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GROUND WATER INVESTIGATION IN GNEISSIAN ROCK, SYSTEMATIC STUDY OF A SMALL AREA

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Careful investigations should precede drillings in hard rocks for drinking water. A description is given of a method for groundwater prospecting in hard rocks which integrates studies of petrography, tectonics, and groundwater chemistry with well-logging of well diameter, self-potential, electric conductivity, and groundwater temperature.

At the institute of Land Improvement and Drainage, Royal Institute of Technology, Stockholm, Sweden, a special routine has been developed for ground water prospecting in hard rocks. This routine is based on the integration of several already well-known prospecting methods and has made possible a more comprehensive approach to the study of ground water in hard rocks.

The routine includes such items as petrography, tectonics, ground water chemistry and well-logging. It is obvious that an integration of all these methods in a proper order is preferable to the use of single techniques.

The ground water investigations reported here were carried out on the island of Tosterö in Lake Mälaren, 60 km SW of Stockholm, Sweden. Here a shortage of drinking water within a holiday housing area, Björktorp, necessitated the installation of new wells.

According to previous drillings and test pumpings, both soils (sand and gravel) and the gneissian bedrock had proved to be poor aquifers with yields seldom exceeding 1000 l/h. For this reason and also because of the fact that the geology of this area is fairly typical for middle Sweden, it was considered appropriate to study in more detail the ground water conditions, applying a routine of different techniques. The area chosen was small, only 1.5 km^2, and afforded favourable possibilities of testing a number of different prospecting techniques.

TOPOGRAPHY AND GEOLOGY

The area investigated is situated in the Central Swedish Lowlands, a depression area in the Archaean rocks of Sweden. The topography is very flat and never exceeds 50 m above sea level. Roches moutonnées, cropping out of the lowlands of clay and moraine, are very characterictic for the area. The higher parts are sparsely covered with pine and spruce, while most of the clay areas are cultivated.

The rocks of the area belong to the Sveco-Fennian system in the Baltic shield. Gray gneisses of supercrustal facies predominate (Welin 1970). The gneisses strike, apart from local deviations, in NW – SE and have a dip of about 40° – 50° towards the East.

Locally, the gneisses are homogenized by potassium metasomatosis and appear as migmatites or more or less granitoide types of rock, especially in the NW part of the investigated area. In some parts the gneisses have a structural appearance of a B-tectonite with distinct lineations and tension cracks, perpendicular to the B-axis ("ac-cracks"). In general, however, the gneisses have a strong schistocity, which is rather steep. Therefore the hills of the area protrude in an assymmetrical way, with the face of erosion following the dip of the schistocity.

Well-developed schistocity and lineation seem to imply in some way an increase of the power of resistance to ruptural deformation of the rock. Homogenization into a more granitoide type of rock seems to make it more brittle, as the frequency of fractures is much higher than in the normal gneiss. This is a vital factor in deciding the location of the well. By ruptural tectonics, as will be discussed later, the rocks of the area have been dissected into blocks of different sizes (see Fig. 1).

In the blocks A, B, C and the southernmost part of E and F, the strike of the gneiss is about NW (Fig. 1). In the block D and the northern part of E, the strike has a NNE direction. This unconformity may be explained by the intense granitization of the gneiss in the blocks D and E at which the original direction of strike was changed.

