Prospecting for geothermal energy in the Iddefjord granite, Østfold, Norway

GISLE GRØNLIE, TOMM E. JOHANSEN, BJØRN KARLSTAD & KNUT S. HEIER

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The Iddefjord granite in Østfold, Norway, which is a continuation of the Båhus granite in Sweden, was studied with respect to its possible use as a geothermal hot water reservoir. Two holes (123 & 128 m long) drilled specifically for this project and a total of 22 deep water wells were measured. The temperature gradient of the granite increases towards the east where a maximum of 21.5°C/km is reached. The average gradient near the border of the granite is as low as 15°C/km.

Conductivities from the two drilled holes were measured. The heat flow in the thickest part of the granite is 1.88 hfu (78.6 mW/m²), which is high compared to the Norwegian average of 1.02 ± 0.21 hfu.

G. Grønlie, T. E. Johansen & B. Karlstad, Institutt for geologi, Universitetet i Oslo, Blindern, Oslo 3, Norway. K. S. Heier, Norges Geologiske Undersøkelse, Postboks 3006, 7001 Trondheim, Norway.

Prospecting for geothermal energy sources has lately been very popular and partly successful in various areas throughout the world. The reason for this 'hunt' for geothermal energy sources has been the explosive rise in cost of conventional energy (electricity, coal, petroleum). The international development of techniques and expertise in prospecting for and utilizing these sources of vast heat reservoirs is promising and has been expanding at a tremendous rate. Also the Scandinavian countries have been looking at the possibility of making use of geothermal energy (Ahlbom et al. 1979, Ehrenreich 1978, Kivekäs 1978, Gustafson 1978, Landstrøm et al. 1980). These investigations have been partly successful.

Recently Det Kgl. Olje- og energidepartement (The Norwegian Department of Petroleum and Energy) has supported a project to examine the possibility of utilizing the Iddefjord granite in Østfold as a possible heat reservoir. We decided to examine the Iddefjord granite with respect to its possible use as hot water geothermal energy source for the following reasons:

The Iddefjord granite is radioactive above average and produces a substantial amount of heat (Raade 1973, Killeen & Heier 1975).

It is a continuation of the Båhus granite in Sweden which has been closely examined and has given promising results (Landstrøm et al. 1980, Ahlbom et al. 1978).

The geographical position of the granite is favourable because of its closeness to major cities in Østfold (Halden, Moss, Sarpsborg, Fredrikstad), which will be potential users of a geothermal hot water source.

A gravity study of the Iddefjord granite indicated a rather thick body (3–5 km) (Ramberg & Smithson 1971).

Many water wells have been drilled in the Østfold area because of water shortage. Measurements of the temperature gradient in these holes would be a valuable supplement to the temperature gradients measured from drilled holes especially for this purpose.

Field work and data reduction

Two holes (123 and 128 m deep) were drilled in homogenous granite especially for this purpose (holes Nos. 12 and 14, Fig. 1). In addition we measured the temperature in 22 water wells deeper than 50 m (Fig. 1). A few of the temperature/depth plots are shown in Fig. 2. All the plots reflect the temperature minimum of last winter at a depth of about 12–15 m. Below 15 m there is a more or less linear increase of temperature with depth. Most of the departures from linearity are probably caused by water influx in fractures and small faults in the wells (Fig. 2:2, 3, 5, and 18). This was, of course, to be expected for most of

