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Seismic profiling survey of the Ogasawara Plateau and the Michelson Ridge, western Pacific : evolution of Cretaceous guyots and deformation of a subducting oceanic plateau

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Abstract : The Ogasawara Plateau and a seamount chain to the east of the plateau (Michelson Ridge) in the western Pacific were studied by seismic profiling survey. The Ogasawara Plateau is a topographic high about 2000 to 3000 m high from the abyssal plain and more than four seamounts rest on the plateau. Three of the seamounts in the Ogasawara Plateau and seamounts of the Michelson Ridge are guyots drowned in the middle Cretaceous age. The flat summit of the guyots is always underlain by coherent reflections interpreted as lagoon sediments and massive reflection rims probably composed of reefs. The lagoon sediments in the four guyots can be divided into three units which are correlative with each other. The sediments thicken westward, suggesting a westward increase of subsidence rate during the period of the growth of the reef complexes. If the guyots are hot-spot volcanos, the westward increase of subsidence rate can be interpreted by an eastward increase of the ages of the volcanic mounds formed on the eastward moving oceanic plate. The present Ogasawara Plateau is colliding with the Ogasawara Arc at the Ogasawara Trench and highly faulted. The faulting in and around the Ogasawara Plateau is presumably related to the E-W extension due to westward bend of the subducting oceanic floor, because the faults are predominant in the area within a distant of 100 km from the trench. Two orientations of the faults are predominant, NW-SE and N-S in direction. The NW-SE orientation is sub-parallel to the fracture zone of oceanic floor around the plateau, suggesting that the faults are related to the ancient mechanically weak zones. On the contrary, the N-S faults parallel to the trench are formed by westward bending of oceanic crust at the trench. These faults are high-angle normal faults and no compressional deformation such as folding is observed, showing that the Ogasawara Plateau has been underthrusting beneath the Ogasawara Arc.

1. Introduction

The Ogasawara Plateau is a western extension of the Marcus-Wake seamount chain in the western Pacific, and colliding with the Ogasawara (Bonin) Arc at the Ogasawara Trench (Fig. 1). Smoot (1983 a, b) presented a detailed bathymetric contour map of the Ogasawara Plateau and three seamounts linearly aligned in the E-W direction to the east of the plateau based on multi-beam echo sounder data. The map showed that the Ogasawara Plateau is composed of a plateau and seamounts (Fig. 2a). The plateau is about 1500-3000 m high from the surrounding abyssal plain and extending 160 km in N-S and 140 km in E-W directions. There are four major seamounts called the Higashi (meaning east in Japanese), Minami (south), Nishi (west) and Kita (north) seamounts and smaller knolls on the

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Keywords : west Pacific, mid-Cretaceous, guyot, reef, hot spot, oceanic plateau, subduction

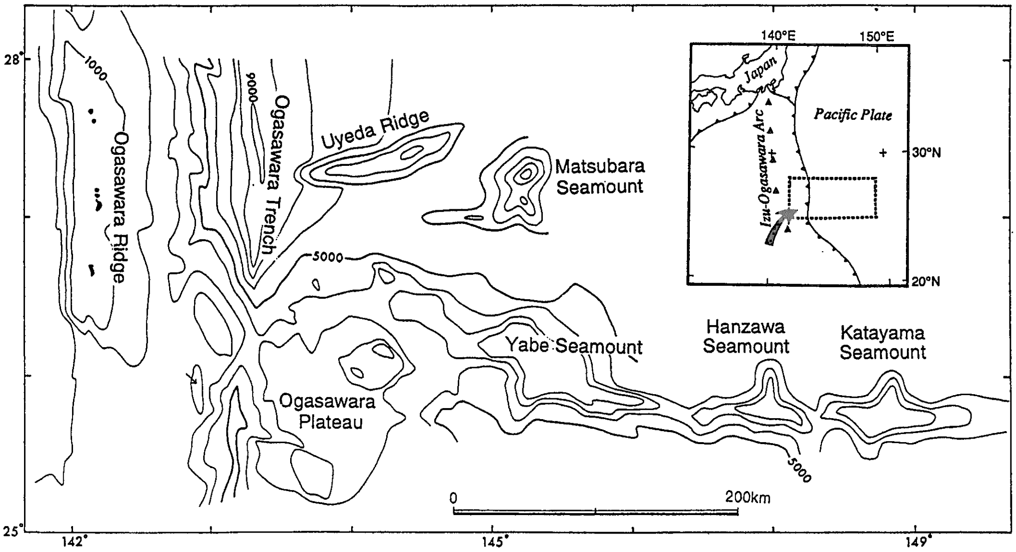

Fig. 1 Index map of the Ogasawara Plateau and Michelson Ridge.

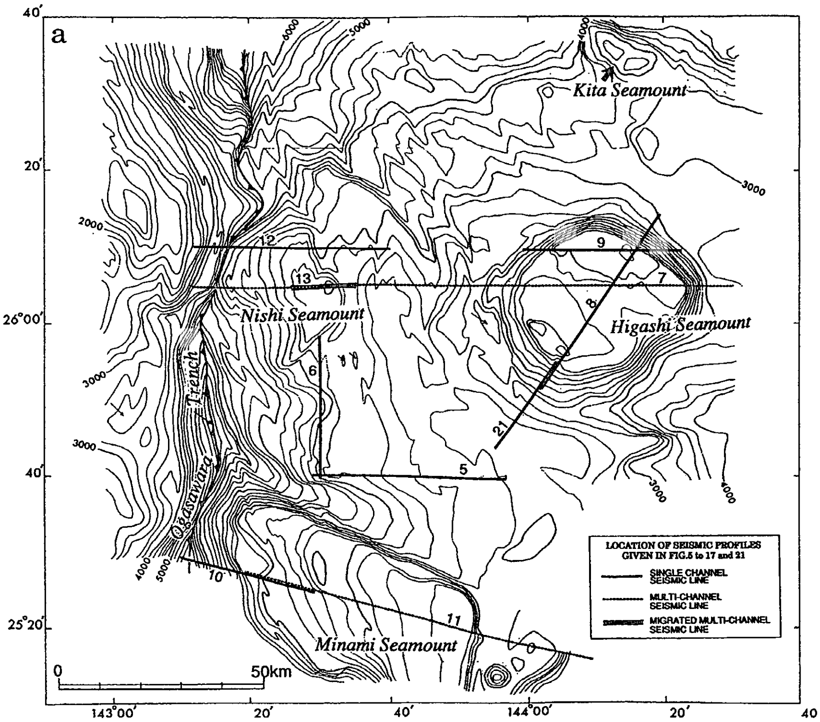

Fig. 2 Bathymetric contour map of the Ogasawara Plateau (a), Yabe seamount (b), Hanzawa and Katayama seamounts (c). Locations of seismic profiles given in figures 5-17 and 21 are shown.

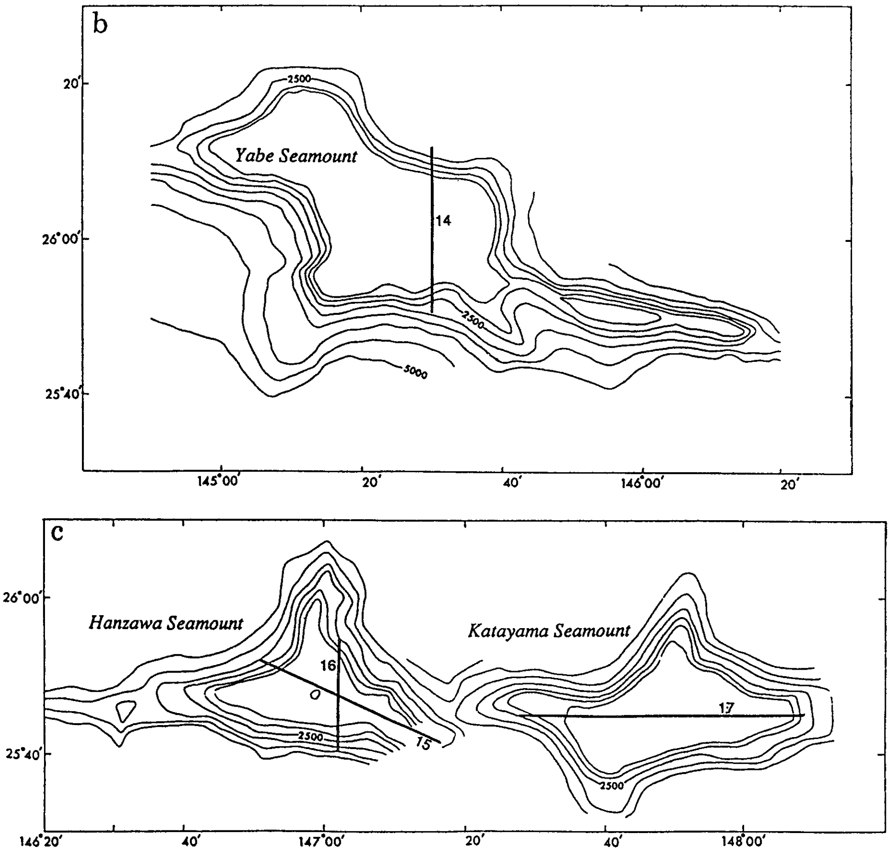

Fig. 2 Continued

plateau (Fig. 2a). Three of the seamounts are guyots characterized by a flat summit. The Higashi seamount was named as the Broken Top seamount by Smoot (1983a), but renamed by Maritime Safety Agency of Japan. The other seamounts to the east of the Ogasawara Plateau are also guyots (Figs. 2b and 2c) and Smoot (1983a) called the seamounts the Michelson Ridge. The seamount neighboring to the east of the Ogasawara Plateau was named Yabe seamount by Shiba (1979). Smoot (1983a) called the guyot the Smoot seamount and named the other two seamounts as the Castol and Pollucs seamounts from west to east. These seamounts were renamed as Yabe, Hanzawa and Katayama seamounts from the west to east by Maritime Safety Agency of Japan. The Japanese names are used in this paper.

