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PROPOSAL NO.

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TITLE OF PROJECT

Japan-United States Cooperative Study of the Relationship Between Sediment Physical Properties and Subduction Processes in the Nankai Trough

TECHNICAL ABSTRACT (LIMIT TO 22 PICA OR 18 ELITE TYPEWRITTEN LINES)

We propose to examine the relationship between physical properties and subduction processes in the Nankai Trough. The structural response to convergence is probably most dependent on the physical properties of the deforming rocks of which there are few measurements. We will characterize the physical properties by collecting high resolution MCS data and expanding spread profiles (ESP) at 20 locations across the margin near DSDP Sites 582 and 583. These data should adequately define the variations in properties with time and increasing cumulative strain.

This will be a cooperative program with Japanese scientists. We will use a U.S. ship for recording and the R/V Tansei Maru as the shooting ship. The ESP program will use a 400 cubic inch water gun and a 48-channel, 12.5 m group streamer to provide the resolution required to examine detailed changes in velocity and angle dependent amplitudes. The program will also provide the detailed perspective needed for siting a single new ODP deep hole for physical properties and fluid studies. The new site would also allow significantly better calibration of the ESP data and extrapolation to the margin cross section.

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RESULTS FROM PRIOR NSF SUPPORT (G. F. Moore and T. H. Shipley)

- a) OCE 8024402 and 8414401, \$214,268, 11/1/81 to 4/30/84
- b) "High Resolution Studies of Sediment Accretion and Subduction Along the Middle America Trench"
- c) Below is an excerpt of the "summary of completed project" for the most recently completed NSF program.

Convergent margins have been the subject of intense interest since the first simple dynamic models for accretion at the base of inner trench slopes were published by Seely et al. and Karig in 1974. The mechanics of the accretion process remain obscure, partly because of the lack of high-resolution data from the base of trench slope.

The purpose of this project was to conduct an integrated high-resolution (broad-band) digital single channel seismic reflection and Sea Beam bathymetric study of three sites along the Middle America Trench. The combination of techniques provided an excellent method to study structural variations over large areas of the sea floor.

The primary results of this project are the following: (1) Off Costa Rica, we can demonstrate that the subducting plate fabric actually has little influence on the subduction and accretion processes; (2) Examination of the region off Guatemala, where erosion is postulated on the lower slope, the bathymetric trace of the deformation front is linear and at an angle to oceanic plate fabric. If erosion occurs at the base of slope, the trace of the slope base should be indented where horst blocks are being subducted. Thus erosion may not be occurring, at least at this shallow level; (3) Further north, off Mexico, the trench contains more sediments and folds form in the trench floor associated with ramping of the decollement. The folds tend to parallel the underlying plate fabric but as they are accreted, they reoriented to the trend of the base of slope. This implies that the decollement may be locally directed by plate fabric or by physical properties in the sediments draped over the basement, but that the dominant convergence direction determines the gross trend of the trench.

- d) Silver, E. A., Ellis, M. J., Breen, N. A., Shipley, T. H., 1985, Comments on the growth of accretionary wedges, *Geology*, v. 13, pp. 6-9.
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Introduction

We are now able to image a class of convergent margins which have thick sedimentary deposits that are being slowly accreted to continental and island arcs such as the Nankai Trough, central Aleutians, and Sunda (Nasu et al., 1982; Aoki et al., 1982; Leggett et al., 1985; McCarthy and Scholl, 1985; Moore and Curray, 1980). Yet the developing structures on the inner slope show significant diversity. This diversity of structures either may indicate fundamental differences in external factors such as convergence rate and angle, sediment volume, and subducting plate roughness, or variations in the underlying material properties, which control mechanical response to stress. Trench lower slopes are zones of intense deformation because of the convergence and strain rates in sediments within this zone which are probably the greatest of any geologic environment. Most of the strain is limited to a very narrow zone close to the deformation front (J. C. Moore et al. 1982). Fluid pressures play an important role in reducing friction at the relatively shallow structural levels where the plates are sliding past each other. There is abundant evidence for rapid time and spatial variations in physical properties in this region. It is in this same region that offscraping and sediment subduction and tectonic erosion occur. A number of hypotheses have been developed to explain the variations in these lower slope processes as a function of sediment volume, sediment type, and roughness of the subducting plate. However, the underlying structural response is probably most dependent on the physical properties of the deforming rocks, a topic about which very little is known.

