

22. STRATIGRAPHY AND TECTONIC INTERPRETATIONS OF MULTICHANNEL SEISMIC REFLECTION RECORDS ACROSS THE JAPAN TRENCH OFF SANRIKU, NORTHEASTERN JAPAN¹

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ABSTRACT

New F-K migrated multichannel reflection profiles establish the seismic stratigraphy between Sites 438/439 on the deep-sea terrace and Site 584 on the midslope terrace of the continental slope off Sanriku, northeastern Japan. Prominent downlapings of the basal strata are observed at places where the Cretaceous basement has been uplifted, and surface reflectors terminate or top lap at the same place. Uplift of the basement causes tensional stress and arching in the overlying Neogene strata along the outer margins of the midslope terrace and deep-sea terrace, forming both downlapping and toplapping. Graben within the subducted lithosphere may influence tectonic erosion along the base of the overlying prism.

INTRODUCTION

The two main objectives of this report are (1) to establish a new seismic stratigraphy that clarifies the subsidence and uplift history of the continental margin off northern Honshu; and (2) to interpret tectonic mechanisms associated with subduction in the toe area of the accretionary wedge.

It was surprising to find that the steep dips of bedding were developed throughout almost the entire section of Site 584 at the midslope terrace. Contrary to the seismic section across the deep-sea terrace, where landward-dipping normal faults were observed near Site 438/439, no visible faults were identified on the seismic sections near Site 584. The shipboard party believed, however, that small landward-dipping faults must have developed to compensate for steep bedding dips co-occurring with the nearly horizontal seismic and paleontologic correlation among the three holes drilled at Site 584 (Karig et al., 1983).

Three seismic sections from Japan National Oil Corporation (JNOC) and two from the Ocean Research Institute (ORI) (ORI 78-3, ORI 78-4) cross the northern part of the Japan Trench (Fig. 1 and Nasu et al., 1980; Nasu et al., 1979). During the presite survey for Leg 87, additional multichannel seismic sections (ORI 80-2 and ORI 81-9) were obtained (Kagami, Tokuyama, et al., 1980; Kagami et al., 1981; Tokuyama et al., 1982). Line ORI 80-2 crosses JNOC A and extends to ORI 78-3, on which Site 584 is situated, affording the opportunity to correlate drilling results and seismic reflectors between Sites 438/439 and 584. Interpretation of the seismic section corresponds in general to the drilling results of Leg 87.

Also, the results allow us to discuss the origin of the downlap of the Miocene horizons.

METHODS

Seismic Reflection Methods

A multichannel seismic reflection survey was carried out across the Japan Trench off the Sanriku district of northeastern Japan during the KH80-1 and KH81-3 cruises. A 12-channel seismic system composed of sound source, hydrostreamer, amplifier, and recording blocks was used in these cruises (Kagami, Takahashi, et al., 1980).

The sound source was a 300-cubic-inch air gun operated at a pressure of approximately 80 kg/cm² and fired at a time interval equivalent to approximately 50 m. The hydrostreamer block consists of 12 active sections, 3 stretch sections, 3 depth/distance sections, and a tail section. The length of each active section is 50 m. The amplifier block amplifies, filters, multiplexes, and converts (analog to digital—A/D) the 12-channel input signals. Signals from the 12 active sections are fed into 12-channel preamplifiers with preset gains and band-pass filters. The observed signals are then filtered through a band-pass of 0–128 Hz. After multiplexing is complete, serial signals are amplified in 12-dB steps up to 84 dB, depending on each input level, and then digitized by a 15-bit A/D converter. Record length and sampling interval are 4000 ms and 4 ms, respectively.

Data Processing

Almost all of the computer programs used for signal processing applied in this study were originally written by Takeuchi and Saito (1982) and were executed at the Computer Centre of the University of Tokyo. The procedure of analysis is a standard one. First we transformed the data to SEG-X format, for handling with our program. Because there seems to be a low-frequency (~10 Hz) noise in some of the original records, we performed band-pass filtering (10–60 Hz) before stacking. After we made common depth point (CDP) gathers, we applied normal move out (NMO) correction with velocity analysis. The result of the velocity analysis shows no significant difference with that of Kagami and others (1981). Next we applied a perstack deconvolution (40 ms); then we performed 6-fold stacking, 200-ms deconvolution, and 10–50-Hz band-pass filtering. Finally, we displayed the seismic section.

