HOW CAN GEOPHYSICAL EXPLORATION HELP TO DETERMINE GSHP GROUND PROPERTIES?

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ABSTRACT

Surface geophysical reconnaissance for Ground Source Heat Pumps (GSHP) is mainly restricted to geoelectrical, electromagnetic (incl. ground penetrating radar) and seismic refraction methods. Resistivity sounding allows extrapolation of profiles found in boreholes over a larger area, and thus enables the designer to get a spatial image of ground parameters. The depth and thickness of waterbearing layers can be determined with considerable accuracy, if the soundings can be calibrated with borehole measurements on the site.

Geophysical borehole logging yields information on the type of rock and on water content. Geo-electric and nuclear radiation logs (Gamma, Neutron) may be used for site investigations. Borehole logs are of particular interest in tasks to correlate a number of boreholes, or to distinguish between clay- and sand-layers etc. The accuracy of interpretation of geophysical borehole data can be enhanced, if core drilling and well test data (for GSHP using groundwater) are available at least in one borehole on the site.

1. INTRODUCTION

For design of GSHP applications, applied geophysics can play an important role. The elucidation of the distribution of subsurface layers by its physical characteristics is one of the basic goals of geophysical surveying. For practical use in the GSHP business, for instance depth of bedrock or delineation of aquifers may be estimated using geophysical techniques.

Shallow geophysics are used in a variety of applications, in mineral exploration, construction planning, geological mapping etc. Several textbooks give good information on fundamentals, techniques and interpretation of geophysical tools (e.g. Bender, 1985; Burger, 1992.). These tools can be categorized according to their spectrum of use. Geoelectric and electromagnetic methods as static techniques e.g. can record the lateral and vertical changes in the soil type. The seismic tools are considered as dynamic methods to detect the structure skeleton of a specific region. Other geophysical techniques like ground penetrating radar (GPR), induced polarization (IP), gravimetry and geomagnetism can be classified according to the purpose of the work. Well-logging techniques give optimum precise results, but have sometimes rather high costs. Table 1 lists the geophysical methods applicable in the GSHP market. The individual geophysical techniques and their advantages and limitations will be discussed in the following chapters.

Tab. 1: Different methods of shallow geophysical exploration applicable to GSHP design

Method	Depth Range	Target	Remarks
Geoelectric	3 m - 100 m	Layers of different resistivity (sand, clay, etc; water table)	Easy field work, relatively low cost. Frequent ununique solutions.
Electromagnetic	5 m - 200 m	Layers of different conductivity (sand, clay, etc; water table)	Easy field work, relatively low cost. Sensitive for outside interference (electric cables, terrain, etc.)
Seismic Refraction	1 m - 50 m	Layers with different acoustic velocities (bedrock, structures, aquifers, etc.)	Skilled field work required, medium cost. Sensitive for outside interferences (noise: traffic, cattle, etc.)
Seismic Reflection	>50 m - some kilometers	Layers with different acoustic velocities (aquifers, structures)	Complicated field work, high cost. Several long processing steps are needed.
GPR (Ground Penetrat. Radar)	1 m -10 m	Shallow heterogenities	Easy field work., low cost. Highly sensitive for outside effects (electric cables, terrain, etc.)
Well Logging (electric)	according to well depth	Layer differentiation based on resistivity	Medium complications in field work. High cost.
Well Logging (SP)	according to well depth	Distinction of permeable and impermeable layers	Medium complications in field work. High cost.
Well Logging (radioactive)	according to well depth	Identification of clay layers and water content	Medium complications in field work. High cost.

2. GEOPHYSICAL SURFACE METHODS

2.1 Geoelectric and Electromagnetic Sounding

Both the geoelectric and electromagnetic methods have in common the use of one identical physical parameter, which is the electric resistivity or/and conductivity. Nevertheless, there are many differences in the theoretical background, in the measuring instruments and in the field work procedure. The main advantage in their application is the great ability to differentiate between impermeable/confining materials (clays) and the permeable aquifer layers (sands and gravel). Moreover, they can delineate the water table of an unconfined aquifer due to the significant difference between the resistivity (conductivity) values of the saturated and unsaturated parts of the soil. The main limitation is due to the equivalence problem, where a unique solution cannot be given. If no outcrops or boreholes in the vicinity of the survey area can provide the necessary information to decide upon one of the possible solutions, sometimes combination with another electric method, induced polarization, may help.

