Ellog Auger Drilling: Three-in-One Method for Hydrogeological Data Collection

by Kurt Sørensen and Flemming Larsen

Abstract

The Ellog auger drilling method is an integrated approach for hydrogeological data collection during auger drilling in unconsolidated sediments. The drill stem is a continuous flight, hollow-stem auger with integrated electrical and gamma logging tools. The geophysical logging is performed continuously while drilling. Data processing is carried out in the field, and recorded log features are displayed as drilling advances. A slotted section in the stem, above the cutting head, allows anaerobic water and soil-gas samples to be taken at depth intervals of approximately 0.2 m. The logging, water, and gas sampling instrumentation in the drill stem is removable; therefore, when the drill stem is pulled back, piezometers can be installed through the hollow stem. Cores of sediments can subsequently be taken continuously using a technique in which the drill bit can be reinserted after each coring. The Ellog auger drilling method provides detailed information on small-scale changes in lithology, sediment chemistry, and water, as well as gas compositions in aquifer systems—data essential to hydrogeological studies.

Introduction

Hollow-stem auger drilling is a method widely used in subsurface investigations in unconsolidated sediments to acquire sediment samples and to install monitoring wells for ground water studies. Sediment samples are often taken with continuous coring equipment, and detailed stratigraphical information can be obtained. Vertical stratifications in water chemistry can also be investigated through depth representative sampling of water using the "screened auger sampling technique" (Taylor and Serafini 1988). In these well-known techniques, indirect information on the geology in interbedded strata of clay, silt, sand, and gravel can be obtained by observing the changes in auger torque and penetration rate, and by analyzing the cuttings coming up along the auger flights. Further interpretation of the stratigraphic units can later be accomplished by gamma logging inside the auger or in installed piezometers (Taylor and Serafini 1988). However, in a hydrogeological investigation, for example the mapping of subsurface pollution, an in-field planning of the water sampling is often warranted, as abrupt changes in chemical profiles through heterogeneous aquifers can be controlled by the presence of thin, low-permeable layers that are difficult to detect with existing techniques. Therefore, a new hollow-stem auger drilling technique has been developed to address this need. Information about the geology is collected continuously while drilling using geophysical logging tools inside the hollow-stem auger in combina-

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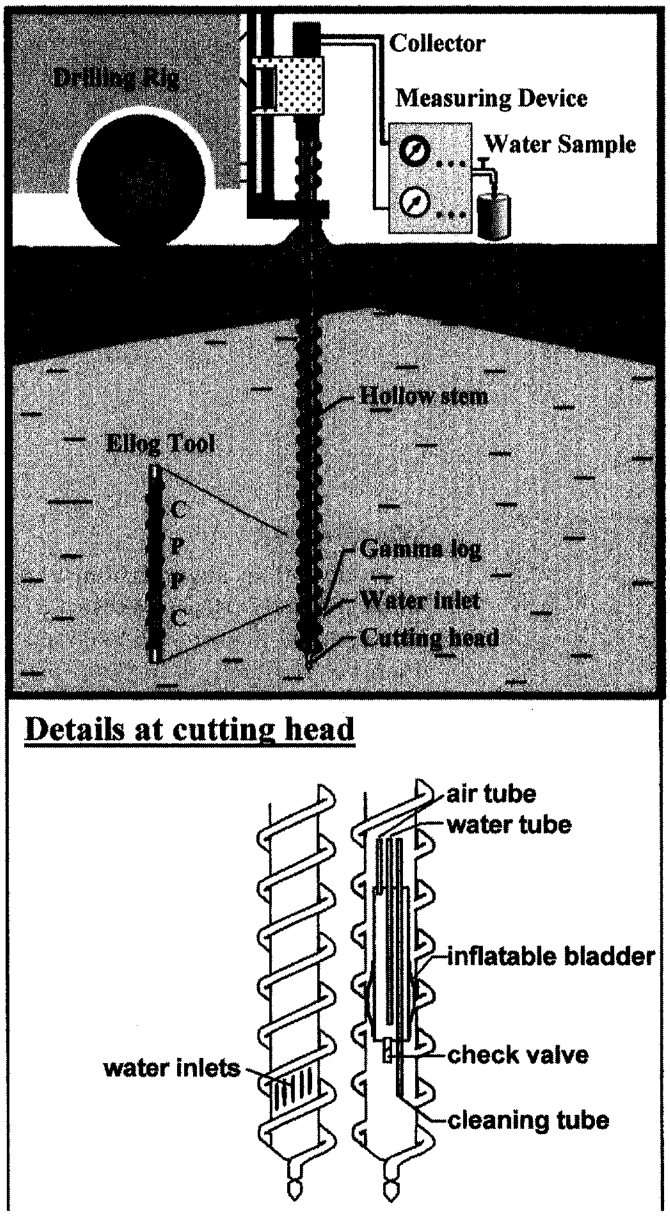