We propose to collect 20 high resolution expanding spread profiles (ESP's) and 550 km of high resolution MCS data in the Nankai Trough region of southwestern Japan (Figure 1). The ESP profiles will provide velocity-depth measurements suitable for detecting velocity discontinuities, reversals and gradients within the entire sedimentary section. The resulting velocity data will be inverted using iterative elastic waveform modeling of the large offset data to obtain critical estimates of porosity, density and fluid pressures across the margin. The MCS lines, after migration and depth conversion using the ESP data, will provide a psuedo-3D image of this area for detailed structural studies.

Convergent Margin Processes

Shallow Structural Levels

There are at least three possible results of convergence at shallow structural levels: sediment offscraping (accretion), sediment subduction, and tectonic (subduction) erosion. Sediment offscraping often occurs concurrently with sediment subduction where only part of the sediment on the subducting plate is accreted (Karig, 1974; J. C. Moore, 1975). This is a process by which sediments are imbricated above the main decollement in thrust bounded packets. The offscraped material is usually the upper portion of the sediments filling the trench. The rest is carried beneath the lower slope to deeper levels where it is either underplated or continues to greater depths and is structurally removed from upper crustal levels (Scholl et al., 1980; Watkins, et al., 1981). Excellent data from the Nankai Trough (Aoki et al., 1982; Karig et al., 1983) and Barbados Trench

