Terrestrial Heat Flow Determinations from Lakes in Southern Norway*

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Twenty-four heat flow determinations based on measurements in lakes are presented from southern Norway. All the measurements lie within the Precambrian Baltic Shield and the Permian Oslo Graben. The mean value, 0.96 ± 0.21 hfu (1 hfu = 10^{-6} cal/cm²s), is in good agreement with previously published results from both Norway and the Baltic Shield in general. The results give additional evidence in favour of the suggested presence of a zone of anomalous low mantle heat flow to the east of the Caledonian mountains in Norway.

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This first determination of terrestrial heat flow in Norwegian lakes was carried out by the Niedersächsische Landesamt für Bodenforschung in Hannover, West Germany in cooperation with Institutt for geologi and Mineralogisk-geologisk museum at Universitetet i Oslo, Norway.

When the measurements began, a project of determining heat flow from boreholes on land had been going for some time, and the first results from this study have now been published (Swanberg et al. 1974). Swanberg et al. present 15 heat flow values of which 11 are from southern Norway and are relevant to this study.

This study had two objectives, the first of which was to supplement the data from Swanberg et al. in order to produce a more reliable heat flow map for southern Norway, and the second was to make a comparison of heat flow between the Precambrian Baltic Shield, the Permian Oslo Graben, the Variscian mountain chain and the north German depression.

The error of the heat flow results presented is up to ± 20 %. Generally, the inaccuracy of the equipment is only ± 3 % and therefore negligible. The major part of the error is caused by uncontrollable natural factors such as: disturbance of the temperature gradient by slowly circulating water, non-representative rock samples, lack of data on temperature oscillation of the water near the lake bottom, and the influence of a strong mountain relief on the topographic correction. Therefore only mean heat flow values should be used.

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Table 1. Heat flow data from 24 lakes in southern Norway.

No.	Lake	Latitude (degree-minute)	Longitude (degree-minute)	Water level (m)	Depth of water (m)	Heat conductivity (10^{-3} calcm^{-1} s^{-1}deg^{-1})	Temperature gradient (10^{-3}°C cm^{-1})	Heat flow (μcalcm^{-2}s^{-1})
1	Bandakvatn	59–23.9	8–17.9	72	260	1.89	0.331	0.63
2	Birkelandsvatn	58– 9.0	7–45.4	43	61	1.68	0.648	1.09
3	Blankvatn	60– 1.6	10–40.2	351	52	1.57	0.664	1.04
4	Eikeren	59–41.3	9–54.4	19	154	1.98	0.649	1.28
5	Gjersjøen	59–47.3	10–46.9	42	51	1.88	0.672	1.26
6	Krøderen	60–17.8	9–40.4	132	110	2.54	0.303	0.77
7	Lundevatn	58–25.1	6–35.7	45	202	3.05	0.321	0.98
8	Lundevatn	58–22.2	6–36.6	45	300	1.91	0.527	1.01
9	Mjøsa	60–38.4	11– 7.2	123	428	3.05	0.336	1.12
10	Mjøsa	60–35.0	11–11.2	123	417	3.58	0.205	0.73
11	Nordsjø	59–19.1	9–16.6	15	164	2.24	0.311	0.70
12	Nordsjø	59–15.9	9–23.7	15	168	2.44	0.361	0.88
13	Rørholtfjorden	59– 0.9	9–19.8	60	85	1.65	0.465	0.60
14	Rørholtfjorden	59– 0.9	9–13.8	60	88	1.75	0.302	
15	Sirdalsvatn	58–37.7	6–42.5	170	157	1.72	0.510	0.88
16	Sirdalsvatn	58–34.2	6–42.4	170	159	1.62	0.782	1.27
17	Sperillen	60–32.4	10– 1.6	150	109	1.90	0.323	0.62
18	Sperillen	60–31.1	10– 4.6	150	82	1.91	0.497	0.92
19	Storsjøen	61–38.5	11–11.2	251	267	1.81	0.496	0.90
20	Svinsjøen	59–49.3	10–22.5	180	34	1.85	0.577	
21	Svinsjøen	59–49.3	10–22.5	180	34	1.88	0.601	1.23
22	Svinsjøen	59–49.3	10–22.5	180	35	2.33	0.567	
23	Tinnsjø	59–50.8	8–58.0	191	357	1.85	0.474	0.88
24	Totak	59–43.8	7–51.0	687	309	3.03	0.564	1.14
25	Totak	59–42.4	7–56.1	687	105	1.64	0.683	1.12
26	Tronstadvatn	58–11.6	7–45.7	41	92	1.65	0.711	1.17
27	Tyrifjorden	59–59.1	10–16.6	63	288	2.34	0.411	0.96
28	Tyrifjorden	59–56.5	10–19.0	63	270	2.04	0.421	0.86