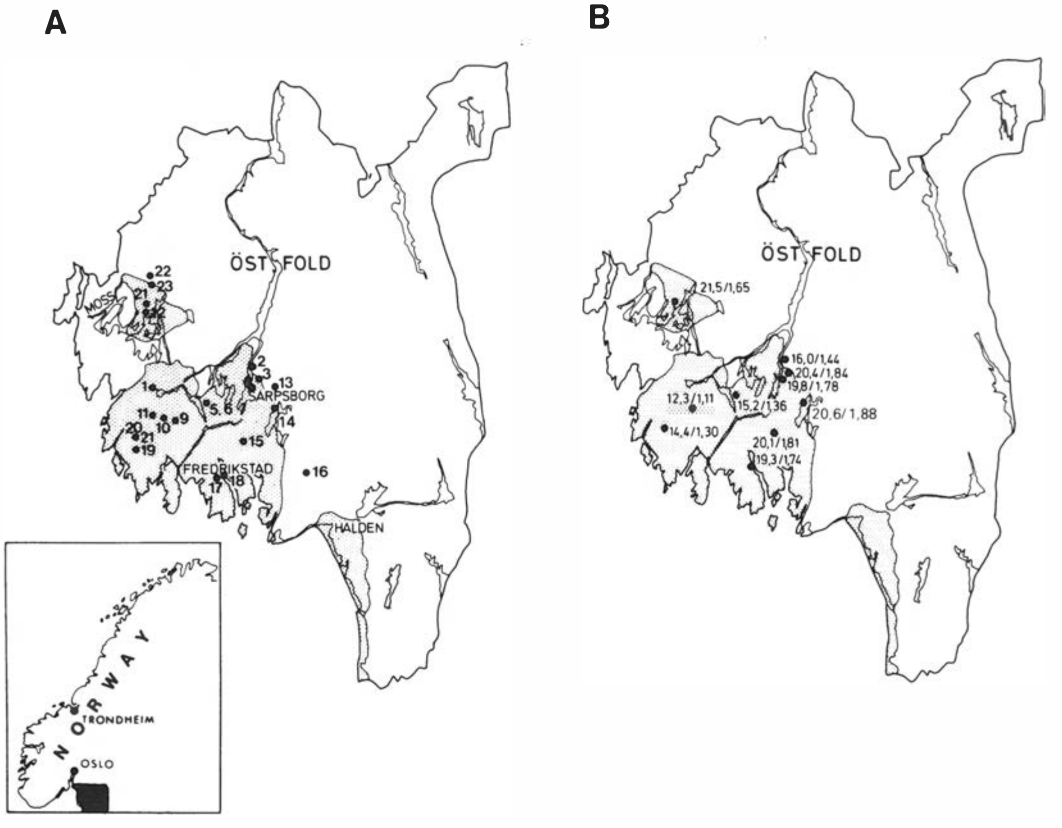

Fig. 1. **A:** Bore hole localities in Østfold county, Norway. Dotted area: Iddefjord granite. **B:** Temperature gradient (°C/km) and heat flow (hfu) from the same localities.

Table 1. Temperature gradient, conductivity and heat flow from 11 holes in the Iddefjord granite, Østfold, Norway. Conductivity only measured in holes Nos. 12 and 14 (*: estimated conductivity).

HOLE NO	DEPTH m	TEMP.GRADIENT °C/km	CONDUCTIVITY 10^{-3}cal/cm s°C	HEAT FLOW hfu	W/m^2s
2	98	16.0	9.00*	1.44	60.2
3	91	20.4	9.00*	1.84	76.9
5	109	15.2	9.00*	1.36	56.8
8	106	19.8	9.00*	1.78	74.4
10	91	12.3	9.00*	1.11	46.4
12	123	21.5	7.37	1.65	69.0
13	101	16.7	9.00*	1.51	63.1
14	128	20.6	9.01	1.88	78.6
15	103	20.1	9.00*	1.81	75.7
18	124	19.3	9.00*	1.74	72.7
21	91	14.4	9.00*	1.30	54.3
Average Norway				1.02	42.6

