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72. *Studies of the Thermal State of the Earth. The 18th Paper: Terrestrial Heat Flow in the Japan Sea (2).*

By Masashi YASUI, Toshio KISHII,
Maizuru Marine Observatory,
Teruhiko WATANABE,
Graduate School, University of Tokyo
and Seiya UYEDA,
Earthquake Research Institute.

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Abstract

Terrestrial heat flow has been measured at 116 stations in the Japan Sea area. Except the western-most part, the whole of the Japan Sea has been covered by these measurements. Major features of heat flow in the Japan Sea are as follows: (1) The heat flow values are anomalously high throughout the area, the average value being 2.17 ± 0.40(s.d.)$\times10^{-6}$ cal/cm^2 sec. The mean of the $1°\times1°$ grid averages is 2.24×10^{-6} cal/cm^2 sec; (2) A weak positive correlation seems to exist between the heat flow and the water depth. Heat flow is higher in the northern deep basin, which has a typically oceanic deep basin, than in the southern part with a continental crust.

Introduction

Terrestrial heat flow measurement in the Japan Sea area was started in May, 1964, and the result of the measurements made in 1964 was reported in a previous paper (Yasui and Watanabe, 1965).[1)]

In 1965 additional 97 measurements were achieved in the same area on *R/V* Seifû-Maru also under a joint project of the Maizuru Marine Observatory and the Earthquake Research Institute as a part of the US-Japan Cooperative Science Program and the Upper Mantle Project of Japan.

These measurements were made in two main cruises in May-June and August-September, 1965. In the former cruise, detailed survey of

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1) M. YASUI and T. WATANABE, *Bull. Earthq. Res. Inst.*, **43** (1965), 549-563.

the heat flow, bottom topography and geomagnetic total force in the area of Yamato bank and Kitayamato bank was intended. The latter cruise was aimed to cover the northern part of the Japan Sea with heat flow stations along with the ordinary routine hydrographic works of the Maizuru Marine Observatory.

In the present paper the general result of these heat flow measurements will be reported. Reliability and quality of all the data, including those which were reported previously, will be examined.

Measurement

Throughout all the measurements Tokyo University type sea bottom thermogradmeters[2] were used. Thermal gradient is measured at two intervals, giving two values of the gradients. Agreement of these two gradients served as a measure of the quality of the data. Thermal conductivity of sediment was determined with the needle probe method.[3]

The accuracy of determining the effective thermal conductivity is within 10 to 15% depending on the nonuniformity of the sediment.

Before 1964, there was no heat flow measurement in the Japan Sea area, except one land measurement at Izuhara in Tsushima Island, the value of which is 2.17×10^{-6} cal/cm^2 sec (Hôrai, 1963).[4]

Since 1964, measurements have been made mainly in four principal cruises. In this paper these cruises are called the 1st, 2nd, 3rd and 4th cruise respectively. The ship's tracks of these cruises are shown in Fig. 1.

In the following, some descriptions of the quality of the data will be made and their reliability assessed. The data are summarized in Tables 1, 2 and 3. For the stations of which no mention is made in the text, the heat flow data may be considered as good.

The 1st cruise *May-June 1964.*

Though eight stations were taken during the first cruise, results obtained at the first four stations, Ako-M1 to Ako-M4, were not of high accuracy. This was due to the fact that the 2 Kohm carbon resistors,[5] which were tentatively inserted in the bridge arms in series to the thermistors to keep the oscillator circuit of the bridge under a stable

2) S. UYEDA et al., *Bull. Earthq. Res. Inst.*, **39** (1961), 115-131.
3) M. YASUI et al., *Oceanog. Mag.*, **14** (1963), 147-156.
4) K. HÔRAI, *Bull. Earthq. Res. Inst.*, **41** (1963), 149-165.
5) M. YASUI and T. WATANABE, *loc. cit.*, 1).

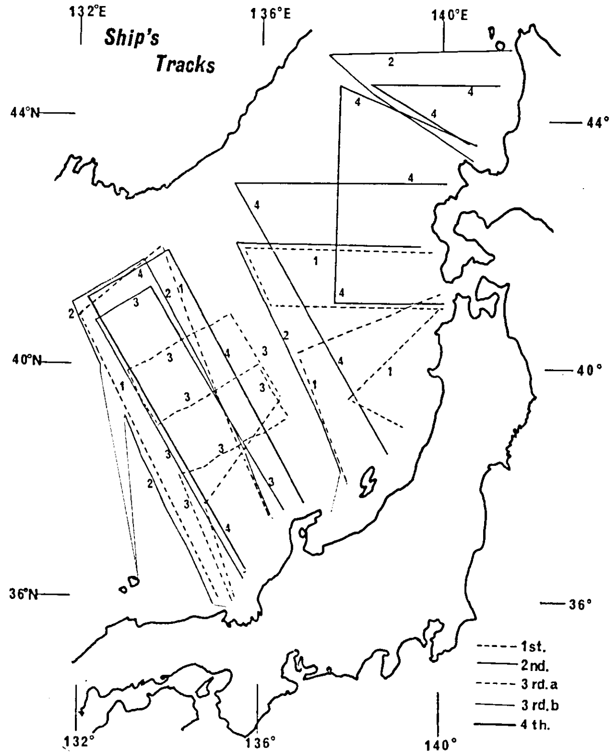


Fig. 1. Ship's tracks of the four principal cruises.

condition, lowered the overall sensitivity of the instrument. The error of the measurement in these cases becomes too large to be corrected. Therefore, these four values should be used only for reference. (In this paper heat flow values, of which probable error is estimated to be in excess of 0.35×10^{-6} cal/cm^2 sec are indicated as "only for reference"). At the latter stations, i.e. Ako-M5 to Ako-M8, 77.5 ohm carbon resistors were put in parallel to the endless helical potentiometers to recover the sensitivity.

