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The Local Characteristics of Earth-Currents

By TAKASABURO YOSHIMATSU

CHAPTER II

UNIVERSAL EARTH-CURRENTS AND THEIR LOCAL CHARACTERISTICS

§ 1. Introduction

In this chapter we dealt with their local characteristics as well as their world-wide natures of so-called universal earth-currents in respect to their spatial distributions and time variations. Since the very beginning of the history, many observations of this part of earth-currents have been carried out in various localities and in different epochs of the sunspot cycle. But owing to both defect of radical considerations of observational method and technique, and the complicated local natures of the earth's crust at the place where the observation is made, we are obliged yet to have little knowledge of their physical meanings, and even of their morphological basic facts as a world-wide phenomena. Therefore, in order to promote quickly this slow progress, as it holds good for the cases of other branches of science developed recently, it is strongly desired to observe them by using more modern techniques and apparatus at more well distributed stations all over the world. And then should be established their phenomenistic backbone of this branch of science. Unfortunately, it is a fact that even this self-evident requirement was not so easily realized. It is grateful, however, to have had recently many valuable material at several places in the world.

In the following paragraphs it is intended to make better understanding of remarkable local characteristics of universal earth-currents by using these available material as many as possible together with some data of earth-resistivity and geomagnetism, and then to contribute to the investigation of earth-currents as a world-wide phenomena.

§ 2. Principal, or restricted direction of the variation of earth-currents.

1. *Distribution of the principal direction deduced from the diurnal variation.*

In the first place, in order to glance the general feature of the spatial distribution of universal earth-currents, so-called principal directions of potential gradients at several places over the earth's surface are summarized in Table 11, and shown in Fig. 17. Here, the principal direction is expressed by the nearest round number of degrees of the angle subtained between the geographical north and the direction of the major axis of a hodograph of the mean diurnal variation at each station, since available data at hand are all confined to the diurnal variation only. At some places, each hourly vector does not always converge to any closely restricted direction, but makes more or less an oval figure, and somewhat differs this direction from that deduced from various kinds of short period variations mostly prevailing during the disturbances. We may be, however, satisfactory to demonstrate the general tendency, if any, of the spatial distribution of the direction of potential gradients. As it is seen in the figure, we have not so many points as a whole, and none in the middle parts of the North America, Africa and Asia, though relatively numerous in two regions, the eastern part of U. S. A. and Japan.

In the next paragraph we will first discuss the mode of distribution of the principal directions in these two regions from the topographical and geological points of views.

Table 11. Principal direction deduced from the diurnal variation.

Place	Principal direction			Lat.			Long.		
Sodankylä [26]	N	90°	W	67°	24′	N	26°	30′	E
Haparanda [27]	N	80	W	65	50	N	24	08	E
Lund [28]	N	60	W	55	42	N	13	11	E
Paris [26]	N	40	W	48	42	N	2	22	E
Berlin [20]	N	20	W	52	30	N	13	25	E
Greenwich [30]	N	10	E	51	44	N	0	0	
Ebro [20]	N	20	W	40	49	N	0	33	E
Watheroo [20]	N	5	W	30	19.1	S	115	52.6	E
Fairbanks [20]	N	30	W	64	54	N	147	48	W
Tucson [20]	N	20	E	32	14.8	N	110	50.1	W
Huancayo [29]	N	50	W	12	02.7	S	75	20.4	W
Toyohara [31]	N	80	W	46	58	N	142	45	E
Kakioka [32]	N	60	E	36	14	N	140	11	E
Chesterfield [33]	N	50	W	63	20	N	90	42	W
Toledo [34]	N	60	E	39	53.1	N	4	02.7	W

