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Report on DELP 1987 Cruises in the Ogasawara Area

Part II: Seismic Reflection Studies in the Ogasawara Trough

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Abstract

Multichannel seismic profiles along two track lines in the Ogasawara Trough were obtained through DELP 1987 cruises. The trough is located between the old volcanic (Ogasawara) Ridge and the present volcanic front (Shichito-Iwoto Ridge). Stratigraphic units are acoustically distinguishable between eastern and western parts of the trough. The sedimentary unit of the trough in the eastern part is acoustically transparent and that in the western part, on the contrary, is opaque. The sedimentary layer becomes thicker toward the southern margin of the trough accompanied by scattering of reflected waves as well as decrease in free air gravity anomaly values. Although the acoustic basement was not clearly identified by the present study, it seems likely that it is dipping eastward in a stepwise manner. This feature can be reasonably interpreted as caused by normal faults which were formed in a tensile stress field during rifting of the trough in the Tertiary period (ca. 26-28 Ma). This tectonic deformation is possibly caused by differential opening of the Parece Vela Basin and Shikoku Basin in a narrow time interval.

1. Introduction

Late in the fall of 1987, as a part of DELP (Japanese version of International Lithosphere Program), geophysical and geological surveys were carried out around the Ogasawara Trough (Fig. 1). We have obtained two sets of seismic reflection profiles, one along a track line parallel to the trough axis from north to south (A), and the other along a line across the trough from east to west (B) (Fig, 1). This area characterized by the following features. 1: Change in the distribution patterns of seismicity and the discontinuity of the Wadati-Benioff zone between the southern and northern parts of the Izu-Ogasawara Arc (KATSUMATA *et al.*, 1969). 2: Collision of a line of seamounts from the east with the Izu-Ogasawara Trench at the southern part of the Ogasawara Trough (SMOOT, 1983). 3:

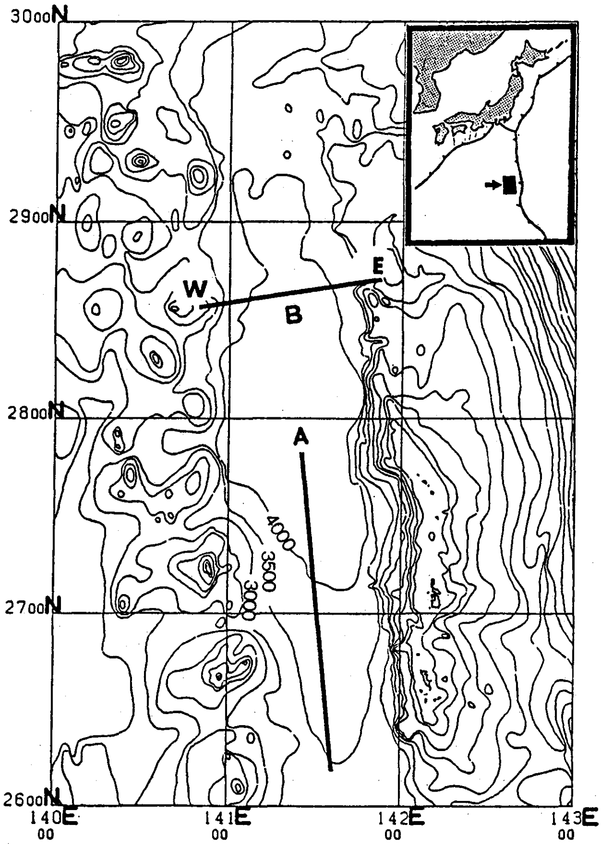


Fig. 1. Survey lines for Multichannel Seismic profiling of the DELP-87 cruise by the Japanese DELP Research Group in in the Ogasawaras.

Southward increase in negative free air gravity anomaly in spite of northward dipping of the bathymetric depths in the trough. 4: Rifting of the back-arc depressions in the Quaternary period (TAMAKI *et al.*, 1981). 5: Existence of a line of active volcanic islands to the west of the trough. 6: Oblique alignments of older and younger tectonic features in the Izu-Ogasawara system (YUASA, 1983).

