It follows that in the period range from 60 sec to 200 sec there exists oblique incidence of natural magnetic waves, the angle of incidence approaches the magnetic inclination in the given region. Consequently, the direction in which the electromagnetic energy propagates in a given region approximately coincides with the direction of the lines of force of the stationary geomagnetic field.

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HEAT FLUX MEASUREMENTS NEAR THE KURILE ISLAND CHAIN, IN KAMCHATKA, AND THE KURILE LAKE[1]

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In July 1968, the heat flux was measured at twenty-four stations in the Sea of Okhotsk, near the Paramushir, Iturup, and Atlasov islands (see Fig. 1). In April-May, 1970, the heat flux was measured through the ice on the Kurile Lake and in boreholes in Kamchatka. The measurements were made with PTG thermal gradient recorders described by Lyubimova [1].

The gradient was calculated from

$$\Delta T = \Delta s_1 \Delta R_1 / (\Delta s_2 \beta l),$$

where β is the temperature coefficient of the thermistor (ohm/°C); Δs_1 is the amplitude of the actual recording (mm); Δs_2 is the amplitude (mm) of the calibration trace; and ΔR_1 is the change in the resistance (ohm) of the calibrating instrument causing the amplitude Δs_2.

The thermal conductivity was determined with the coaxial cylinder technique [2] in a setup assembled by O. Krayev.

One of the PTG modifications, in which the information is transmitted via a cable to the surface and fed to a frequency meter, was used in the work on the Kurile Lake. Depending on the temperature gradient, the frequency of the input signal varied. Knowing the calibration of the frequency meter, one can easily determine the unknown value ΔT. The base was 1.4 m in this PTG modification.

On the Western Kamchatka Peninsula, the heat flux measurements in boreholes were made in the regions of Icha and Tvayan to depths of 500 and 600 m, using thermistors. Other measurements were made in undisturbed Paratunka wells on the eastern coast of Kamchatka, where the wells had been out of exploitation for more than 3 months. Figure 1 and Table 1 show the measurement points and their geothermal parameters. In the Icha area, the geothermal gradient amounts to 4.3°C/100 m in the 200 to 500 m depth range; in the Tvayan area, this gradient is about 3.87°C/100 m in the depth range of 200 to 600 m. In the GK-11 well in the Paratunka area, the gradient varies strongly with depth and is 3.12°C/100 m between 540 to 860 m and 1.75°C/100 m between 860 to 1060 m. The Icha formation consists of mudstone and siltstone with partings of sandstone of low thermal conductivity ($3.1 \cdot 10^{-3}$ cal/(cm·sec·degree)).

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[1] Translated from: Izmereniya teplovogo potoka vblizi Kuril'skoy ostrovnoy dugi, na Kamchatke i Kuril'skom ozere. Doklady Akademii Nauk SSSR, 1972, Vol. 207, No. 4, pp. 842-845.