There are many methods for geoelectric data interpretation. They usually are classified into qualitative and quantitative methods. Use of computer interpretation programs nowadays makes the geological interpretation of the data easier, faster and more precise. Fig. 1 shows a typical field curve and the interpretation results for a geoelectric sounding point in an area in Egypt, using the program package Interpex (1995). The same field curve was interpreted using Resist (1988) and Zohdy (1989), as shown in Fig. 2. All three programs are one-dimensional. Other programs in 2D and 3D are available and also easy to handle.

In electromagnetic data interpretation, some measuring instruments collect data which can only be interpreted qualitatively, while data from others equipment can be interpreted both qualitatively and quantitatively. Typically each measuring instrument has it´s own special interpretation program.

A series of individual geoelectric measurement points in a line on the ground surface can be combined to show a subsurface profile (Fig. 3), which, enhanced or calibrated with additional field data, is a kind of "geological x-ray". It enables the geologist to chose drilling location and depth, in particular for GSHP using groundwater, or for Aquifer Thermal Energy Storage (ATES).

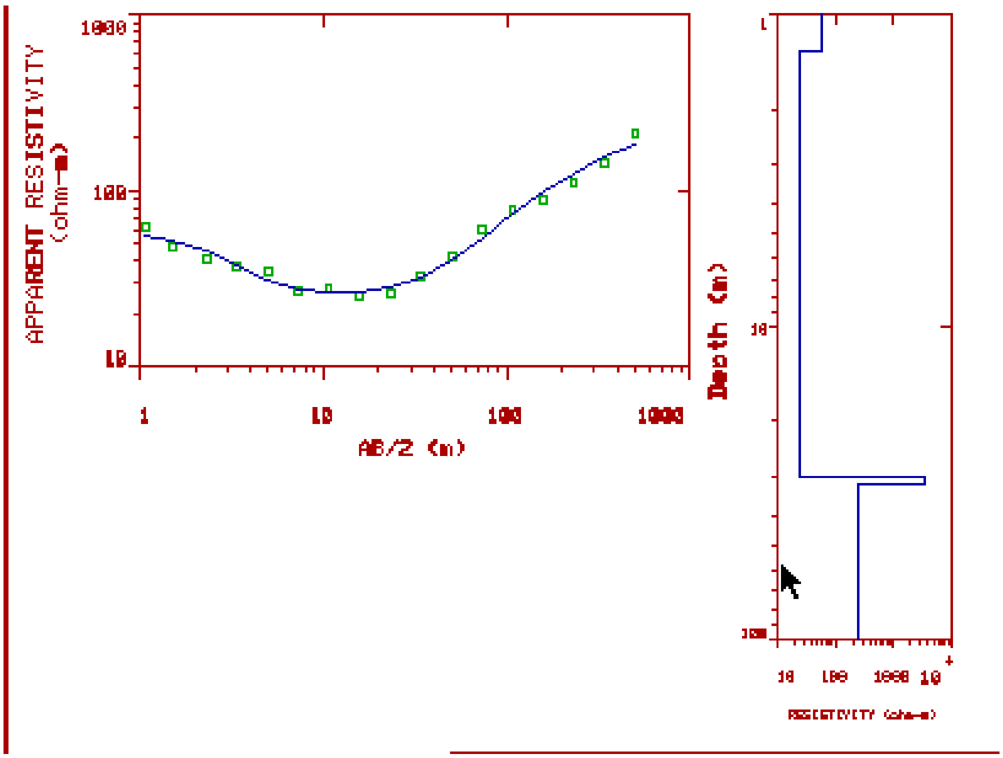
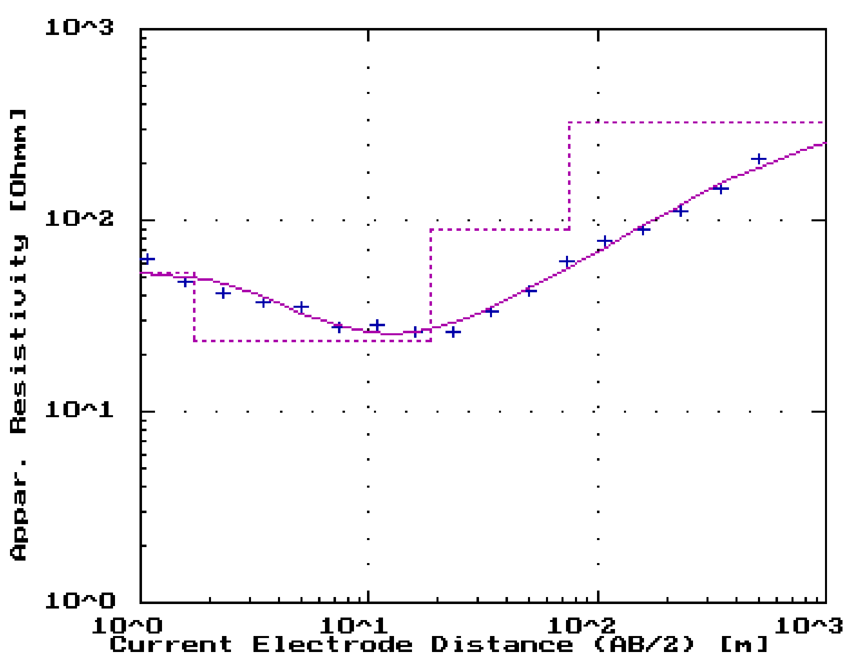