Shiba (1979) showed that the Yabe seamount is a Cretaceous guyot composed of reef limestone. Konishi (1984) also studied the fauna included in the reef limestones of the Higashi and Minami seamounts and concluded that they are atolls drowned in mid-Cretaceous age like the guyots of the Mid-Pacific Mountains (Matthews *et al.*, 1974 ; Winterer and Metzler, 1984). Nemoto *et al.* (1986) supported the idea of the submergence of the Higashi and Yabe seamounts in the mid-Cretaceous age.

Whether the Ogasawara Plateau has been subducted or obducted at the Ogasawara Trench has been controversial. Smoot (1983a, b) and Nagaoka (1989) stated that the plateau is composed of detached seamounts which were forming a E-W aligned seamount chain. In contrast, Kobayashi (1985) and Fryer and Smoot (1985) claimed that the plateau has been underthrusting beneath the Ogasawara Arc.

In this paper, we describe the seismic stratigraphy and geologic structure of the Ogasawara plateau and the Michelson Ridge and discuss the growth patterns of the guyots, middle Cretaceous plate motion and the collision tectonics of the Ogasawara Plateau.

2. Seismic profiling data collection

The Geological Survey of Japan visited the Ogasawara Plateau twice by R/V Hakurei-maru, the first was GH79-3 cruise in 1979 and the second was GH86-3 cruise in 1986. In 1979, the whole of the Ogasawara Arc including the Ogasawara Plateau was surveyed by a single channel seismic (SCS) profiling system shown in Table 1 (Honza *et al.*, 1981). The seismic survey lines in 1979 lie at 15 mile interval in the direction of E-W (Fig. 3). In 1986, the Ogasawara Plateau was surveyed again to clarify detailed geologic structure and the potential of mineral resources. The seismic lines conducted in 1986 were arranged between the seismic lines in 1979, and whole of the Ogasawara Plateau was covered with the seismic lines at 5 miles interval in the direction of E-W (Fig. 3). In addition, several N-S, NW-SE and NE-SW trending lines were also conducted. Three of the lines were surveyed by mul-

Table 1 Instrumentation and techniques used for single channel seismic profiling system in 1979 (GH 79-3 cruise).

Sound source	: Two Airguns, model 1900C product of Bolt Associates Inc.	
	Chamber volume	= 150 in^3×2
	Air pressure	= 1600-1800 psi
Receiver cable	: GSJ SCS streamer cable (handmade)	
	Hydrophone elements	= 200
	Offset	= 150 m
Recording condition	: Graphic recorder, model 196B product of Reytheon Ocean Systems Company	
	Shooting interval	= 10 sec
	Ship speed	= 10-11 knots
	Record length	= 4 and 8 sec
	BP filter	= 20-100 Hz

Table 2 Instrumentation and techniques used for multi-channel seismic profiling system in 1986 (GH86-3 cruise).

Sound source	: Two Water Gun, model S-80 product of Seismic systems Inc.	
	Chamber volume	= 80 in^3
	Air pressure	= 1800 psi
Receiver cable	: GSJ-SEC MCS streamer cable	
	Active sections	= 12
	Hydrophone elements	= 32 per section
	Trace offset	= 25 m
	Near trace offset	= 225 m
	Average cable depth	= 15 m
Recording system	: NE128, product of Nippon Electric Company	
Recording condition	: Shooting interval	= 12 sec
	Ship speed	= 4 knots
	Maximum CDP fold	= 6
	Sampling rate	= 4 ms
	Record length	= 6 sec

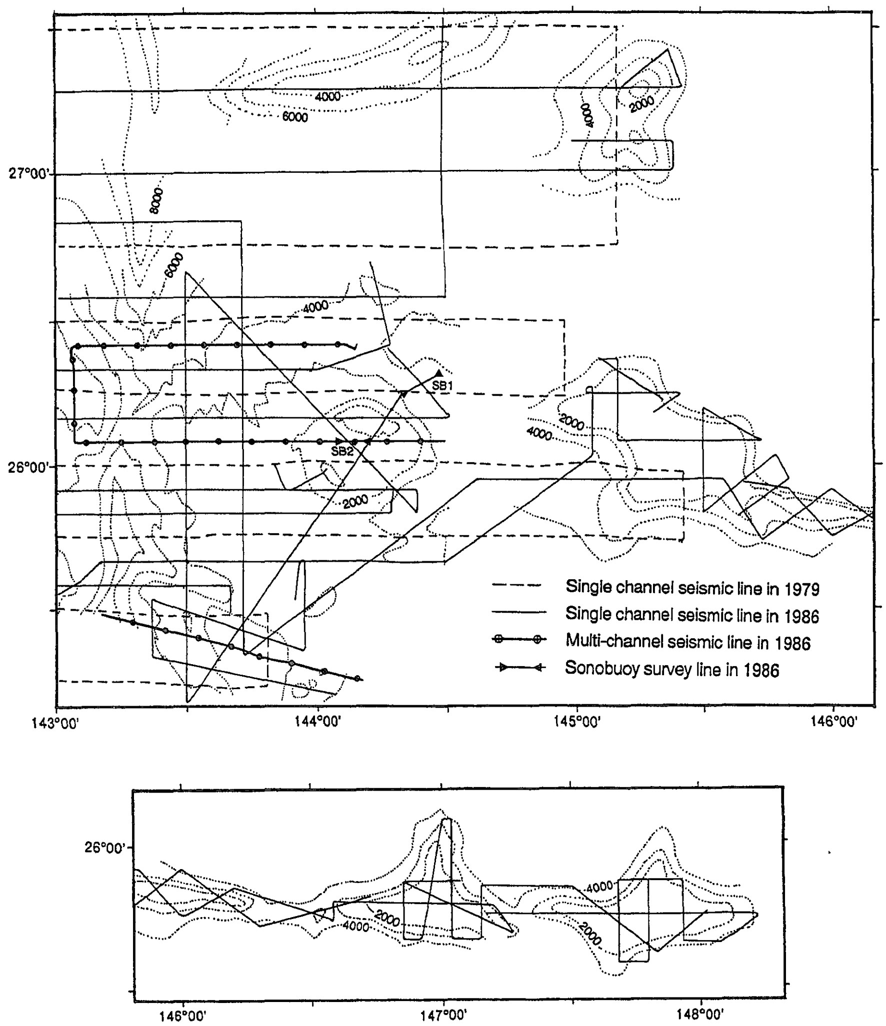

Fig. 3 Seismic lines conducted by Geological Survey of Japan in 1979 and 1986.

ti-channel seismic (MCS) system (Fig. 3). Two 80 in^3 water guns were used as the sound source of the MCS survey in order to get high resolution profiles which make possible more detailed analysis of geologic structure and seismic stratigraphy. The system constructions are shown in Table 2. Other lines in 1986 were surveyed by a single channel seismic system shown in Table 3. The sound source of 1986-SCS systems was two 120 in^3 airguns with wave shape kit (WSK), while the sound source used in 1979 was two 150 in^3 airguns without WSK. The resolution of seismic profiles was improved from about 100 m in 1979 to 40 m in 1986 by WSK. A seismic refraction survey using sonobuoys was conducted in two sites, the flat summit of the Higashi seamount (SB-2; Fig. 3) and the eastern part of the Ogasawara Plateau (SB-1). The system for seismic refraction survey was shown in Table 4. The seismic data transmitted from the sonobuoy were recorded on magnetic tape (PCM, Pulse Coded Modulation, recording) and were also filtered and displayed on a graphic recorder.

The three seamounts of the Michelson Ridge were also surveyed by the SCS system in 1986 along seismic lines spacing at 5-10 mile interval covering the flat summit and upper slopes of these guyots (Fig. 3).

Table 3 Instrumentation and techniques used for single channel seismic profiling system in 1986 (GH 86-3 cruise).

Sound source	: Two Airguns, model 1900C product of Bolt Associates, Inc.	
	Chamber volume	= 120 in^3 with WSK
	Air pressure	= 1500 psi
Receiver cable	: GSJ SCS streamer cable (handmade)	
	Hydrophone elements	= 100
	Offset	= 150 m
Recording condition	: Line scan recorder, model LSR-1811	
	product of Reytheon Ocean Systems Company	
	Shooting interval	= 8 sec
	Ship speed	= 10 knots
	Record length	= 4 sec
	BP filter	= 30-150 Hz

Table 4 Instrumentation and techniques used for sonobuoy refraction survey system in 1986 (GH 86-3 cruise).

