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GEOHYDROLOGIC WELL-LOGGING

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Well-logs have been used to gain geohydrologic information mainly in Precambrian rocks. The logs used are the self-potential, the diameter, the temperature, and the electric conductivity of water. Applications have given general information on the occurrence of ground water in hard rocks. The logging technique seems to be of particular value in connection with underground constructions in rock when detailed local information is necessary in order to avoid ground water leakage even in minor quantities.

Wells and boreholes provide a possibility of getting into the third dimension of an aquifer. Especially in such Precambrian rocks as granites and gneisses, where water occurs in a more or less irregular pattern, borehole loggs add to the geohydrological picture. This is valid whether the purpose of the investigation is to obtain water or to avoid water-bearing zones when locating underground constructions. The latter has become more and more important in urban areas, where tunnels could, by draining ground water from clays, cause extensive damage to buildings.

Borehole logs can be used to locate cracks. Electric conductivity logs, together with chemical analyses, can give information conerning origin and turn-over rate of water in the different crack-systems. Simple recovery tests after instantaneous change of water level can give the transmissibility of the cracks as a whole or of individual ones.

Logging has proved a valuable tool in verifying tectonic hypotheses in local areas.

BOREHOLE LOGS

Diameter measurement

Measuring the diameter gives the location and width of cracks. The measurement can be made with a spring of hardened steel supplied with a Wheatstone bridge of straingauges. The bridge measures the depression of the spring which, via a rolling wheel, is in contact with the borehole-wall.

Self-potential, S.P.

Self-potential or spontaneous potential, is a potential measured between two lead electrodes, one moved in the borehole and one on the ground near the borehole. It reflects two phenomenas in the borehole: differences in pressure between water in the borehole and water in the surrounding strata, and differences in electrolytic content (Moore 1964, Pirson 1970). The first phenomenon, the filtering potential, is insignificant in shallow wells of depths less than 200 m. The second effect is a kind of membrane or Donnan potential and is the one detected in boreholes in Precambrian rocks. This can be proved by introducing salts into the borehole.

Electric conductivity (water)

Electric conductivity of water can reveal the presence of different kinds of water along the borehole. Conductivity generally increases with increasing depth either as a result of a prolonged stay of the water in the rock or because the water is retained sea water. Conductivity thus tells something about the origin and turn-over of the waterbody.

Temperature

Temperature, together with conductivity, can show if there are water movements along the borehole or across it along the cracks. The water movement along the borehole indicates parallel systems of cracks with a difference in pressure. Temperature anomalies are in the order of 0.2°C os less. As temperature is a non-conservative parameter, the size of anomalies reflects the size of water velocities.

Resistivity of the rock

In Precambrian rocks, cracks are often too thin to manifest themselves as changes in profiles of rock resistivity even in a small measuring volume. "Hard limestone log", an electrode arrangement mentioned by Jakosky (1949), has been tried without much success.

Inclination of cracks

The literature describes how the dip of strata can be measured by three S.P. electrodes spaced 120° around the borehole wall. When recorded on a three-channel recorder, the S.P. curves are displaced in relation to each other if the strata are inclined (Pirson 1970). This has been tried in the Precambrian but the S.P. potentials were not distinct enough to make it possible to observe any displacement. The small borehole diameter of 4" is an additional factor making this impossible. Dip of cracks is preferably measured by three diameter strings as described above.

Microseismic recording

Around tectonically disturbed zones, rock pressure is concentrated. This causes local breakage and the energy released can be observed as microseisms in the acoustic part of the spectrum.

Microseismic recording has been tried as a tool in locating cracks. It was found unsuitable mainly because of a large variability in time of the microseisms, which could be due to "earth tides".

Probe and instrumentation

The logs are integrated in the tool as seen in Fig. 1. The gauges are placed on a bar carried on six wheels. The wheels are spaced evenly along three diameter planes to give support from all sides. The purpose of this is to allow the wheels to carry the bar undisturbed over the cracks. On the bar are mounted the gauges, the spring for diameter measurement, the temperature gauge, the conductivity gauge and a lead electrode for self-potential.

When lowering the probe, temperature and electric conductivity are measured, and when raising it, diameter and S.P. are obtained. The spring for diameter measurement can be held in position when lowering the probe and set free at the bottom of the hole, when a bar strikes the bottom and is pushed upwards.