Fig. 1: Field curve and interpretation for a geoelectric sounding point, using Interpex (1995)

Resist (1988)



Zohdy (1989)

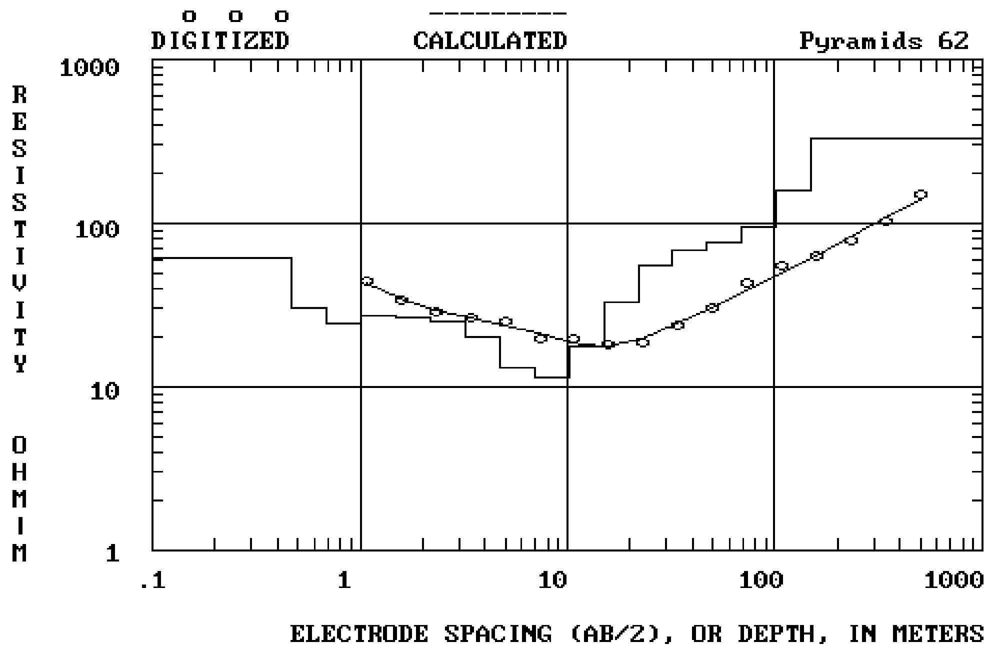
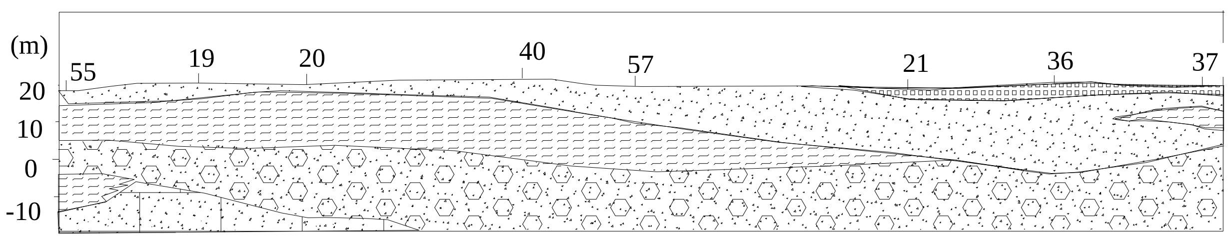