To remove the diffraction wave from some parts of the section, we performed an F-K migration. By the use of an FFT (fast Fourier transform), we can perform an F-K migration easily, but if the lateral velocity change is significant, we cannot apply it. In the case of these recorded sections, the lateral velocity gradient seems to be small and the result is satisfactory.

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DESCRIPTION OF MAJOR REFLECTORS

Several characteristic reflectors are identified in the continental slope off Sanriku, northeastern Japan. Some of the reflectors were successively traced from Sites 438/439 to 584 through seismic Lines JNOC 1, JNOC A, ORI 80-2, and ORI 78-3, (Fig. 1). These reflectors are recognized as follows, mainly based on drilling results.

Reflector Y is relatively continuous, and above this reflector onlapping structure occurs, e.g., at Shot Point (SP) 900 in Figure 2.

Reflector X has a limited continuity and large amplitude in the seismic section. Locally, it represents sediment fill of the forearc basin and is dated as Pleistocene at Site 438.

Reflector C is relatively continuous; locally it merges with a subsidiary reflector and forms a large-amplitude signal. Dated as the late Pliocene, it perhaps corresponds to the boundary between Lithologic Subunits 2A and 2B at Site 438, a change from clay and diatom ooze to claystone and diatomite (Kagami et al., 1981; von Huebner et al., 1980). This boundary also corresponds to a velocity increase from 2.25 to 2.34 km/s measured by sonobuoy (Murauchi and Ludwig, 1980). The numerous faults cutting through this reflector from the basement are thought to be normal faults (fig. 4 in Kagami et al., 1981).

Reflector E (late Miocene; 6–7 Ma) has limited continuity and large amplitude. At Site 438, this reflector corresponds to the boundary between Lithologic Subunits 2B and 2C with increasing amounts of clay below the boundary, but it also corresponds to a hiatus at 6–7 Ma (Akiba, 1983). Above this reflector, onlapping structures mark Pliocene transgression over the continental slope area (SP 1120 in Fig. 2).

Reflector F (middle Miocene, 13–14 Ma) is less prominent than Reflector E in both continuity and amplitude. This reflector corresponds to the boundary between Lithologic Subunit 2C and Unit 3 at Site 438, a 13–14 Ma unconformity (Akiba, 1983). Under this reflector, ash content increases and reflectors show toplap or truncations (SP 700 in Fig. 3).

Reflector G (early Miocene) is relatively continuous and has a large amplitude. This reflector corresponds to the boundary between Lithologic Units 3 and 4 at Site 438, a boundary which separates vitric diatom claystone above from clayey siltstone below.

Reflector J is relatively continuous and has a large amplitude. This reflector corresponds to the boundary between Lithologic Units 6 and 7 at Site 438, which marks a pronounced unconformity between the Cretaceous and Oligocene. This reflector also corresponds to a velocity change of 2.09 to 3.25 km/s as measured by ocean-bottom-seismometer (OBS) observations (Nagumo et al., 1980) and to that of 2.34 to 2.80 km/s as recorded by a sonobuoy survey (Murauchi and Ludwig, 1980).

Saki and others (1980) reported synthetic seismograms derived from the sonic and formation density logs at Sites 438 and 439. Reflections with prominent amplitude in the synthetic seismogram correlate well with those on the seismic record within a limit of half phase above

Reflector E and one phase below it. Reflectors X and C have a characteristic pattern in both sets of logs and are traced for long distances. Lithologic changes in the deeper section cause high-amplitude Reflectors E and F.