The prove in Fig. 1 fits a 3–5" borehole. A probe for a 2" bore has also been used.

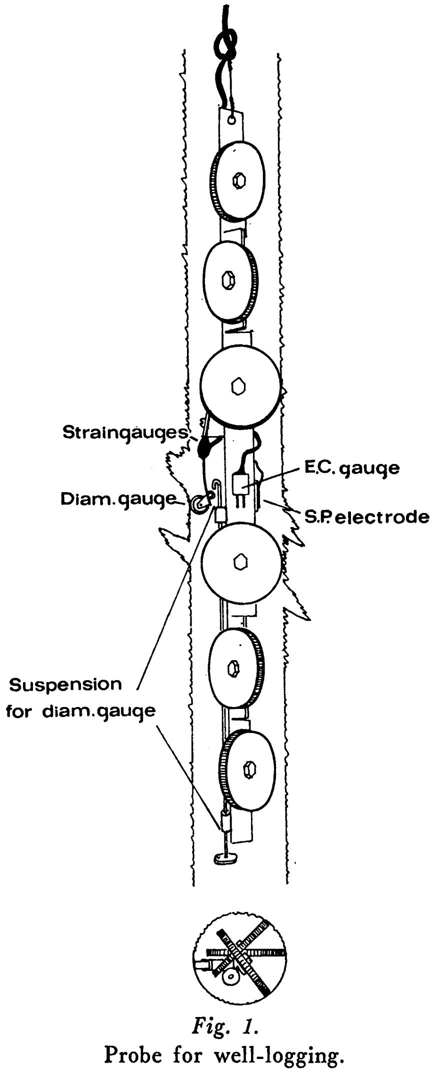

Fig. 1.
Probe for well-logging.

The signals from the probe are fed into a two channel potentiometric recorder. The sizes of these signals are approximately: diameter bridge 0–2 mV, S.P. –50 mV to + 50 mV, conductivity and temperature 0–20 mV. The recorder used is of a laboratory type, powered from a 12 V battery via twn 50 W vibrator converters.

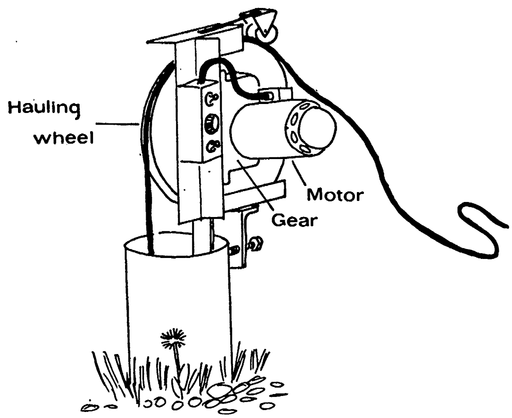

Fig. 2.
Winch for haulage of probe.

The probe is moved with a constant speed along the borehole with a winch consisting of a 12 V D.C. shunt motor with a gear giving the probe a speed variable from 1 to 4 m/minute (Fig. 2).

TRANSMISSIVITY OF CRACKS

The transmissivity can be calculated from simple recovery tests. The water level is changed instantaneously by means of a weight which constricts around 5 liters of water in a 4" borehole as shown in Fig. 3. This gives a water level change of around 0.5 m. The recovery is then measured by hand or by an electric pressure gauge. If the recovery is rapid, a sounding level gauge and a chronometer are useful. The level change can be made several times without much delay in time. The electric pressure gauge is of special value in narrow boreholes and inclined ones, as diamond boreholes of 46 or 56 mm diameter.

The influx of water in the boreholes can be treated with Toricellis law of discharge: $Q = k \sqrt{2gh}$ where Q is outflow per unit of time, k is a constant determined by area and shape of the outflow-opening, and h is the pressure height. The validity of this is obvious from Fig. 4, where water level is plotted versus $\sqrt{t}$. The plots are linear except near the original water level. The result can be extrapolated safely down to the first crack. If this crack is the major water-bearing one in the well, lowering of the water level below the crack will give no additional capacity.

