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# UNDERGROUND CONTAINMENT BARRIERS FOR THERMAL STORAGE IN AQUIFERS USING GRAVEL WASHING SLIMES

Gabriel de los Cobos, Aurèle Parriaux
Laboratory of Geology (GEOLEP), Swiss Federal Institute of Technology (EPFL)
CH - 1015 Lausanne, Switzerland
Fax ++41-21-6934153

## ABSTRACT

Gravel washing silt from alluvium or crushed rock constitute an industrial waste whose utilisation, at the present time, is very limited and whose disposal is an environmental problem. The recovery of this by-product can be envisaged through the use of the intrinsic properties of this clayey silt: low hydraulic conductivity, homogeneity and isotropy. The basic idea would be to use this material in the construction of underground containment barriers for the management and protection of groundwater in the domain of geothermal storage. Tests on samples and specific tests on large-scale physical models have led to a better understanding of the properties of the gravel washing silt. Measurements on physical models have demonstrated the promising potential of the silt to be used as a water-tight confinement barrier.

## 1. INTRODUCTION

Alluvial materials have long been used both as aquifers and as sources of sand and gravel. The working of new sources of clean, good quality gravel is becoming more and more difficult due to the shortage of adequate sites. Given this situation, the possibility of using other sources of granular materials such as alluvium, moraines or compact rocks may be seen as an interesting alternative. However, this type of material may contain a large percentage of clay and silt, and the washing necessary in order to separate the fine particles generates a large quantity of mud. The disposal of this mud constitutes an important environmental problem.

On the other hand, the interest in thermal storage in underground water has long been the basis of numerous projects. Even though the energetic interest of seasonal thermal storage in groundwater no longer needs to be proven, the implantation of new projects using this concept implies the need for new systems adapted for other geological conditions, notably in aquifers with high permeability.

In this context, other possible uses which are both technically and economically feasible should be researched. This is the reason why the GEOLEP, in collaboration with the LMS (Soil mechanics laboratory of the Swiss Federal Institute of Technology Lausanne), began a study of the specific properties of this silt with the aim of evaluating its potential for use in the domain of groundwater management, geothermal storage and contaminated sites. Thus, the GEOLEP sought to make a contribution to the use of this by-product through

recycling in nature to permit an economically interesting use. The specific properties of this material were planned to be taken advantage of, especially its low hydraulic conductivity.
Measurements carried out on samples, placement in test vats and the construction of model underground barriers permitted the analysis of the behaviour of the silt with the aim of evaluating its potential for use in the domains listed above.

## 2. BASIC PROPERTIES

A series of samples of various types of geological alpine deposits (sensu lato) were taken as a function of the type of geological deposit worked and its petrography, with the intention of characterising the gravel washing silt for potential future use. This a priori typology was tested by specific investigations on the resulting mud. The choice of a test mud representative of that found in the Lake Geneva region was able to be made in conjunction with the results of other studies. This test mud was used for all of the measurements and specific tests carried out in this study.

The analysis of a large number of properties was necessary in order to understand the behaviour of the mud as a function of possible future applications.

### 2.1 Mineralogical properties

Mineralogical analyses by X-Ray diffractometry determined the mineralogical composition of the mud and the distribution of the potentially swelling clay minerals. These compositions were replaced in the general clay properties in order to understand better the strong correlation which exists between their structure and their physical-chemical properties.

Generally speaking, the gravel washing silt is composed of silicates (quartz, feldspaths, clay minerals) and carbonates (calcite). For the sample of test mud, the presence of a large quantity of calcite shows good correlation with the location of the deposit used, in the superficial deposits of the Rhone glacial moraine, since the location is on the Jura flanks. For this sample, 33% of the mud was composed of phyllosilicates, of which 3% were represented by smectites, potentially swelling minerals.

### 2.2 Mechanical properties

The various mechanical stresses which are developed in a mud mass used as an underground barrier, and especially the effects of these stresses on the barrier itself, were analysed. A silty mass placed under the phreatic surface is liable to be subjected to a wide range of mechanical effects which will depend essentially on the structure of the material and the conditions of its immediate surroundings. Notably, the presence of water influences the behaviour of the silt, which will react differently depending on its degree of saturation.

