Hill, I.A., Taira, A., Firth, J.V., et al., 1993
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 131

17. VELOCITY, POROSITY, AND PORE-FLUID LOSS FROM THE NANKAI SUBDUCTION ZONE ACCRETIONARY PRISM[1]

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ABSTRACT

Seismic velocity-depth profiles are available from four types of measurements in the area of Ocean Drilling Program Leg 131, Site 808; (1) laboratory measurements on core samples, (2) downhole velocity logs, (3) a downhole vertical seismic profile (VSP), and (4) split-spread (SSP) surface ship seismic reflection. The borehole velocity data sets are in general agreement where they overlap in depth, although the velocity scatter in this turbidite section is large—about 200 m/s. The surface ship SSP velocities from a line seaward of the drill site are similar to those from the boreholes; those from a line landward of the site are substantially higher between 400 and 800 m sub-bottom depth. The main deviations at the site from the general increase in velocity with depth are higher velocities in the upper 200 m associated with coarse-grained trench-fill sediments, and abrupt downward velocity decreases associated with an intersected thrust and the décollement. The velocities are substantially higher than those from DSDP Site 582 located to the southwest along the margin where the sediments are generally finer grained.

A velocity-porosity relation has been used to convert the velocity data to porosity-depth sections. Restoring the estimated vertical offsets aligns the porosities above and below the penetrated frontal thrust and the décollement, indicating that there has been little porosity adjustment to the thickening section and thus probable high pore pressures. An offset-restored porosity-depth profile, $P = 0.60\, e^{-Z/1350}$, is obtained as an estimated equilibrium profile for the adjacent basin. The borehole and SSP data indicate that, just landward of the frontal thrust, the porosity for much of the sediment section is about 4% higher than this equilibrium basin profile, probably as a consequence of high pore-fluid pressures in the thickening section. Further inland the average porosity is slightly lower than the equilibrium profile, probably as a consequence of tectonic consolidation.

The estimated amount of pore-fluid expulsion with distance across the seaward portion of the accretionary prism is estimated to be at least a factor of five less than for the DSDP Leg 87 profile to the west, because of the much shallower seafloor slope angle in the area of the drill site and lower wedge taper. The shallower seafloor slope in the Site 808 area may result from higher pore pressures and thus a weaker detachment surface.

INTRODUCTION

An important objective of drilling in accretionary prisms such as Nankai is provision of constraints on the progressive consolidation and porosity loss of the sediments being incorporated in the prism. As drilling can give only local measurements, one function of the boreholes is also to calibrate surface ship seismic measurement. The calibration includes both confirmation of the velocities obtained and provision of transforms that allow estimates of porosity-depth profiles from the ship-based velocity data. Ocean Drilling Program (ODP) Leg 131 provided data from only one site, just landward of the deformation front (Fig. 1), but the boreholes penetrated through the complete sediment section to the oceanic crust.

Although there were considerable difficulties in getting data, particularly downhole logs, velocity information was obtained by three methods; (1) laboratory measurements on a large number of core samples, (2) downhole velocity logs, and (3) a downhole vertical seismic profile (VSP). These results were complemented by split-spread (SSP) surface-ship seismic reflection data. In addition, the combination of velocity and porosity data from the cores and velocity-resistivity downhole log data allows development of a velocity-porosity transform that can be used to convert surface-ship velocity data to porosity.

The holes at the site penetrated the frontal thrust and the décollement, located at a subbottom depth of about 960 m, 330 m above the oceanic crust. The décollement along which most of the convergence appears to be accommodated is expressed as a strong negative seismic reflector. The negative polarity reflector first appears about 6 km seaward of the drill site and is evident to some 20 km landward of the site (Fig. 2). The drilling through the frontal thrust and the décollement allowed estimates of the disequilibrium in porosity-depth profiles resulting from rapid thrusting and décollement sealing. Finally, the porosity-depth relations have been used to estimate the progressive upward fluid expulsion landward of the deformation front.

VELOCITY DATA

Laboratory Measurements

Laboratory measurements of compressional-wave velocity were made on core samples, both in the vertical and horizontal direction, at approximately 70-cm intervals to the base of the hole near 1300 m (Moran et al., this volume; Taira, Hill, Firth, et al., 1991). Other measurements included bulk density, grain density, water content, porosity, and thermal conductivity. The velocity measurements in the unconsolidated upper sediments were made from an accurate delay time determination using a pair of piezoelectric transducers spaced 7 cm apart inserted in the split sediment cores. Measurements on consolidated sediments were made using a vertical frame apparatus (e.g., Hamilton, 1965) on samples cut with parallel faces, again using the time delay between two transducers, one mounted on a calibrated feed screw. Corrections were made for *in-situ* temperature and pressure. Due to voids and disturbance in the sand samples, and gas in some samples, there are only few measurements above 360 m subbottom depth, and these are biased to the finer grained lithologies. For the remaining section the core recovery was approximately 50% and sampling biases are thought not to be significant. Acoustic anisotropy averages about 2.5%; only the vertical velocity is used in this study.

The measurement scatter is large, about ± 200 m/s. This approximately corresponds to the local variation resolved in the downhole velocity log, so it probably represents real variation in formation

[1] Hill, I.A., Taira, A., Firth, J.V., et. al., 1993. *Proc. ODP, Sci. Results,* 131: College Station, TX (Ocean Drilling Program).

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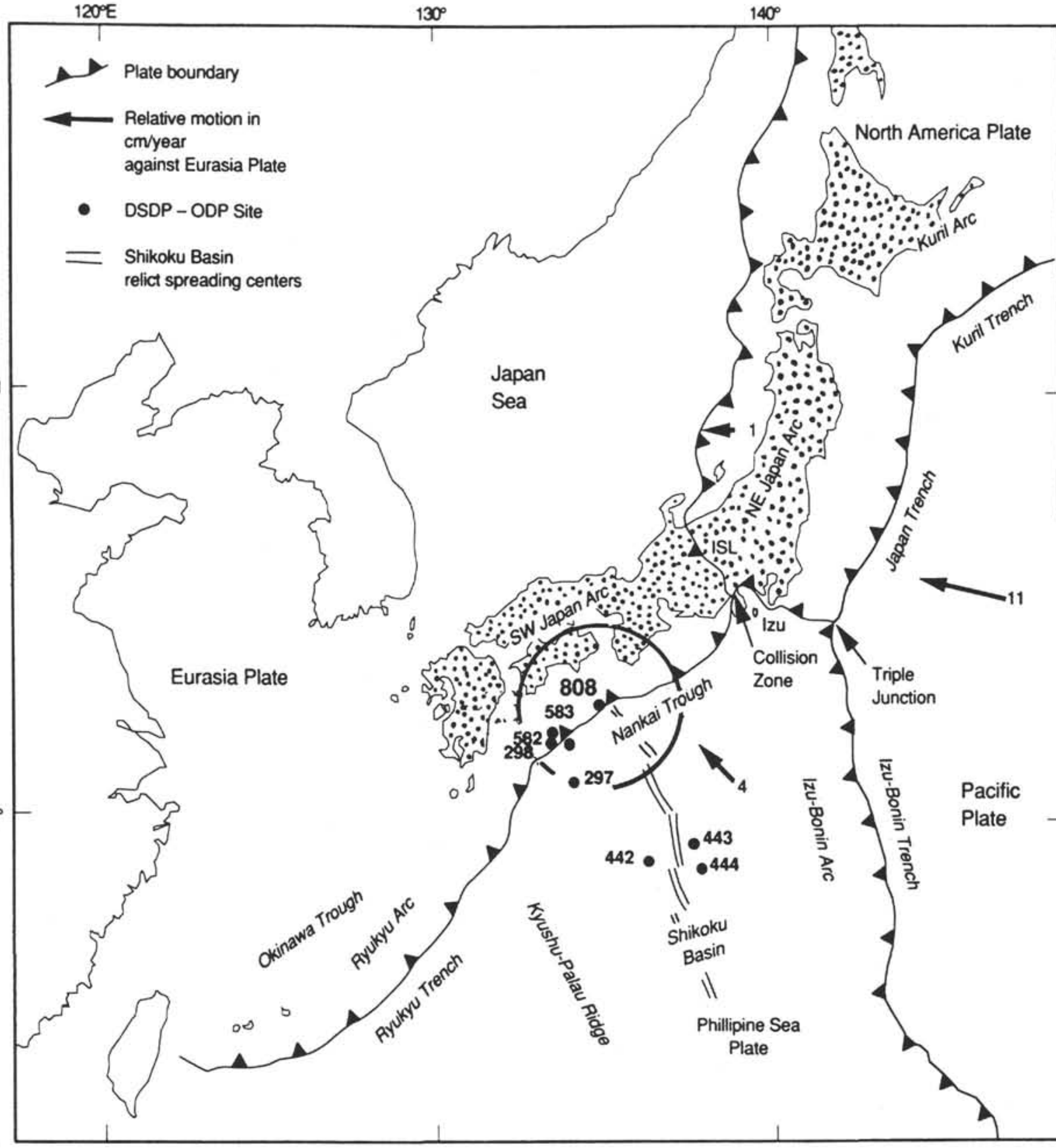

