NGU Rapport 93.119

Groundwater in bedrock - Hvaler project.
Investigations at Testsite Reffsgård,
borehole 1.
(Capacity enhancement using EDTA)

NORGES GEOLOGISKE UNDERSØKELSE

Postboks 3006 - Lade
7002 TRONDHEIM
Tlf. (07) 90 40 11
Telefax (07) 92 16 20

RAPPORT

Rapport nr. 93.119	ISSN 0800-3416	Gradering: Åpen

Tittel:

Groundwater in bedrock - Hvaler project. Investigations at Testsite Reffsgård, borehole 1. (Capacity enhancement using EDTA).

Forfatter: H.Skarphagen, D.Banks, E.Rohr-Torp	Oppdragsgiver: NGU/Norsk Hydrologisk Komité
Fylke: Østfold	Kommune: Hvaler
Kartbladnavn (M=1:250.000) Oslo	Kartbladnr. og -navn (M=1:50.000) 1913-III, Fredrikstad
Forekomstens navn og koordinater: Reffsgård, Kirkeøy, $^{6}1613$ $^{65}4965$	Sidetall: 26 Pris: 55,- Kartbilag:

Feltarbeid utført: 1992-1993	Rapportdato: 31.12.93	Prosjektnr.: 63.2462.00	Ansvarlig: Tor Erik Finne

Sammendrag:

A 3" borehole was drilled to 42 m at Reffsgård, and was found to have a negligible yield (< 0.1 l/hr). In-situ stress measurement was then carried out, using hydraulic fracturing. Following this, the borehole was test-pumped and a short term yield of 156 l/hr (24 m drawdown) was recorded. This enhancement was believed to be due to hydraulic fracturing. The borehole was then subjected to simple treatment using the surfactant EDTA, resulting in an apparent further increase to 170 l/hr (24 m drawdown). This may be due to the EDTA, but it may also have been an artifact of excess head applied during treatment.

Et 3" borehull ble boret til 42 m ved Reffsgård, og hadde en neglisjerbar (< 0.1 l/t) vannytelse etter boring. In-situ spenningsmålinger ble så utført vha. hydraulisk trykking. Borehullets kapasitet ble etterpå målt (kort-tidspumping) til ca. 156 l/t (24 m senkning). Denne økningen tilskrives hydrulisk trykking. Borehullet ble så behandlet med overflatekjemikalien EDTA, som resulterte i en ytterligere økning i kapasitet til 170 l/t (24 m senkning). Det er imidlertid uklart om økningen skyldes EDTA-behandlingen, eller om den er et resultat av overtrykk fra behandlingsprosessen.

Emneord: Hydrogeologi	Grunnvannsbrønn	Grunnvann
Berggrunn		
		Fagrapport

Table of Contents

1 Introduction - The Hvaler Study

The Geological Survey of Norway (NGU) have, since 1989, used Hvaler as a research area. The objective has been to investigate the practical, water resources aspects of the hydrogeology of a coastal granite aquifer, namely the Iddefjord granite. The area was chosen for the following reasons:

- it is near Oslo, with good road connections
- excellent bedrock exposure
- there are real problems with water resources on the islands
- the climate is mild, allowing a long field season
- the fracture pattern appeared (at first sight) to be relatively straightforward
- it's a pleasant place !

The investigations undertaken at Hvaler so far have included

- literature study
- mapping of fracture systems from aerial photos, topographic maps and field surveys
- survey of hydrochemistry
- assessment of various geophysical methods for detection of transmissive fractures (VLF, magnetometry and georadar have proved to be particularly interesting.
- establishment of four test boreholes at Pulservik to investigate two major fracture zones
- development of test-pumping methods
- establishment of six boreholes at a second testsite at Reffsgård
- investigation of methods to artificially enhance yields
- measurement of in-situ stresses and investigation of borehole yield in relation to these.

2. Hvaler - Geology and Tectonics

2.1 Geology

The Hvaler municipality (Fig. 1a) consists of a group of islands (*Hvalerøyene*) in the mouth of Oslofjord in south-east Norway. The dominant lithology is the Precambrian Iddefjord Granite, described by Oxaal (1916). The granite is typically grey in colour when fresh, but tends to weather to the characteristic red colour of the islands' exposed coastline. The granite has been extensively worked for building and ornamental stone in numerous small quarries, some of which are still in operation today. Well-known Iddefjord Granite structures include the quay at Dover, England and the statues at the Vigeland Sculpture Park in Oslo.

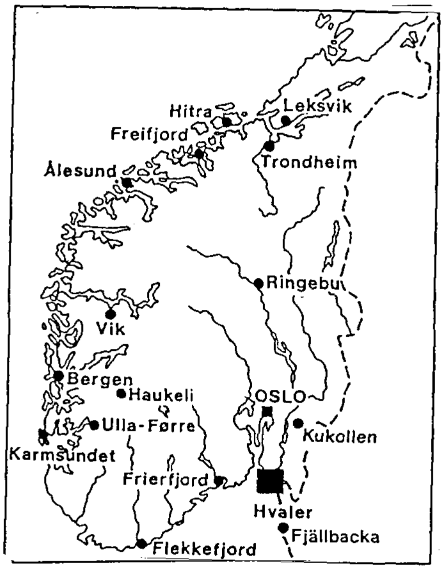


Figure 1a. Map of S. Norway, showing location of Hvaler and other sites mentioned in text

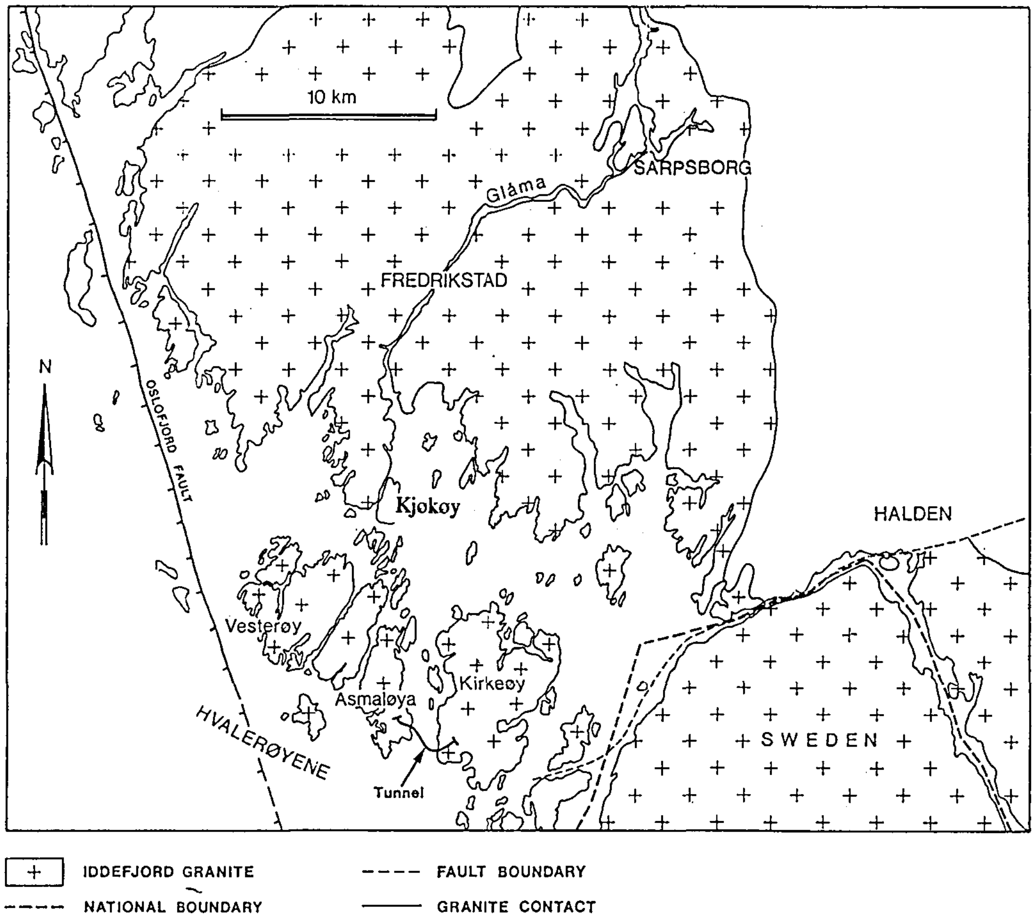


Figure 1b. Map of outcrop of Iddefjord Granite. Surrounding rock consists of Precambrian gneisses.

