VI. STRUCTURAL ANALYSIS OF THE FRONTAL ARC OF THE NORTHERN PART OF THE OGASAWARA ARC BASED ON SEISMIC REFLECTION PROFILING

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Continuous seismic reflection measurements were carried out along the traverse lines for the purpose of constructing a Geological Map of the Area Northeast of Hachijojima (Hachijo) Island (Fig. I-3).

Methods and equipment used for these measurements are summarized in Table VI-1. The sound output pulse of a BOLT PAR 1900C air gun with a

Table VI-1 Equipment and conditions of the seismic reflection survey

1)	Equipment	
	Air Gun	Bolt Par Air Gun 1900C×2
	Compressor	Norwalk APS-120 (120 S.C.F.M.)
	Receiver	GSJ Hydrostreamer (with 98 elements of Teledyne TI 18 cm spacing and Ithaco 125L preamp) Jul. 3–Jul. 25
		GSJ Hydrostreamer (with 100 elements of Geo Space MP18-200 20 cm spacing and Ithaco 125L preamp) Jul. 25–Aug. 3
	Amplifier	Ithaco 451 Amplifier
	Recorder	Raytheon UGR-196B and LSR-1811
2)	Conditions	
	Volume of air gun	120 in^3 (1967 cm^3) with wave-shape kit
		150 in^3 (2458 cm^3)
		120 in^3 (WSK) + 150 in^3 = 270 in^3 (4425 cm^3)
	Pressure	1500 p.s.i. (105 kg/cm^2)
	Shot interval	7 sec
	Filter range	50 to 160 Hz for 120 in^3 (WSK) air gun shot
		40 to 125 Hz for 150 in^3 and 270 in^3 air gun shot
	Record range	4 sec
	Ship speed	10 knots
	Ship speed	10 knots

120 in^3 firing chamber and wave-shape kit is sharper in wave shape and lower in output energy than that of a 150 in^3 firing chamber. A sharp output pulse shape is advantageous in analysing the reflectors of a rather shallow sea bottom, but a low energy pulse is not very useful for determining deep structures. In the greater part of the surveyed area, especially in the southern area, the water depth is less than 1000 m, and we could obtain useful data in a record range of three

or four seconds. The air guns were shot alternatively in the areas where the water depth was less than about 1500 m and simultaneously in the areas where the depth was greater. The air gun with the 150 in^3 firing chamber was shot three seconds after the air gun with the 120 in^3 firing chamber and wave-shape kit. For each air gun the shot interval was seven seconds. We obtained two different reflection profiles along each traverse, as shown in Figures VI-1a, b.

Eleven profiles are presented in Figures VI-1 to VI-11. Lines 4, 8, 10, 13, 16, 24, 28 and 33 are east-west sections and lines 53, 56 and 60 are north-south sections. In the text, the sediment thicknesses are expressed indirectly in terms of two-way acoustic travel time.

Only preliminaly results and discussions are given here. More detailed interpretation of the data will be reported in the Geological Map of the Area Northeast of Hachijojima Island, one of the maps to be included in the Marine Geology Map Series of the Geological Survey of Japan.

The eastern continental slope

The eastern continental slope appears on the eastern flank of the Kitakurose Bank and the Shinkurose Bank and dips at about two degrees to the east. The continental slope is composed of three distinct layers, an upper stratified layer, a middle wavy layer and a lower highly reflective and massive layer (See Figs. VI-2, -6 and -9. U: upper layer, M: middle layer, and L: lower layer).

The upper layer appears to be composed of mudstone or silty sandstone according to the rock sampling, and seems to have been transported from the banks. The upper layer thickens to the east to approximately half a second at about 1500 m water depth.