Figure 1. Location of ODP Site 808 off southeastern Japan.

velocity associated with layered variations in grain size. The velocity increases approximately linearly with depth with an offset at a thrust at about 330 m and a large offset at the décollement at 960 m. The high velocities and low porosities at the base of the hole are ash layers and basaltic oceanic crust.

Downhole Logs

The downhole logging data was acquired with a Schlumberger Ltd. digital sonic tool (SDT) employing two acoustic transmitters and two receivers. It measures the increment in travel time required between the two receivers, for sound waves traveling through the borehole wall, e.g., an in-hole seismic refraction experiment (see "Explanatory Notes", Taira, Hill, Firth, et al., 1991). Data are obtained for three source-receiver distances, 2.4, 3.0, and 3.6 m. The vertical resolution is about 60 cm. Although hole conditions were generally poor with extensive washouts, the velocity data appear to be little affected. Hole collapse was a severe problem and only two open-hole velocity logs were obtained, from 80 to 180 mbsf and from 525 to 615 mbsf. The upper section is in the coarse-grained trench-fill sediments that have atypically high velocities. There are few laboratory sample data within the upper interval, but good comparison is possible for the lower interval (Fig. 3). Three small-scale features of the largely turbidite section were apparent in the upper logged section that also are seen on the shallow penetration resistivity and gamma-ray logs. First, there is a large variability in velocity, about ± 200 m/s, comparable to that seen in the laboratory samples. Second, there are a number of thin (1–2 m) high-velocity layers (i.e., velocities of over 2 km/s) at a depth where the average is about 1.8 km/s (Fig. 4). They probably represent coarse sand layers. Third, there are common inferred upward-fining (and sometimes upward coarsening) grain-size trends with variable scale lengths (e.g., 10 m).

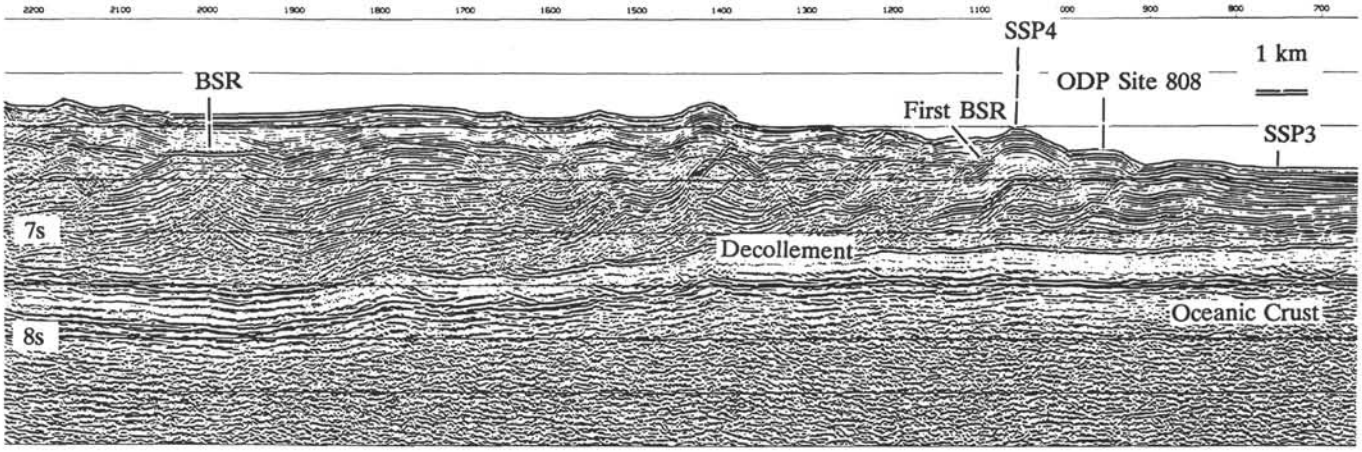

Figure 2. Multichannel seismic reflection section across the deformation front area of the Nankai accretionary prism, through ODP Site 808 (after Moore et al., 1990). The locations of ODP Site 808 and the two SSP profiles are shown. The "BSR" is a methane hydrate "bottom-simulating reflector" that parallels the seafloor.

Vertical Seismic Profile (VSP)

The VSP technique obtains a velocity-depth profile using the traveltime from a sea-surface source to a tool containing geophones that is clamped against the borehole wall at depth increments down the hole (Gal'perin, 1974; Kennett et al., 1980). The energy source was a 6.6-L (400- in.^{3}) water gun and the receiver a Schlumberger Ltd. well-seismic-tool (WST). Measurements were made at 9.1-m (30 ft) intervals within a cased section of the hole (76–524 m) and in the upper 64 m of the open hole below (524–588 m) (Moore, this volume; Taira, Hill, Firth, et al., 1991). The very strong ocean currents in this area resulted in noisy signals, but first arrivals could be detected reliably. The traveltime vs. depth in the hole is generally smooth with a few spurious points that have been deleted. The average velocity has been estimated for 50- to 100-m intervals downhole.

The VSP velocities are found to be systematically about 100 m/s slower than the log velocities where they overlap in the upper part of the hole (80–180 m), and systematically about 100 m/s faster than the measured core values in the interval 300–450 m. This is larger than expected, but the drilled section is highly variable in this depth range.

Split-spread Two-ship Data

A series of two-ship split-spread profiles were obtained parallel to the margin in the area of Site 808 (Wood, 1989; Stoffa et al., 1992). In this technique, one ship carrying the air-gun source remains stationary and the second ship towing the hydrophone array runs profiles past the first. In this method there is not a common reflection point, and corrections for dip are required. The modeled velocity-depth sections are shown in Figure 5 for profiles about 3 km seaward (SSP3) and about 2 km landward (SSP4) of drill Site 808. The method has limited depth resolution in the 4–5 km water depth but allows information to be obtained on the variation in velocity and thus porosity, landward across the accretionary wedge. Both profiles exhibit velocity reversals associated with the décollement. The profile SSP3 just seaward of the drill site is in general agreement with the velocity-depth trend from the borehole data, although the detailed modeled SSP layering is not seen in the borehole data. Profile SSP4 landward of the drill site has a modeled velocity inversion; the estimated velocity over the 400 to 800 mbsf interval of 2570 m/s (estimated bound of 2410 to 2610) is substantially higher than from the borehole data and may represent tectonically induced pore-fluid expulsion.

