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# 2. Data Report: Structural Setting of the Leg 190 Muroto Transect[1]

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## ABSTRACT

Prior to Leg 190 drilling, we conducted a three-dimensional seismic reflection survey across the central Nankai Trough south of Shikoku Island. These new data helped establish the regional structural setting of the Leg 190 drill sites. Seaward of the trench axis, buried basement topography of the Kinan Seamount chain is imaged as a broad ridge overlain by 0.7 s (750 m) of sediment. Seaward of the ridge, the sediment thickness increases to ~1.75 s (2 km); the deepest ~1.0 s of sediment onlaps the ridge, indicating that the ridge was formed before sedimentation began. The youngest 0.6 s (700 m) of hemipelagic sediment is draped over the ridge and continues into the trench axis, where it is buried by 0.3 s (350 m) of trench turbidites.

The trench strata and the upper hemipelagic deposits are stripped off the subducting plate and accreted. The accretionary complex is divided into several segments based on structural styles. Between the deformation front and the frontal thrust is a zone of diffuse structural thickening, the protothrust zone. The frontal section of the accretionary prism is characterized by 700- to 800-m-thick thrust-bounded slices. There are 12 major thrust packets with a thrust spacing of ~1.5–2.0 km. The thrusts sole into a well-defined décollement ~0.25–0.30 s above the oceanic crust. Approximately 20 km landward of the frontal thrust is a major out-of-sequence thrust (OOST) that thickens the prism from 1.6 to 1.9 s. A 6.25-km-wide slope basin with ~0.6 s of sediment is ponded behind this OOST. Strata within the basin are tilted landward with dips

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that increase with depth, indicating continued relative uplift along the OOST during sedimentation.

Approximately 30 km landward of the frontal thrust, the thrust packets abruptly increase to at least 1 s in thickness, with thrust spacing increasing to 2–3 km. These thrust slices are formed of strata equivalent to the deeper section seaward of the Kinan Seamounts. The décollement cuts down closer to the oceanic crust beneath these thrust packets. Another major slope basin has formed above these thrust slices. Landward of this zone, the prism is characterized by less distinct, landward-dipping reflections; the décollement is obscured by the seafloor multiple.

# INTRODUCTION

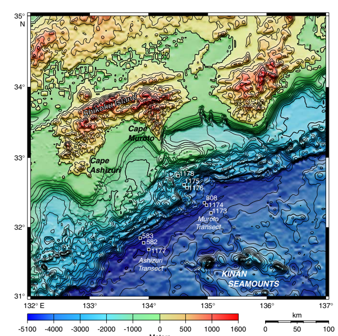
Leg 190 returned to the central Nankai Trough accretionary prism southeast of Shikoku Island, revisiting the region drilled previously during Deep Sea Drilling Program Legs 31 and 87 and Ocean Drilling Program Leg 131. Seismic reflection surveys conducted in 1987 defined the regional structural setting of this area (Moore et al., 1990, 1991). A more detailed three-dimensional (3-D) seismic reflection program was carried out off the Muroto Peninsula during 1999 (Bangs et al., 1999; Moore et al., 1999) and provided additional information for locating the drill sites for Leg 190. The purpose of this paper is to amplify the structural setting of the Muroto Transect based on these new seismic reflection data.

# REGIONAL TECTONIC SETTING

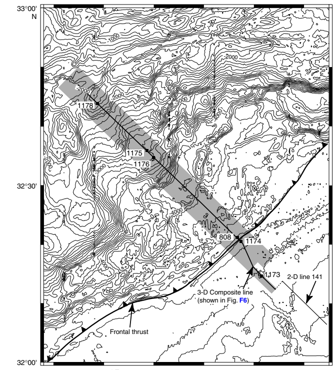
The Nankai Trough is the subducting plate boundary between the Philippine Sea plate and the Eurasian plate (Fig. F1). The Shikoku Basin is part of the Philippine Sea plate, which is subducting to the northwest under southwest Japan at a rate of 2-4 cm/yr (Karig and Angevine, 1986; Seno, 1977), slightly oblique to the plate margin. Active sediment accretion is presently taking place at the Nankai Trough. The record of present-day accretion extends landward to Shikoku Island, where older (Cretaceous to Tertiary) accretionary prism rocks are exposed (Taira et al., 1988).