Sound source for SB1	: Two Airguns, model 1900C product of Bolt Associates, Inc.	
	Chamber volume	= 120 in^3 with WSK
	Air pressure	= 1700 psi
Sound source for SB2	: Two Water Gun, model S-80 product of Seismic systems Inc.	
	Chamber volume	= 80 in^3 Air
	Pressure	= 1800 psi
Hydrophone receiver	: Sonobuoy model OC-1, product of OKI Electric company	
	Hydrophone depth	= 20 m
	Transmission freq.	= 169.25 or 169.65 MHz
Receiver system	: Model NRA-8A, product of Japan Radio Co. Ltd.	

3. Outline of topography and geology

3.1 Ogasawara Plateau

3.1.1 *Plateau*

The plateau is nearly horizontal or gently westward dipping in the eastern part and highly faulted and relatively steeply inclined westward in the western part (Fig. 2a). The shallowest part is located between the Minami and Higashi seamounts and is about 2000 m deep below sea-level. The depth of the plateau increases westward and attains 4000 to 6000 m at the western margin in the trench. The southern margin of the plateau is marked by a clear scarp, while the northern margin of the plateau is gradually descending to the abyssal plain except on the north and east of the Kita seamount. No clear fault is observed between the plateau and abyssal plain. At the northeastern margin of the plateau, the western part of the Yabe seamount appears to stand from the plateau. Many faults are concentrated in a few fault zones (Fig. 4) and displacement of the faults generally increases westward nearer the trench. Sedimentary sequences covering the plateau attain a maximum thickness up of to 1.2 s (two-way travel time in second, 1.0 s corresponds to 750m in the water column) in the area surrounded by the Minami, Nishi and Higashi seamounts. The sedimentary sequences decrease in thickness northward and eastward. The sequences are composed of the alternation of reflective units and less reflective units (Fig. 5). The reflective units are characterized by clear and continuous reflections, while less reflective units show weak and discontinuous reflections. The boundaries between the units are generally

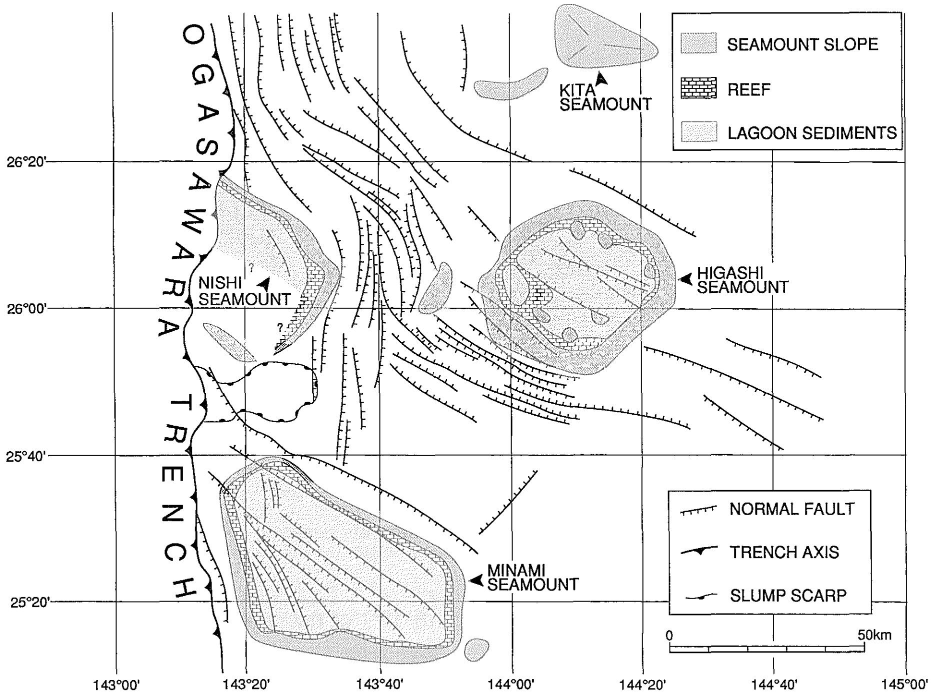

Fig. 4　Structural map of the Ogasawara Plateau.

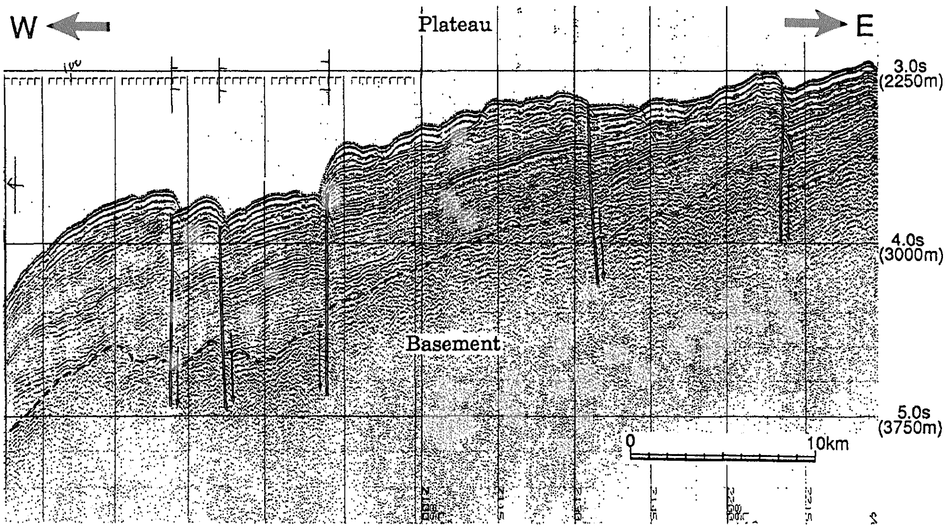

Fig. 5　Sedimentary sequences covering the plateau of the Ogasawara Plateau. V.E. (Vertical exaggeration) =13

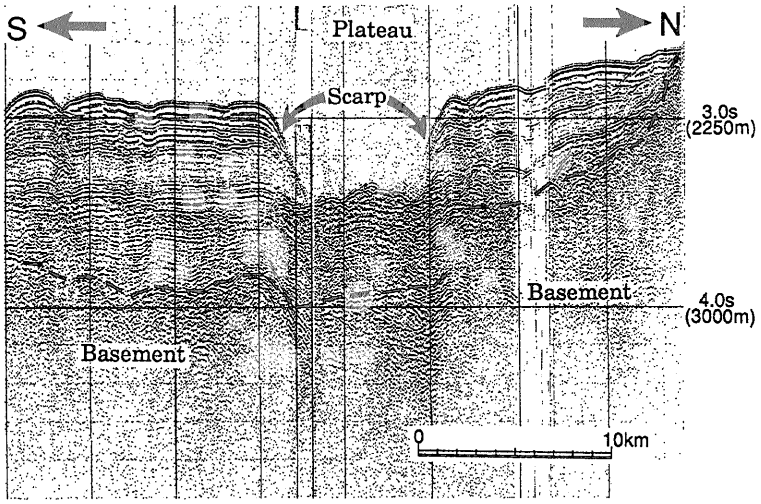

Fig. 6 Slide scarp removing the upper units of the sediments covering the plateau of the Ogasawara Plateau. V.E.=13

gradual. The upper 0.4 s thick units cover the entire plateau except the eastern and northern margin, and lower units onlap against the basement between the Nishi and Higashi seamounts and do not extend northward. The thickness of the sediments on the plateau is significantly thicker than that of the abyssal plain sediments (Yuasa *et al.*, 1982). In addition, the reflection characters are different between the sediments on the plateau and those on the abyssal plain. They suggest that the plateau has been shallower than the abyssal plain as well as the CCD resulting the high sedimentation rate.

A large scale slide scarp (more than 400 m high, 15 × 25 km wide) is observed near the trench in which the upper two units or entire units are removed (Fig.6), but no chaotic sediments are observed in the trench downslope of the scarp. The acoustic basement of the plateau occasionally shows discontinuous and strong reflections (Figs. 5 and 7), suggesting that parts of the basement are composed of coarse grained sediments like pyroclastic rocks rather than volcanic rocks.

3.1.2 *Higashi seamount*

The bathymetric contours of the guyot are rhomboid in shape with rounded corners (Fig. 2a). The sides are about 40 km long and trends in the NE and NW direction. The steep slopes (8-18°) of the seamount rise about 1000 to 2000 m high from the plateau. The flat summit of the seamount is about 30 km in diameter. Seismic profiles show that the sedimentary sequences characterized by slightly discontinuous and notched reflections up to 1.0 s in thickness lie under the flat summit of the seamount, while the rim of the summit that often show low mounds up to a few tens of meter high is underlain by massive, incoherent reflections (Figs. 8 and 9). A few NW-SE trending fault scarps up to 200 m high cut the flat summit (Fig. 8). Several conical shaped knolls of 100 to 450 m high and less than 5 km in diameter stand on the mound (Figs. 8 and 9).