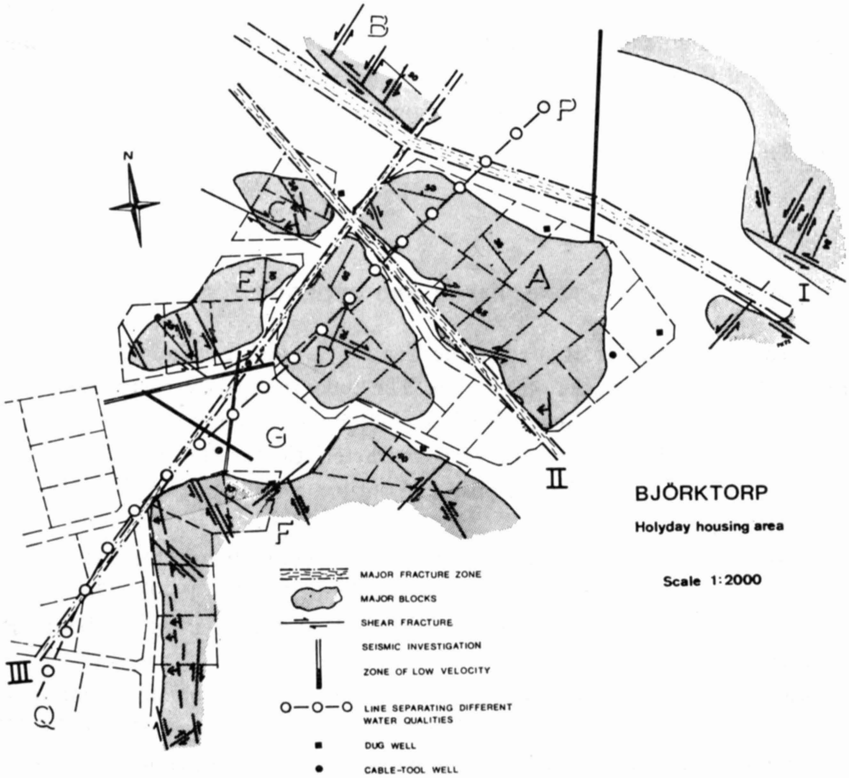

Fig. 1

Real estate ground-plot map of Björktorp holiday housing area, Sweden. Tectonic dissection of the rocks into blocks, major fracture zones, seismic investigations and border line for different qualities of ground water are plotted.

RUPTURAL TECTONICS OF THE AREA

Sundius (1948) gave a general picture of the ruptural patern of the Lake Mälaren region. Movements in the crust in NW–SE direction are characteristic (Fig. 2). These have probably been repeated during many orogene periods in the long history of the Baltic shield. The fractures have dissected the rocks into major blocks which most often protrude as islands, while the fracture zones appear as channels and longitudinal bays in the lake. The directions of the ruptures, however, have obviously been steered by the strike of the veined gneisses of the area. Thus the topographical and tectonical patterns of today owe their origin to very old structures in the Baltic shield.

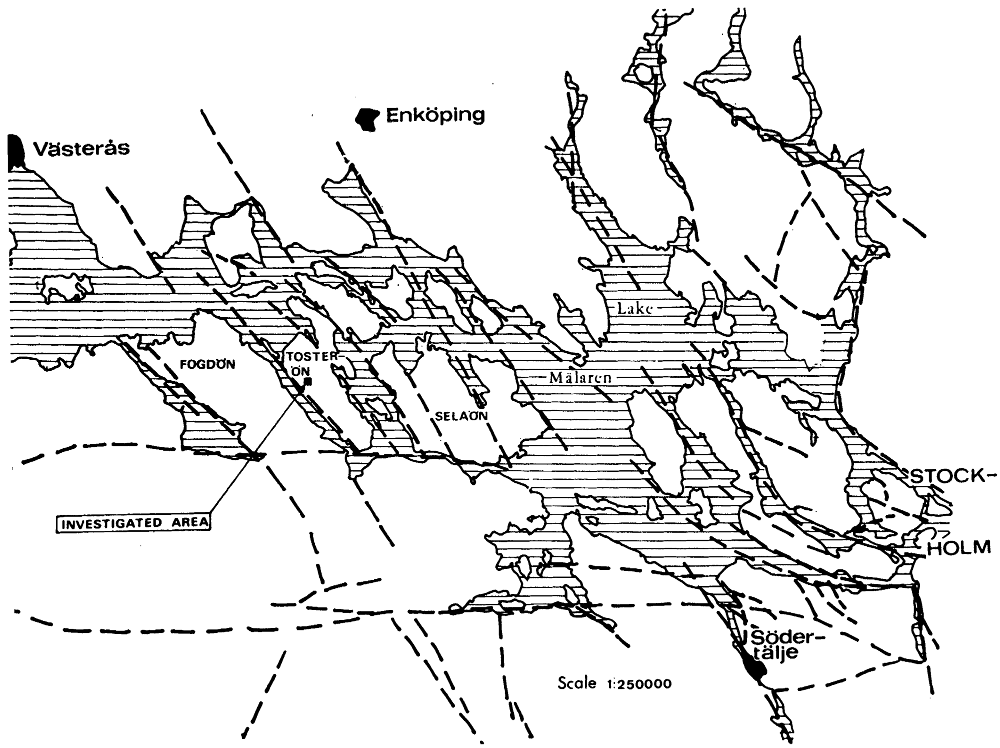

Fig. 2

Major fracture zones in the Lake Mälaren region according to Sundius (1948), De Geer (1910) and the authors.

