Tectonic regime of the southern Kurile Trench as revealed by multichannel seismic lines

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Abstract

The analysis of the two multichannel seismic reflection records P-855 and P-856 reveals the complexity of the tectonic structure of the Kurile margin. The absence of trench fill and the relatively constant thickness of the subducted sediments on top of the oceanic basement shows that little or no accretion is occurring at present. The lower slope is characterized by active thrusting within a small accretionary prism. The toe of the middle slope is a more consolidated unit that constitutes an efficient buttress. A piggy back basin, possibly filled by sediments that have drifted down slope, has formed on top of this unit. A narrow high marks the transition to the edge of the continental terrace. Furthermore, the upper slope reveals an unconformity marking the top of the basement. The similarity of this unconformity and its sedimentary cover with the well documented data acquired around DSDP Legs 56–57 suggests that northern Japan and the southern Kurile forearcs may have experienced a similar Cenozoic vertical history.

1. Regional setting

The southwestern part of the Kurile arc in the vicinity of the so-called ‘Hokkaido corner’ underwent a polyphase tectonic evolution during the Tertiary. Kurile subduction is believed to have begun in the Early (Jolivet, 1986) or Late (Kimura and Tamaki, 1985) Cretaceous, after the accretion of the Okhotsk terrane to the continent of Siberia. Both the Nemuro Peninsula and the islands of the frontal Kurile arc (Shibotu to Shikotan islands) consist of Late Cretaceous to Early Paleogene volcanic rocks (Yamada et al., 1990). The volcanic hiatus during the Paleocene and Eocene, associated with uplift during the Paleocene and subsidence during the Eocene of the forearc basin area, are interpreted by Kimura and Tamaki (1985) as an indication of the subduction of Kula–Pacific active spreading ridge. Kula–Pacific spreading ceased 43 m.y. ago and the fossil Kula rift now intersects the western Aleutian Trench near 171°E (Lonsdale, 1988).

According to De Mets (1992), the model that fits all of the trench slip vectors suggests that

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northern Honshu and most of the Hokkaido islands belong to the North American plate, while southern Hokkaido and the southwestern Kurile forearc belong to the south Kurile sliver microplate (Fig. 1). The N–S trending Hokkaido Central belt results from a polyphase tectonic

![Image of a map showing the location of multichannel seismic records of southern Hokkaido island across the Kurile and Japan trenches. DSDP drill sites are indicated by numbers. Tectonic features of the northeastern and southwestern margins of the Southwest Kurile arc are taken from Kimura et al. (1983), Kimura and Tamaki (1985) and Kimura (1986). Mesozoic magnetic anomaly lineations and fracture zones are after Nakanishi et al. (1989). Grey lines = lineations, identified by M numbers. Anomalies are numbered in accordance with the Mesozoic magnetic anomaly sequence of Larson and Hilde (1975), Cande et al. (1978), Handschumacher and Gettrust (1985) and Tamaki and Larson (1988). Isobaths are at 1000 m intervals. Shaded lines = seismic reflection and refraction profiles (from Den et al., 1971); barbed lines = the volcanic front (after Yamada et al., 1990). The convergence vector is after De Mets (1992). New seamounts and knolls are taken from Ogawa et al. (1993).]
evolution from the Mesozoic to the present (Jolivet et al., 1992). After a period of transpressional dextral strike-slip crustal faulting, from the Oligocene to the Middle Miocene, a drastic change to transtensional deformation occurred at 10 m.y., which is contemporaneous with the end of the opening of the Japan Sea and Kurile Basin (Jolivet and Tamaki, 1992). If both events are related, then about 400 km of dextral displacement are expected (Jolivet et al., 1992).

Recent tectonic evolution is characterized by an E-W trending compression and rapid uplift of the metamorphic core of the Hokkaido central belt, the Hidaka mountains (Kimura et al., 1983). The largest islands of the Kurile arc consist of Oligocene to Middle Miocene and Quaternary volcanic and marine sedimentary rocks (Yamada et al., 1990). These islands are arranged en échelon as small basins located between the volcanic and frontal arcs (Fig. 1). These observations suggest the presence of a dextral strike-slip fault bounding the islands to the south (Gnibidenko et al., 1983). The westernmost part of the fault is observed on land in Hokkaido (Kimura, 1981; Kimura et al., 1983). Kimura (1986) interpreted these features as the result of the oblique subduction of the Pacific plate in the southern Kurile Trench, which was responsible for the southwest migration of a forearc sliver. The relative convergence rate between the subducting Pacific plate and the North American plate in southern Kurile is 8.6 cm/yr, in a N62°W direction, according to the model of NUVEL-1 (De Mets et al., 1990). According to the magnetic anomaly lineations (Nakanishi et al., 1989) and the Mesozoic timescale (Kent and Gradstein, 1985), the subducting oceanic plate is 125 ± 15 m.y. old.

