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IMPROVED TIDAL CHARTS FOR THE WESTERN PART OF THE NORTH PACIFIC OCEAN

Hideo Nishida*

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Abstract

The co-tidal charts of M_2 and K_1, and the co-range charts of $2(M_2+S_2)$ and $2(K_1+O_1)$ for the western part of the North Pacific Ocean drawn by Ogura (1933) have been re-examined and revised on the basis of new tidal data. The co-tidal charts of S_2 and O_1, and ratio charts of S_2/M_2 and O_1/K_1, have also been prepared. The co-tidal charts of M_2 and S_2 indicate a very weak counterclockwise rotation in the Philippine Sea. The comparison between M_2 and S_2, and between K_1 and O_1 show that they generally have the same features in phase and amplitude. But, a peculiar bending of the S_2 nodal line, which is not found in the M_2 tide, are seen in the Caroline Islands.

1. Introduction

Several authors have drawn tidal charts based on harmonic constants in the western part of the Pacific Ocean (Harris, 1904 ; Sterneck 1920, 1921 ; Ogura, 1933a ; Dietrich 1944). Harris drew the co-tidal chart of the semi-diurnal tide (M_2) for the world. Sterneck drew the co-tidal chart of the diurnal tide (K_1) as well as the semi-diurnal tide (M_2). But the number of the data stations which were used by these authors is not sufficient to show detailed features in this portion of the Pacific Ocean. Dietrich drew the co-tidal charts of four major components (M_2, S_2, K_1, O_1) for the world, and also showed the amplitude along the coasts. His charts, based on 1665 tidal stations in the world, are considered to be the most reliable. But his work is confined to the open ocean and the conditions in the marginal seas are not shown in his charts.

The most comprehensive work on the tides in the western part of the North Pacific Ocean is Ogura's (1933) work. He compiled his earlier works (Ogura 1923a, 1923b, 1926, 1932) in his paper. He collected data from over 600 tidal stations in this area and drew the co-tidal charts of M_2 and K_1, and also the co-range charts of $2(M_2+S_2)$ and $2(K_1+O_1)$. The principal features in the western part of the North Pacific Ocean and the marginal seas (Okhotsk Sea, Japan Sea, Eastern China Sea, Yellow Sea, Bo Hai, Liaodong Wan and South China Sea) are described in his paper.

Four major tidal components which have relatively large amplitude were chosen. They are M_2, S_2, K_1, and O_1. Eight charts were prepared. Four of them are the co-tidal charts of each component. Two of them are the co-range charts of the semi-diurnal and diurnal spring tides, that is $2(M_2+S_2)$ and $2(K_1+O_1)$. The other two are the amplitude

* Oceanographic Division

ratio charts of S_2/M_2 and O_1/K_1.

Ogura's charts were used as basis for the co-tidal charts of M_2 and K_1, and also for the co-range charts of $2(M_2+S_2)$ and $2(K_1+O_1)$. His charts were examined based upon new tidal data, and in some portions of these charts modification of contors were made. The co-tidal charts of S_2 and O_1, and the ratio charts of S_2/M_2 and O_1/K_1 were newly drawn by the author.

In this paper, some characteristics obtained from the detailed examination of the Ogura's charts and from the charts drawn by the author are described.

The original purpose of this work was to estimate tidal constants for each one-degree square in the western part of the North Pacific Ocean from 0° to 55° N and from 115° to 160° E. Those tidal constants were read from the prepared charts and were intended for use in the processing of satellite altimetry data from the offshore regions. A table of the tidal constants can be obtained from the Oceanographic Division, Hydrographic Department.

2. Data and results

Tidal data are mainly from Ogura's collection (Ogura 1933a). These data cover Japanese islands, the coast of the Okhotsk Sea, the Tyosen Peninsula, the coast of China and the scattered islands in the western part of the North Pacific Ocean. In these areas no new tidal data important to tidal charts can be added to his collection. But along the coast of New Guinea, his collection is insufficient. Many tidal data have become available since then. In these regions, the IHB bulletin was referred for new tidal data.

The tidal data at Okino-Torisima (20° 25′N, 136° 03′E) obtained by the Central Meteorological Observatory (Kitagawa, 1943) and recently analyzed by the Hydrographic Department for harmonic constants, have also become available. The specifications of these data are shown in the table 1.

Table 1 Harmonic constants at Okino-Torisima

	H(cm)	κ(deg)	g(deg)		H(cm)	κ(deg)	g(deg)
K_1	15.9	209.7	209.0	N_2	8.3	195.7	179.6
O_1	12.2	185.7	175.1	L_2	1.9	77.2	70.9
P_1	5.3	209.7	208.2	ν_2	1.6	195.7	180.2
Q_1	3.2	168.6	153.1	μ_2	1.7	199.9	179.5
M_2	41.5	203.7	192.4	M_4	0.9	359.1	336.6
S_2	18.1	227.8	225.7	MS_4	1.0	3.1	349.7
K_2	4.9	227.8	226.4				

Figure 1 shows the geographical names referred to in this report.

Figure 2 and Figure 4 are the co-tidal charts of M_2 and K_1. The northern halves are almost the same as Ogura's charts. In the southern halves, small modifications were made to Ogura's charts. In some portions of these charts, the contors of 0.5 hour were added for convienience of estimation.

Figure 3 and Figure 5 are the co-tidal charts of S_2 and O_1 which were prepared by the author. Contors are drawn at every 1 hour, and in some places 0.5 hour contors are drawn.

The hours in all co-tidal charts are referred to 135° E.

Figure 6 and Figure 7 are the amplitude ratio charts. Contors are drawn at every 0.1 with additional 0.05 line.

The charts of the spring range of the semi-diurnal and diurnal tides, $2(M_2+S_2)$ and $2(K_1+O_1)$, are not shown in this paper, because they are essentially the same as Ogura's charts.

The amplitude of each tidal component, calculated from the range of spring tide and the ratio, are shown in Figures 8 to 11.

3. The co-tidal charts of four major tidal components

(1) M_2 tide

The number of tidal stations along the western coast of Kamchatka Peninsula is still small and we have no islands which can be used as tidal stations in the open ocean east of Japan. Therefore, the co-tidal lines in the eastern Okhotsk Sea and in the eastern sea of Japan are uncertain. In other areas, we have a good amount of tidal data along the coasts and at scattered islands, so co-tidal lines were drawn with higher confidence.

There appear eight amphidromic points in the marginal seas. Two of them, in the Bo Hai and the Liaodong Wan were confirmed by Ogura (1934, 1936), base on the offshore tidal observations which show very small amplitudes. The other amphidromic points though they very probably exist near the points shown on the charts, have not been confirmed by a direct observation.

There is an area along 148°E which has very crowded contors in the southeastern part of this chart. This is a nodal line, which was first pointed out by Ogura (1933a) and later confirmed by Dietrich (1944). The additional data on the north coast of New Guinea and in the Admiralty Islands, taken from the IHB bulletin, show that the M_2 tide wave progresses from east to west. This supports the existence of the nodal line.