The Iddefjord Granite (Fig. 1b) forms the northern extension of the Swedish Bohus batholith. The Iddefjord granite consists of 13 separate plutons (Pedersen & Maaløe 1990), ranging in composition from diorite to true granite, some of the youngest of which yield a Rb/Sr age of 918 ± 7 million years, corresponding to the end of the Sveconorwegian orogeny. Quartz, microcline and plagioclase are the dominant minerals in the granite. Accessory minerals include biotite, hornblende, muscovite, iron-oxides, chlorite, apatite, titanite & zircon (Pedersen & Maaløe 1990) and occasionally garnet. The granite commonly includes basic clots, pegmatites and xenoliths of gneissic host-rock. In some areas the xenolith content may be extremely high; in the new Hvaler tunnel the gneiss content reached some 55 % (Larsen 1990, Banks et al. 1992a). Ramberg & Smithson (1971) describe the Iddefjord granite as a tabular intrusion on the basis of geophysical evidence.

In common with most high latitude areas, the Hvaler area has no regional development of a heavily degraded layer of weathered granite. Relatively fresh bedrock outcrops over large areas of the islands, often showing signs of glacial scouring, or sub-glacial potholes.

The Hvaler islands' Quaternary deposits are to a large extent limited to the lineament-controlled valleys, and consist mainly of shallow marine (or littoral) sands, silts and clays (Olsen & Sørensen 1990). Limited deposits of peat, wind-blown sand, and coarser gravelly/pebbly beach deposits can be found on the southern part of Kirkeøy. The remains of one of the outermost terminal moraine trains from the last glaciation in Oslofjord can be found near Arekilen - the so-called Hvaler moraine train. The massive areas between the lineament valleys consist of bare bedrock or bedrock with a thin covering of humus.

The islands have undergone substantial isostatic uplift in the past 10,000 years or so. The highest marine limit is c. 170 m above current sea-level (Selmer-Olsen 1964). The islands have therefore only emerged from the sea within the last several thousand years.

2.2 Tectonic situation

Hvaler is bounded to the west by the Oslo Graben boundary fault. The two islands *Nordre & Søndre Søstre* (North & South Sisters) lie to the west of the boundary fault and consist of rhomb porphyry conglomerates. Immediately west of the islands can also be found the so-called Hvaler Deep, a SW-NE graben structure believed to be seismically active today, and responsible for the magnitude 5.4 earthquake experienced in the region on October 23rd 1904 (Størmer 1935).

To the southeast the Hvaler area is bounded by the major Iddefjord fault, with the granite downthrown on the southern (Swedish) side (Pedersen & Maaløe 1990).

The Iddefjord granite area is dissected by a pattern of linear valleys resulting, at least in part, from preferential glacial erosion along zones of fractured and crushed rock. These valleys are usually partially infilled by Quaternary deposits, rendering the surface outcrops of the fracture zones unexaminable. The linear channels between the islands of the Hvaler group, such as the two straits between Vesterøy and Asmaløy and the channel between Asmaløy and Kirkeøy, are also believed to have arisen by such a process. The origin of the fracture zones themselves is uncertain. It is likely, however, that they date from an early period of the granite's history, as a result of regional tectonic stresses or stresses related to emplacement and cooling of the granite. The fracture pattern is likely to have been reactivated or modified several times during its history; for example, during the Permian opening of the Oslo rift, post-rifting strike-slip movements along the Oslo graben boundary fault (Størmer 1935), and possibly even by glacial and post-glacial stresses.

The dominant lineament directions are NNE/NE-SSW/SW (primarily) and NNW/NW-SSE/SE. Ramberg & Larsen (1978) consider these directions to be typical of pre-Permian (i.e. pre-Oslo Graben) deformation of the Oslo region. Preferred orientations of lesser fractures (from field mapping) are primarily NW/NNW-SE/SSE and also NNE/NE-SSW/SW (Banks et al. 1992b).

Across the Swedish border, the continuation of the Iddefjord Granite (the Bohus Granite) has been investigated in great detail in connection with a geothermal energy project at Fjällbacka. The same dominant fracture directions were found here. Both at Fjällbacka (Eliasson et al. 1990) and Hvaler, fracture mineralisations consisting of calcite, fluorite, smectite, hematite, chlorite, quartz, biotite, muscovite, epidote and iron oxyhydroxide (rust) have been found; calcite, fluorite and epidote occur predominantly along NNE/NE-SSW/SW fractures (epidote also on NW-SE fractures), while clay fillings predominantly occur on NNW/NW-SSE/SE fractures (Banks & Rohr-Torp 1991, Kocheise unpubl.data [see Banks et al. 1993a], Sundquist et al. 1988). Eliasson et al. (1990) connect four major episodes of fracture generation/activation with four different types of mineral infilling: (1) pegmatites, quartz, ± epidote, related to cooling of granite; (2) haematite, chlorite, calcite ± quartz ± epidote, high temperature filling, post consolidation; (3) smectite, related to low-temperature (< 80°C) alteration, possibly during burial metamorphism in the late Palaeozoic; (4) iron oxyhydroxide deposition due to circulation of oxidizing groundwater (down to c. 250 m depth at Fjällbacka).

3 Testsite Reffsgård

Reffsgård (Fig. 2) lies towards the middle of the northwestern peninsula of Kirkeøy, one of the Hvaler island group, in the Precambrian Iddefjord granite group of plutons (Pedersen & Maaløe 1990). Work at the previous Pulservik testsite (Banks et al. 1991) had focussed on assessing the significance of topgraphically and geophysically prominant fracture zones on borehole yield. The results of work at Pulservik indicated that, at least on Hvaler, the presence of such a