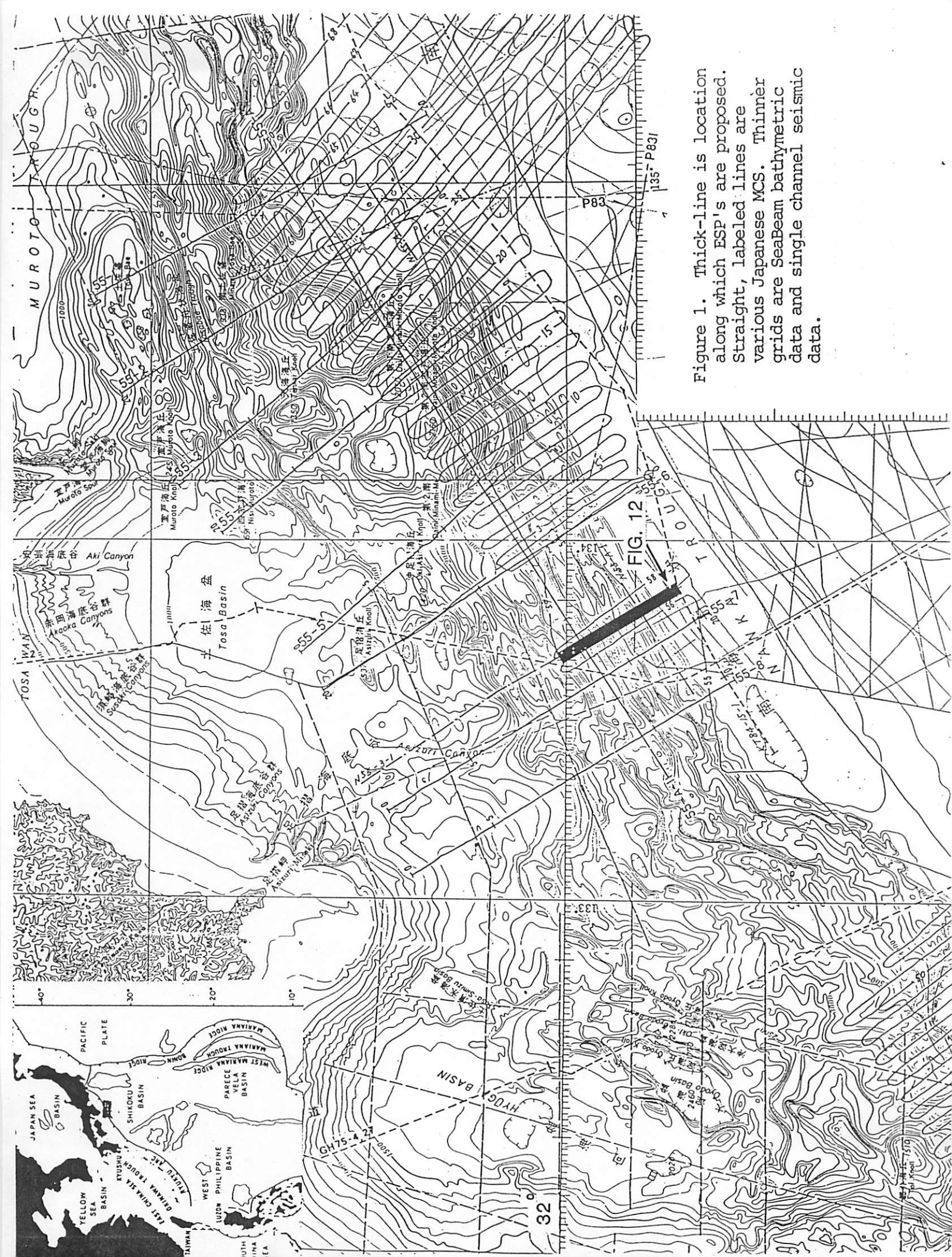


Figure 1. Thick-line is location along which ESP's are proposed. Straight, labeled lines are various Japanese MCS. Thinner grids are SeaBeam bathymetric data and single channel seismic data.

(J. C. Moore et al., 1982; Westbrook and Smith, 1983) attest to the dual offscraping and subduction processes.

It is probable that variations in the physical properties control the mechanical state and the style of deformation at convergent margins, but these variations are virtually unknown. Porosity, permeability, pore pressure, and sediment strength are partially coupled variables of importance. Strength of the material is the most immediate factor, but itself depends upon pore pressure, porosity, lithology and state of strain (at least in the highly porous sediments of accretionary prism toes). None of these factors, including the lithologies, is adequately known.

Deeper-Level Processes

The recognition that thickening of an accretionary prism must involve processes other than those operative near the foot of the slope was first clearly demonstrated from combined seismic reflection and DSDP results off Mexico. There the attitudes of landward dipping reflections reach high values within a few tens of kilometers of the trench, beyond which dips no longer increase (Shipley, 1982; J. C. Moore et al., 1982). Thus, underthrusting of wedge shaped packets of sediments cannot explain the uplift and thickening of prisms more than 10 to 20 kms from the trench axis.

One explanation is a model of an accretionary prism as a zone of large scale viscous flow. This idea was developed from experimental studies in which clay atop a moving plate was "accreted" to a vertical wall (Cowan and Silling, 1978). The kinematic pattern observed provided insight into possible megascale movement patterns by which blueschists are uplifted. Quantitative modeling of the effect of viscous flow in a wedge-shaped corner such as that likely off a convergent plate margin provides a possible explanation for generating the chaotically mixed, blueschist-bearing mud-matrix melange that comprises a large portion of the Franciscan complex of California and Oregon (Cloos, 1982).

Thickening and uplift of the wedge may also be modeled by the imbrication of thrust packages. One method is by the successive downramping of master thrusts or decollements which separate the accretionary wedge from subducting materials. Thickening of the wedge occurs by the underplating of thrust packages, and this process has been well documented in foreland fold and thrust belts (Boyer and Elliott, 1982; Suppe, 1983). Ramping of the decollement has been documented in submarine thrust systems also (Westbrook and Smith, 1983), but thus far the resolution of seismic data has been insufficient to clearly image duplex structure. Leggett et al. (1985) suggested that the Nankai margin may be interpreted as a growing duplex structure (Figure 2).

