短　報

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Preliminary Report on Heat Flow in the Central Part of Kagoshima Bay, Kyushu, Japan

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Abstract

Heat flow measurement was carried out under shallow seas in the central part of Kagoshima Bay by using a submersible thermopile heat flux transducer. Heat flow values higher than 1,200 mWm^{-2} along the structural depression with NNW–SSE trend in the center of the bay were obtained. The results indicate the presence of a large heat source and fractures for hydrothermal circulation in the igneous rocks which underlie the thick sediments of the bottom of the central part of Kagoshima Bay.

1. Introduction

Attempts have been made to measure the heat flow of the earth's crust under shallow water (SCLATER *et al.*, 1970; NOMURA, 1970). There is a difficulty to evaluate several kinds of disturbance which affects the temperatures in the uppermost part of sea bottom sediments. In regions of late Cenozoic or present volcanic activity, we usually find heat flow by one or two order-of-magnitude higher than normal areas of the earth. One of the examples of high heat flow under shallow water is that reported by MORGAN *et al.* (1977) who measured at the bottom of Yellowstone Lake. In such a case, a small thermal disturbance caused by an annual variation of water temperature at the bottom may have little effects on heat flow values. It is reported by EHARA and YUHARA (1977) that a high heat flow (up to 5,000 mWm^{-2}) is observed in the central deep area (about 200 m) of Aira Caldera, which composes the northern part of Kagoshima Bay. The heat flow apparatus used by Ehara and Yuhara was a submersible thermopile heat flux transducer with a known thermal conductivity. In this paper, some additional data of anomalously high heat flow measured with the same type of transducer at the bottom in the central part of Kagoshima Bay are presented.

2. Measurement

For this heat flow survey, we hired a harbor tug of 200 ton 'Kinko Maru' for 8 days. Our initial concern was to calibrate heat flow values of our submersible thermopile transducer in an actual shallow sea environment with a modified thermogradmeter which has long been used for deep sea bottom measurement by the Earthquake Research Institute group. In order to know the thermal conductivity of sediments, samples of sediments were collected at 4 sites by using a gravity corer which was dropped from the sea surface for full penetration. But we could get no sandy bottom materials. Hence, the thermal conductivity values reported below may have a sampling bias and only represent mud

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Table 1. Heat flow in Kagoshima Bay measured with a submersible thermopile transducer.

Station No.	Position		Depth (m)	Heat flow	
	Lat. (N)	Long. (E)		(mWm^{-2})	(HFU)
K1	31°30′	130°40′	80	>1200*	>29
K2	31 28	130 40	100	>1200*	>29
K2W	31 28	130 38	210	>1200*	>29
K3	31 26	130 40	225	130	3
K3W	31 26	130 38	230	>1200*	>29
K4	31 24	130 40	160	>1200*	>29
K5	31 22	130 40	210	>1200*	>29
K6	31 20	130 40	200	>1200*	>29
K7	31 22	130 36	170	550	13
K8	31 22	130 38	220	710	17
K9	31 22	130 42	190	71	1.7
K10	31 22	130 44	170	>1200*	>29
2**	31 11.2	130 42.1	100	80	1.9
3**	31 35.6	130 44.7	170	76	1.8
4**	31 39.5	130 46.3	205	>1200*	>29
5**	31 38.7	130 41.4	154	27	6.5

* higher than 1,200 mWm^{-2} (29 HFU) but the accurate values are not obtained due to short recording time.
** reported by EHARA and YUHARA (1977).

thermal conductivity. Data of heat flow was obtained using a disk-shaped submersible thermopile transducer which have a diameter of 43.2 cm and thickness of 8.9 cm produced by Thermonetics Co.. The output voltage of the transducer was fed to a strip chart recorder on board through a cable. The sensitivity is as high as 67 mWm^{-2}/mV (1.5 HFU/mV). The values of thermal conductivity, specific heat, and density of the plastic core of the transducer are 0.26 $Wm^{-1}K^{-1}$ (0.62×10^{-3} cal $cm^{-1}sec^{-1} deg^{-1}$), 1.47 $Jg^{-1}K^{-1}$ (0.35 cal $g^{-1}deg^{-1}$), and 1.44 g cm^{-3}, respectively. A study of data reduction of the transducer output is now in progress and will be discussed in a separate paper. Table 1. summarizes heat flow values preliminarily estimated for 12 stations in this work (shown in Fig. 1) and 4 stations by EHARA and YUHARA (1977). The mean value of thermal conductivity of sediments determined by a needle probe method (VON HERZEN and MAXWELL, 1959) is 0.766 $Wm^{-1}K^{-1}$ (1.83×10^{-3} cal $cm^{-1}sec^{-1}deg^{-1}$) for samples of stations K2W, K3, K5, and K7. Using a thermistor thermometer, the bottom water temperature at the station K3W was found to be normal (14.9°C) which indicates broad dissipation rather than localized discharge of hot water into the sea water at the interface between sediments and water where we observed high heat flow in this survey.