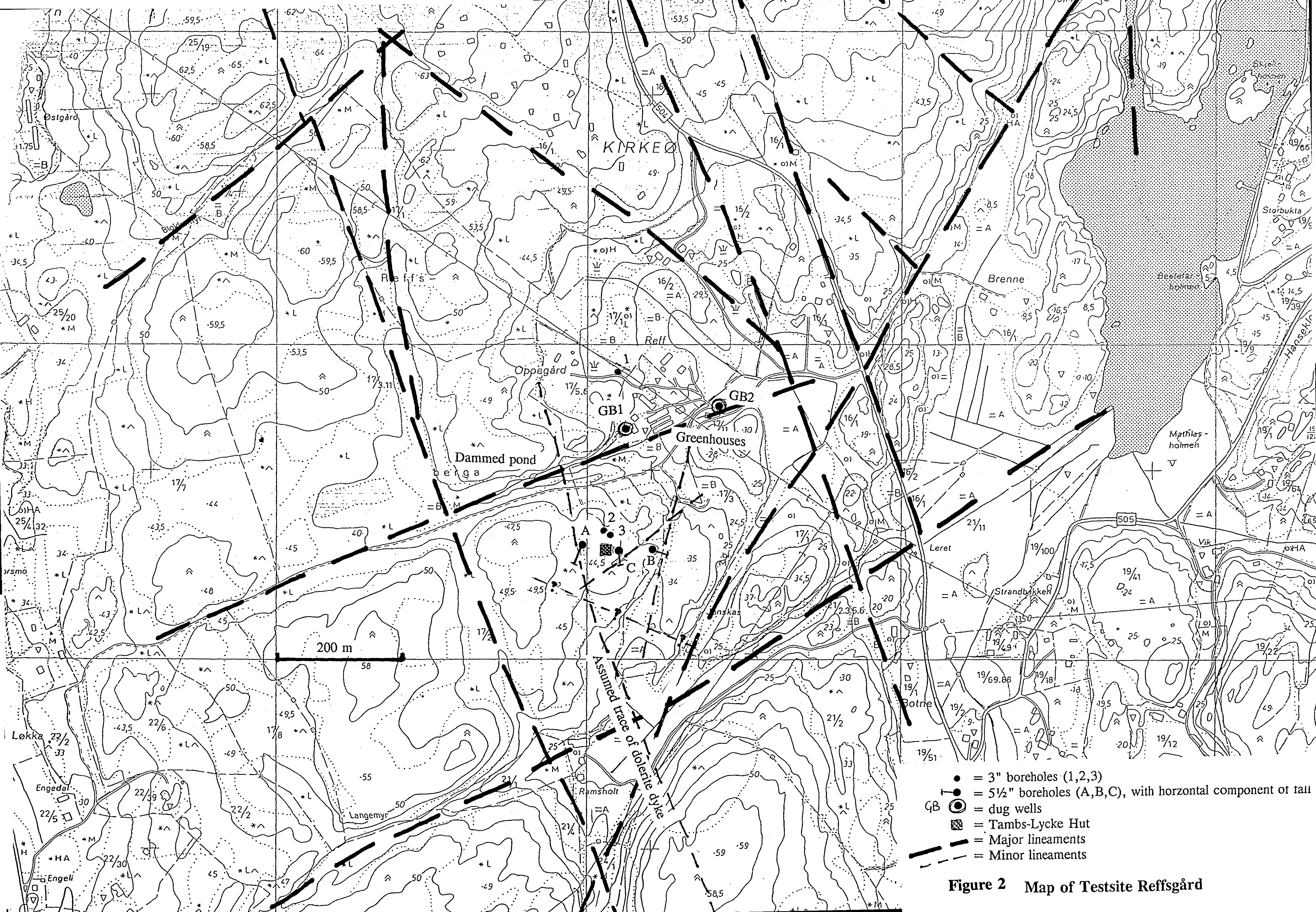


Figure 2 Map of Testsite Reffsgård

fracture zone was no guarantee of high yield, partly due to the fact that many fracture zones are "tightened" by secondary clay mineralisations.

The Reffsgård site has been chosen for four purposes:

- to examine the water resources aspects of more massive granite, away from major fracture zones.
- to investigate the effects of in-situ stress and borehole orientation on borehole yield.
- to investigate the hydrogeological properties of a probable dolerite dyke.
- to investigate methods of artificial capacity enhancement of dry boreholes.

4 Drilling and hydraulic fracturing of borehole 1

Towards the end of September 1992, three 3" diameter boreholes were drilled at Reffsgård (boreholes no. 1, 2, 3 - Fig. 1) in apparently massive granite (away from prominent fracture zones) to a depth of c. 35 m by Brødrene Skolt of Moss, using a top-hammer, air flush percussion-type rig. Borehole details are shown in Table 1 below, and drilling logs are presented in Appendix 1. No casing was installed in the boreholes.

	Borehole 1
Drilled length (along borehole axis)	42.4 m
Nominal Diameter	77 mm
Fall / Direction	90°
Yielding fractures (after drilling)	None
Yield / drawdown (after drilling)	Negligible < 0.1 l/hr / c. 11 m
Yield / drawdown (after hydrofraccing)	155 l/hr / 24 m
Rest water level (Date)	11.79 mbgl (17/8/93)

Table 1: Borehole and short-term testing details; 3" borehole 1 at Reffsgård

Prior to *in-situ* stress determination, in June 1993, borehole 1 was filled with water and the subsequent decline in water level measured. This simple "slug-test" indicated a negligible borehole yield, the decline, when full, being less than 0.5 cm in 15 mins (i.e. with over 11 m excess head). This would imply a short term yield not exceeding 0.1 l/hr with a similar drawdown.

The measurements of *in-situ* stress were carried out in boreholes 1 and 2 by Helge Ruistuen of SINTEF, Trondheim. The method employed involved hydraulic fracturing of the granite using water pressure applied between packers. The pressure at which the fracturing occurs is carefully recorded, and can be related to the magnitude of the *in-situ* stress plus the tensile strength of the rock. The directions of the principle stresses are obtained by using an oriented impression packer, which retains a "cast" of the newly created fracture. The fracture will typically be created perpendicular to the direction of minimum horizontal stress (Myrvang 1979, Fairhurst 1986).

The stress measurements were carried out in the period 10-16 June 1993 by Helge Ruistuen of SINTEF and Helge Skarphagen of NGU. Three borehole sections in borehole 1 were tested, giving the following results:

BOREHOLE 1

Test depth (m)	P_b (MPa)	P_{isi1} (MPa)	P_{isi2} (MPa)	P_{o1} (MPa)	P_{o2} (MPa)	Fracture orientation
10	-	8.5	8.6	7.9	8.7	N173°E (somewhat uncertain)
20	-	8.1	-	10	-	N195°E
35	10.2	2.6	1.9	10.4	2.8	Non-vertical Poor impression

P_b = fracturing pressure
P_{isi} = instantaneous shut-in pressure
P_o = opening pressure

Table 2: Details of *in-situ* stress measurement in Borehole 1, Reffsgård

In October 1992, borehole 1 was geophysically logged by NGU (Appendix 3). Rest water level was c. 11½ m under ground level during logging. The temperature log shows a section with stable or slightly decreasing temperature between 12½ and 17 m (c. 7.1°C). Below 17 m the temperature increases evenly, due to the prevailing geothermal gradient, from 7.1° at 17 m to

7.4°C at 42.5 m, a gradient of 0.012°/m. A rather small anomaly, possibly indicating inflow, can be noted at 34.5 m.

The fluid resistivity log reflects the ρ_f of the formation water, namely c. 50-60 ohmm = c. 170 -200 μS/cm. Anomalies can be seen at 15½ m, 36½ m and 41 m, possibly indicating minor inflows of formation water.

The resistivity logs display minima at c. 13½ m, c. 37 m and c. 41½ m potentially indicating enhaced fracturing or mineralisation. The latter two depths agree well with anomalies on the fluid resistivity log. The anomaly at 37 m may correspond to a biotite-rich vein noted in the drilling log. The middle part of the log is rather featureless with ρ_a values around 15000 ohmm (short normal - SN) and 20000-30000 ohmm (long normal - LN), indicating unfactured bedrock.

5 First test-pumping

The borehole was cleaned of cuttings using a flowing hosepipe in connection with *in-situ* stress measurement in June 1993.

The borehole was short-term test-pumped on 17. August 1993, i.e. after hydraulic fracturing. The weather preceding this period has been very wet. As the yield of the hole was fairly low, a small 2" diameter Grundfos MP1 pump was used. The techniques described by Banks (1993) were used for test-pumping and analysis. The pump was placed at a given level in the hole (40 m) and the pump was switched on. The water level was drawn down to the pump intake level (taking c. 70 mins.). The pump was then taken out of the borehole and the recovery of the water level in the borehole was monitored using a manual dipper.

It was assumed that the hole's yield is limited by low-transmissivity feeder fractures (i.e. fractures linking the borehole to the wider fracture system) rather than aquifer storage. With this assumption, it is possible to calculate specific capacity, apparent transmissivity and fracture location from the rate of recovery in the borehole water level and the angle of the borehole (if non-vertical). The analytical method is described in Banks (1993), and the designation Q_a is used to describe the flow of groundwater from fracture (aquifer) to borehole.

A yield of up to 156 l/hr water with 24 m drawdown was obtained during the short-term testing of borehole 1. The Q_a vs. water level curve is well-behaved, straight and intersects the x-axis at the rest water level (RWL)-value. This implies that the yielding fractures are all below the lowest measured water level, namely 36 m.

The water pumped up was heavily loaded with drilling cuttings at the beginning of pumping (drawing in slurry from the base of the hole), then progressively clearer (drawing clean water from higher up the hole) then more turbid again (formation water from fractures loaded with cuttings).

3" Borehole 1	Date : 17/8/93
RWL (time)	11.79 mbgl (1524 hrs)
Pump level	40 mbgl
Pump switched on	1534 hrs
Approx. pump rate	3 - 7 l/min
Pump draws air (i.e. PWL at pump intake)	1646; 40 sec
Gradient of Q_a vs water level plot	6.5 l/hr/m
Fall of borehole	90°
Level of yielding fracture(s)	c.36.5 m (+ deeper ?)
Specific capacity of fracture(s)	0.156 m^2/d
Apparent transmissivity of fractures	0.17 m^2/d
Saturated borehole length	30.6 m
Apparent hydraul. conductivity of saturated borehole length	0.0057 m/d = 7×10^{-8} m/s
Yield / drawdown	156 l/hr with 24 m drawdown

Table 3. Details of pre-EDTA short-term testing; borehole 1 Reffsgård.

