Heat flow measurements around the Antarctica

Contribution of R/V Hakurei

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Abstract: Various kinds of geophysical data are steadily increasing around the Antarctic Continent. However, increase rate is not so high due to severe environmental conditions such as bad sea state. Especially, heat flow data are one of the most lacking geophysical parameters. Concerning heat flow measurements in the southern ocean, contribution of Japanese R/V Hakurei is substantial. During the past two decades, R/V Hakurei has made circum Antarctic research cruises. In this paper, we summarize R/V Hakurei's heat flow data and the general feature of heat flow distribution around the Antarctica.

Key words: Heat flow; Antarctica; thermal conductivity; R/V Hakurei.

Introduction. Heat flow measurements in the southern ocean around the Antarctic Continent are very few in comparison with those in other areas of the world. Heat flow measurements are hindered frequently by sea ice and ice bergs. Heat flow data on the continental shelf are really sparse because the areas are normally covered by sea ice throughout the year.

R/V Hakurei has been engaged with geophysical surveys such as bottom topography, gravity, magnetic and heat flow measurements during the past two decades (from 1980 to 1999) around the Antarctic Continent until her retirement in March, 2000. We consider that it is a good time to introduce her observational results, in particular her heat flow measurements. In the past, Hakurei's general preliminary results have been published routinely in the journal of National Institute of Polar Research.^{1),2)} Heat flow measurements around the Antarctica by R/V Hakurei have been reported only partly by the authors' group.³⁾⁻⁵⁾ In this paper, we summarize the whole heat flow data and the general feature of heat flow distribution around the Antarctica.

Heat flow data. R/V Hakurei's scientific survey was supported by the Ministry of International Trade and Industry (MITI) and performed by the Technology

Research Center, Japan National Oil Corporation (Tokyo, Japan). It started in the 1980-1981 Antarctic summer season. Fig. 1 shows the surveyed area of every year.

Research items were: 1) multi-channel reflection seismic survey, 2) refraction seismic survey together with ocean bottom seismometers, 3) gravity survey, 4) magnetic survey, 5) dredge sampling, 6) core sampling, and 7) heat flow measurements. Among these observations, only preliminary results have been reported on heat flow measurements because of frequent absence of specialists on board. Therefore, we re-analyzed both of the temperature gradient and thermal conductivity data. The temperature gradient was measured with the 5 to 8 meter-long probes attached to a gravity corer. The thermal conductivity was measured by a Quick Thermal Conductivity Meter (QTM) on board.⁶⁾

Table I summarizes the results of the heat flow measurements. The total numbers of reliable heat flow data are 78. Fig. 2 shows the heat flow values by the size of circles. Generally, the heat flow measured in a deep ocean, in accordance with the plate cooling theory, is proportional to $1/\sqrt{t}$, where t is the age of sea floor.^{7),8)} The obtained heat flow values in the southern ocean by R/V Hakurei, however, are about 10-30% higher than those expected (Fig. 3).

Consideration on the thermal conductivity measurements. In this paper, we introduce two different ideas to explain the systematically high apparent heat flow shown in Fig. 3.

One possible explanation is temperature decrease of

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Fig. 1. Survey area of each cruise around the Antarctica.

the bottom water around the Antarctica, which could have been caused by a recent enhanced inflow of water from melting glaciers/icesheet and icebergs. By a temperature decrease, the surface temperature of sea bottom sediment could have been lowered and the apparent temperature gradient in the topmost sediment layer would become higher to make the heat flow values appear higher than true stationary values. We need further investigation on this possibility because the geothermal gradient measurement in the southern seas may provide some useful information on the recent environmental changes.

The other possible explanation is the systematic error of the thermal conductivity measurement. As mentioned above, R/V Hakurei used a Quick Thermal Conductivity Meter (QTM). QTM adopt a transient line heat source placed on the surface of a core sample,

which is treated as an infinite half space medium. For practical reasons, the line source is placed parallel with the length of the core. Since the device measures the direction of thermal conductivity perpendicular to the line heat source, QTM measures the thermal conductivity in the horizontal direction. On the other hand, for marine heat flow study, the needle probe (NP) method is most frequently used for thermal conductivity measurement.⁹⁾ The NP method is also a transient heating method within an infinite space medium. However, NP is usually inserted perpendicular to the core tubes. Therefore, it measures the average thermal conductivity in the vertical and horizontal directions (Fig. 4). Recently, Tokai University scientists studied the heterogeneity of the thermal conductivity of sediment core samples. It was found that the horizontal thermal conductivity is systematically higher than the vertical one by

Fig. 2. Compilation of heat flow data around the Antarctica as of August, 2001, including the data of this study (hatched circles).