TECTONIC INTERPRETATION OF THE SEISMIC SECTION

The seismic section ORI 80-2 parallels a broad depression or valley on the continental slope and is oriented perpendicular to the trench (Fig. 1); therefore, the sedimentary section at ORI 80-2 is thicker than at JNOC 1, located along a broad culmination of the continental slope. At SP 1020, Profile ORI 80-2 crosses JNOC A (Fig. 2), along which most reflectors can be traced from Sites 438/439. From SP 960 landward on ORI 80-2, Reflector G is identified above Reflector J. For about 40 km, from SP 100 to 900 (Figs. 2–4), Reflector G is missing in an area probably underlain by a ridge of Cretaceous basement uplifted during the Paleogene or early Miocene (Kagami et al., 1981). The ridge constitutes outer margin of the Sanriku deep-sea terrace (Nasu et al., 1980). Downlapings of the middle Miocene section occur at two places on the ridge; the first place is situated at SP 600–700, where strata lower than Reflector F downlap onto Reflector J (Fig. 3), and the second place is located at SP 100–300 (Fig. 4). The downlapping of strata was previously interpreted to result from onlap onto a regional high, indicating a marine transgression over an unconformity (Nasu et al., 1980). We propose, however, that the downlapping geometry was caused by the series of normal faults and clockwise rotation of beds, which are only observed at the basement uplift areas. Local uplifts have developed at the outer margin of the mid-slope terrace and deep-sea terrace since the middle Miocene. The surface reflectors toplap or truncate within (or slightly landward of) the area where the downlaps develop. Reflector Y truncates at about SP 750 (Fig. 2), and Reflector X at about SP 200 (Fig. 4). These facts indicate a strong relationship between downlapping of the basal reflectors and toplapping of the surface reflectors at the same place. Both phenomena were formed by uplifting of the basement at the margin of these terraces. From the age of the surface reflectors and from drilling results of Site 584 (site chapter, Site 584, this volume), the main phase of the local uplifting is estimated to have occurred since the late Pliocene. The reason for uplift could be an increase in the accumulation rate of diatomaceous sediments since the late Miocene in the northern Japan Trench area (site chapter, Site 584, this volume).

In another example of toplapping, Reflector C truncates at SP 180 on Line ORI 78-3 (Fig. 5). These sequential truncations of reflectors from Y (upper Pleistocene), X (lower upper Pleistocene), to C (upper Pliocene) toward the trench axis are once more encountered at SP 270, the location of DSDP Site 584 (Fig. 5). We recovered lower Pliocene strata at very shallow sub-bottom depths at Site 584 and steep dips of bedding which reached 70° near the bottom of the hole (Karig et al., 1983). On seismic Profile ORI 78-3, the lower strata downlap between SP 0 and 300 (Fig. 5), perhaps representing mi-