Velocity-depth Profile

The velocity-depth profile at the drill site is approximately linear with depth, with surface intercept of about 1600 m/s (Fig. 5). The main deviations are higher velocities in the upper 200 m associated with coarse-grain trench-fill sediments, and downward velocity decrease offsets, associated with the an intersected thrust and with the décollement. Smaller changes are associated with changes in lithology (see Taira, Hill, Firth, et al., 1991).

To obtain a velocity-depth profile approximating that in the adjacent deep-sea basin prior to deformation, the two offsets have been restored in the laboratory core velocity data (Fig. 6) (see discussion in Porosity Section), i.e., a vertical offset of 146 m associated with the frontal thrust and 300 m for the thickening of the sediment section from where the décollement reversed-polarity reflector first becomes apparent about 6 km seaward of the drill site (Fig. 2). There is good continuity of the velocity data across the two discontinuities after the offsets have been restored, indicating that there has been very little recovery of these offsets toward the equilibrium velocity-depth profile.

The resulting reference profile (Fig. 6) has an approximately linear velocity increase with depth, with a gradient of about 0.8 m/s per meter depth. These velocities are substantially lower than those from DSDP Site 582 (Bray and Karig, 1986), located to the southwest along the margin where the sediments are generally finer grained (about 0.35 m/s per meter). The Site 808 profile is in general agreement with velocities from multichannel seismic reflection data off the northern Cascadia margin that has a similar clastic accretionary wedge (Davis et al., 1990), and where the basin water depths are shallow, allowing high-resolution multichannel seismic velocities.

POROSITY

Porosity data at Site 808 was obtained by direct measurement on core samples (Moran et al., this volume), and from downhole velocity data using a velocity-porosity relationship. Porosity information is also available from two sections of downhole resistivity logs (Taira, Hill, Firth, et al., 1991). The latter were particularly useful for delineating thin (1–2 m) resistive and presumably low-porosity sand layers (Fig. 4). A quantitative resistivity-porosity relation has not yet been developed for these sediments, but a brief discussion is given in Taira, Hill, Firth, et al. (1991). The resistivity data are not discussed further here.

Laboratory Core Porosity Data

The core laboratory porosity data from Site 808 (Moran et al., this volume; Taira, Hill, Firth, et al., 1991) exhibit a generally exponential decrease with depth, with offsets at the frontal thrust and décollement similar to those in the velocity data. To obtain a porosity-depth profile approximating that in the adjacent deep-sea basin prior to deforma-

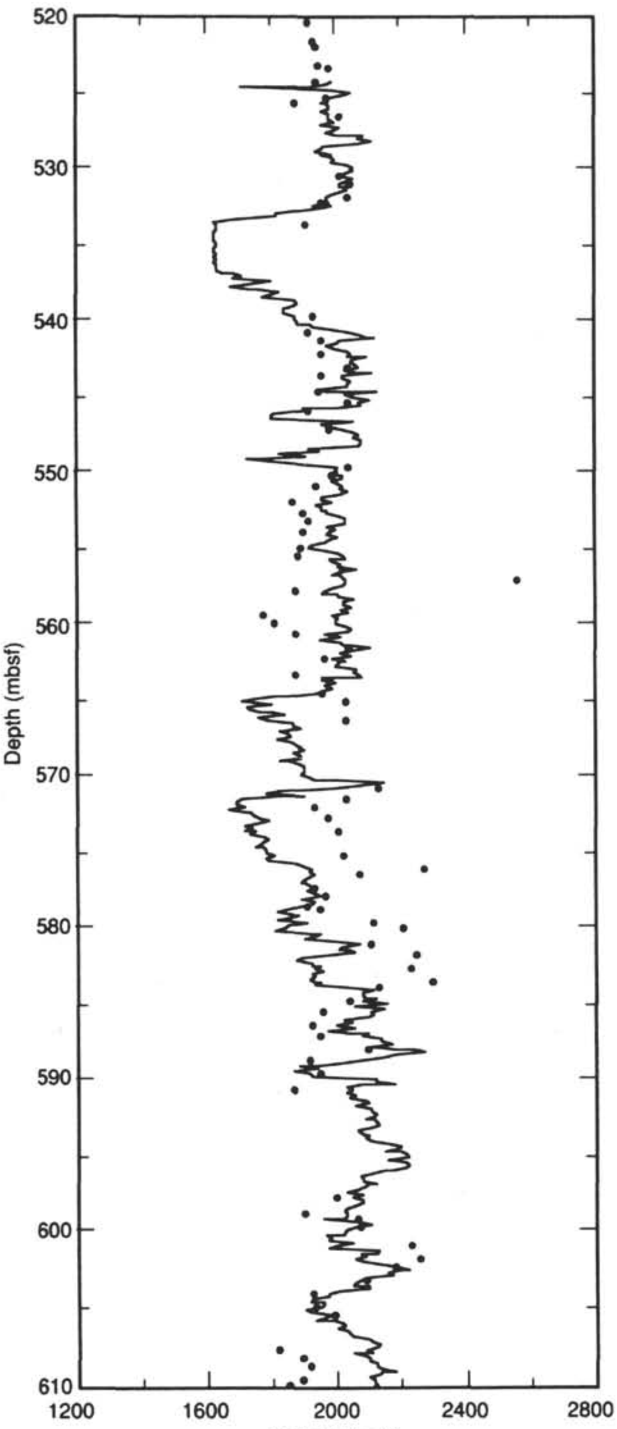

Figure 3. Detailed comparison of the velocities measured on core samples in the laboratory (dots) and velocities from one section of the downhole log (solid line).

tion, we have restored the two offsets. The vertical offset associated with the frontal thrust of 146 m (Taira, Hill, Firth, et al., 1991) has been restored by simply moving the deeper data up by that amount. The effect of the décollement is more complex. We have taken the limiting case, that an equilibrium porosity-depth profile extends through the décollement level in the Shikoku Basin. This profile is preserved in the section below the décollement as the sediment moves to the region of the drill site. Hydraulic sealing of the décollement is thus assumed to occur where the characteristic negative-polarity décollement reflector is first apparent in the basin about 6 km seaward of the drill site. This polarity indicates lower velocity below the reflector. From that point landward, no porosity loss from beneath the décollement associated with the sediment thickening and loading is assumed. The overlying sediment section thickens about 300 m in this distance, and that amount of offset has been restored (see also velocity offsets section). In spite of the variations in lithology, the porosity-depth profile with offsets restored has an approximately exponential decrease in porosity with depth (Fig. 7). The largest deviation is in the scattered data from the coarse-grained trench-fill sediments near the top of the hole. This profile should approximate that in the adjacent basin. The relation $P = 0.60\ e^{-Z/1350}$ that gives a good fit (excluding the coarse-grained low porosity trench-fill sediments at the top of the section) is shown for comparison. This function gives 60% porosity at the seafloor and 30% porosity just above the oceanic crust.

