ON ANALYSIS AND GEOLOGICAL INTERPRETATION FOR THE RECORDS OF CONTINUOUS SEISMIC PROSPECTING

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Abstract

Sonic survey is one of the most useful means for marine geological surveying. When surveying courses are properly arranged and some knowledges on bottom rock are prepared by any method else, it is possible to compose an under-sea geological map as well as continuous profiles by analysing sonic records.

In this paper, the present writer describes his analysing method and interpreting procedures which have been used in the case of Tsugaru and Akashi Straits, with some illustrations of reflective pattern as characteristic features corresponding to lithological conditions.

1. Introduction.

In Japan, sonic survey was performed at the first time in summer of 1959 by Marine Geophysical Services International Inc. with its Continuous Seismic Profiler (so-called Sparker) at several localities as shown in Table 1.

The records obtained in Tsugaru and Akashi Straits have been analysed and interpreted by the present writer comparing them with the great many bottom samples which were previously bored or dredged, and their geological structure becomes remarkably clearer than it was.

TABLE 1. SONIC SURVEY IN JAPAN, IN 1959.

Surveyor	Locality	Date	Motive
Japan Petroleum Exploration Co.	Off the coast of Akita, Sakata, Niigata and Kashiwazaki	21, Mar.—20, June	under-sea oil field
Road Bureau, Ministry of Construction	The Inland Sea of Seto	21, June—3, July	over-sea bridge
Geological Survey	The Bay of Ariake	4,—23, July	embankment for reclamation
Japanese National Railways	Straits of Akashi, Naruto and Tsugaru	24, July—19, Aug.	interisland-through railway (under-sea tunnel or over-sea bridge)
Pacific Coal Mine Co.	Off the cost of Kushiro	20,—31, Aug.	under-sea coal field

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In this paper, he wants to write on his analysing method refering especially to the reflective patterns of various formations corresponding to their lithological, textural and outcroping features.

2. Procedure for Analysing C.S.P.'s Records.

Looking from the essential properties of sonic prospecting, C.S.P.'s records should be analysed and interpreted in the following order:

(1) All patterns due to diffractions or abnormal reflections are ignored, and only those reflections from physical boundaries showing geological structure are picked up.

(2) By comparing these picked-up reflections with dredged samples or bored cores from the sea bottom, it is to be determined to what rock or formation they correspond. If we have no bottom rock samples to be compared, we must seek similar patterns among many records on neighbouring survey cources, and temporary assumption on rock or formation should be made.

(3) On every intersection point of two survey courses, after the depth of water and the charactor and apparent thickness of rock or formation are cheked to see if they coincide with each other, the dip direction should be determined on every bedding plane, and the strike and dip of that is calculated.

(4) For these calculations, every survey course must be exactly positioned. If remarkable mispositioning is found by the above checks, the real track of the survey boat should be supposed by the relief of the sea bottom expressed in C.S.P.'s record, comparing with previously drawn detailed sea-bottom contour map.

(5) Faults, unconformities, synclinal and anticlinal structures can easily be found on well "Sparkered" records, and their extension will be traced considering the distribution of strike and dip.

(6) All the data thus obtained are expressed into a geological map and, if necessary, the thickness of bed or formation is calculated and geological section profiled.

3. Reflective Pattern of Formation

Seeing from many C.S.P.'s records compared with bottom rock samples, geological condition seems to be most characteristic to the reflective pattern, though this depends on many factors such as mechanical or electrical control, ship's speed, wave or swell of sea-water, bottom topography, etc.

In egneous rocks, heavy diffraction occurs usually and reflective pattern is often so strongly complicated that definite texture can hardly be recognized (Figs. 1 & 8). Similar pattern is generally common in hard, blocky formations such as Palaeozoic system or tuff breccia, too.

On the contrary, soft, loose and massive rock is poorly reflective and its pattern shows misty appearance, on which, however, steep stripes are some-times conspicuous as if swept with a brush (Fig. 5). These would be caused by diffraction due to topographic relief of sea bottom.

In layered formation, banded pattern appears according to its manner and grade of stratification. For instance, muddy zones in Kunnui Formation, intercalated with some tuff or tuff breccia, are intensely reflective and show distinct bedding, each stripe of which, however, is undulated and continues laterally not so far (Figs. 3 & 7), while in Yakumo Formation, characterized by well banded structure of typical hard shale, all the stripes can be clearly traced far away (Figs. 4 & 8). The markedly continuous bands in Fig. 6 represent marly layers in massive, relatively loose, tuffaceous siltstone of Kuromatsunai Formation, and they serve us as best key to reveal geological structure.