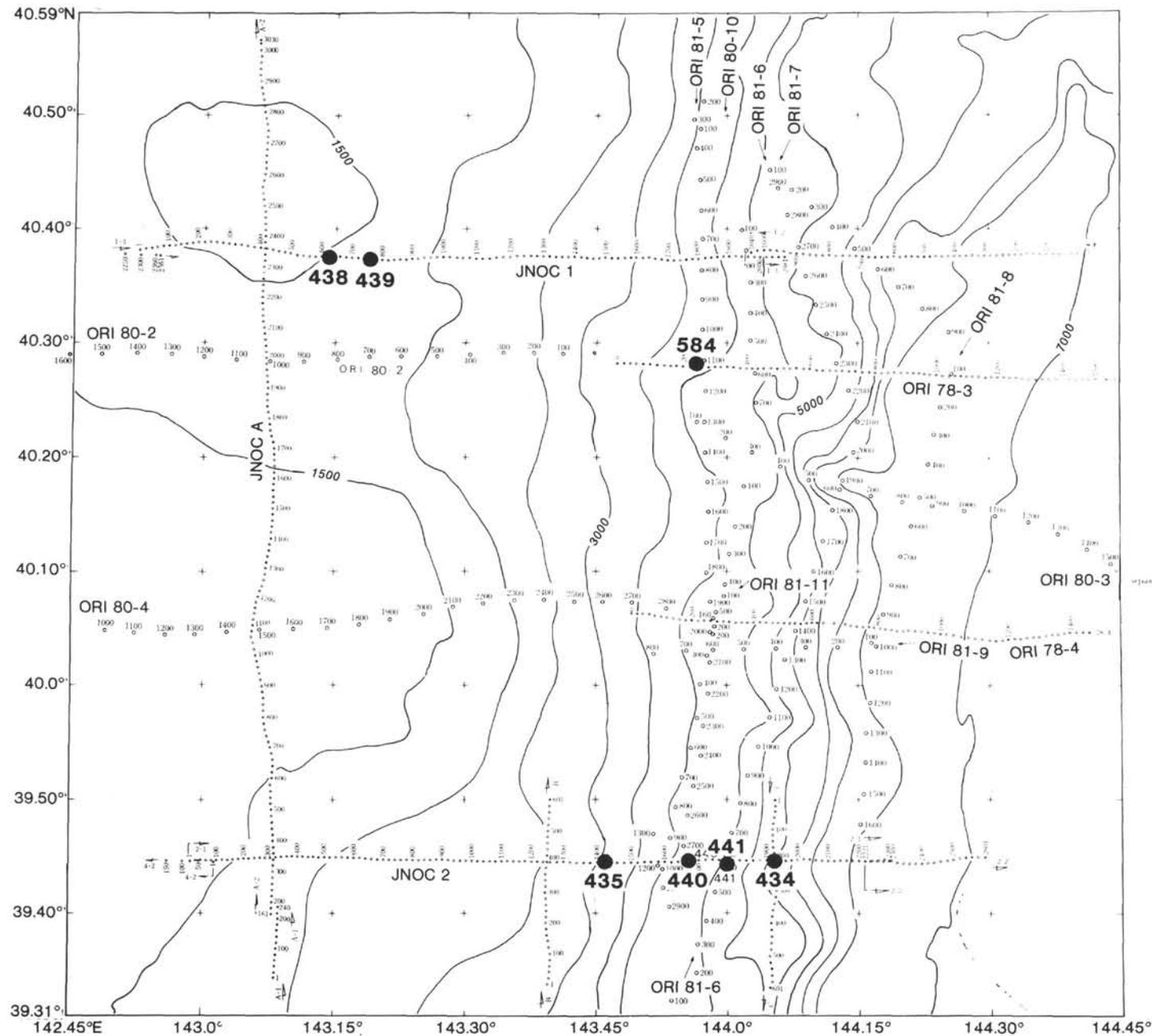


Figure 1. Tracklines of all available multichannel seismic reflection profiles near the Japan Trench, off Sanriku, northeastern Japan. Numbers on the tracklines are shot numbers.

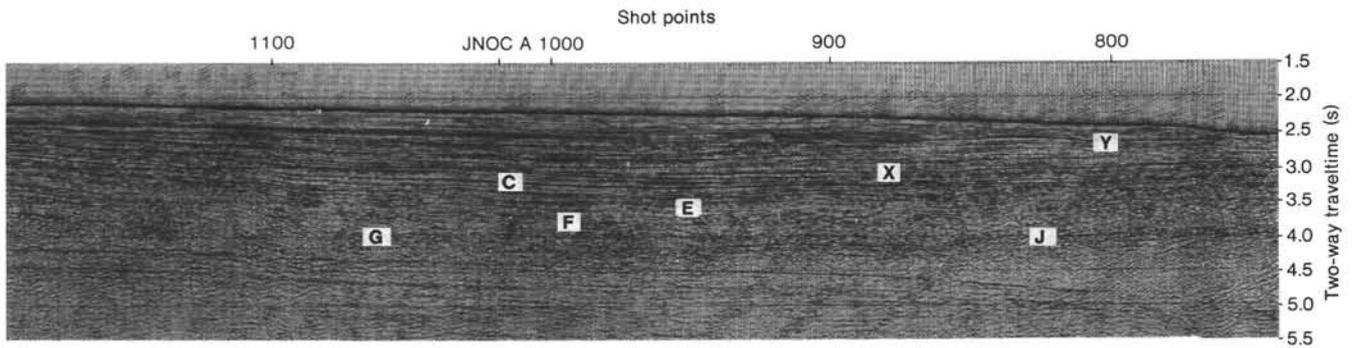


Figure 2. Common-depth-point stacked traces of ORI 80-2 (SP 740 to 1195). Capital letters inside profile indicate reflectors.