Porosity from Velocity

The primary source of information on regional porosity variations for the accretionary sedimentary wedge is velocity data from surface ship seismic measurements. Thus, an important function of the borehole is to provide constraints on the applicable velocity-porosity relation. We have plotted the laboratory core velocity-porosity data along with several previously developed relations (Fig. 8). Of the commonly used relations, that of Hamilton (1974) was derived using primarily seafloor samples with a range of grain sizes; it predicts quite low porosities for particular velocities compared to most DSDP/ODP data. Even lower porosities are predicted by the Raymer et al. (1980) relation obtained from petroleum industry log data. In contrast, the standard Wyllie time average equation predicts very high porosities for unconsolidated sediments that have velocities less than about 3.0 km/s. An "unconsolidated" correction is often applied to bring this relation into agreement with log data for unconsolidated sediments.

Relations that give reasonable correspondence to DSDP/ODP laboratory and log data in clastic sections include: (1) A combined relation merging the Wyllie relation for low porosities and the theoretical Wood equation for high porosities (Nobes et al., 1986), found to fit a compilation of DSDP core data, (2) A combination of the relations by Hamilton (1978) for high and for low porosity (Fig. 8), found to give agreement with core data from previous drilling in the Nankai trough (D. Karig, pers. comm., 1990), (3) a comprehensive study of both laboratory core and downhole log data by Jarrard et al. (1989), which gives a relation very close to that by Hamilton (1978) for high porosity.

Han et al. (1986) found that the primary velocity control for semiconsolidated and consolidated clastic sediments is clay content (Fig. 8) (see also Klimentos, 1991). A smooth polynomial fit to the results of Jarrard et al. (1989) for high porosities and the results of Han et al. (1986) for low porosities as recommended by E. Davis (pers. comm., 1990) assuming 50% clay, gives an excellent fit to the Site 808 laboratory data (Fig. 8). This is much higher clay content than shown in XRF data, about 20%. In part the discrepancy is associated with the thin-section point-counting clay estimation used by Han et al. (1986) compared to the Site 808 XRF data. The former substantially overestimates the clay content (e.g., Klimentos, 1991). Although this discrepancy remains unresolved, the 50% curve gives a good fit to the Site 808 and the Jarrard et al. data sets and has been used to convert velocity to porosity. It is applicable for the velocity range from about 1600 m/s to 2500 m/s, or porosity from about 30% to 60%. The porosity (%) is given in terms of velocity V (km/s) by:

$$P = -1.180 + 8.607\ (1/V) - 17.89\ (1/V)^2 + 13.94\ (1/V)^3.$$

This relation has been used to convert the Site 808 velocity-depth profiles to porosity-depth profiles. The nearly linear laboratory velocity-depth profile converts to an approximately exponential porosity-depth

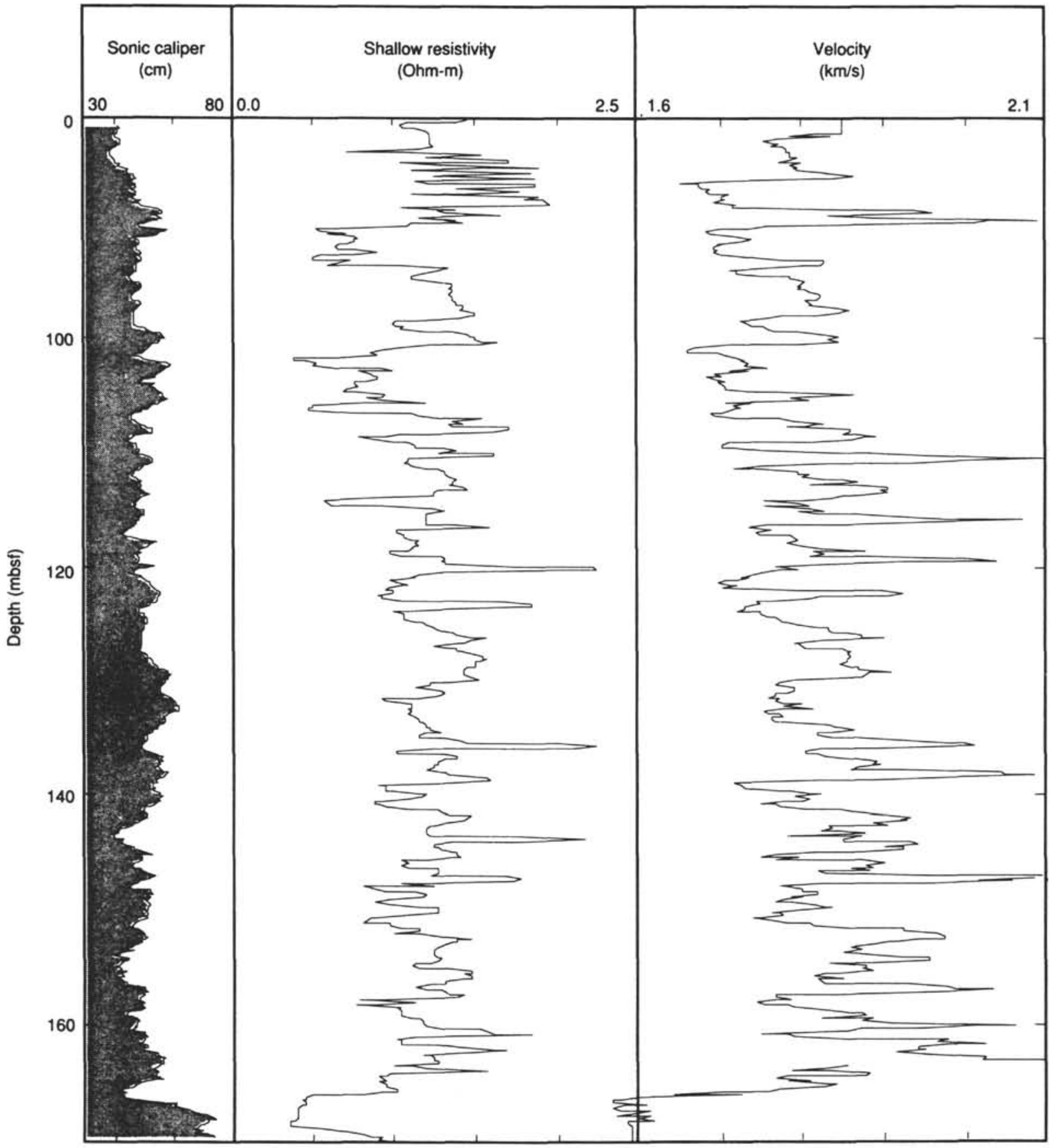

Figure 4. Downhole velocity and resistivity logs for a section in the upper part of Hole 808B, illustrating the large variability with thin high-velocity, high-resistivity layers.

profile, with scattered lower porosities in the upper coarse-grained sequence, and inversions to lower porosities downward at the thrust and décollement. The inferred porosities from the laboratory velocities are compared to the measured porosities (usually measured within a few centimeters) in Figure 9. The excellent agreement at all depths indicates that this velocity-porosity relation can give porosities from velocity data within a few percent in the Nankai prism type of sediments (30% to 60% porosity).

The porosities inferred from the split-spread profiles are shown in Figure 9. The SSP3 profile just seaward of the drill site has porosity depth profile similar to that obtained from the borehole data, except for the upper 300 m of the section where higher velocities in the SSP profile may result from coarse-grained trench-fill sediments that are not as well represented in the core data. The SSP4 porosity profile landward of the drill site has porosities substantially lower than for the borehole data between 400 and 800 mbsf and higher porosities below the décollement.