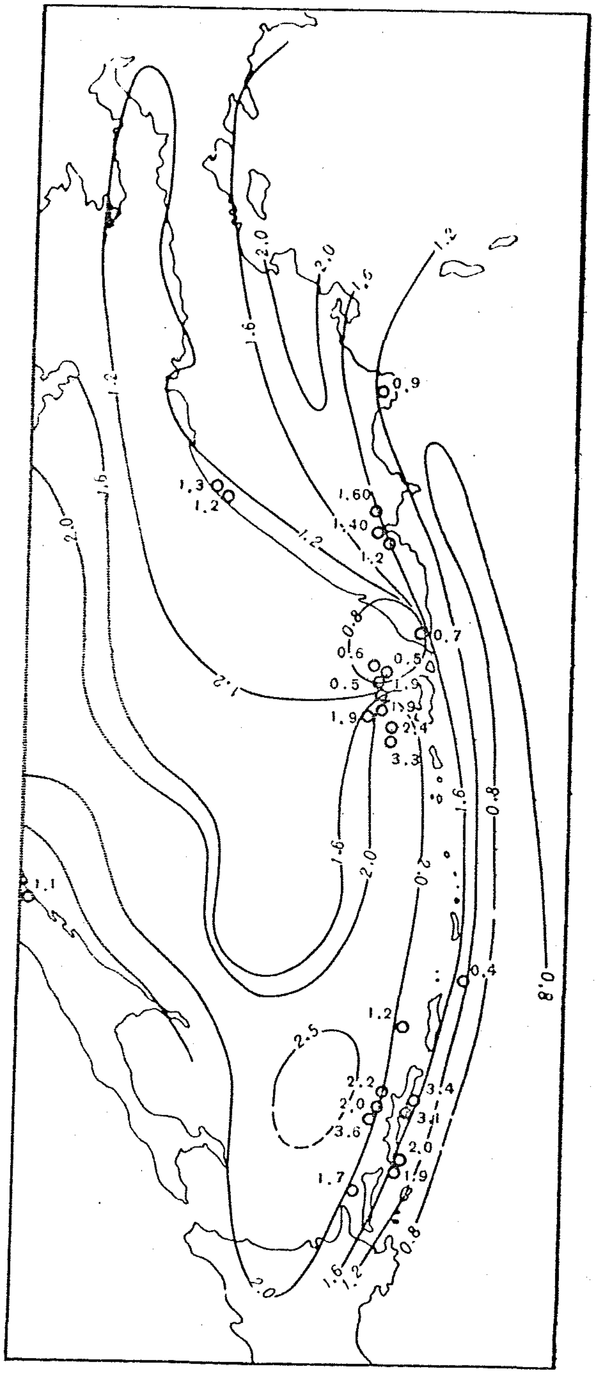

Fig. 1. Map indicating the points of heat flux measurements in the Kurile-Kamchatka area. The values 0.9, 1.6 and 1.4 in eastern Kamchatka are the results of [2]. The lines of equal flux were drawn using data from the literature [6,7, 11,13].

Table 1

Geothermal data on the Kurile-Kamchatka region

Station number	Depth, m	Coordinates		$\gamma\cdot10^3$ (degree/cm)	$\lambda\cdot10^3$ cal/(cm·sec·degree)	$q\cdot10^6$ cal/(cm^2·sec)
		N	E			
1	700	51°05′	155°51′	0.39	1.6	0.6
2	680	51°14′	155°55′	0.33	1.6	0.5
3	580	51°26′	156°08′	0.29	1.8	0.5
4	1000	50°53′	155°12′	1.0	1.9	1.9
5	1100	50°42′	154°58′	1.12	1.7	1.9
6	1100	50°44′	155°06′	1.05	—	1.9
7	720	50°31′	155°21′	1.08	2.2	2.4
8	1000	50°36′	155°11′	1.05	1.8	1.9
9	1500	50°03′	154°38′	1.5	2.3	3.3
10	1200	45°15′	147°38′	1.35	1.6	2.2
11	1400	45°07′	147°21′	0.90	2.2	2.0
12	1350	45°02′	147°14′	1.6	2.3	3.6
13	~2000	43°13′	146°43′	0.87	2.2	1.9
14	~2000	43°13′	146°43′	0.97	2.1	2.0
15	~2000	45°36′	151°32′	0.12	3.4	0.4
16	2000	45°48′	149°15′	0.33	3.6	1.2
17	1000	44°28′	145°34′	0.00	1.7	1.7
18	1900	45°02′	147°45′	0.19	1.7	3.1
19	700	45°01′	147°49′	0.24	1.7	3.4
20	500	55°38′	156°05′	0.43	3.1	1.3
21	600	55°30′	156°10′	0.39	3.1	1.2
22	1000	53°00′	158°15′	0.18	6.6	1.2
23	202	51°26′	157°30′	0.43	1.7	0.7
24	276	51°26′	157°06′	0.25	2.7	0.7

The Paratunka formation consists of basaltic tuff and basalt of average thermal conductivity [(4.8 to 6.6)·10^{-3} cal/(cm·sec·degree)]. The following values for the heat flux, in cal/(cm^2·sec), were obtained: Icha, borehole No. 3: $q = 1.3\cdot10^{-6}$; Tvayan, borehole No. 1: $q = 1.2\cdot10^{-6}$; Paratunka, borehole GK-11: $q = 1.2\cdot10^{-6}$.

In the Paratunka area, the measurements were made in a borehole situated on a flank of a hydrothermal system at depths of over 600 m, which greatly exceed the depth of the gradient-free zone found in other boreholes in the Paratunka area. The heat flux there proved slightly lower than the values of 1.50, 1.25, and 1.54·10^{-6} cal/(cm^2·sec) previously obtained [2] in three other boreholes (to depths of 500 m) of the Paratunka area and in three boreholes of the Koryak-Avacha basin, where the heat flux was 1.47, 1.51, and 1.6·10^{-6} cal/(cm^2·sec).

Low heat flux values of 0.79 and 1.05·10^{-6} cal/(cm^2·sec) [2] were observed in two rather deep boreholes (1000 m) on the Kronoki Peninsula. Western Kamchatka, which tectonically differs from eastern Kamchatka, exhibits moderate to low heat fluxes, as indicated by our data for the Icha area.

The paradoxical geothermal characteristics of Kamchatka are emphasized by very low concentrations of radioactive elements such as uranium, thorium, and potassium in the volcanic rocks, concentrations lower than the clarkes as already mentioned by Leonova and Udal'tsova [3,14], as well as Duchkov [4], who estimated the contribution of dispersed radioactive elements to the heat flux. In Kamchatka, the heat evolved by dispersed radioactive elements contributes about 30 percent of the total flux, which is half the contribution made on the continent in, e.g., the Altay-Sayan' region. In collaboration with I. G. Berzina, we used fission-product radiography to estimate the concentration of uranium in 10 samples of ultramafic Kamchatka rocks (collection of Yu. M. Puzankov). We found that the average concentration of uranium in these rocks (primarily meymechite) is 1500 ppb, which means very low heat liberation in the crust and the underlying mantle.