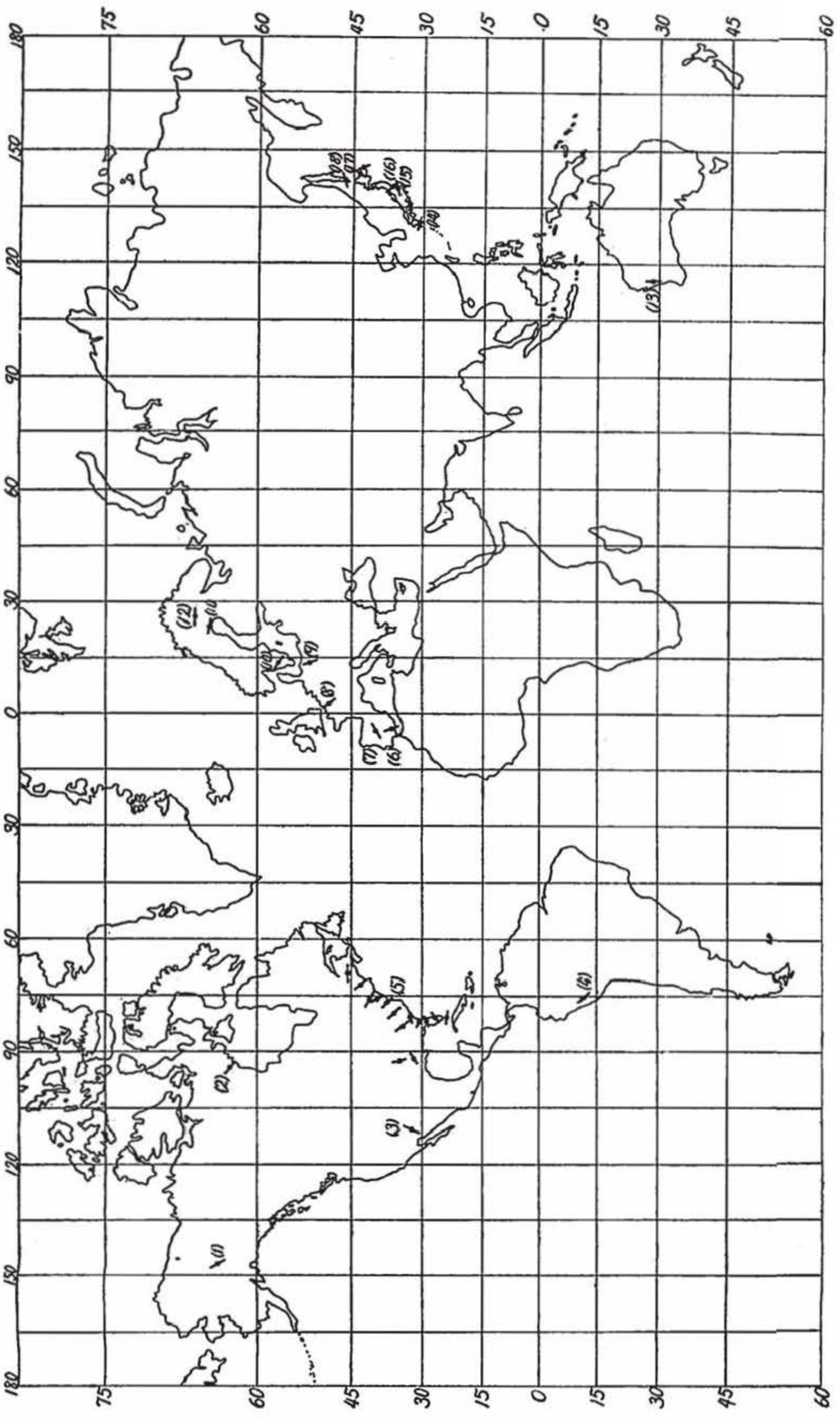

Fig. 17. Principal direction of earth-current potential gradients.
(1) Fairbanks (2) Chesterfield (3) Tucson (4) Huancayo (5) Houlton etc
(6) Ebro (7) Toledo (8) Paris (9) Berlin (10) Lund (11) Haparanda
(12) Sodankylä (13) Watheroo (14) Kanoya (15) Kakioka (16) Haranomachi
(17) Memanbetsu (18) Toyohara

2. *Principal direction observed in Japan.*

[A] *Recent observations of earth-currents in Japan.*

In recent years, on the occasions of the total solar eclipses and destructive earthquakes we have had several lucky opportunities to obtain numerous available data of earth-currents at fixed and temporary stations all over the Japan Island. They could afford a chance to understand more precisely and more synthetically the characteristic distribution of earth-currents in different localities. These stations and their principal directions are shown in Fig. 18-33, and tabulated in Table 12. The values in this table

Table 12. Mean principal direction deduced from short period variations.

No.	Place	Lat. N	Long. E	Principal direction (θ_0)	θ_c	Period
1	Shirutori [35]	48° 36′	142° 50′	N 84°W	N 76°W	June 19—20, 1936
2	Toyohara	46 58	142 45	N 78 E	N 70 E	Mar., May, June, 1934 Sept., 1935
3	Memanbetsu	43 55	144 12	N 43 E	N 43 E	June, 1936
4	Koshimizu [35]	43 52	144 28	N 30 E	N 20 E	June 19—20, 1936
5	Nemuro [37]	43 20	145 35	N 40 W	N 29 W	Jan., Feb., 1943
6	Obihiro	42 55	143 03	N 18 W	N 49 W	Jan., Feb:, 1943
7	Ikutora	43 10	142 35	N 84 W	N 37 E	1947
8	Asamushi [35]	40 53	140 52	N 43 E	N 63 E	June 19—20, 1936
9	Morioka	39 43	141 06	N 54 E	N 74 E	Dec., 1946—Dec., 1947
10	Sendai [35]	38 15	140 52	N 39 W	N 61 W	June 19—20, 1936
11	Haranomachi	37 37	140 36	N 56 W	N 88 W	Dec., 1946—Dec., 1947
12	Kakioka	36 14	140 11	N 73 W	N 82 E	Dec., 1946—Dec., 1947
13	Miyakonojo	34 58	138 46	N 77 E	N 78 E	Dec:, 1946—Dec., 1947
14	Heda	34 58	138 46	(A) N33W (B) N79W	N 25 W N 79 W	Aug., 1944
15	Owashi	34 04	136 12	N 76 E	N 66 E	Dec., 1946—Dec., 1947
16	Shikano [36]	35 27	134 04	N 13 E	0	Sept., 17—Oct., 2, 1943
17	Tanabe [40]	33 38	135 22	N 52 E	N 43 E	Jan.—Feb., 1947
18	Muroto [40]	33 17	134 17	N 55 E *(N 73 E)	N 55 E	Jan.—Feb., 1947
19	Kanoya	31 25	139 54	N 75 E	N 69 E	Dec., 1949 Jan.—Feb., 1950
20	Yamakawa [39]	31 12	130 38	N 15 E	N 15 E	May, Sept., 1950
21	Ishigaki [37]	24 20	140 10	N 56 W	N 50 W	Sept., 1941
22	Yonakuni [38]	24 28	123 00	N 34 E	N 30 E	Sept., 1941
23	Rebun	45 20	141 03	N 24 E	N 24 E	May, 1948
24	Fukui (Kawaimura) [41]	36 6.9	136 11.4	N 45 W	N 59 W	July, 1948