Gravel beds or conglomerates are generally highly reflective, but each stripe is not so continuous, and cross bedding is often found in some younger deposits (Figs. 3 & 8). The light and dark expressed in the pattern of Akashi Formation (Fig. 2) are understood as they correspond to some slight difference in their gravelly constituents.

It is to be noticed that different patterns may be obtained at the same locality according to the angle between the direction of survey course and strike of bed, especially in case of formation alternated with members of fairly different lithological characters.

4. Determination of Strike and Dip.

Strike and dip of a reflective bed is to be determined at a crossing point of two survey courses. In Fig. 9, say

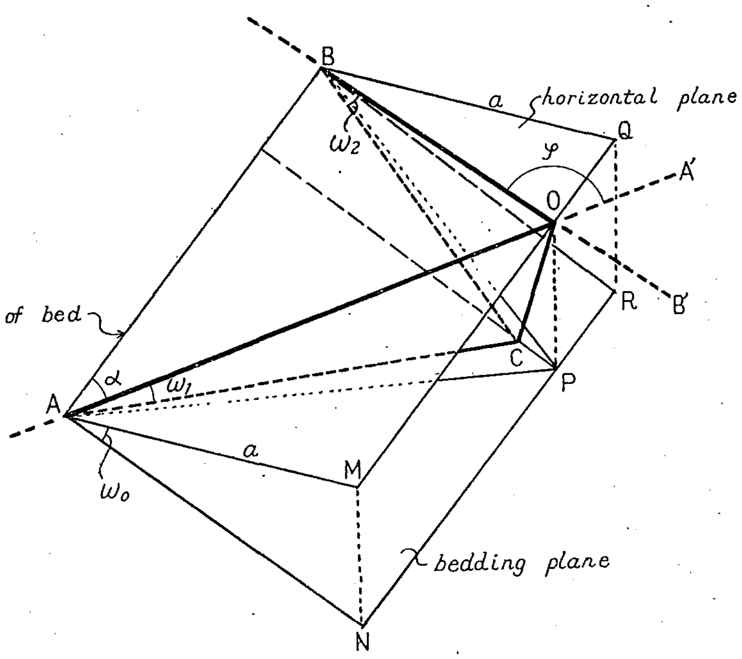


Fig. 9 Determination of strike and dip of a bed.

A–B .... strike of a bed
AOA' .... a survey course
BOB' .... another survey course
$BAMOQ$ .... horizontal plane
$BANPR$ .... plane of reflective horizon
O .... a crossing point of two survey courses
OC .... a normal from point O to the bedding plane BANR
OCA, OCB ...... planes of reflection, perpendicular to bedding plane

ω_0 = true dip of a bed

ω_1 = apparent dipping angle measured on a length-scaled profile derived from the sonic record along course A–A'

ω_2 = ditto along course B–B'

$a = AM \equiv BQ$

α = angle between strike of the bed and survey course AOA'

φ = angle from survey course AOA' through the strike of bed to course BOB'

then the following relations are found.

$$\begin{cases} OC = a \sin \omega_0 \\ OA = a \operatorname{cosec} \alpha \\ OB = a \operatorname{cosec} (\varphi - \alpha) \end{cases}$$

$$\therefore \begin{cases} \sin \omega_1 = OC/OA = \sin \omega_0 \sin \alpha \\ \sin \omega_2 = OC/OB = \sin \omega_0 \sin (\varphi - \alpha) \end{cases}$$

So α and ω_0 are given by next equations.

$$\begin{cases} \cot \alpha = 1/\sin \varphi \left(\dfrac{\sin \omega_2}{\sin \omega_1} + \cos \varphi \right) \\ \sin \omega_0 = \dfrac{\sin \omega_1}{\sin \alpha} \end{cases}$$

$$\text{or} \qquad \sin \omega_0 = 1/\sin \varphi \, (\sin^2 \omega_1 + \sin^2 \omega_2 + 2 \sin \omega_1 \sin \omega_2 \cos \varphi)^{\frac{1}{2}}$$

In order to get ω_1 and ω_2 in practical analysis of C.S.P.'s record which ordinate and abscissa are both scaled in time function, it is necessary to know the actual distance between every marked position and the velocity with which sonic wave propagates. Though the latter (velocity of rock) cannot be exactly determined unless a refractive seismic survey is made, the auther proposed a particular method by which approximate velocity is directly obtained from C.S.P.'s record itself (Chapter 7).

5. Recognition of Geological Structure.

On well "Sparkered" records, it is not difficult to find faults, unconformities, synclinal and anticlinal structures. Faults are noticed by sharp shift (Fig. 2) or interruption (Figs. 5 & 7) of a layer, sudden change of dip (Fig. 3), turn up or down of layers, existence of disturbed (Fig. 4) or feeble-reflective zone (Fig. 7) and so on.