3. Discussion

Results of heat flow measurements in this work together with those by EHARA and YUHARA (1977) are shown in Fig. 2. We suspect if hydrothermal convective heat transport through some fracture or fissure in the igneous basement is responsible for anomalously high heat flows which exceed 500 mWm^{-2}. Although the number of stations is not enough to discuss the wavelength and mode of such a convection, there seems to be a good correlation of heat flow with topography (Fig. 1) and the sub-

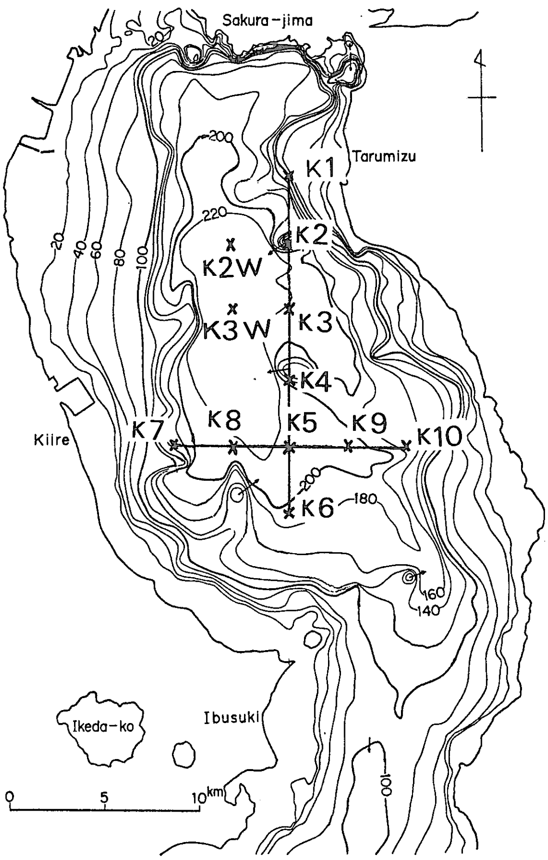

Fig. 1 Map showing the stations of heat flow measurement in this survey superimposed on a topographic chart.

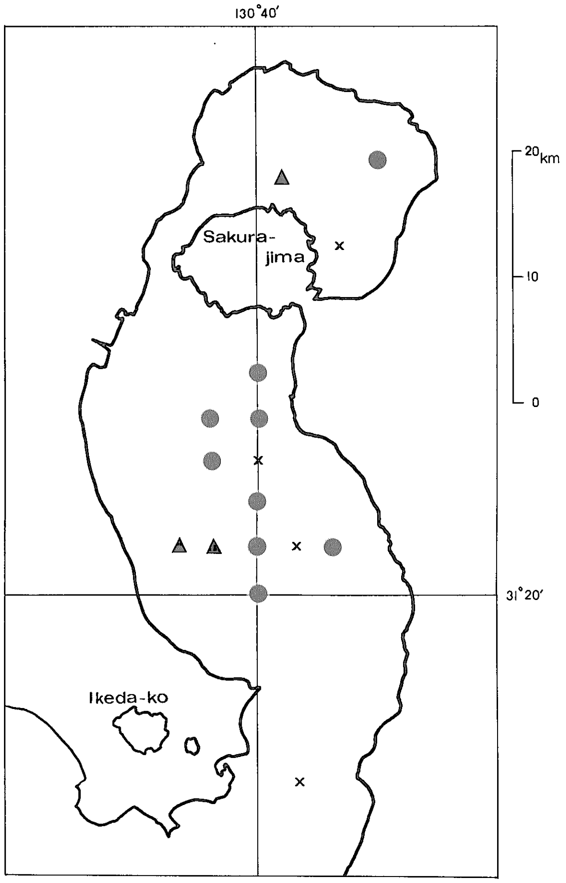

Fig. 2 Results of heat flow in Kagoshima Bay. Solid circles denote heat flow higher than 1,200 mWm^{-2}, crosses indicate that lower than 200 mWm^{-2}, and triangles between 200 and 1,200 mWm^{-2}.