Our investigations of the heat flux in the Kurile Lake in the southernmost end of Kamchatka supplement the pattern outlined above. Measurements of the flux at the bottom of the lake were made at two points about 300 m deep during April-May, the quietest season in lakes

Table 2

Station 1, depth 292 m			Station 2, depth 276 m		
Zero level	Reading	Gradient	Zero level	Reading	Gradient
6.0	22.0	16.0	14.0	22.0	8.0
5.0	18.0	13.0	12.5	20.0	8.0
4.0	18.0	14.0	12.0	20.0	8.0
Average: Scale divisions		13.5	Average: Scale divisions		8.0
°C/cm		0.43	°C/cm		0.25

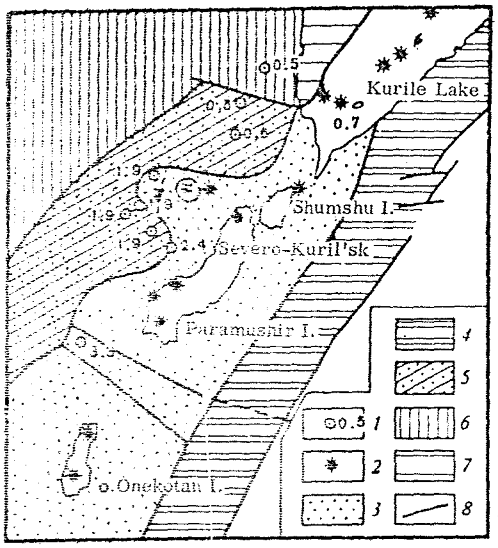

Fig. 2. Comparison of the measured heat fluxes with the tectonics [5] of the northern Kurile arc: 1) heat flux (μcal/(cm²·sec); 2) active volcanoes (surface and underwater); 3) inner (volcanic) arc; 4) outer (nonvolcanic) arc; 5) contemporary rear trough of the Kurile Island arc; 6) Sea of Okhotsk syneclise: 7) contemporary western Kamchatka platform; 8) active faults.

of this kind [5]. A modified PTG instrument was used, with the information transmitted to the surface. The geothermal gradients are listed in Table 2. The zero gradient 40 to 50 m above the bottom is shown in the first column; the readings of the frequency meter upon penetration of the thermal probe into the bottom soil are listed in the second column, and the gradients in the third column. All values are expressed in relative units of the scale of the frequency meter, thereafter converted to °C/cm (1 scale division corresponds to 0.0045°C). The temperature of the bottom layer of the water was measured by differential thermometers and was 3.5°C.

The bottom sediments are clayey oozes, whose thermal conductivity generally varied from 1.7 to $2.7 \cdot 10^{-3}$ cal/(cm·sec·degree).

The heat fluxes at the bottom of the Kurile Lake are low [(0.67 to 0.73) 10^{-6} cal/(cm²·sec)]. This is water-filled relict lake of the caldera type, about 8000 years old [15]. These low values seem to characterize a certain small anomaly which also encompasses the area of low values which we found on our marine traverse over the continental shelf between the southern promontory of Kamchatka and the Atlasov and Shumshu islands. In Fig. 1, this zone is enclosed by an equal flux line as an area of fluxes lower than $0.8 \cdot 10^{-6}$ cal/(cm²·sec). High flux values and the typical distribution in island arcs of such fluxes across the strike of the arc commence to the south of Paramushir Island (Fig. 1 and Table 1). Most values are close to $2.0 \cdot 10^{-6}$cal/(cm²·sec), and help us define more precisely the 2.0 isoline which we have previously drawn from the reported data [6,7]. Our stations are within the 150-mile coastal zone not previously analyzed by other researchers.

Heat fluxes in excess of $3 \cdot 10^{-6}$ cal/(cm²·sec) were found near Iturup Island, where they apparently are due to the nearby submarine volcanoes [9,12]. The same flux was found between Paramushir and Opekotan Islands in the immediate vicinity of inferred [8,9] transverse faults (Fig. 2). Figure 2 also shows one of the possible explanations of the transition from low to high heat flux, namely the transition from the tectonics of the Mesozoic platform of the Sea of Okhotsk to that of the mobile zone of the Kurile Island arc.

Figure 1 shows that several heat flux values were determined on the Pacific Ocean side of the Kurile arc. Of particular importance is the value $0.4 \cdot 10^{-6}$ cal/(cm^2· sec), farthest from the arc toward the deep-sea trough. Such a decrease in heat flux is observed in all island arcs and is the reason why we speak of a characteristic minimum on the heat flux curve across island arcs. The minimum was explained as a reflection of thermal processes which accompany the evolution of ocean arcs upon subduction of an oceanic lithospheric plate under a continent [10]. Our results indicate that these processes seem also to occur under the Kurile Island arc, but seem to be attenuated near the Kamchatka promontory. In the peripheral zones of eastern and western Kamchatka, the heat flux is relatively weak. From magnetotelluric sounding data, higher values can be expected in the center of the Kamchatka basin and in northeastern Kamchatka where only shallow boreholes, not suitable for measurements, exist so far.

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HORIZONTA

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O. Yu. Shmidt Ins
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