The tests showed that the test mud used may be assimilated by a relatively clayey silt, containing between 25 and 30% clay (Figure 1). The Atterberg limits permitted the classification of this silt according to the USCS as CL. Oedometric tests showed this clayey silt to be very deformable ($mv=0.046x10^{-3}$ for $\sigma$=500-1000 kN/m2). Its consolidation was slow for constant saturation. Variability of the placement conditions did not affect the behaviour.

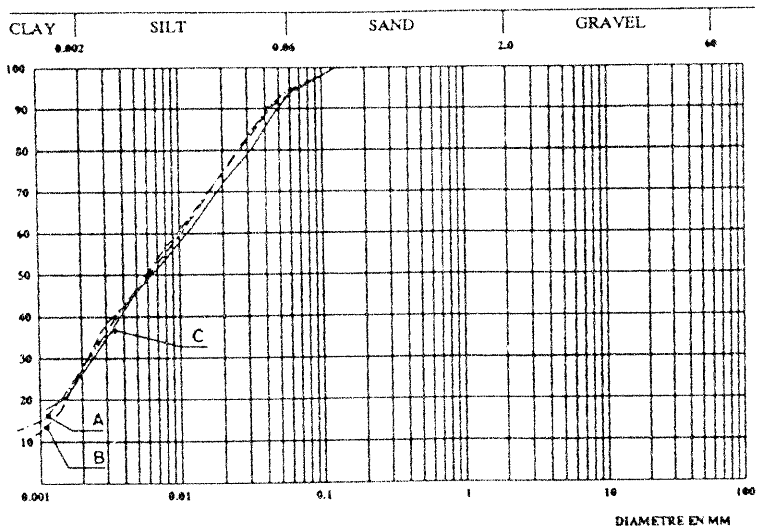


Figure 1: Grain size distribution curves of the test mud (decantation basin - A: upstream; B: downstream; C: hydraulic press)

## 3. HYDRAULIC TESTS

The permeability values calculated from sample test results using different methods (permeameters, oedometers and triaxial cells) were very low, on the order of $10^{-8}$ to $10^{-9}$ m/sec. In order to take scale factors into account, large-scale physical models permitted a better understanding of the behaviour of the silt in the case of a vertical hydraulic barrier (Figure 2).

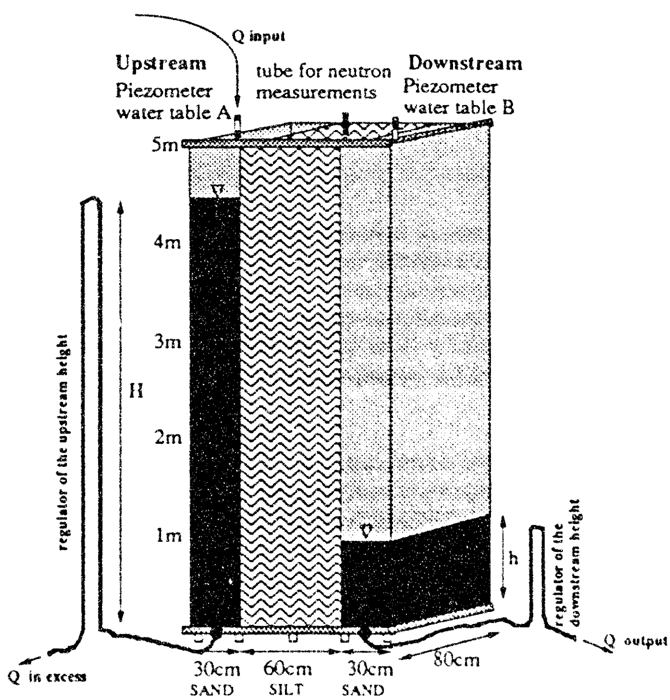


Figure 2: Scheme of the experimental column

These large-scale tests showed a decrease in performance with respect to the sample tests. Notably, they showed the important role played by the variations in water content in the silt mass, and the sensitivity of the mud to drying, evidenced by the appearance of desiccation cracks. These cracks contributed to the decrease in barrier performance. Through rehumidification, this situation was seen to be reversible. In any event, the barrier permeability values remained low (on the order of $10^{-7}$ m/sec) in spite of the desiccation. In order to avoid extreme decreases in performance due to desaturation, wide curtains which are insensitive with respect to desiccation should be required for the case of placement above the phreatic surface (e.g., lowered groundwater, locally deeper groundwater).