When folding, every layer bends gradually and continuously, and unconformity is recognized as a younger formation covers the older with discordant bedding plane (Figs. 2, 3 & 8).

6. Calculation of Thickness of Bed.

When the sea bottom is practically even, true thickness Q of a bed can be obtained by next formula.

$$Q=H\sin\omega_0 \qquad (2)$$

where: H=exposed width of a bed measured along the direction of true dip.

ω_0=angle of true dip.

But along a survey course which does not coincide with the direction of true dip, we can get only an apparent dip angle ω_1 which has next relation (Chapter 4 & Fig. 9),

$$\sin\omega_1=\sin\omega_0\sin\alpha=\sin\omega_0\cos\beta \qquad (2)$$

where: α=the angle between the direction of survey course and strike.

β=angle between survey course and direction of true dip.

While in Fig. 10b,

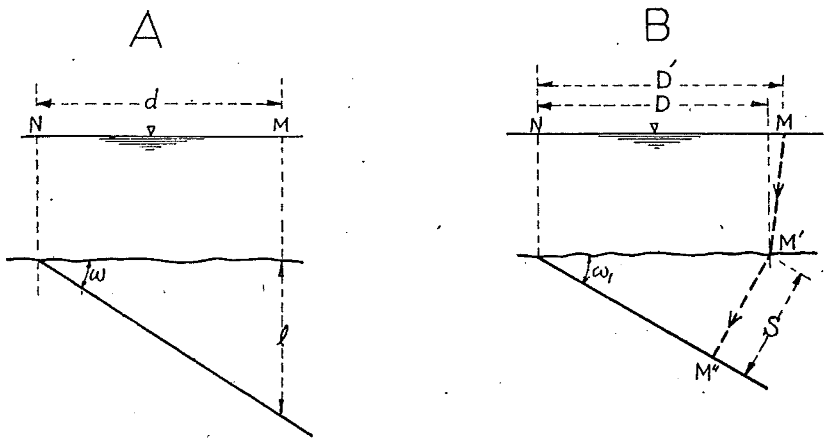


Fig. 10 CSP's record (A) and actual profile (B)

$$\sin\omega_1=S/D \qquad (3)$$

and S is to be calculated from C.S.P.'s record as a travel-time of reflected wave approximately by equation (4), because S is a normal to a reflective boundary from a point M′.

$$S=\frac{T}{2}\times\frac{l}{L}\times v \qquad (4)$$

where : v=velocity (m/sec) of sonic wave in the bed.

T=sweep time(sec).

L=length(cm) of abscissa of C.S.P.'s recording paper corresponding to the given sweep time.

l=reading(cm) on abscissa from sea bottom to the reflective boundary at the point M on C.S.P.'s record.

While in Fig. 10a,

$$l = d \tan \omega \tag{5}$$

where : d=lateral length(cm) between neighbouring position marks M and N on given C.S.P.'s record.

So, from (2), (3), (4) and (5), $\sin \omega_1$, S and l are eliminated as

$$\sin \omega_0 = \frac{T}{2} \times \frac{1}{L} \times v \times \frac{d}{D} \tan \omega \operatorname{cosec} \alpha = \frac{T}{2} \times \frac{1}{L} \times v \times \frac{d}{D} \tan \omega \sec \beta .$$

Then, thickness Q may be determined from (1) as follows.

$$Q = \frac{T}{2} \cdot \frac{1}{L} \cdot v \cdot \frac{d}{D} \cdot H \tan \omega \operatorname{cosec} \alpha$$

$$= \frac{T}{2} \cdot \frac{1}{L} \cdot v \cdot \frac{d}{D} \cdot H \tan \omega \sec \beta$$

Here, though D means essentially the horizontal distance between M' and N in Fig. 10b, we can substitute the horizontal distance between M and N if ω is so smaller and D is so larger comparing with depth of water that the refraction around M' could be practically ignored.

7. Determination of Velocity with which Sonic Wave Propagates.

When a cylindrical syncline assumable to a part of a circle is found, sonic velocity may be directly determined from C.S.P.'s record itself.

In Fig. 11,

v=velocity in a bed.

R=radius of circular syncline.

H=horizontal distance from an outcrop at sea bottom to the centre of syncline.

T=travel time of reflected wave from the sea bottom to the reflective bed, at the centre of syncline.

t=travel time of reflected wave from the sea bottom to the reflective bed, at a point $H/2$ apart from synclinal centre.