Fig. 3. Theoretical age-depth relation (solid line), which is generally supported by data from other oceanic areas, and R/V Hakurei's data. Systematic offset can be seen. Particularly large value of TH89 cruise measured around the Kergelen Plateau may be correlated with the re-heating process of the oceanic lithosphere at the time of plateau formation. The heat flow data on the continental shelves are not included.

Table I. Summary of heat flow measurements by R/V Hakurei. For latitude and longitude, minus sign means “S” and “W”, respectively. “Core” means the length of recovered sediment core

Cruise	Station	Longitude (degree)	Latitude (degree)	Depth (m)	Core (cm)	dt/dz (mK/m)	K (W/mK)	Heat flow (mW/m ²)
TH80	PC101	-97.99	-63.68	5010	808	72.0	0.76	54.8
	PC103	-97.97	-65.99	4786	416	42.7	1.34	56.9
	PC104	-80.97	-67.78	3980	224	80.0	0.99	78.7
	PC106	-71.87	-65.81	3355	174	65.5	1.13	73.6
	PC107	-81.55	-67.71	3937	354	83.2	0.98	81.6
	PC108	-84.67	-65.82	4525	626	55.6	1.01	56.1
	PC109	-104.51	-65.91	4859	490	67.0	0.89	59.8
TH81	PC201	-9.31	-62.56	5252	123	20.8	1.31	27.3
	PC203	-5.28	-69.41	1794	170	15.3	1.08	16.5
	PC204	-5.34	-69.56	1844	380	12.3	1.06	12.9
	PC208	-34.21	-69.90	4360	710	74.9	1.14	85.0
	PC209	-34.24	-69.89	4364	365	82.9	1.10	91.3
TH82	HF301	-176.72	-77.12	638	166	54.1	1.36	73.6
	HF302	-178.03	-77.11	597	100	84.9	1.43	121
	HF304	179.00	-77.11	692	75	96.6	1.22	117
	HF305	-179.96	-76.70	602	166	86.9	1.27	110
TH83	PC401	137.01	-62.83	3816	720	56.7	0.99	56.1
	PC402	127.88	-63.89	3667	775	41.7	1.03	43.0
	PC403	104.05	-60.89	4432	535	74.6	0.84	62.7
	PC404	105.15	-63.93	3536	784	97.5	0.87	84.9
	PC405	108.00	-62.63	3868	764	85.1	0.80	68.1
	PC406	127.84	-63.89	3671	786	71.9	1.00	71.9
	PC407	127.76	-64.82	2227	737	16.8	0.97	16.3
TH84	PC502	75.01	-64.21	3538	361	59.1	0.96	56.7
	PC503	78.99	-65.83	3119	351	58.8	0.96	56.4
	PC505	69.87	-65.86	2481	695	43.1	1.05	45.3
	HF501	73.00	-67.50	591	96	81.3	1.15	93.5
	PC507	75.12	-62.81	3805	775	52.2	1.00	52.2
TH85	PC601	40.01	-60.93	5281	780	60.1	0.88	52.9
	PC603	43.13	-66.00	3157	643	53.9	0.85	45.8
	HF601	40.02	-65.73	4640	732	59.1	0.81	47.9
	PC605	24.04	-67.41	4418	669	75.2	0.90	67.7
	PC606	27.55	-66.09	4791	773	51.0	0.84	42.8
TH88	GC901	-58.99	-62.74	1455	298	205	0.84	172
	GC902	-55.09	-61.70	2173	233	127	0.84	107
	GC903	-61.30	-60.53	3639	239	106	1.05	111
	GC904	-59.69	-61.76	1687	239	69.8	0.92	64.2
	GC905	-63.69	-64.42	510	209	137	0.97	133
	GC906	-57.92	-62.28	1940	239	484	0.86	416
	GC907	-58.44	-62.64	1623	239	170	0.83	141
	GC908	-61.58	-63.40	1099	214	152	0.89	135
TH89	GC1001	80.31	-60.99	2363	167	134	0.91	122
	GC1002	78.89	-63.80	3658	396	56.3	1.14	64.2
	GC1003	81.05	-63.12	3327	553	56.5	1.10	67.1
	GC1004	74.99	-68.86	721	300	121	0.92	111
	GC1006	72.50	-68.24	805	210	83.4	0.98	81.7
TH92	GC1301	145.01	-64.82	3341	514	55.7	1.00	55.7