## 4. THERMAL TESTS

Applying the concept of heat storage in an aquifer to an alluvial setting having high permeability leads to inadequacy with respect to geothermal storage. To resolve this problem, the necessity of barriers which strongly limit any flow is obvious. The potential use of gravel washing silt in the case of geothermal storage has many interesting implications (Figure 3).

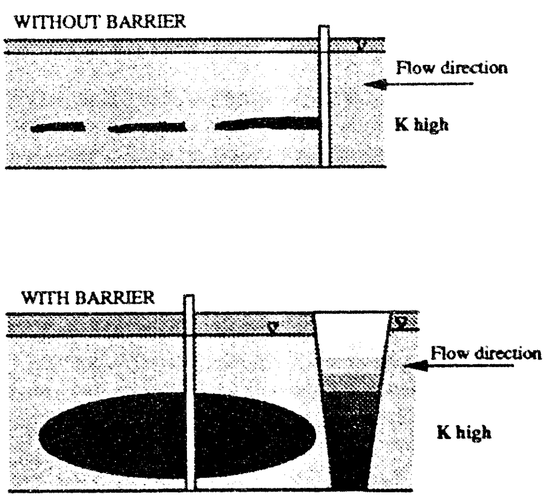


Figure 3: Thermal stabilisation through the use of barriers

Thermal tests with the help of physical models to simulate the storage of hot water (up to 80° C) in an aquifer with high permeability were carried out (Figure 4). The aim of these tests was to obtain a first approximation of the thermal behaviour of a water-tight curtain in various circumstances:

- pure conduction:

The case of a zero difference in hydraulic head between the two compartments (no hydraulic transport), but with an imposed difference in thermal conditions (the upstream compartment was constantly heated while the downstream compartment was kept at low temperature through slow circulation of cold water in the sand).

- conduction and advection

The case of a difference in hydraulic head between the upstream and downstream compartments: test of the barrier under the conditions of "forced advection" (an hydraulic transport which provoked a thermal transport was imposed).