6 EDTA Treatment and repeat testing

Treatment using the chemical EDTA[1] was carried out on the borehole, in an attempt to enhance fracture transmissivity, and the borehole was re-testpumped. EDTA is a surfactant and complexing agent which is reported to have some positive effect in helping to remove clay minerals from fractures and enhancing their permeability. It is, however, normally used in conjunction with hydraulic fracturing[2] (Cecil Less, Dept. of Water Affairs, RSA, pers. comm.).

By 0927 hrs. on 18/8/93, the water level had recovered to 11.93 mbgl (i.e. almost total recovery), and 5 mins. pumping was carried out to obtain a good sample of formation water.

---

[1] Ethylene diamine tertiary acetate. Preferred for use as a surfactant over polyphosphates; the latter being nutritious for microbiological growth.

[2] At concentrations of 0.15 - 0.25 % in the hydrofraccing water.

At around 1520 hrs on 18/8/93, around 1.5 Kg of EDTA powder was dissolved in 80 l water and injected via hosepipe at 35 m depth (i.e. near the suspected yielding fracture) into the borehole. This led to the borehole being filled almost to overflowing. Thereafter, clean (farm water supply) water was added at the top of the borehole at 3.75 l/min for 10 mins (c. 37.5 l total). While water was being added at the surface, the hole was agitated using a thick weight on a rope. At shortly after 1530 hrs the operation was complete, and the hole was left to stand while the water level sank back towards its static level.

By 1617 hrs. the water level was 8.47 m bgl. The Grundfos MP-1 pump was placed at 40 m deep and was started at 1622 hrs 30 sec. The pump frequencies and the duration were intended to be duplicates of the previous test. Again, very turbid water was obtained initially, becoming clearer and then more turbid again later in the test. The pump drew air and was switched off at 1728 hrs. 48 sec. and the recovery was monitored. During this repeat test-pumping running water could be heard when the water level fell below 36.5 m, indicating, as expected, contributing fracture(s) at about, or slightly above, that level. This is consistent with a significant anomaly noted on the geophysical logs run prior to hydraulic fracturing, and also with the fracture stimulated by hydraulic fracturing at the 35 m level.

3" Borehole 1	Date : 18/8/93
RWL (time)	11.79 mbgl (1524 hrs; 17/8/93)
Pump level	40 mbgl
Pump switched on	1622, 30 sec.
Approx. pump rate	3 - 7 l/min
Pump draws air (i.e. PWL at pump intake)	1728; 48 sec.
Gradient of Q_a vs water level plot	7.3 l/hr/m
Fall of borehole	90°
Level of yielding fracture(s)	c.36.5 m (+ deeper ?)
Specific capacity of fracture(s)	0.176 m^2/d
Apparent transmissivity of fractures	0.20 m^2/d
Saturated borehole length	30.6 m
Apparent hydraul. conductivity of saturated borehole length	0.0064 m/d = 7 x 10^{-8} m/s
Yield / drawdown	170 l/hr with 24 m drawdown

Table 4. Details of post-EDTA short-term testing; borehole 1 Reffsgård.

The initial reaction to the test results was very positive. The borehole yielded more water for a given drawdown (170 l/hr with PWL at 35.79 m i.e. drawdown = 24 m) and the slope of the Q_a vs. water level plot appeared steeper, indicating increased apparent fracture transmissivity.

However, on closer inspection, the x-axis intercept of a line drawn through the data is deeper than the recorded rest water level of 11.79 m (and deeper than the 11.93 m recorded on the morning of 18/8/93). One explanation of this may be that the borehole had not fully recovered from the application of excess water used to provide a head to force the EDTA into the fractures. This would lead to an apparently enhanced capacity for early data, but with the Q_a vs. water level (WL) data converging with the "true" Q_a vs WL line (from the first test) during the recovery, as the excess head in the formation decays. This explanation appears to fit with the observed data.

7. Conclusion

The repeat treatment of Reffsgård borehole 1 with EDTA as a potential capacity enhancement technique has produced ambiguous results. Test-pumping of the borehole following treatment led to an apparent increase in specific capacity and fracture transmissivity, implying a satifactory outcome. On closer examination, however, it appears that this apparent increase in capacity may be explained by a residual excess head in the formation, applied during the treatment to force the EDTA solution into the fractures. A further test-pumping, with "static" initial conditions, is required to investigate whether the yield increase was real or a "hydraulic artifact".

It should be mentioned that Reffsgård 1 was perhaps not the ideal borehole to carry out the experiment, as there is little evidence of clay mineralisation in the fractures here. In addition, the yielding fracture appears to have been stimulated (created ?) during hydraulic fracturing, and may thus be expected to be relatively free from mineralisation.

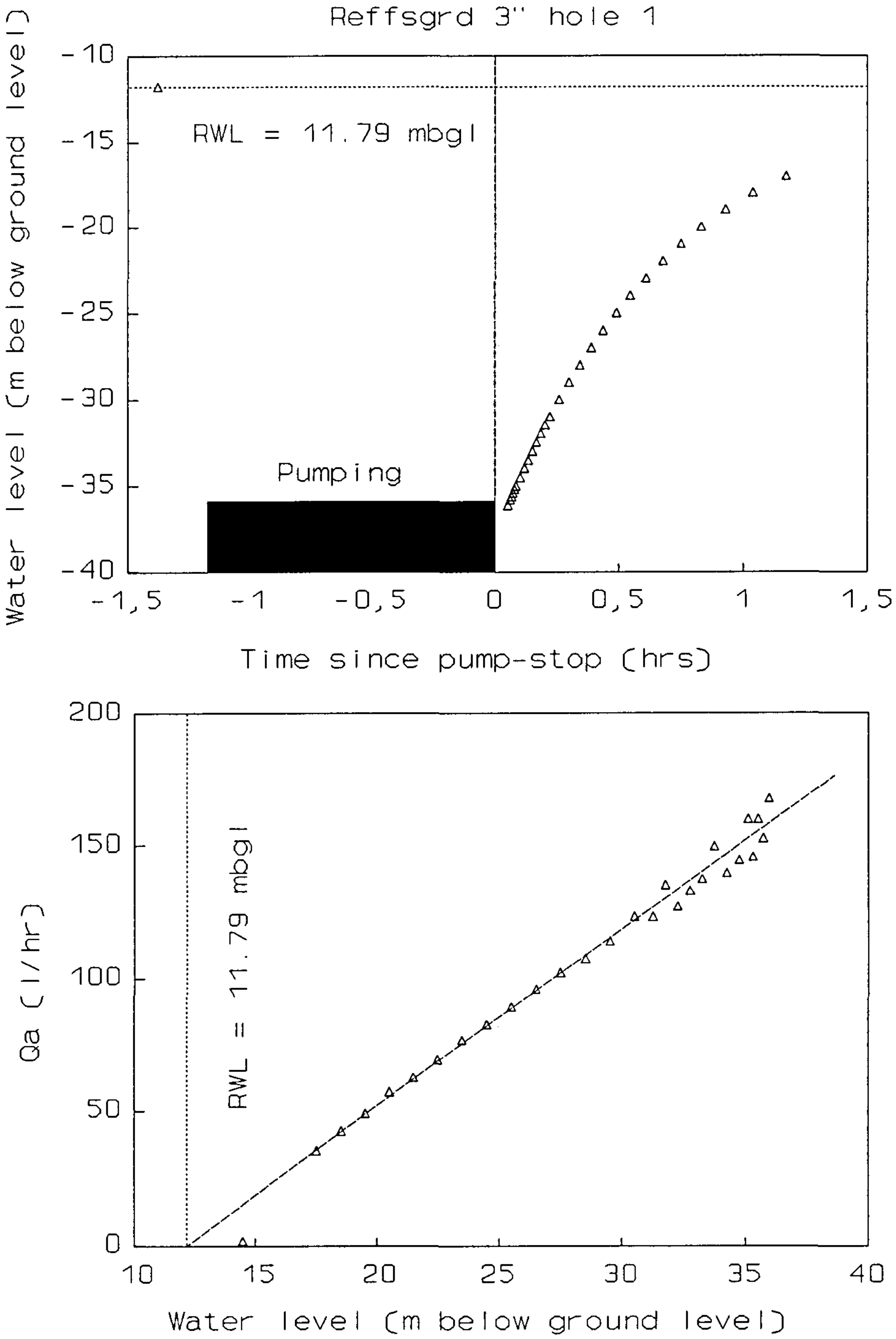


Figure 3. Water level vs. time, and Q_a vs. water level plots for the pre-EDTA testing of borehole Reffsgård 1.