In the more conventional interpretations of accretionary structure by coherent thrusts and bedding planes, we would expect lithostatic fluid pressures only along the decollement and in the active thrusts near the toe of the wedge. We would not expect the landward dipping reflectors located farther upslope to show evidence of such abnormal overpressures. This limitation contrasts with that expected from the Cloos (1984) model, in which overpressures should occur on all landward dipping reflectors to cause observable reflections.

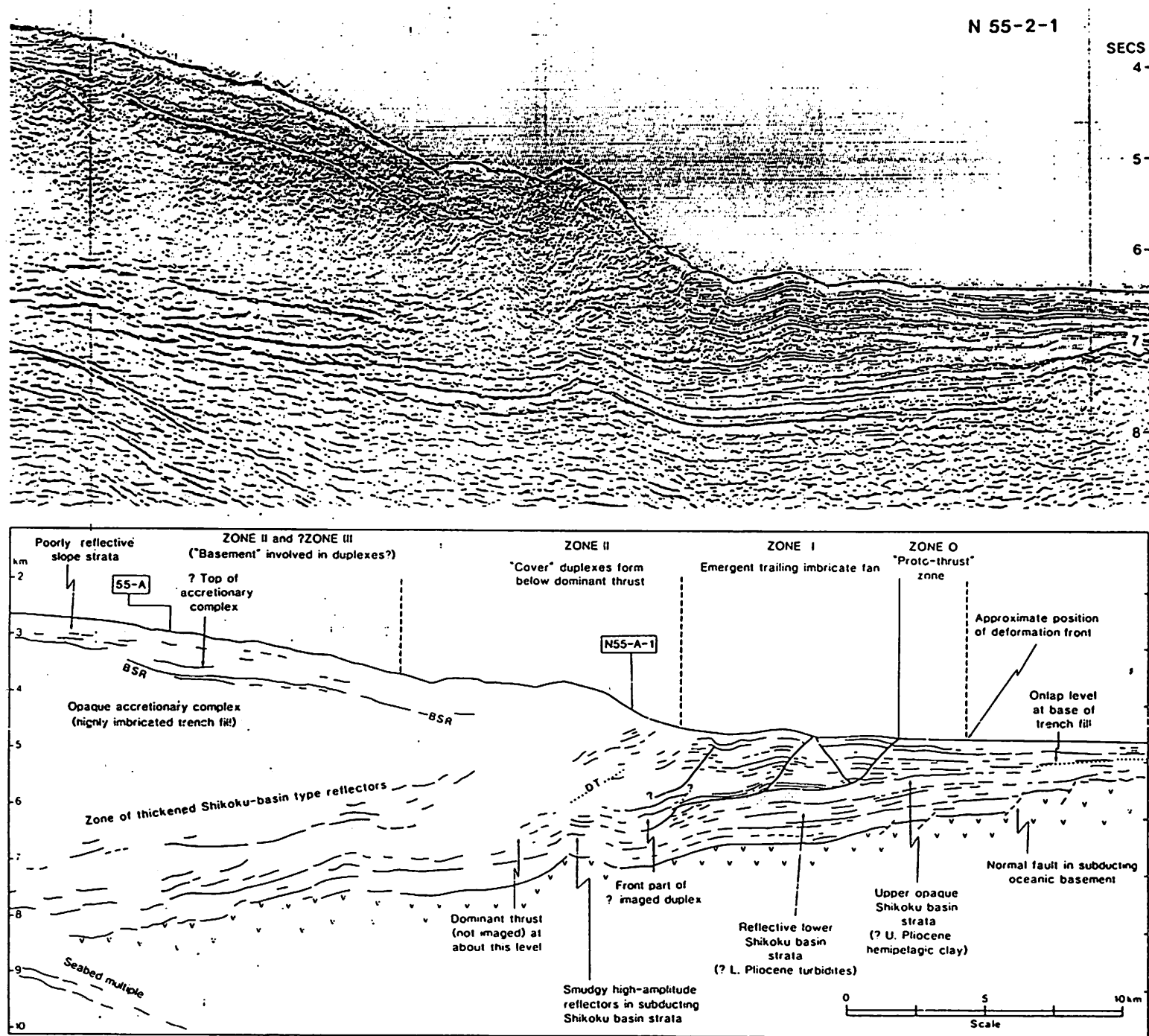


Figure 2. Migrated seismic section N55-2-1 and line drawing interpretation from Leggett et al. (1985). BSR is bottom simulating reflection associated with gas hydrates.