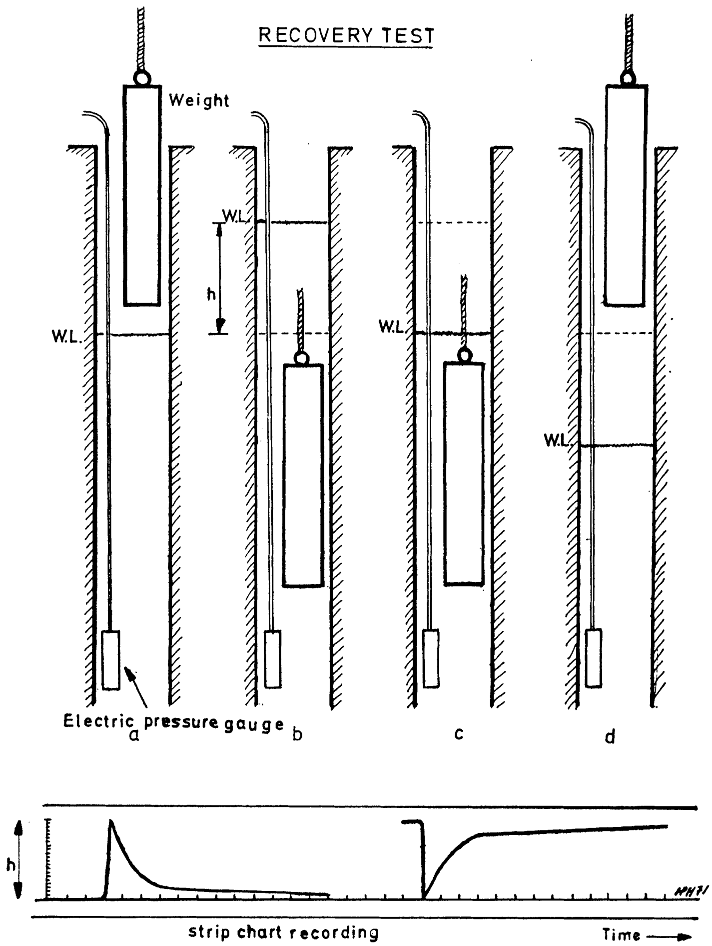

Fig. 3.
Performance of recovery test.

In order to distinguish the transmissibility of different cracks from each other, an arrangement for closing the lower part of the well has been used (Fig. 5). It consists of a small compressor with storage and regulation tanks for compressed air connected with a balloon in the well.

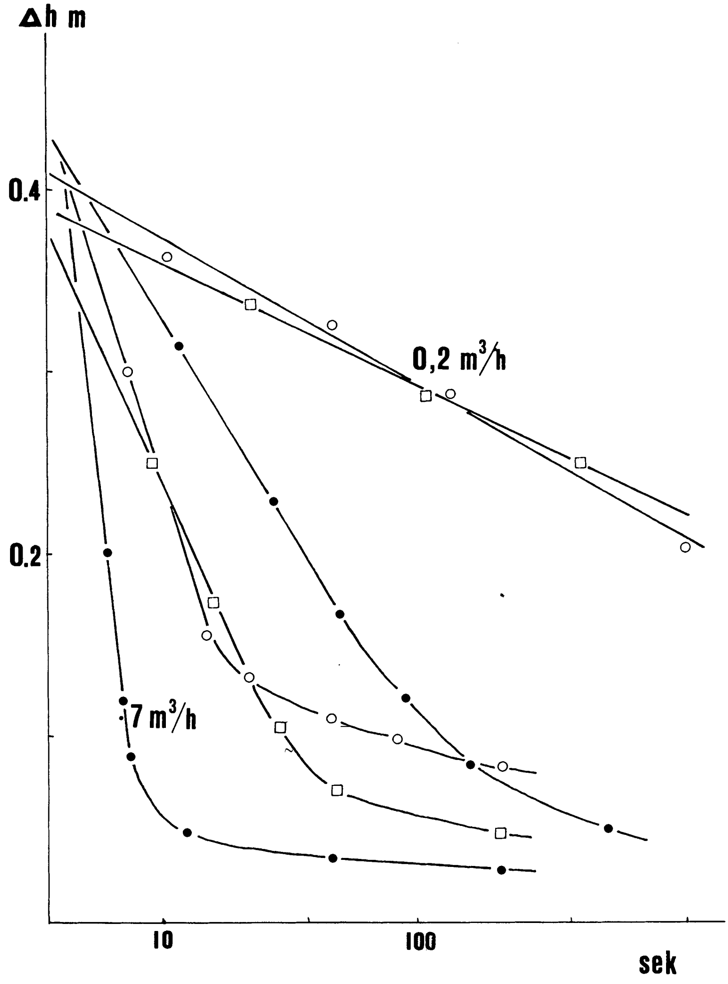

Fig. 4.
Plots of recovery tests.