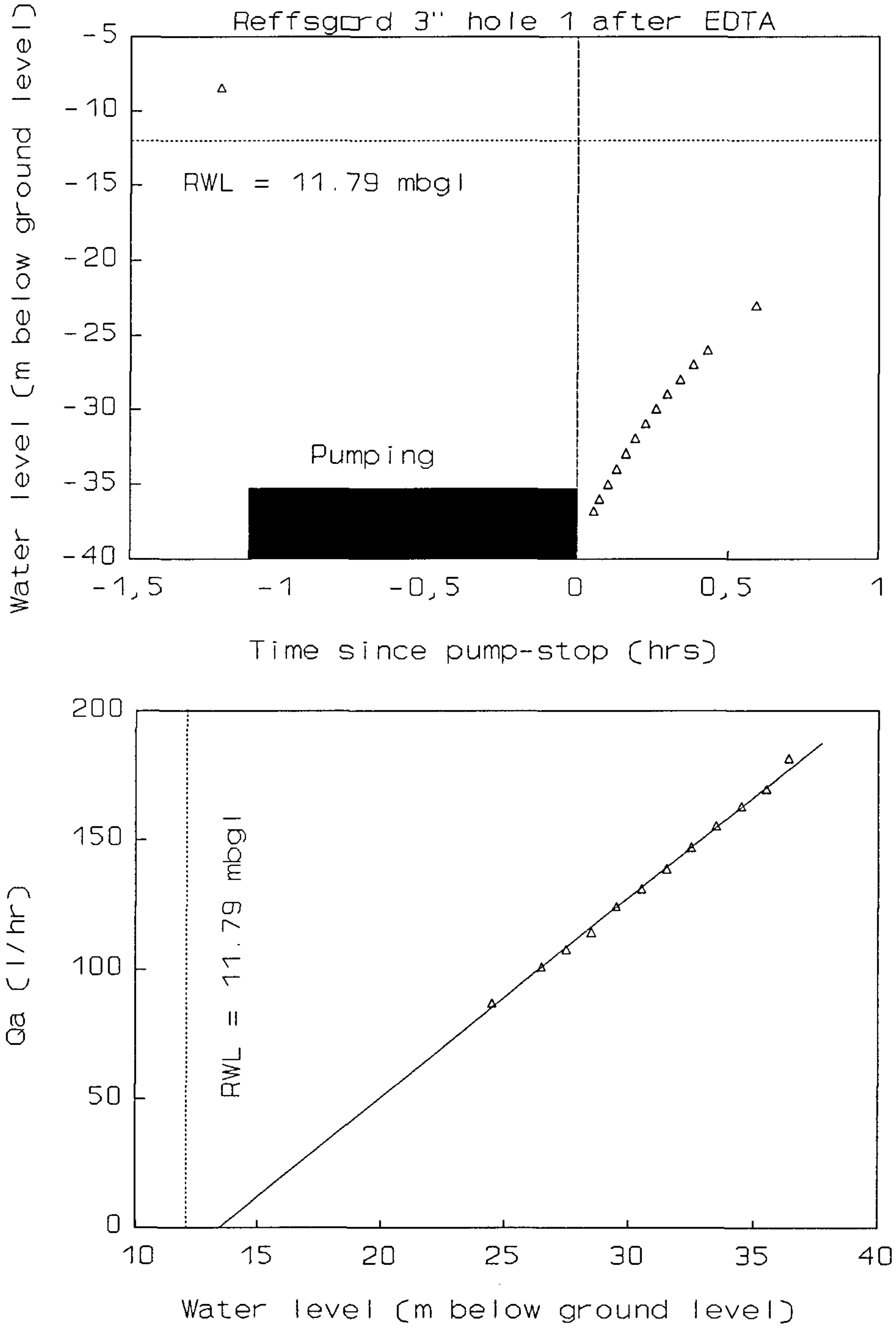


Figure 4. Water level vs. time, and Q_a vs. water level plots for the post-EDTA testing of borehole Reffsgård 1.

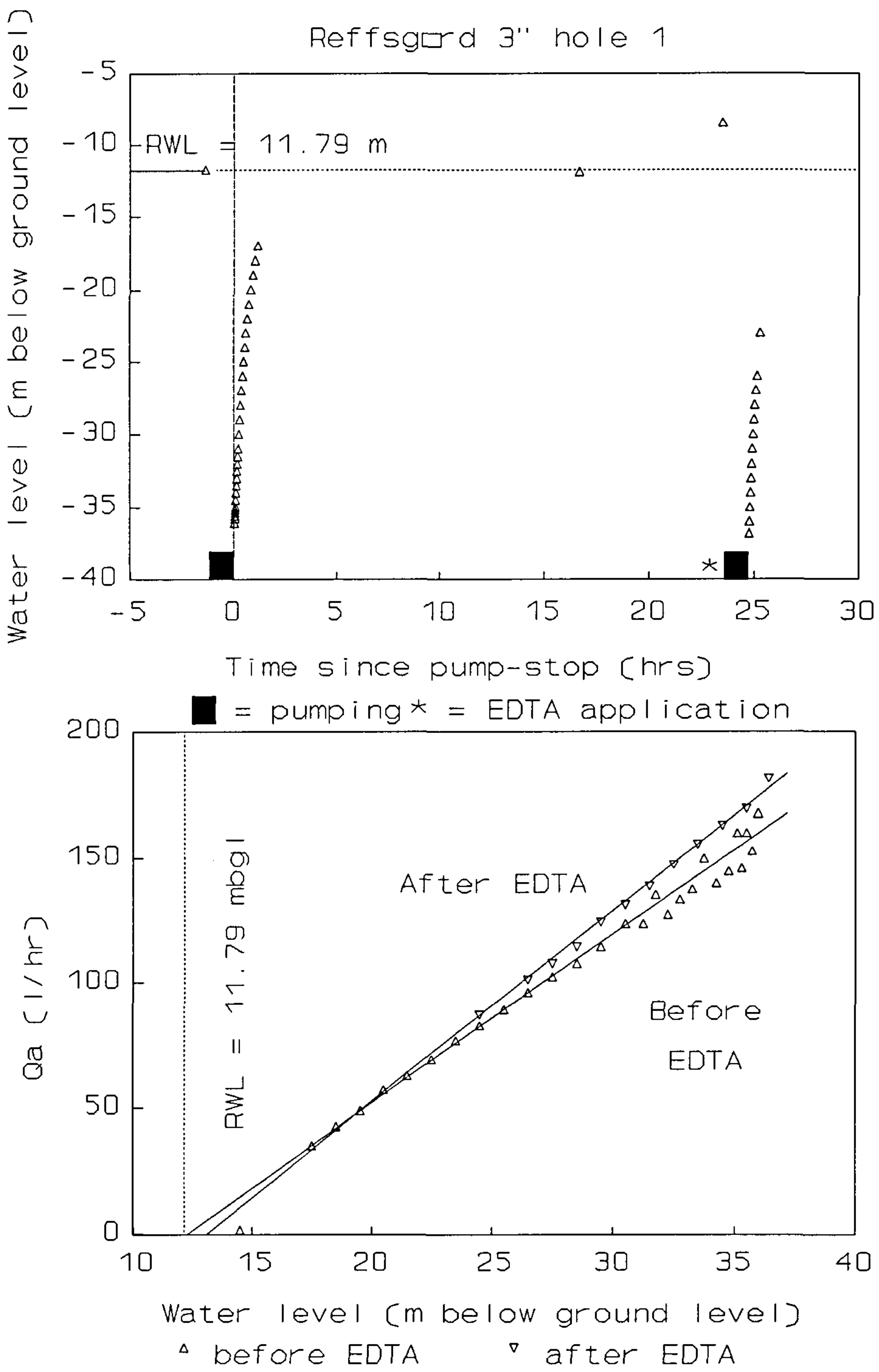


Figure 5. Water level vs. time, and Q_a vs. water level plots for the pre- and post-EDTA testing of borehole Reffsgård 1.

8. References

General Geology of the Hvaler Area

Bjørlykke, H. 1939. Feldspat V - De sjeldne mineraler på de norske granittiske pegmatittganger. *(Feldspars V - rare minerals of Norwegian granitic pegmatites).* Nor.geol.unders. 154.