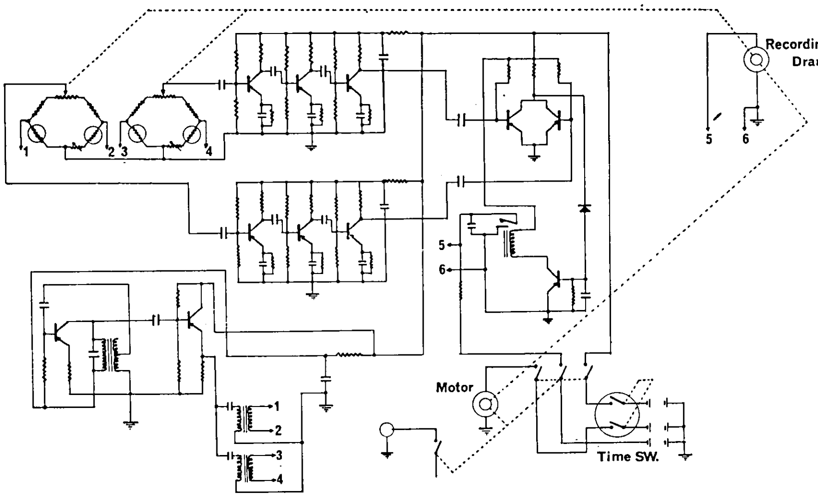
The 2nd cruise. *August-September, 1964.*

After the first cruise, simple improvements were made upon the oscillator circuit of the recorder so as to increase the stability against the change of the load resistance of the thermistors. The improved circuit is shown in Fig. 2.

At station Saiko-3, the record for the 1.0 m thermistor separation could not be obtained because of a miscontact of a trimmer potentiometer

Table 1. Data of the heat flow measurements in the Japan Sea during the 1st and 2nd cruises. The unit of thermal gradient, thermal conductivity and heat flow are 10^{-3}°C/cm, 10^{-3}cal/cm·sec·°C and 10^{-6}cal/cm^{2}sec respectively. F and P mean full penetration and partial penetration.

Date	Station #	Position		Depth (m)	Thermal Gradient			Penetration	Thermal Conductivity	Heat Flow Value	Remarks
		Lat.	Long.		1.5 m	1.0 m	Mean				
May 25	Ako-M1	38-11N	133-45E	970	0.99	1.17	1.08	F	1.98±0.10	2.13	Only for Ref.
26	M2	40-47	132-04	3080	0.30	0.35	0.33	F	1.78±0.10	0.63	Only for Ref.
27	M3	40-48	134-34	3400	1.17	1.43	1.30	F	1.79±0.10	2.33	Only for Ref.
28	M4	38-01	135-57	2550	1.21	1.56	1.39	F	1.75±0.10	2.44	Only for Ref.
June 5	M5	40-13	136-52	2525	0.80	?	0.80	F	1.70±0.10	1.40	
11	M6	40-59	137-24	3420	0.96	?	0.96	F	2.08±0.10	1.98	
12	M7	40-23	139-11	2670	1.18	?	1.18	F	1.95±0.10	2.02	
13	M8	39-29	137-59	2510	0.72	?	0.72	F	1.81±0.10	1.30	
Aug. 20	Makko- 1	37-21N	134-07E	2440	1.47	1.43	1.45	F	1.83±0.10	2.66	
21	Makko- 2	39-10	133-02	2720	1.17	1.18	1.18	F	1.57±0.05	1.84	
26	Saiko - 3	40-01	132-29	3330	?	1.36	1.36	F	1.65±0.15	2.24	
27	Saiko - 4	41-01	132-54	3470	1.29	1.36	1.33	F	1.59±0.10	2.13	
28	Saiko - 5	41-20	132-48	3600	1.21	?	1.21	F	1.56±0.15	1.89	
28	Makko- 3	41-34	133-35	3650	1.26	1.32	1.29	F	1.56	2.0	
29	Makko- 4	39-55	134-50	1450	1.07	1.11	1.09	F	1.65±0.05	1.80	
30	Makko- 5	38-58	135-25	3180	1.17	1.14	1.16	F	1.69±0.13	2.08	
30	Makko- 6	38-02	135-57	2740	1.33	1.36	1.35	F	1.65±0.08	1.80	
Sept. 2	Makko- 7	38-13	137-52	1970	1.21	1.28	1.25	F	1.80±0.09	2.25	
3	Makko- 8	39-13	137-25	2340	1.09	1.03	1.06	F	1.96±0.09	2.07	
4	Makko- 9	40-08	136-44	2650	1.50	1.43	1.47	F	1.78±0.15	2.62	
4	Makko-10	41-03	136-06	3450	1.24	1.25	1.25	F	1.56	2.0	
6	Makko-13	42-00	138-10	3670	1.40	1.25	1.33	F	1.88±0.15	2.51	
6	Makko-14	41-59	139-23	1480	1.43	1.39	1.41	F	1.92±0.15	2.70	
10	Makko-15	43-32	140-20	1700	1.10	1.20	1.15	F	1.62±0.03	1.87	
11	Makko-16	43-59	139-20	1710	1.22	1.22	1.22	F	1.80±0.15	2.19	
11	Makko-17	44-31	138-26	2430	1.14	1.11	1.13	F	1.72±0.15	1.94	
12	Makko-18	44-59	137-29	1630	1.31	1.36	1.34	F	1.73±0.05	2.32	
12	Makko-19	45-00	138-36	2150	0.47	0.43	0.45	P	1.80±0.06	0.8	Only for Ref.
12	Makko-20	45-02	139-37	855	0.86	1.00	0.93	F	1.92±0.25	1.92	
12	Makko-21	45-05	140-44	330	1.29	1.32	1.31	P	2.04±0.09	2.7	Only for Ref.