Figure 1. Schematic presentation of the Ellog auger drilling method.

tion with a screened auger. Using this device, geophysical logging and water sampling can be done in the same operation. This drilling technique is referred to as Ellog auger drilling. The first developments in this method have been reported (Sørensen 1989a, 1989b, 1994), but new features have been developed during a study of pyrite oxidation in a sandy aquifer (Sørensen and Søndergaard 1991; Larsen 1996; Larsen and Postma 1997, Elberling et al. 1998). These features are described in this article. In Denmark, the Ellog auger drilling method has been used extensively over the last 10 years in hydrogeological studies in unconsolidated sediment. Drilling has been undertaken down to 100 m in unconsolidated, sandy and clayey deposits, and to date 20,000 m have been drilled.

Method Principles

With the Ellog auger drilling method, a 6-inch (O.D.) hollow-stem auger is operated with a small hydraulic drilling rig. Geophysical logging, water/gas sampling, and the installation of piezometers are done in one drilling operation, while the coring of sediments is done in a separate operation.

Geophysical Logging

The apparent resistivity of the formation is measured with a tool that is an integrated section of the hollow-stem auger (Figure 1). The tool has a steel core with an electrically insulating coating shaped as a flight, allowing the cuttings from the cutting head to bypass the tool section. The measuring electrodes are embedded in an insulation material with aboveground connections to the measuring instrument through cabling inside the drill stem with connectors at each joint. The insulation material has an average durability of 500 m of drilling in deposits of clay till, sand, and gravel, after which it is replaced. In order to obtain adequate vertical resolution, a Wenner array with electrode spacing of 20 cm is chosen (Sørensen 1989a). The center of the measuring array is placed approximately 2 m above the cutting head, and sampling with intervals of 2 to 5 mm/sec is performed while drilling downward. As the height of the flight is only 16 mm, the distortion of the measured apparent resistivity due to the cuttings in the flight of the tool is negligible (Sørensen 1989b). Hence, the measured apparent resistivity is a close, detailed estimate of the true apparent formation resistivity.

For logging of the natural gamma radiation of the formations, a gamma log tool is placed inside the hollow auger. The natural gamma radiation of the formation is reduced by approximately 30% due to the damping effect of the steel wall of the tool. However, as drilling speed is approximately 25 cm/min—low compared to logging speed in general (2 to 3 m/min)—the recorded log has a high vertical resolution. Data processing takes place in the gamma log tool, and the results are transmitted digitally to the surface through the cable inside the stem.

During drilling operation, the recorded logs are shown on a PC, which enables the field hydrogeologist to concurrently and optimally plan the water and gas sampling according to the lithology interpreted from the log features.

Water Sampling

Water flows into the interior of the stem through a 15 cm slotted section, 20 cm above the cutting head (Figure 1). Inside the stem is a water-sampling chamber with a volume of 3.5 L. The chamber is mounted with a check valve at the bottom, and water and air tubes are placed at the bottom and the top, respectively (Figure 1). The tubing continues to the surface with connectors at every joint. Thus, water samples can be brought to the surface by gas displacement using N_2 or another inert gas. At the surface, the water-sampling tube is normally connected to a flow cell, and in-field analyses of parameters such as pH, Eh, O_2, electrical conductivity, and water temperature can be performed in a sealed system without contact with the atmosphere. A third tube from the surface to below the sampling chamber is used for cleaning purposes. By pressing a small amount of distilled water through the slots, fine particles are removed from the screen (Figure 1).

Gas Sampling

In the unsaturated zone, the water-sampling system can be used for taking soil-gas samples by suction. During gas sampling, the check valve at the bottom of the sampling chamber is lifted by the gas flow, and soil gas flows into the water tube inside the auger while the other tubes are closed. After flushing the system, gas sampling is done through the upper tube. Sample volumes of soil gas can be measured by filling a plastic bag during sampling. Gas sampling can be done in a closed system, and the tubing can be connected directly to a field gas chromatograph (GC) or other measuring devices.