The modern episode of subduction is documented by widely distributed volcanic activity, which started at ~8 Ma in southern Kyushu and by 6 Ma in southwest Japan (Kamata and Kodama, 1994). Subduction of the Shikoku Basin crust at the Nankai Trough formed a frontal accretionary prism to the southwest Japan forearc (Nankai Trough accretionary prism) (Taira, Hill, Firth, et al., 1991; Taira et al., 1992; Le Pichon et al., 1987) and shaped the forearc basins (Okamura et al., 1987; Sugiyama, 1994). One of the prominent topographic features in the vicinity of the Leg 190 sites is an embayment of the trench landward slope (Figs. F1, F2). Yamazaki and Okamura (1989) interpreted this embayment as an indentation caused by the collision of seamounts with the prism. Recent seismic reflection work and ocean-bottom seismometer experiments on crustal structure support this interpretation (Park et al., 1999; Kodaira, 2000).

**F1.** Shaded relief map of the central Nankai Trough, p. 9.




**F2.** Bathymetric map showing location of 1999 3-D seismic reflection grid and composite seismic line, p. 10.

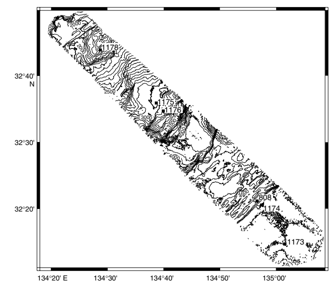


# DATA ACQUISITION AND PROCESSING

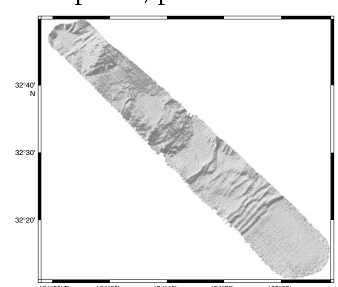
## Mulitbeam Bathymetry

We collected multibeam bathymetric data over the Leg 190 Muroto Transect area of the Nankai Trough in June and July, 1999, with the *Maurice Ewing*'s Hydrosweep system. Data processing with the Lamont-Doherty Earth Observatory MB-System software (Caress and Chayes, 1996) consisted of determination of the sound velocity profile (using Levitus data), ray tracing through the water column to determine the depth of each beam point, manual ping-by-ping editing to remove spurious depth values, along- and across-track filtering to remove artifacts, and gridding at 100-m intervals. The grid was then contoured to produce a bathymetric map (Fig. **F3**) and was fitted with a smooth surface and illuminated to produce a shaded relief image (Fig. **F4**). This image was then combined with data from the Japan Hydrologic Office (Okino and Kato, 1995) to produce a regional shaded relief image for regional interpretations (Fig. **F5**).

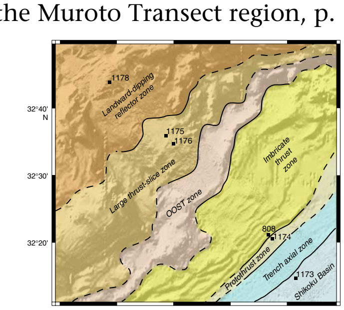
**F3.** Contour plot of 1999 Hydrosweep multibeam bathymetric data, p. 11.



**F4.** Shaded relief map of Hydrosweep data, p. 12.



**F5.** Tectonic/structural domains in the Muroto Transect region, p. 13.



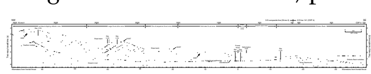
## 3-D Seismic Reflection Data

We also collected a 3-D multichannel seismic data set on the *Maurice Ewing*. This survey imaged an 8 km × 80 km area with 81 individual lines, each 80 km long with a cross-track spacing of 100 m (Fig. **F2**). The ship's position was located at 1-s intervals with a commercial differential Global Positioning System (DGPS) navigation system supplied by Fugro Geodetic. Acquisition used a source array of 14 air guns with a total volume of 70 L (4276 $in^3$) that was fired at 50-m intervals. Seismic reflection returns were received by a 6000-m, 240-channel digital streamer with a group interval of 25 m. Streamer navigation used 20 compasses and periodic DGPS location of the streamer's tail buoy. We recorded the seismic reflection data at 2-ms sample intervals in SEG-D format on 3490E tapes with the *Maurice Ewing*'s Syntrack 480-24 recording system. In addition to the 3-D seismic lines, we collected several segments of two-dimensional (2-D) data at each end of the 3-D survey.