Seismic velocity structures of the lithosphere around the Izu-Ogasawara and Mariana areas have been studied by several authors (HOTTA, 1970; LATRAILLE and HUSSONG, 1983; KARIG and RANKEN, 1983; BIBBEE *et al.*, 1980; AMBOS and HUSSONG, 1982; SINTON and HUSSONG, 1983; HUSSONG and SINTON, 1983; HAMBERGER *et al.*, 1983; KASAHARA *et al.*, 1985). The most extensive structural study across the northern margin of the Ogasawara Trough (32°N) was done by HOTTA (1970) and it was shown that there exists a thick layer (ca. 5 km) with a seismic P-wave velocity of 5.39 km/s underneath this area. This is explained by a thick accumulation of low velocity materials due to thick sediments (or turbidites) partially consolidated beneath this area.

The origin of the turbidite-like materials occupying the southern half of the trough was clarified by a series of Seabeam mapping surveys performed by the Hydrographic Department, Japan Maritime Safety Agency (JMSA) (KASUGA *et al.*, 1988; Maps from JMSA; unpublished). It is explained that the acoustically chaotic sediments are part of the volcaniclastic materials which erupted around Iwoto and they were transported northward filling the deeper part of the basement of the trough (ABE *et al.*, 1988).

2. Operation and processing

Seismic surveys were carried out by using a multi-channel seismic profiler with six active sections as well as a single channel profiler along the track lines A (N–S) and B (E–W) shown in Fig. 1. Ship speed was kept at 5 kt and the electronically controlled shot interval from pneumatic airguns was 16.5 seconds. The volume of the airgun chamber was 15 liters, the water depth of shooting was about 10 meters and the pneumatic pressure of shooting was kept at 110 atmospheric pressures. Line A was very short compared to the length of the trough axis from north to south due to shortage of ship-time. Acoustic signals (frequency as high as a hundred hertz) reflected from the ocean bottom and underlying geological sections were captured by six sections of active acoustic elements and were digitized and stored on magnetic tapes for further processing onshore. Common depth stacking, deconvolution filtering, migration and other measures which are common to MCS profiler data processing were applied to the original data. The processed data from lines A and B are shown in Figs. 3 and 2 respectively.

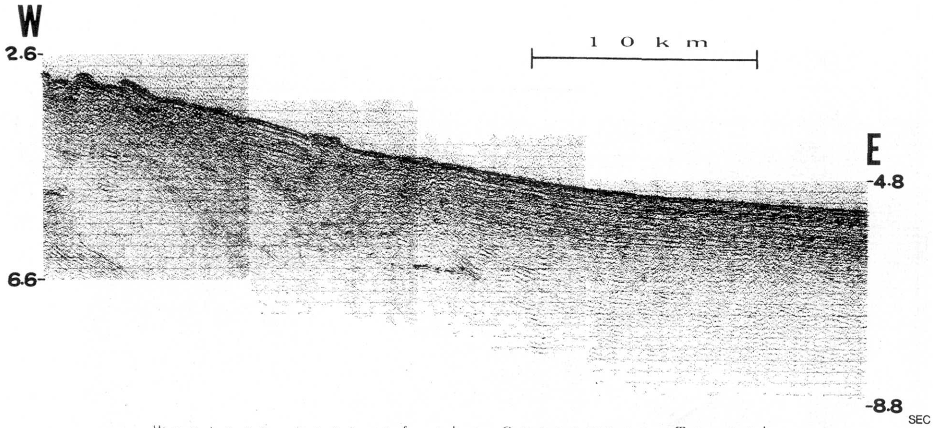
3. Seismic stratigraphy

It is clear from the processed profile of the MCS that there is a difference in the sediment structure between the eastern and western parts of the trough. The eastern part is characterized by a stratified structure with a number of reflectors representing the sedimentary history of the area. The western part is, however, filled with opaque sediment and there do not seem to exist clear reflective layers within it. This feature corresponds to the Seabeam observation by Japan Maritime Safety Agency (JMSA) in which they show that there are fan-like deposits in the southwestern corner of the trough area. More detailed descriptions along the two track lines are given in the next two sections.