Installation of Piezometers

The logging, water, and gas instrumentation can be removed from the interior of the drill stem by means of an attached water-inflated packer system (Figure 1). This leaves free access for installation of multiple piezometers and other permanently installed devices for water and gas sampling through the drilling stem. The inner diameter of the hollow-auger stem is 95 mm, and typically 25 mm, 40 mm, or 63 mm piezometers are used. Plugs of bentonite have been successfully deployed between the piezometers by pumping a bentonite slurry out into the borehole through tubing kept inside the stem. The formation materials (running sands) are kept out of the drill stem by balancing with water in the stem.

Coring of Sediments

Cores of sediments can be taken at multiple levels during hollow-stem auger drilling without withdrawing the drill stem in between. A technique has been developed by which an inflatable packer device (PD) is employed above the cutting head. The device is retrieved before each coring and re-employed afterward.

The PD is lowered to the drill stem with a reinforced combined electric and tubing cable. The cabling is connected to the PD by an employment/retrievement device (ERD), which is controlled from the surface. This device is also based on the use of inflatable packers. Through the ERD, electrical and fluid connection is established to the PD and the magnetic flow valves in the PD can then be operated. When the PD is set, the packer in the device is inflated with water (six to 12 bar), fixing the PD firmly to the drill stem. The valves in the PD are then closed, so the pressure is maintained in the packer after the ERD is retrieved. The use of the PD has two functions: (1) It withstands the hard grinding from the earth formation while drilling, and (2) it prevents the formation water and materials from entering the interior of the drill stem during drilling. When the PD is employed, the drill stem is emptied for water, so that formation water in the stem (possibly polluted) is not moved from one coring level, to

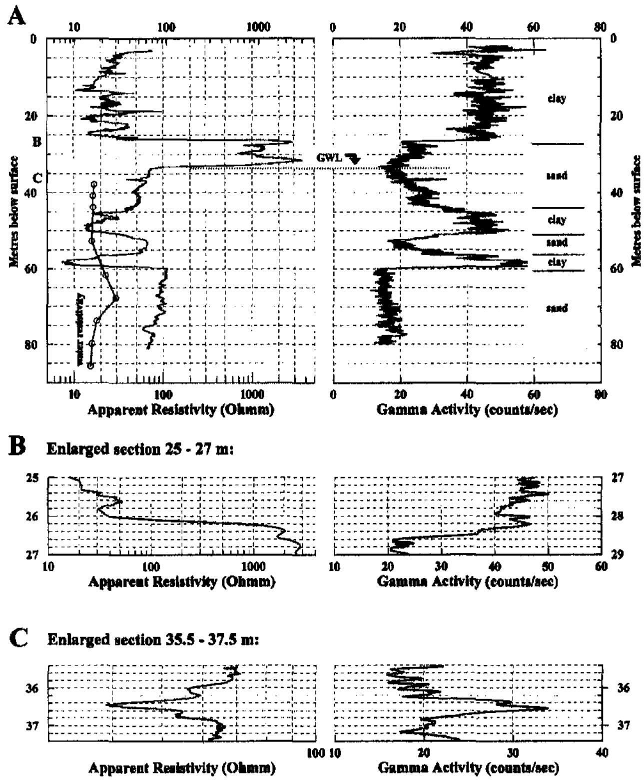

Figure 2. Ellog auger drilling results showing the electrical and gamma logs from a drilling site in the Beder Aquifer (Boring Beder K).

the next. At the next coring level, the drill stem is flushed with water, and pure water is filled in the stem to balance the formation water pressure before retrieving the PD.

The successful functioning of the PD and the ERD is based on the use of inflatable packers. It should be remembered that these devices are to operate in an environment with formation water mixed with sediments. Hence, the devices and their connections to each other and to the drill stem have to be flexible in order to adjust to the presence of detrital material. Devices based on mechanical systems often fail due to sediment obstructing their employment and retrievement.

The PD can be retrieved and employed whenever wanted with the ERD, and cores can be taken (with the Waterloo 90 cm plastic liner [O.D. 50 to 70 mm]) through the cutting head.

Results

The usefulness of the Ellog auger drilling method is demonstrated with results from a study of the Beder Aquifer, which is 12 km south of Aarhus, Denmark. This aquifer is in unconsolidated, sandy deposits of Quaternary age. The aquifer sand is in a buried valley, with a cover of till clays and interbedded fluvial sand and silt.