The well in Fig. 6 has some shallow cracks and some cracks below 50 m. By means of measuring recovery of the whole well and the upper part, it could be shown that almost all the yield of the well (2 m³/h) entered via the shallow cracks. Using a deepwell pump would not be necessary for this well.

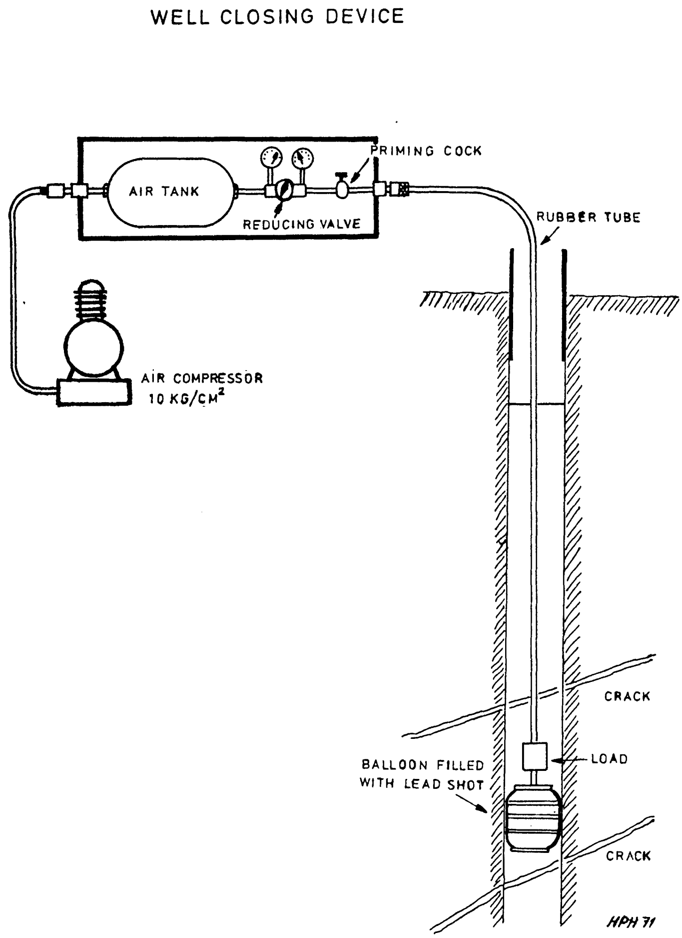

Fig. 5.
Well closing device.

Water sampling for chemical analyses

Chemical analysis is of value when estimating the origin and turnover of the different waterbodies penetrated by a borehole in an aquifer. The degree of chemical equilibrium between water and silicates in the rock is a measure of the age of the water (Eriksson & Khunakasem 1968). Chloride indicates retained sea water or sea water intrusion.

The water sampling should be made at appropriate depths and it should be possible to collect the water without aerating it. A water sampler made of plexiglass with a volume of 2 liters has been used. It has two valves opened when lowering the sampler in the hole. The valves are closed with a falling weight at the desired depth.

Applications

Water wells in Precambrian rocks in Sweden

Figs. 6 and 7 show typical logs from water wells in Precambrian granites. The diameter measurement reveals some distinct fractures. From the temperature logs and electric conductivity logs it can be concluded that there are vertical movements of water in the wells. The hole is a major connection between the water bearing fractures which are not in pressure-equilibrium with each other.

The salinity generally increases with depth depending mainly on two factors.

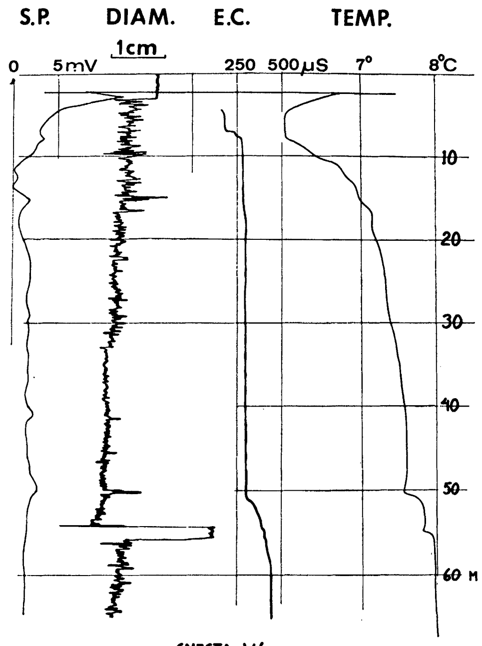

Fig. 6.
Logs from well in Gnesta, south of Stockholm, Sweden.