3-1. Seismic stratigraphy along the E-W line (B)

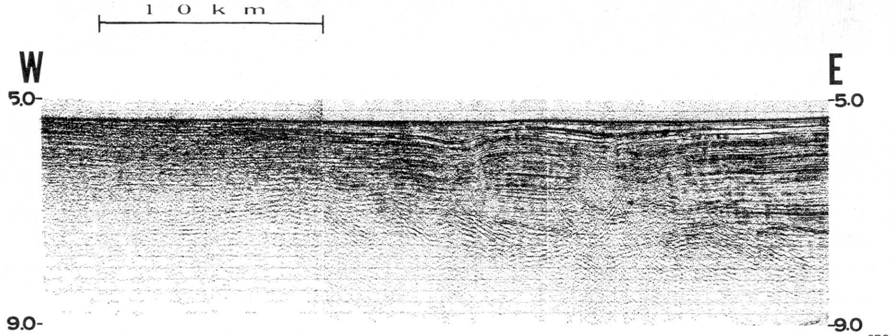
Figs. 2a, 2b and 2c are three sections of continuous records of seismic profiles of the Ogasawara Trough along the E-W line (line B in Fig. 1). Fig. 2d is an enlarged seismic profile from line B. We can recognize a high reflective layer across the trough (Fig. 2b. 2d). We call this reflector provisionally the sedimentary basement hereafter. This sedimentary basement deepens toward the east. At around the central portion of the trough, the basement reflector is dislocated (Fig. 2d). It looks likely that the fine structure of this dislocation takes the form of stepwise tilting of the basement block from west to east, i. e., blocks on the eastern side slipped down relative to blocks on the western side. The tilting surface of the sedimentary basement which we can idetify is the fault surface. The block rotated around a horizontal axis in the sense that the original acoustic interface, assumed to have been originally horizontal, tilted counterclockwisely when observed from the south. The degree of rotation induced by the slippage of each block, however, cannot be determined from the present data.

The upper part of the sediments on the eastern part of the trough is divided into three acoustically stratified sub-units as shown later in the interpretative explanation in Fig. 4. These stratified sub-units may not be hemipelagites but turbidites based on acoustic characteristics. They are continuously traced toward the south referring to data obtained by



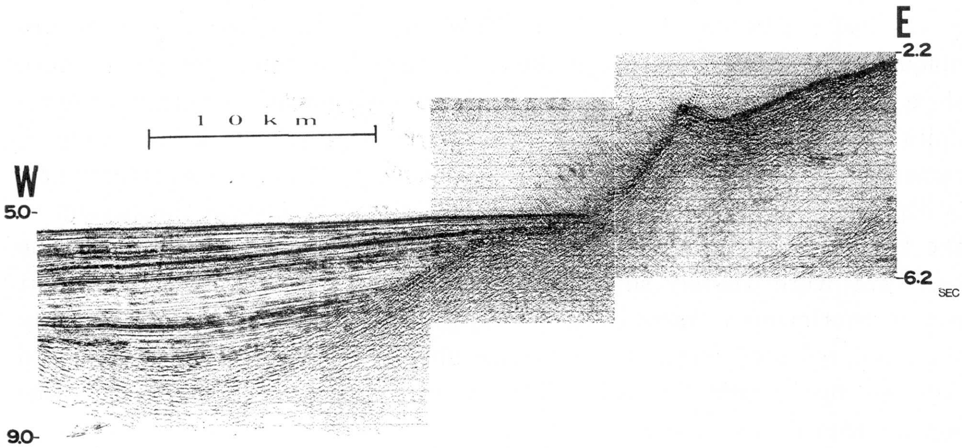
Western part of the Ogasawara Trough

Fig. 2(a)



Central part of the Ogasawara Trough

Fig. 2(b)



Eastern part of the Ogasawara Trough

Fig. 2(c)