Observations of the Barbados accretionary wedge (J. C. Moore and Biju-Duval, 1984) showed measured lithostatic fluid pressures associated with an active listric thrust near the toe of the wedge (site 542) and inferred (from structural effects) high fluid pressure at the decollement in site 541, but no abnormal pressures on a listric (or out of sequence) thrust in site 541 upslope from the toe. The latter thrust, however, did not form a prominent reflector.

Critical Significance of Lower Slope Regions

The lower trench slope is a zone of maximum gradients in instantaneous shortening, in porosity, and probably in other physical properties that control mechanical state. The distribution of instantaneous shortening (as opposed to cumulative shortening) clearly is strongly skewed toward the toe of the accretionary prism (Karig et al., 1979; J. C. Moore et al., 1982). More quantitative estimates across the well-constrained Nankai lower slope indicate that 75% of instantaneous shortening occurs within 15 km of the toe. A large part of this concentration of shortening can be explained by the Davis et al. (1983) constant slope wedge, but, as reflected in convex upward toes of accretionary prisms, deformation is even more strongly concentrated than the model predicts, implying a landward increase in strength of accreted material.

Most workers agree that this increase in strength reflects the state of pore fluids in the sediments, but agreement ends there. The dominating effect could be porosity, acting to control cohesion and/or internal friction, or it could be more through pore pressure acting to control effective stresses.

Porosity decreases and water losses across the toe are still very poorly known, with highly divergent viewpoints. Carson et al. (1974) used dredge samples to suggest a rapid landward decrease in porosity across the Cascade prism toe, a conclusion echoed by Fowler et al. (1985) across the Makran arc using porosity data derived from seismic velocities. A much more modest arcward decrease in porosity was observed in drill sites across the Lesser Antilles slope (J. C. Moore and Biju-Duval, 1984). The porosity across the Nankai toe was calibrated by 3 deep drill holes which also show a very modest arcward decrease in porosity at similar depths (Bray and Karig, 1985). These data were extended, with much less accuracy, using seismic velocity-porosity relations, to show a gradual upward convergence of porosity contours in this prism as well as in the Sunda arc (Bray and Karig, 1985).

Although porosity gradients change slowly, rapid tectonic thickening of the prism results in a large total water loss across the Nankai prism toe, primarily from the deeper levels (Bray and Karig, 1985). Thus the average porosity drops from 40% to 20% over the first 15 km of the prism. Data from Costa Rica suggest a 50% water expulsion from subducted sediments within 4 km of the deformation front (Shipley and Moore, 1986). A similarly rapid water loss from Shikoku basin sediments as they are loaded by the Nankai Trough fill (Bray and Karig, in press) attest to the possibility of rather rapid consolidation toward a "normal" porosity-depth relationship in some prisms.

The flow of water within lower slope prism is supported by observation of biologically active vents (Cascade prism toe, Kulm et al., 1986; Nankai and Japan toe, A. Taira and J. P. Cadet, personal communication), mud diapirs (Silver et al., 1986; Westbrook and Smith, 1983), and by abnormally high heat flow (Langseth and Burch, 1980; Yamano et al., 1982; Davis and Hussong, 1984). The fluids are methane rich and contain significant oversaturation of carbonates, producing local carbonate-cemented seafloor. These observations suggest rapid fluid flow out of the lower slope regions. However, the mode and exact location of fluid escape pathways is a critical unknown.