In the large area between the Philippine and Mariana Islands, the tidal hour is almost the same, taking the value of 6.5 to 7.0. But closer examination shows that the tidal hour in the western Caroline Islands is 30 minutes later than along the Pacific coast of the Philippines. This fact, along with the fact that the close contors in the nodal line spread as it goes northward, seems to show that there is a weak counterclockwise rotation of the M_2 tide wave.

(2) S_2 tide

The obtained co-tidal chart is similar to the M_2 tide chart. It has the same characteristics with respect to amphidromy and node.

In marginal seas, the pattern is almost the same as M_2's. The difference in phase (S_2-M_2) is about one hour in almost every marginal sea. But it takes a little higher value in the Okhotsk Sea, that is, 1.5 hours along the Kuril'skie Islands and 2 hours in the east of Sakhalin.

The greatest difference between the M_2 and S_2 phase diagrams is shown on the nodal line between Japan and New Guinea. To the north of 15°N, the nodal line of S_2 exhibits the same pattern and position as M_2. But it bends westward between 15°N and 8°N, and south of 8°N, the nodal line of S_2 is located about 200 miles west of the M_2 nodal line. The difference between the above-mentioned two nodal lines in the Caroline Islands was pointed out by Ogura (1933a).

Similar to the M_2 phase, the S_2 phase in the western Caroline Islands is 30 minutes later than along the Pacific coast of the Philippines. But this is not represented on the chart because of the irreguralities of data.

(3) **K_1 tide**

The discussions concerning the density of data stations and uncertainty of co-tidal lines on the M_2 tide also are able to apply to the K_1 tide.

As for the area in the South China Sea a small correction was made to Ogura's chart.

(4) **O_1 tide**

The co-tidal chart of O_1 resembles the K_1 chart. The differences in phase (O_1-K_1) in most locations are about 2 hours, and these values in the open ocean in the western North Pacific are one hour.

4. The ratio charts of S_2/M_2 and O_1/K_1

(1) **S_2/M_2**

In the greater part of the marginal seas, the ratio between the amplitudes of S_2 and M_2, S_2/M_2, takes the value of 0.3 to 0.45. However there are several localities where it takes a higher value. These localities are the southeastern part of the Okhotsk Sea (including the Sōya Strait), which has the value of 0.45 to 0.6, the Tusima Strait, which has the value of 0.45 to 0.5 and the Celebes Sea, which has the value of 0.6 to 0.7.

On the eastern coast of Sakhalin, we can find the area where the ratio takes a very small value (0.1). This area is very near to the amphidromic points of both M_2 and S_2. This amphidromy may be the cause of this extreme small values.

At the location of about 8°N, 148°E, a very high value (over 6.0) is found, and at 200 miles west of this location, we find a very low value (below 0.2). These two extremes are due to the difference in the positions of the M_2 and S_2 nodal lines.

(2) **O_1/K_1**

The ratio between the amplitudes of O_1 and K_1, O_1/K_1, takes a relatively high value of about 1.0 in the area from the southwestern Okhotsk Sea to the Japan Sea. It is between 0.7 and 1.0 in the Eastern China Sea and the Yellow Sea. In the South China Sea, it is slightly higher, being about 0.9. In the major part of the Philippine Sea between the Philippine and Mariana Islands, the ratio is under 0.6. But we have very few data in this region, so this conclusion should be reexamined in the future.

5. The amplitude charts of four major tidal components

(1) **M_2 tide**

From the Kuril'skie Islands to New Guinea, a relatively low amplitude belt runs in a north-south direction. The southern part of this belt, where the amplitude is less than 10cm, coincides with the nodal line. This low amplitude belt stretches as far north as the Kurile Islands and continues to the low amplitude area of the southwestern Okhotsk Sea. When entering the Japan Sea, the amplitude decreases, reaching less than 10 cm.

In the western part of this nodal line, the amplitude increases as we proceed westward. Meanwhile, in the South China Sea, it is considerably smaller (less than 20 cm).

(2) **S_2 tide**

In general, the amplitude of the S_2 tide has a similar pattern to the amplitude of the M_2 tide. The low amplitude belt along the nodal line is deflected from a north-south direction corresponding to the bending of the S_2 nodal line itself.

(3) **K_1 tide**

We find a tendency for the amplitude to increase as we proceed from east to west. An area of relatively small amplitude stretches to the west as far as the Celebes Sea along 5°N. The amplitude of K_1 in the Japan Sea is as small as the M_2 tide, but, in the South China Sea it is large, contrary to the M_2 tide.

(4) **O_1 tide**

The amplitude of the O_1 tide has features similar to the K_1 tide. But, in the open sea where the amplitudes are small, high confidence should not be put on this chart.

acknowledgement;

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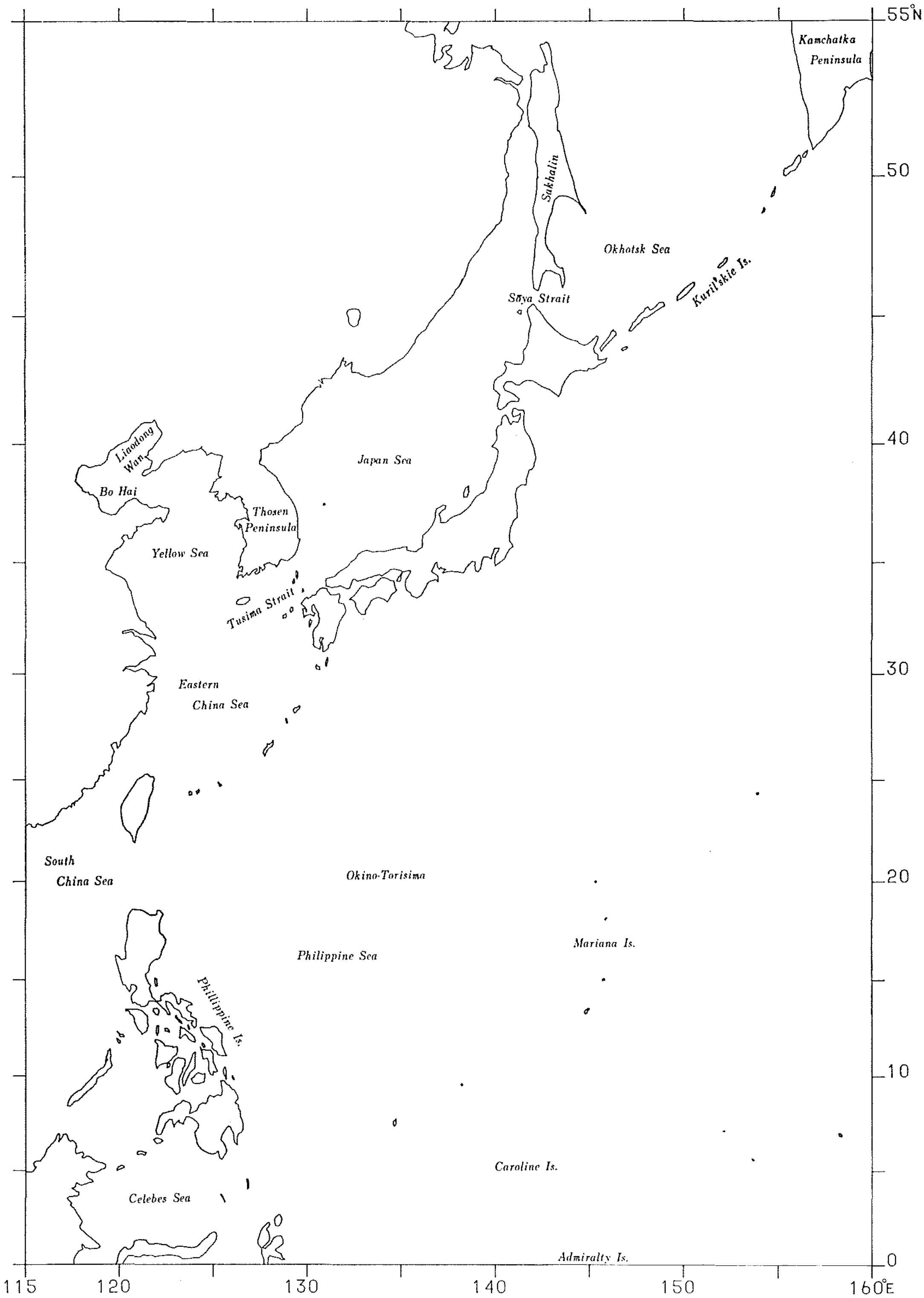