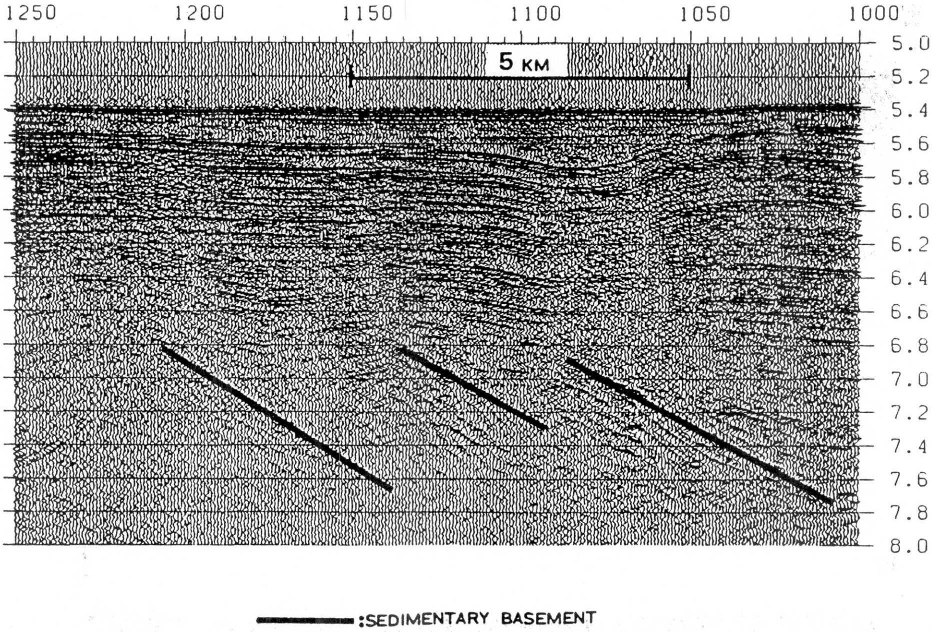


Fig. 2(d)

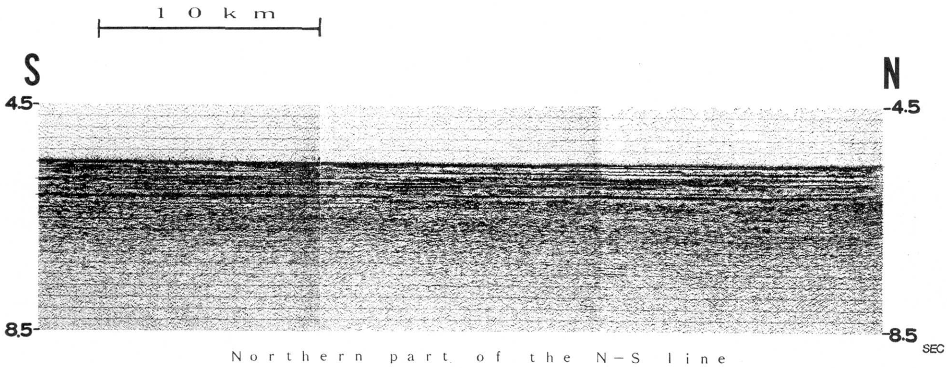
Fig. 2. Image of seismic reflection profiling digitally processed along the E–W seismic survey line B of Fig. 1. Entire track line is divided into three sections. a: western section, b: middle section and c: eastern section, d: enlarged seismic profile. The vertical scales are two-way acoustic travel time in seconds.

other organizations (GEOLOGICAL SURVEY OF JAPAN, 1981; KANEKO *et al.*, 1988; KASUGA *et al.*, 1988). This implies that these sub-units are ubiquitous in the eastern part of the entire trough system. On the western slope of the Shichito-Iwoto Ridge, however, we cannot separate acoustic units from one another. In this area, scattering of the reflected wave is remarkable. On the slope of the Shichito-Iwoto Ridge, the scattering unit is dipping continuously toward the east disappears beneath the bottom of the trough. The units overlying the irregular and acoustically opaque basement were possibly supplied by slumping of the volcaniclastics and it can be continuously traced as far as the Shichito-Iwoto Ridge. Also, highly scattered reflected waves support the unit to be comprised of unsorted deposits by pyroclastic flow. This volcaniclastic sediment reaches the central part of the trough.