Circuit Diagram

Fig. 2. Circuit diagram of the improved sea bottom thermogradmeter.

with which the bridge thermistor resistance is adjusted. However this record was regarded as useful because the record from the 1.5 m thermistor separation was good. At station Saiko-5, the 1.0 m record was not obtained and the 1.5 m record was not valid. It had once gone off scale, although it returned in later, the time of recording not being long enough to make a reliable data reduction. So, it would be proper to regard this record as only for reference. At station Makko-3 and Makko-10, amounts of bottom sediment were not enough to determine the effective thermal conductivity, so that the thermal conductivities for these stations were assumed to be the same as that of station Saiko-5. The nature of the sediment core at station Saiko-5 (fine greenish silt) appeared to be the most similar to that at Stations Makko-3 and Makko-10. Makko-19 is a station of partial penetration. At Makko-21, the record indicated disturbances probably due to partial pull-outs caused by not paying out enough wire. Both values should be only for reference. Preliminary report on these cruises has already been made by Yasui and Watanabe.[6]

The 3rd cruise. *May-June, 1965.*

This cruise was a part of a project that intended to make a general

6) M. YASUI and T. WATANABE, *loc. cit.*, 1).

geophysical survey in the Yamato-bank and Kitayamato-bank area in the central to southern Japan Sea. Terrestrial heat flow was measured at 56 localities.

The cruise was made over three legs; the 1st leg was for the magnetic and topographic survey; the 2nd leg mainly for the heat flow measurement; and the 3rd leg for the heat flow and general hydrographic work.

The 2nd leg of the 3rd cruise.

As shown in Table 2, 47 measurements were made. Station intervals along the three tracks parallel to the axis of the banks were approximately 10 miles and for saving time core sampling for the thermal conductivity measurement was made at every 30 miles. Accordingly, the thermal conductivity at stations without coring was estimated by the interpolation of the measured values at the nearby stations. These values are shown in Table 2 without any description in the column of the expected error of the conductivity.

At stations 65-01 and 65-02, neither the 1.0 m record nor full penetration was attained. So, the records are regarded as "only for reference." On the other hand, the record is considered to be good for station 65-03 because the 1.0 m record is reliable.

Stations 65-35, 65-41 and 65-44 are only for reference because of partial penetration less than 1.0 m.

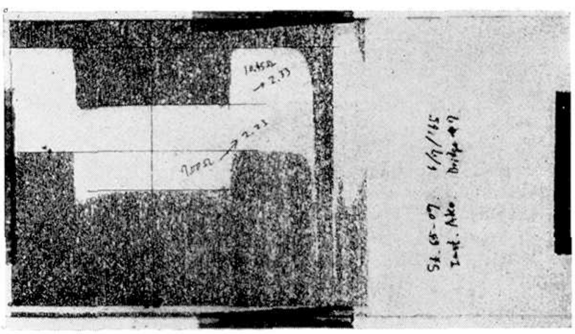


Fig. 3. Record at station 65-09. Thermal gradients are 2.33 and 2.23×10^{-3}°C/cm. Scale in 1/2.

At station 65-09, an extremely high heat flow value of 4.5×10^{-6} cal/cm^2 sec was obtained. The record at this station is shown in Fig. 3.

The 3rd leg of the 3rd cruise.

Nine stations were taken as shown in Table 2. Station 65-54 is only for reference because of a miscontact in the trimmer potentiometer and the partial penetration less than 1.0 m.

During the 3rd cruise extremely high heat flow values, such as 4.56, 3.02, 3.46, 3.06, 3.02 and 3.02, were observed at stations 65–08, 65–11, 65–14, 64–32, 65–34 and 65–35 respectively. It may be noted that such high values are observed only in the area of Yamato bank and Kitayamato bank. These high heat flow values show very localized distribution as will be shown in Fig. 5 later.

The 4th cruise.

Heat flow was measured at 44 localities in this cruise along with the ordinary routine hydrograghic work of the Maizuru Marine Observatory, the result of the measurements being shown in Table 3.

At stations 65–59 and 65–92, penetrations were less than 1.0 m, so the values are good only for reference. At station 65-70, the 1.5 m record was not obtained on account of a break of the connector of the thermistor bridge, but the record is useful since the 1.0 m record is good.

Since the instrument which has been used throughout these measurements recorded two thermal gradients at the two different intervals, the agreement of the two values could be taken as a kind of criterion of reliability. In the Japan Sea the authors made 133 measurements of thermal gradients and obtained 116 good values. Among these 116 values 100 records were perfect in the sense that both of the two thermal gradients were obtained. The agreement of these two values are good to within 2.5% for 28 stations, within 5% for 70 stations, within 10% for 95 stations and within 15% for all 100 stations.

As for the reproducibility, there are few but the following supporting pieces of evidence. At station 65–88, thermal gradient was recorded twice within a 30 minutes interval. The procedure was as follows; During the operation of the measurement the condition of the sea was so rough that the first bottom contact was not detectable, so after a lapse of the ordinary recording time, the second trial was made; the probe was brought up to about 200 m above the bottom and then brought down into the bottom again. During this operation, no sign of pull-out of the probe from the bottom was felt on the tension gauge. Moreover, the probe was straight when it came up on board. So, it is quite likely that both penetrations were made in an ideal condition. The agreement of these records is satisfactory as is clearly seen in Fig. 4.

Another example of the reproducibility was obtained at station 65–51 and station 65–60. These two stations were taken at the same location

Table 2. Data of the heat flow measurements in the Japan Sea during the 3rd cruise. Units and symbols are same as in Table 1.