Figure 1 Chart showing geographical names.

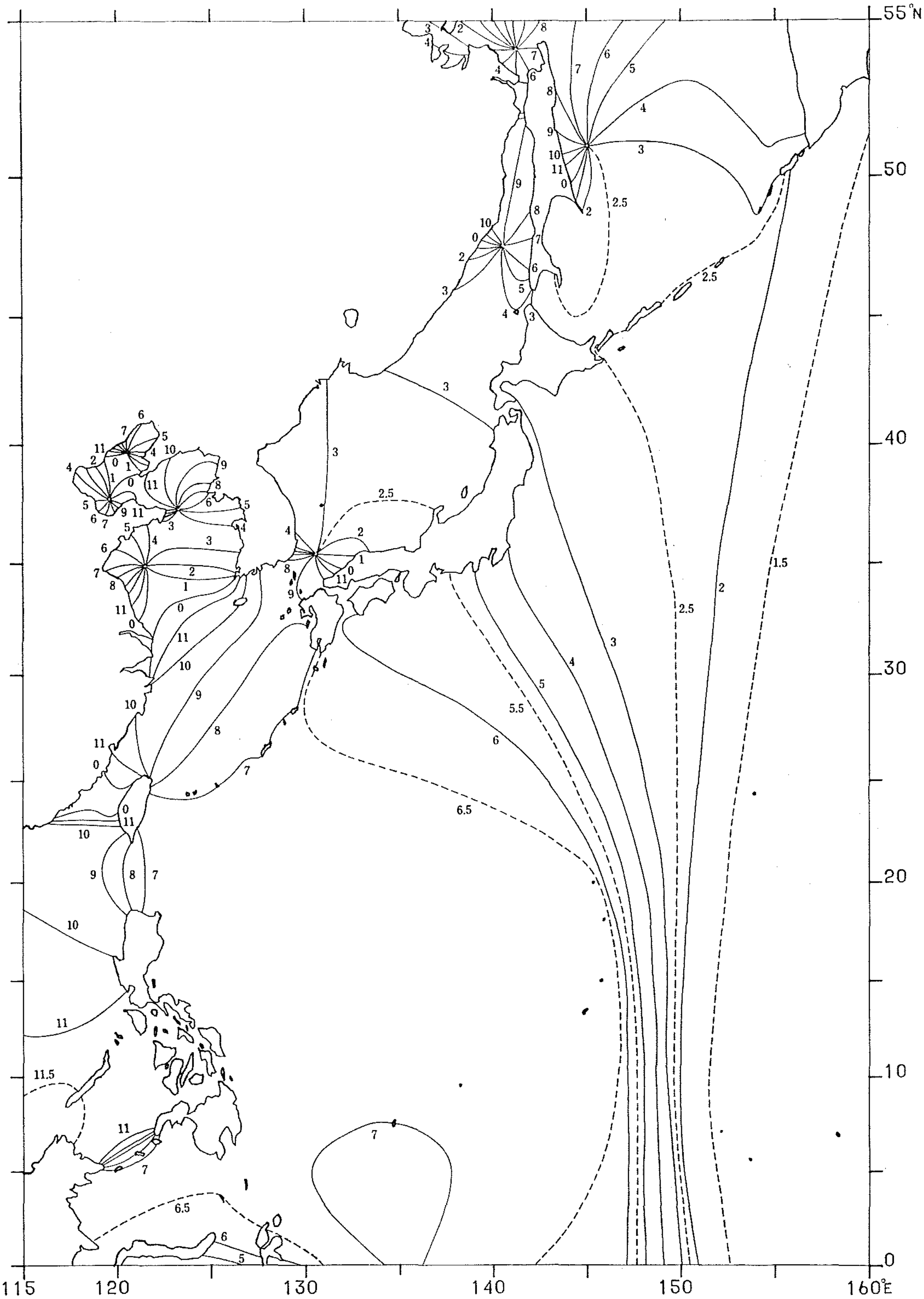

Figure 2 The co-tidal chart of M_2 referred to 135°E (unit ; component hours).