POROSITY-DEPTH VARIATIONS ACROSS THE DEFORMATION FRONT

Porosity-depth Equilibration at the Frontal Thrust and Décollement

For both the core velocity and porosity data, restoring the complete vertical offset aligns the data both across the frontal thrust and across

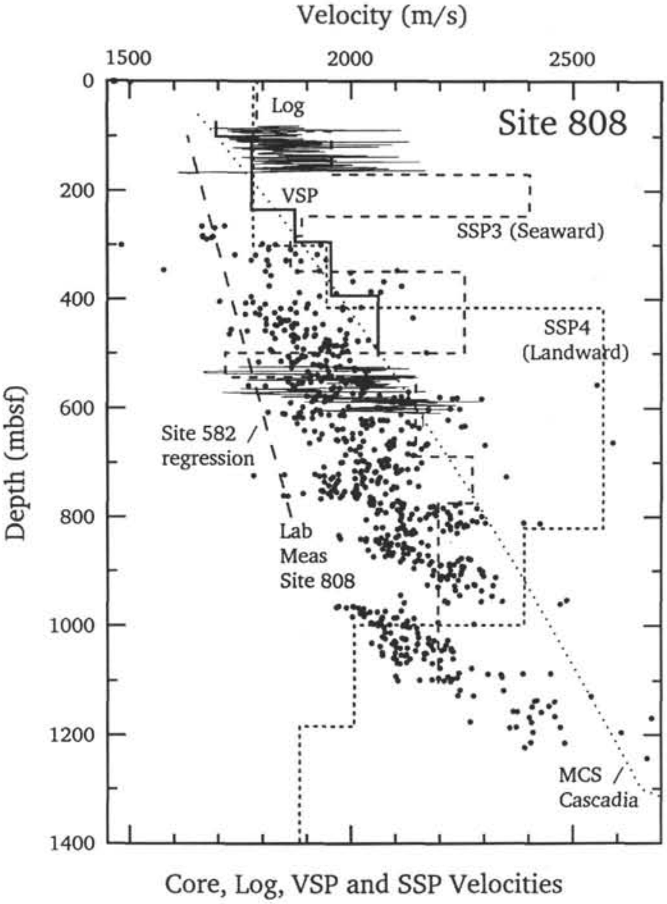

Figure 5. Comparison of the velocities obtained from core samples, downhole logs, VSP, and SSP surface ship data. A linear fit to the laboratory data from DSDP reference Site 582 seaward of the deformation front (to the southwest of Site 808, see Fig. 1), and the average basin velocity-depth profile from northern Cascadia margin multichannel velocity data, are shown for comparison.

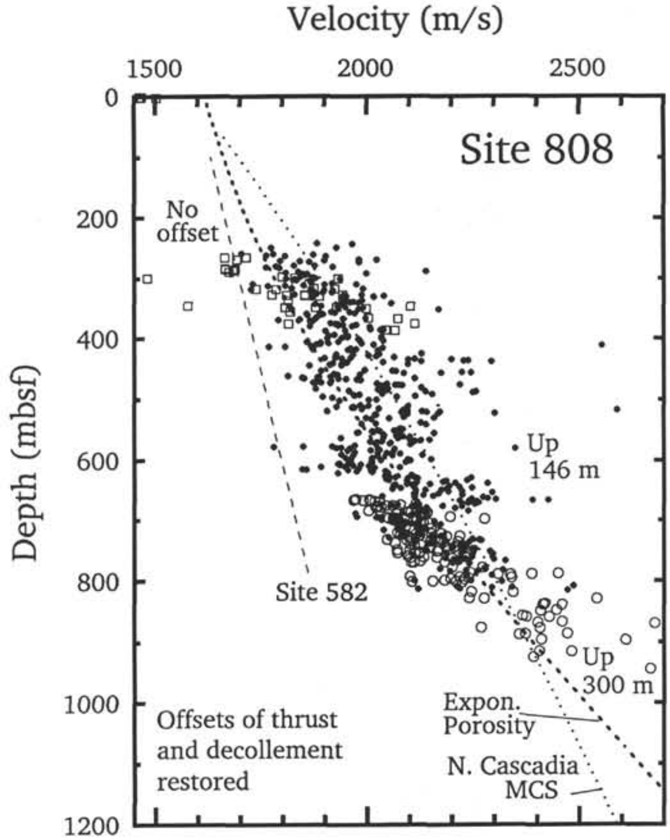

Figure 6. Laboratory core-velocity data plotted as a function of depth with the 146-m vertical offset of the frontal thrust restored and the section below the décollement moved 300 m up to the same sub-bottom depth it had seaward, where the negative polarity décollement reflector first appears. The open squares denote samples from above the thrust, the dots denote samples between the thrust and the décollement, and the open circles denote samples below the décollement.

the décollement, indicating that there has been little readjustment toward the equilibrium depth profile. The depth adjustment appears slightly too great for the thrust, indicating some re-equilibration, but no re-equilibration is evident at the décollement. The offset at the frontal thrust is probably active at present. Assuming that it is accommodating most of the relative plate rate, the offset requires the order of 5000 yr; porosity-depth re-equilibration thus must require a time longer than this. Pore-fluid expulsion associated with this disequilibrium is suggested by the pore-pressure data from the LAST tool (K. Moran, this volume). A similar result is found for the décollement. However, in this case the time for the 6-km movement from where the characteristic reflector first appears, to the borehole site, is about 150,000 yr. The negative reflector persists at least 20 km farther inland (at least 0.5 Ma). Very low permeabilities at the depth of the décollement are thus required.

Porosity Variation across the Deformation Front Area

The deviations in velocity and porosity from the estimated basin equilibrium depth profiles are shown in Figures 10 and 11. The velocities at the drill site are 100–200 m/s slow between the thrust and the décollement, and 500 m/s slow below the décollement (Fig. 10) compared to the basin. The porosities are about 3%–4% too high between the thrust and the décollement, and 7% too high beneath the décollement (Fig. 11). Overall, the sediment section has an average porosity about 4%–5% too high at the drill site.

The SSP4 data allows an estimate of the porosity variation a further 2 km landward. The velocities at this location are about 400 m/s faster than the basin values between 400 and 800 mbsf, and reverse to be about 500 m/s too slow below the décollement. This is even slower than at the drill site, although the difference is probably not significant. The porosities at SSP4 are about 8% too low between 400 and 800 mbsf and over 10% too high below the décollement compared to the basin profile. The overall average porosity of the complete sediment section to the oceanic crust at SSP4 is slightly lower than the basin section average.

PORE-FLUID EXPULSION WITH LANDWARD DISTANCE

The amount and distribution of pore-fluid expulsion with distance across the seaward portion of the accretionary prism has been an important objective of drilling and other studies in accretionary wedges. We present only the simplest model here to compare the results for the margin near Site 808 and for the DSDP Leg 87 area to the west. The cumulative fluid production is derived by differencing the mean porosity in a vertical column of the incoming sedimentary section from the predicted mean over the thickening accretionary prism.