Date	Station #	Position		Depth (m)	Thermal Gradient			Penetration	Thermal Conductivity	Heat Flow Value	Remarks
		Lat.	Long.		1.5 m	1.0 m	Mean				
May 31	65- 1	38-09N	134-24E	1070	1.0	?	1.0	P	1.87±0.10	1.87	Only for Ref.
31	2	38-13	134-35	2520	1.2	?	1.2	P	1.80	2.16	Only for Ref.
31	3	38-18	134-46	3050	?	1.13	1.13	F	1.73	1.95	
June 1	4	38-24	134-57	3060	1.29	1.31	1.30	F	1.66±0.08	2.16	
1	5	38-29	135-08	3060	1.27	1.31	1.29	F	1.64	2.12	
1	6	38-34	135-21	3060	1.25	1.18	1.22	F	1.62	1.98	
1	7	38-38	135-31	3080	1.29	1.28	1.29	F	1.59±0.08	2.05	
1	8	38-44	135-44	2900	1.18	1.05	1.12	F	1.80	2.02	
8	9	38-48	135-53	2510	2.33	2.23	2.28	F	2.00	4.56	
2	10	38-52	136-07	2340	1.12	0.95	1.04	F	2.20±0.10	2.29	
2	11	38-58	136-16	2760	1.43	1.37	1.40	F	2.16	3.02	
2	12	39-04	136-28	2680	1.14	1.09	1.11	F	2.12	2.35	
2	13	39-10	136-38	2640	1.20	1.13	1.17	F	2.08±0.13	2.44	
2	14	39-33	136-18	2470	2.07	2.06	2.07	F	1.67±0.07	3.46	
3	15	40-00	135-59	1430	0.89	0.78	0.84	F	1.93	1.62	
3	16	39-56	135-49	1260	1.17	1.14	1.16	F	1.99	2.31	
3	17	39-50	135-36	1055	0.80	0.75	0.78	F	2.06	1.61	
3	18	39-45	135-26	1050	0.99	0.91	0.95	F	2.12	2.01	
3	19	39-40	135-16	900	0.86	0.83	0.84	F	2.29±0.13	1.92	
3	20	39-35	135-05	845	0.83	0.83	0.83	F	2.46	2.04	
4	21	39-29	134-52	560	0.49	0.57	0.57	P	2.63±0.15	1.50	
4	22	39-25	134-42	730	0.73	0.73	0.73	F	2.36	1.72	
4	23	39-20	134-31	990	0.77	0.72	0.74	F	2.09	1.55	
4	24	39-15	134-18	1600	0.97	0.92	0.95	F	1.81±0.07	1.72	
4	25	39-10	134-07	1870	0.94	0.94	0.94	F	1.81	1.70	
4	26	39-05	133-57	1850	1.04	0.97	1.01	F	1.82	1.84	
4	27	39-00	133-48	1690	1.01	1.02	1.02	F	1.82±0.08	1.86	

(to be continued)

Table 2. (continued)

Date	Station #	Position		Depth (m)	Thermal Gradient			Penetration	Thermal Conductivity	Heat Flow Value	Remarks
		Lat.	Long.		1.5 m	1.0 m	Mean				
June 5	65-28	39-28E	133-28N	1440	1.06	0.96	1.01	F	2.01±0.15	2.03	
5	29	39-53	133-07	3320	1.27	1.26	1.27	F	1.74±0.08	2.21	
5	31	40-02	133-30	1770	0.81	0.86	0.84	F	1.99	1.67	
5	32	40-07	133-41	1720	1.24	1.45	1.45	P(1.4 m)	2.11	3.06	
5	33	40-12	133-52	1540	0.63	0.88	0.88	P(1.1 m)	2.08	1.82	
5	34	40-17	134-04	2020	1.24	1.48	1.48	P(1.2 m)	2.04	3.02	
6	35	40-21	134-12	2400	1.00	1.50	1.50	P(1.0 m)	2.01	3.02	
6	36	40-28	134-25	3000	1.22	1.19	1.21	F	1.97	2.38	
6	37	40-32	134-36	2950	1.19	1.15	1.17	F	1.93	2.26	
6	38	40-37	134-48	2900	1.19	1.18	1.19	F	1.89±0.10	2.25	
6	39	40-41	134-59	2990	1.15	1.19	1.17	F	1.86	2.18	
6	40	40-47	135-09	2920	1.13	1.10	1.12	F	1.82	2.04	
7	41	40-52	135-20	3025	1.00	1.07	1.07	P(1.4 m)	1.78	1.90	
7	42	39-51	136-05	1460	1.08	0.99	1.04	F	1.74	1.81	
7	43	39-43	136-12	1780	1.24	1.18	1.21	F	1.79	2.16	
7	44	39-35	136-18	1995	0.68	0.99	1.00	P	1.62	1.62	Only for Ref.
7	45	39-30	136-23	2685	1.25	1.24	1.25	F	1.70	2.13	
7	46	39-27	136-24	2685	1.14	1.16	1.15	F	1.78	2.05	
8	47	39-17	136-32	2685	1.20	1.16	1.88	F	1.96	2.31	
16	48	36-25	135-42	580	0.96	0.97	0.97	F	1.80±0.08	1.74	
16	49	36-49	135-21	1660	1.06	1.05	1.06	F	1.70±0.08	1.79	
16	50	37-14	135-04	1260	1.42	1.44	1.43	F	1.83±0.07	2.33	
16	51	37-37	134-47	2990	1.17	1.28	1.24	F	1.67±0.05	2.07	
17	52	38-36	134-02	1550	0.91	0.91	0.91	F	1.85±0.07	1.68	
18	53	40-16	132-43	3480	1.20	1.28	1.24	F	1.84±0.08	2.28	
19	54	40-43	132-24	3460	1.23	?	1.23	P	1.75±0.08	2.15	Only for Ref.
19	55	41-00	133-00	3520	1.17	1.15	1.16	F	1.72±0.07	2.00	
19	56	41-15	133-35	3580	1.26	1.28	1.27	F	1.60±0.08	2.03	

Table 3. Data of the heat flow measurements in the Japan Sea during the 4th cruise. Units and symbols are same as in Table 1.