	GC1303	-161.18	-77.44	672	255	52.2	1.98	103
	GC1305	-169.77	-77.43	570	216	66.1	1.47	97.2
TH93	GC1401	136.56	-62.66	3990	475	48.8	0.95	46.4
	GC1405	133.28	-65.05	575	229	70.2	1.25	87.8
	GC1407	130.51	-63.74	3687	535	70.2	1.00	70.2
	GC1408	130.49	-64.32	2220	379	67.6	1.21	81.8
	GC1409	130.49	-64.58	1318	530	57.6	0.99	57.0
TH94	GC1501	112.33	-63.72	3060	540	55.3	0.96	53.1
	GC1503	115.99	-63.29	3368	524	49.6	0.99	49.1
	GC1504	116.00	-63.32	3310	523	48.0	1.01	48.5
	GC1505	103.50	-63.53	3607	371	77.6	0.91	70.6
	GC1507	110.03	-64.58	2604	453	43.1	1.01	43.5
	GC1508	118.43	-63.99	3232	532	56.6	0.96	54.3
	GC1509	118.28	-63.99	3198	539	51.1	0.96	49.1
TH95	GC1604	168.00	-74.54	922	254	118	1.21	143
	GC1605	167.57	-76.00	595	107	106	1.27	135
	GC1606	166.87	-76.77	751	296	109	1.07	117
TH96	GC1702	-65.19	-64.37	522	316	82.6	0.95	78.5
	GC1703	-65.65	-63.87	451	159	76.4	1.40	107
	GC1707	-57.84	-62.56	1564	350	163	0.83	135
TH97	GC1801	-38.90	-59.69	2130	296	98.8	1.04	103
	GC1802	-49.86	-59.00	3838	312	141	1.14	161
	GC1804	-50.26	-61.74	3269	403	141	1.18	64.0
	GC1805	-52.00	-62.00	2834	299	69.8	1.17	81.7
	GC1806	-55.50	-60.18	3531	474	88.7	1.14	101
TH99	GC2001	67.59	-62.45	4277	600	50.9	0.80	40.7
	GC2002	64.81	-59.85	4642	300	89.3	0.76	67.9
	GC2003	74.24	-62.07	3959	565	50.4	0.92	46.4
	GC2005	64.31	-63.75	4124	600	48.6	1.11	53.9
	GC2006	73.12	-66.00	2565	580	54.7	1.20	65.6
	GC2009	75.12	-65.14	3122	620	59.6	1.12	66.8

Fig. 4. Schematic diagram of the thermal conductivity measurements.

a few to 10% (Dr. Masataka Kinoshita, private communication). Considering the layered structures of sediments, this result appears quite reasonable.

In fact, it has been sometimes pointed out that the thermal conductivity measured by the QTM shows 5 to 10% higher values in comparison with the NP method.^(6),10) The problem of higher than expected values of R/V Hakurei heat flow may be solved at least partly by this directional effect. We would like to pay more attention to this effect also in future.

Future direction. This paper presents 78 new heat flow data measured by R/V Hakurei in the past 20 years. One of the most unknown factors, especially around the Antarctic Continent, is the water temperature change at sea bottom. In autumn, sea surface begins to be covered by ice. It means cold high-saline water descends to the sea bottom and causes annual sea bottom water temperature change even in deep-sea area. Sometimes, temperature gradient data have been seriously affected by some non-steady bottom temperature. We would like to monitor long-term temperature variation in future to remove their effects on heat flow as much as possible. On the other hand, the analysis of the disturbed geothermal field would greatly help the environmental research of the Antarctica.

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