Constant Porosity-depth Function across Deformation Front

We first assume: (a) vertical fluid expulsion only, (b) that the porosity-depth function (above the décollement) remains constant

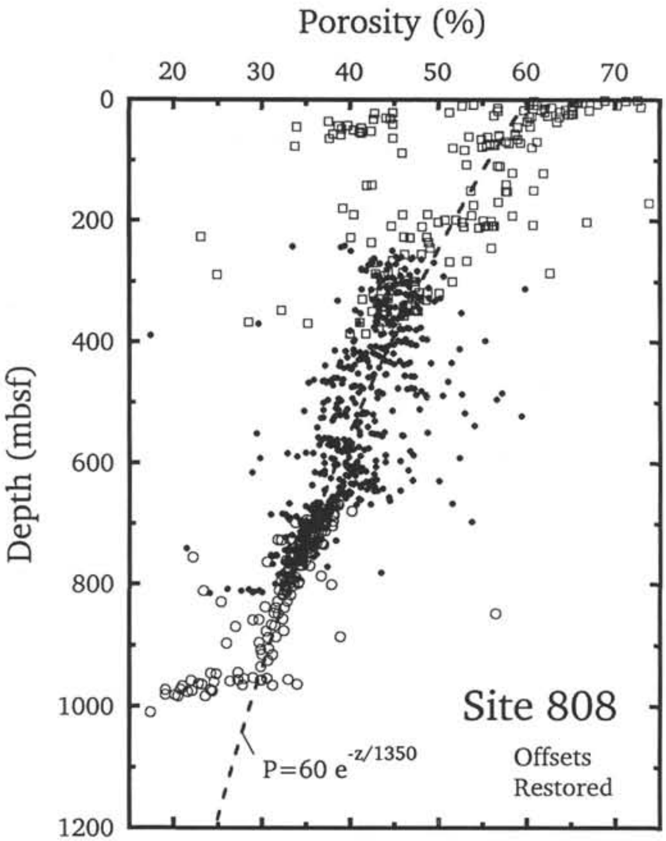

Figure 7. Laboratory core-porosity data plotted as a function of depth with the vertical offset of the frontal thrust restored (146 m) and the section below the décollement moved up 300 m (an additional 154 m) to the same sub-bottom depth it had seaward where the negative polarity décollement reflector first appears. The open squares are for samples from above the thrust, and the open circles are for samples from below the décollement.

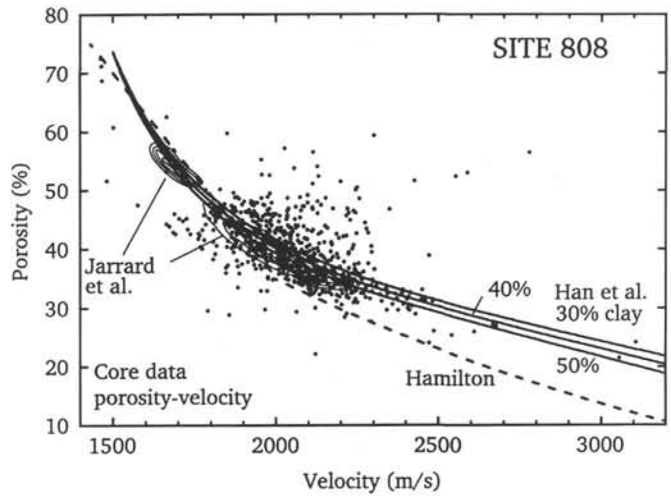

Figure 8. The porosity-velocity data for the Site 808 laboratory measurements and other data and relations for deep-sea clastic sections.

landward across the accretionary prism. The first assumption is justified by the aspect ratio of the prism, i.e., several kilometers thick by tens of kilometers across. However, there is extensive evidence for deviations from this one-dimensional model. Focused fluid discharge in the deformation front area has been widely studied (e.g., Henry et al., 1989). That the porosity-depth function remains approximately constant has been inferred in numerous studies (e.g., Bray and Karig, 1985; LePichon et al., 1990; Davis et al., 1990), although there have been indications of porosity decreasing slightly inland (e.g., Davis et al., 1990), and locally some landward increasing porosity (e.g., Cochrane et al., 1988). We briefly discuss deviations in the porosity-depth profile below. We have assumed no porosity loss from the sediments below the décollement based on the Site 808 and SSP4 data. The integrated pore-fluid expulsion of Figure 12 includes a correction for stratigraphic thickening landward and assumes no pore-fluid loss from below the décollement. The depth section of Moore et al. (1990) has been used. This volume is the total fluid expelled through a unit area of seafloor as it moves landward from the deformation front. The upward fluid transport near the surface is given by dividing this volume by the porosity, i.e., about a factor of two higher.

An order-of-magnitude fluid expulsion rate is also given simply from the time-derivative of the expulsion, assuming that each seafloor area moves landward from the deformation front at the plate convergence rate. This neglects both the seaward migration of the deformation front and the slowing of the landward motion of a point on the seafloor as it changes from being carried by the ocean crust to being attached to the land block. The smoothed fluid expulsion rate from this simple approach (Fig. 12) is about a factor of two greater than given by the formulations of LePichon et al. (1990) and of Bekins and Dreiss (1992).

Because of the shallow seafloor slope angle in the area of the drill site and low wedge taper, the predicted fluid expulsion is small, only several tens of cubic meters per square meter of seafloor (m^3/m^2) (about 100 m upward fluid motion near the seafloor) at the drill site, increasing to only about 200 m^3/m^2, 20 km inland. The modeled expulsion rate is only about 0.5 mm/yr. For comparison we have also computed the total expulsion inland of the deformation front along a profile crossing the margin to the west (Moore et al., 1990) where holes were drilled on Leg 87. A minimum total expulsion of about 1000 m^3/m^2, and a rate of up to 4 mm/yr, 20 km inland of the deformation front (Fig. 13) is obtained assuming the same porosity-depth profile as estimated for the Site 808 profile. The actual porosities on the former profile are substantially higher (see velocity profile in Fig. 5) and the fluid expulsion should be even higher. The greater fluid expulsion along the Leg 87 profile is a consequence of a much steeper seafloor slope and a much faster landward thickening loading of the sediment section. The shallower seafloor slope in the Site 808 area may result from lower permeabilities, higher pore pressures, and thus a weaker detachment surface.

Effect of Variations in Porosity-depth Function across Deformation Front

The effect of deviations from the assumption of constant exponential porosity-depth function across the deformation front through Site 808 can be qualitatively estimated from the porosity-depth profile variations (Fig. 11). Near the drill site the average porosity above the décollement is about 4% too high, which represents about 50 m^3 per m^2. This amount is close to the total predicted fluid expulsion given in Figure 12. Thus, as expected from the disequilibrium illustrated by the restoration of the thrust and décollement offsets in Figure 7, there is little or no fluid expulsion indicated at the drill site. This is consistent with the borehole geochemical data indicating little or no expulsion at the site. Two km further landward at SSP4, the average porosity above the décollement is about 5% too low, indicating that the Figure 12 fluid expulsion should be about 50 m^3 per m^2 higher, i.e., about 120 m^3 per m^2. This location is close to the first appearance of a hydrate BSR (Fig. 2), which may be related to fluid expulsion.