Initial data processing was conducted on the *Maurice Ewing* and consisted of reading the SEG-D tapes, antialias filtering, resampling from 2 to 4 ms, and writing the data in SEG-Y format on digital linear tapes. We also edited each shot for bad/noisy traces during the cruise. The 2-D line segments were processed through a standard 2-D sequence of geometry (12.5-m common midpoint [CMP]) bins, velocity analysis, normal move-out (NMO) correction, top mute, CMP stack, and F-K poststack time migration. The 3-D data were sorted into bins that arc 25 m wide in the inline direction and 50 m wide in the crossline direction. Three-dimensional processing consisted of velocity analysis, NMO correction, inside and top mute, 3-D stack, and 3-D poststack migration.

Figure **F6** is a composite line consisting of the seaward extension of a 2-D line and an "arbitrary" 3-D line that passes through each of the Muroto Transect drill sites. This line illustrates the main structural elements of the Muroto Transect.

**F6.** Regional seismic reflection line along the Muroto Transect, p. 14.



# STRUCTURAL SUBDIVISIONS

Based on our seismic reflection data, we subdivide the accretionary prism along the Muroto Transect into several tectonic/structural domains (Fig. F5, F6): Shikoku Basin, Nankai Trough Trench axial zone, protothrust zone (PTZ), imbricate thrust zone (ITZ), out-of-sequence thrust (OOST) zone, large thrust-slice (LTS) zone, and landward-dipping reflector (LDR) zone.

## Shikoku Basin

The Shikoku Basin region seaward of the Nankai Trough is characterized by several distinct seismic stratigraphic units. The uppermost unit is <100 ms thick at the edge of the Nankai Trough and thins seaward. This unit is the distal facies of the Nankai Trough axial deposits described below. Underlying this thin unit are two seismic sequences that were drilled at Site 1173. The upper sequence has high-amplitude, laterally discontinuous internal reflections. The lower sequence has very low amplitude reflections that are parallel to the underlying oceanic crust reflection. Both of these sequences are hemipelagic strata deposited far seaward of the Nankai Trough axis. Both sequences continue westward where they are buried by trench turbidites.

Seaward of the high basement topography of the Kinan Seamounts is a unit stratigraphically below the Shikoku Basin hemipelagic units described above. It is characterized by a well-stratified sequence ~0.7 s thick (labeled "Shikoku Basin turbidites" on Fig. F6). This section may correlate with the Pliocene–Miocene turbidite unit identified along the Ashizuri Transect (Fig. F1) and recovered at Sites 297 and 1177 within the lower Shikoku Basin facies (hereafter called the Pliocene–Miocene turbidite unit). Seaward of the trench axis, buried basement topography of the Kinan Seamount chain is imaged as a broad ridge overlain by 0.7 s (750 m) of sediment. Seaward of the ridge, the sediment thickness increases to ~1.75 s (2 km); the deepest ~1.0 s of sediment onlaps the ridge, indicating that the ridge was formed before sedimentation began.

## Nankai Trough Trench Axial Zone

The trench axis of the Nankai Trough is characterized by a thick, seaward-thinning wedge of trench turbidites that overlie the Shikoku Basin sequence described above. The wedge is 550 ms (~500 m) thick at the western boundary of the trench and thins to ~110 ms (~100 m) at its seaward edge. The turbidite unit was supplied mostly through an axial transport system from a source region to the northeast in the Izu collision zone, as indicated by a mixture of volcanic, sedimentary, and metamorphic provenance (Taira and Niitsuma, 1986; Underwood et al., 1993). This unit diachronously onlaps the Shikoku Basin sequence (Bray and Karig, 1985).

## Protothrust Zone

The trench strata and the upper hemipelagic deposits are stripped off the subducting plate and accreted. The accretionary complex is divided into several segments based on structural styles. Between the deformation front and the frontal thrust is a zone of diffuse structural thickening, the PTZ. This area represents a zone of incipient deformation and initial development of the décollement within the massive hemipelagic unit. Above the décollement, the sediment thickness increases landward, probably as a result of tectonic deformation with the development of small faults and ductile strain, as documented by Morgan and

Karig (1995a, 1995b). Trench strata are tilted seaward at the seaward edge of the PTZ because of this thickening.

## Imbricate Thrust Zone

Landward of the PTZ, a zone of well-developed seaward-vergent imbricate thrust packages can be recognized. The thrust packages are sigmoidal in cross section and are 700–800 m thick with a mean angle of ~30°. The thrusts are associated with hanging-wall anticlines that form linear ridges that are laterally continuous for 15–20 km (Figs. F4, F5, F6). There are twelve major thrust packets, with a thrust spacing of ~1.5–2.0 km. The thrusts sole into a well-defined décollement ~0.25–0.30 s above the oceanic crust. The frontal thrust forms the seaward edge of the ITZ. Site 808 (Leg 131) cored the frontal part of the ITZ. A bottom-simulating reflector (BSR) is developed just landward of the frontal thrust and appears discontinuously throughout the ITZ.