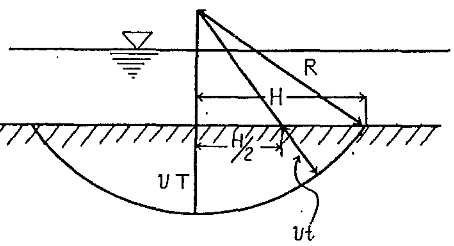


Fig. 11 Circular syncline

then right-angled triangle leads to following relation.

$$\begin{cases} R^2 = H^2 + (R - vT)^2 \\ (R - vt)^2 = \left(\dfrac{H}{2}\right)^2 + (R - vT)^2 \end{cases}$$

So R is eliminated as

$$v=\frac{H}{2}\sqrt{\frac{3T-4t}{tT(T-t)}}$$

In this way, $v=3050\ m/sec$ is obtained for Kuromatsunai Formation from the key of marly layers on the north-western wing (right-side in Fig. 6) of a large syncline newly found in the midst of western passage of Tsugaru Strait.

Explanation of Plates

Fig. 1

Course No. A 7, Akashi Strait, 1.5km off the coast of Nagahama, Awaji Island, Hyogo Prefecture.

Kb : Kobe Formation, alternation of sandstone and mudstone (Miocene).

G : granite.

Kobe Formation (right) abuts upon granite (left) unconformably.

Fig. 2

Course No. A 9, Akashi Strait, 2km off the coast of Tarumi, west of Kobe.

C : conglomalate.

B : conglomalate with some clayey layers.

A : basal boulder conglomerate.

A, B, & C: Plio-Pleistocene.

Kb : Kobe Formation.

Fig. 3

Course No. T 5, Tsugaru Strait, about 1.6km off the Cape of Shirakami, southernmost of Hokkaido Island.

Sd. : Komukai under-sea sand and gravel "dune", which is growing and migrating now.

Kn_2: lower muddy zone in Kunnui Formation, Miocene.

Kn_1: lowest green tuff and tuff breccia in Kunnui Formation.

F_{10} : fault

F_{51} : fault

Fig. 4

Course No. T 7, Tsugaru Strait, about 2.7km southeast of Yoshioka, Hokkaido.

Typical pattern of well-banded Yakumo Formation.

Note the disturbed pattern near "289".

Fig. 5

Course No. T 17, Tsugaru Strait, about 4.5km northeast of Tappi Cape.

Km_2: middle horizon (massive tuffaceous siltstone) of Kuromatsunai Formation, lower Pliocene.

ml : marly layers in Km_2.

Km_1: basal horizon of Kuromatsunai Formation.

Yk : Yakumo Formation, upper Miocene.

Kn : Kunnui Formation (tuff breccia).

F_3, F_{14}, F_{17} : faults.

Fig. 6

Course No. T 19, Central part in the western passage of Tsugaru Strait.

Tc : deposits of drowned coastal terrace.