Along the adjacent northern margin of Japan, intense bathymetric swath mapping, seismic reflection surveys and deep sea drilling have been conducted (Fig. 1), (Von Huene et al., 1978; Cadet et al., 1987a). These data will be very

![Diagram](image_url)
helpful for the interpretation of the two multichannel seismic lines, acquired by Shell in 1974, which we recently processed with modern prestack migration techniques. During DSDP legs 56 and 57 (Leg 56 and 57 Scientific Party, 1980), massive subsidence of the Japan margin was established by drilling a subaerial unconformity that cuts across tilted beds and is buried beneath subhorizontal strata of the outer shelf and slope. The continental upper slope and shelf stratigraphy was traced throughout a network of seismic lines in the vicinity of DSDP sites (see Fig. 1 for location), as shown on seismic record Shell P-849 in Fig. 2 (Von Huene and Lallemand, 1990). Beds of Cretaceous age constitute the acoustic basement drilled at site 439. The top of the Cretaceous sequence is truncated along a Paleogene unconformity. Across the unconformity, seismic velocities increase abruptly from 1.9 to 4.2 km/s (Murauchi and Ludwig, 1980) consistent with the contact between moderately consolidated Oligocene-Quaternary strata and well consolidated Cretaceous rocks.

A 2–3 km thick Neogene sequence, containing benthic foraminifers of Late Miocene and younger ages overlies this unconformity. The lithofacies transition from Oligocene conglomerate and sandstone to lower Miocene claystone and siltstone, and further upward to upper Miocene and Pliocene massive mudstone has been explained by progressive subsidence of the landmass during the last 26 m.y. (Keller, 1980; Von Huene et al., 1982). The unconformity can be followed over a 150 km area throughout the Japan margin (Nasu et al., 1980; Von Huene et al., 1982) and shows no sign of ending beyond the published seismic coverage. A similar unconformity is recorded at the Joban basin in southern Japan (Mitsui, 1971; Kato, 1980).

Subcrustal and frontal tectonic erosion of the upper plate during the Neogene, especially at the toe of the continental slope has been evoked to explain the seismic record (e.g., Murauchi and Ludwig, 1980; Von Huene et al., 1982; Von Huene and Lallemand, 1990). The Japan margin would have subsided differentially, from 0 km near the coastline to as much as 6.4 km near the trench since the Early to Middle Miocene (Von Huene and Culotta, 1989) and has shrunk by more than 80 km (Lallemand et al., 1992a) in both the northern and southern parts. There is, therefore, a good chance that the southern Kurile margin underwent similar tectonic processes.

2. Acquisition and processing of seismic records

Off Hokkaido, the two records P-855 and P-856 were acquired in 24 channels by Shell International Petroleum Maatschappij in 1974. The source was an array of air guns, displacing a total volume of 1900 inch³. The streamer was 2,400 m long and 15–20 m deep in water, probably too deep since the data set has a rather low frequency. The sampling rate was 4 ms, the shot interval was 50 m and the receiver interval was 25 m. Line P-855 begins about 51 km seaward of the trench axis at 41°23'N, 146°35'W and continues for 50 km on the arc at 42°04'N, 145°35'W. The line is subparallel (7° oblique) to the direction of convergence (predicted by NUVEL-1; De Mets et al., 1992) and is 23° oblique to the normal to the trench axis. Line P-856 begins about 57 km seaward of the trench axis at 41°22'N, 146°35'W and continues 112 km on the arc at 42°54'N, 146°07'W. This line is 48° oblique to the direction of convergence and 18° oblique to the normal to the trench axis (Fig. 1).

