreholes. The subsurface is Lower Freshwater Molasse, mainly variegated shales, clays and sandstone beds. The uppermost 40 m are a succession of fluviatile, lacustrine and terrigenous environments.

For the assessment of the landfill's safety, a hydrogeological model was developped already in early phases of the project. Correlations of the different formations showed rock layers with a very strong anisotropy in hydraulic conductivity. The relationship between the geological body size and the relevant flow distances made obvious that averaging of hydraulic parameters would lead to incorrect results. Observations of the hydraulic heads showed an upward gradient, causing infiltration into the landfill. With ongoing investigations, the model became increasingly sophisticated. With the new geologic data and additional information in other domains, e.g. clay-organics interaction, it became necessary to revise the initial safety assessment, dating from the early seventies. When reviewing the latter, three systematic types of error could be identified: