

ON THE SOUND CHANNEL AND SOUND TRANSMISSION IN THE OKHOTSK SEA

By

Masao ŌUTI

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The long range transmission of sound in the sea is carried out through the sound channel which is determined by the bottom topography and the distribution of sound velocity, so that the sound channel transmission (so called SOFAR) is different for different regions of the sea. In a previous paper the author¹⁾ discussed the structure of SOFAR in a marginal sea which is very small as compared with the oceans and examined it in a practical example of the Japan Sea. Adjacent to the Japan Sea, another marginal sea—the Okhotsk Sea—communicates it through shallow straits. It has nearly the same dimension as the Japan Sea, but has many different features. In a cold sea like the Okhotsk the axis of a sound channel lies, if any, usually in a shallow superficial layer. This situation is different from a warm sea and deserves attention. Basing on observational materials in the Okhotsk Sea, the author examined the character of SOFAR in this area.

Preliminary remarks

1. Effects of surface noise. In a cold sea, the depth of the axis of a sound channel is very shallow. In the northern part of the Okhotsk Sea, for example, it lies in a 50m layer and the top of the sound channel is very near the sea surface. According to Anderson²⁾ (1950), the top of a sound channel is defined to be a depth near the sea surface where the sound velocity reaches a maximum. In Okhotsk Sea the velocity maximum usually appears on the sea surface in summer, though it is locally seen in a 10m layer, and entirely disappears in the superficial layer in winter. When the velocity maximum is on or very near the sea surface,

the layer between the axis of a sound channel and the sea surface will form a part of the sound channel and any sound generated in the surface layer will be transmitted through it and disturbs the sound channel transmission.

The noise in the sea was studied by Knudsen³⁾ et al (1948), Kuyama⁴⁾ (1953) and others. The sound pressure of the noise by the motion of the sea water is about 0.4 dyne/cm² and 2.8 dyne/cm² on a calm day and moderately rough day respectively. According to Kuyama, the mean sound pressure of natural noise and fish sound is of the order of 10⁻² and 10² dyne/cm² in the minimum and maximum respectively. The noise from a ship gives a pressure of 10⁴ dyne/cm² at a point nearest the engine, the corresponding sound energy being 6.5×10² erg/cm². The sound energy is equal to the square of the sound pressure divided by impedance (density times sound velocity). If we use 1 kg of TNT for SOFAR signal, its energy is 4.2×10¹³ erg and about half of it is transmitted by the compressional wave. Then, the sound intensity at a distance of 100 m from the point of explosion is 2.1×10⁵ erg/cm² on the assumption of spherical wave. In SOFAR propagation the damping of a sound wave is ascertained to be only 10db per 1000km, so the sound energy at a distance of 3000km from the origin becomes 2×10² erg/cm².

Inferring from these materials, the natural noise or ordinary artificial sound in the surface layer will not materially affect the sound channel transmission—a fact which is also supported by the record of SOFAR⁵⁾ of Myojin volcanic eruption obtained at the coast of California.

2. Practical top of a sound channel. The sea surface where velocity maximum occurs may be assumed as the top of a sound channel, because any sound ray emanating upwards from the axis which is refracted at the surface and can proceed without reflecting at the bottom is assumed as a limiting ray. But, owing to the irregular undulations of the surface by wind waves, the energy of such a ray may be scattered and reflected and will lose the character of a limiting ray. Beside waves, air bubbles and sea ices also disturb the sound transmission. In this respect, it may be reasonable to fix a practical limit of the top in a layer where such actions have no appreciable influence.

As the Okhotsk Sea has a limited fetch, the height of wind waves will not exceed 10m in this sea and the air bubbles entrained by wave actions will not penetrate much deeper than the wave height.

The thickness of the sea ice in this area is 1~1.5m and even the thickness of icefield in the arctic sea does not exceed, according to N. N. Zubov, 3~5m. The suspension in the sea occasionally scatters the sound waves as pointed out by Raitt⁽⁶⁾ (1948) and Dietz⁽⁷⁾ (1948), but in a superficial layer the effect may be negligible.

Considering these points, the author tentatively fixed a 20m layer as a practical limit of the top of a sound channel in the case where the velocity maximum occurs on or very near the sea surface.

Character of the sound channel in the Okhotsk Sea

Using the observational materials of the Okhotsk Sea obtained by a joint survey of the Japanese Hydrographic Office and the Central Meteorological Observatory on board the Ryofumaru from June to August, 1942, the sound velocity was calculated by the sound velocity diagram prepared by the present author⁽⁸⁾. The observation stations are shown in Fig. 2 by dots. The observations

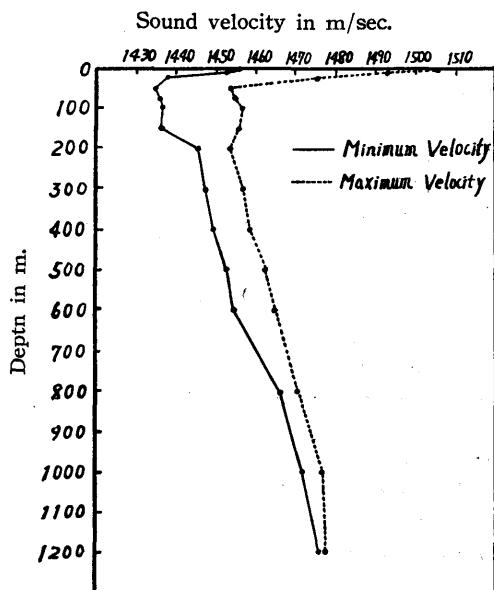


Fig. 1. Vertical distribution in the maximum and minimum sound velocity at each depth in the Okhotsk Sea.

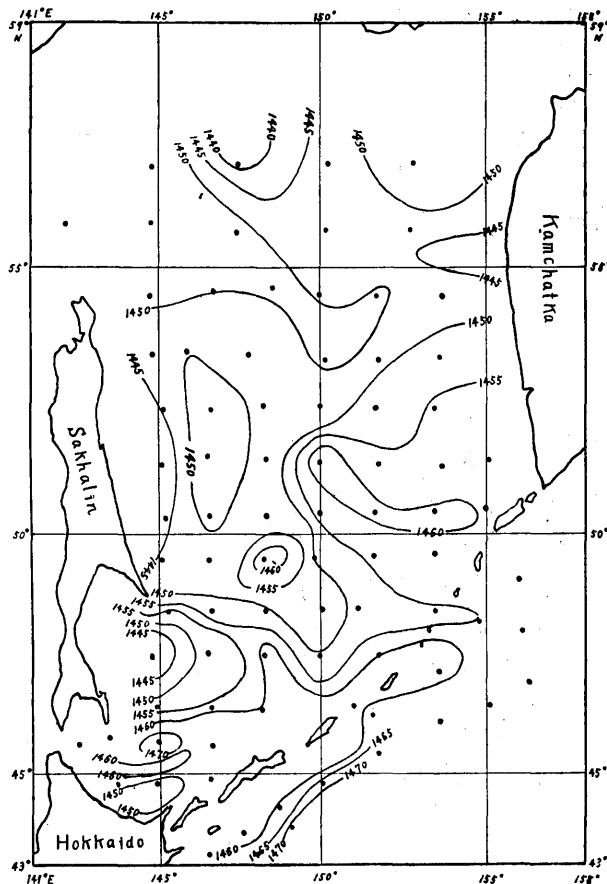


Fig. 2. Distribution of sound velocity (m/sec) at the depth of 25m.

reached the depth of 1200m

In order to get a general picture of the distribution of the sound velocity, the vertical distribution of the maximum and minimum sound velocity in each level of the Okhotsk Sea are shown in Fig. 1.

Below 200m level, the difference of the maximum and minimum sound velocity is relatively small, but it is greater as compared with the Japan Sea and amounts to 4m/sec even at a 1000m layer.

In Fig. 2 the horizontal distribution of sound velocity at a 25m layer which nearly represents the top of the sound channel is shown. As is seen from the figure, equal velocity lines indicate several curly patterns and the sound velocity changes from 1460m/sec of the southern part to 1440m/sec of the northern part. A high velocity region develops into the central region of the sea from north Kurile.

The distribution of the sound velocity on the axis of a sound channel and the depth of the axis are shown in Fig. 3. The sound velocity gradu-

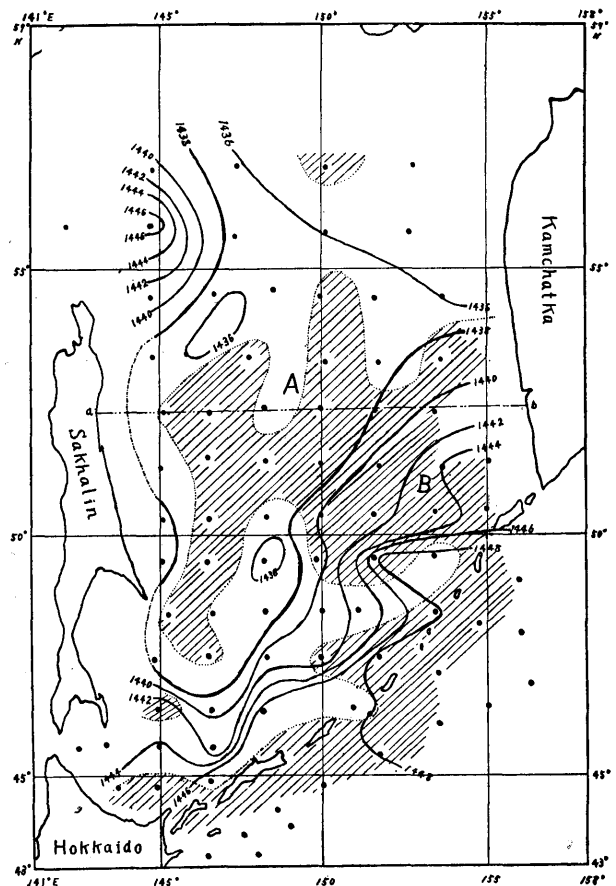
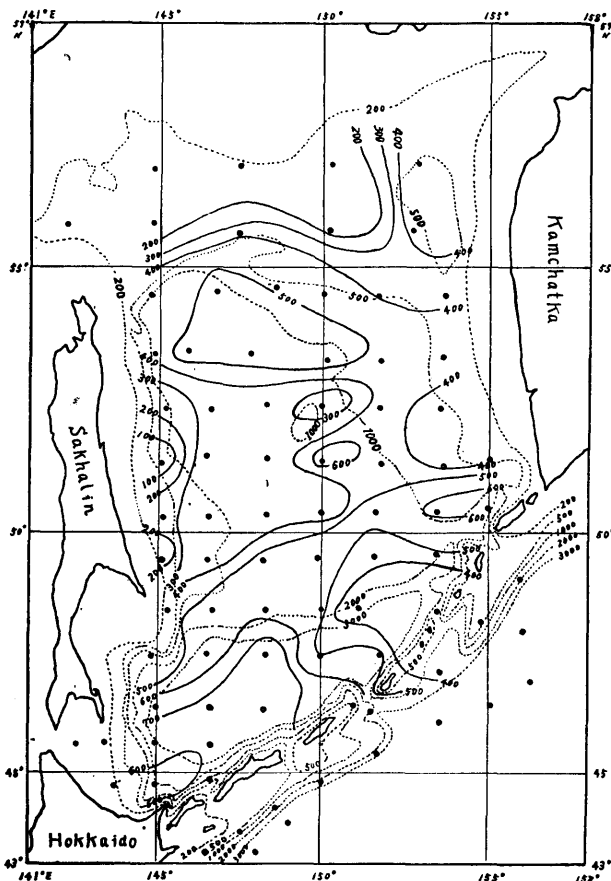


Fig. 3. Distribution of sound velocity (m/sec) on the axis of sound channel and the depth (m) of the axis.



ally decreases from the maximum value of 1448m/sec around north Kurile towards north and reaches 1436 m/sec in the north of 55° N. The area contained between 1438m/sec and 1436m/sec iso-lines occupies the major part of the central region of the Okhotsk Sea where the velocity gradient is most gentle. The axis of a sound channel is usually found in the layers of 50, 75 and 100m. In Fig. 3 a shadowed zone represents the part where the axis lies below 75 m, while the other region represents the part where it is found in a 50m layer.

The thickness of a sound channel which is the distance between the top and the bottom of the channel is shown in Fig. 4, together with iso-bathymetric lines of the sea. In this figure the distance between a 20

Fig. 4. Distribution of the thickness (m) of sound channel and bathymetric chart (depth in m, dashed line) of the Okhotsk Sea.

layer and a lower layer of the same velocity is shown. The thickness of the sound channel varies from 100m to 700m and is generally large in the southern part and decreases towards the north.

In Fig. 5 vertical section of the sound channel along the parallel circle of 52°30'N and the vertical distribution of the sound velocity in the same section (line ab in Fig. 3) are shown. The equal velocity lines of wavy form run symmetrically with respect to the axis and their phases vary in a reverse direction with the depth.

The distribution of the limiting angle which is the angle between the limiting ray and the axis is shown in Fig. 6.

It changes from 4° to 10° and, as a whole, its pattern is very complicated. The limiting angle is given by the following formula,

$$\theta_0 = \arccos \frac{v_0}{V} \dots \dots \dots (1)$$

where θ_0 , V and v_0 denote the limiting

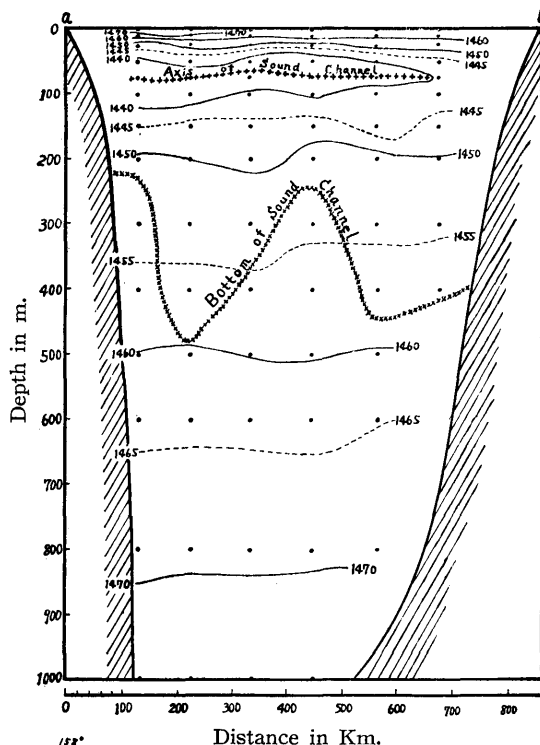
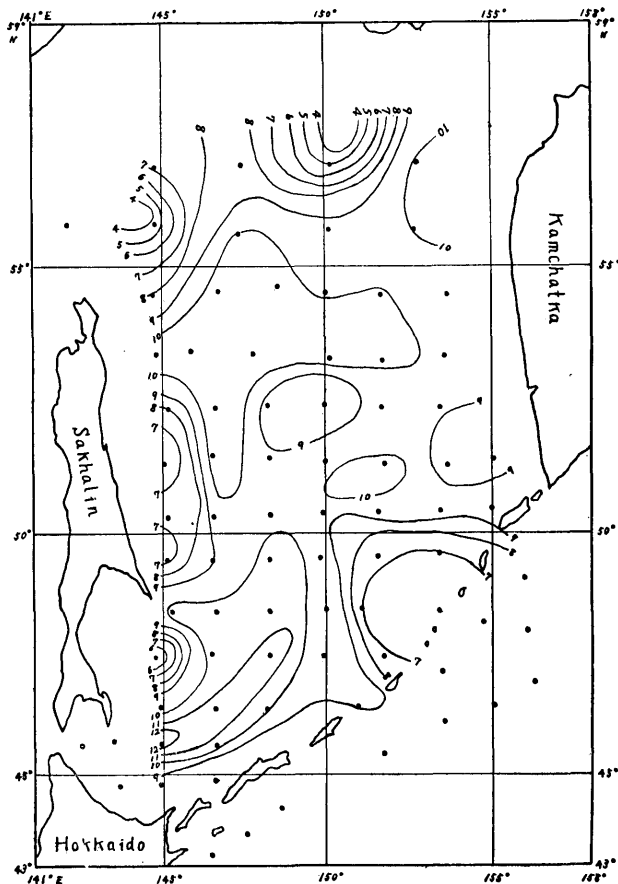


Fig. 5. Distribution of sound velocity (m/sec) in the vertical section shown by the line ab in Fig. 3.



angle, the velocity at the top and axis respectively. Denoting the mean value of v_0 as v_{0m} and putting $V - v_0 = \delta v$, we get from (1)

$$\theta_0 = \arccos \left(\frac{v_{0m}}{v_0 + \delta v} \right) \dots \dots \dots (2)$$

In the Okhotsk Sea v_0 varies from 1436 to 1448m/sec and δv is less than 40m/sec. In Fig. 7, the relation between θ_0 and δv as given by (2) is shown graphically. This diagram may be used to calculate the limiting angle for different levels of the top with the assumed 20m layer and is also useful for the estimation of the horizontal bending of a sound ray from the horizontal distribution of the sound velocity.

The average sound intensity I_{av} of sound channel is given by the formula

Fig. 6. Distribution of limiting angle (degree) of sound channel.

$$I_{av} = \frac{2\theta_0}{h} \dots\dots\dots(3)$$

where h means the thickness of a sound channel. In Fig. 8 the distribution of I_{av} is shown. It increases from $5 \times 10^{-4}/m$ of

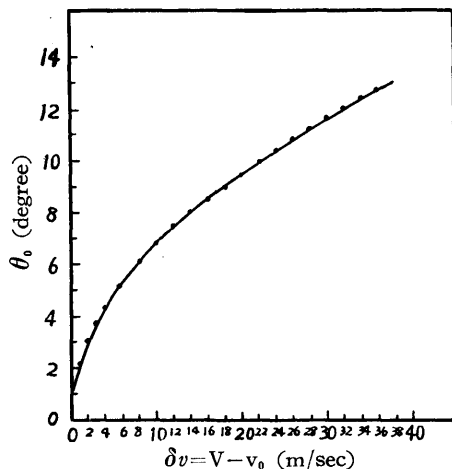


Fig. 7. $\theta_0 - \delta v$ diagram

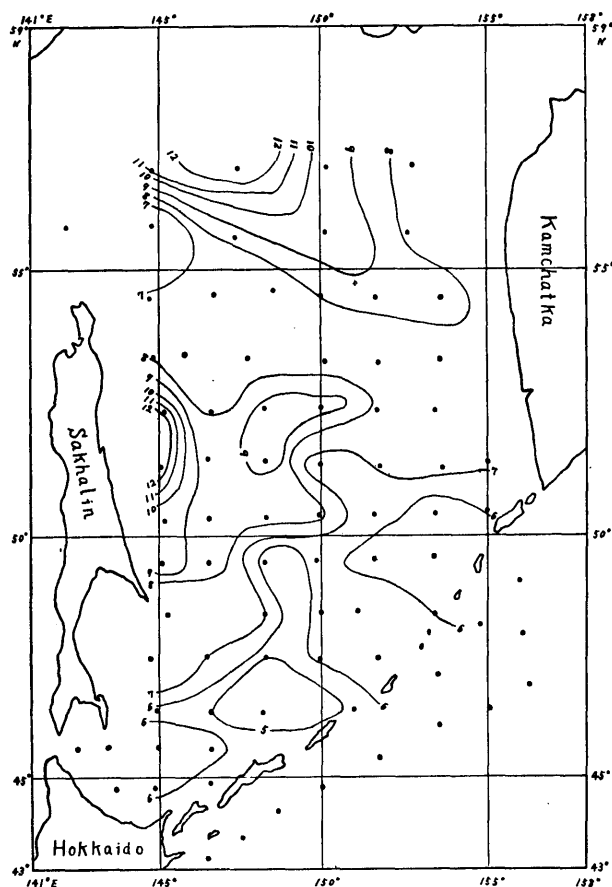


Fig. 8. Distribution of intensity ($10^{-4}/m$) of sound channel.

the southern part to $12 \times 10^{-4}/m$ of the northern part. With respect to the sound channel characteristics hitherto considered, the Okhotsk Sea may be divided into several regions and the author provisionally divided it into two regions A and B.

The region A occupies the part where the sound velocity at the axis lies between 1436 and 1438 m/sec, while the region B indicates the part south of 1438 m/sec isoline and has a larger sound velocity. The parts other than A and B occupy a major part of the region shallower than 200 m and have little meaning for SOFAR. The regions A and B may be further divided into subregions which have the same level of the axis and are denoted by A_{50} , A_{75} and B_{75} , B_{100} where suffix means the level of the axis. The mean sound velocity at each level of these subregions is shown in Table 1 and is also graphically shown in Fig. 9. In every subdivision an inflection point is clearly found at a depth of 150 m. In Table 2, an average character of the sound channel derived from Table 1 is outlined. As is seen from Table 2, the subregions A_{50} and A_{75} have similar character, while the subregions B_{75} and B_{100} indicate a different character.

Table 1. Average sound velocity classified by sound channel axis in the Okhotsk Sea

Region	A_{50}	A_{75}	B_{75}	B_{100}
Depth (m)				
0	1482.5	1478.9	1477.0	1472.0
10	78.8	72.0	73.1	70.4
25	48.6	51.7	53.5	56.3
50	36.8	38.7	44.2	48.3
75	37.8	36.7	40.9	46.2
100	40.8	39.2	45.1	45.3
150	47.6	47.6	47.3	46.9
200	49.9	50.2	50.3	49.6
300	52.8	53.3	53.4	53.3
400	55.7	56.0	56.3	57.2
500	59.3	60.4	59.8	60.5
600	62.8	64.1	63.4	63.5
800	69.1	69.2	68.9	69.8
1000	73.1	73.1	72.8	73.2
1200	76.5	76.6	76.3	76.5

Table 2. Character of sound channel in the Okhotsk Sea.

Region	Sound velocity		Limiting Angle	Thickness of C. S.	Velocity gradient (per m)		Half wave length of L. R.		Propagation time for one wave Length of L. R.	Propagation time of L. R. for 100km (Lt)	Propagation time of a ray on the axis for 100km (At)	At - At
	On the top and bottom of S. C.	On the axis of S. C.			Upper side of axis	Lower side of axis	Upper side of axis	Lower side of axis				
A ₅₀	(m/sec) 1458.6	(m/sec) 1436.8	(°) 9.55	(m) 460	(m/sec) 0.7267	(m/sec) 0.0507	(m) 690	(m) 9910	(sec) 7.338	(sec) 69.23	(sec) 69.60	(sec) 0.37
A ₇₅	1458.5	1436.7	9.55	440	0.3964	0.0566	1270	8870	7.019	69.22	69.60	0.38
B ₇₅	1460.1	1440.9	9.18	490	0.3491	0.0441	1350	10690	8.318	69.08	69.40	0.32
B ₁₀₀	1461.1	1445.3	8.26	500	0.1975	0.0372	2170	11390	9.347	68.93	69.19	0.26

S. C. denotes sound channel, and L. R. limiting ray.

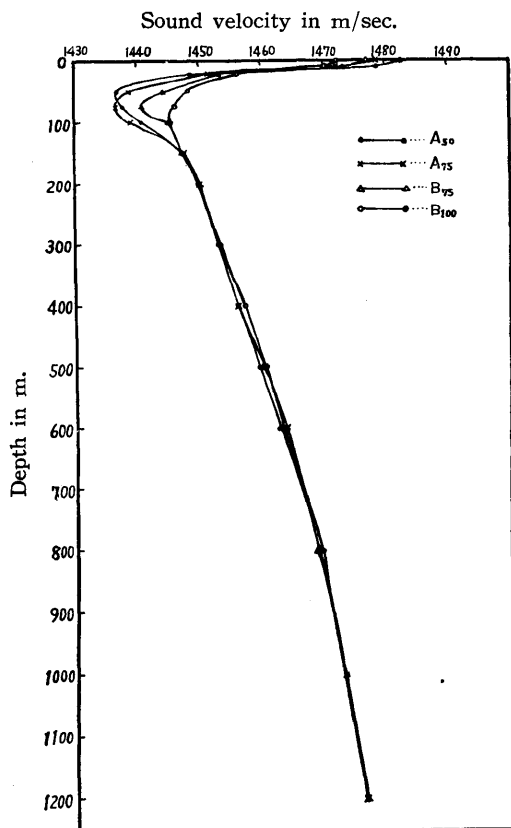


Fig. 9. Vertical distribution of the average sound velocity classified by sound channel axis.

Sound channel transmission in the Okhotsk Sea

The long range sound transmission in the Okhotsk Sea may be inferred from

the character of its sound channel. In the Okhotsk Sea, as was discussed in the previous chapter, a sound channel is formed in its entire region deeper than 200m. It approaches most closely to Hokkaido at a point about 5km off Shiretoko promontory. In the region A which is enclosed by 1438 m/sec iso-line, an area of the minimum sound velocity at the axis of the sound channel is found. A sound wave, therefore, will converge into the region A and the energy loss will be small in the same region. The region A is supposed to be caused by anticyclones developed over there. Although the horizontal distribution of sound velocity in the vicinity of the top is somewhat complicated, it will not appreciably affect the sound transmission, because a large portion of the sound energy is confined near the axis. The sound intensity in a layer of 50m in thickness containing the axis is about three times larger than the mean intensity in the total layer of the sound channel.

The sound transmission in winter deserves special attention. As an example, the vertical distribution of sound velocity in winter is shown in Fig. 10. It is derived from the observed temperature and salinity at one station (Lat. 44°09' N, Long. 155°36' E) in the south of Kurile Islands obtained by Tenyomaru—a survey ship of the Tokai Fisheries Research Institute—on May 5, 1953. As is seen from this figure, the sound velocity is minimum at the surface and increases downwards. From December to

April of the next year a similar condition seems to prevail in the Okhotsk Sea. During this season the sound channel can not be formed and the sound channel transmission will be impossible. In the Okhotsk Sea the horizontal extension of the sound channel is about 1000km which seems to be short for this type of sound transmission.

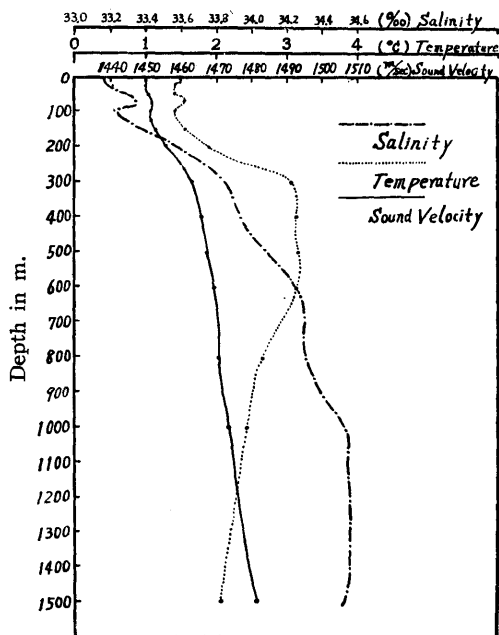


Fig. 10. Vertical distribution of sound velocity at one station (44.°09' N, 155.°36' E) in the south of Kurile Islands.

Summary

1. In a cold sea like the Okhotsk, the top of a sound channel, if any, lies on or very near the sea surface and various disturbances of the sea surface affect the sound channel transmission. Considering the acoustical and oceanographical conditions, the author provisionally fixed a 20m layer as a practical limit of the top.

2. In the Okhotsk Sea a sound channel is formed in the entire region deeper than 200m except in winter and SOFAR transmission is possible.

3. In the central region of the Okhotsk Sea which is enclosed by 1438m/sec iso-line the sound velocity decreases inwards, so that a sound ray tends to coverge into this region.

4. From December to April of the next

year the sound velocity is supposed to be minimum at the sea surface. During this season a sound channel can not be formed and the use of SOFAR is hopeless.

5. The sound channel approaches most closely to Hokkaido at a point 5km off Shiretoko promontory.

6. The horizontal extension of the sound channel in the Okhotsk Sea is about 1000 km which seems to be short for this type of transmission.

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