The island of Tosterö is bordered in the West and East by deep fractures (Fig. 2). In the West, the fracture zone runs as a narrow channel between Tosterö and the peninsula of Fogdö. The fracture line to the east of Tosterö runs partly as a narrow channel and partly as a deep valley. These two fracture lines dominate the tectonic picture of the area. Within Tosterö Island this general pattern is reiterated in a smaller scale.

Fig. 1 shows a map of the area invstigated. Roads and real estate boundaries indicate the location of the holiday housing area, Björktorp. The NW–SE ruptural movements in the rocks along the fracture lines, discussed above, appear in this area as the two major zones of fracture I and II. Almost perpendicular to them a smaller zone, No. III, runs in SW–NE direction, Fig. 1 and 3.

An exhaustive study of the slickensides at the fracture planes reveals that

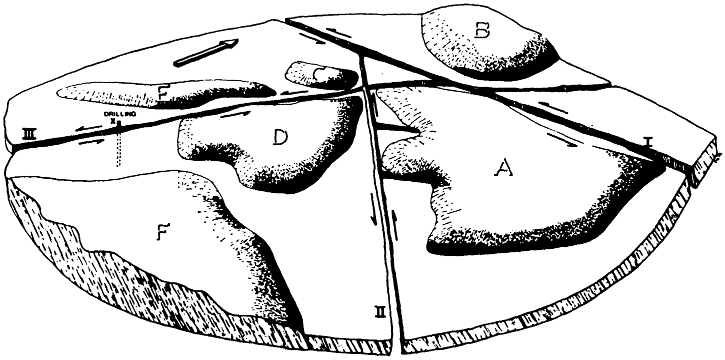

Fig. 3

Block diagram showing the main tectonic structures of the area. Higher parts are screened.

movements along the line II have caused secondary shear fractures in WNW–ESE direction, especially between the blocks A and D. This indicates a considerable rate of movement along the fracture. Possibly some rotational effects have been involved in the shear movements. Block D may have rotated in a clockwise direction, resulting in the southern part of the fracture line II having been opened up.

The fracture zone I is topographically the most well-developed in the area. A seismic cross-section, perpendicular to the zone, Fig. 1, indicates a low velocity zone with a width of about 20 m and a speed of 3000 m/sec.

The third fracture zone, III, is well recognized from the seismic measurements, Fig. 4. It passes the little field G, between the blocks D, E and F. The velocity of the zone ranges between 3200 and 4000 m/sec. The high frequency of low velocity zones in this area indicates that the borders between the three D, E and F have been split up and crushed by the tectonic movements.

The basin of Lake Mälaren has been submerged between the last glacial period and the post-glacial uplift of Fennoscandia (about 2000 years). The moraine cover is thin and disappears almost completely from the tops of the rocky "hills" from where it has been washed out over the glacial and post-glacial clays which occupy the depressions in the Archaean basement