## Frontal Out-of-Sequence Thrust Zone

From 20 to 30 km landward of the frontal thrust, the imbricate thrust packages are overthrust by a younger generation fault system. Because this fault system cuts the preexisting sequence of imbricate thrusts, it is called an OOST (Park et al., 2000). The prism thickens from 1.6 to 1.9 s (~1.9–2.3 km). A 6.25-km-wide slope basin with ~0.6 s of sediment is ponded behind this OOST. Strata within the basin are tilted landward, with dips that increase with depth, indicating continued relative uplift along the OOST during sedimentation. Significant deformation also appears within the underthrust Shikoku Basin hemipelagite. The hemipelagic unit seems to be tectonically thickened, probably as a result of duplexing.

## Large Thrust-Slice Zone

Approximately 30–35 km landward of the frontal thrust, at least four distinctive OOSTs separate tectonic slices of either previously imbricated packages or relatively coherent sedimentary sequences. The thrust packets abruptly increase to ~0.7–1 s in thickness, with the thrust spacing increasing to 2–3 km. These coherent thrust slices are formed of strata that closely resemble the deeper section seaward of the Kinan Seamounts. Underneath these thrust slices, there are packages of strong reflectors that may be composed of thickly underplated Shikoku Basin hemipelagic units, and the décollement cuts down closer to the oceanic crust. Slope sediment in this zone shows landward tilting, suggesting recent active uplift. BSRs are patchy and weakly developed in this zone.

## Landward-Dipping Reflector Zone

This LDR zone is characterized by landward-dipping, semicontinuous strong reflectors. The zone appears to be divided into several discrete packages by thrust faults overlain by a thick sequence of slope sediments. Because the uppermost slope sediment layer is relatively undeformed, some of these faults may not have been active for some time. This zone might be composed of sediments that are more consolidated and rigid than those in zones closer to the trench. A BSR is well developed throughout this zone and diminishes abruptly at the boundary between this zone and the LTS zone.

## ACKNOWLEDGMENTS

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**Figure F1.** Shaded relief map of the central Nankai Trough showing the regional morphology of the accretionary prism and subducting Shikoku Basin.

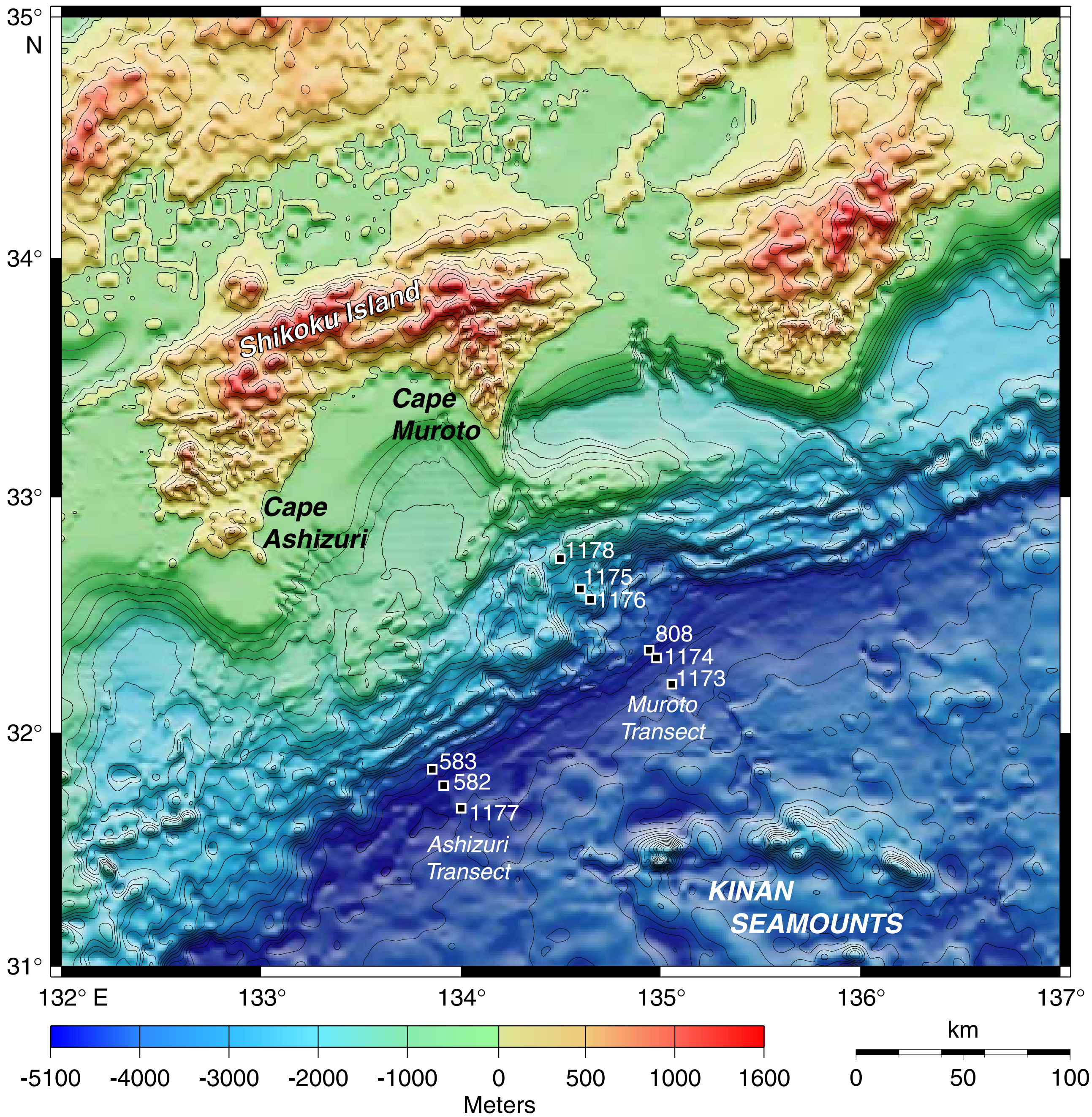

**Figure F2.** Detailed bathymetric map showing location of 1999 3-D seismic reflection grid (shaded region) and composite seismic line (bold line) shown in Figure F6, p. 14. Small squares are Legs 131 and 190 drill sites. Barbed line is the frontal thrust. Contour interval = 100 m.