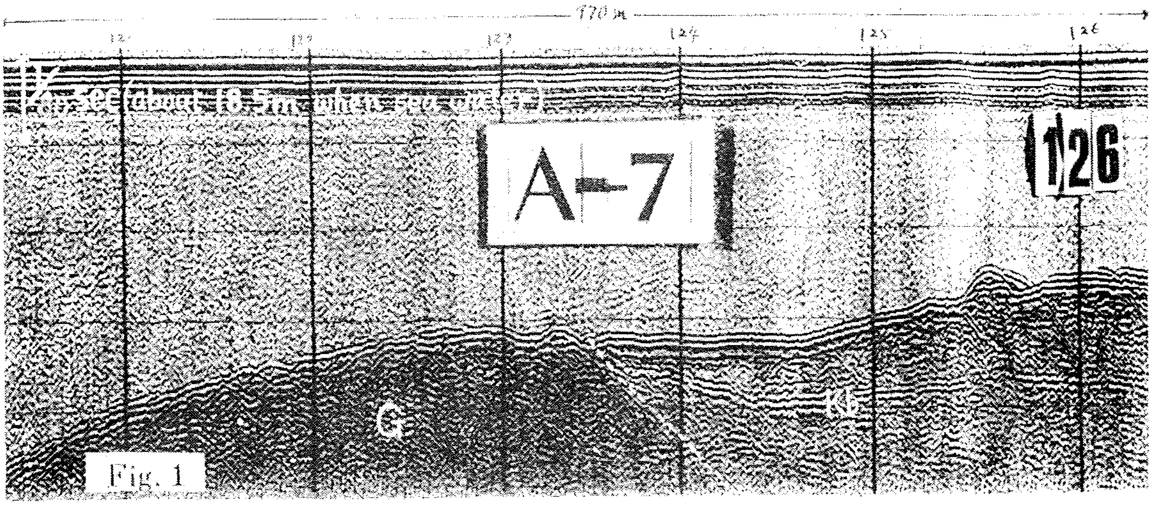

770 m
124
125
126
A-7
126
G
Kb

Fig. 1

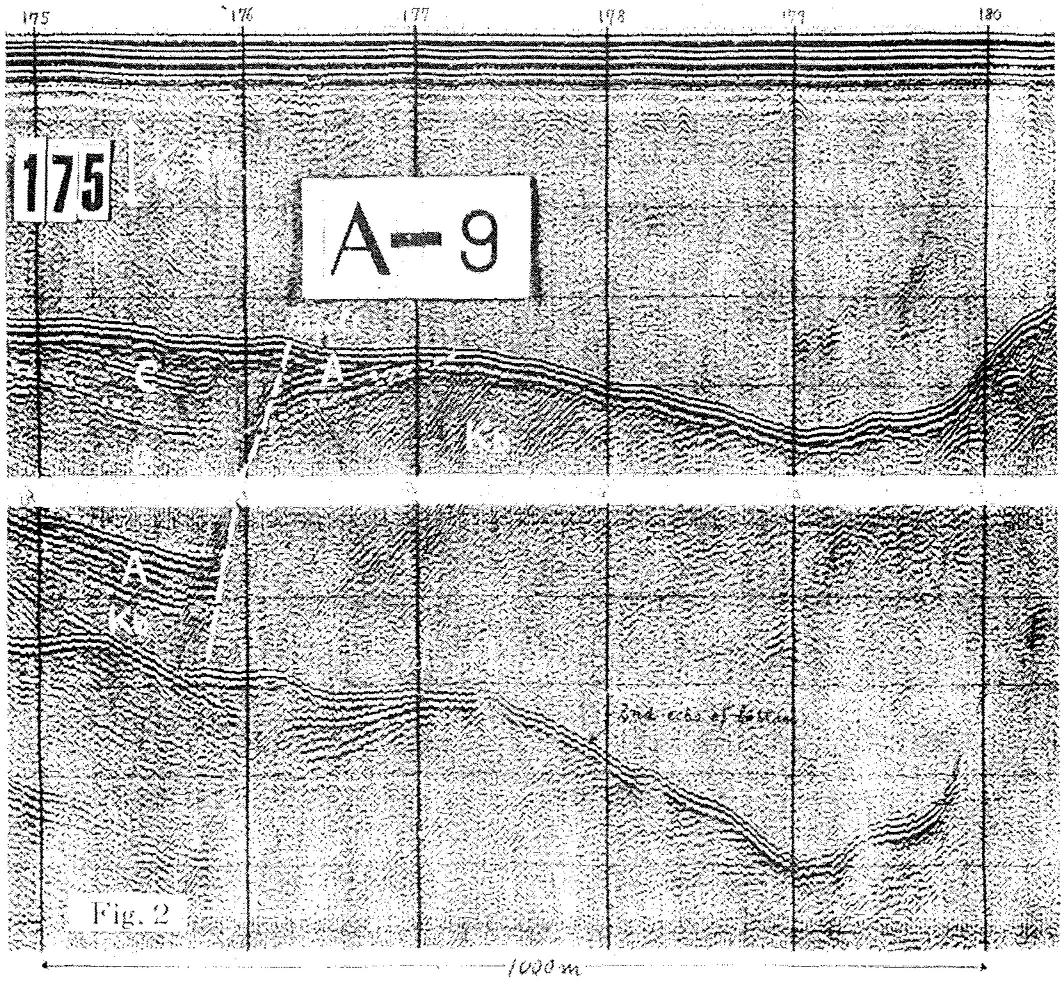