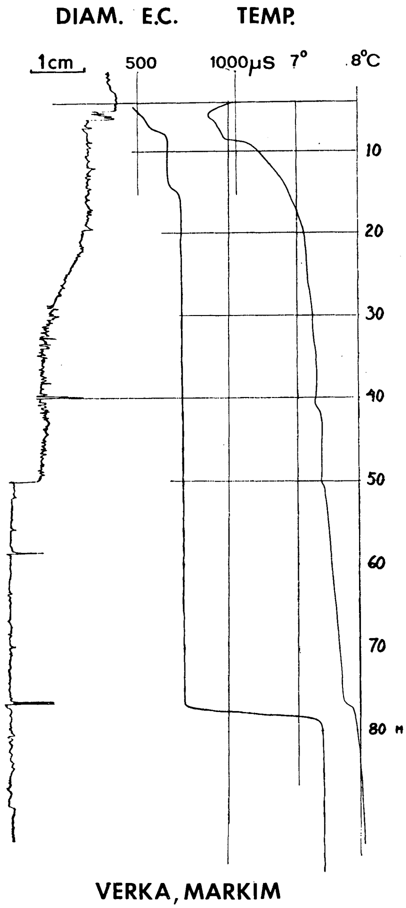

Fig. 7.
Logs from Markim, north of Stockholm, Sweden.

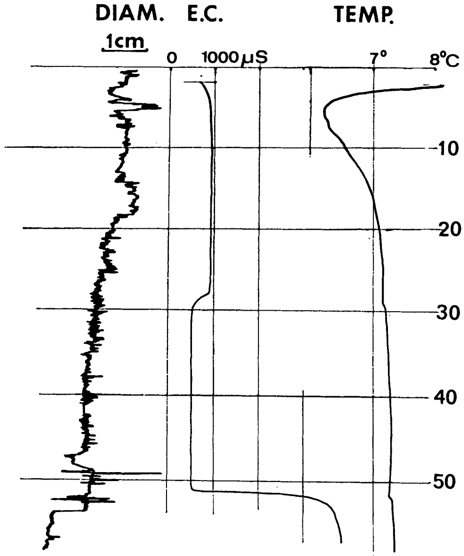

Fig. 8.

Logs from Bergby, north of Stockholm, Sweden. About 1 km from the Markim well.

In Fig. 6 the increase is due to natural weathering reactions. The water at the bottom of the hole is the oldest and has reached equilibrium with its mineral environment. The water higher up in the well is still able to dissolve some mineral constituents. The high salinity in the wells in Figs. 7 and 8 is due to retention of sea-water dating from glacial times. It is thus obvious that the turn-over of the aquifer has been very slow, as the actual area was lifted up from the sea a couple of thousand years ago.

The well in Fig. 8 has not the normal increase in salinity with depth. The well is drilled through a major shear zone (Larsson 1968) which is seen in the lower part of the borehole. The yield of the well is approximately 30 m^3/h while the other two wells in Figs. 6 and 7 give only 2 m^3/h. The lower salinity of the water in the shear zone is most probably due to the high transmissibility. Washing out of sea salts has gone further in the zone than above and below it. The same effect is seen in Angered near Gothenburg, Sweden, where wells with smaller capacities are seen to be more saline than wells with higher capacities.