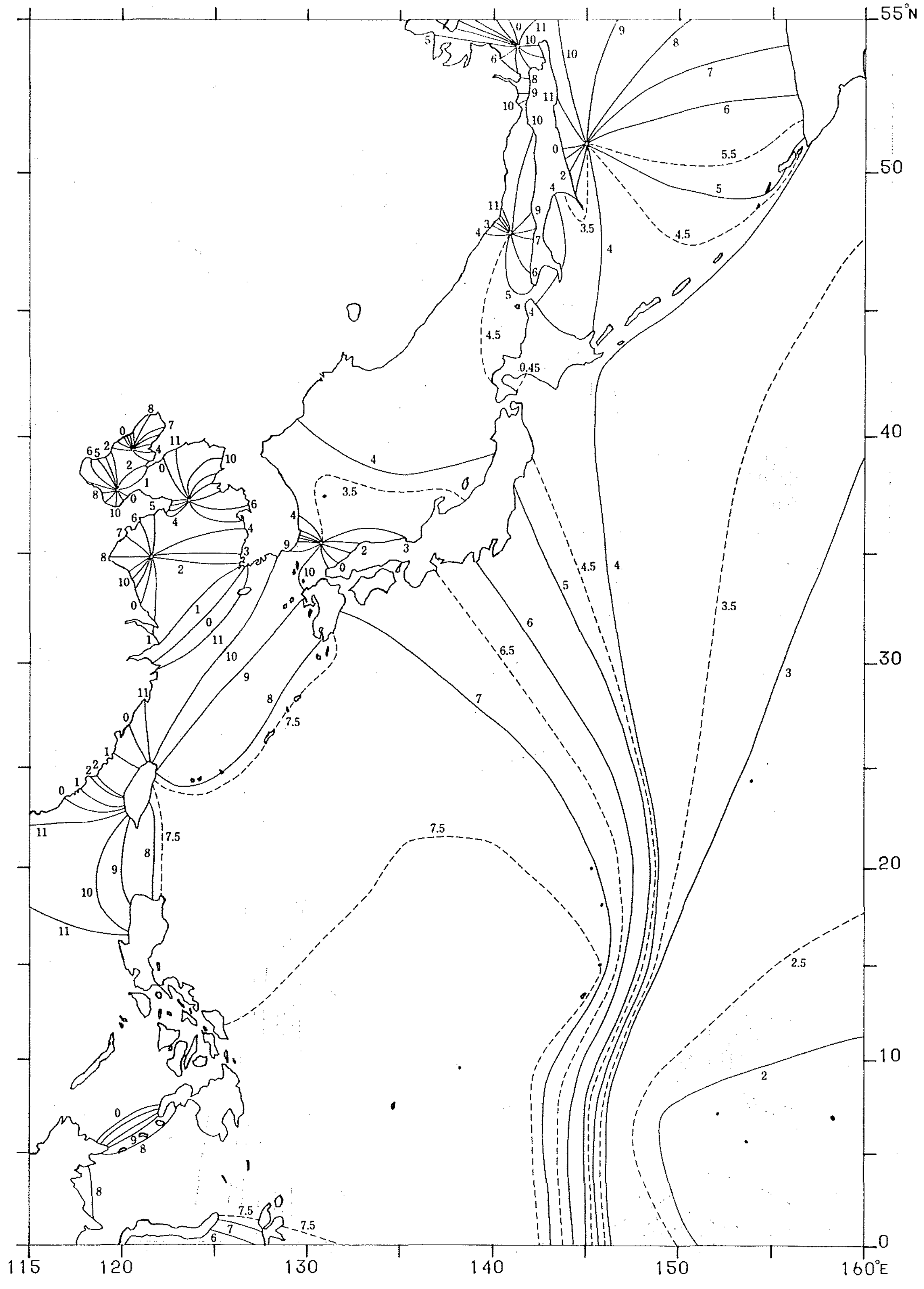

Figure 3 The co-tidal chart of S_2 referred to 135°E (unit; component hours).

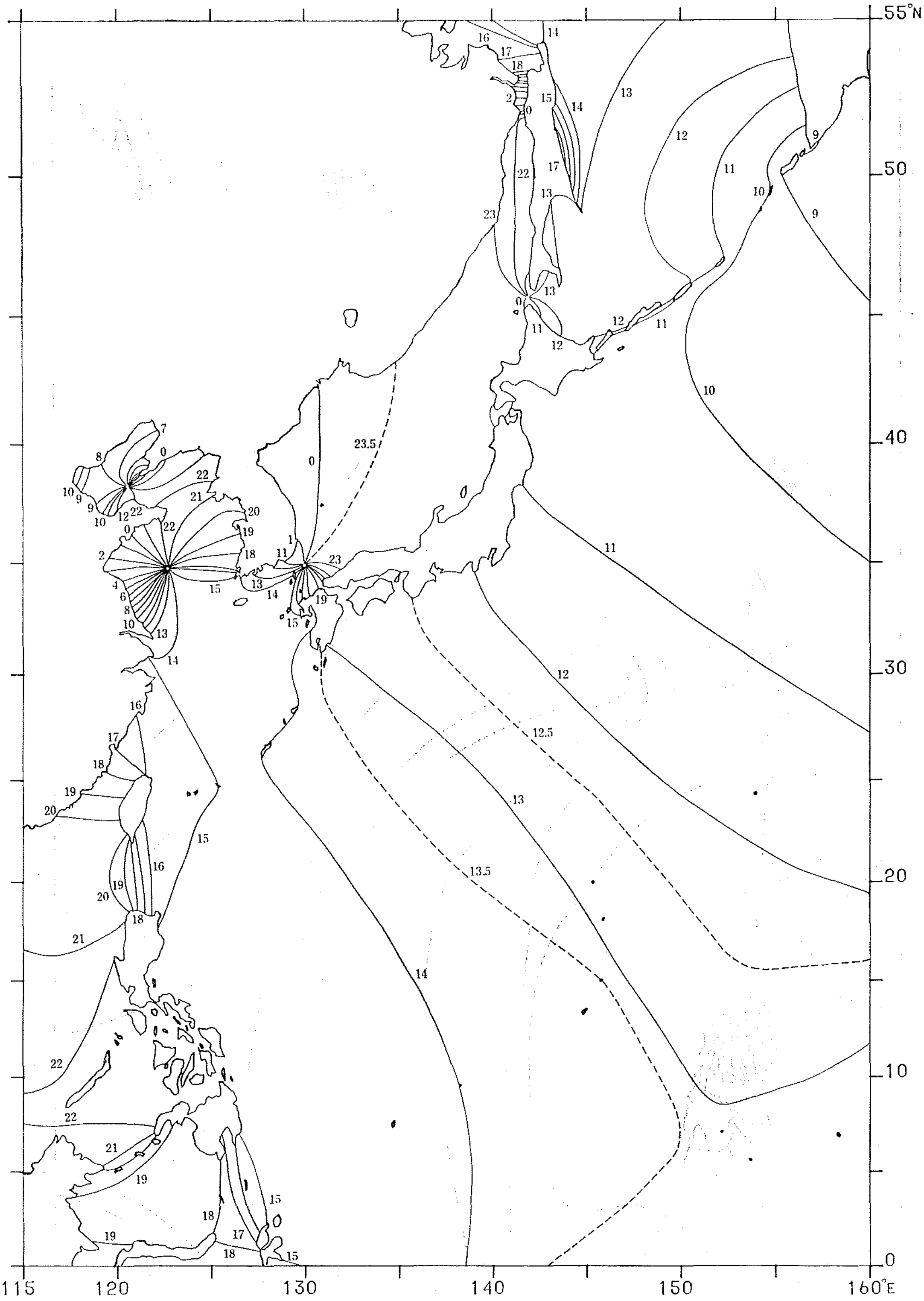

Figure 4 The co-tidal chart of K_1 referred to 135°E (unit; component hours).