The wavy feature of the middle layer suggests the existence of a transportation current. The thickness of the middle layer is almost uniform at half a second over the entire continental slope. However, the wavy feature in each section is not uniform. To the northeast of the Kitakurose Bank the wavy feature is not as well developed as those in the other parts of the eastern continental slope. To the southeast of the Shinkurose Bank, the lower half of the middle layer becomes transparent (Fig. VI-2).

In the northern half of the surveyed area, the upper layer is cut by three canyons running in an east-west direction, the canyons do not cut the middle layer at any place, whereas in the southern half no canyon cuts the continental slope. This difference indicates a considerable variation in the depositional environment and tectonic history of the northern and southern parts of the continental slope.

The lower layer is thought to be composed of volcanic rock and/or sandstone or conglomerate originating from volcanic rock. Such rocks are exposed on the southeastern margin of the Shinkurose Bank (Figs. VI-1 and -4). The distribution of this layer is restricted to the eastern side of the Kitakurose and Shinkurose Banks; no corresponding layer exists in the other sub-area. (Figs. VI-1 and -3 to -6). The lower layer seems to disappear on the extension of the eastern rim of the banks (Figs. VI-2, -7 and -8). To the north of the Kitakurose Bank, the lower layer ends at the point where an intrusive body (Fig. VI-7) or a normal fault exists (Fig. VI-8). The disappearance point of the layer on the profile is south-southeasterly traced from the northern margin of the surveyed area to the southern margin, via the eastern rims of the Kitakurose and Shinkurose Banks.

The banks region

In this sub-area the Kitakurose, Nakanokurose and Shinkurose Banks are surrounded by rather steep cliffs, which form the uppermost part of the continental slope, and the platforms which are part of the frontal arc of the Izu-Shichito volcanic arc.

The Nakanokurose Bank is connected with the Shinkurose Bank by a submerged isthmus. This bank is not well understood from the seismic reflection survey, because no distinctive reflectors are observed under the multiple reflectors. The shape of the bank and the rocks of which it is composed are similar to those of the other two banks, but the results of the gravity and geomagnetic surveyes do not show similarity. (See Chapter IV and V.)

These banks have flat, eroded summits tilting to the north or the northeast (Figs. VI-5, -6 and -10). The 300 m bathymetric contour line on the southwestern part of these banks, including the Nakanokurose Bank, indicates the hinge of this tilt (Fig. II-1).

Within the Shinkurose Bank a large northwest-trending antiform was observed, and within the Kitakurose Bank anticlines and synclines, having wave length of approximately ten kilometers, are found under the multiple reflectors (Figs. VI-5 and -6). No distinct reflective layer like the lower layer of the eastern continental slope was observed under the banks nor between the banks (Fig. VI-10). There is no doubt that the anticlinorium of the Kitakurose Bank had formed before the summit of the strata was eroded, but there is no evidence to determine whether the formation of the limestone platform preceded or succeeded the formation of anticlinorium. It is also difficult to determine whether the antiform of the Shinkurose Bank is a form of stratovolcano or an anticlinal fold.

From the west of the Kitakurose Bank to the southwestern part of the Shinkurose Bank there is a south-southeasterly trending line of sporadically arranged volcanic features (Figs. VI-5 and -6). In the northern part of the row the cones are separated from the Kitakurose Bank, whereas in the southern part they are combined with the Shinkurose Bank, and overlain by limestone.

The frontal area of Hachijojima Island

The sediments of this sub-area show an highly reflective and stratified pattern. The sediments are broadly folded and delineate northeast to north-northwest trending anticline and syncline axes (Figs. VI-1 to -4).

To the east of Hachijojima Island the sediments of the axial part of the anticline are cut by many faults. Some of the faults extend up to the sea floor and morphologic displacements were observed on the PDR and the 3.5 kHz echo sounder profiles (Fig. VI-3). However, it is difficult to say whether these are active faults, because there is no evidence that they cut the recent sediments. The recent sediments, composed of ejecta from the volcanoes of Hachijojima Island, thin eastward from the island and disappear around the anticlinal axis which runs along the western side of the Takunanyama Knoll (Fig. VI-3). Where the faults cut the sea floor, no recent sediments can be observed on the seismic survey profiles. Similar faults were observed on the western flank of this anticline in the area of the northwestern extension of its axis, but they do not cut the younger, overlying sediments (Figs. VI-1, -3 and -4). Moreover to the north of the Kitakurose Bank similar faults were observed (Fig. VI-8).