Fig. 9 shows two diameter logs from the above-mentioned area of Angered. The area is characterized by overthrust movements manifesting themselves as

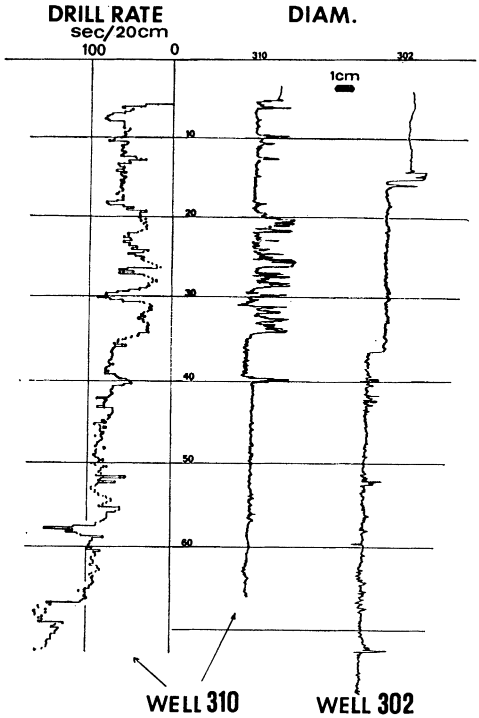

Fig. 9.
Diameter logs for wells 310 and 302 at Angered, Gothenburg, Sweden.
Drill rate observations for well 310.

valleys in the terrain. Well 310 is drilled in the slope of one of the valleys, and has penetrated the overthrust zone which consists of multiple sliding planes separated by intact rock. There is a good agreement between the diameter record and the drilling rate expressed as seconds per 20 cm penetration. Well 302 is drilled in a block between two valleys, where only solitary cracks are seen. The capacity of well 310 is about three times that of well 302, while the salinities have a reverse ratio.

Water wells in Precambrian in India

The electric conductivity logger was brought to India during a ground water survey in the Coimbatore District in Southern India. The main purpose of the

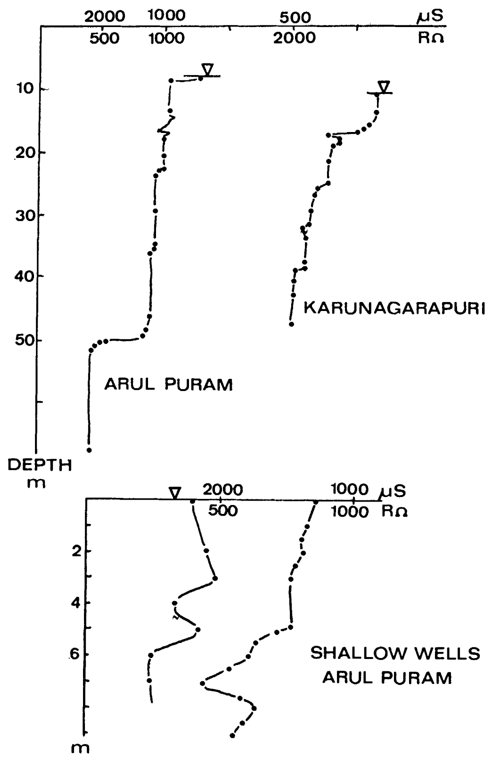

Fig. 10.
Conductivity logs from wells in Coimbatore District, Southern India.

survey was to determine whether the ground water in the district was over-pumped or was renewed at a satisfactory rate. One of the questions concerned the nature of the aquifers – whether they consisted of thoroughly weathered rock or of solitary fractures.

The logs showed a "staircase pattern" of salinity with depth (Fig. 10) indicating that water entered or left the wells in solitary fractures. The total "pore volume" was thus in the order of only 1–2 %.

The logs also showed a vivid infiltration; a top layer of low salinity was still present in the wells from the last monsoon. Shallow wells recently pumped, showed a marked stratification in salinity.