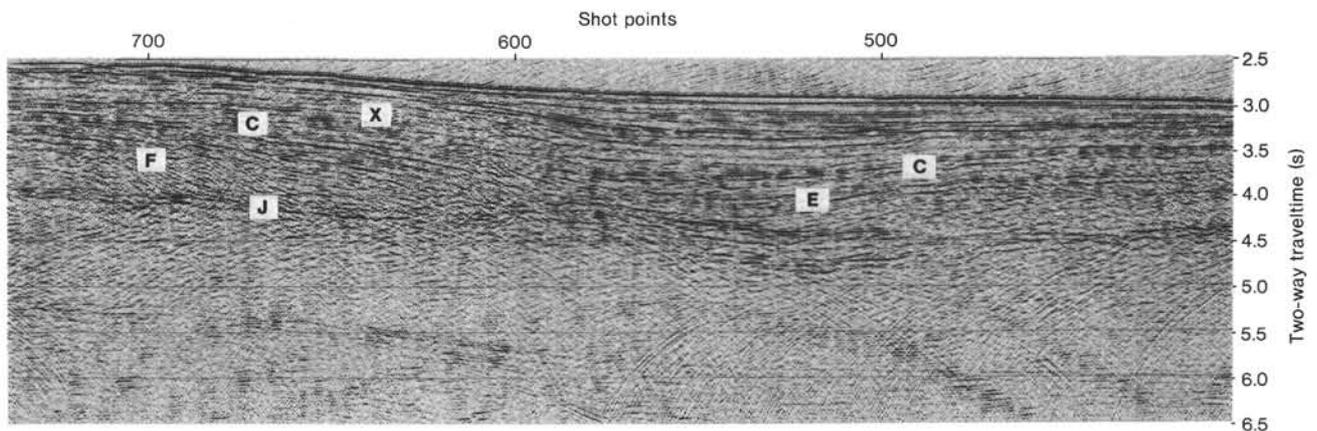


Figure 3. Migrated section of ORI 80-2 (SP 405 to 740). Velocity used to perform migration was 2000 m/s. Capital letters as in Figure 2.

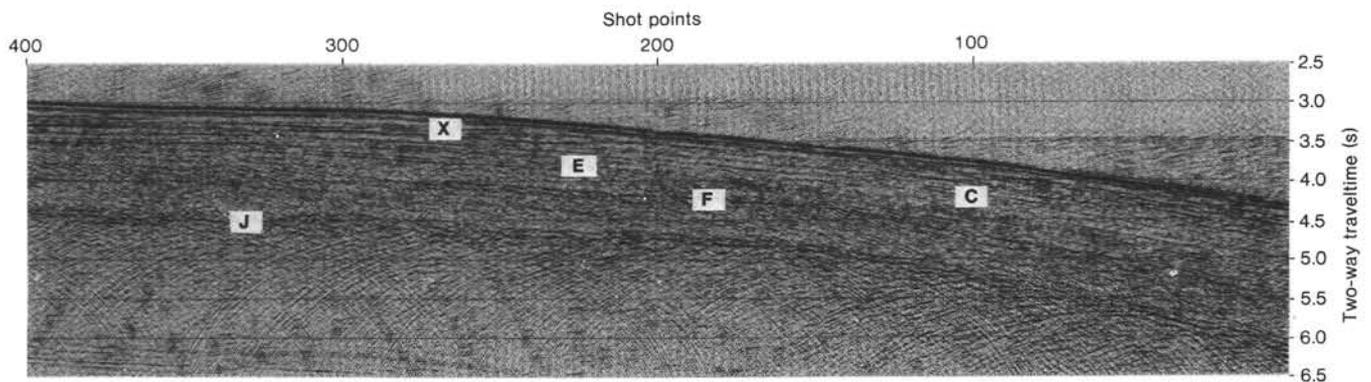


Figure 4. Migrated section of ORI 80-2 (SP 0 to 400). Velocity used to perform migration was 2000 m/s. Capital letters as in Figure 2.

crofracturing instead of large-scale faulting. Although this relationship differs little from the above-mentioned cases on the uplifted ridge at the outer margin of the deep-sea terrace, it suggests that this site is also situated on another active, uplifted ridge that forms a midslope terrace on the trench slope. The basement uplift at the outer margin of the deep-sea terraces and midslope terraces might be caused by seismotectonic deformation at the consuming plate boundary (Nagumo, 1970).