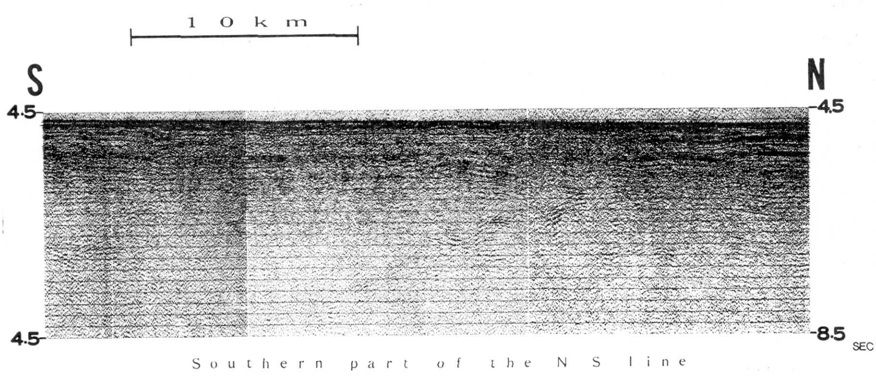
No acoustic units are identifiable on the slope of the Ogasawara Ridge. The slope is steep and there is a sharp discontinuity between the ridge and the trough sediments. The sediment traced from the Ogasawara Ridge is covered by the stratified sub-units in the eastern part of the trough.

3-2. Seismic stratigraphy along the N-S line (A)

Figs. 3a and 3b are two continuous sections of seismic profiles along the N-S line. We can hardly recognize the acoustic basement. This fact suggests that the reflected waves are scattered by disordered structure for some reasons similar to the case of the western side of the E-W track line. We selected the position of this line along the trough axis. However, the reflection patterns are variable from stratified to chaotic in a quite erratic manner. This suggests that this line is running just along



(a)



(b)

Fig. 3. Image of seismic profiling digitally processed along the N-S seismic survey line A of Fig. 1. Entire line is divided into two sections. a: northern section and b: southern section. The vertical scales are two-way acoustic travel time in seconds.

the boundary between the eastern and western sedimentary portions of the E-W line.

In the northern part of the N-S lines, two sedimentary units are identified. Of those two units, the upper unit is acoustically transparent and corresponds to the sedimentary unit in the eastern part of the trough along the E-W line, and the lower unit is acoustically chaotic and corre-ponds to the sedimentary unit in the western part of the trough. The scattering of the reflected wave from the units becomes remarkable toward the south. On the other hand, the water depth becomes shallower toward the south. In the southern part of the N-S line, we can only recognize a chaotic sedimentary unit. This suggests that the volcaniclastic sediment supplied from the Shichito-Iwoto Ridge is probably accumulated in large amount in the southern part of the trough.

4. Discussion

The block motion of the basement materials in the Ogasawara Trough must reflect to some extent the tectonic situation of the region. The motion and origin of the Philippine Sea plate have been studied by several authors (SENO and MARUYAMA, 1984, BEN-AVRAHAM *et al.*, 1983). If the drift velocity (direction: ca. 60–70 deg. West from North, NISHIWAKI, 1981) of the Pacific plate relative to the Philippine Sea plate has been constant, the Ogasawara Plateau and its continuation (aligned ca. 50–60 deg. West from North) presently colliding with the Izu-Ogasawara arc must have started colliding with the Ogasawara at a point north of the present collision. Shift of the colliding front toward the south might have influenced the time sequence of tectonism in the Ogasawara Trough. We have, however, little knowledge to what extent the seamount chain colliding with the Ogasawara Ridge has influenced the tectonic structure of this area.