* Values after the great earthquake, "Nankaidō Earthquake".

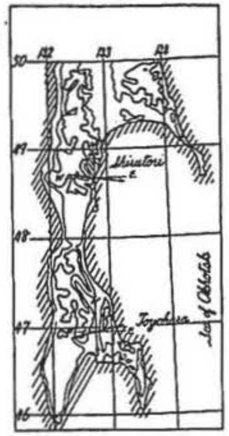

Fig. 18

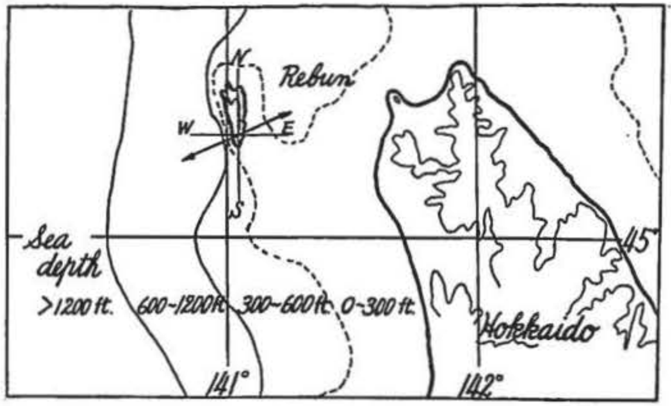

Fig. 19

Fig. 20

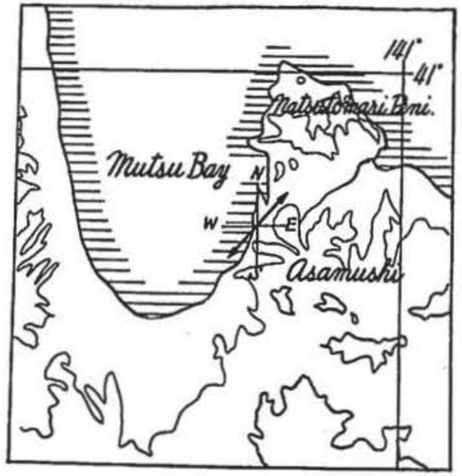

Fig. 21

Fig. 22

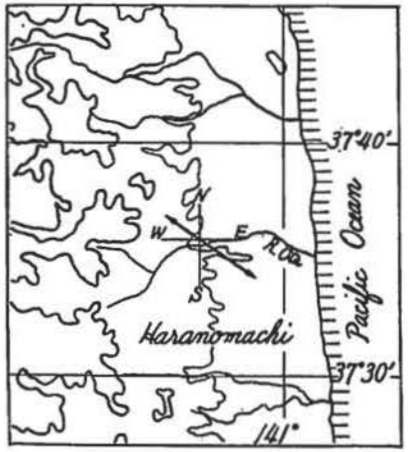

Fig. 24

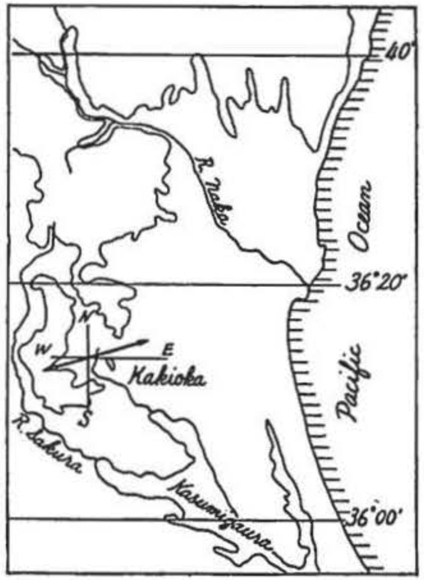

Fig. 25

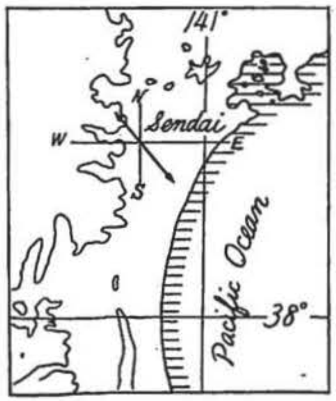

Fig. 23

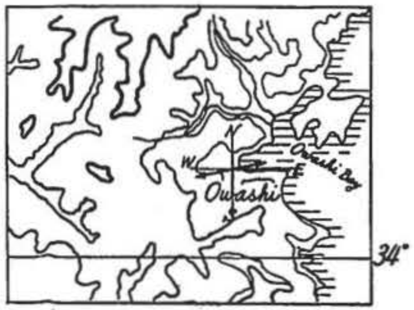

Fig. 26

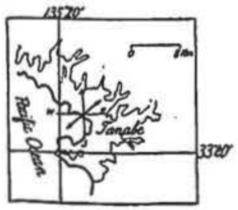

Fig. 27

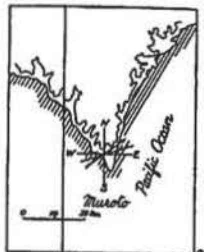

Fig. 28

Principal direction of earth-current potential gradients.