Reef limestones including Cretaceous Nerineiid were dredged from the western flank of the flat summit. Konishi (1984) reported Albian to Cenomanian (middle Cretaceous) reef limestone from the northern and eastern slope of the Higashi seamount. These lines of evidence strongly suggest that the Higashi seamount was an atoll of the middle Cretaceous age. The coherent reflections under the flat summit and massive reflections under the rim can be interpreted as the lagoonal sediments and reef shoals of a atoll respectively. Basaltic rocks dredged from the knolls indicate that they are volcanos. The flank of one of the knolls apparently overlies the stratified reflection of the lagoon sediments (Fig. 8), showing that the knoll was formed after the submergence of the

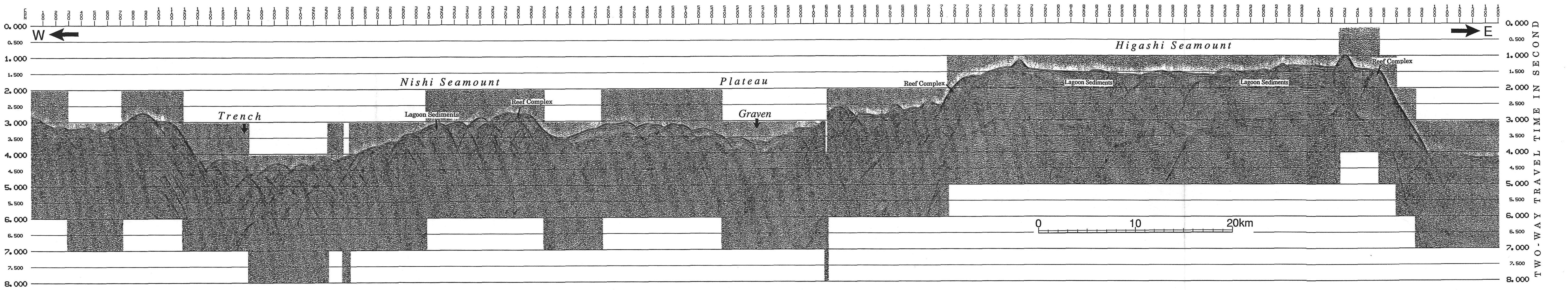

Fig. 7 Stacked multi-channel seismic profile along the E-W line from the Higashi seamount to the trench through the Nishi seamount. V.E.=4.5

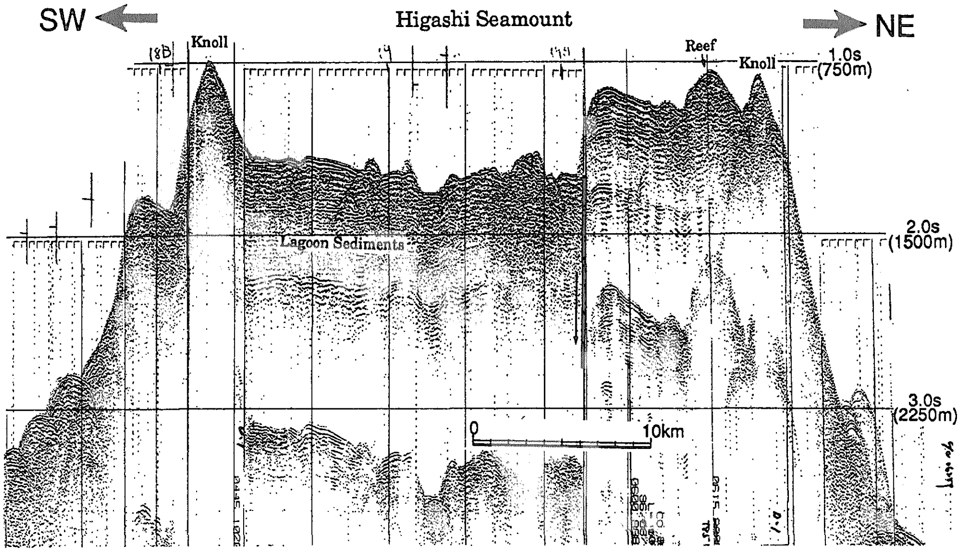

Fig. 8 Seismic profile of the Higashi seamount showing thick lagoonal sedimentary sequence, a fault, volcanic knolls and reefal mound. V.E.=13

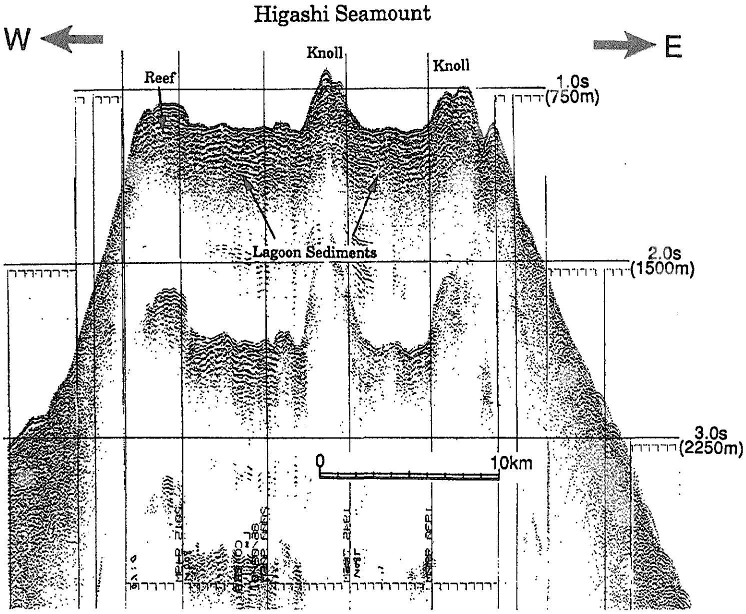

Fig. 9 Seismic profile of the Higashi seamount showing thick lagoonal sedimentary sequence, volcanic knolls and reefal broad mound. V.E.=13

guyot.

3.1.3 *Minami seamount*

The Minami seamount is the largest guyot on the Ogasawara Plateau. Its summit is rectangular in shape about 70 km long in the ESE-WNW direction and 45 km wide in the N-S direction and higher than the plateau about 1000 to 2000 m (Fig. 2a). The summit is shallowest on the eastern margin (about 1100 m) and descends west-

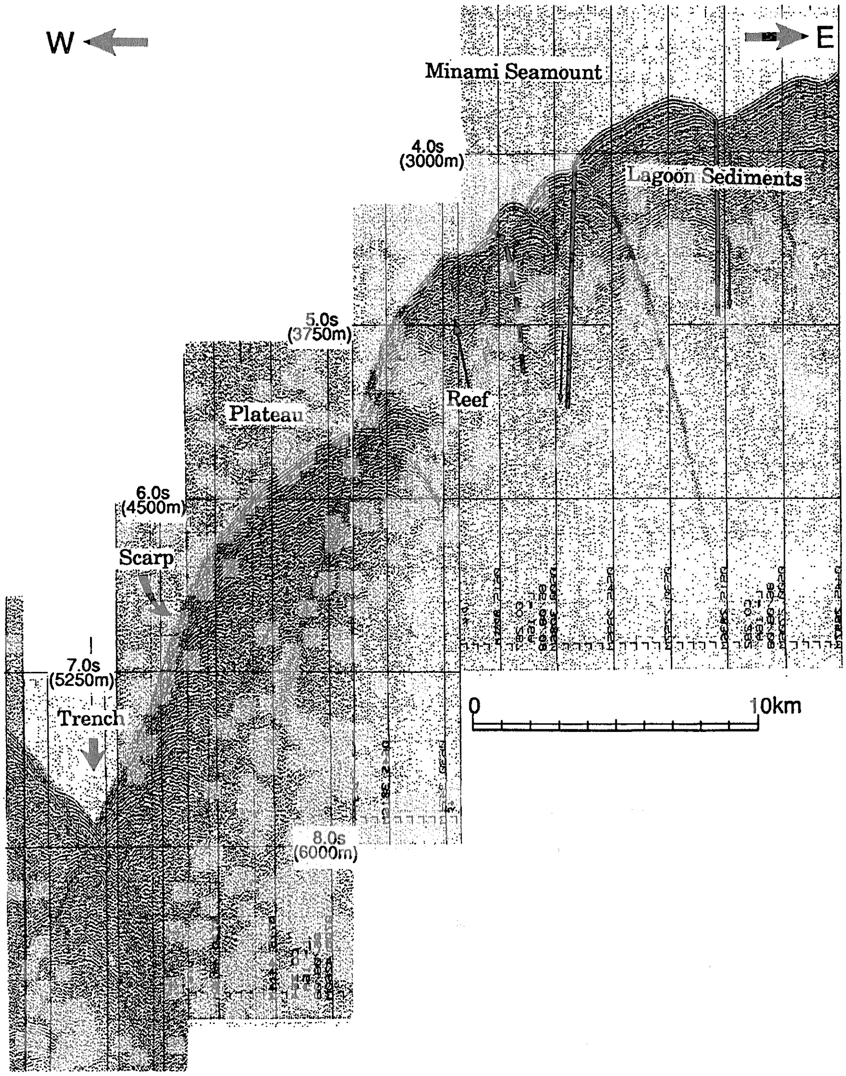

Fig. 10 Seismic profile showing the western part of the Minami seamount and trench to the west of the seamount. V.E.=8

ward toward the trench at about 1 to 2 degree. The water depth of the summit is about 3000 to 3500 m at the western margin of the seamount at the distance of 10 km from the trench (Fig. 10). To the west of the seamount, the water depth of the plateau increases rapidly westward from 4300 m up to 6000 m within the distance of 10 km from the trench by a large-scale fault scarp up to 1500 m high (Fig. 10). No trench fill is observed to the west of the Minami seamount.