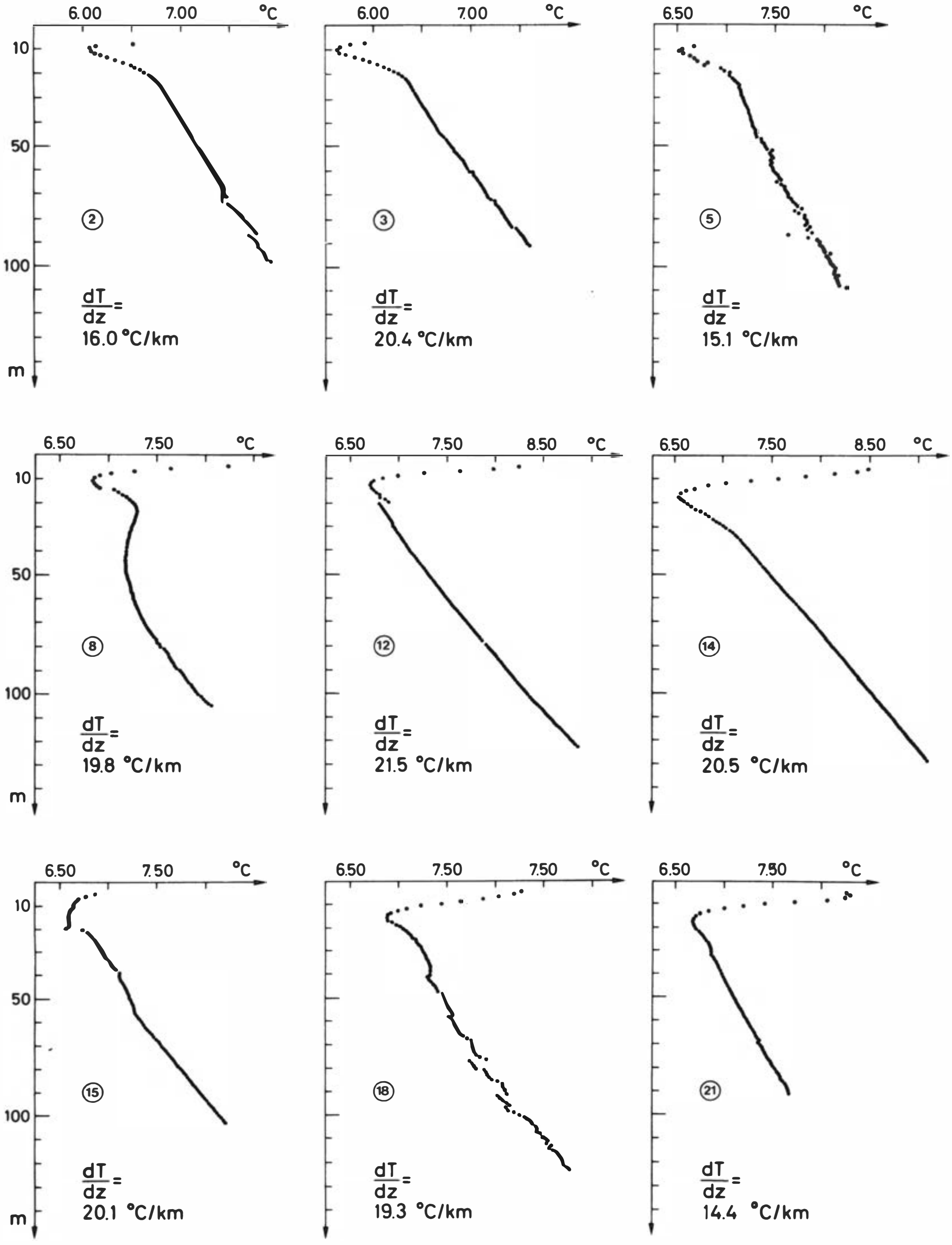

Fig. 2. Temperature versus depth plots from 9 of the locations in Fig. 1 A. Note the good results in holes Nos. 12 and 14 and the high temperature gradients.

the water wells, since most of the time they are drilled in fractured areas in order to increase permeability and water production.

The best gradients are from the two holes which were drilled into homogenous granite (Fig. 2; Table 1, Nos. 12 and 14).

The conductivities were measured in the laboratory using the divided bar technique (Birch 1950, Combs & Simmons 1973, Swanberg et al. 1974). The values are 9.01 and 7.37×10^{-3} cal/cms°C in the two holes respectively (Table 1). Hole No. 14, which shows the highest value, was drilled in solid granite, while the lower value in hole No. 12 is probably caused by the fact that portions of the hole were drilled through gneiss.

Results and discussion

The temperature gradients are higher to the east towards the edge of the granite (Fig. 1, Table 1) and a maximum of 21.5°C/km is found in hole No. 12. The gradients to the west are low (holes Nos. 5, 10, and 21) with a minimum of 12.3°C/km in hole No. 10.

The corresponding heat flow values (Fig. 1, Table 1) show rather high values to the east (maximum 1.88 hfu (78.6 W/m^{2}s) in hole No. 14) and lower values to the west (minimum 1.11 hfu in hole No. 10). The maximum value is 84% higher than the Norwegian heat flow mean which is 1.02 ± 0.21 hfu (65 values Hänel et al. 1979) and definitely of interest in a geothermal context.

No correction to the temperature gradients for glaciation effects has been made. Landstrøm et al. (1980) calculated an increase in the gradient of 5–6°C/km because of glaciation cooling effects at 100 m depth for the Båhus granite. If one assumed the same glacial conditions prevailed for the Iddefjord granite, then one should add the same amount to the gradients in Table 1, bringing the maximum gradient to approximately 27°C.