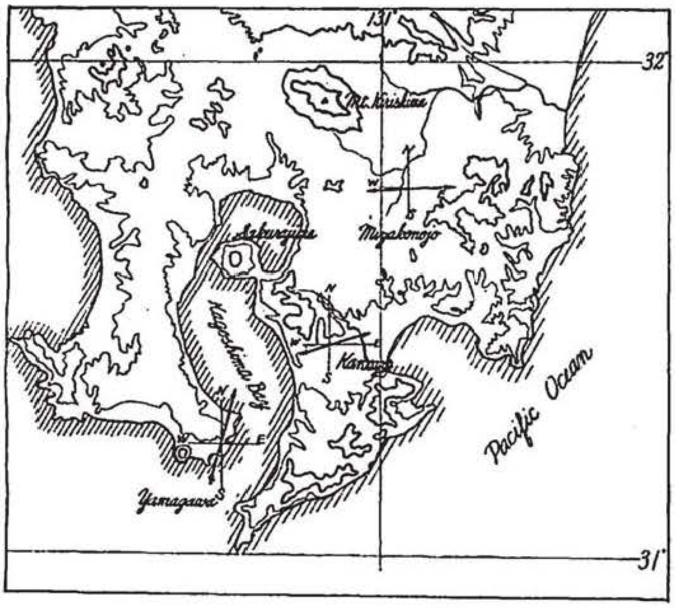

Fig. 29

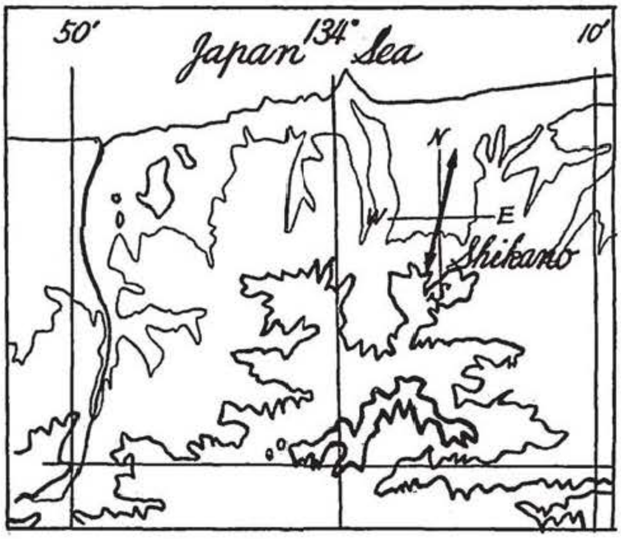

Fig. 30

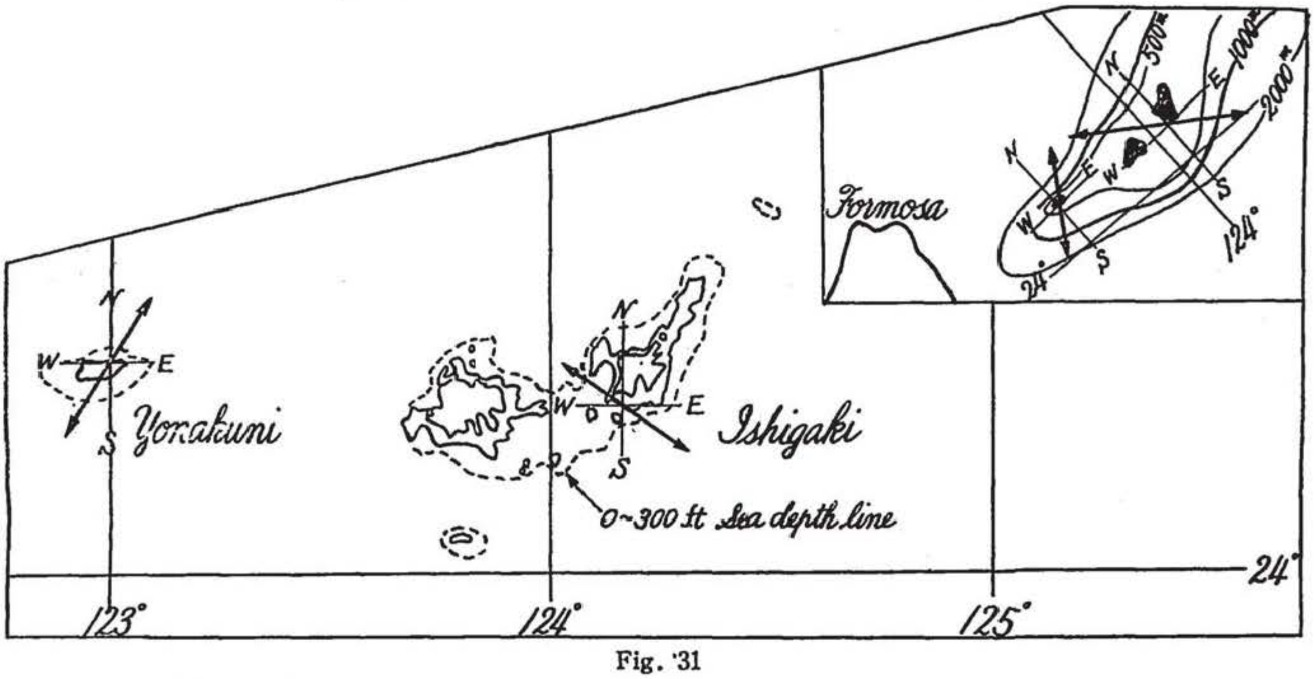

Fig. '31

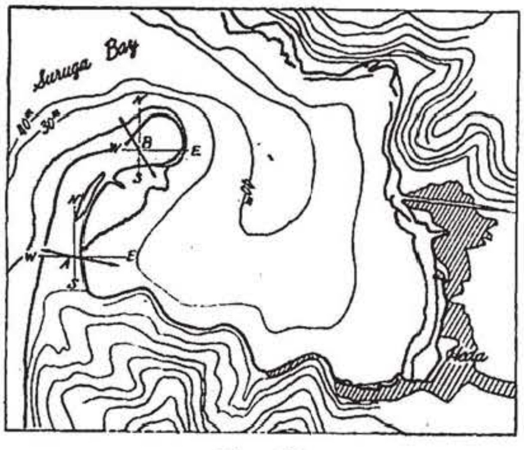

Fig. 32

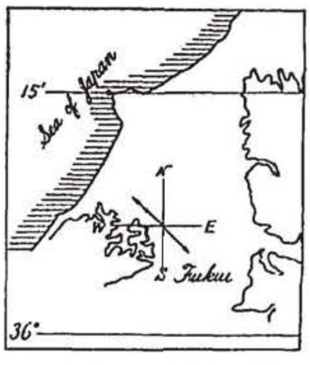

Fig. 33

Principal direction of earth-current potential gradients.

are almost deduced from the mean directions for many short period variations on account of the unpublished hourly values at most of stations and also troublesome gradual time variations of contact potentials. As it is seen in the table, since the epochs of observations are inevitably scattered in the interval of more than fifteen years, it may be hardly possible to avoid some errors due to time variations, if any, of the principal directions.

The short period variations adopted here are meant by ordinary fluctuations of universal earth-currents accompanied with simultaneous variations in the geomagnetic transient field. Most of the selected variations have so simple form that they make approximately linear changes lasting a few minutes to their extreme points. At Ikutora, however, the direction was exceptionally computed from the time variation between two succesive hourly values during so disturbed intervals that they were hardly affected by the diurnal variation field, while at Rebun every ten minutes values were utilized.

〔B〕 *Principal direction and topography in Japan.*

As it is clearly seen in the figures above-mentioned, the mean principal direction in the Japan Island shows a characteristic distribution in respect to the topography in the vicinity of the station, or as contrasted with the relative distribution of land and sea. That is to say, for the most stations being situated near the coast, the directions are much more nearly at right angles to the coast line than along it. At some points in a narrow peninsula their principal directions coincide generally with the directions of shortest pathes of the land at that points; Nemuro, Heda, Yamagawa and so on. The similar mode can be also seen at a station in a small island when the adjacent shallow portion of the sea is taken into account; Rebun, Ishigaki, Yonakuni and so on.