Resolution of Lithology

The first example demonstrates the high vertical resolution of the method and, hence, the possibility of achiev-

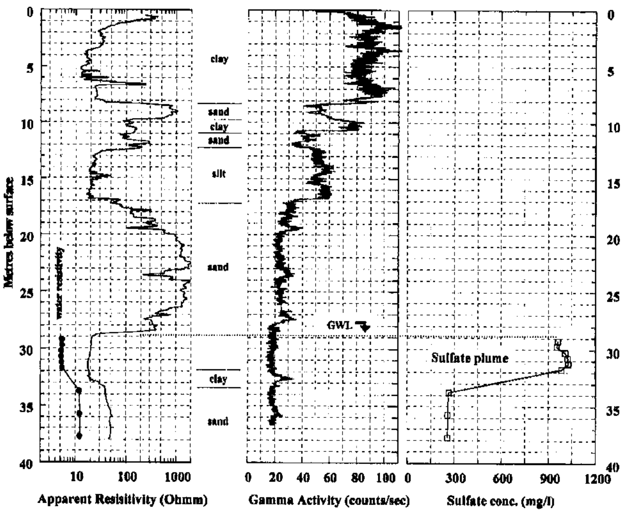

Figure 3. Results from Ellog auger drilling showing logging results and water quality (Boring Rokballe No. 3).

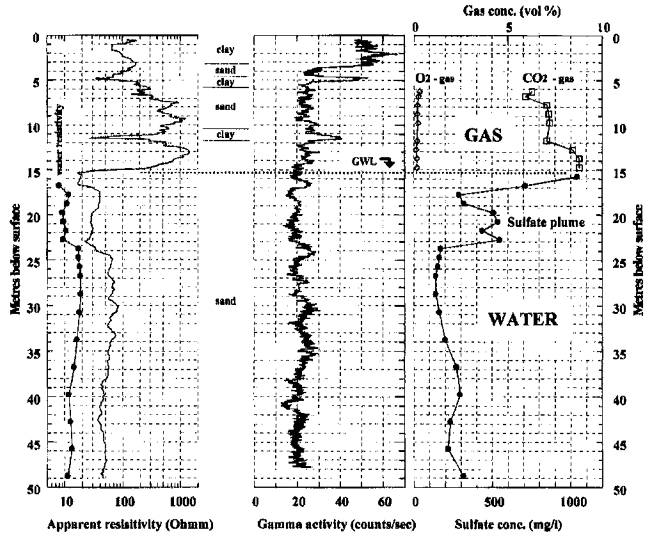

Figure 4. Results of Ellog auger drilling showing logging results with results from water and gas sampling (Boring Rokballe No. 11).

ing detailed geological information. Figures 2a through 2c present the logs and selected enlarged sections from an Ellog auger drilling carried out to a depth of 82 m. As seen, the measured natural gamma radiation of the clay layers gives 40 to 60 counts/sec, and the clean sand yields 15 to 20 counts/sec. The apparent resistivity of the clay is 10 to 30 ohm-m, whereas the overall resistivity of the sand is controlled by the water content and the composition of the water. The location of the water table at 33 m is accurately determined by the abrupt decrease in resistivity from the unsaturated to the saturated sand. In the sandy unsaturated zone (26 to 33 m), the formation resistivity is up to 1200 ohm-m, and in the saturated sand it is typically 60 ohm-m.

Figure 2a shows a good correlation between the gamma and the electrical log in the saturated and unsaturated zones. From the surface to a depth of 26 m the lithology is dominated by a massive clay deposit. A sand layer is present from 26 to 45 m, and a few clay layers are seen in this sand. A sequence with interbedded sand and clay is found from 45 to 60 m, and below this depth is the main aquifer.

The high resolution of the logs is seen in an enlarged section of the depth interval from 25 to 27 m (Figure 2b). A transition zone between a low-resistive clay formation and a high-resistive unsaturated sand formation is recorded. A sharp lithological boundary (transition less than 0.1 m) is indicated by the Wenner "shoulders" on the electrical log (due to separated transitions of the electrodes through the boundary). Finally, an enlarged section of the depth interval, 35.5 to 37.5 m (Figure 2c), displays the ability of the method to identify and locate thin clay layers embedded in sandy formations. A low-resistive clay layer of approximately 0.15 m thickness is recorded in otherwise higher resistive homogeneous sand in 36.4 m. A layer this thin would probably not be detected by any other method, apart from perfect coring of the sediments. Wenner "shoulders" are present, indicating sharp lithological boundaries between the clay layer and the surrounding sand formation. As mentioned, the logs are sampled with a vertical resolution of 2 to 5 mm, depending on the drilling velocity. Hence, a recorded log of 80 m has a wealth of detailed log features that can be interpreted into a detailed lithology, as demonstrated by the two enlarged sections previously discussed.