The variation in geothermal gradient and heat flow which is observed is probably closely related to the thickness of the granite and the variation in radioactive mineral content. Ramberg & Smithson (1971) demonstrated the occurrence of negative gravity anomalies and concluded that the thickness of the Iddefjord granite varied from 3 to 5 km with the thickest part in the east where the granite plunges underneath the gneiss. The granite is rather thin to the west according to the gravity model. The geothermal gradient and the heat flow strongly suggest that the interpretation of the gravity data is correct.

The surface rocks in the Oslo Region were sampled and tested for radioactivity by Raade (1973), and Killeen & Heier (1975) sampled the southern Norway granites. Although the samples from the Iddefjord granite are few, the results show that it is enriched in uranium and thorium compared to what is normally found throughout the crust (Lambert & Heier 1968, Heier & Grønlie 1977). This is also the case for the Båhus and the Flå granite which, together with the Iddefjord granite, lie on the same cogenetic line. The geothermal investigations in the Båhus granite have been promising, but more work needs to be done also in this area.

The temperature gradient and the heat flow results are interesting and more work should be done in order to find the most promising prospective area for possible future geothermal exploitation. We therefore suggest that detailed gravity and radioactivity surveys are undertaken as soon as possible to define the thickest and most radioactive part of the granite where a new 3–400 m deep hole, below the depth where glaciation effects are present, should be drilled and measured.

Finally, we would like to stress that at present and for the immediate future geothermal energy in Norway is not an economic energy alternative. However, it might develop into one sooner than we think because of rapidly increasing technology and spiralling costs of the conventional energy sources.

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References

Ahlbom, K., Landstrøm, O., Larson, S. Å., Lind, G. & Malmqvist, D. 1978: Prospecting for hot dry rock geothermal energy in Sweden. *In* Svensson & Larson (eds.), *Nordic Symposium on Geothermal Energy*, 1–14, Göteborg.

Birch, F. 1950: Flow of heat in the Front Range, Colorado. *Bull. Geol. Soc. Am. 61*, 567–630.

Combs, J. B. & Simmons, G. 1973: Terrestrial heat-flow determination in the north central United States. *J. Geophys. Res. 78*, 441–461.

Ehrenreich, S. 1978: Geothermal pilot plans in Denmark. Background and future plans. *In* Svensson & Larson (eds.), *Nordic Symposium on Geothermal Energy*, 71–83, Göteborg.

Gustafson, G. 1978: Geothermal energy in south-west Scania, Sweden. Drilling and production tests. *In* Svensson & Larson (eds.), *Nordic Symposium on Geothermal Energy,* 84–87, Göteborg.

Heier, K. S. & Grønlie, g. 1977: Heat flow–heat generation studies in Norway. *In* Saxena, S. K. & Bhattacharji, S. (eds.), *Energetics of Geological Processes,* 217–235, Springer Verlag.

Hänel, R., Grønlie, G. & Heier, K. S. 1979: Terrestrial heat flow determination in Norway and an attempted interpretation. *In* Cermák, V. & Rybach, L. (eds.), *Terrestrial Heat Flow in Europe,* 232–239, Springer Verlag.

Killeen, P. G. & Heier, K. S. 1975: Radioelement distribution and heat production in Precambrian granitic rocks, Southern Norway. *Skr. Nor. Vidensk. Akad. i Oslo. Mat.-Naturvidensk. Kl.,* No. 55, 32 pp.

Kivekäs, L. 1978: Prospecting for geothermal energy in Finland. Geothermal data. *In* Svensson & Larson (eds.), *Nordic Symposium on Geothermal Energy,* 112–119, Göteborg.

Lambert, I. B. & Heier, K. S. 1968: Estimates of the crustal abundances of thorium, uranium and potassium. *Chem. Geol. 3,* 233–238.

Landstrøm, O., Larson, S. Å., Lind, G. & Malmqvist, D. 1980: Geothermal investigations in the Båhus granite area in south western Sweden. *Tectonophysics 62.*

Raade, G. 1973: Distribution of radioactive elements in the plutonic rocks of the Oslo Region. *Unpubl. cand. real. thesis, Universitetet i Oslo,* 162 pp.

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

Swanberg, C. A., Chessman, M. D., Simmons, G., Smithson, S. B., Grønlie, G. & Heier, K. S. 1974: Heat flow–heat generation studies in Norway. *Tectonophysics 23,* 31–48.