The summit is underlain by continuous and parallel reflections up to 1.5 s thick and they are cut by many faults (Figs. 10 and 11), resulting in many linear scarps on the flat summit. Only one knoll of about 70 m high is observed on the summit. The rim of the summit is always underlain by massive reflections like the Higashi seamount (Figs. 10 and 11). During the GH 86-3 and GH 79-3 cruise, no basalt or reef limestone was obtained from the seamount; however, Konishi (1984) described the Albian to Cenomanian reef limestone from the Minami seamount. This fact as well as the reflection character similar to the Higashi seamount strongly suggests that

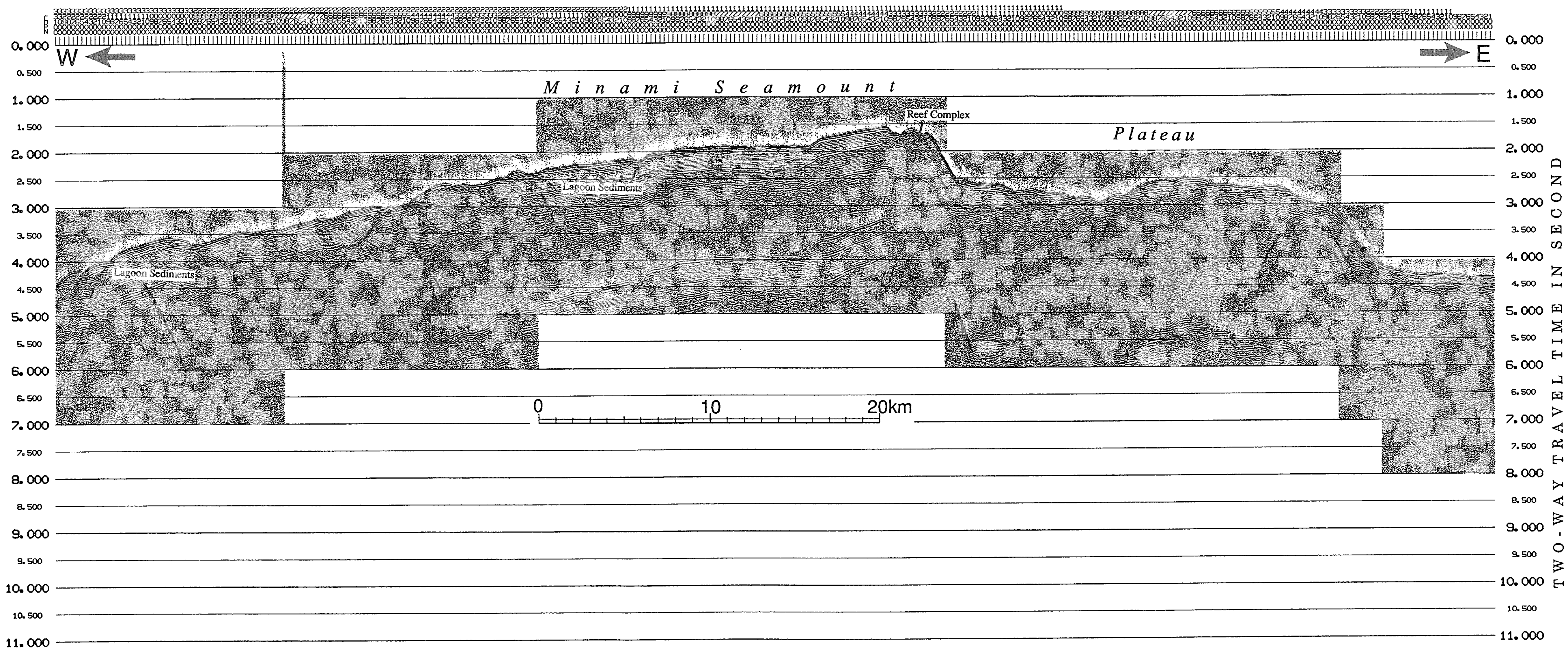

Fig. 11 Stacked multi-channel profile of the Minami seamount. V.E.=4.3

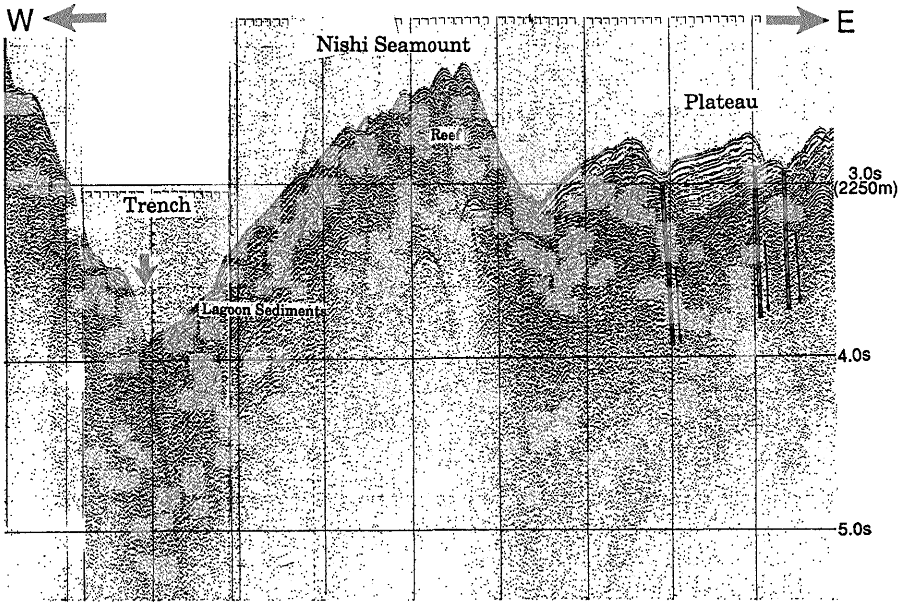

Fig. 12 Seismic profile of the Nishi seamount showing the westward tilted guyot. V.E. =13

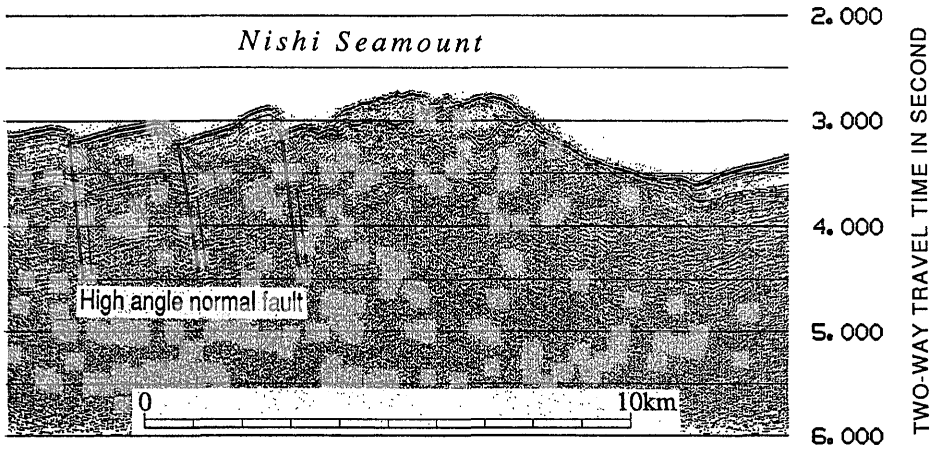

Fig. 13 Migrated seismic profile of the Nishi seamount showing the high angle normal faults. V.E. =2.9

this seamount was a middle Cretaceous atoll.

3.1.4 *Nishi seamount*

The Nishi seamount has NW and NE directed steep slopes in its eastern margin and a gentle slope dipping westward at 3-4° (Fig. 2a). The seamount is shallowest at the eastern end of the flat summit ; its water depth is about 2000 m. Seismic profiles show that the gentle slope is underlain by continuous, parallel reflections up to 1.0 s thick, while the eastern flank of the summit is underlain by massive reflections (Figs. 7 and 12). Limestones were sampled from the summit, indicating that the Nishi seamount is composed of a carbonate mound. These facts suggest that the Nishi seamount is a guyot like the Higashi and Minami seamount. The coherent reflections under the gentle slope and massive reflections of the eastern margin are presumably lagoon sediments and reef respectively. Part of the western slope of the seamount is highly faulted, but no folding or deformation suggesting compressional deformation

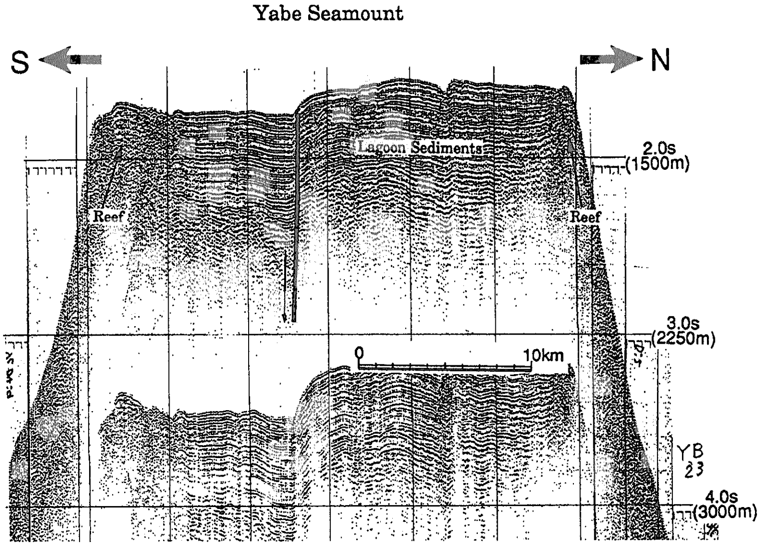

Fig. 14 Seismic profile of the Yabe seamount showing the thick lagoon sediments, a fault and reef. V.E.=13

is observed (Figs. 7,12 and 13). The faults appears to be high angle normal faults on a migrated seismic profile (Fig. 13). The trench show a V-shaped profile indicating no trench fill (Figs. 7 and 12).