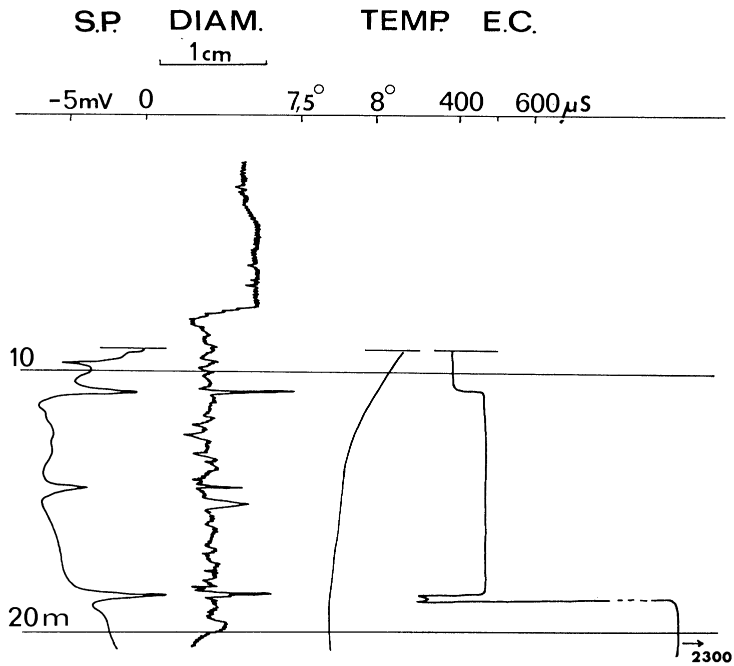

Fig. 11.
Well 1 over gas-storage in Gothenburg, Sweden.

Control wells over gas-storage

Some wells situated over an underground gas-storage were investigated in order to locate leakage. In such storages ground water is used to "keep the gas in place" by means of a slight overpressure of ground water in comparison with the gas-pressure. There must be no big leakage of ground water into the storage as this could lead to a dangerous lowering of ground water level. By means of logging, a leaking crack could be located. In Fig. 11 it is seen at the depth of 19 m in borehole 1, which shows a low ground water level. A narrow zone of water with a low salinity is recorded at the depth of the crack; that means that newly infiltrated water is "rushing" down the crack into the storage room.

Fig. 12 shows logs for borehole 3 where infiltration has been good, raising the ground water level during the previous year. A very thoroughly fractured rock could be seen from the logs. There was no stratification of salinity, and the temperature showed a recent influx of cold water as well as a summer influx of warmer water. The measurement was made in December.

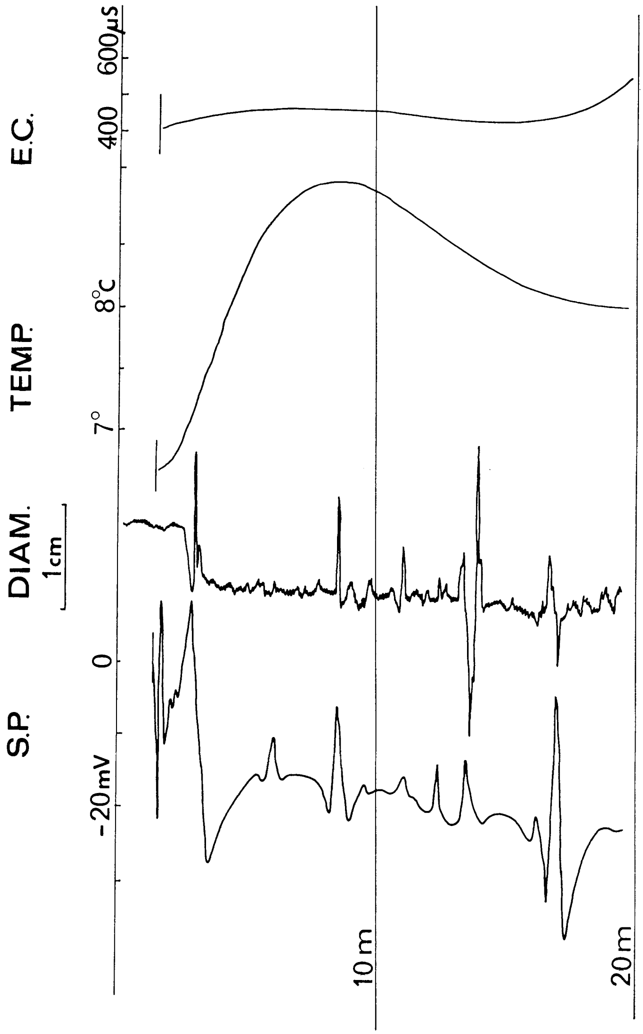

Fig. 12.
Well 3 over gas-storage in Gothenburg, Sweden.