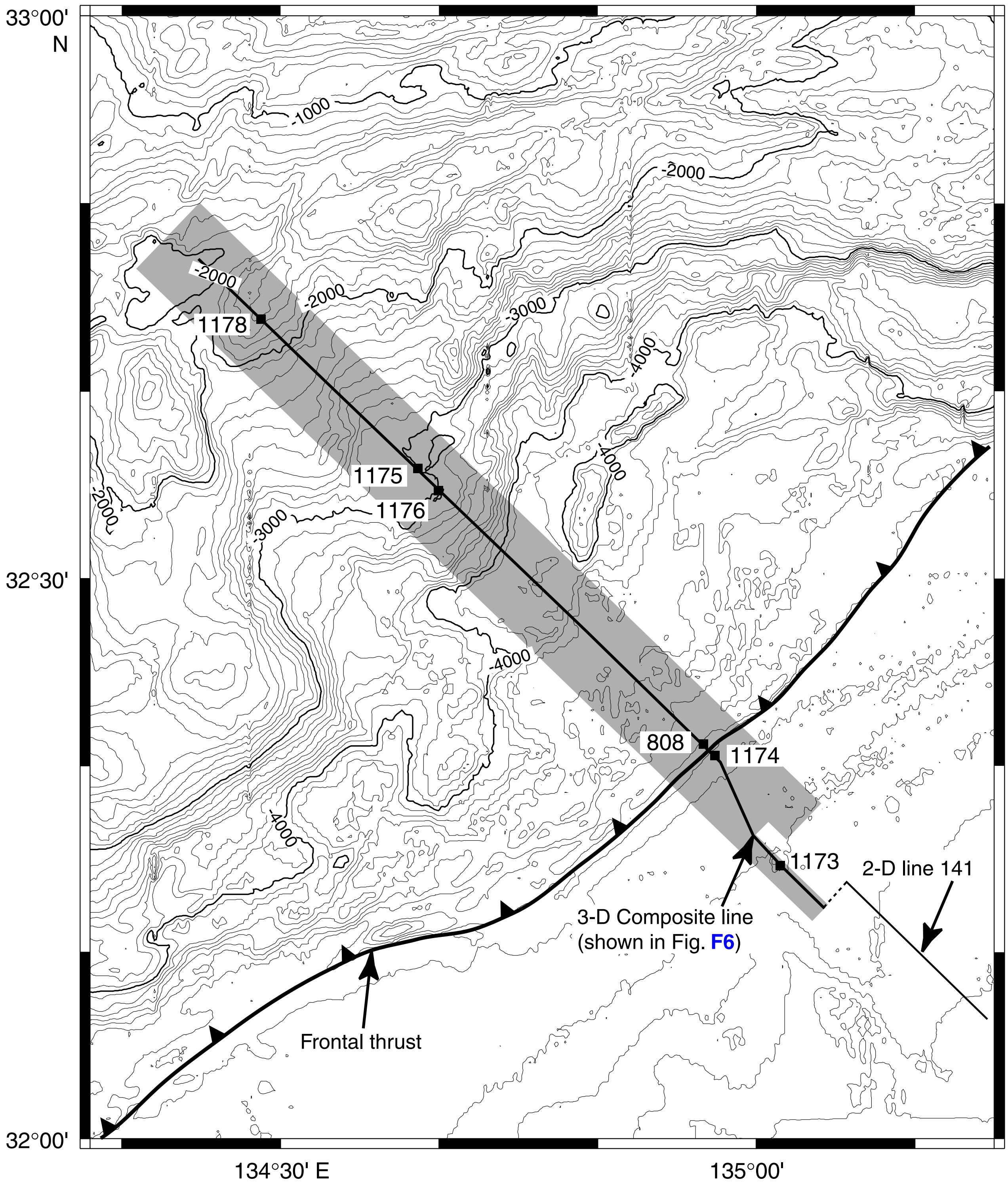

**Figure F3.** Contour plot of 1999 Hydrosweep multibeam bathymetric data. Small squares are Legs 131 and 190 drill sites. Contour interval = 50 m.