The entire P-855 record was scaled with the GEOSYS software (PRAKLA), using band pass filtering, deconvolution (on record P-855 only), constant velocity analysis, normal move-out (NMO), dip move-out (DMO), and automatic gain control operators and a post-stack, time-migrated section was obtained. We then processed record P-855 with five iterative pre-stack depth migrations, refining the migration velocity model, \( V_m \), with focusing analysis, using MIG-PACK software (TOTAL-CFP). The migration velocity model, decreased by 10%, provided an improved stacking velocity model, \( V_s \). The proximity of the two lines allowed us to optimize this stacking velocity model to fit the rough structure of the second line, P-856, and to perform a post-stack time migration of record P-856. Finally, five iterative pre-stack depth migrations of the lower and middle slope
Fig. 3. (a) DMO post-stack time-migrated section, in time, of the seaward trench and lower slope of Kurile seismic record P-856 interpreted to time. The vertical exaggeration at the seafloor is ×2.5. (b) DMO post-stack time-migrated section, in time, of the middle and upper slope of Kurile seismic record P-856 interpreted to time. Vertical exaggeration at the seafloor is ×2.5.
of record P-856 were made. Our migration velocity model is in good agreement with the OBS velocity structure models off Tokachi, Hokkaido (Den et al., 1971; Iwasaki et al., 1989; see location in Fig. 1).

3. Description and interpretation of the stratigraphy and structure

3.1. The upper slope, record P-856: 72–112 km

The seaward part of the upper slope is imaged over 40 km, from a depth of about 2,600 m to 3,100 m, and has a gentle slope of 1–2° (Fig. 3). The upper slope sedimentary strata are well imaged layers paralleling the slope. A 2–3 s (two-way travel time) thick sequence, cut by numerous (mostly seaward dipping), high-angle normal faults with a small offset, unconformably overlies basement strata with few continuous reflections, gently dipping seaward. The seismic velocities increase across the unconformity, producing high amplitude reflections, structural discontinuity and prominent diffractions on unmigrated sections (Nasu et al., 1980; Von Huene and Culotta, 1989). A similar unconformity can also be recognized at the same location on the multi-channel seismic record acquired during the KH 92-3 cruise (see Fig. 1 for location; Ariie and Suyehiro, 1993). We will call this unconformity on the upper slope of record P-856 'unconformity X'.

Fig. 4 shows sections of the upper slope (continental terrace) of northern Japan (Shell P-849) and southern Kurile (Shell P-856) seismic images, in time and at the same scale. The strata se-
sequence imaged on record P-856 is remarkably similar to that of seismic record P-849. We will therefore infer that the sedimentary cover overlying unconformity X is post-Oligocene and suppose that unconformity X is Paleogene. It is unclear whether the numerous normal faults cutting the overlying sediments penetrate the basement.

The seaward edge of the continental terrace is limited by a narrow high (about 250 m high) associated with a major break in the slope (Fig. 3). A 10 km wide basin, with a surface dipping gently seaward, has formed against the high at the lowest part of the upper slope. This narrow high extends northeastward for 180 km, parallel to the Kurile Trench axis, as shown on the conventional bathymetry (Onodera and Honza, 1977), SEABEAM bathymetry (Ogawa et al., 1993) and seismic reflection profiling surveys (L39–L42, Tamaki et al., 1977). No explanation has yet been proposed concerning the origin and structure of this narrow high.

3.2. The middle slope, record P-856: 28–72 km, and record P-855: 28–50 km

The middle slope is about 45 km wide, from 3,000 to 5,500 m below sea level and with a constant continuous slope with a dip of about 4° (Fig. 3). Along the middle slope, a 600 m thick series of low amplitude reflections paralleling the slope unconformably overlies weakly folded beds, gently dipping arcward and cut by normal faults. We will call this unconformity at the base of the transparent layers ‘unconformity Y’. Reflections are not good enough to trace the inferred Neogene strata and unconformity X of the upper slope seaward of the narrow high with certainty. However, unconformity X seems to continue seaward throughout the middle slope with the same seaward-dipping trend as on the upper slope. The inferred Neogene beds appear to vanish progressively seaward on top of the basement (Fig. 3). The change in dip of these beds, from gently seaward to arcward, from the upper to the middle slope suggests some tectonic contact at the edge of the continental terrace, around km 72.

At the foot of the middle slope, unconformity Y flattens beneath a narrow piggyback basin (Figs. 3, 5 and 6). The deposits reach 1400 m in thickness on both records and form a nearly horizontal terrace. According to the bathymetric SEABEAM map (Ogawa et al., 1993), this basin extends subparallel to the trench axis for more than 150 km, at depths of around 5,700–5,400 m. This piggyback basin separates the lower and middle slope.