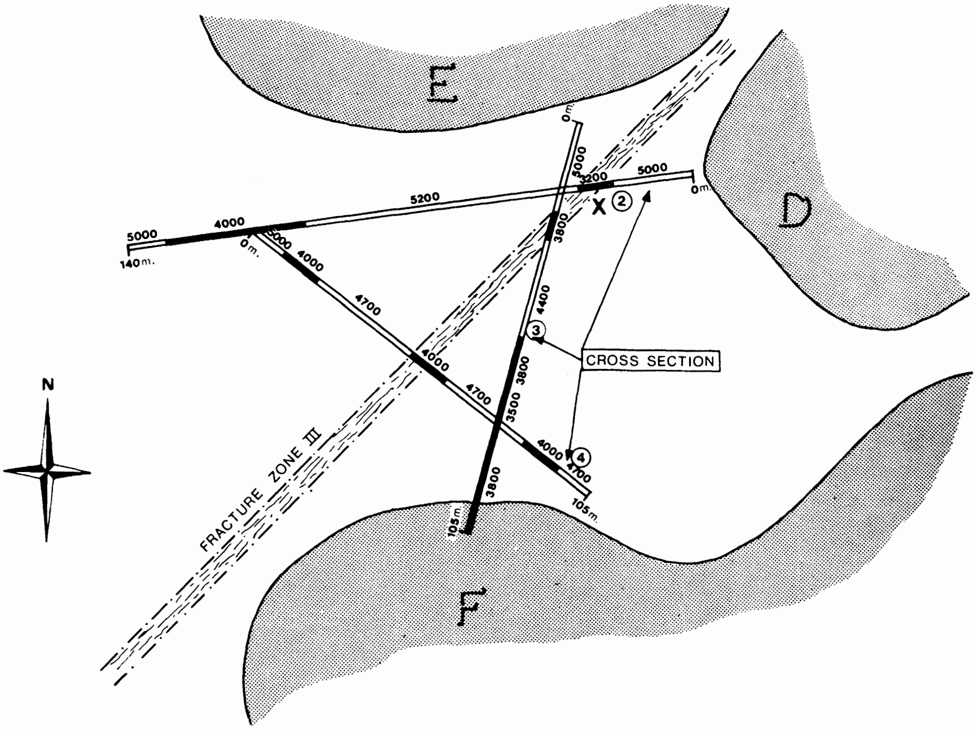

Fig. 4.
Seismic investigations between the blocks D, E and F. Selected figures of velocity in m/sec are plotted. Zones with figures below 400 m/sec are black.

GROUND WATER HYDROLOGY

The mean precipitation in the southern part of the island of Tosterö amounts to 528 mm/year (1931–1969, personal communication from the Swedish Meteorological and Hydrological Institute). As the distance between the weather station and the investigated area is only about 6 km, the precipitation figure should be valid also for the investigated area.

The evapotranspiration amounts to about 375 mm/year, based on water-balance calculations (Tamm 1959).

In 1966, chemical analyses were made of the ground water in 16 wells in the area. The analyses show that the wells east of the line PQ on the map (Fig. 1) have high contents of iron and manganese. This fact may depend on formations of weathering products from inclusions of a basic rock, amphibolite, in the normal gneissian bedrock. In the wells west of the line PQ, the contents of iron and manganese do not exceed critical figures. In this area the rock is more granitic. Thus from a chemical point of view, the area to the west of the line PQ is to be preferred for drilling operations in the rock.

Geologic Evidences and Ground Water Chemistry. Forecast

As mentioned above, the western part of the area is more granitic than the eastern one, especially block E. This is favourable for ground water extraction as the granite is more fractured than the gneisses.

The three tectonic zones, I, II and III, probably contain ground water be-

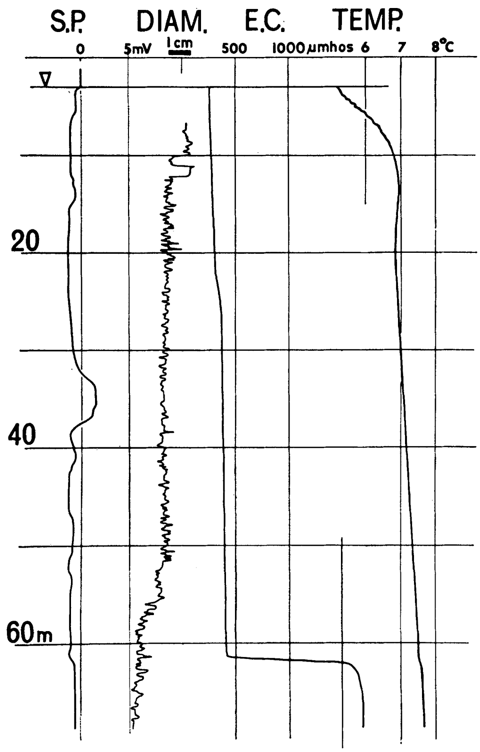

Fig. 5
Diagram, showing the logging of the bore-hole. The curves indicate self-potential, diameter, electric conductivity, and temperature of the water.

cause of the high degree of movement along the zones. This has caused a crushing of the rocks, which in general gives a free pore space to a zone, opening it up for infiltration from precipitation. As the iron and manganese contents east of the line PQ are too high for drinking water purposes, Zone I and II must be omitted from the discussion, being unsuitable aquifers.