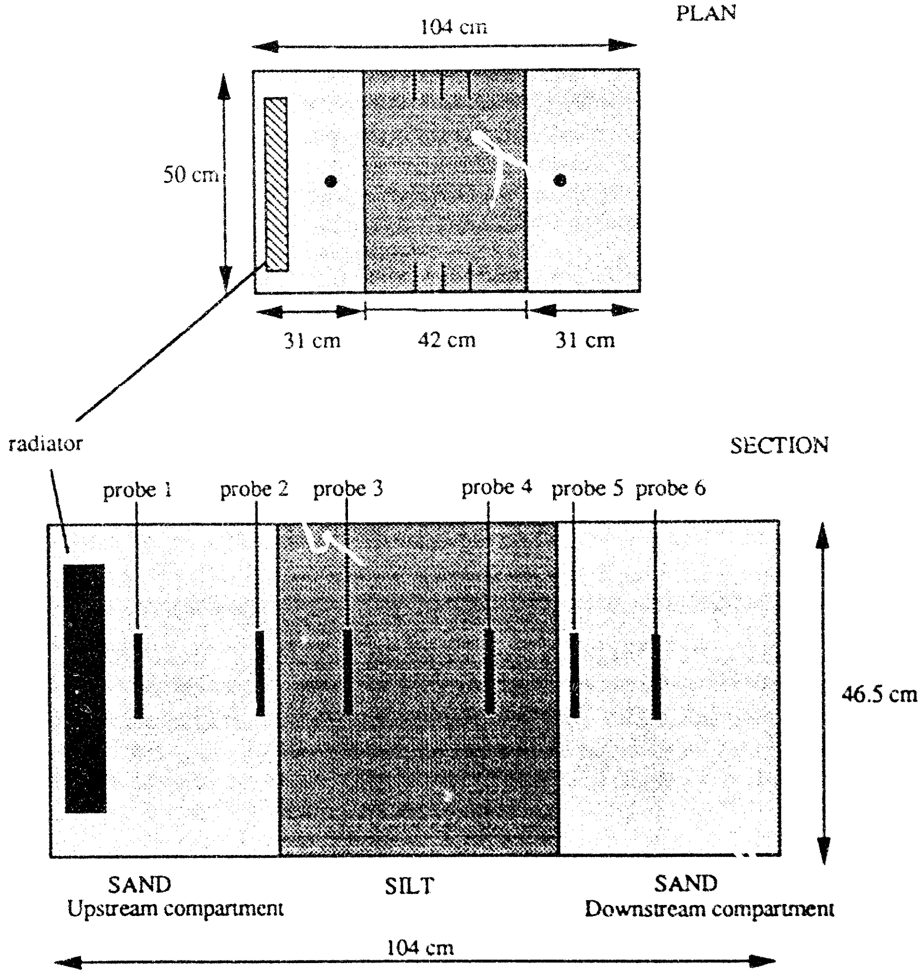


Figure 4: Scheme of the experimental vat for thermal tests

Figure 5 shows the case of pure thermal conduction. A relatively marked thermal gradient was imposed between the upstream and downstream compartments. The downstream water was maintained at a relatively low temperature (between 12 and 15° C) by a weak flow of cold water in the sand. Only one temperature level was carried out, at 80° C, which lasted more than 300 hours. It was observed that the thermal conditions of the model reacted slowly, since after approximately 100 test hours virtually stable conditions were attained.

The entire test program showed an increase in permeability with temperature, practically in agreement with the general form of Darcy's law. The permeability remained sufficiently low in order that the conductive behaviour was dominant over the advective, and confirmed the interest of using gravel washing silt to stabilise the heat 'bubble". This provides an efficacious and applicable solution is areas where the permeability is too high to consider geothermal storage.

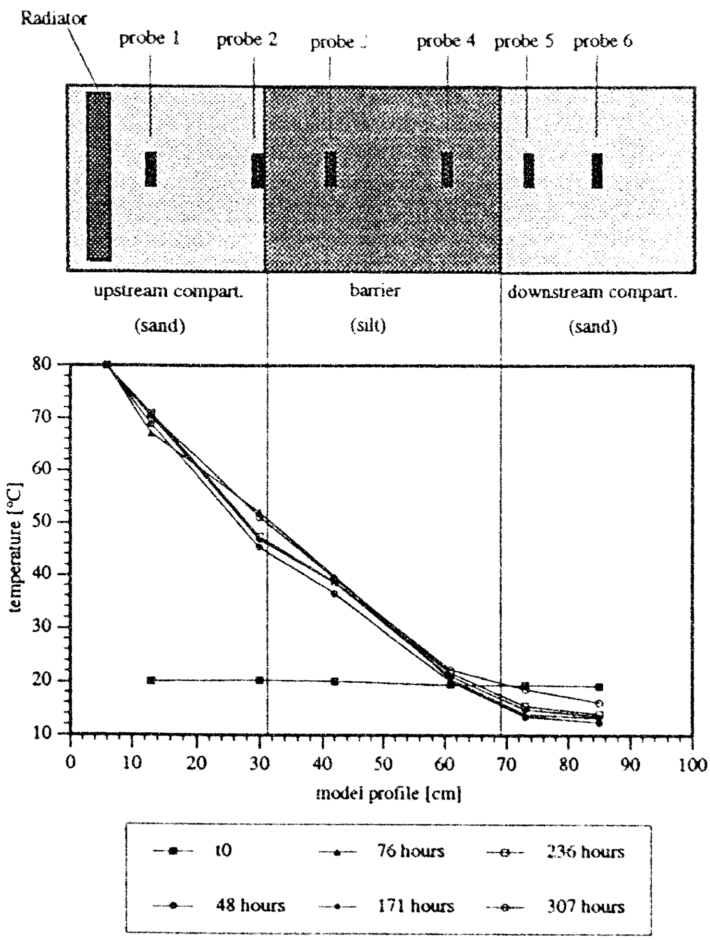


Figure 5: Heat transfer through the model as a function of time. Case of pure conduction

## 5. IN SITU FEASIBILITY

The various tests carried out on physical models showed that, at the conceptual level, the construction of underground barriers using gravel washing silt is an interesting possibility for an underground thermal storage project. These barriers permit the increase of the temperature and of the stored water accumulated in the aquifers by controlling advective losses. In keeping with the aim of using this by-product of the gravel washing process, a technology linking the use of traditional construction machines to a simple placement concept, i.e. at reduced cost, was developed. This technology consists of digging a trench at the barrier location using a mechanical shovel (Figure 6).