It is also difficult to determine the direction of displacement on these faults. Around the Takunanyama Knoll, depressional structures were observed (Figs. VI-2 and -4). This knoll and the other small knolls in the area seem to be either residuals which did not subside during the general subsidence caused by the depression, or they seem to be intrusive bodies which have formed after the formation of the depression. There are few recent sediments within the depression and the extension of the lower layer of the eastern continental slope exposed. Although we have not yet determined whether there is lateral offsetting along these faults, judging from the depressional structures, they might be normal faults which developed around the anticlinal axis and the western flank of the axis.

To the east of the Takunanyama Knoll, there is a steep-walled canyon running south-southeasterly in a straight line. The disappearance point of the lower layer of the eastern continental slope coincides with this canyon on the east side of the knoll (Fig. VI-4), whereas to the southeast of the knoll there exists a fault which cuts the lower layer under the canyon and the lower layer extends westward through the fault to the neighborhood of the knoll (Fig. VI-3). South of the mouth of the canyon but still in line with it, the lower layer is cut by a fault, however the layer extends to the west and disappears about 10 km west of the fault (Fig. VI-2). Thus the disappearance points of the lower layer are not in a direct straight line to the south of the Shinkurose Bank, and do not lie on a single fault.

Shichito volcanic chain sub-area

As mentioned above, the recent volcanoes erupted along the synclinal axes of the former structures. To the north of Hachijojima Island, a small volcano which has a large geomagnetic anomaly (See Chapter V), destroyed the former structure and is almost completely covered by ejecta from the Kurose Hole northwest of the volcano (Figs. VI-1, -4 and -11).

To the west of the Kitakurose and Nakanokurose Banks many ridge-like features were observed, but the detailes of their structures and origin are not clear at present (Figs. VI-6 and -11).

Discussion

Almost all of the surveyed area comes under the category of 'frontal arc' of the northern part of the Ogasawara Arc, which was introduced by KARIG (1970). The Arc has a thin continental crust (HOTTA, 1970) and forms an intra-oceanic arc-trench system with the Ogasawara Trench, limiting the eastern extent of the Philippine Sea plate.

The frontal arcs of intra-oceanic arc-trench systems with thin continental crusts have three or four common characteristics. First, the older andesitic volcanic rocks exist in the frontal arc region. For example, Limestone Caribbees of the Lesser Antilles (40–20 Ma: Martin-KAYE, 1969; BRIDEN *et al.*, 1979), the Tonga Islands (Eocene: KARIG, 1970; EWART and BRYAN, 1972), and the Mariana Islands (Eocene to early Miocene: KARIG, 1971; SHIRAKI *et al.*, 1977). Second, almost all these frontal arcs have limestone platforms, which record past subsidence or uplift, and deformed structures characterized by tilting or gentle folding. Third, these frontal arcs often have positive gravity anomalies greater than those of the volcanic chains (BOWIN, 1976; WATTS, 1976). Fourth, and rather exceptionally according to our present knowledge, there exist some metamorphosed, basic volcanic rocks considered to be derived from an older oceanic crust, such as those of La Désirade Island of the Lesser Antilles (ca. 150 Ma: FINK, 1970; MATTINSON *et al.*, 1980; or ca. 90 Ma: BRIDEN *et al.*, 1979) and Yap Island (Oligocene or older: SHIRAKI, 1971).

In the surveyed area, the banks are composed of old andestic volcanic rocks and limestone platforms with flat, tilting summits. The sub-area of the banks has a large positive gravity anomaly (See Chapter IV).