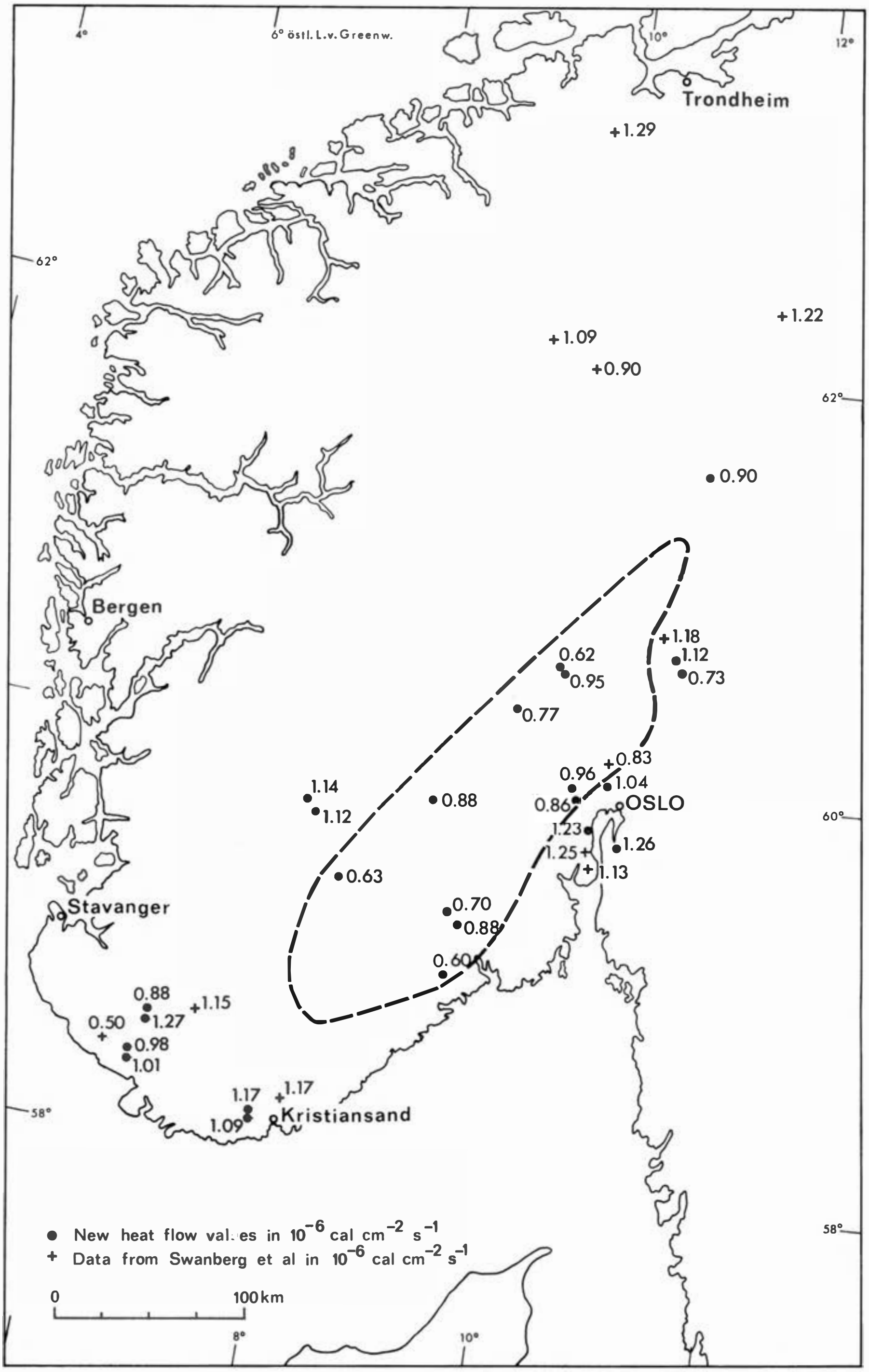

Fig. 1. Heat flow map of southern Norway.