DSDP (Leg-31) data show that active volcanism occurred in the Ogasawara Ridge in the Late Oligocene, and, after this volcanism, the Shikoku Basin and Parece Vela Basin started spreading (KARING, 1975). From our observation, we suggest that the faulting and slumping of the basement blocks of the Ogasawara Trough was activated in conjunction with the initiation of the volcanic activities of the Ogasawara Ridge system. This is inferred from the observation that the block faulted basement in the Ogasawara Trough was buried soon after cessation of the rifting. Fig. 4 shows the interpretative stratigraphic sequences along the E-W line (B). Geologic ages of the sediment layers are assigned for

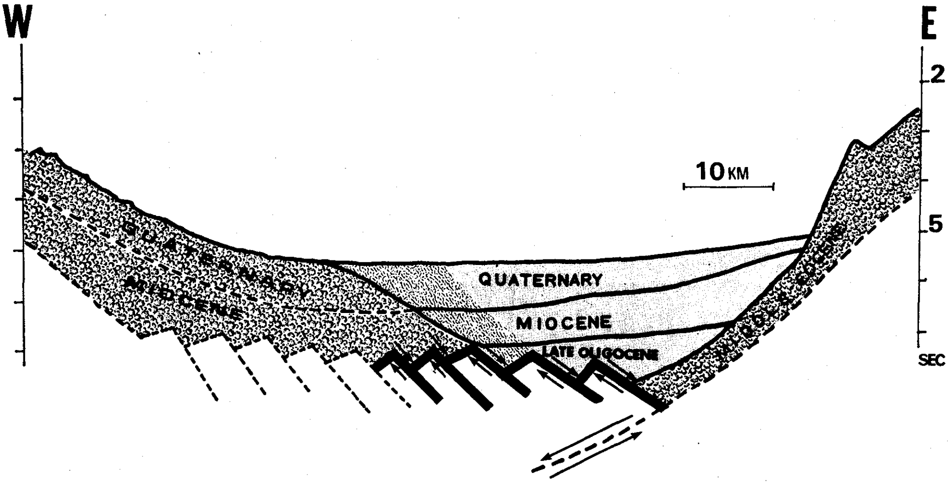


Fig. 4. Our interpretation of the reflectors and the blocking of basement materials assumed to have occurred during or after rifting of the trough. The vertical scales are two-way acoustic travel time in seconds.

comparison with the geologic ages of the sediment materials from the Ogasawara and Shichito-Iwoto Ridges.

Further, there is little indication of large scale deformation in the upper sedimentary sequences. The crustal structure of the trough is very similar to a graben covered by a thick sediment. These facts suggest that the Ogasawara Trough has been in a tensile field since its formation. This stress field pattern is also reflected in the alignments of the back-arc depressions behind the Izu-Ogasawara arc. These depression are bounded by north-south trending normal faults on both sides (TAMAKI *et al.*, 1981; HONZA and TAMAKI, 1985). They suggest that the back-arc depression (to the west of the Ogasawara Trough) may be rifted in the Quaternary.

YAMAZAKI and MURAKAMI (1987) reported that the old depressions run from the Shikoku Basin across the Shichito-Iwoto Ridge by NE-SW trending normal faults and some thick sediments are observed in these depressions. If we look at gravity and magnetic data obtained by the Hydrographic Department, Japan Maritime Safety Agency (to be published in 1989), these NE-SW trending structures continue further to the eastern side of the Shichito-Iwoto Ridge (KANEKO *et al.*, 1988). Namely, these old depressions continue to the Ogasawara Trough area, and they influence the crustal structure of the trough. This part of the oceanic basin is surrounded by various types of oceanic basins and ridges of different ages.

The age constraint of rifting of the Ogasawara Trough can be deduced by referring to the geomagnetic anomaly patterns. Paleontological data from dredged as well as drilled sediments and absolute ages of rocks from islands and dredged samples in this area, also give good estimates of the age of formation of the Ogasawara Trough.