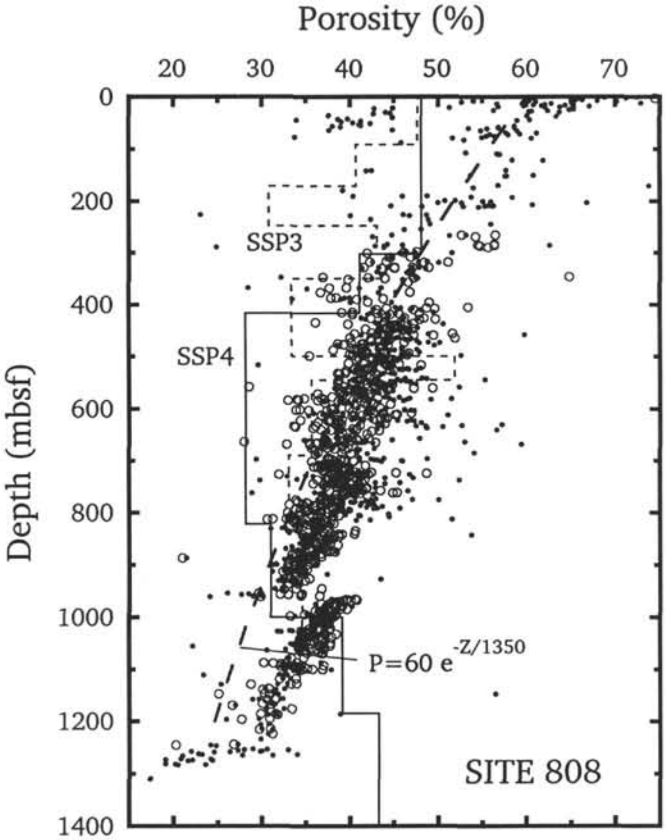

Figure 9. Porosity estimated from core velocity data using the relation of Figure 8 for 50% clay (circles), compared to the core porosity data (dots). The estimated exponential porosity-depth function for the basin and the porosity-depth profiles computed from the SSP velocities are also shown.

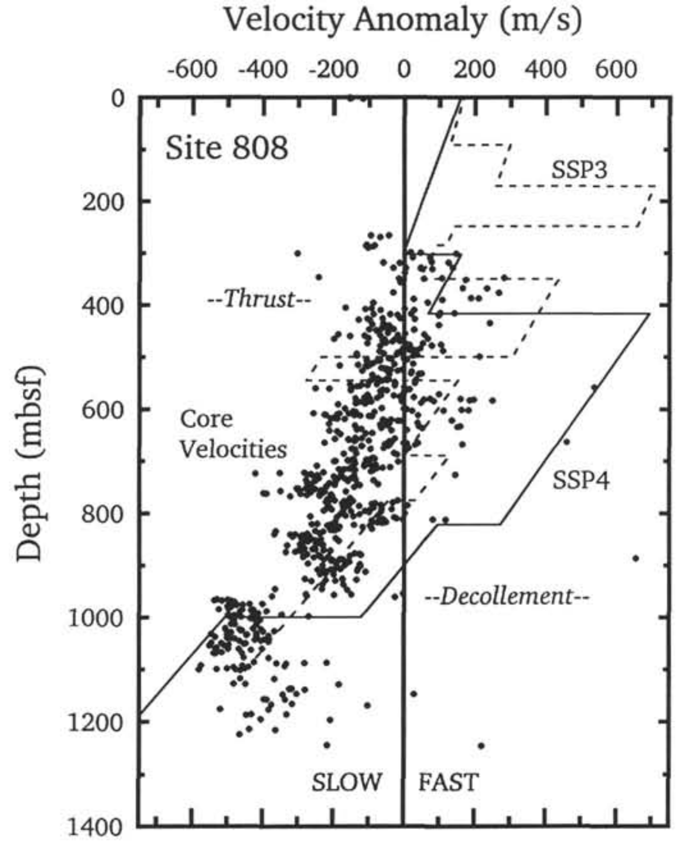

Figure 10. Deviation of core sample and SSP velocities from the estimated equilibrium velocity-depth profile for the basin just seaward of the deformation front.

While the variations in porosity-depth do make a significant difference in local fluid expulsion, they do not change the order-of-magnitude difference in fluid expulsion between the Site 808 (Nankai East) and Leg 87 (Nankai West) profiles.

DISCUSSION

The very extensive laboratory data on the Site 808 core provides the most important information on the porosity and velocity of the sediment section. The short sections of downhole logs provide confirmation that the core measurements are representative of *in-situ* velocity and porosity, and with the VSP provides information in the upper part of the hole where core disturbance limited the amount of useful laboratory velocity data. A velocity-porosity relation has been obtained from the Site 808 laboratory data and data from other similar sections, that has been used to obtain porosities from surface ship SSP seismic measurements.

The abrupt velocity decrease and porosity increase beneath the frontal thrust and the décollement indicate that the equilibrium exponential porosity-depth profile is restored only slowly, and that there are probably high pore pressures present. It is surprising that the porosity below the décollement reflector seems not to decrease starting from a point some 6 km seaward of the deformation front. Quite low vertical permeability is required. One possible explanation is that the horizontal stress is much larger than the vertical stress above the décollement but not below it, so that dewatering is faster above the décollement than below it (R. Jarrard, pers. com., 1991). Reference velocity-depth and porosity-depth profiles that approximate those for the basin seaward of the site, have been obtained by restoring the two offsets. The borehole data with the SSP profiles have allowed a porosity profile across the deformation front area to be estimated. Landward from the basin, the porosity first increases in the deformation front area and then decreases further inland.

Rough estimates of the pore-fluid expulsion through the seafloor seaward of the deformation front have been obtained. Using the estimated equilibrium porosity-depth profile for the whole profile, the expulsion is five times less on the Leg 131 Site 808 profile, where the seafloor slope is very low, compared to the DSDP Leg 87 profile, where the slope is much steeper. The high pore pressures inferred below the décollement probably allow maintenance of the very gentle slope in the former profile. Allowance for variations in porosity-depth along the Site 808 line gives smaller predicted fluid expulsion near the site and greater expulsion several kilometers further inland.

ACKNOWLEDGMENTS

We acknowledge the outstanding support of the *JOIDES Resolution* crew and ODP technical staff during Leg 131. Geological Survey of Canada Publication No. GSC 13192.

REFERENCES

Bekins, B.A., and Dreiss, S.J., in press. A simplified analysis of parameters controlling dewatering in accretionary prisms. *Earth Planet. Sci. Lett.*

Bray, C.J., and Karig, D.E., 1985. Porosity of sediments in accretionary prisms, and some implications for dewatering processes. *J. Geophys. Res.*, 90:768–778.

———, 1986. Physical properties of sediments from the Nankai Trough, Deep Sea Drilling Project Leg 87A, Sites 582 and 583. *In* Kagami, H., Karig, D.E., Coulbourn, W.C., et al., *Init. Repts. DSDP*, 87: Washington (U.S. Govt. Printing Office), 827–842.

Cochrane, G., Lewis, B.T.R., and McClain, K.J., 1988. Structure and subduction processes along the Oregon-Washington margin. *Pure Appl. Geophys.,* 128:767–800.

Davis, E.E., Hyndman, R.D., and Villinger, H., 1990. Rates of fluid expulsion across the northern Cascadia accretionary prism: constraints from new heat flow and multichannel seismic reflection data. *J. Geophys. Res.,* 95:8869–8889.

Gal'perin, E.I., 1974. *Vertical Seismic Profiling.* Spec. Publ. -Soc. Explor. Geophys., 12.

Hamilton, E.L., 1965. Sound speed and related properties of sediments from Experimental Mohole (Guadalupe Site). *Geophysics,* 30:257–261.

————, 1974. Prediction of deep-sea sediment properties: state of the art. *In* Inderbitzen, A.L. (Ed.), *Deep-Sea Sediments: Physical and Mechanical Properties:* New York (Plenum), 1–44.

————, 1978. Sound velocity-density relations in sea-floor sediments and rocks. *J. Acoust. Soc. Am.,* 65:909–922.

Han, D., Nur, A., and Morgan, D., 1986. Effects of porosity and clay content on wave velocities in sandstones. *Geophysics,* 51:2093–2107.