3.1.5 *Kita seamount*

The Kita seamount located at the northeastern edge of the Ogasawara Plateau is small in comparison with the other three seamounts (Fig.4). Its diameter does not exceed 15 km at its flank and the water depth of the summit is about 2700 m. The seamount has a relatively flat summit less than 10 km wide under which no coherent reflection is observed. Basaltic rocks were dredged from the seamount but no limestone was obtained. The Kita seamount presumably consists of volcanic rocks without a carbonate reef mound.

3.2 Yabe seamount

The Yabe seamount is the largest guyot around the Ogasawara Plateau and is located just east of the Ogasawara Plateau. Its western flank contacts with the Ogasawara Plateau (Fig. 2b). It stands up from the surrounding 5500 m deep abyssal plain and the flat summit is located at 1100-1300 m deep (Figs. 2b and 14). The flat summit extends about 80 km in the ENE direction and 46 km in the N-S direction. A few small knolls are observed on the summit. A southward dipping normal fault scarp in the N70°W direction about 50-200 m high cuts the seamount summit (Fig. 14). This flat summit is underlain by sedimentary sequences up to 1.2 sec and fringed by massive reflections (Fig. 14). Shiba (1979) described the middle Cretaceous limestones (probably Cenomanian) from the Yabe seamount. Reef limestones including Nerineiid and coral are dredged from several dredge sites during GH 86-3 cruise, although detailed paleontological studies have not yet been completed. They strongly suggest that the seamount was a Middle Cretaceous atoll. At the eastern end of the seamount, a linear ridge in the E-W direction connects the Yabe seamount with the Hanzawa seamount to the east of the Yabe seamount (Fig. 2b). The ridge also has a narrow flat summit at 1300 m deep.

3.3 Hanzawa seamount

The Hanzawa seamount is a star shaped guyot with three arms extending to west, north and ESE (Fig. 2c). Each of the arms has flat summits of 20 to 25 km long from the center of the seamount. The summit is composed of the upper and lower terraces and many knolls stand up from the terraces (Figs. 15 and 16). The height of the high-

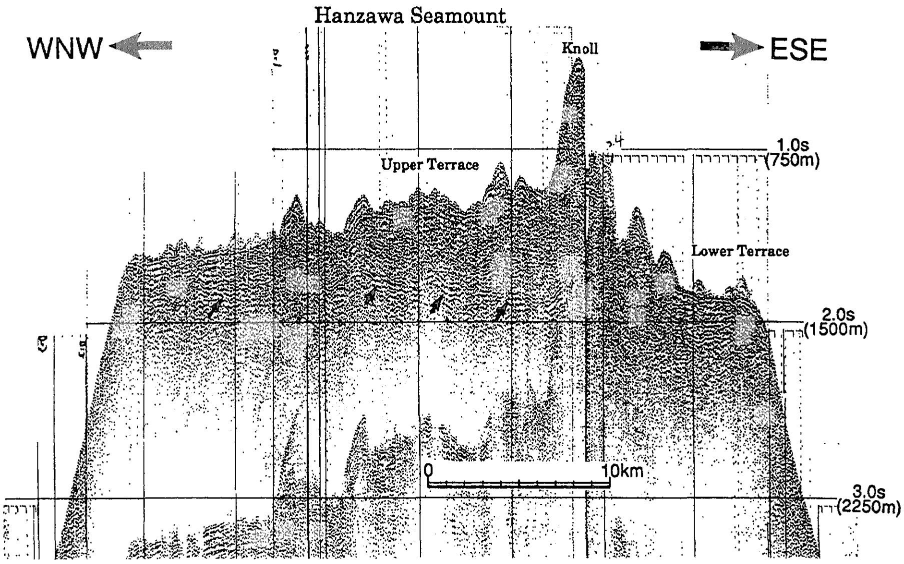

Fig. 15 Seismic profile showing the upper and lower terraces and knolls on the summit of the Hanzawa seamount. Arrows indicate the strong, discontinuous reflections correlative with the lower terrace. V.E.=13

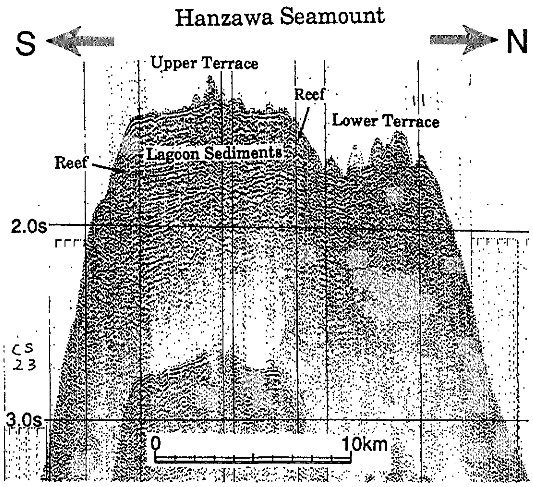

Fig. 16 Seismic profile showing the lagoon sediments under the upper terrace of the Hanzawa seamount. V.E.=13

est peak is about 600 m from the terrace and its summit is located at about 350 m below sea level (Fig. 15). The water depth of the terraces ranges from 1000 m to 1400 m descending from the center to the flank of the seamount (Fig. 15). The upper terraces are underlain by sedimentary sequences up to 0.5 s (Fig. 16). The reflections of the sequences is hummocky and discontinuous. Cretaceous reef limestones were obtained from the upper and lower terraces and Miocene shallow marine limestone was hauled from the upper terraces. The depth of the lower terrace and the flat summit of the Yabe and Katayama seamounts are almost the same (Figs. 14,15 and 17). Discontinuous reflections that appear to be correlative to the lower terrace are recognized under the upper terrace (Fig. 15). These facts suggest that the lower terrace and the discontinuous reflections under the upper terrace are a middle Cretaceous reef complex correlative with the Yabe and Katayama seamounts, and that the upper terrace is probably underlain by an upper Cretaceous reef. The Miocene shallow marine limestone may be debris from the higher knolls.

3.4 Katayama seamount

The Katayama seamount is composed of an E-W elongated ridge and a couple of subsidiary ridges extending north and south (Fig. 2c). It has a flat summit at the water depth of 1350-1450 m. The summit is about 55 km long in the E-W direction and 17 km wide and has a 12 km long subsidiary ridge extending northward. Two small knolls of 100-200 m high rest on the summit and the sur-

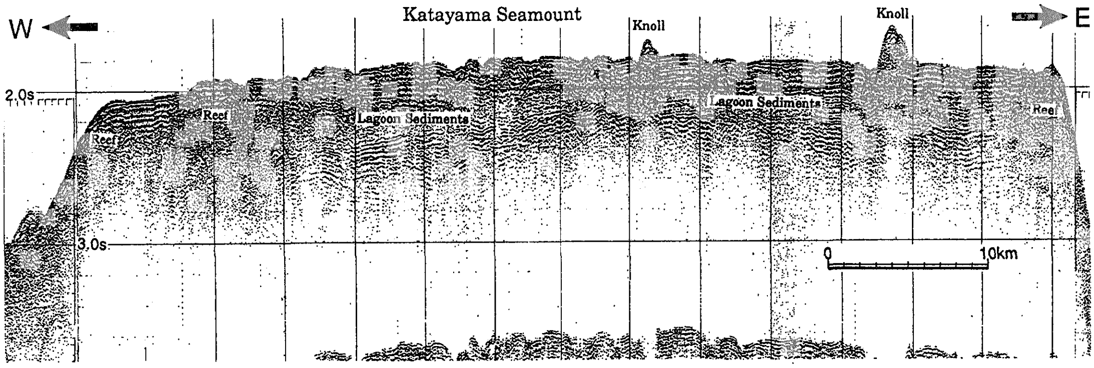

Fig. 17 Seismic profile of the Katayama seamount showing the lagoon sediments and reef under the flat summit. V.E.=13

face of the summit has irregular relief of about 50 m (Fig. 17). The summit is underlain by sedimentary sequences of more than 0.5 s thick and is surrounded by a massive reflection rim (Fig. 17). Dredged samples from the seamount include Cretaceous reef limestone and basaltic rocks ; thus, the seamount is presumed to have been a middle Cretaceous reef.