The geomagnetic anomaly patterns show that the spreading of the Shikoku Basin started at about 27 Ma (WATTS *et al.*, 1975 ; ISEZAKI, 1973 ; KOBAYASHI and NAKADA, 1978 ; KLEIN and KOBAYASHI, 1980) and the Parece Vela Basin started spreading at about 30 Ma (MOROZOVSKI and HAYES, 1979 ; SCOTT *et al.*, 1980). Therefore, the Parece Vela Basin is older than the Shikoku Basin.

There is a distinct structural boundary between the Shikoku Basin and the Parece Vela Basin. Some structural discontinuity such as a fault was probably formed in the junction area between area between the Shikoku Basin and the Parece Vela Basin during the time gap between the initiation of formation of the two basins. The ages of rocks around the Ogasawara Ridge indicate that in the ridge as old as 48 Ma volcanic activity started again at about 26 Ma (DSDP Leg-31). Assuming all these data to be reliable, it is probable that the rifting of the Ogasawara Trough occurred shortly after the initiation of spreading of the Parece Vela and shortly before the initiation of spreading of the Shikoku Basin. The temporal discontinuity which was encountered between the opening of the Parece Vela Basin and the Shikoku Basin must have caused rifting of the Ogasawara Trough. On this occasion the Paleo-Ogasawara Ridge was divided into the present Ogasawara Ridge and the Shichito-Iwoto Ridge, the Ogasawara Trough formed within a very short time interval (26–28 Ma.)

Combining all this information, we postulate the history of the formation of the Ogasawara Trough and its adjacent areas as in Table 1.

Table 1. Tectonic history of the Ogasawara Trough and its adjacent areas.

Ages	Basin formation	Eridences
Eocene-Oligocene	West Philipine Basin	Deep Sea Drilling Project (fossils) Magnetic lineation
Oligocene-Miocene	Parece Vela Basin	ditto
Miocene	Ogasawara Trough	Rock age Stratigraphy
Miocne	Shikoku Basin	ditto
Quaternary	Back-arc of Ogasawara	(presently active)

5. Summary and conclusion

The following features of the rifting mechanism and the tectonic history of the Ogasawara Trough are postulated from the present and past studies.

1) Faulting of the trough occurred after formation of the Ogasawara Ridge.

2) Tectonic deepening of the trough was induced by thinning of crustal layers associated with faulting and subsequent tilting.

3) The tilting of basement materials of the trough occurred in the sense that the eastern part of the trough became deeper.

4) The southern part of the basin was completely covered by volcaniclastics which erupted from later (Miocene to Quaternary) volcanic activities of the Shichito-Iwoto Ridge.

5) The Paleo-Ogasawara Ridge was divided into the present Ogasawara Ridge and the Shichito-Iwoto Ridge by rifting, and the Ogasawara Trough was formed during a short time interval after this rifting.

6) Rifting of the Ogasawara Trough was caused by the development of the structural discontinuity (old depressions) between the Shikoku Basin and the Parece Vela Basin which formed a back-arc basin of the Paleo Ogasawara Ridge.

7) The rifting of the Ogasawara Trough occurred shortly after the initiation of formation of the Parece Vela Basin and shortly before the initiation of formation of the Shikoku Basin.

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Appendix. Ages of geologic elements around the Ogasawara area

A summary of paleontological, geomagnetic absolute age determinations is presented in Fig. A-1. Values of the age are given in units of Ma. The references for these ages are obtained from review papers and are cited here separately from general references cited in the text.