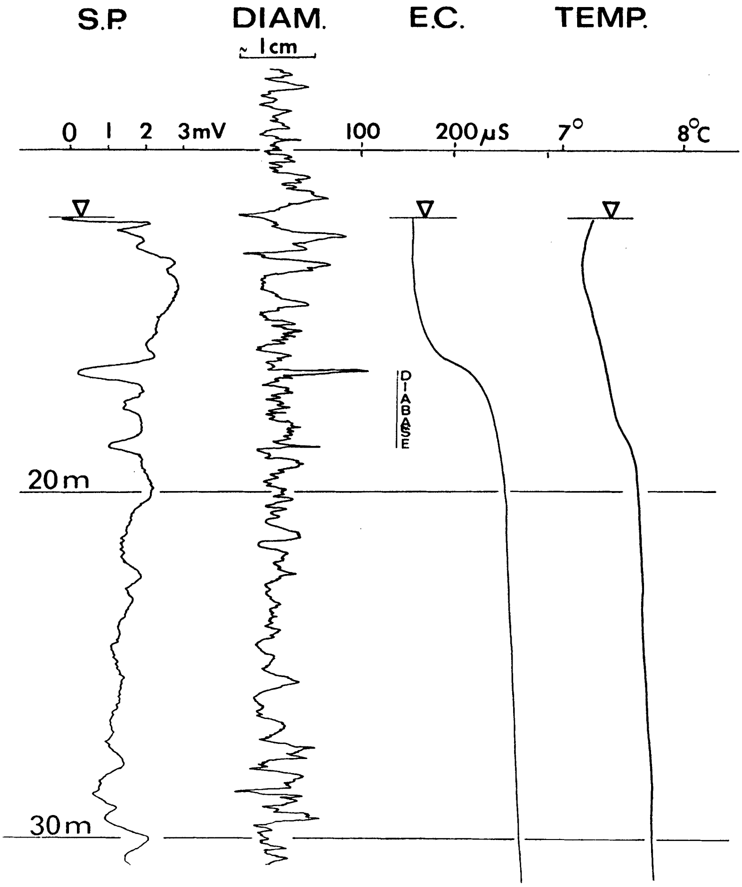

Fig. 13.
Detail of logs from well in Ordovician shist, Oslo, Norway.

Water wells in Ordovician Shist, Oslo, Norway

In the Oslo Fjord there are many islands and areas where water supply is a problem. The shisty rock is very tight and a bad aquifer. NGU, The Geological Survey of Norway, tested the idea that it should be possible to find water at the junctions between the shist and vertical diabases. Slightly inclined wells were drilled towards the dikes and they yielded water. In order to verify that

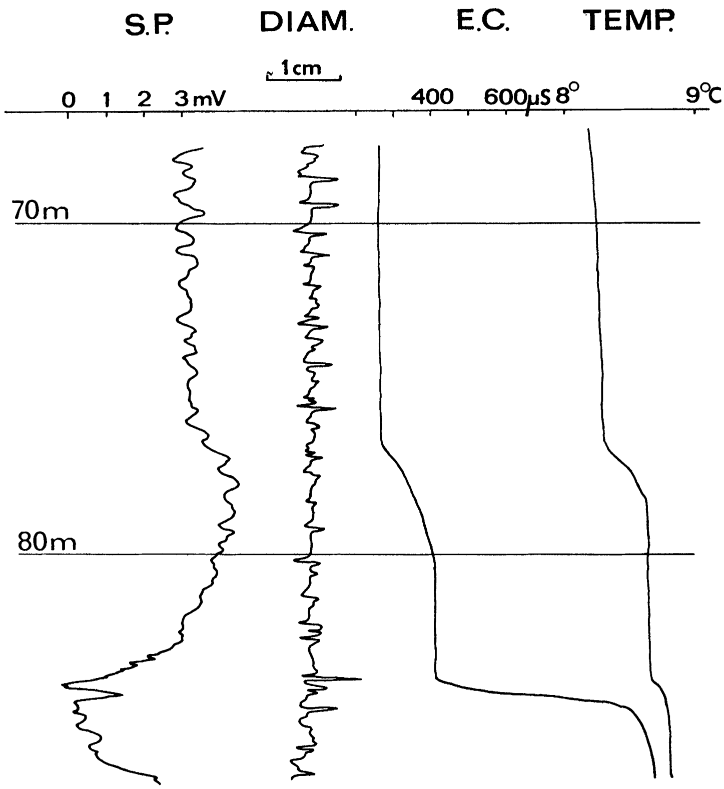

Fig. 14.
Detail of logs from well in Ordovician shist, Oslo, Norway.

the water actually came from the above-mentioned junctions, the holes were logged. Fig. 13 shows that water enters the borehole at such junctions. The regular bedding of shist interstratified by limestone was nicely shown on the S.P. and diameter logs as seen in Fig. 14. The limestone is harder and gives the relief.

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