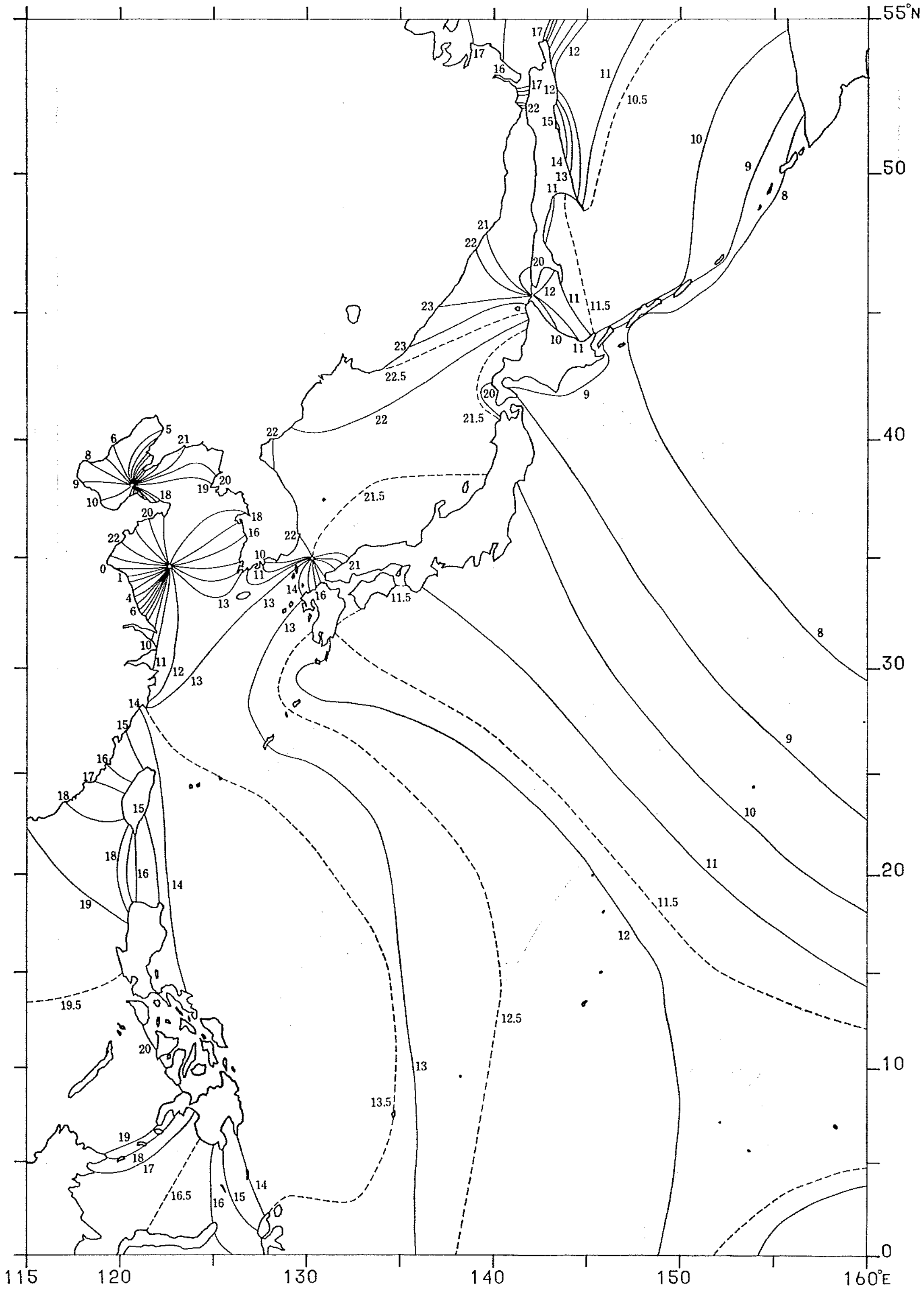

Figure 5 The co-tidal chart of O_1 referred to 135°E (unit ; component hours).

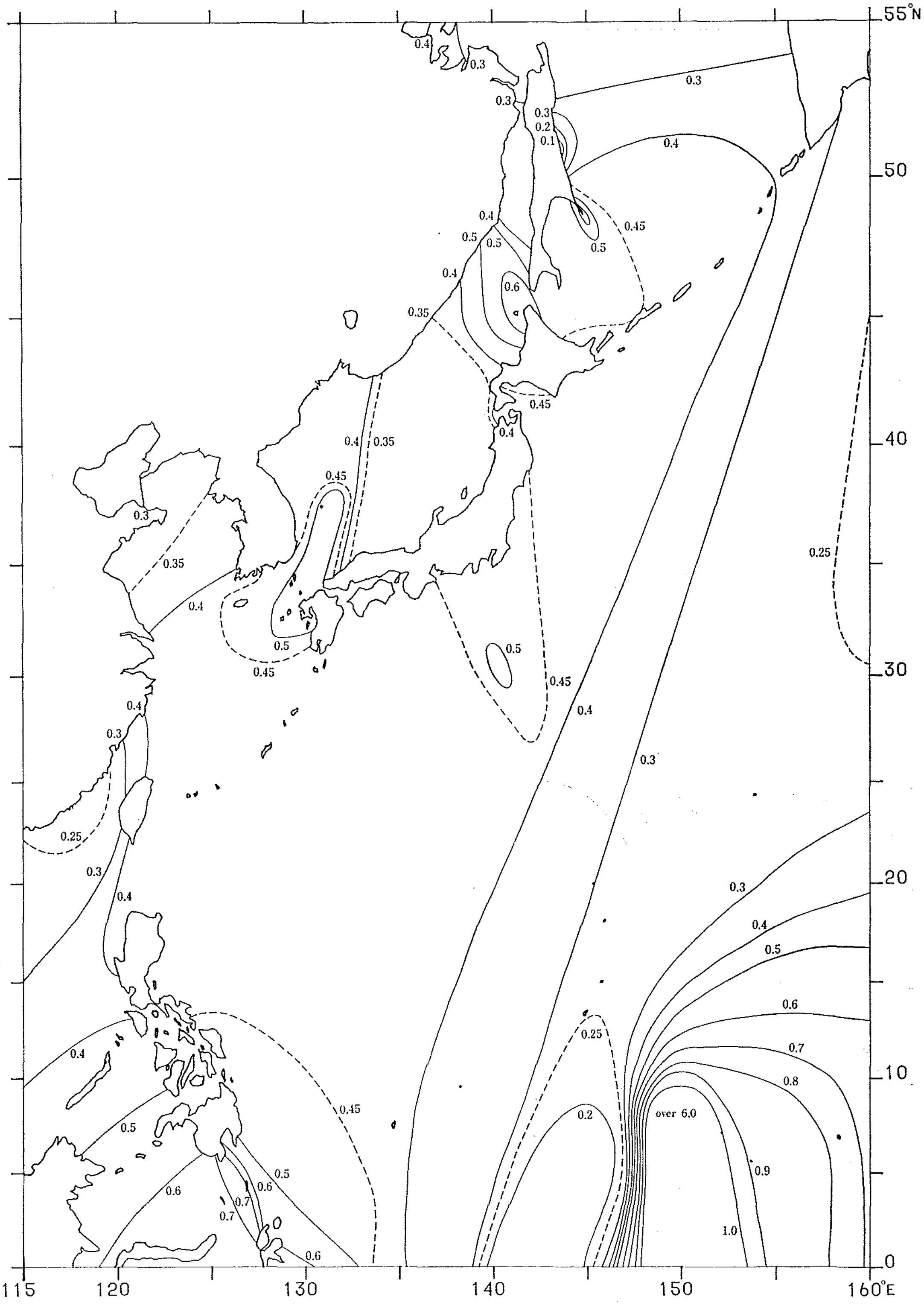

Figure 6 The ratio chart of S_2/M_2.