Date	Station #	Position		Depth (m)	Thermal Gradient			Penetr-ation	Thermal Conductivity	Heat Flow Value	Remarks
		Lat.	Long.		1.5 m	1.0 m	Mean				
Aug. 13	65-57	36-46N	135-25E	1140	?	1.15	1.15	F	1.85±0.10	2.13	
13	58	36-54	135-19	1830	1.23	1.22	1.23	F	1.62±0.05	1.99	
14	59	37-21	134-55	1800	0.70	0.82	0.76	P	1.66±0.07	1.26	Only for Ref.
14	60	37-38	134-46	2990	1.22	1.20	1.21	F	1.67±0.07	2.02	
14	61	37-49	134-39	3020	1.25	1.21	1.23	F	1.80±0.07	2.21	
16	62	41-03	132-13	3450	1.23	1.23	1.23	F	1.68±0.05	2.07	
17	63	41-25	132-45	3470	1.12	1.12	1.12	F	1.67±0.07	1.87	
18	64	41-54	133-58	3590	1.20	1.21	1.21	F	1.75±0.07	2.12	
20	65	39-05	136-02	2620	1.06	1.01	1.04	F	1.75±0.08	1.82	
20	66	37-02	135-57	490	1.91	1.95	1.93	F	1.70±0.07	3.28	
27	67	39-06	138-26	1420	1.30	1.42	1.36	F	1.61±0.05	2.19	
28	68	39-32	138-01	2470	1.15	1.20	1.18	F	1.66±0.07	1.96	
28	69	39-58	137-42	2700	1.11	1.02	1.06	F	1.69±0.07	1.79	
28	70	40-05	137-39	2780	?	1.20	1.20	F	1.94±0.08	2.33	
29	71	40-15	137-28	2890	1.17	1.23	1.20	F	1.76±0.07	2.11	
29	72	40-23	137-29	2700	1.28	1.38	1.33	F	1.89±0.07	2.45	
29	73	40-33	137-12	2400	0.96	0.94	0.95	F	1.84±0.08	1.75	
29	74	40-42	137-12	3190	1.21	1.31	1.26	F	1.90±0.10	2.39	
30	75	40-51	137-01	3240	1.15	1.13	1.14	F	1.86±0.07	2.12	
30	76	40-59	136-51	3270	1.07	1.09	1.08	F	1.77±0.07	1.91	
30	77	41-11	136-47	3360	1.10	1.09	1.10	F	1.88±0.07	2.07	

Table 3. (continued)

Date	Station #	Position		Depth (m)	Thermal Gradient			Penetration	Thermal Conductivity	Heat Flow Value	Remarks
		Lat.	Long.		1.5 m	1.0 m	Mean				
Aug. 30	65-78	41-15N	136-39E	3390	1.15	1.19	1.17	F	1.75±0.07	2.05	
31	79	41-44	136-17	3560	1.28	1.19	1.24	F	2.05±0.15	2.53	
31	80	42-09	136-03	3650	1.33	1.38	1.36	F	1.82±0.07	2.48	
Sept. 1	82	42-58	135-25	3240	1.60	1.54	1.57	F	1.69±0.07	2.65	
2	85	43-03	136-44	3700	1.45	1.55	1.50	F	1.73±0.07	2.60	
3	86	43-00	137-09	3720	1.45	1.52	1.49	F	1.76±0.07	2.62	
3	87	43-02	137-42	3690	1.46	1.50	1.48	F	1.81±0.10	2.66	
3	88	42-59	138-05	3660	1.35	1.37	1.36	F	1.89±0.10	2.57	
4	89	43-01	138-34	3590	1.33	1.33	1.33	F	1.79±0.07	2.38	
4	90	43-04	138-58	3490	1.41	1.40	1.41	F	1.68±0.07	2.37	
4	91	43-05	139-50	2160	1.16	1.15	1.15	P	1.79±0.07	2.06	
9	92	44-28	140-02	650	0.75	0.85	0.85	P	1.67±0.07	1.42	Only for Ref.
9	93	44-32	139-44	1220	1.35	1.50	1.50	P(1.3 m)	1.65±0.07	2.48	
9	94	44-33	139-10	1100	0.97	1.00	0.99	F	2.05±0.10	2.03	
9	95	44-36	138-49	1220	1.12	1.12	1.12	F	2.35±0.15	2.63	
10	96	44-30	138-17	2460	1.51	1.51	1.51	F	1.84±0.07	2.78	
13	97	42-22	137-38	3700	1.58	1.60	1.59	F	1.81±0.07	2.88	
13	98	42-03	137-41	3720	1.50	1.52	1.51	F	1.78±0.07	2.69	
13	99	41-22	137-40	3720	1.27	1.31	1.29	F	1.69±0.07	2.18	
13	100	41-02	137-49	3700	1.23	1.37	1.37	P(1.3 m)	1.90	2.60	

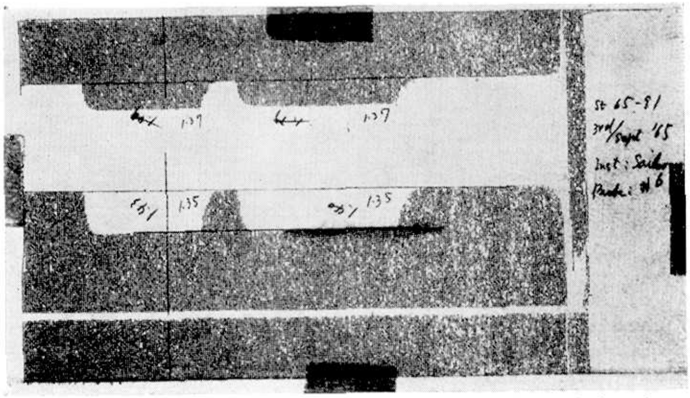


Fig. 4. Record at station 65-88. Average value of the thermal gradients is 1.36×10^{-3}°C/cm. Scale in 1/2.