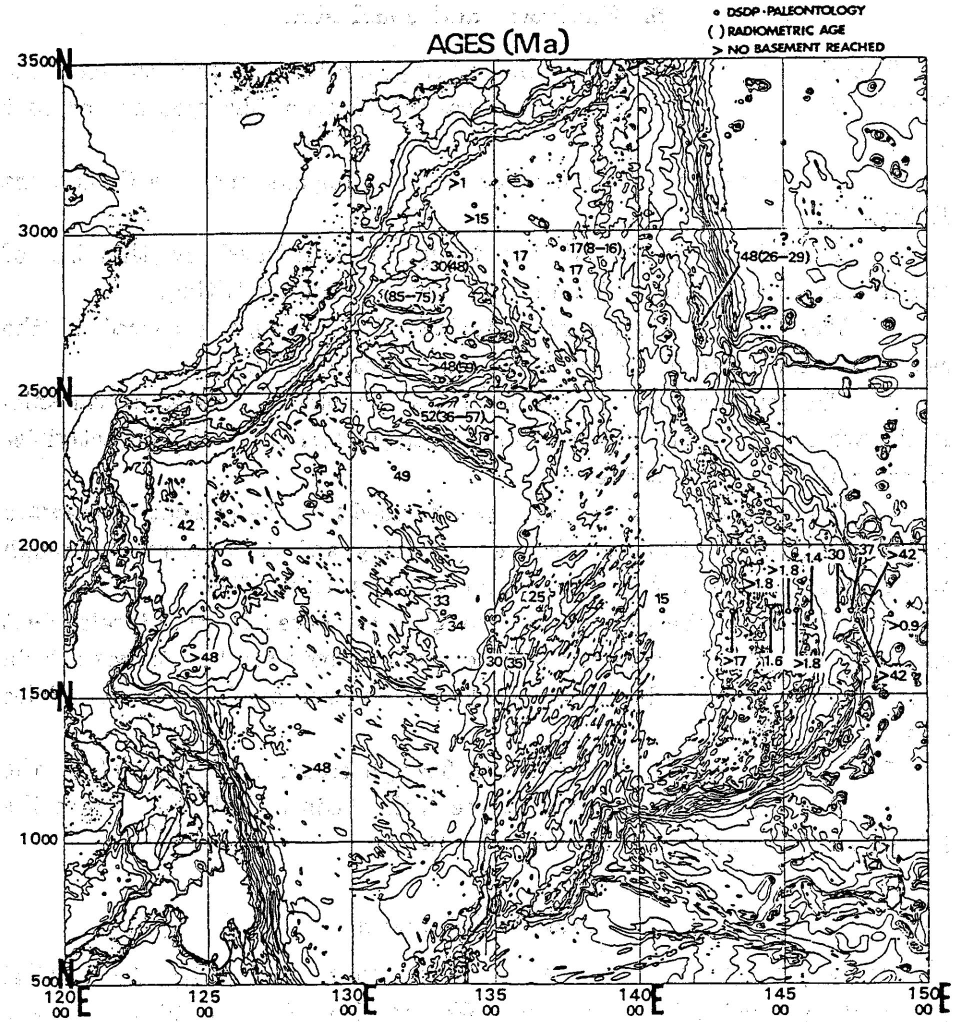

Fig. A-1. Distribution of ages of various geological elements in the northwestern corner of the Pasific region including the Shikoku, Parece Vela and West Philippine Basins and adjacent troughs. Ages are given in units of Ma.

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DELP 1987年度　小笠原海域航海報告

II. 反射法音波探査

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1987年11月小笠原トラフ周辺海域において DELP 研究航海が実施された．小笠原トラフは，第三紀の火山弧である小笠原海嶺と現在の火山弧である七島・硫黄島海嶺の間に位置する．トラフ内の堆積構造は，トラフ内の東側と西側で，音響学的に大きく異なっている．東側では音響学的に透過性の良い堆積物が，西側では音響学的に散乱の激しい堆積物が堆積している．トラフ南部に向かうほど堆積物は厚くなり，その散乱の度合も激しくなる傾向がある．音響基盤については，東西測線のトラフ底中央部においてのみ明瞭に確認することができた．それによると，七島・硫黄島海嶺から続いてくると思われる音響基盤が，東落ちの正断層を伴いながら，ブロック状にステップダウンしている．このことは，かつてこの地域がテンションの場にあったことを示唆し，小笠原トラフがリフティング起源であることを示す．その時期については，四国海盆拡大開始の前後で，しかも非常に短期間のうちに形成されたと推定する．このような構造的変形は四国海盆とパレスベラ海盆の拡大過程の違い，特に拡大開始時期のわずかな時間的ずれによって引き起こされたものと考えられる．