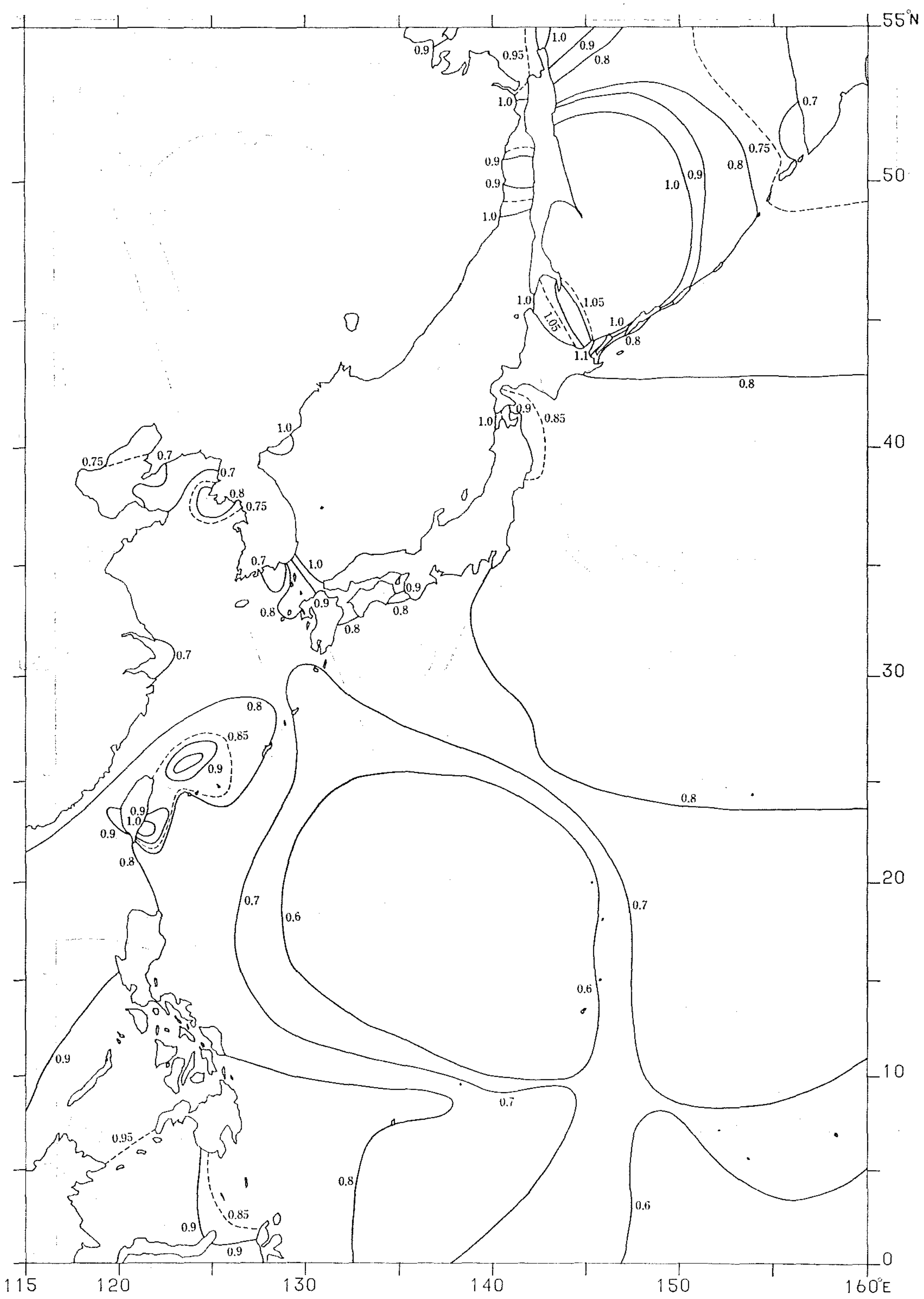

Figure 7 The ratio chart of O_1/K_1.