4. Seismic stratigraphy of guyots and its implication

There are six guyots in the surveyed area. Their flat summits show common seismic characteristics : coherent reflections ranging from 0.5 to 1.5 s in thickness and a massive reflection rim. These reflection characteristics as well as middle Cretaceous reef limestones dredged from the guyots support the idea that the guyots were atolls drowned in the middle Cretaceous age. The coherent reflections and massive reflection rims are interpreted as lagoon sediments and reefs. The larger guyots like the Minami and Yabe seamounts have more continuous and smooth reflections in the lagoon sediments (Figs. 10,11 and 14) compared with those of the smaller seamounts like the Higashi and Katayama seamounts (Figs. 8,9 and 17). This difference of reflection character may suggest that the larger lagoons were deeper and filled mainly by finer sediments under low-energy condition, while the smaller lagoons were shallower and filled by coarser sediments and patchy reefs under high-energy condition.

Four of the guyots (Minami, Higashi, Yabe and Katayama seamounts) have similar successions of lagoon sediments which can be divided into three sedimentary units on the basis of reflection character (Fig. 18). Unit I, the uppermost unit, is characterized by distinct and continuous reflections. Its sound velocity (measured by sono-buoy refraction survey) is 1.8 km/s in the Higashi seamount. Unit II (2.2 km/s in the Higashi seamount), the second unit, is represented by absent or weak reflections. The boundary between Unit I and II is generally gradual. Unit III (3.4 km/s in the Higashi seamount), the lowest unit, is defined by strong reflections at its top but its internal reflections are generally unclear. The thickness of Unit III varies from 0.05 to 0.5 s. The base of Unit III is also unclear and its sound velocity is 4.7 km/s. The base is probably composed of older reef complex and volcanic rocks.

The limestones dredged from the Minami, Higashi and Yabe seamounts yield similar fauna of the Albian to Cenomanian age (Shiba, 1979 ; Konishi, 1984). Although the detailed comparison of the fauna through the other guyots has not been studied yet, the similarity of the reflection characters of the lagoon sediments and the water depth of the flat summit strongly suggest that the guyots on the Ogasawara Plateau and Michelson Ridge grew during early to middle Cretaceous and drowned sometime in middle Cretaceous simultaneously. Therefore, the seismic units I to III are presumably correlative with each other. Guyots drowned in the middle Cretaceous are widely recognized in the Mid-Pacific seamounts and the Japanese seamounts (e.g., Matthews *et*

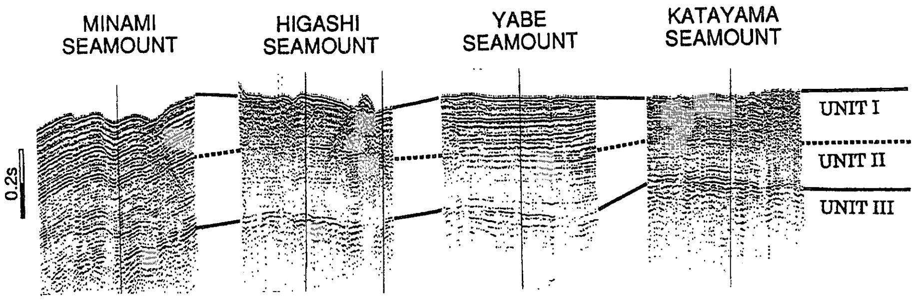

Fig. 18 Comparison and correlation of the seismic units under the flat summit of the guyots.

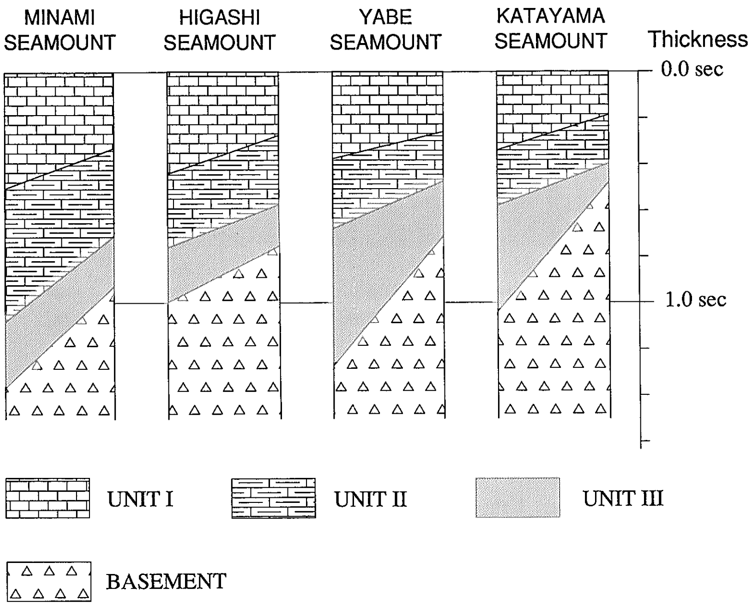

Fig. 19 Columnar section showing the thickness of the lagoon sediments Unit I to III. See text for explanation of Units I to III.

al., 1974 ; Winterer and Metzler, 1984), suggesting that the submergence of the reef was related to the Cretaceous global climatic and sea-level changes (Matthews *et al.*, 1974) or tectonic movements of the Pacific plate (Winterer and Metzler, 1984).

Although the thickness of the lagoon sediments varies in each of the seamounts, the average thickness of the upper two units decreases to the eastern guyots (Figs. 18 and 19). The thicknesses of Unit I and Unit II of Minami seamount are 0.3-0.45 s and 0.4-0.6 s. They are thickest in the four guyots. The Higashi seamount has a 0.3-0.4 s thick Unit I, and a 0.35-0.45 s thick Unit II. They are slightly thinner than those of Minami seamount. Unit III partly shows reflections up to 0.4 s in thickness. The Yabe seamount is underlain by a 0.26-0.38 s thick Unit I, a 0.24-0.42 s thick Unit II and a 0.3-0.55 s thick Unit III. The upper terrace of the Hanzawa seamount is presumably younger than Unit I, as discussed already. The Katayama seamount is underlain by Unit I of 0.2-0.3 s thick and Unit II of 0.2 s thick. The units are thinnest among the guyots in this area.

Because the reefs can not grow up above the sea-level, the thickness of the lagoon sediments approximately shows the amount of the subsidence of the guyots. Thus, the westward increase of the thickness of the lagoon sediments of the guyots

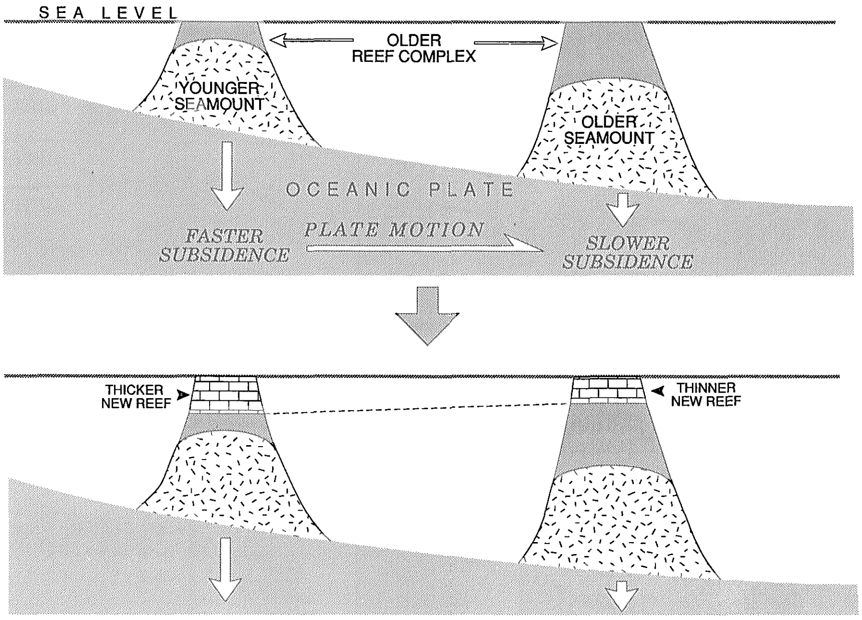

Fig. 20 Model to interpret the westward thickening of lagoon sediments due to eastward plate motion during the formation of volcanic mounds in and around the Ogasawara Plateau.

shows a westward increase in the subsidence rate, if Unit I, II and III are same age through the guyots. Crough (1978) showed that rises and hot-spot volcanos on the oceanic plates subside at the same rate as younger, hotter lithosphere, which means that the subsidence rate decreases as the seamount becomes older. Because the linear E-W alignment of the Michelson ridge strongly suggests that they are hot spot volcanos, the westward increase of subsidence rate can be interpreted by westward decreasing age of hot-spot volcanoes formed on an eastward shifting plate (Fig. 20).

In the Mid-Pacific Mountains (about 4000 km east of the Ogasawara Plateau), Winterer and Metzler (1984) estimated westward motion of the mid-Cretaceous Pacific plate on the basis of eastward increase of the depth of the guyots. The opposit estimation, the eastward or westward plate motion, are based on the assumption that the E-W alignments of the Michelson Ridge and the Mid-Pacific Mountains are hot-spot origin and the reefs of the guyots grew and drowned simultaneously. Further investigation of the guyots are necessary to clarify their age and origin.