bottom structure (CHUJO and MURAKAMI, 1976): a high heat flow belt extends along the central depression which have a NNW–SSE trend and thick sedimentary cover in most part to the south of Sakurajima. From the data of aeromagnetic and shipborn surveys (MATSUZAKI and UTASHIRO, 1966; YOSHIKAWA *et al.*, 1973), the western half of the central part of Kagoshima Bay is interpreted to have very thick non-magnetic uniform sedimentary rocks and the eastern half to have small sheetlike intrusives or andesitic rocks (burial depth$\lesssim$500 m) interbedded in the former. According to ONO *et al.* (1978), a pyroclastic flow which was formed on land and subsided later to underlie marine formations has a K–Ar age of 2.8 m.y. and this event may mark the beginning of the submergence of Kagoshima Bay resulting in a large volcanotectonic depression. This is another supporting evidence for a large heat source in the central part of the bay where we observed high heat flow. If this depression was situated on land, hot springs would be aligned in the structural trend like Taupo Volcanic depression in New Zealand (HEALY, 1964). It is also interesting to compare the high heat flow area found in this work with the deep sea tectonic depression having high heat flow in Okinawa Trough (HERMAN *et al.*, 1978). The mechanisms which gave rise to anomalously high heat flows of Kagoshima Bay and

Okinawa Trough may have been similar, although Kagoshima Bay has an active volcano, Sakurajima, situated to the northern end of the Ryukyu Arc whereas the high heat flow area in Okinawa Trough is located at the back of the southwestern end of the arc. Occurrence of both depressions with high heat flow might be related to the underthrusting movement of the Philippine Sea Plate during late Tertiary to Quaternary time. A more detailed survey of heat flow in Kagoshima Bay is expected to reveal the nature of hydrothermal circulation systems in submarine depressions formed by extensional tectonics associated with island arcs. As pointed out by ANDERSON (1978), heat transport by water movement through permeable crustal rocks should be investigated to understand the problems of marine heat flow in the world.

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References

ANDERSON, R. N. (1978) Oceanic heat flow. *The Sea*, vol. 7 (in press).

CHUJO, J. and MURAKAMI, F. (1976) The geophysical preliminary surveys of Kagoshima Bay. *Bull. Geol. Surv. Japan*, vol. 27, p. 807–826 (in Japanese with English abstract).

EHARA, S. and YUHARA, K. (1977) Heat flow in Kagoshima Bay (abstract). *Bull. Volcanol. Soc. Japan*, vol. 22, p. 284–285 (in Japanese).

HEALY, J. (1964) Volcanic mechanisms in the Taupo Volcanic zone, New Zealand. *New Zealand Jour. Geol. Geophys.*, vol. 7, p. 6–23.

HERMAN, B. M., ANDERSON, R. N. and TRUCHAN, M. (1978) Extensional tectonics in the Okinawa Trough. *Am. Assoc. Petroleum Geologists Memoir* (in press).

MATSUZAKI, T. and UTASHIRO, T. (1966) On the aeromagnetic surveys in the Kagoshima Bay and its vicinity. *Rep. Hydrographic Res.*, vol. 1, p. 23–26 (in Japanese with English abstract).

MORGAN, P., BLACKWELL, D. D., SHAFFORD, R. E. and SMITH, R. B. (1977) Heat flow measurements in Yellowstone Lake and the thermal structure of the Yellowstone Caldera. *Jour. Geophys. Res.*, vol. 82, p. 3719–3732.

NOMURA, K. (1970) Measurement of heat flow in shallow seas. M. Sci. Thesis, Univ. Tokyo (MS.).

ONO, K., ITO, K., HASEGAWA, I., ICHIKAWA, K., IIZUKA, S., KAKUTA, T. and SUZUKI, H. (1978) Explosion seismic studies in south Kyushu especially around the Sakurajima volcano (abstract). International Geodynamic Conference, Tokyo, March 12–17, 1978, p. 122–123.

SCLATER, J. G., VACQUIER, V. and RHORHIRSH, J. H. (1970) Terrestrial heat flow measurements on Lake Titicaca. *Earth Planet. Sci. Letts.*, vol. 8, p. 45–54.

VON HERZEN, R. P. and MAXWELL, A. E. (1959) The measurement of thermal conductivity of deep-sea sediments by a needle probe method. *Jour. Geophys. Res.*, vol. 64, p. 1557–1563.

YOSHIKAWA, K., YUWAKI, Y. and SUMITOMO, N. (1973) Offshore geomagnetic survey in Kagoshima Bay. *Bull. Disaster Prevention Ints., Kyoto University*, no. 16–A, p. 3–8 (in Japanese with English abstract).

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鹿児島湾中部の熱流量(序報)

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要 旨

鹿児島湾中部の海底熱流量を熱流板測定器を用いて測定した. 海底地形・重力異常などから推定されるNNW-SSE方向性の火山構造性陥没の中央部において1200mWm^{-2}を超える高熱流量が観測された. この結果から, 鹿児島湾中部の地下に熱源が存在し, 海底面までの熱輸送を担う熱水対流系が生成していることが示唆される.

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