Hageskov, B. 1985. Hin Hånes harvespor *(Old Nick's furrows).* Varv, 2 (1985), 35-42 *(in Danish).*

NVE 1975. NVE nuclear power plants, Oslofjord. Oslo region tectonic map. Produced by Norwegian Geotechnical Institute (NGI) for Norges Vassdrags- og Energivesenet (NVE), 1975.

Olsen, L. & Sørensen, E. 1990: Fredrikstad. 1913 III. 1:50000 kvartærgeologisk kart. *(Fredrikstad map sheet 1913 III, 1:50,000 Quaternary geological map)* Nor.geol.unders. Unpublished manus form. Due for publication 1992.

Oxaal, J. 1916. Norsk granitt *(Norwegian granite).* Nor. geol. unders., 76.

Pedersen S. & Maaløe S. 1990. The Iddefjord Granite: geology and age. Nor. geol.unders., 417, 55-64.

Ramberg, I.B. & Larsen, B.T. 1978. Tectonomagmatic evolution. In "The Oslo Paleorift, a review and guide to excursions". Nor. geol. unders. 337, 55-73.

Ramberg, I.B. & Smithson S.B. 1971. Gravity interpretation of the southern Oslo graben and adjacent precambrian rocks, Norway. Tectonophysics, 11, 419-431.

Samuelsson, L. 1971. The relationship between Permian dikes of dolerite and rhomb porphyry along the Swedish Skagerrak coast. Sver. geol. unders. Series C, 663.

Størmer, L. 1935. Contribution to the geology of the southern part of the Oslofjord.Norsk geol.tidskr., 15, 43-114.

NGU Reports on Hvaler Hydrogeology

Banks, D., Lauritsen, T., Skarphagen, H. & Rohr-Torp, E. 1991. Hvaler-prosjekt -grunnvann i fast fjell. Boring og kapasitetstesting av fire hull, ved Pulservik, Kirkeøy *(Hvaler project, groundwater in bedrock. Drilling and capacity testing of four boreholes at Pulservik, Kirkeøy)* Nor.geol.unders. report 91.215.

Banks, D. & Rohr-Torp, E. 1991. Hvaler-prosjekt - grunnvann i fast fjell. Sprekkekartlegging: Iddefjordgranitten. *(Hvaler project, groundwater in bedrock. Fracture mapping in the Iddefjord granite)* Nor.geol.unders. report 91.214.

Banks, D., Lauritsen, T., Rohr-Torp, E., Rønning, J.S. & Skarphagen, H. 1993c. Groundwater in bedrock - Hvaler project. Investigations at Testsite Utengen. Nor. geol. unders. report 93.117.

Banks, D., Lauritsen, T., Rohr-Torp, E., Rønning, J.S. & Skarphagen, H. 1993d. Groundwater in bedrock - Hvaler project. Investigations at Testsite Reffsgård. Nor. geol. unders. report 93.118.

Klemetsrud, T. & Rohr-Torp, E. 1992. Grunnvannsforsyning Skjærhallen, Hvaler kommune. *(Groundwater supply for Skjærhallen, Hvaler kommune)* Nor. geol. unders. report 92.235.

Lauritsen, T. & Rønning, J.S. 1992. Geofysiske målinger over mulige vannførende sprekkesoner på Kjerkøy, Hvaler, Østfold. *(Geophysical measurements over potentially water-bearing fracture zones on Kirkeøy, Hvaler, Østfold)* Nor. geol. unders. report 92.173.

Rohr-Torp, E. 1991. Grunnvann i krystallin bergrunn. Sluttrapport av forprosjektet. *(Groundwater in crystalline bedrock. Final report from preliminary study)* Nor.geol. unders. report 91.189.

Rohr-Torp, E. & Nordahl-Olsen, T. 1992. Grunnvann i Hvaler kommune *(Groundwater in Hvaler kommune)*. Nor. geol. unders. report 92.050.

Other Publications on Hvaler Hydrogeology

Banks, D. 1993. Estimation of apparent transmissivity from capacity-testing of boreholes in bedrock aquifers. Accepted for publication in Applied Hydrogeology.

Banks, D. & Rohr-Torp, E. 1990. Hvaler-prosjektet - et integrert studium av grunnvann i fast fjell *(The Hvaler project - an integrated study of groundwater in bedrock)*. Geonytt, 17, No.4, 25-26 & 59, Dec. 1990.

Banks, D., Solbjørg, M.L. & Rohr-Torp E. 1992a. Permeability of fracture zones in a Precambrian granite. Quart. J. Eng. Geol., London 25, 377-388.

Banks, D., Rohr-Torp, E., & Skarphagen, H. 1992b. An integrated study of a Precambrian granite aquifer, Hvaler, Southeastern Norway. Nor.Geol.Under. Bull., 422, 47-66.

Banks, D., Rohr-Torp, E., & Skarphagen, H. 1993a. Groundwater resources in hard rock - do any general rules exist ? Experiences from the Hvaler study, Southeastern Norway. In Banks, S.B. & Banks, D. (eds.) Proc. XXIVth Congress Int. Assoc. Hydrogeol. "Hydrogeology of Hard Rocks", Ås, 28/6/93-2/7/93.

Banks, D., Rohr-Torp, E. & Skarphagen, H. 1993b. Groundwater chemistry in a Precambrian granite island aquifer, Hvaler, Southeastern Norway. In Banks, S.B. & Banks, D. (eds.) Proc. XXIVth Congress Int. Assoc. Hydrogeol. "Hydrogeology of Hard Rocks", Ås, 28/6/93-2/7/93.

Banks, S.B. & Banks, D. 1993. Groundwater microbiology in Norwegian hard-rock aquifers. In Banks, S.B. & Banks, D. (eds.) Proc. XXIVth Congress Int. Assoc. Hydrogeol. "Hydrogeology of Hard Rocks", Ås, 28/6/93-2/7/93.

Larsen, M.L. 1990. Riksvei 108 Hvalertunnelen, geologisk sluttrapport *(Highway 108 Hvaler tunnel. Final geological report)*. Statens Vegvesen Østfold. Vegkontoret, report no. 88/3744, 31 pp.

Skjernaa, L. & Jørgensen, N.O. 1993. Detection of local fracture systems by azimuthal resistivity surveys: examples from South Norway. In Banks, S.B. & Banks, D. (eds.) Proc. XXIVth Congress Int. Assoc. Hydrogeol. "Hydrogeology of Hard Rocks", Ås, 28/6/93-2/7/93.

Storås, I. 1988. Ingeniørgeologisk analyse av vannlekkasjer og injeksjon i Hvalertunnelen *(Engineering geological analysis of water leakages and grout injection in the Hvaler tunnel)*. Unpublished thesis, Geologisk Institutt, Norges tekniske høyskole, Trondheim. 80 pp.

Taugbøl & Øverland A/S 1987: Ingeniørgeologisk rapport; Hvalertunnelen *(Engineering geological report - Hvaler tunnel)*. Report No. 2479.9, Taugbøl & Øverland A/S, Oslo, 8 pp. plus diagrams.

Publications on the Fjällbacka Research Site, Sweden

Eliasson, T.M., Tullborg, E.-L. & Landström, O. 1990. Fracture filling mineralogy and geochemistry at the Swedish HDR research site. In Baria, R. (ed.) "Hot Dry Rock", Proc. Camborne School of Mines Int. Conf., Robertson Sci. Publ., London. 425-435.

Sundquist, U., Wallroth, T. & Eliasson, T. 1988. The Fjällbacka HDR Geothermal Energy Research Project: Reservoir characterisation and injection well stimulation. HDR Geothermal Energy Project, Dept. Geology, Chalmers Univ. Tech. / Univ. of Göteborg, Publ. Fj9.

Wallroth, T. 1992. Hydromechanical breakdown of crystalline rock. Chalmers Tekn. Högskola / Göteborgs Univ., Geol. Instit. Publ. A71.

Other References

Fairhurst, C. 1986. In-situ stress determination - an appraisal of its significance in rock mechanics. Proc. Int. Symp. on Rock Stress and Rock Stress Measurements, Stockholm 1-3 Sept. 1986, 3-17.

Myrvang, A. 1979. Bergtrykksmålinger fra dagen i dype borehull - nye metoder *(Rock stress measurements from the surface in deep boreholes - new methods)*. In "Fjellsprengningsteknikk, bergmekanikk, geoteknikk" 1979, Tapir forlag, Trondheim.