5. Swelling and faulting of the Ogasawara Plateau and Michelson Ridge

The depth of flat summit of the guyots decreases westward from the Katayama seamount (1350 to 1450 m) to the Higashi seamount (900 to 1400 m) and then increases westward to the Minami (1200 to 3300 m) and Nishi (1600 to 3000 m) seamounts. The Higashi seamount, the shallowest guyot, is located at a distance of 100 km from the trench and its flat summit is about 500 m higher than that of the Katayama seamount that is located at the distance of 450 km from the trench. The marginal swells seaward of the trench generally have dimensions of about 200-500 km wide and 500 m high at the distance of 100-200 km from the trench. Therefore, the change of the depth of these flat summits is attributed to the flexure of the oceanic plate.

Faults becomes abundant close to the trench. The Ogasawara Plateau is cut by numerous faults, while only one fault was recognized in the Yabe seamount and no fault is observed in the Hanzawa and Katayama seamounts. This fact strongly suggests that the faulting is related to the deformation of the oceanic crust due to subduction or collision of the Ogasawara Plateau at the Ogasawara Trench.

The faults on the Ogasawara Plateau are concentrated in a few fault zones or areas (Fig. 4). The Minami seamount is one of the highly faulted areas in the Ogasawara Plateau. NW-SE trending faults are predominant except in the southwestern part of the seamount in which faults trend in NNW-SSE direction subparallel to the trench axis. The vertical displacement of faults usually ranges from 0.15 to 0.5 s and a few faults near the trench and northern margin of the seamount have up to 1.0 s vertical displacement.

Another fault zone forms a graben on the plateau to the southwest and west of the Higashi seamount (Figs. 4,7 and 21). The direction of the faults is NW-SE to the southwest of Higashi seamount and N-S to the west of the seamount. The wall of the graben is cut by several faults and descends to the graben axis stepwise (Figs. 7 and 21). The vertical displacement of the faults ranges from 0.2 to 0.5 s and the total vertical displacement between the axis and the outside of the graben attains about 1.0 s or more.

The fault zone apparently extends northwestward to the northeast and north of the Nishi seamount (Fig. 4). The direction of the faults changes from NW-SE to NNW-SSE to the north of the Nishi seamount. All faults in this area are eastdown. Vertical displacement of the faults ranges from 0.2 to 1.0 s.

The plateau between the Nishi and Minami seamounts is cut by N-S trending faults. Several NW-SE and NE-SW trending faults cut the flat summit of the Nishi seamount. A migrated seismic profile of the Nishi seamount (Fig. 13) shows that the faults are high angle normal faults, supporting the idea that the faults in and around the Ogasawara Plateau are normal faults and an extensional stress field due to bending of the oceanic crust before the subduction prevails in the Ogasawara Plateau.

There are two predominant directions of the faults; N-S or NNW-SSE and NW-SE directions (Fig. 4). The NW-SE lineation can be recognized as the outline of the guyots on the Ogasawara Plateau, suggesting that they are reactivated faults or fracture zones related to the formation of

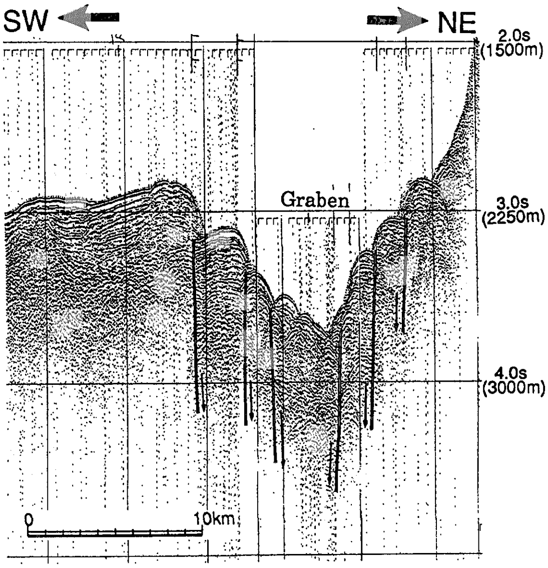

Fig. 21 Seismic profile of the graben to the southwest of the Higashi seamount. V.E.=13

the oceanic crust or the Ogasawara Plateau. The magnetic lineations map presented by Nakanishi *et al.* (1989) shows that oceanic floor around the Ogasawara Plateau was formed in the Jurassic age, and the fracture zone FZ-J4 reaches to the Ogasawara Plateau from the southeast. The direction of the fracture zone is nearly NW-SE, which is sub-parallel to the faults on the Ogasawara Plateau; therefore, the NW-SE faults are presumed to be related to ancient mechanically weak zone like fracture zones. Sea-Beam maps of the Ogasawara Trench to the north of the Ogasawara Plateau presented by Seta *et al.* (1991) clearly showed the two groups of faults: NW-SE trended faults almost parallel to the fracture zone and NNW-SSE faults parallel to the trench.

The N-S trending faults parallel to the trench began to grow in the zone within 30-40 km from the trench, while the NW-SE directed faults are observed outside of the area of the distance about 100 km from the trench (Fig. 4). These facts suggest that the mechanically weak zones are first broken as NW-SE faults and then N-S trending faults parallel to the trench are formed due to westward increase of the bend of the Pacific Plate.

6. Subduction or obduction

The seismic profiles of the inner trench slope show no coherent reflections nor accreted wedges. Ishii (1985) revealed that the dredged rocks from the topographic high on the inner trench slope have an arc affinity. They show that the Ogasawara Plateau has been underthrusting at the trench without accretion (Fryer and Smoot, 1985; Kobayashi, 1985).

Smoot (1983b) and Nagaoka *et al.* (1989) stated that the present Ogasawara Plateau is composed of offscraped seamount fragments which were originally linearly aligned in the E-W direction like the Michelson Ridge. Nagaoka *et al.* (1989) interpreted that the grabens to the north of the Minami seamount and to the southwest and the west of the Higashi seamount are the sutures of the offscraped seamounts. If their idea is correct, the walls of the graben have been upthrusting over the abyssal plain between the seamounts and the sediments on the abyssal plain must be offscraped forming an accretionary prism in which sediments are fairly folded and deformed. The seismic profiles, however, show no deformation suggesting compressional deformation around the graben, and the sediments around the grabens are slightly tilted and simply cut by the faults (Figs. 7 and 21). The sediments covering the plateau can be correlated almost across the entire plateau. These observations show that no contraction has occurred between both sides of the wall of the graben. Therefore, the faults are presumed to be normal faults as shown on the migrated seismic profiles of the Nishi seamount (Fig. 13). The Ogasawara Plateau is not a collage of the offscraped seamount fragments, and it was initially formed as a plateau.

7. Conclusion

Six guyots drowned in the middle Cretaceous age were found in and around the Ogasawara Plateau. They are capped by middle Cretaceous (probably Albian to Cenomanian) reef complex consisting of lagoon sediments showing coherent reflections and reef mounds showing massive reflection. Four of the guyots have similar succession of lagoon sediments that can be divided into three units, i.e., Unit I, II and III in descending order. They are presumably correlative. The units generally thicken westward, showing a westward increase of subsidence rate during the growth of the reef complexes. If the guyots were hot-spot volcanos, the westward increase of subsidence rate can be attributed to the eastward plate motion during the formation of the volcanic mounds. Faults are abundant on the Ogasawara Plateau and become scarce eastward, showing that faulting is related to the subduction or collision of the Ogasawara Plateau. Two predominant directions of the faults, NW-SE parallel to the fracture zone around the plateau and N-S parallel to the trench, are recognized. No folding of the sediments on the plateau is observed, and a migrated seismic profile shows that the faults are high-angle normal faults. They show that the plateau has been faulted by extensional stress due to westward bend of the oceanic plate. Lack of the compressional deformation on the Ogasawara Plateau suggests that the plateau has been underthrusting at the Ogasawara Trench.

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西太平洋，小笠原海台および Michelson Ridge の音波探査調査
—特に白亜紀のギヨーの成長と，沈み込む海台の変形について—

岡村行信・村上文敏・岸本清行・斎藤英二

要　旨

太平洋プレートの西端に位置する小笠原海台およびその東方に伸びる Michelson Ridge の音波探査記録の解析から，白亜紀のギヨーの成長と海台の沈み込みに伴う変形構造の検討を行った．小笠原海台は，周囲の海洋底より1500-3000 m 高い高原状の台地でそのうえに海山が 4 つ以上乗る．海台の東方にはほぼ直線状に 3 つの海山が連なっていて，Michelson Ridge と呼ばれている．海台上の 3 つの海山および Michelson Ridge の 3 つの海山は平坦な山頂を持つ白亜紀のギヨーである．音波探査記録では，平坦な山頂下のよく成層した最大1.5秒に達する礁湖（lagoon）の堆積物と，山頂を取り巻く反射面が全く見

えない石灰礁が明瞭に識別できる．礁湖の堆積物は西側の海山ほど厚くなるが，それらが同時代の堆積物である可能性が強いことから，西側の海山ほど沈降速度が早かったことを示している．西側への沈降速度の増加は，西ほど若い hot spot 起源の海山を考えることによって説明可能である．小笠原弧に衝突している小笠原海台には，海溝から約100 km 以内で断層が顕著になる．これらの断層の中には NW-SE 方向のものと，ほぼ N-S 方向のものがあって，前者はこの付近の海洋プレートの fracture zone と，後者は海溝とほぼ平行である．NW-SE 方向の断層の方がより東方まで認められることから，まず力学的に弱い古い弱線が海洋性地殻の曲げによって破断し，曲げが大きくなってから海溝に並行な断層が形成されると考えられる．

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