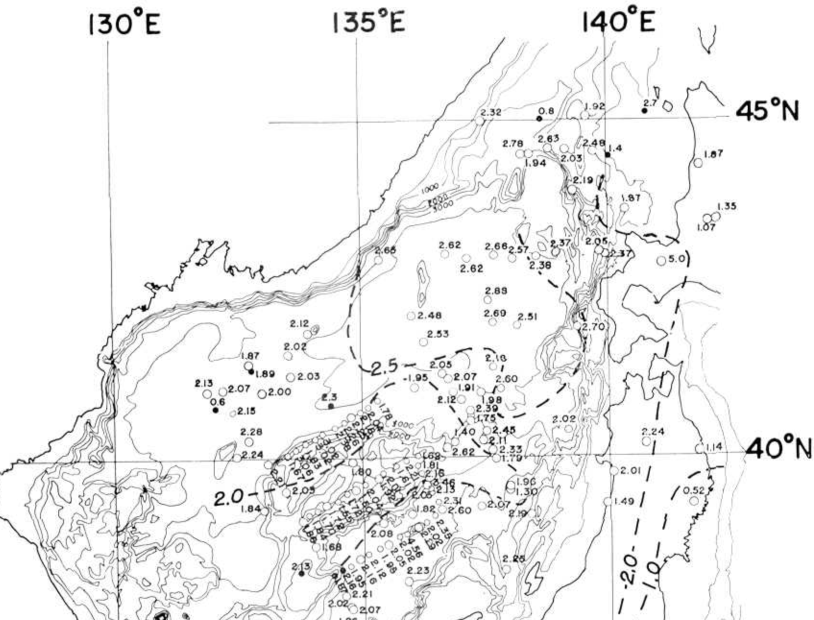


Fig. 5. Heat flow distribution and bottom topography in the Japan Sea. Contour map is drawn after Chart No. 6301, Hydrographic Office. Land values are drawn after Uyeda and Hôrai, 1965. Unit of heat flow is 10^{-6} cal/cm^2 sec.

within two months' interval. The identity of the ship's position was, of course, subject to the customary errors of navigation. The obtained heat-flow values are 2.02 and 2.07 in 10^{-6} cal/cm^2 sec respectively. It might be added that the instrument which was used for station 65-51 was lost after the measurement and a different instrument was used for station 65-60.

These two examples will strengthen the validity of the reproducibility of the measurement.

All the values of the measurements and bottom topography are shown in Fig. 5. Large open circles show the values with the best accuracy (error less than 10%) small open circles show good records without measurement (error less than 20%), small closed circles show stations which are good only for reference. Thick dotted lines are the roughly contoured equal heat flow lines and thin lines are the equal depth lines contoured at every 500 m.

Discussion

As is clearly seen in Fig. 5, the most characteristic feature of the heat flow in the Japan Sea area is its high values distributed almost all over the area. The average of all the 116 good values is $2.17 \pm 0.40 \times 10^{-6}$ cal/cm^2 sec. The histogram of these values, in Fig. 6, shows a highly condensed high heat flow distribution. Fig. 7 is the map of $1^\circ \times 1^\circ$ grid

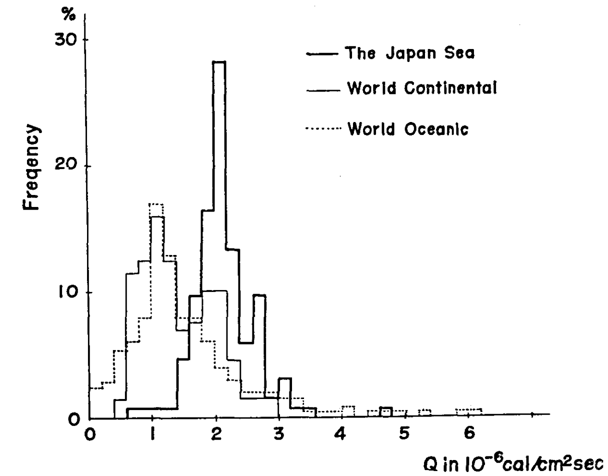


Fig. 6. Histogram of heat flow values in the Japan Sea. Compared world continental and oceanic histograms are drawn after Lee and Uyeda, 1965.

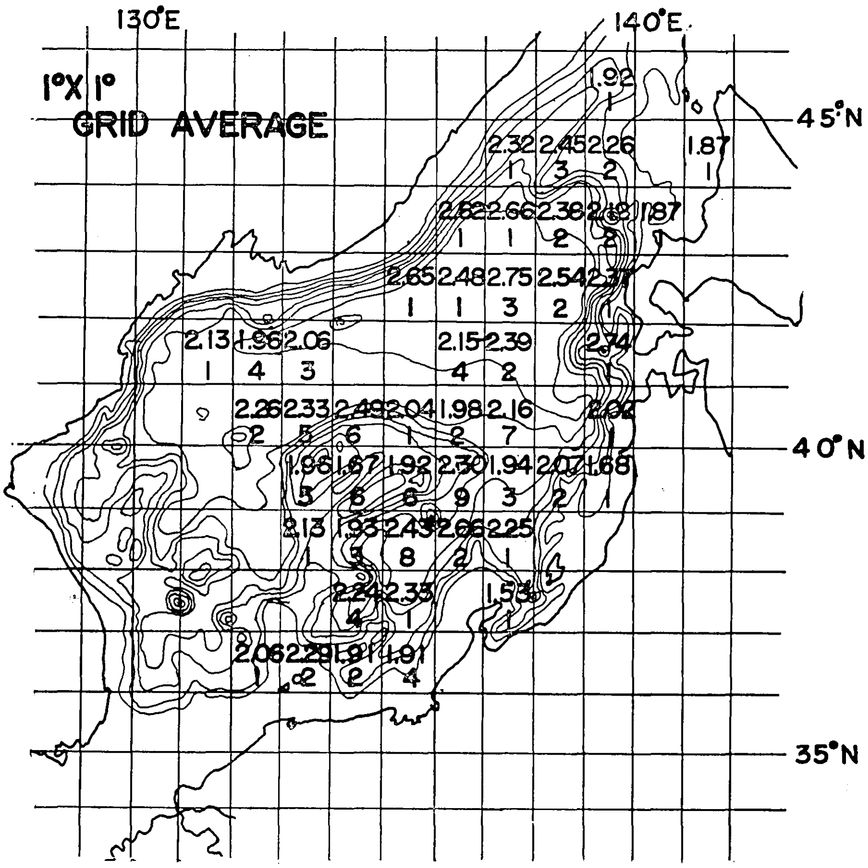


Fig. 7. Number and arithmetic mean value of heat flow data in 1°×1° grid.