Fig. 2: Field curve and interpretation for a geoelectric sounding point



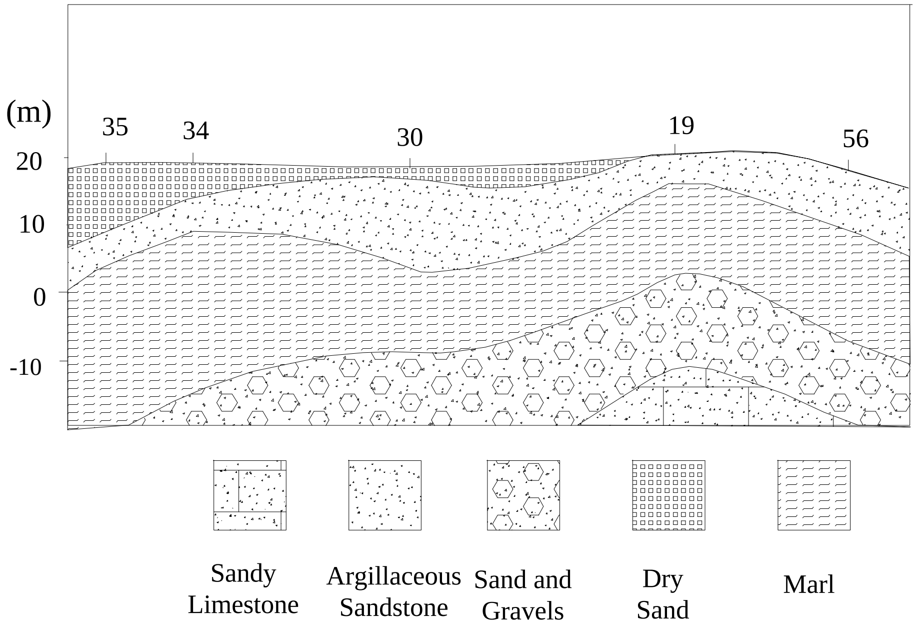


Fig. 3: Above: Geoelectric section P1 (N-S), below: Geoelectric section P6 (W-E)
Sections cross at sounding point 19

2.2 Ground Penetrating Radar (GPR)

GPR is relatively new geophysical method. It is in fact an electromagnetic tool, using short pulses in a frequency range from 10-1200 Mhz. The penetration depth into the ground depends upon rock and soil properties, and varies between 2 and 50 m (Aprison & Aigner, 1997). The higher the water content of the material, the shorter in general is the penetration depth.

Typical radar signatures allow to distinct sedimentary units, and to locate aquifers in unconsolidated sediments and even in sedimentary rock. Application in various kinds of grounds are published (Beres at al., 1995, Meschede et al. 1997, Aprison & Aigner, 1997). In particular for open-loop systems with relatively shallow groundwater wells, GPR is a promising tool.

2.3 Seismic Refraction and Reflection

These techniques are considered as dynamic methods, and they are applied to define the structural elements controlling a specific region. Their signal depends mainly on a sudden disturbance which is transferred from the source (origin) to the receiver, causing a displacement in the particles of the subsurface media. From the acoustic running time / velocity, the material of the subsurface can be evaluated. The anomalies due to structure interference can be delineated. Consequently, seismic work will provide special knowledge about the thickness and extension of layered strata and of other structures of the earth (e.g. tectonic structures like faults), which is essential to solve geological and hydrological problems. For GSHP tasks of shallow depth, it is preferred to apply seismic refraction, while seismic reflection is more successful for deeper targets (>50 m).

The interpretation techniques of refraction are not as complicated as those for seismic reflection. Reflection data need intensive processing stages before showing the final seismographic sheets for interpretation. One limitation of seismic techniques is their high sensitivity to outside noise interference (urban areas, traffic, cattle movement etc.).

2.4 Gravimetry and Geomagnetism

Gravimetric investigation in shallow depths has some promising applications where a strong density contrast exists in the bed rock. Nevertheless, the application of gravity survey to GSHP is not recommended because of high cost and difficult field work. Looking for very small gravity anomalies, the survey needs to be prepared by precise leveling to eliminate the strong influence of even minor topographic features.

Geomagnetic measurements detect principally a signal due to the contrast of rock magnetization. It may have a minor role in aquifer exploration, where the aquifer is expected to be a fractured igneous rock or sedimentary rock of some inductive and remnant magnetization.