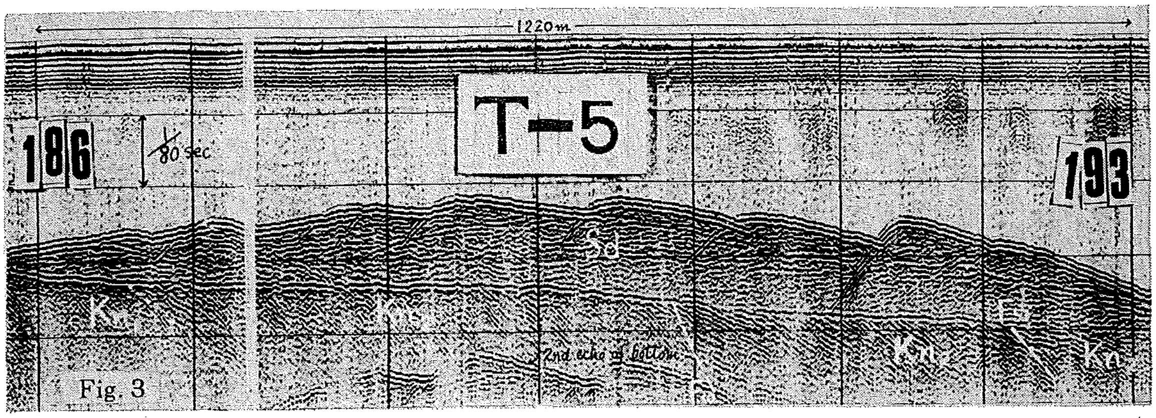
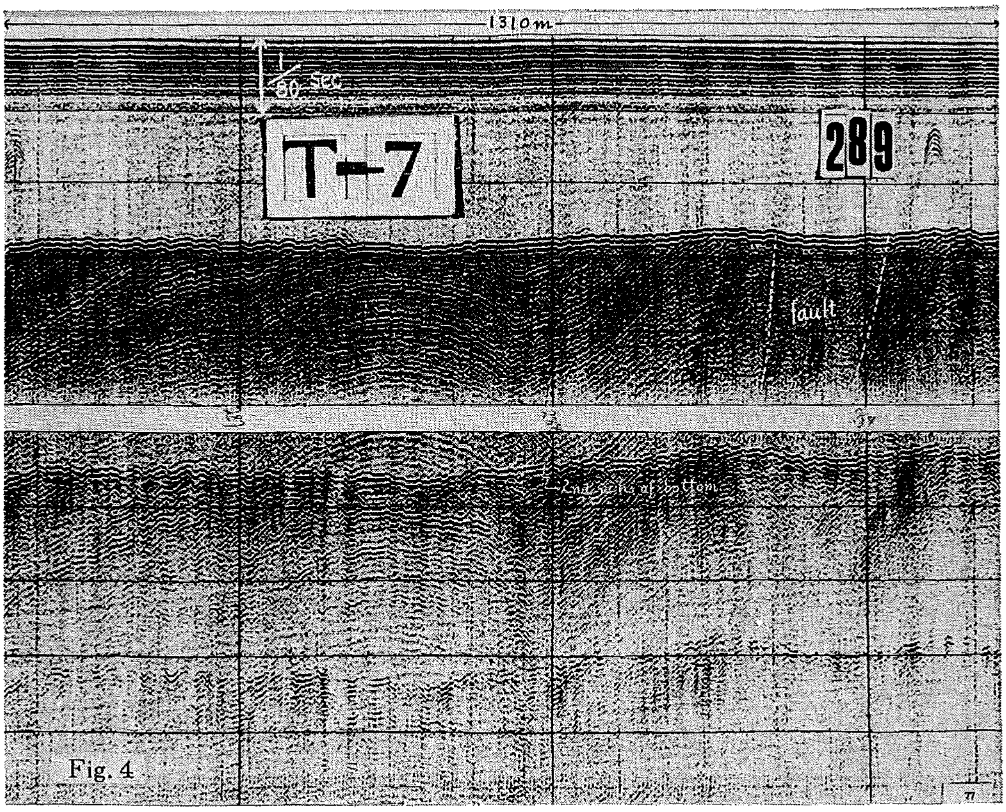