Selmer-Olsen, R. 1964. Alminnelig geologi og ingeniørgeologi *(General geology and engineering geology)*. Tapir forlag, Trondheim, 409 pp.

Appendix 1 - Drilling logs, boreholes 1

Logged by H. Skarphagen

Borehole 1 - 24/9/92, vertical hole, drilling bit diameter at start = 77 mm.

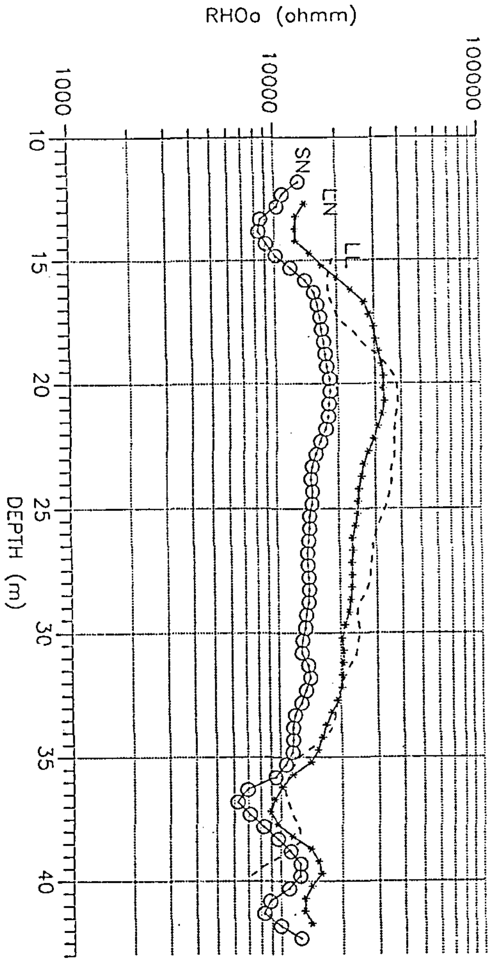
2 m	Very small fracture
9.5 m	Dark cuttings but sound rock
c. 16 m	Light reddish rock, sound rock. The lighter rock is somewhat harder than the darker. Bone dry.
30.9 m	Small fracture, less red.
c. 37 m	Biotite lens/layer
42.4 m	Stop

Appendix 2. Raw pumping test data. Reffsgård Borehole 1

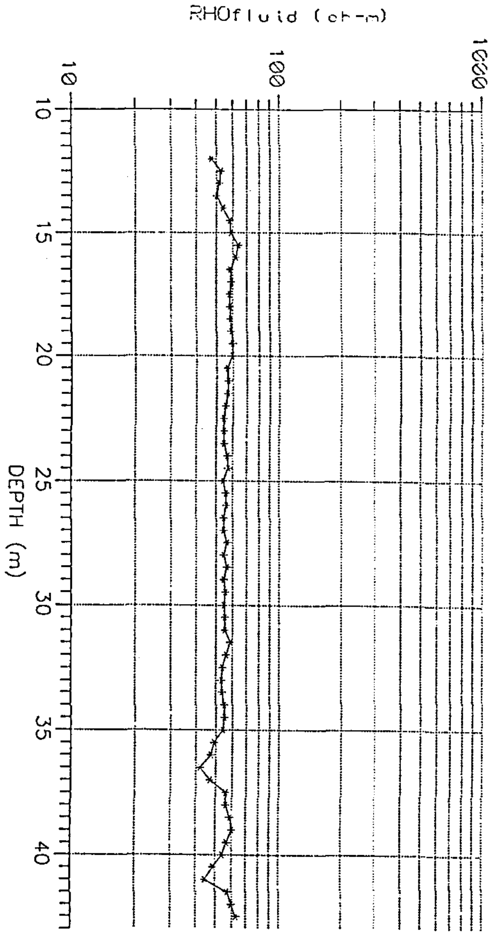
Reffsgård Hull 1		Time after pump stop		Water level (m bgl)	Qa (l/hr)	Average time (hrs)	Average water level (m bgl)
Date	Time	Days	Hours				
17-aug-93	03:24:00 pm	-0,057	-1,38	-11,79			
17-aug-93	03:34:00 pm	Pump on, pump at 40 m					
17-aug-93	04:34:00 pm	Sample taken					
17-aug-93	04:46:40 pm	*Pump sucks air, removed from borehole*					
17-aug-93	04:49:46 pm	0,0022	0,052	-36,1			
17-aug-93	04:50:16 pm	0,0025	0,060	-35,8	167,6	0,056	35,95
17-aug-93	04:50:38 pm	0,0028	0,066	-35,6	152,4	0,063	35,7
17-aug-93	04:50:59 pm	0,0030	0,072	-35,4	159,7	0,069	35,5
17-aug-93	04:51:22 pm	0,0033	0,078	-35,2	145,8	0,075	35,3
17-aug-93	04:51:43 pm	0,0035	0,084	-35	159,7	0,081	35,1
17-aug-93	04:52:41 pm	0,0042	0,100	-34,5	144,5	0,092	34,75
17-aug-93	04:53:41 pm	0,0049	0,117	-34	139,7	0,109	34,25
17-aug-93	04:54:37 pm	0,0055	0,133	-33,5	149,7	0,125	33,75
17-aug-93	04:55:38 pm	0,0062	0,149	-33	137,4	0,141	33,25
17-aug-93	04:56:41 pm	0,0070	0,167	-32,5	133,0	0,158	32,75
17-aug-93	04:57:47 pm	0,0077	0,185	-32	127,0	0,176	32,25
17-aug-93	04:58:49 pm	0,0084	0,203	-31,5	135,2	0,194	31,75
17-aug-93	04:59:57 pm	0,0092	0,221	-31	123,3	0,212	31,25
17-aug-93	05:02:13 pm	0,0108	0,259	-30	123,3	0,240	30,5
17-aug-93	05:04:40 pm	0,0125	0,300	-29	114,0	0,280	29,5
17-aug-93	05:07:16 pm	0,0143	0,343	-28	107,5	0,322	28,5
17-aug-93	05:10:00 pm	0,0162	0,389	-27	102,2	0,366	27,5
17-aug-93	05:12:55 pm	0,0182	0,438	-26	95,8	0,413	26,5
17-aug-93	05:16:03 pm	0,0204	0,490	-25	89,2	0,464	25,5
17-aug-93	05:19:26 pm	0,0228	0,546	-24	82,6	0,518	24,5
17-aug-93	05:23:05 pm	0,0253	0,607	-23	76,5	0,577	23,5
17-aug-93	05:27:08 pm	0,0281	0,674	-22	69,0	0,641	22,5
17-aug-93	05:31:36 pm	0,0312	0,749	-21	62,6	0,712	21,5
17-aug-93	05:36:30 pm	0,0346	0,831	-20	57,0	0,790	20,5
17-aug-93	05:42:13 pm	0,0386	0,926	-19	48,9	0,878	19,5
17-aug-93	05:48:48 pm	0,0431	1,036	-18	42,4	0,981	18,5

17-aug-93	05:56:47 pm	0,0487	1,169	-17	35,0	1,102	17,5
18-aug-93	09:27:00 am	0,6947	16,672	-11,93	1,5	8,920	14,465
18-aug-93	03:20:00 pm	c. 80 l water with 1.5 Kg EDTA injected at 35 m depth					
		Thereafter, "pure" water added at well top at 10 l per 160 s for 10 min.					
18-aug-93	03:25:00 pm	Hole is agitated with weight					
18-aug-93	03:30:00 pm	Quit filling with water					
18-aug-93	04:17:00 pm			-8,47			
18-aug-93	04:22:30 pm	Pump start at 40 m					
18-aug-93	05:28:48 pm	Pump sucks air, removed from borehole					
18-aug-93	05:32:05 pm	0,0023	0,055	-36,8			
18-aug-93	05:33:19 pm	0,0031	0,075	-36	181,2	0,065	36,4
18-aug-93	05:34:58 pm	0,0043	0,103	-35	169,3	0,089	35,5
18-aug-93	05:36:41 pm	0,0055	0,131	-34	162,8	0,117	34,5
18-aug-93	05:38:29 pm	0,0067	0,161	-33	155,2	0,146	33,5
18-aug-93	05:40:23 pm	0,0080	0,193	-32	147,1	0,177	32,5
18-aug-93	05:42:24 pm	0,0094	0,227	-31	138,5	0,210	31,5
18-aug-93	05:44:32 pm	0,0109	0,262	-30	131,0	0,244	30,5
18-aug-93	05:46:47 pm	0,0125	0,300	-29	124,2	0,281	29,5
18-aug-93	05:49:14 pm	0,0142	0,341	-28	114,0	0,320	28,5
18-aug-93	05:51:50 pm	0,0160	0,384	-27	107,5	0,362	27,5
18-aug-93	05:54:36 pm	0,0179	0,430	-26	101,0	0,407	26,5
18-aug-93	06:04:15 pm	0,0246	0,591	-23	86,9	0,510	24,5