In the Nankai Trough, the first several thrust faults are seismically imaged, implying a strong impedance contrast, and indirectly, a strong porosity contrast within the fault zone. Aoki et al. (in press) interpret the fault reflection as having a reversed seismic phase and enhanced porosity (Figure 3), whereas Bray and Karig (1985) interpret the same data (and similar data elsewhere) as representing reduced porosity within the shear zone. Basically there is a question as to whether the thrusts are zones of high or low porosity, enhanced or reduced permeability, and increased or normal pore pressure. There is some geotechnical evidence for reduced porosity due to compactive shear, but water flow out these zones would indicate enhanced permeability. Reduced porosity could co-exist with increased fracture permeability, but water will flow into and along the faults only if there is a hydraulic gradient, which would imply reduced pore pressure in the fault zones. This in turn would lead to increased strength within the fault zone and complications in explaining continued motion on the fault. Clearly we must have better constraints on the physical properties and mechanical state of these faults.

The values and variations of pore pressure are equally tenuous. A number of examples where in-situ pore pressures approach lithostatic pressure have been cited (e.g., J. C. Moore and Biju-Duval, 1984), but variations among and within prisms remain totally hypothetical. Attribution of increased strengths to landward decrease in pore pressure (Suppe, 1983) is countered by the occurrence of mud diapirs and dilational veins in the more rearward sections of the accretionary prism.

Direct measurement of pore pressures will always be sparse and difficult to obtain, even in drill holes in prism toes, but such pressures can also be estimated indirectly if the distribution of porosity, stress levels, and consolidation characteristics of the sediment are known, through the geologic application of consolidation theory. An application of this approach was used by Bray to estimate pore pressures within the consolidating (compacting) Shikoku Basin clays beneath the Nankai Trough fill. The study suggested lambda values of .6 to .66 (only slightly above hydrostatic). A different indirect approach, using the stress state as manifested by the orientation of shear fractures and the estimated mechanical properties (Coulomb coefficient) of the deforming sediments within the Nankai toe led to a moderately elevated pore pressure estimate, with lambda about 0.75 (Karig, in press). The coupled porosity and solid mass flow trajectories in the Nankai prism led to a very rough idea of dewatering patterns (Bray and Karig, 1985), which could be greatly improved, even to include pore pressure estimates, when the porosity field was better constrained. Because we are basically dealing with a 2 phase continuum (water and grain mass), any data on field strength of either medium (e.g., temper-

ature distribution, solute composition) will help constrain the flow and pressure patterns.

It is clear that of all measurable parameters the most useful is porosity, which is linked to so many others. Furthermore, porosity values can be estimated by the empirical relationship between porosity and seismic velocity over a far greater range of depths than will ever be drilled. As hinted above, the problems are that 1) the velocity is also a function of lithology, which is often poorly known; and 2) seismic velocities in the prism are not highly resolved and the accuracy of stacking or migration velocities are often suspect. Our ESPs, tied to Leg 31 and 87 DSDP sites should produce the best data set from a subduction zone.

Velocity data from the Nankai Trough are also relevant to another problem. An interesting seismic feature common to many active margins is a BSR (bottom simulating reflection) which is associated with the base of the stability field of gas hydrates (Shipley et al., 1979; Daniels and Vidmar, 1982). The occurrence of the reflection has been used as a measure of thermal gradients in active margins (Shipley et al., 1979) and Yamano et al. (1982) used the BSR in the Nankai Trough to illustrate increased heat flow near the base of slope. They explained this heat flow distribution as a consequence of advection of warm waters up from deeper parts of the prism. The acoustic nature of the BSR and in particular both the vertical distribution of hydrates in the section are poorly known and do not agree with limited drilling results (e.g., Mathews and von Huene, 1985; Shipley et al., 1979). It has been suggested that the hydrate may act as a barrier to fluid flow and thus act as a cap rock which is a concern to open hole drilling. A number of questions could be addressed with this data set which may bear on safety issues for the drilling program. Particularly, what is the vertical distribution of hydrates, is it concentrated near the BSR, how thick of a zone is fully hydrated, are fluids or gas always trapped below the BSR if the reflection is present? Because of the influence of hydrates on the velocity of sediments, we should be able to resolve most of these questions.