The determination of the terrestrial heat flow in the lakes was carried out according to the method described by Hänel (1970) and with a heat flow probe developed for this method. Measurements were made in 24 lakes, four of which proved to be unsuitable because of an intense water inflow near the measuring point (Årdalsvatn, Engeren, Sandungen, Øyeren). The results from two other lakes (Bygdin, Gjende) could not be interpreted because of water convection. The results of the heat flow measurements are tabulated in Table 1 and shown in Fig. 1. This figure also includes the relevant heat flow values from Swanberg et al.

In order to calculate the temperature gradient given in Table 1, consideration was given to the inclination of the heat flow probe in the sediments, the sedimentation rate, topographic influence and, where necessary, the mean annual temperature wave in the water.

The clinometer measured to an accuracy of $\pm 1°$, thereby producing a negligible error.

The sedimentation rate is only available for one lake, Svinsjøen. The average value for the last few years is 0.23 mm/yr (Kjensmo 1968), which gives a correction of + 1 %. For all the other lakes, values of + 2 % to + 3 % were taken, in analogy with lakes in Austria, Germany and Italy. This error is small enough to be ignored.

The accuracy of the topographic correction is about ± 5 %.

More problematic is the influence of the mean temperature wave at the lake bottom. For meromictic lakes and lakes with fossil salt water we need no correction, because the temperature is practically constant over many years (Birkelandsvatn, Blankvatn, Rørholtfjorden, Svinsjøen, Tronstadvatn (Kjensmo 1968, Strøm & Østtveit 1948)). Temperature values were available for Mjøsa, Tinnsjø and Tyrifjorden and therefore an individual temperature correction was possible. All other lakes were corrected with a 'mean temperature wave'. This mean temperature wave is based on temperature records of different lakes in Norway (Hauge 1957). The inaccuracy for single values is therefore estimated at ± 15 % to ± 20 %.

Results and discussion

Our heat flow values are shown in Fig. 1 together with values from Swanberg et al. All the measurements are from lakes which are situated east of the Caledonian mountains. Consequently our heat flow values indicate heat flow from the Precambrian (Baltic Shield) in Norway and the Permian Oslo Graben.

Swanberg et al. concluded that there was an anomalous low mantle heat flow from the Baltic Shield in Norway but the basis of their argument was a plot of heat flow versus heat generation with only 5 values.

Our 24 new heat flow values seem to favour Swanberg et al.'s conclusion that there is a zone of low (mantle) heat flow in the Baltic Shield to the east of the Caledonian mountains (Fig. 1, inside the dashed line). Swanberg et al.'s results from the Caledonian give a mean value of 1.18 hfu and their results from the Precambrian Shield give an average of 0.99 hfu (3 values). Our lake measurements give a mean of 0.96 hfu (standard deviation 0.21 hfu), which compares well with the shield values of Swanberg et al. and also within the error limits with their Caledonian mean value. No heat generation study has been made specifically for this project, but a general heat generation study on Precambrian granites in southern Norway is in progress. This study shows that the heat production from the Precambrian in southern Norway is not negligible and will make contribution to surface heat flow as observed in the lakes.

Very few heat flow data have till now been published from other parts of the Baltic Shield. Lubimova et al. (1972) have reported values of mantle heat flow between 0.6 and 0.75 hfu for the Kola peninsula, USSR. Five heat flow values of 0.90 ± 0.22 hfu are reported by Puranen et al. (1968) from Finland near to latitude 62°. From Poland 197 heat flow values from the Precambrian Shield give an average of 1.01 (Majorowicz 1973, and pers. comm.). Our results seem to be consistent with these.

In the north German depression Hänel (1971) found a mean of 1.18 hfu based on three values near Hamburg, and for the Variscian mountains a mean from 146 values of 1.71 hfu. This may show a trend of increasing heat flow values from Norway through Germany to the Alps. However, because of the large standard deviation on our heat flow values there still exists a possibility that our values and the values from the north German depression are the same. This would imply that we for Europe have the same conditions as are shown to exist in the United States, where distinct heat flow provinces have rather sharp and well defined boundaries (Roy et al. 1968).

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