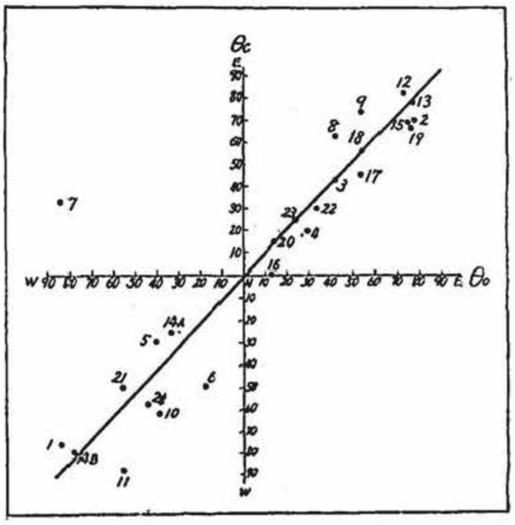

Fig. 34. Relation between θ_0 and θ_c

Furthermore, in order to show the above-mentioned fact clearly, the observed principal direction θ_0, which is reckoned from the geographical north, is compared with the calculated angle θ_c sustained between the north and the line connecting the station to its nearest point on the coast line, provided that at a station near the top of a narrow peninsula the latter line is taken perpendicularly to the length of the peninsula. The result is shown in Fig. 34. As mentioned above, the angles θ_0's are approximately equal to θ_c's in spite of wide range of θ_0's except only one station, Ikutora, which is situated in the high mountained part of the Hokkaido District and far remote from the sea-side. It may be, however, worthy to note that the direction of the shortest linear path in this district passing through Ikutora is N 70° W, while θ_0 is N 84° W.

It may be worthy further to remark that the residual, $\theta_0 - \theta_c$ seems to be distributed more or less in regular manner as shown in Fig. 35. That is to say, 13 positive values out of 24 points are appeared in the larger part of the islands, while 7 negative ones

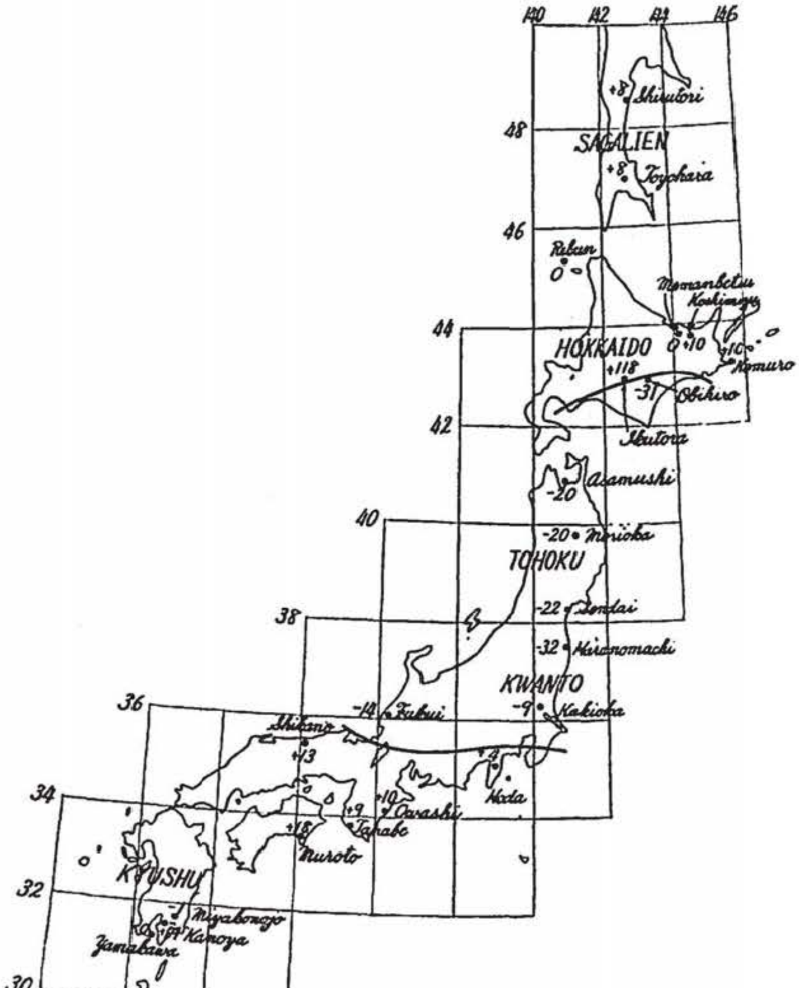

Fig. 35. Distribution of $\theta_0 - \theta_c$.

are all crowded in the limitted zone in the middle and northeastern parts of Japan. The rest 4 are zero or nearly zero. In the Sagalien all stations show positive values in spite of its northerly elongated figure like that of the Tohoku District. On the other hand, it can be noted that the negative area of $\theta_0.-\theta_c$ seems to coincide approximately with the well-known geological structure zone in Japan, "North-East Japan". At any rate, it may be then suggested that these facts may afford a clue to investigate the relationship between earth-currents and geological structure in rather large scale, though it is desired to have more stations to decide it, especially both on the coasts of the Sea of Japan and Seto Inner Sea, together with those in the central mountained regions.