175
176
177
178
179
180
175
A-9
C
A
Kb
A
Kb
2nd echo of bottom
1000 m

Fig. 2



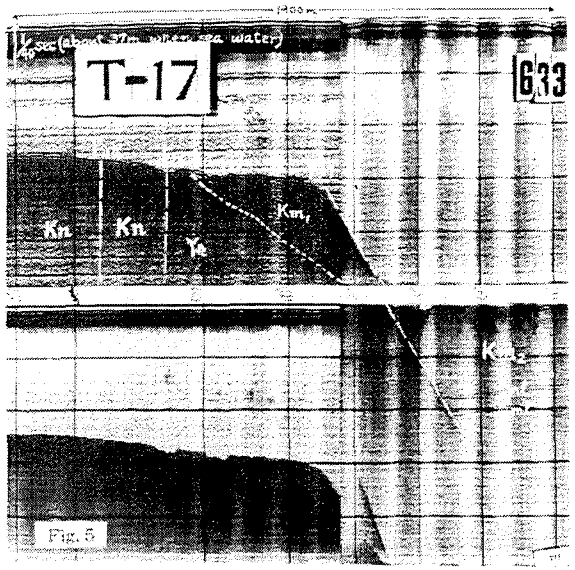
1220m
T-5
186
1/80 sec
193
Sd
Kn
Kns
2nd echo of bottom
Kn
Kn