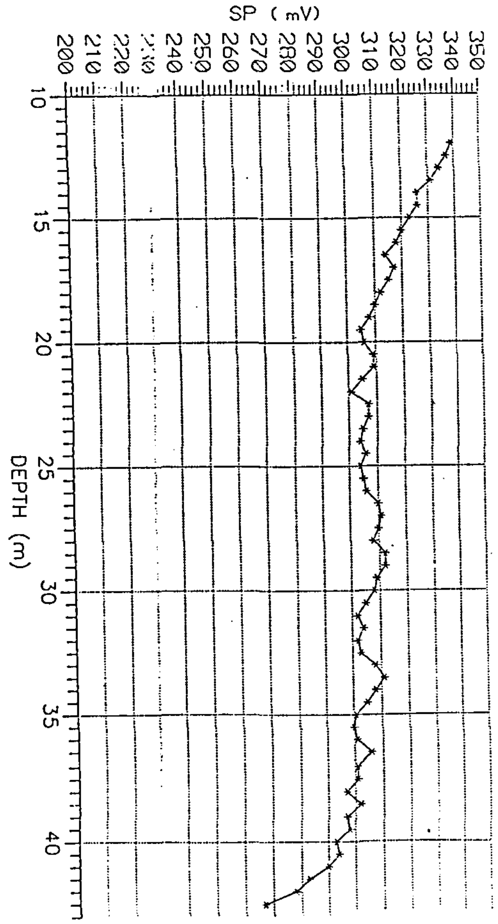
RESISTIVITY LOG



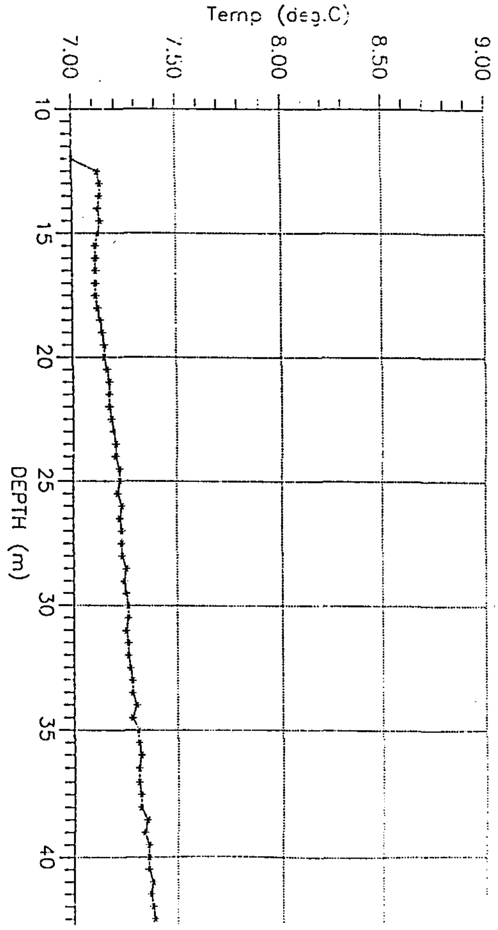
FLUID RESISTIVITY LOG



SELF POTENTIAL LOG



TEMPERATURE LOG



Appendix 3. Borehole logs from 3" borehole nr.1 at Reffsgård

Appendix 4. Product Information Sheet - EDTA.

PRODUKTDATABLAD
(Sikkerhetsdatablad)

Nr.: 050031
Dato : 201289

Carl Bøyesens Eftf. A/S
Postboks 37 Risløkka
0516 OSLO 5
Tlf.: 02-652730

Handelsnavn:
EDTA, Pulver (Trilon B/Detarex 200)

Anvendelse :
Kompleksdanner

1.KLASSIFISERING/MERKING

Faresymboler

R-Setn.
- Farlig ved svelging
- Irriterer øynene

S-Setn.
- Unngå innånding av støv.
- Får man stoffet i øynene, skyll straks grundig med store mengder vann og kontakt lege.
- Unngå hudkontakt.

YL-Gruppe
Yl-Tall

2.TRANSPORTKLASSIFISERING

UN NR	IMDG	ADR/RID	TU-KORT
1759	-	8	-

3.SAMMENSETNING

Inneholder	Vekt%	Fareklasse	Adm.Norm
Etylendiamintetraeddiksyre	min.83%	Xn	
Vann			

CAS.NR.: 64-02-08

4.FYSIKALSKE DATA

Farge/Lukt : Hvitt / ingen lukt
Form/Konsist: Pulver

....

Damptrykk (oC) Løselighet , Vann 20oC
- mmhg- kPa lett løselig 1000 g/l

Damptetthet (luft=1):-	Tetthet (oC)	Viskositet	pH/kons:-
	550 g/cm3	-	pH/ 1%:11,3

Smeltepkt./Omr.	Kokepunkt/Omr.	Andre data:
ca. 400 oC *	-	*Fra ca. 200oC:dekomponering

Eksplosjonsgrense:	Tenntemp.:	Flammepkt.:	Metode:
-	-	> 150 oC	-

Reaktivitet:
Angriper aluminium, kopper, nikkel, sink og deres legeringer. Lagres i plast eller rustfritt stål.

Emballasje :

Sekker a 25 kg

5.TOKSIKOLOGISKE DATA

Oral LD50	-	Rotte: 1000-2000 mg/kg
LC50	-	
Hud	-	
Slimhinne	-	

6.HELSEFARE (Generelt,innånding,svelging,hud,øyne)

Virker irriterende på øyne og slimhinner.
Farlig ved fortæring.
Langvarig gjentatt hudkontakt kan forårsake irritasjon.
Innånding av støv kan irritere luftveiene.

7.BRANN OG EKSPLOSJONSFARE

Ikke brannfarlig, men giftig CO gasser kan dannes ved oppheting.
Svakt støveksplosjonsfarlig.

Brannslukkingsmiddel:
Vanntåke, skum, CO2, pulver.

8.VERNETILTAK

Verneutstyr:
Vernebriller

Forsiktighetsregler ved bruk:
Det må ikke spises, drikkes eller røykes under arbeidet. Ved håndtering av større mengder uten avsug brukes egnet åndedrettsvern.

Forsiktighetsregler ved lagring:
Oppbevares tørt.

9.FØRSTEHJELP (Generelt,innånding,svelging,hud,øyne)

Innånding : Frisk luft. Omgående legehjelp. Skyll munn og nese med vann.

Hud : Fjern tilsølte klær. Vask straks huden med såpe og vann.

Øyne : Skyll straks grundig med store mengder vann og kontakt lege.

Svelging : Dersom den skadede er ved full bevissthet, gi et par glass vann å drikke. Ikke fremkall brekninger. Til sykehus.

10.INFORMASJON TIL HELSEPERSONELL

11.TILTAK VED SPILL OG LEKKASJE

Rengjøring/Destruksjon:
Feies opp. Kan i overensstemmelse med lokale forskrifter brennes sammen med avfall.

Utslipp til vann:
Fisketoksitet: LC50 (guppies) 500 mg/l/96 h

12.ANDRE OPPLYSNINGER

SPESIELLE EGENSKAPER

Opplysningene i dette datablad er gitt på grunnlag av vår nåværende viten.Hensikten er en beskrivelse av produktet med tanke på sikkerheten.
Databladet er utarbeidet av Carl Bøyesens Eftf A/S , og opplysningene er hentet fra produsent.

Ansvarlig for utarbeidelsen : Bjørn-Olav Larsen

Oslo, ..26/8-93..........
pr. Carl Bøyesens Eftf. A/S
....