3.3. The lower slope, record P-856 and P-855: 0–28 km

The lower slope, about 28 km wide, from 5,700 to 7,200 m deep, has an average dip of 4° but is locally much steeper. This slope is characterized by many ridges or domes and troughs (Ogawa et al., 1993). Similar topography is recognized in the northern Japan Trench (Kobayashi, 1991). The toe of the Kurile margin is formed by an imbricated and folded wedge of sediments (Figs. 5 and 6). There is a sharp transition between gravitationally driven sliding and slumping in the middle slope and trench sub-parallel thrusting in the lower slope, as suggested by Ogawa et al. (1993). Two major ‘imbricates’ about 10 km wide, covered progressively by sediments, can be recognized along the two transsects until the foot of the middle slope. It is difficult to show a distinct transition from accreted to highly consolidated basement strata, although a considerable increase in velocity (from 2500 to 3200 m/s) is indicated by the focusing analysis through pre-stack depth migrations around km 30 (CMP 3520–3600 on record P-856 and 640–720 on record P-855). The layers dipping 20° arcward at this position, on top of the subducted sediments, may indicate the buttress against which further accretion occurred.

On record P-855, around km 19 (CMP 1120) and at a depth of 8,750 m, an intense seaward-dipping reflector breaks the landward-dipping layers on top of the subducted section. Important focusing errors are associated with this reflector and reveal the out-of-plane origin of the reflector (Fig. 6).
4. Oceanic crust and sediments

4.1. The trench and seaward slope, record P-856: −13−0 km

The oceanic plate sedimentary cover, as drilled 200 km southwestward, at DSDP site 436 (Leg 56 and 57 Scientific Party, 1980; Langseth et al., 1981; Von Huene et al., 1982), consists of a sequence of pelagic, Upper Cretaceous carbonates and cherts overlain by about 10−15 m of Paleogene-Lower Miocene brown clay and then by 750 m of Middle Miocene-Quaternary hemipelagic diatomaceous argilites and silty clay. The carbonates and cherts produce a prominent reflector (at about 1 s below the seafloor) which is easy to track further landward in the subducted oceanic sedimentary sequence. The top of the igneous oceanic crust is indistinctly imaged because of the small velocity contrast between carbonate, chert and vesicular basalt (Figs. 3, 5 and 6). Several intra-crustal reflectors are imaged in the oceanic basement (Fig. 3).

Little trench fill is observed on the seismic records although collapses of the toe of the landward slope into the trench axis form a number of knolls (see Fig. 1 for location; Ogawa et al., 1993). A similar morphology was reported in the Japan Trench area off Miyako during the KH 90-1 cruise (Kobayashi, 1991). Normal faults, predominantly dipping seaward, parallel to the magnetic anomalies (Ogawa et al., 1993; Cadet et al., 1987b), cut the oceanic basement and its sedimentary cover in a stepwise horst and graben arrangement. The spacing of the faults is between 1 and 6 km. The vertical offsets are of the order of several tens of meters, rarely reaching 200 m on record P-856. The oceanic crust dips 3.6° (in the direction of convergence) when entering the subduction zone, compared to the 3.5° at the Japan Trench.

4.2. The subducting sequence

Most of the sediments entering the subduction zone are subducted. Only a small part of the hemipelagic sediments are scraped off and incorporated into the toe of the wedge (Figs. 3, 5 and 6). The rest of the hemipelagic and the pelagic sediments on top of the oceanic crust subduct below the décollement and are clearly imaged. The precise location of the décollement at the front of this margin is not detected by a velocity reversal with pre-stack depth migration focusing analysis, so that its level is uncertain. Inherited normal faulting is preserved beneath the accretionary mass for the first 35 km of the subduction zone. The high amplitude reflections below the middle slope suggest that either the thickness of the subducting sediments increases progressively arcward, or that underplating accounts for the apparent thickness on top of the oceanic crust. Finally, the top of the oceanic basement can be traced northward for a distance of about 57 km (Fig. 3), at a depth of 15 km and for an average dip of 5.8°, compared to the 6.8° at the Japan Trench.