Tests at a pilot site were carried out in order to explore the application of this concept in the field. It was shown that it is possible to construct a trench 3 to 4 m deep under the phreatic surface using a traditional construction machine and gravel washing silt whose characteristics did not correspond to those required for the construction of bentonite slurry walls (Table 1 and Figure 7).

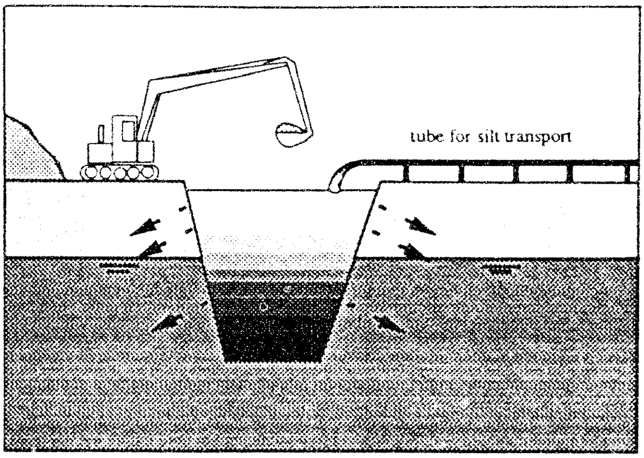


Figure 6: Principle of wall stability due to penetrating mud

| | pH | Marsh Viscosity (1lt) | Density | Colature | Cake |
|---|---|---|---|---|---|
| Bentonite | 8 - 12 | 32 " | 1.02 - 1.05 | ≤ 30 $cm^3$ | ≤ 2mm |
| Gravel washing silt used | 7 | 28 " | 1.08 - 1.11 | 150 $cm^3$ | 5 mm |

Table 1: Characteristics of required (bentonite) and measured (gravel washing silt) mud for trench excavation

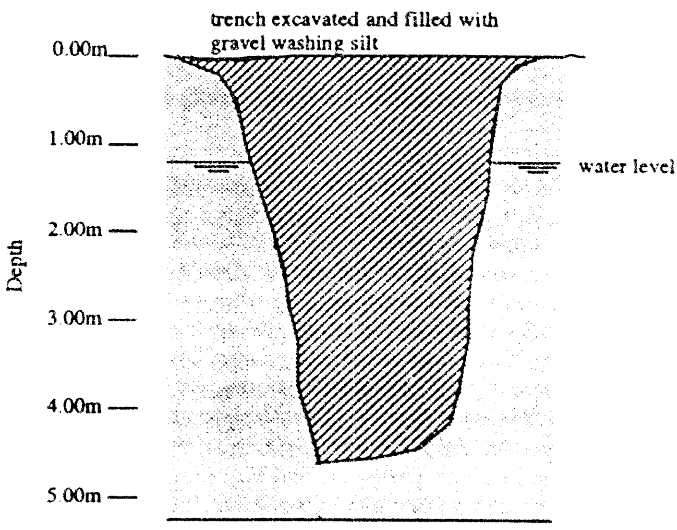


Figure 7: Test trench excavated by mechanical shovel with gravel washing silt instead of bentonite

## 6. CONCLUSIONS

The potential for use of this material for underground barriers in applications of thermal storage was shown with the help of measurements carried out on samples and physical models. However, the use is rather delicate, as it is necessary to pay attention to certain phenomena which could alter the material performance, as for example, prolonged desiccation. In the case of aquifers, constant immersion of the silt eliminates this sort of problem. The field tests permitted a favourable verification of a simple placement technology for these silt barriers.

In comparison with other methods, confinement using gravel washing silt presents many advantages, particularly concerning the economical use of this industrial by-product. The socioeconomical and environmental impact is important, and should contribute to developments in future confinement work. The stabilisation of flow through the placement of underground barriers would permit the construction of such systems for geological sites considered a priori to be unfavourable due to high permeability. This would tend to generalise the concept of hot water storage in aquifers, leading to a reduction in production costs and would thus render the storage energy cost efficient. In comparison with the other systems of thermal accumulation, this type of storage offers undeniable advantages, such as the accessibility of large volumes, the possibility of having a large amount of energetic power at disposal, the efficacy of high storage potential and a minimum of territory used.

## ACKNOWLEDGEMENTS

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