However, it is difficult to interpret all of these characteristics only as the general characteristics of the frontal arc. The Izu-Shichito Islands are on the northeastern margin of the Philippine Sea plate. The Philippine Sea plate is moving northwest relative to the Eurasian plate, and underthrusts along the Sagami Trough. The Philippine sea plate is underthrust by the Pacific plate along the Ogasawara Trench. These three plates form a trench-trench-trench type triple junction in the northeast of the surveyed area, so the structure of this area is complicated by the geometry of the three plates and by the triple junction. (SENO, 1977).

The structure of the surveyed area is characterized by northwest to north-northwest trending structural lines which lie sub-parallel to the volcanic chain. These lines are formed by folding axes, the arrangement of volcanic cone-like features to the west of the banks, the depressional structure, and the disappearance line of the lower layer of the eastern continental slope.

It is important to consider the process of subsidence and tilt of the banks' flat summits in investigating the structure of this area. The folding preceded the formation of the depressional structure. Both the folding and the formation of the range of volcanic cone-like features preceded the formation of the banks' flat summits. The disappearance of the lower layer may be related to the formation of the depressional structure. However it is not clear whether the formation of the depressional structure preceded or succeeded the formation of the banks' flat summits.

Although the axis of the structure could not be fixed accurately in the preliminaly analysis, the folding axes and the axis of the depressional structure are evidently sub-parallel, so the stress fields inferred from these structures are not consistent with each other; the stress field of the folding appears to be, approximately, an east-west compressional field, whereas that of the depressional structure appears to be, approximately, an east-west tensional field. However. the depressional structure may not be active now. The east-west tensional field may represent a former tectonic environment when this sub-area of the Philippine Sea plate was located further southeast, about in the present area to the east off Torishima Island (MATSUBARA and SENO, 1980).

In the Ogasawara Arc, the stress fields near the volcanic chain are east-west extensional ones (MAKI, 1976). If the past stress fields of the Ogasawara Arc was the same as it is now, the inactivity of the depressional structure in the surveyed area could have been caused by the change from the general stress fields accompanying the approach of the area to the Sagami Trough.

The subduction of the Philippine Sea plate under the Eurasian plate and the stability of the triple junction might influence the deformation of the banks. The hinge of the tilt is almost parallel to the Sagami Trough. Judging from this, the tilt may be caused by the bending of the Philippine Sea plate associated with its subduction along the Sagami Trough. The outer marginal swell associated with subduction lies on the outer side of the trench at distances of one hundred to two hundred kilometers (WATTS *et al.*, 1976). The sub-area containing the three banks is within this distance of the Sagami Trough. The extraordinarily high gravity anomaly of the sub-area might be the result of both bending of the lithosphere and the frontal arc gravity anomaly.

The banks are divided into two areas; the northern Kitakurose Bank and the southern Nakanokurose and Shinkurose Banks. Rising from the boundary between the two areas, a large canyon runs eastward to the Ogasawara Trench. This canyon coincides with the boundary between the source and aftershock area of the great earthquake, the Boso-Oki Earthquake of November 26, 1953 (SEISMOL. Sec., C. M. O., 1954; HATORI, 1975) and that of the other two great earthquakes occurring in close proximity to the east off Hachijojima Island of February 29, 1972 and of December 4, 1972 (HATORI, 1972, 1973; KASAHARA *et al.*, 1973a, b). The aftershock area of the earthquake of December 4, 1972 has a north-northwest trending marginal line bordering on that of the earthquake of February 29, 1972 and dips southward. The northern extent of the aftershock area of the earthquake of December 4, 1972 corresponds to the canyon (KASAHARA *et al.*, 1973a, b). These facts suggest that the structure of the surveyed area is subject to a fracturing process at the Ogasawara Trench and can also be related to the stability of the triple junction.

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