5. Discussion

Imaging within the two seismic records is disturbed by many out-of-plane reflections, as revealed by the focusing analysis of several structures. The 36° obliquity of the convergence induces dextral migration of the forearc sliver, as recorded along the ENE-WSW trending Kurile mid-arc strick-slip fault (Fig. 1), bounding the Kurile island to the south (Gnibidenko et al., 1983) and observed along its western part on Hokkaido (Kimura, 1981, 1986; Kimura et al., 1983). The right lateral strike-slip along the Kurile volcanic front started in the Late Miocene (Kimura and Tamaki, 1985). The proximity of the Hokkaido bend probably introduces contraction in a compressional zone, perpendicular to the trench axis, at the southern end of the Kurile subduction zone (Tada and Kimura, 1987). With such complexity, 2-D seismic shooting has little chance of producing a clear image.

The sharp morphological boundary between the middle and upper slope, at the edge of the continental terrace at km 72 (Fig. 3), might be a good candidate for the trace of a dextral strike-slip fault. Thus, the shear partitioning might be accommodated along more than one single transform fault, as is documented in the Aleutians (Ryan and Scholl, 1989) or Sumatra (Malod et al.,
At the Sunda Trench, the slip motion (at least between 100°E and 104°E) is accommodated both on the Sumatra fault and on the intra-forearc Mentawai fault (Diament et al., 1992). De Mets (1992), on the basis of horizontal slip directions derived from 397 shallow thrust earthquakes from the Kurile and Japan trenches and the convergence rate predicted by NUVEL-1, account for a partitioning of slip that implies a 6–11 mm/yr translation parallel to the southern Kurile Trench. Most of the earthquakes that occurred at the leading edge of the southern Kurile forearc offer the clearest evidence for southwestward translation of a sliver. Five of them are consistent with thrust motion along fault planes that strike nearly orthogonal to the nearby trench (Suzuki et al., 1983; Seno, 1985). Furthermore, three earthquakes, labelled by De Mets: 6, 25 and 26, are located closer to the trench axis and may indicate that the shear induced by oblique subduction is distributed along two or more subparallel strike-slip faults in the forearc (De Mets, 1992; Klaeschen et al., 1994). Earthquake 26 is located just at the northern edge of line P-856 and supports the hypothesis of a trench-parallel, strike-slip fault cutting the section at the edge of the continental terrace (km 72).

As a matter of fact, the absence of trench fill and the relatively constant thickness of subducted sediments through the seismic reflection sections implies that most, if not the entire, column of sediments entering the subduction zone on the trench floor was subducted during the last million years (70–75 km of seismic record assuming a convergence rate of 86 km/m.y.). Thus, little or no frontal accretion is documented at the present.

Furthermore, the thickness of subducted sediments seems to increase arcward (Figs. 3, 5 and 6). In fact, the high amplitude reflections below the middle slope suggest that either the thickness of the subducting sediments increases progressively arcward or that underplating accounts for the apparent thickness on top of the oceanic crust, depending of the position at the top or within the subducting layers. Therefore, such a thickness can be interpreted either by frontal or basal tectonic erosion of the frontal wedge, or by the formation of a duplex at the transition between the lower and middle slope. The possible formation of a duplex, below the middle to lower slope transition at km 26, favoured by a major horst at km 36, supports the latter hypothesis (Figs. 3, 5 and 6).

Horst and graben structure are known to induce some erosion of the overriding wedge, by passive transport within the graben. Lallemand et al. (1992b, 1994), based on both the observation of modern convergent margins and sandbox modelling, pointed out that the subduction of positive features is accompanied by tectonic erosion of the front of the margin, mainly in the wake of the subducting asperity. In seismic record P-856, the path of the décollement deviates from the top of a larger horst located around km 18 (CMP 3057 on record P-856 and 1400 on record P-855) and passes over the top of the smaller horsts encountered up to the trench. Consequently, a 1 km thick shielded area of subducting sediments is trapped in the wake of this asperity. A large seamount, the Takuyo-Daiichi seamount, 45 km in diameter and 3 km high, and a few knolls are located close to the area studied. One small knoll, 3 km in diameter is located just at the trench, at 142°52'E (Fig. 1; Ogawa, 1993). Cumulative subduction of such asperities certainly contributes to the removal of material at the front of the Kurile margin.