The seismic stratigraphy indicates that Reflector F can be traced over the entire continental slope except for a distance of ~5 km on ORI 80-2 (near SP 550, Fig. 3).

This gap does not indicate emergence of the Oyashio landmass but is related to some local phenomenon. Because Reflector F is observed over almost the entire continental slope, we could safely say that the entire continental slope is under the depositional environment. Drilling results at Site 584 also indicated abyssal bottom conditions since the early middle Miocene (site chapter, Site 584, this volume).

TRENCH ACCRETIONARY WEDGE

The Japan Trench and base of the landward slope are shown in Profile ORI 81-9 (Fig. 6), which is situated just

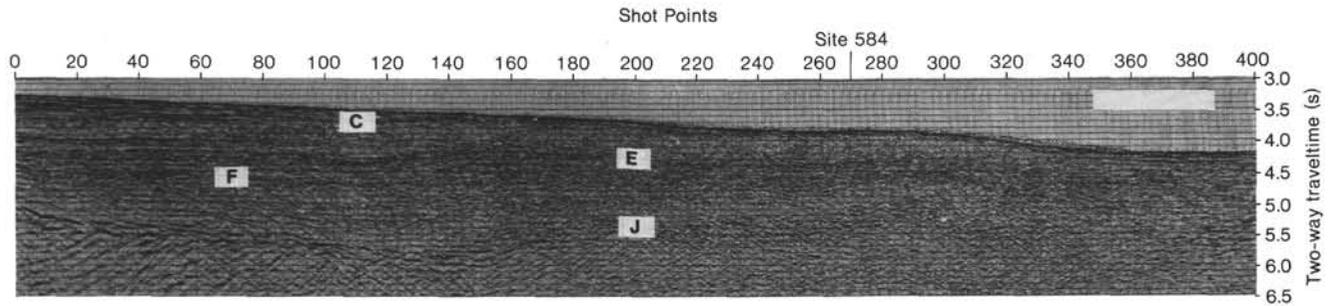


Figure 5. Migrated depth section of ORI 78-3 (SP 0 to 400). This section was prepared by JNOC through the courtesy of Dr. Yasufumi Ishiwada. Capital letters as in Figure 2.