3. WELL LOGGING

Well logging is considered as one of the most successful tools to figure out the subsurface strata. However, it first requires a borehole of certain depth to be drilled, before investigation may start. Many types of logs (gamma ray log, density log, neutron log, electric log, self-potential log, sonic log, temperature log, calibre log etc.) can be operated in one borehole. Each of them can measure a specific parameter. Integrated finally to form a composite log it illustrates the rock distribution with depth in the borehole. When calibrated, some logs can give rather good assessment of rock parameters. For instance methods based on radioactivity, like gamma ray or neutron, can show moisture content and give data on porosity.

Well logging equipment is available from 2" diameter upwards (for a 4"-borehole). The smaller the diameter is ("slimhole-equipment"), the more complicated the probes have to be and the lower usually is the precision. On the other hand, small diameter means narrow boreholes and thus lower cost. In greater depth with accordingly larger diameters, as in oil or deep geothermal drilling, borehole logging is a standard procedure.

There are two main limitations to well logging:

- expensive equipment and services
- collected logs are valid only for the direct vicinity of the borehole

This means the well log has either to be combined with surface techniques covering larger areas, or many boreholes have to be drilled and logged to give a proper interpretation for an area. Another method to get similar or even better data from the subsurface is core drilling and subsequent laboratory tests with drill cores; thus for shallow applications like GSHP it always has to be checked wether core drilling and testing of samples or normal rotary drilling and well-logging are more cost-effective at a given site.

For groundwater heat pumps or ATES applications, the flow log should be used to describe the pattern of inflow to a given well. A vertical propeller is lowered or raised in the water-filled part of the borehole with constant velocity while water is pumped. The speed of rotation is proportional to the percentage of water entering the borehole at a certain depth. This information is essential especially for hydrothermal modelling and simulation.

Well logs have been used frequently for larger UTES installations. A very recent example is the new high temperature heat store in Neckarsulm/Germany (Seiwald & Hahne, 1997), planned by Stuttgart University. This plant uses borehole heat exchangers to store heat in Upper Triassic shales and marls. Flow log ("Flowmeter") was used to detect a thin, dolomitic zone carrying water on fractures. This zone has either to be avoided when drilling or to be treated specially (grouting), to prevent thermal losses due to the groundwater flow. In the unsaturated zone of the boreholes measurements with a kind of neutron log are carried out by Landtechnik Weihenstephan to investigate moisture movements.

4. GEOPHYSICAL SURVEY CAMPAIGN

As a recommendation, two or three geophysical tools should be executed in a combined field measurement campaign and combined interpretation to consolidate the results. Field work should pass through different stages. It could get started with general reconnaissance evaluation, followed by a more detailed survey to check the areas that need further investigation. The final results should be verified by drilling a hole. In a case study in the Pyramids area (Giza, Egypt; Abbas et al., 1995), it is possible to show how the location of an aquifer had been established through geophysical survey. Three types of measurements have been conducted in the area:

- Geoelectric (Schlumberger and Wenner method)
- Electromagnetic (TEM)
- Seismic Refraction

The two cross-sections in Fig. 3 have been plotted after the field data had been analyzed and interpreted. The figure shows the presence of two aquifers separated by a lens of marl. Depending on the ranges of the resistivity values, the first aquifer is expected to consist of argillaceous sandstone, and the second one of sand and gravel. Other cross-sections exhibiting the electromagnetic and seismic refraction data were matched and prove the same results.

Using the water level measurements in some boreholes in the area and based on the geophysical results, a hydrogeological model in 3D was established. All these data and results are important in the determination and estimation of the ground properties which may be used for any future GSHP- or UTES-projects helping in the modernization process affecting the Pyramids area. Hotels and touristic facilities in Gizeh need air conditioning, and cold storage may be one method to limit energy consumption while providing high comfort level.

5. CONCLUSIONS

"The only component of any UTES (Underground Thermal Energy Storage) system which can not be changed by engineering is the underground" (Andersson et al., 1997). This is also true for GSHP, which have a lot in common with UTES-systems. Therefore a good knowledge of the subsurface at a proposed construction site is a key factor for successful GSHP design, installation and operation. Shallow geophysical investigations can help in several ways:

- Elucidate different layers and structure patterns in the subsurface to select drilling locations
- Allow extrapolation of a geological profile from a borehole or outcrop over a wider area
- Follow laterally certain layers known in a borehole
- Yield additional information in a borehole through well logging

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