averages of the heat flow values. The numbers written under the average heat-flow values are the number of stations in each grid. Thin lines show equal depth lines contoured in every 500 m. The mean of these grid averages is 2.24×10^{-6} cal/cm^2 sec.

The chart of the grid averages indicates another feature also: a weak positive correlation between heat flow values and the water depth. In the shallower part of the Japan Sea, Yamato bank and Kitayamato bank area, there exist rather depressed grid average values, 1.67, 1.96, 1.92 and so on. The extremely high values found occasionally in the bank area have been eliminated through averaging. As pointed out already, these extremely high values are localized. On the other hand, in the deeper part, almost all the grid average values are higher, say

2.65, 2.75, 2.54, 2.66 and so on. The average heat flow values in the area deeper than 3,500 m is 2.46, while in the area where the water depth is between 2,000 m and 3,500 m it is 2.22 and in the area shallower

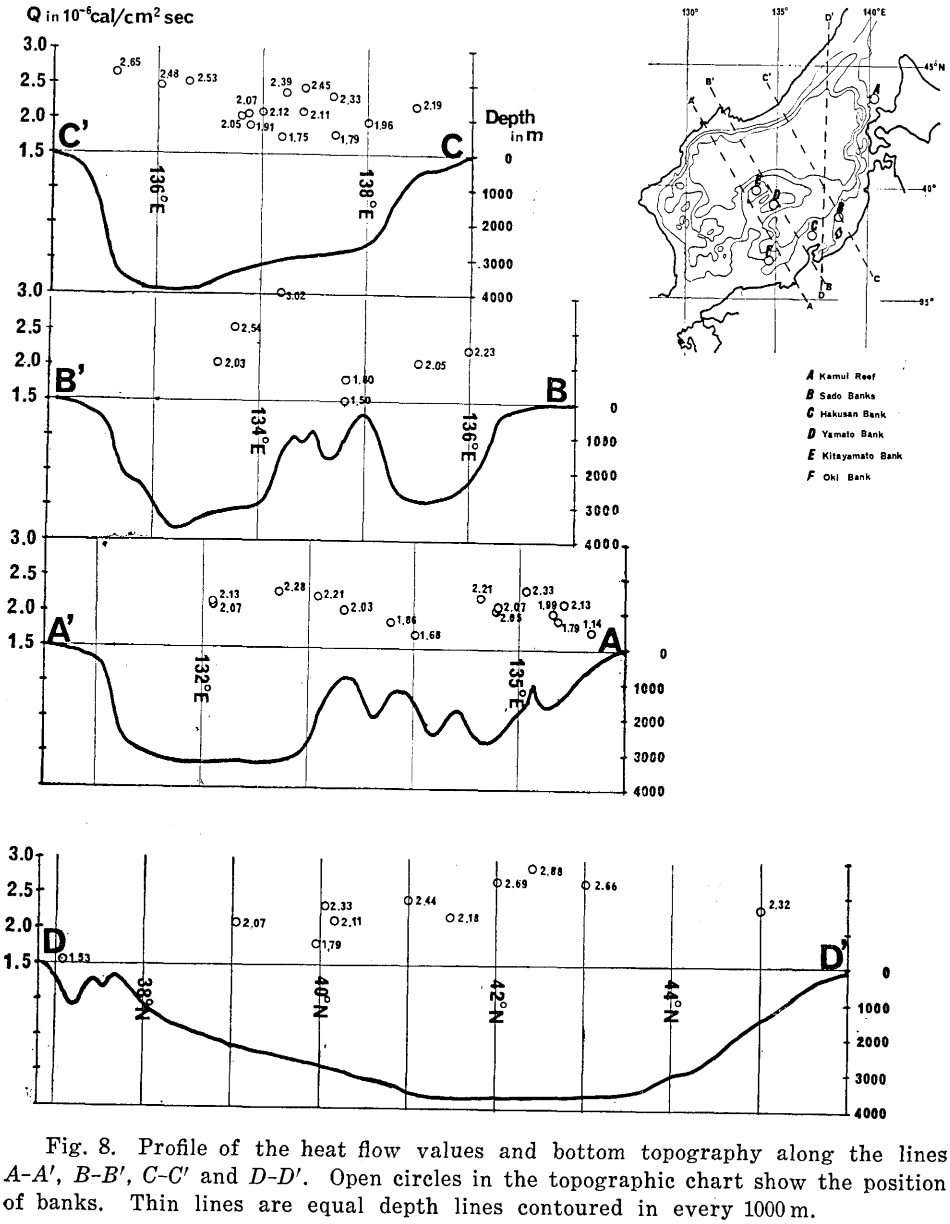


Fig. 8. Profile of the heat flow values and bottom topography along the lines *A-A'*, *B-B'*, *C-C'* and *D-D'*. Open circles in the topographic chart show the position of banks. Thin lines are equal depth lines contoured in every 1000 m.