3. *Principal direction observed in the eastern part of U.S.A.*

In the preceding article, we described observational facts regarding characteristic local distribution of the principal direction in Japan and her vicinity. As an another example to examine the minute feature of the mode of distribution of the principal direction, in this paragraph are treated the results obtained in the eastern United States.

During the second polar year, 1932-1933, G. C. Southworth[42] observed the earth-current potentials at about a dozen points crowded in this region. According to his report, near the coast, especially near and in the peninsula Florida including Key West, which is located in a small island laid between the peninsula and Havana (Cuba), earth-current potential gradients mostly tend to direct perpendicularly to the nearest coast-line, or to the length of the peninsula including the adjacent shallow part of the sea (Fig. 17). This general tendency of the distribution of the principal direction is very similar with that obtained in Japan, although the directions here are deduced from the diurnal variations. It is to be noted, however, that at two points, Denmark and Houlton, the potential gradients are of relatively small amplitude and their principal directions deviate markedly from this general tendency. They suggest apparently some local behaviours of the electrical conductivities near the stations, though we have no data of resistivities of their subterranean masses.

At an inland station, Wyanet (Illinois) the hourly vectors do not show the similar northwest-southeast direction, but make more rotary variations than those at other stations. It is somewhat notable that along this section of Mississippi Valley as pointed out by Southworth the principal direction seems to become more northerly, or more perpendicularly to the coast-line of the Gulf of Mexico. But the latter point should be discussed from other possible points of views.

4. *Principal directions at some other places.*

Here is also examined whether any apparent relation does exist between their principal directions and topographies at some of the well-known observatories which are already given in Table 11.

At Ebro and Chesterfield, which are respectively located near the Mediterranean Sea and the Hudson Bay, their principal directions are more perpendicular than parallel to the coast. And it is also noted that the principal direction at the former place is nearly along the part of the river Ebro near it. The similar mode can be found at San Miguel in Argentine (Fig. 36). Haparanda is situated near the coast of the so jugged Gulf of Bothnia that its principal direction seems to be not so simply relatable to the topography, but takes more or less similar mode with that at a station near the coast (Fig. 37)*. The principal direction at Greenwich is not directed to the mouth of the Thames, but deviates slightly from the north. It coincides approximately with the direction of the shortest path in the island at the station, from the English Channel to the North Sea, including its adjacent shallow part of the Sea (Fig. 38). But it is possible to suppose that the principal direction may be controlled by the southern, or north-eastern hilly region provided its larger resistivity in the northern direction than that perpendicular to it. At Lund the direction runs northwest-southeasterly across the top of the peninsula in the direction of approximately the shortest path of the land (Fig. 39).

In the next place, we will examine the subject at some other stations more remote from the coast. At Paris the principal direction runs towards N 40° W along the route of the river Seine. However, it may be considered to be rather perpendicular to the coast of the English Channel (Fig. 17). The well-known result at Berlin by Weinstein also shows the similar mode with that at a station near the coast (Fig. 17). The principal direction, N 20° W, at this place does not point to the general direction, northwest-southeast, of the topographical features, that is, routes of the rivers Elbe and Oder, or mountain ranges in the southern part of Berlin.

At Huancayo in Peru, where the high mountain system of Andes runs northwest-southeasterly along the coast, the principal direction is directed towards N 50° W along

* Even at a station as high as Scoreby Sund, Greenland (Lat. 70°30′), its principal direction shows this type.