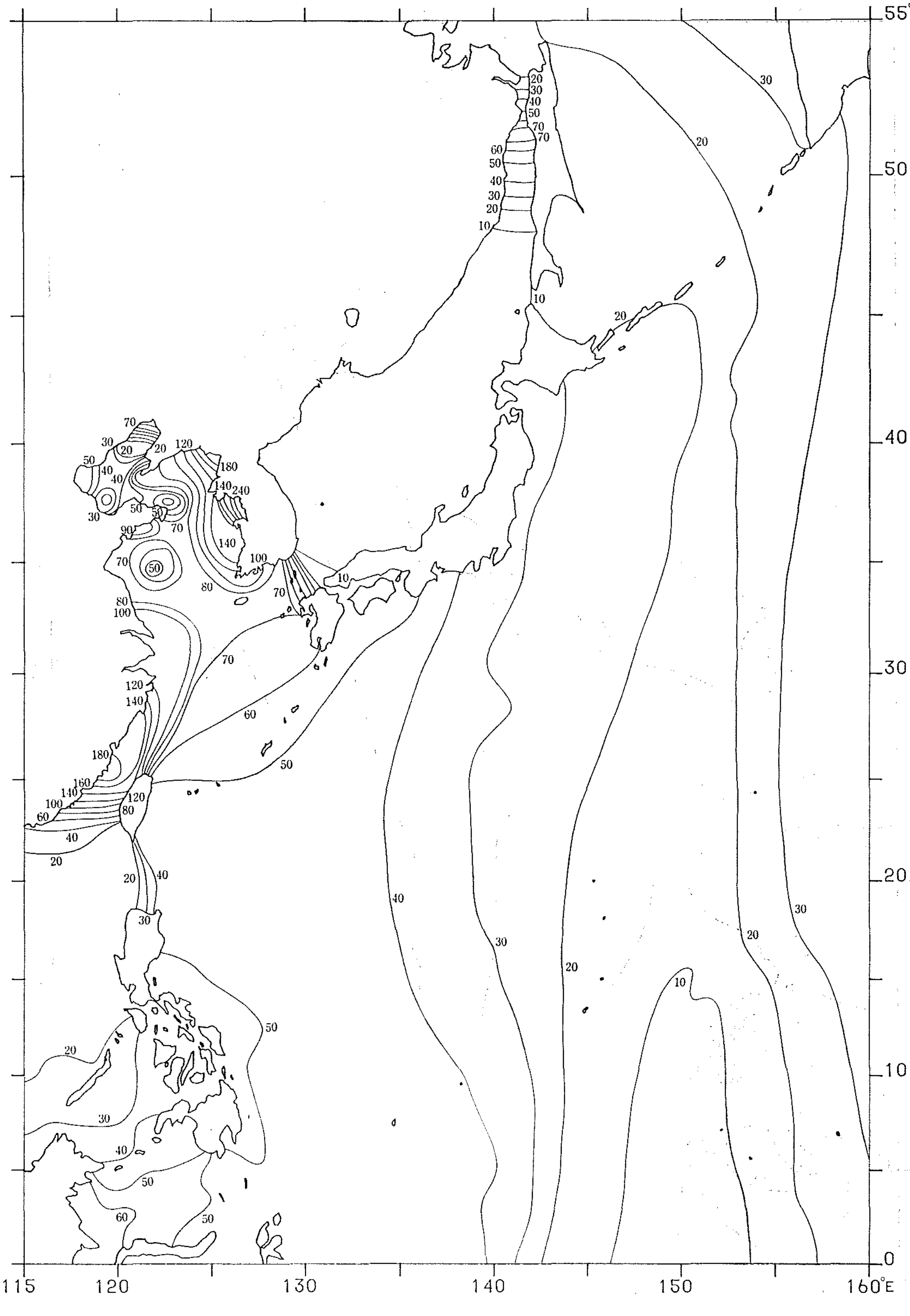

Figure 8 The amplitude chart of M_2 (unit; centi-metres).

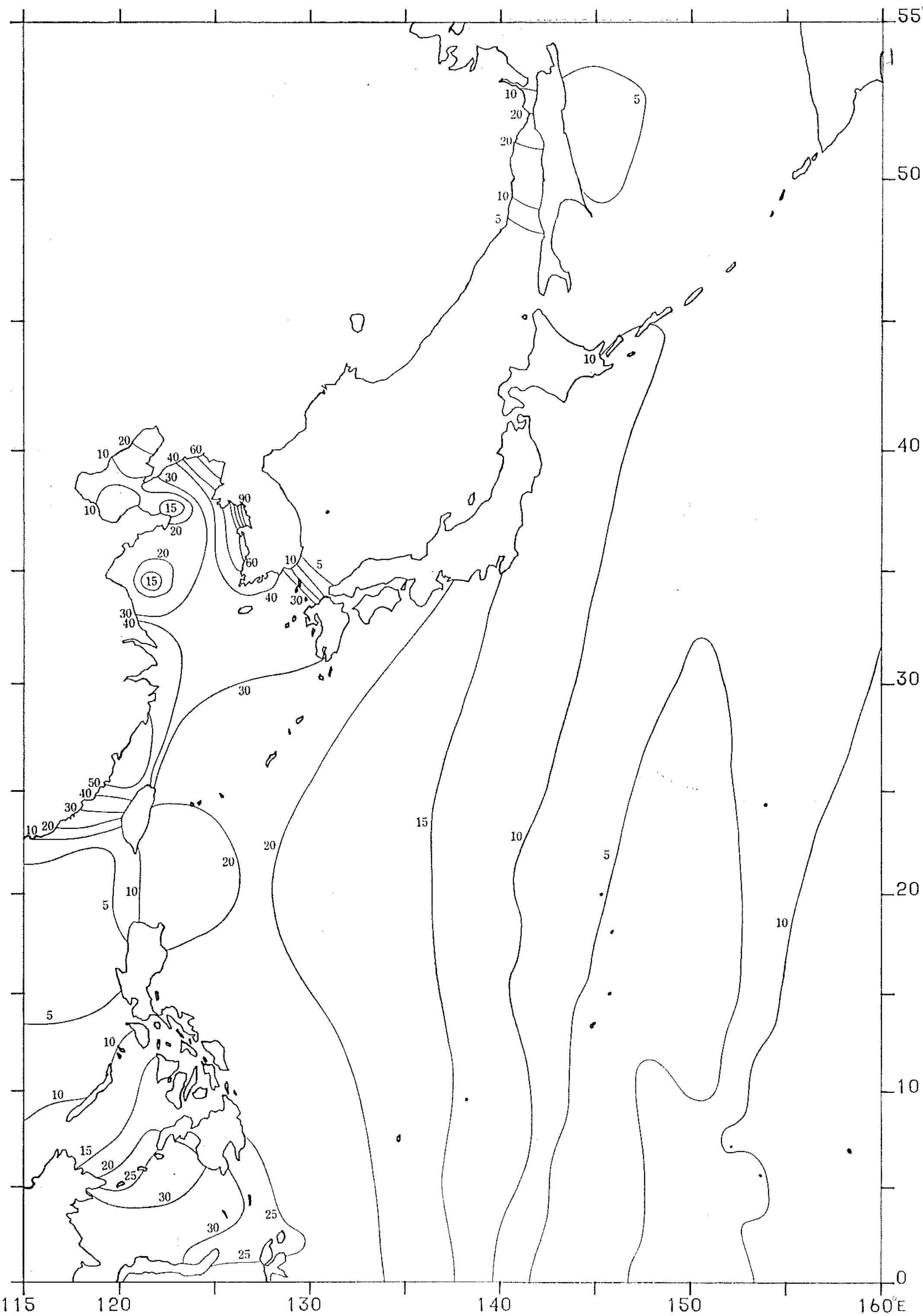

Figure 9 The amplitude chart of S_2 (unit ; centi-metres).