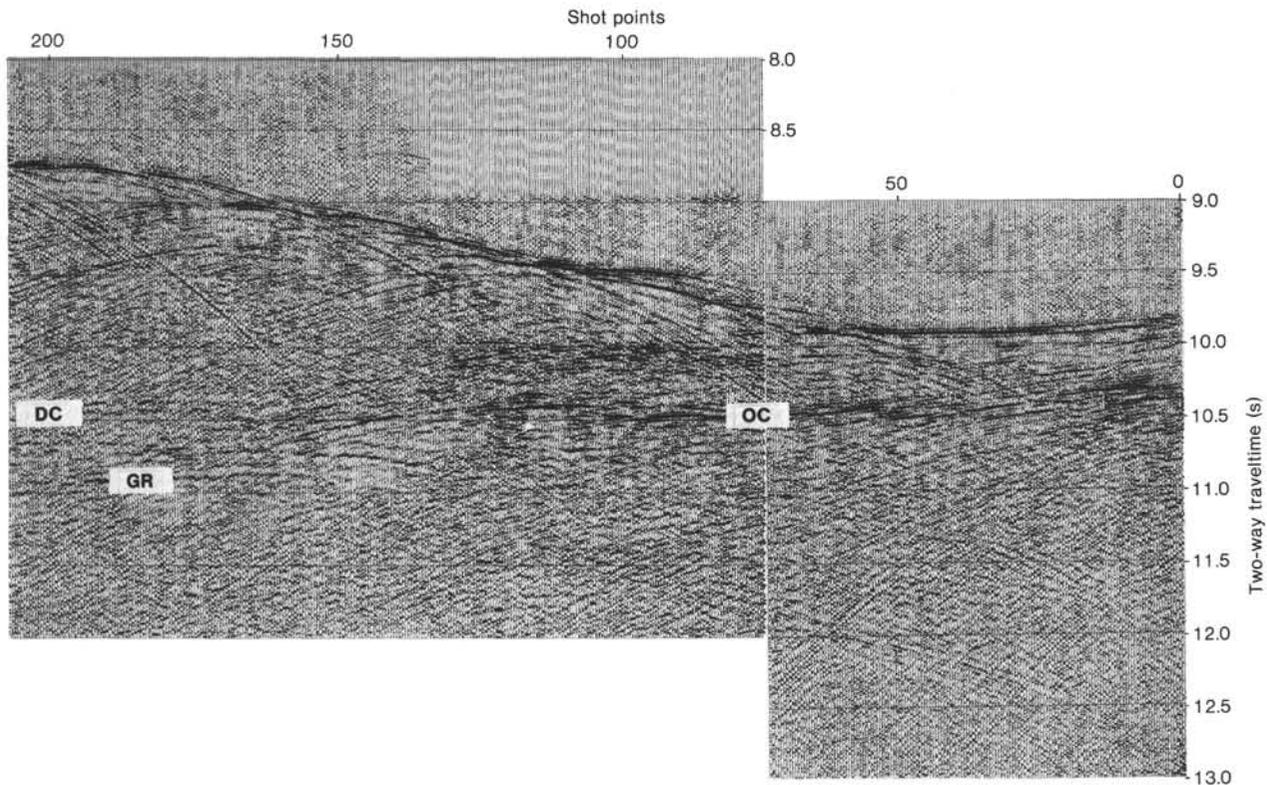


Figure 6. Common-depth-point stacked traces of ORI 81-9 (SP 0 to 210) showing the accretionary toe of the Japan Trench. OC: ocean crust, GR: graben, DC: décollement.

to the south of ORI 78-4. A well-developed graben can be seen at SP 150 landward of the trench axis (GR in Fig. 6). The surface of the subducted ocean crust drops to a depth of more than 1000 m sub-bottom, and the structure is quite similar to the graben shown on the outer trench slope (Hilde, 1983). An important feature displayed on our profile is a décollement near the top of the graben at about 10.5 s in two-way traveltime (DC in Fig. 6). The décollement is represented by a line from horst to horst and appears to be a straight-line extension of the top surface of oceanic Layer IIA (Tokuyama et al., 1982). Thrust faults prevailing in the toe of the accretionary wedge seem to verge with the décollement in the lower part of the sequence.

Hilde (1983) proposed a mechanism of subduction of trench-fill sediments within grabens developed on the out-

er trench slope and named it the chain-saw mechanism. The normal fault system of the graben thus still appears to be active even after subduction beneath the inner slope. Tensional events have occurred in the upper portion of the subduction plate as far as 100 km landward from the trench axis (Yoshii, 1977). Activity on the normal faults increases the vertical offset between the floor of the graben and the décollement. The development of the décollement above the graben leads to the conclusions that accretionary sediments are perhaps scraped off, then once again incorporated to the ocean plate and subducted.

There is another hypothesis which explains subduction erosion. Kagami and others (in press) reported seismic thrust-faults developing in the accretionary wedge. They argued that whether these faults produce subduction or accretion depends on their location. When the

thrusts develop or migrate into the accretionary wedge, that causes accretion; when they develop or retreat into the continental crust, that causes subduction. On the other hand, Moore and Biju-Duval (1984) pointed out that rapid accumulation of sediments in the trenches causes sediment accretion.

CONCLUSIONS

We compare the seismic stratigraphy of Sites 438/439 of the deep-sea terrace and of Site 584 on the mid-slope terrace by using multichannel reflection profiles obtained from the Japan Trench continental slope off Sanriku, northeastern Japan. These profiles show that prominent downlap of the basal strata exists at places where the Cretaceous basement has been uplifted and also that surface reflectors top lap at the same places. We conclude that uplift of the basement is probably the cause of tensional stress in the overlying Neogene strata along the outer margins of the mid-slope terrace and deep-sea terrace. Development of the décollement above the graben appears to control subduction erosion or accretion.

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