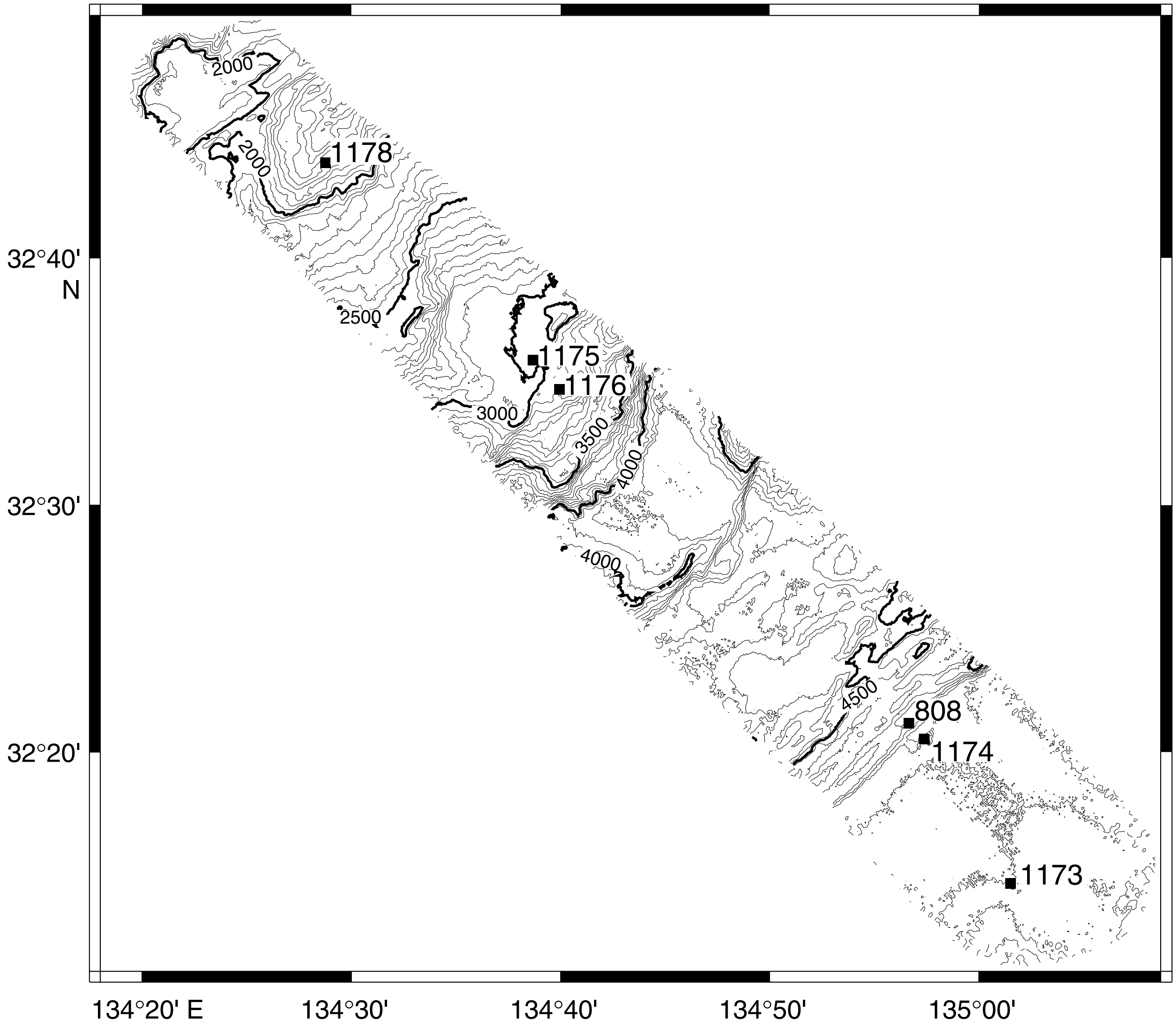

**Figure F4.** Shaded relief map of Hydrosweep data. Illumination is from the northeast.

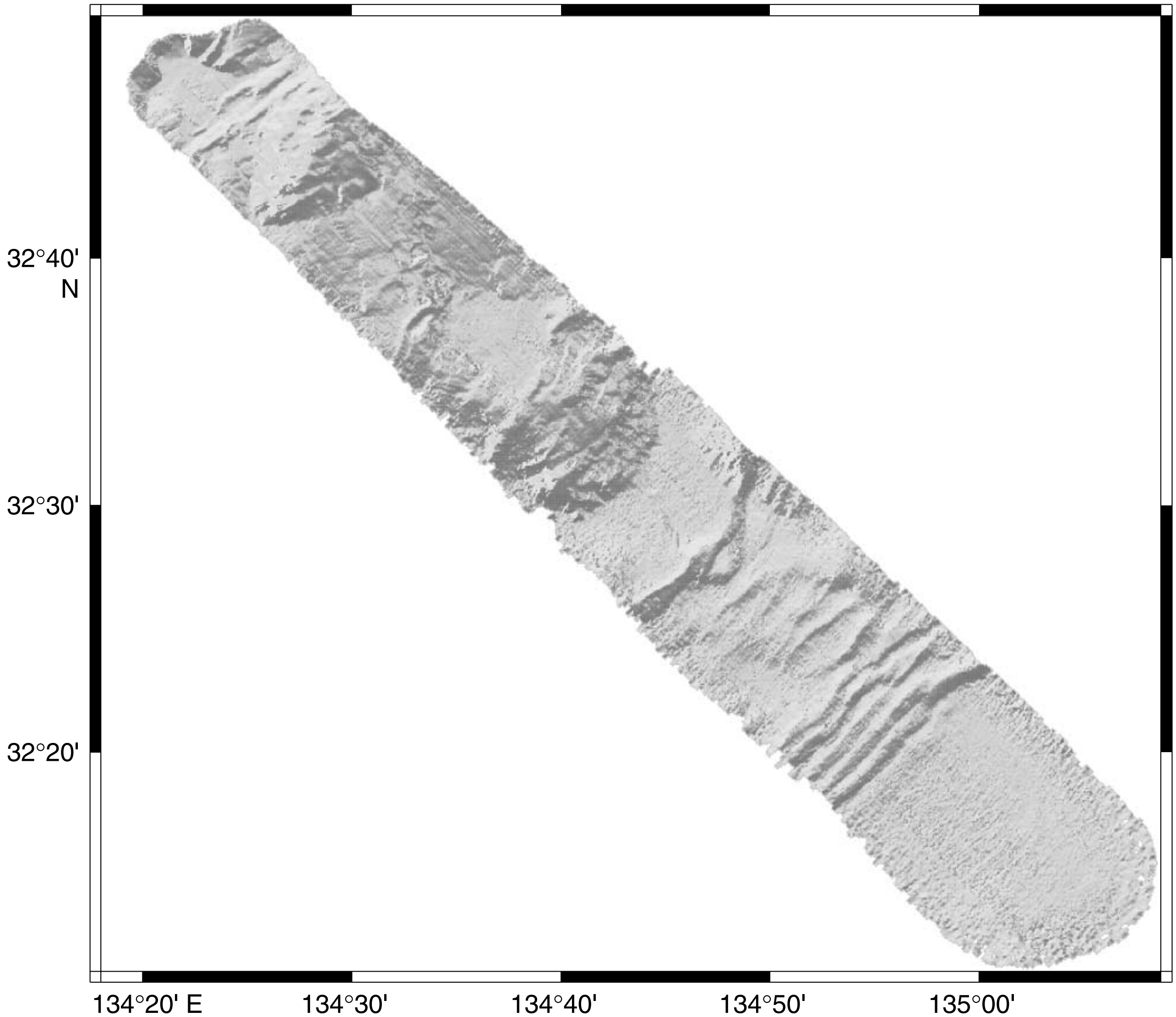

**Figure F5.** Map of tectonic/structural domains in the Muroto Transect region interpreted from bathymetry and seismic reflection data. Legs 131 and 190 sites are shown by squares.