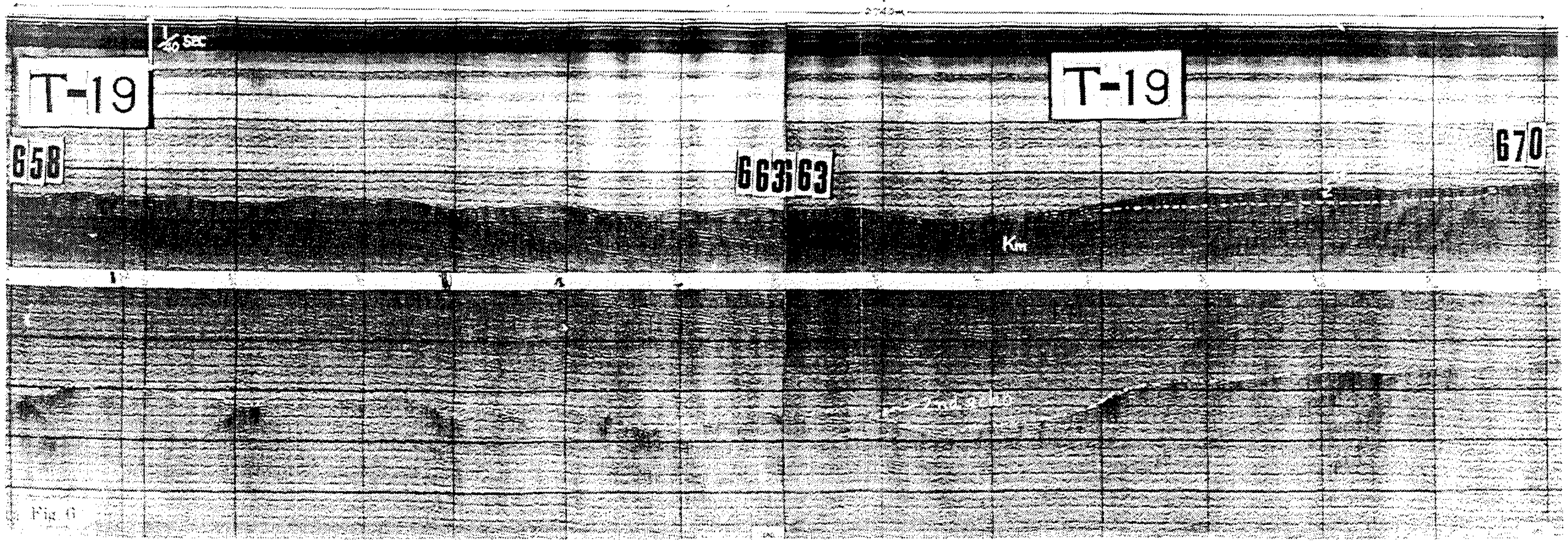
Fig. 3



1310m
1/80 sec
T-7
289
fault
2nd echo of bottom

Fig. 4


T-17
633
Kn
Kn
Ye
Km_1
Fig. 5


$\frac{1}{40}$ sec
T-19
658
663
63
T-19
670
Km
Fig. 6

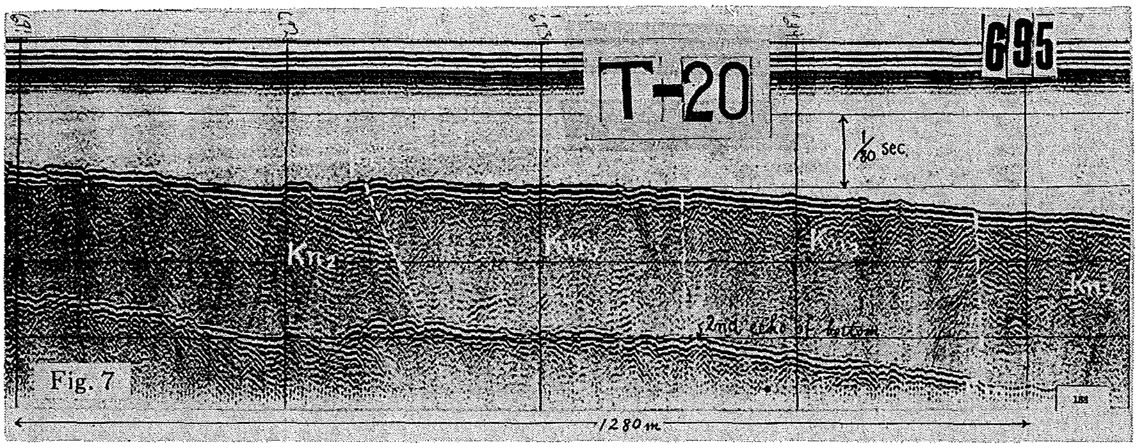

T-20
695
1/80 sec.
2nd echo of bottom
1280 m

Fig. 7

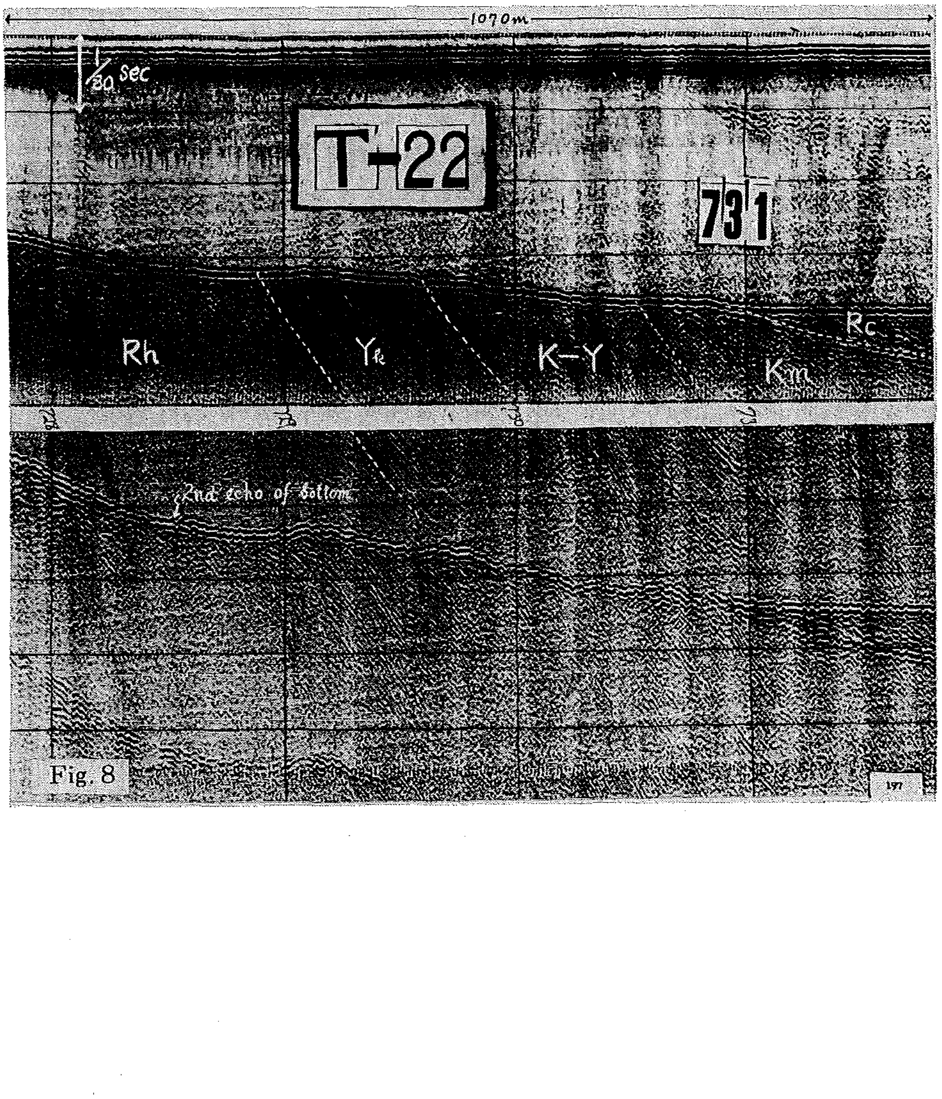

1070 m
1/30 sec
T-22
731
Rh
K-Y
Km
Rc
2nd echo of bottom

Fig. 8

Km : Kuromatsunai Formation, mainly composed of tuffaceous massive siltstone. Distinct bands are marly layers.

Note and contrast the "Cuesta" relief in left and quite even bottom surface in right.

Fig. 7

Course No. T20, Tsugaru Strait, about 1.7km off Yoshioka, Hokkaido.

Kn_3: middle tuffaceous zone in Kunnui Formation.

Kn_2: lower muddy zone in Kunnui Formation.

F_{10} : fault

F_{55} : fault

F ?: fault (may be)

Note feesible reflection between F_{55} and F_{10}.

Fig. 8

Course No. T 22, Tsugaru Strait, 2km off the coast of Tsugaru Peninsula.

Rc : drowned terrece deposit.

Km : Kuromatsunai Formation, massive tuffaceous siltstone.

K-Y: transitional zone between Km and Yk (tuffaceous siltstone with some marly layers).

Yk : Yakumo Formation, characterized by well banded structure of typical hard shale.

Rh : rhyolitic intrusives.