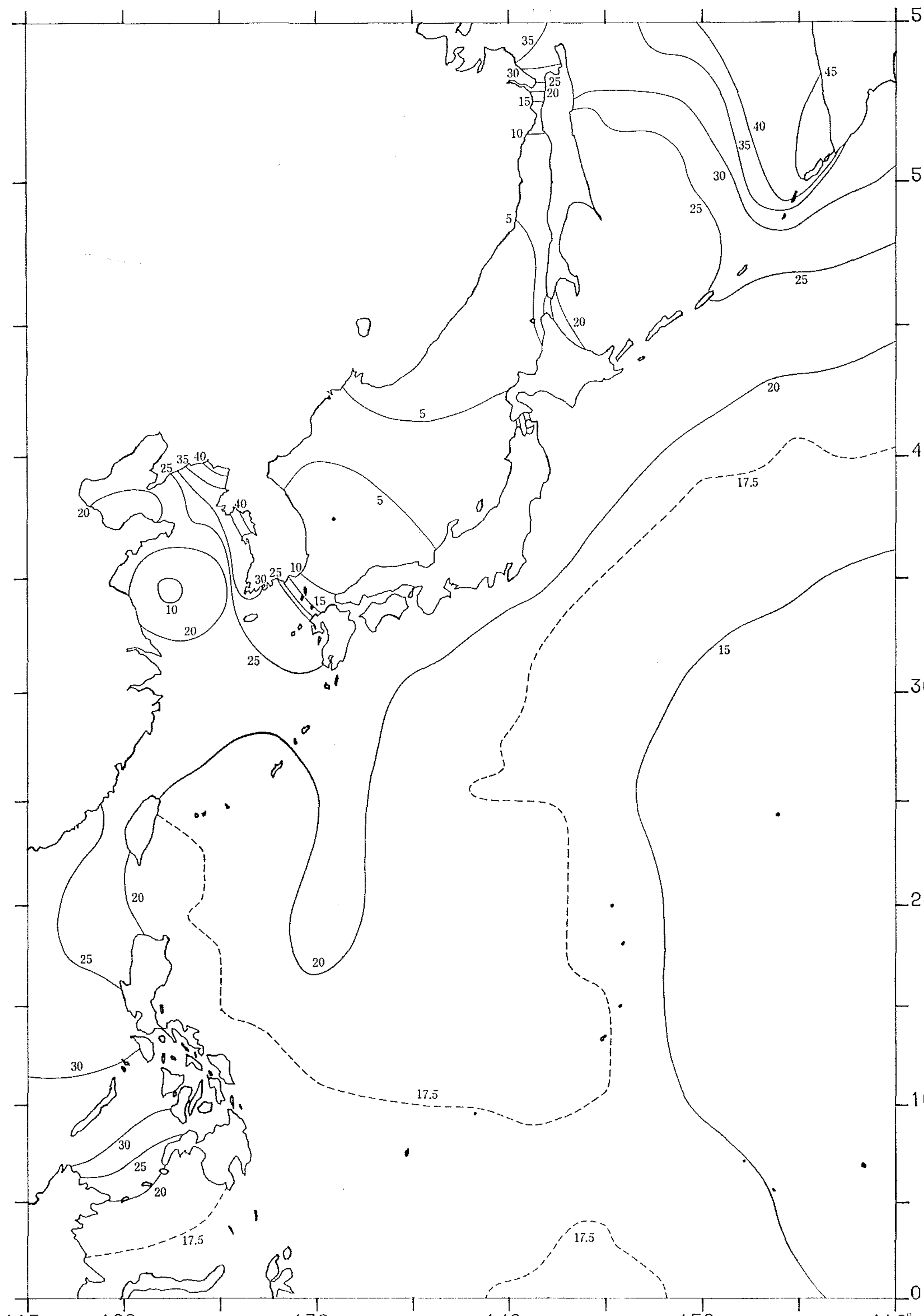

Figure 10 The amplitude chart of K_1 (unit ; centi-metres).

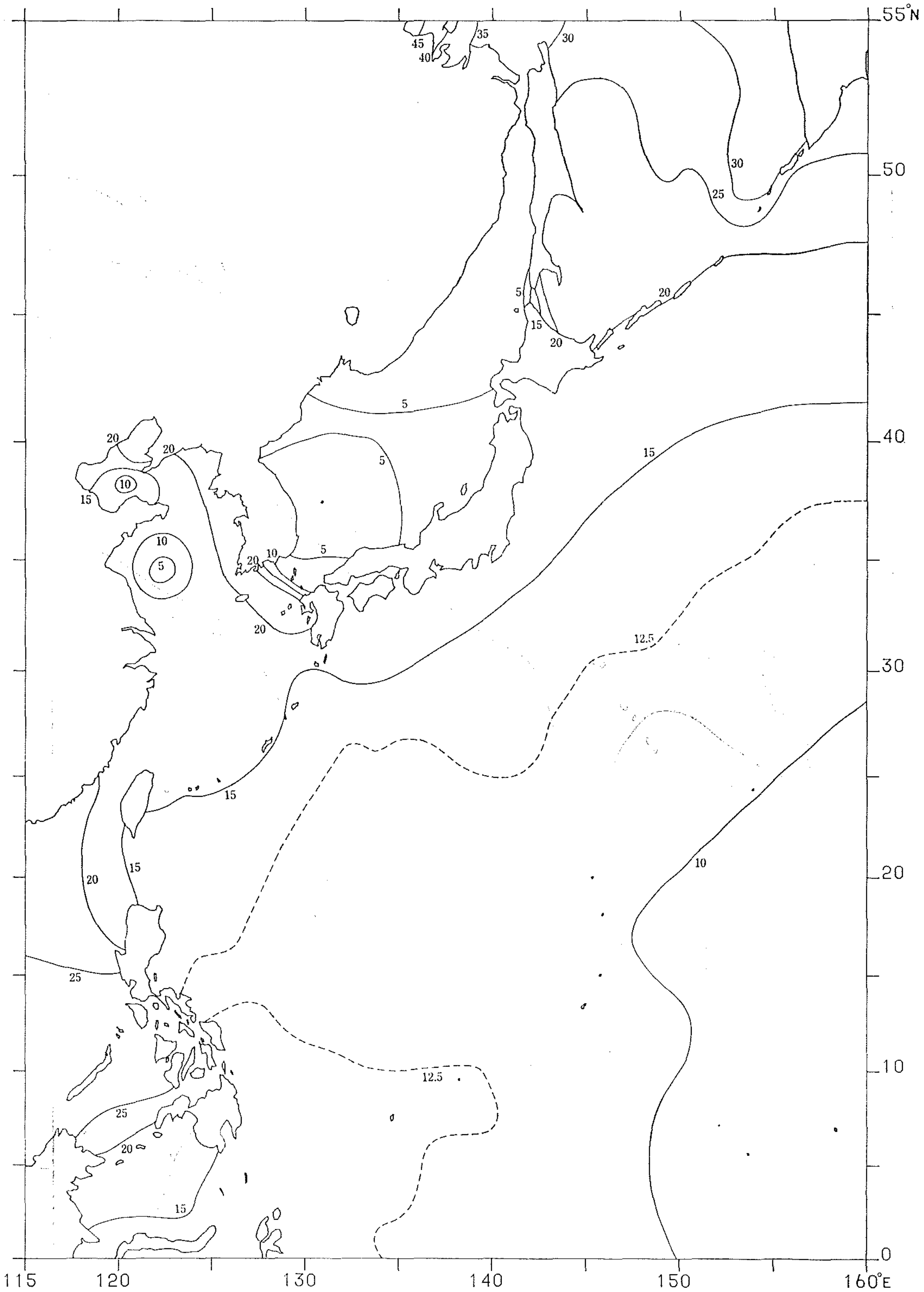

Figure 11 The amplitude chart of O_1 (unit ; centi-metres).