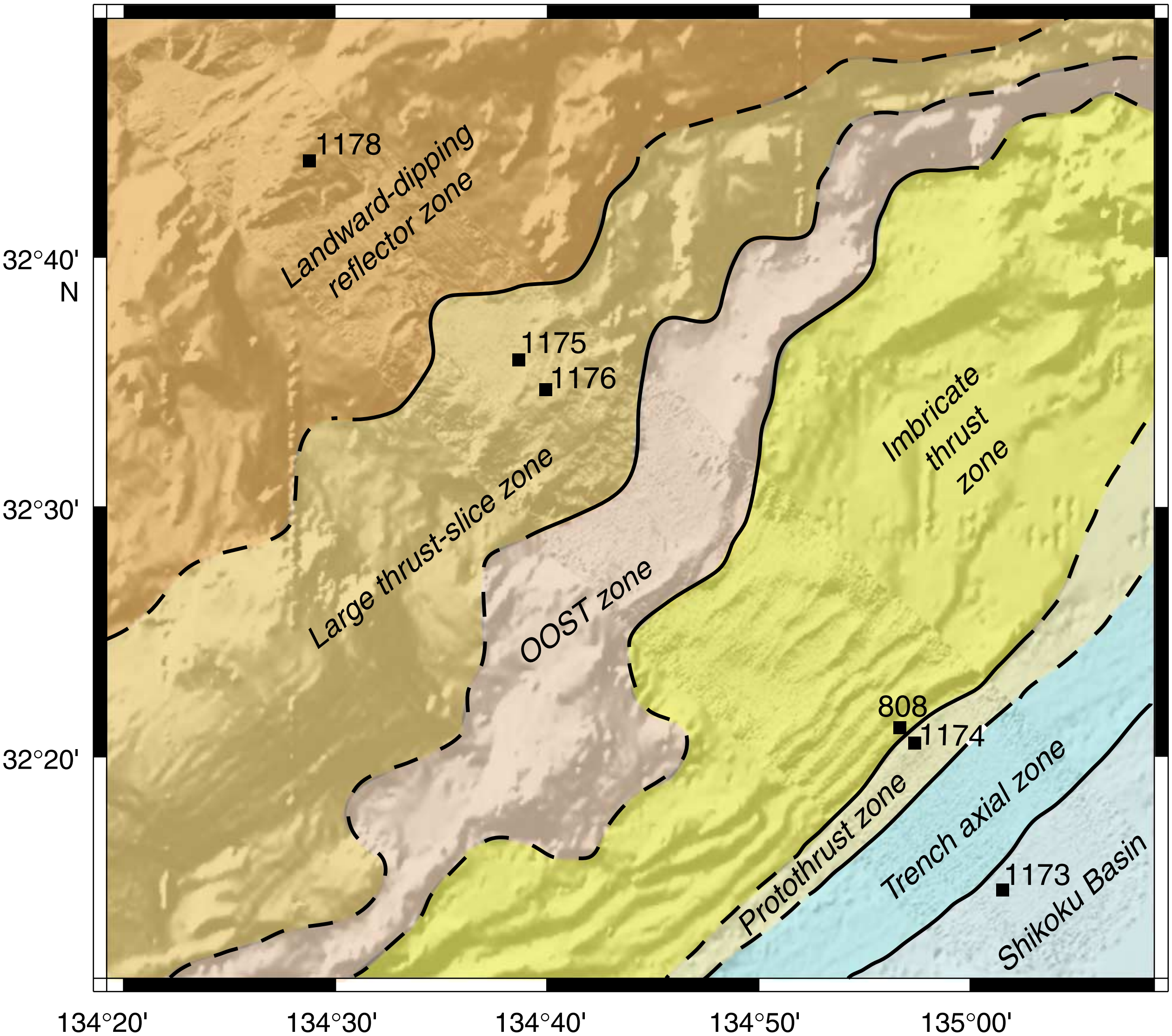

**Figure F6.** Regional seismic reflection line along the Muroto Transect. The location is shown in Figure **F2,** p. 10. Xline = crossline, OOST = out-of-sequence thrust, BSR = bottom-simulating reflector, CDP = common depth point. (This figure is also available in an **oversized format.**)