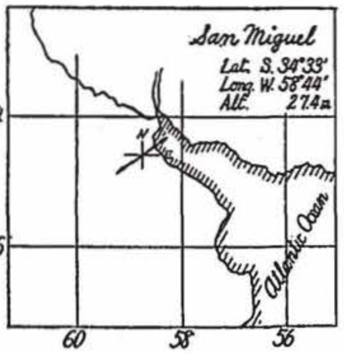

Fig. 36

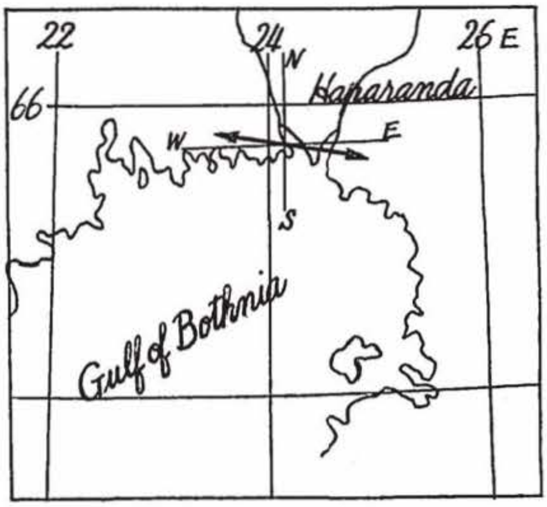

Fig. 37

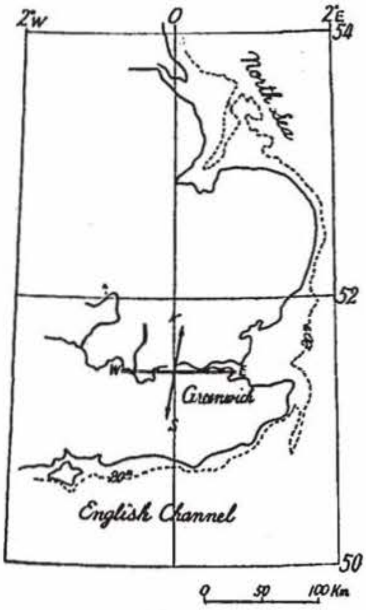

Fig. 38

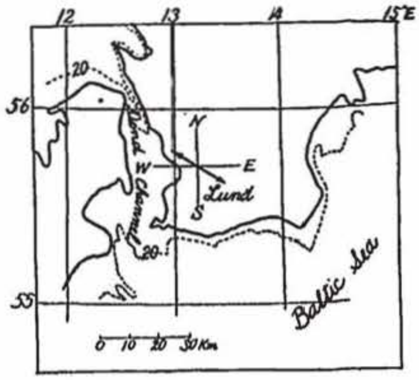

Fig. 39

Principal direction of earth-current potential gradients.

this trend, or the valley of the river Mantaro, but not perpendicular to the coast line. It is more or less similar with that at Toledo in Spain, where the principal direction, N 60° E, is nearly along the general trend of the river Tajo, or mountain chains in this vicinity. The result of the second polar year's observations at Fairbanks shows the similar manner as those given above. The principal direction, N 30° W, at this place merely remains in the same northwestern quadrant as the general direction of the Tanana, a branch river of the Yukon, or its valley, but deviates rather by large angles from it.

At Watheroo the principal direction, N 5° W, coincides approximately with that of the mountain-ranges running along the coast of the Indian Sea, at which eastern margin being situated the observatory. But the principal direction does not tend towards the general direction of the rivers, or their valleies, which are mostly originated in these mountained regions. Then, in this case the direction of the river, or its valley, itself seems to take no important role for the distribution of the principal direction. It is, however, to be noted that the rivers in this region are all of minor scale. On the other hand, according to the resistivity survey[43] near the observatory the values in the northern part are about three times larger than those in the eastern one as it may be expected from the topographical views. Then it is not surprising that we have such order of amplitude ratio of the north-component to the east one. In the vicinity of Tucson the Rocky mountains generally appears to run northerly or northeasterly, and joins the Sierra Madre Occidental running northwesterly on the coast of the Gulf of California. The principal direction, N 20° E, is rather parallel to the running direction of the former mountains.

At Sodankylä the mode of the diurnal variations on quiet days are quite different from those on disturbed days, that is, in the former case the east-component is predominant, while north-component so in the latter case. Then, any further description can not be done based on the same idea as that regarding the stations in the middle or low latitudes.

5. *Summary of the observational results regarding the principal direction.*

From the topographical point of view, general features of the distribution of the principal direction above-mentioned are summarized as follows.

Coast-type. At a station located near the coast its principal direction appears frequently to be more perpendicular to the nearest coast line than along it.

Peninsula-type. When a station is situated in a narrow peninsula its principal direction runs appoximately perpendicularly to the length of it. And similar manner can be seen at a station being situated near the top of a peninsula, or in a small island, when the adjacent shallow part of the sea is taken into consideration. In other words, the principal direction coincides approximately with direction of the shortest path of the region considered passing through that point.

Inland-type. The principal direction at an inland station far remote from the coast seems to take its own way characterized by the surrounding topography, probably electrical conditions of the subterranean mass. As a whole, however, the principal direction is apt to be parallel to the general trend of the mountained regions in rather vast area including the station ; say, Huancayo, Toledo, Fairbanks, Watheroo and so on.

It is a fact that at present there are few local measurements of resistivity, and it is much difficult to make so large scale electrical survey that effective portions of the earth controlling the earth-current flow at the very point can be satisfactorily examined and located. Of course, it is not seldom to have remarkable distortion of the potential gradient due to the heterogeneous distribution of the electrical conductivity in the adjacent part of one electrode or one component only. But, actually above-mentioned classification based on so many available data at present can picture up more substantially the locality of the principal direction than hitherto done.

On the other hand, a mathematical treatment being described later will help us to make more quantitatively the above-mentioned statements.

(to be continued)