Furthermore, a large amount of fluids are subducted within the incoming sediments. Using the mass balance approach of Von Huene and Scholl (1991), the 750 m of oceanic sedimentary input arriving in the trench, once corrected for porosity, represents a supply of 12 km³/m.y.(/km along trench axis) of water. Convergence rates faster than dewatering may cause hydrofracturing of the basal front of the upper plate. Consequently, an upward migration of the décollement to a level of minimal efficient friction will favour tectonic erosion, as discussed by Von Huene and Lee (1983), Platt (1989) and Moore (1989).

At the present, the closed depressions, hills, lobate bodies and canyons, imaged on SEABEAM maps (Iwasaki et al., 1989; Ogawa et al., 1993; Cadet et al., 1987a) of northern Japan, as well as the seismic profiles indicate that active, gravity-
Fig. 5. Pre-stack depth-migrated time section of Kurile record P-856 interpreted in depth. Vertical exaggeration at the seafloor is ×2.5 in the time section and ×2 in the depth section.
Fig. 6. Pre-stack depth-migrated time section of Kurile record P-855 interpreted in depth. Vertical exaggeration at the seafloor is ×2.5 in the time section and ×2 in the depth section.
driven collapses and superficial extensional tectonics occurs. Furthermore, the sediments accumulated in the piggy back basin at the base of the middle slope suggest down-slope mass wasting. The possible truncation of the inferred Neogene beds beneath unconformity Y favours the hypothesis of gravity-driven mass wasting. In contrast, the lower slope, which exhibits the same surface slope as the middle slope, is affected by active thrusting (Figs. 5 and 6). This change in tectonic style might be explained by variations in pore fluid pressures between the lower and middle slope (e.g. Xiao et al., 1991; Lallemand et al., 1994).

When regarding the similarities between the seismic record P-856 and those published from the northern Japan Trench, we are in favour of adopting a comparable tectonic history for the southwestern Kurile and northern Japan forearcs. The concordance in seismic stratigraphy of the upper slope, on top of the presumable Paleogene unconformity X, suggests a similar Neogene subsidence history to that described by Von Huene et al. (1982). If the chronology of tectonic events is the same as documented in the northern Japan Trench (e.g., Von Huene and Lallemand, 1990); that is, emergence of the present basement above sea level in the Oligocene and subsidence in the Miocene–Pliocene, the paleo-bathymetry recorded by unconformity X was subaerial before the Late Oligocene. Up to the present, subsidence would have reached 4,800 m at the beginning of seismic record P-856 (km 110). It is unclear, however, whether unconformity X is a subaerial erosional surface, as in northern Japan, because the nearest drilling sites, 438 and 439, are located 350 km to the southwest. Unconformity X may also mark the boundary between sediments and post-accretional slope and shelf sediments. Thus, unless drilling data can give more precise information on the nature of unconformity X, Cenozoic tectonic erosion of the southern Kurile margin remains speculative.

6. Conclusion

The two multichannel seismic reflection records studied, P-855 and P-856, emphasize the complexity of the tectonic history of the Kurile margin. The southwestward translation of the forearc sliver since the Late Miocene introduced compressional structures at the southern end of the Kurile subduction zone and probably strike-slip faulting in the forearc, which compromises clear imaging of the data sets. Such a strike-slip fault may account for the major tectonic contact between the upper and middle slope at the edge of the continental shelf.

At present, little frontal accretion is documented and most of the sedimentary input is subducted below the upper plate. A small imbricated and folded wedge of sediments has been accreted at the toe of the southern Kurile margin. The increase in seismic velocity at the toe of the middle slope marks the transition to a more consolidated buttress 30 km into the trench. The increasing thickness of the subducted sequence towards the arc suggests either underplating phenomena or that basal tectonic erosion is active at this position. The possible formation of a duplex, below the middle to lower slope transition at km 26, favoured by a major horst at km 36, supports the first hypothesis. The large amount of pore fluids within the subducted sediments and the fast convergence rate, however, provide the basic conditions for an erosional tectonic style. The concordance in seismic stratigraphy of the upper slope, on top of the presumably Paleogene unconformity X, may indicate a Neogene subsidence history which is similar to that of the adjacent northern Japan Trench. The suspected gravity collapse imaged in the middle slope may account for the deposit within the piggy back basin at the toe of this slope and favours this hypothesis. Subduction of a number of asperities could also have contributed to the removal of material from the Kurile margin. However, until further data on this margin, such as from drill holes, become available, the subsidence of the Kurile margin remains hypothetical.

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