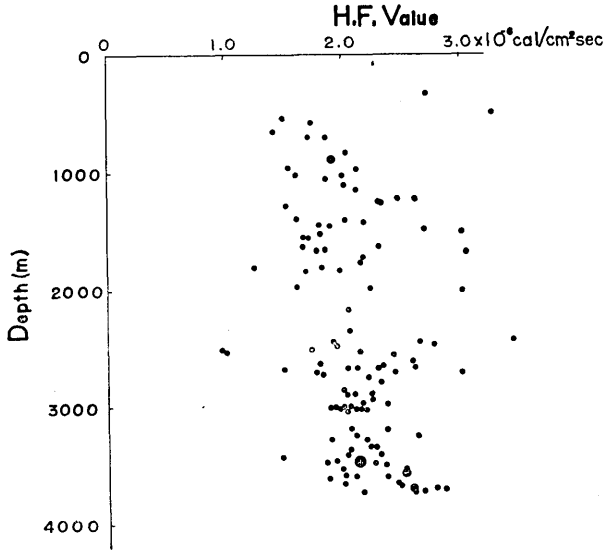


Fig. 9. Correlation between heat flow values and the water depth.

than 2,000 m it is 1.96×10^{-6} cal/cm^2 sec. The same trend is also shown in Fig. 8 and Fig. 9. Fig. 8 shows the profile of the heat-flow values and bottom topography along the lines, *A–A′*, *B–B′*, *C–C′* and *D–D′*. Fig. 9 shows the correlation between the heat flow values and the water depth.

There are some dredge haul stations taken on the banks in the Japan Sea and specimens of igneous rocks indicated some late Mesozoic volcanic activity in these areas as was described in the former paper (Yasui and Watanabe, 1965).[7] Especially in the Yamato bank and Oki bank areas a large amount of welded tuff accompanied by rhyolite shows that these areas were once land (Satô and Ono, 1963).[8]

These volcanic activities are supported by the heat-flow data. In Fig. 4, values higher than 3.0 are restricted within the area of Yamato bank and Kitayamato bank and they are highly localized. Both of the highest values of 4.56 and 3.46 are accompanied with no other extremely high values even though the authors made a rather detailed survey around the stations. On land, an area with such a high heat-flow value is generally a geothermal or volcanically active area.

On the contrary, the general pattern and the grid averages of these

7) M. YASUI and T. WATANABE, *loc. cit.*, 1).
8) T. SATÔ and K. ONO, *J. Geol. Soc. Japan*, **70** (1963), 434–445.

bank areas show that they have a rather depressed heat flow, while in the deeper part of the Japan Sea, the heat flow is higher. The bottom topography of the deeper basin is extremely flat and there appears no sign of volcanic activity.

According to the recent studies of explosion seismology in the Japan Sea, the crustal structure of the Japan Sea is continental in the bank area and oceanic in the deeper area (Murauchi et al., 1966).[9] Schematic profile of the crustal structure is shown in Fig. 10. According to the

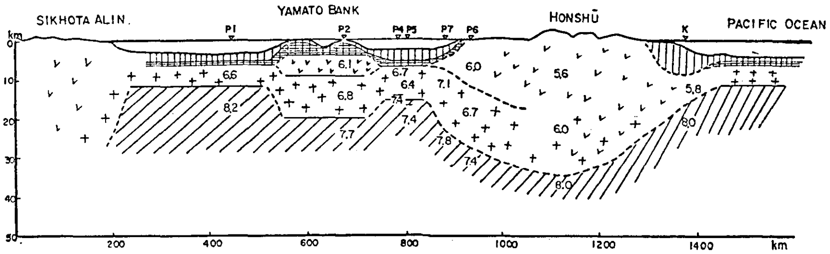


Fig. 10. Schematic profile of the crustal structure across Yamato bank, after Murauchi, 1966.

result of studies of radioactive heat sources contained in rocks, the continental crust would produce more heat than the oceanic crust, so that the observed heat flow should be higher in the bank area than in the deeper part, provided that the mantle is uniform. This simple idea has been found not to be the case on a worldwide basis, heat flow being found equal over the land and sea. Now, in the Japan Sea area the situation seems to be even more peculiar: i.e., the observed heat flow values are lower in the bank area, where they should be higher, and are higher in the deeper part, where they should be lower.

It may be said that the generally high heat flow values observed in the Japan Sea and their peculiar distribution are difficult to explain unless some special ad hoc hypothetical process is assumed underneath the crust of the Japan Sea area. Igneous activity hidden in the mantle may be one of the possible processes, but we would leave the discussion about the processes to another paper.

Acknowledgement

The authors wish to express their thanks to Professor T. Rikitake, under whose constant encouragement the present work has been done.

9) S. MURAUCHI, *Second Progress Report on the Upper Mantle Project of Japan*, (1966), 11-13.

They also thank the scientists and the crew of *R/V* Seifû-Maru of the Maizuru Marine Observatory for their kind cooperation throughout the survey work.

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72. 地球熱学 第18報 日本海における海洋底地殻熱流量 (2)

舞鶴海洋気象台 安井 正 / 岸井敏夫
東京大学大学院 渡部暉彦
地震研究所 上田誠也

1964年に着手された日本海の地殻熱流量観測は，1965年も引続き舞鶴海洋気象台観測船「清風丸」により行なわれ，測定点は，西部を除く日本海全域に渡り116点を数える．この結果，(1) 地殻熱流量値は測定海域の全域に渡り異常に高く，その平均値は $2.17\pm0.40\times10^{-6}$ cal/cm^2 sec，日本海を1°毎の網目に切つた1°×1°網による一種の荷重平均値は 2.24×10^{-6} cal/cm^2 に達する．(2) 水深と熱流量値の間に弱い正相関があり，北部深海域で熱流量値が高く，中央部大和，北大和堆周辺で熱流量値は低い．

地質学的にも熱学的にも火山活動の形跡の顕著な大和堆，北大和堆周辺で平均熱流量が低いことは，日本海の高熱流量は，日本列島日本海側のように表面に現われた火成活動と結びつけられうるものではなく，何らかの強制的に作られた温度場を考えねば説明し難いことを意味している．