Henry, P., Lallemant, S.J., LePichon, X., and Lallemand, S.E., 1989. Fluid venting along Japanese trenches: tectonic context and thermal modelling. *Tectonophysics,* 160:277–291.

Jarrard, R.D., Dadey, K.A., and Busch, W.H., 1989. Velocity and density of sediments of Eirik Ridge, Labrador Sea: control by porosity and mineralogy. *In* Srivastava, S.P., Arthur, M.A., Clement, B., et al., *Proc. ODP, Sci. Results,* 105: College Station, TX (Ocean Drilling Program), 811–835.

Kennett, P., Ireson, R.L., and Conn, P.J., 1980. Vertical seismic profiles: their application in exploration geophysics. *Geophys. Prospecting,* 28:676-699.

Klimentos, T., 1991. The effects of porosity-permeability-clay content on the velocity of compressional waves. *Geophysics,* 56:1930–1939.

LePichon, X., Henry, P., and Lallemant, S., 1990. Water flow in the Barbados accretionary complex. *J. Geophys. Res.,* 95:8945–8967.

Moore, G.F., Shipley, T.H., Stoffa, P.L., Karig, D.E., Taira, A., Kuramoto, S., Tokuyama, H., and Suyehiro, K., 1990. Structure of the Nankai Trough accretionary zone from multichannel seismic reflection data. *J. Geophys. Res.,* 95:8753–8765.

Nobes, D.C., Villinger, H., Davis, E.E., and Law, L.K., 1986. Estimation of marine sediment bulk physical properties at depth from seafloor geophysical measurements. *J. Geophys. Res.,* 91:14033–14043.

Raymer, L.L., Hunt, E.R., and Gardner, J.S., 1980. An improved sonic transit time-to-porosity transform. *Trans. SPWLA 21st Annu. Log. Symp.,* Pap. P.

Stoffa, P.L., Wood, W.T., Shipley, T.H., Moore, G.F., Nishiyama, E., Bothelo, M.A.B., Taira, A., Tokuyama, H., and Suyehiro, K., in press. High resolution expanding spread and split-spread marine seismic profiles: acquisition and velocity analysis methods. *J. Geophys. Res.*

Taira, A., Hill, I., Firth, J., et al., 1991. *Proc. ODP, Init. Repts.,* 131: College Station, TX (Ocean Drilling Program).

Wood, W.T., 1989. One and two-dimensional seismic velocity inversion in the domain of intercept time and ray parameter: an example in the Nankai Trough [M.Sc. thesis]. Univ. Texas, Austin.

Date of initial receipt: 1 October 1991
Date of acceptance: 25 March 1992
Ms 131SR-125

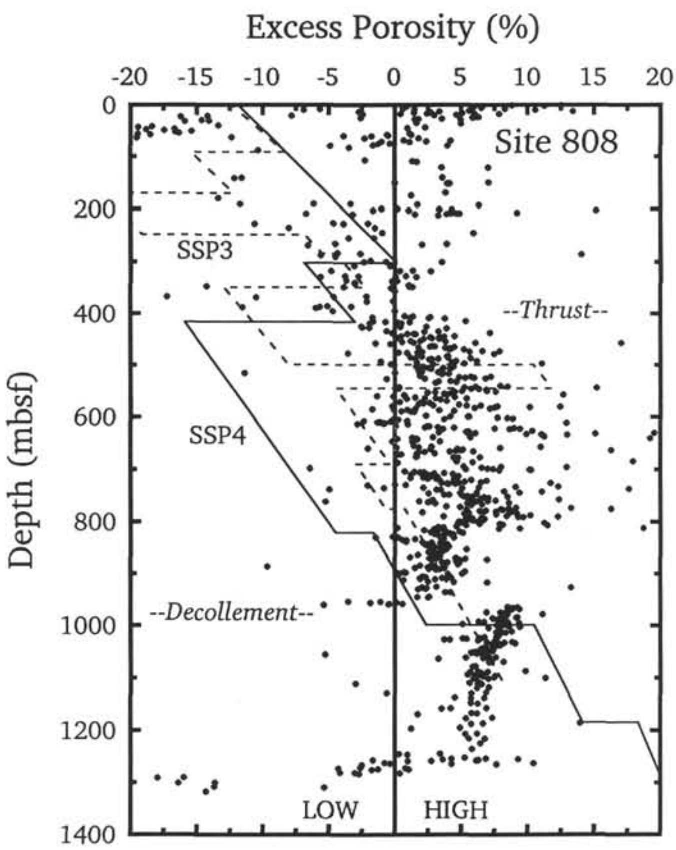

Figure 11. Deviation of core sample and SSP porosities from the estimated exponential porosity-depth profile for the basin just seaward of the deformation front.

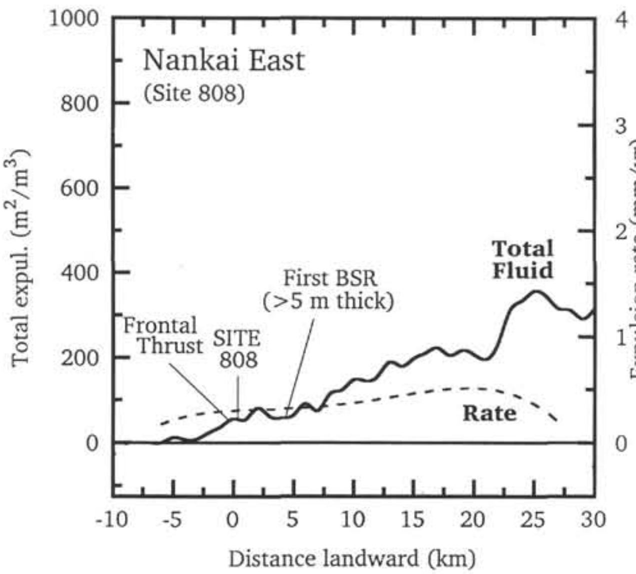

Figure 12. Total fluid expulsion and expulsion rate as a function of distance from the deformation front on a profile through Site 808 (see Figs. 1 and 2). The same exponential porosity-depth function has been assumed along the whole line.

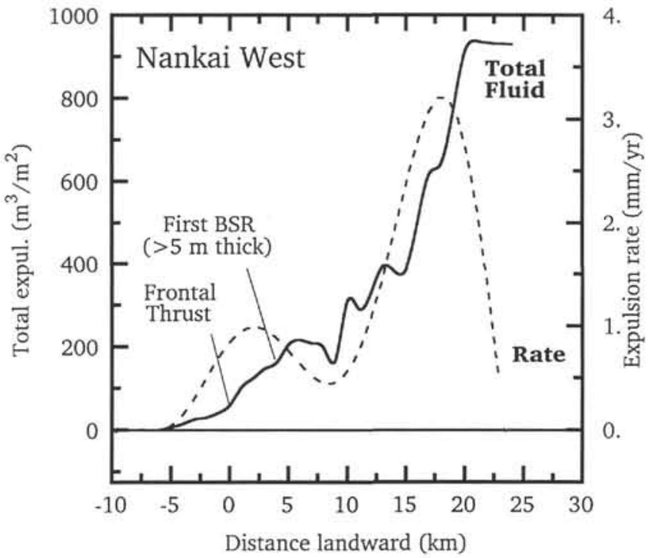

Figure 13. Total fluid expulsion and expulsion rate as a function of distance from the deformation front on a profile through Site 582, DSDP Leg 87 (see Fig. 1). The same exponential porosity-depth function has been assumed along the whole line.