At first sight the NW part of the zones I and II may seem acceptable as they are well outside of the critical Fe-Mn area. As the land surface rises from NW towards SE, the drainage in the fracture zanes I and II probably runs from SE towards NW, whereby they must be contaminated with the Fe-Mn from the critical area, east of the PQ-line.

As regards the blocks between the tectonic zones, it is anticipated that these contain little or no ground water, so they too can therefore be excluded from the discussion of potential aquifers.

Finally there is zone III, which has been well determined by seismic operations. It crosses the field G outside the critical area. From a tectonic point of view a well could be drilled in any place along the zone. To the north of the field G, however, the zone is situated below a road and surrounded by houses (Fig. 1), which makes this portion risky from a pollution point of view. In the field G the zone has been found in all the seismic cross-sections (Fig. 4). The northernmost part of the field borders on the granite area of block E, which makes this part the most favourable location for a well. The field may in that case serve as a protection area.

As a result of the different evidences discussed above, it was decided to locate the well at the point X, Figs. 1 and 4. This decision has been based on petrographic, tectonic, geophysic, chemical and pollution considerations.

Drilling Operation

The well was made by percussion drilling down to a depth of 69 m. From the surface to a depth of 56 m, the rock was gneissic. Typical for this rock is the very few fractures that were recorded. Between 56 and 59 m, schists of gneiss and granite appeared. Below the depth of 59 m the rock was quite granitic.

Throughout the gneissic part, the hole was completely dry. At the border between gneiss and granite the first flow of ground water occurred, see Fig. 6. In the granite the amount of ground water increased considerably. According to the technique developed by Jacks (1970), the bore hole was logged, and variations of the well diameter, and the self-potential, electric conductivity, and temperature of the ground water were recorded, see Fig. 5.

The diameter recordings show smooth walls in the hole from the surface down to 55 m. Below this level the diameter becomes smaller and the diagram

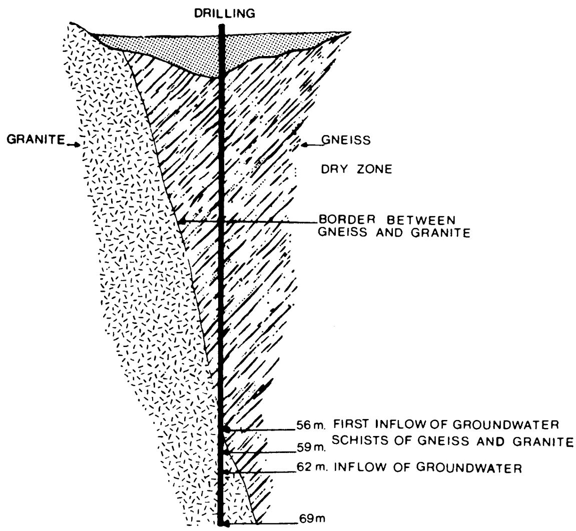

Fig. 6.
Cross-section through the bore hole. The direction of the border line betwen gneiss and granite is only approximative except at the depth of 56 m.

(Fig. 5) shows a curve that is more rugged. This coincides well with the border zone between gneiss and granite. From the electric conductivity and temperature curves it is obvious that a ground water inflow occurs at 62 m. The water in the well emanates mainly from this level or below.

Test Pumping

The well was pumped for 22 hrs at a total yield of 29 m^3 with a draw-down of 30 m. The capacity was stabilized at a discharge of 1350 l/h during the test. The inflow of water in the bore hole was concentrated to a depth below 56 m with a total yield of 1750 l/h at 56 m. With a pumping intensity equivalent to a draw-down of 62 m, a yield of about 2000 l/h may be obtained. During the test pumping a sample was taken which produced the following data:

pH	7.75
Temperature	+ 7.8° C
Redox-potential	+ 170 mV

This indicates a "deep" ground water without excessive chloride or iron content. The conductivity indicates a small content of old sea water. The concentration of chloride is about 200 mg/l.

CONCLUSIONS

Drillings in hard rocks for the purpose of obtaining drinking water are expensive. Therefore it seems to the authors that careful investigations must precede the drilling operations. The costs of the investigations are very small in relation to the costs of the drilling. Furthermore, the chances for making accurate forecasts increase with the intensity of the investigations. As mentioned earlier, none of the methods used in the present investigation are new. Nevertheless it seems to the authors that the *integrated* use of these methods has considerable advantages.

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