Nankai Trough Relevant Data

To solve the problems related to fluid behavior in deforming sediment wedges, we need to obtain more precise and accurate seismic velocities over a wide area of these prisms and we also need to study prisms in which the distribution of deformation and lithologies are relatively well known. The toe of the Barbados Trench has been investigated by drilling, MCS and COP work (Ladd et al., 1986). While these data are in an early stage of analysis (see abstract by Ladd et al., 1986), the experimental design was directed at imaging the deep crustal structure of the prism using 5 km offset COP's with conventional air gun and streamer group spacings. Their objective is to characterize the gross structure and average porosity gradients across the entire prism. In the Barbados drilling transect, where the most is known about the lithologies, the accreted sediments are predominantly calcareous pelagic (up to 30-40% carbonate) and hemipelagic sediments. Accretionary margins with dominantly terrigenous clastic lithologies are more common (e.g., Nankai, Oregon-Washington, Aleutians, Sunda), and terrigenous sediments will respond differently to deformation than calcareous sediments. The Barbados work will therefore characterize

the response to convergence of a different lithology, and the results will be complemented by our proposed study. In addition, our proposed work will be at a smaller scale, with greater resolution at the toe of the slope than the Barbados work.

We believe the Nankai prism is the best setting in which to study porosity, pore pressure distribution and specific pathways of fluid migration. It has a relatively simple 2-dimensional geometry, with extremely well imaged structures, including the enigmatic frontal thrusts. The distribution of lithologies is well understood from two drilling legs and there is a better data base of physical properties for this prism than any other. The data base also includes detailed (seabeam) bathymetry, submersible observations, and extensive heat flow data. These data are all from shallow levels of the prism, but will aid immeasurably in extrapolation to depth. We propose to exploit high resolution velocity data to derive estimates of the state of physical properties and their change across the critical zone within 50 km of the deformation front in the Nankai Trough.

Figure 1 illustrates the underway geophysical data in the region. Heavy lines are the multichannel seismic lines collected by Japan. The lighter pattern of continuous grid-like data are Sea Beam bathymetric lines. These data have been extensively studied and the results published in both the Japanese and English literature. The most comprehensive, but general, study of the MCS data was made by Leggett et al. (1985) in which they examined shallow structure as well as the regional setting of this area. Of particular importance is the demonstration of the two-dimensionality of lower slope features in the region of N55-3 (Figure 1). They also found evidence for significant amounts of shallow-level(?) extensional tectonic features in the NW and speculate on the fate of the subducted Shikoku Basin sediments. They proposed that an underplating process thickens these sediments, by duplexing within 10 to 25 km of the trench and that slightly farther back this duplexing may even involve basement (Figure 2).

Some geophysical evidence derived from the existing MCS data have been analyzed for evidence of a low velocity zone in the subducting unit beneath the decollement (Aoki et al., in press). These data suggest a possible velocity inversion beneath the decollement from about 2700-2850 m/s above to 2210/2630 m/s below. These analyses were based on conventional MCS techniques and give a gross indication of velocity structure, but suffer from small aperture and from the complicated geometry normal to the line shooting direction. These data yield statistically useful data which suggest the likelihood of an overpressured zone at depth, but are not at the scale necessary to clearly confirm the present status of the physical properties (Figure 3). A study of the phase along a reflecting fault zone indicates a reversal in phase, possibly related to a low velocity-density zone on one of the splays that ramp up to the surface (Aoki et al., in press).