Lithology and Water Chemistry

The second example demonstrates how a situation with a geological control of the vertical chemical water profile can be resolved, and how a solute high-concentration plume with low resistivity can be located (Figure 3).

In this part of the investigated area, the clay sequence above the aquifer sand formation is found from the surface to 17 m. The aquifer sand is unsaturated from 17 to 28 m. In the unit above the aquifer, three clay layers, with different natural gamma radiation, and two sand layers are present. The upper clay layer, from the ground to 8 m, is a reworked marine clay, composed of smectitic, potassium-rich clays. The gamma radiation of this clay is significantly higher (80 to 100 counts/sec), and the identification of this unit can be based on this. This clay is found in exposures close to the study area.

In the saturated zone, the apparent resistivity of the formation is relatively low in the uppermost 3 to 4 m. The resistivity in this zone is 20 ohm-m, compared with 40 to 50 ohmm below this. Field analyses showed that water samples from the upper zone had a high electrical conductivity corresponding to a low resistivity. Later laboratory analyses revealed that the low resistivity of the water was due to high concentrations of sulfate (Larsen and Postma 1997). Thus, the contaminant plume, containing water with a high load of sulfate, can be seen directly from the geophysical log motif, a fact that facilitates the mapping of the plume. As indicated by the logs, a thin clay layer is found at the lower boundary of the plume, indicating that the vertical distribution of the sulfate plume, at least in this part of the aquifer, is controlled by the presence of a thin clay layer.

Gas Sampling

Samples of soil gas from the sandy unsaturated zone have been collected and analyzed for O_2 and CO_2 in another borehole (Figure 4). The aquifer sand is found below a 5 m thick cover of the glacial reworked marine clay. The thickness of the unsaturated zone below the capping clay is 10 m. The sand is homogeneous, but a 0.2 m thick clay layer is found 12.3 m below the surface. The composition of the soil gas in the unsaturated zone is characterized by low concentrations of O_2 and high concentrations of CO_2 caused by oxidation of pyrite with atmospheric air and dissolution of calcite and production of CO_2 (Larsen 1996). Degassing of CO_2 from the saturated zone is indicated by a CO_2 gradient from the saturated zone to the unsaturated zone. An abrupt change in CO_2 concentration across the clay layer shows that the thin clay layer has a notable impact on the gas transport in the unsaturated zone.

Conclusions

The Ellog auger drilling method can be used in unconsolidated sediments and, with a relatively strong rotary machine, drilling can be carried out to between 80 to 100 m below the surface. Using this method, data collection can be done relatively quickly, and the resolution of the data is high. With the integration of the geophysical logging techniques and the water sampling, lithologically controlled changes in water quality can easily be detected. Thus, during drilling, the field hydrogeologist is provided with a good physical model of the subsurface, which gives the best prerequisites for sampling of sediment, water, or gas. Furthermore, an optimal design of a monitoring system of piezometers can be obtained with data recorded with the presented method. Using a 6-inch (O.D.) hollow auger, piezometers with a diameter up to 90 mm (O.D.) can be installed. In these relatively large diameter piezometers, other devices can be used, such as MP-1 pumps and downhole logging tools.

Cores of sediments can subsequently be taken in a new borehole without withdrawal of the auger in between each sampling. This is possible by using a packer device that prevents intrusion of the formation material into the stem. Coring is performed down through the stem and the packer device is employed again, significantly reducing drilling.

Apparent electrical resistivity of formations recorded with the presented tool provides a high resolution and thereby a better understanding of the nature of the formation resistivity. The obtained depth-specific values of apparent resistivities of the strata allow a much more precise interpretation of surface electrical and electromagnetic signatures, which are often used in geophysical surveys before extensive drilling is undertaken. These data are often essential for the set-up of reliable three-dimensional geological models, which again are fundamental to achieving a good ground water flow model.

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Bibliographical Sketches

Kurt Sørensen *is a senior geophysicist at the University of Aarhus, Denmark (Department of Earth Sciences, Finlandsgade 6, DK-8200 Aarhus; e-mail: kurt.sorensen@geo.aau.dk). He has an M.S. and a Ph.D. in geophysics from the University of Aarhus.*

Flemming Larsen *is an assistant professor of hydrogeology at The Technical University of Denmark (Department of Geology and Geotechnical Engineering, Building 204, DK-2800 Lyngby; e-mail iggfl@pop.dtu.dk). He has an M.S. in geology from the University of Copenhagen and a Ph.D. in hydrogeology and geochemistry from the Technical University of Denmark.*