Bray and Karig (1985) exploited the DSDP drilling results (Legs 31 and 87) and existing velocity control to examine the porosity structure and discuss possible dewatering pathways of the Nankai margin (Figure 4). They examined the dewatering processes in terms of mass trajectories as sediments enter the margin. This provides a method to consider the mechanical

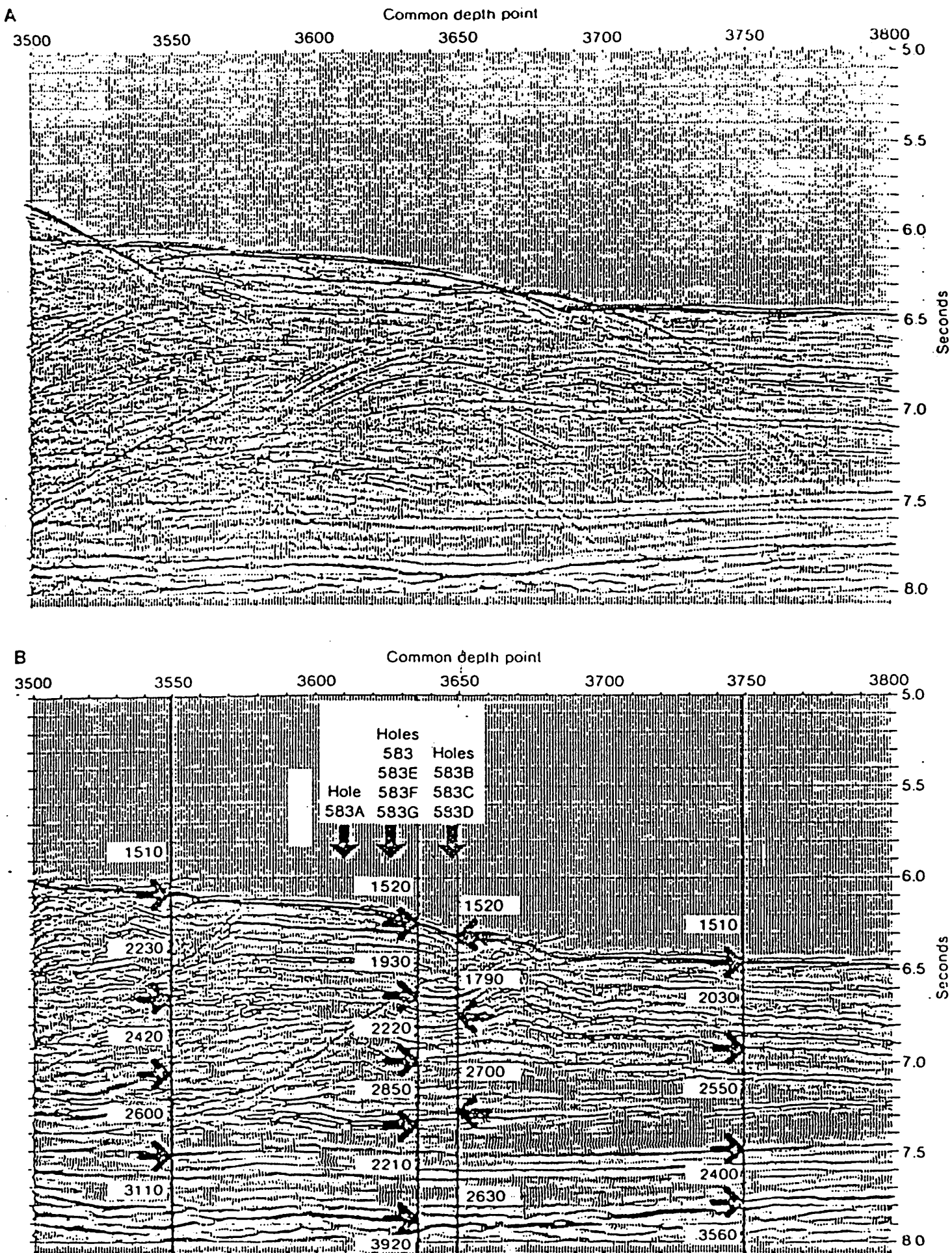


Figure 3. Unmigrated (A) and migrated (B) seismic profile N55-3-1 (see Figure 1 for location). Seismic reflection derived interval velocities are shown (from Aoki et al., in press).

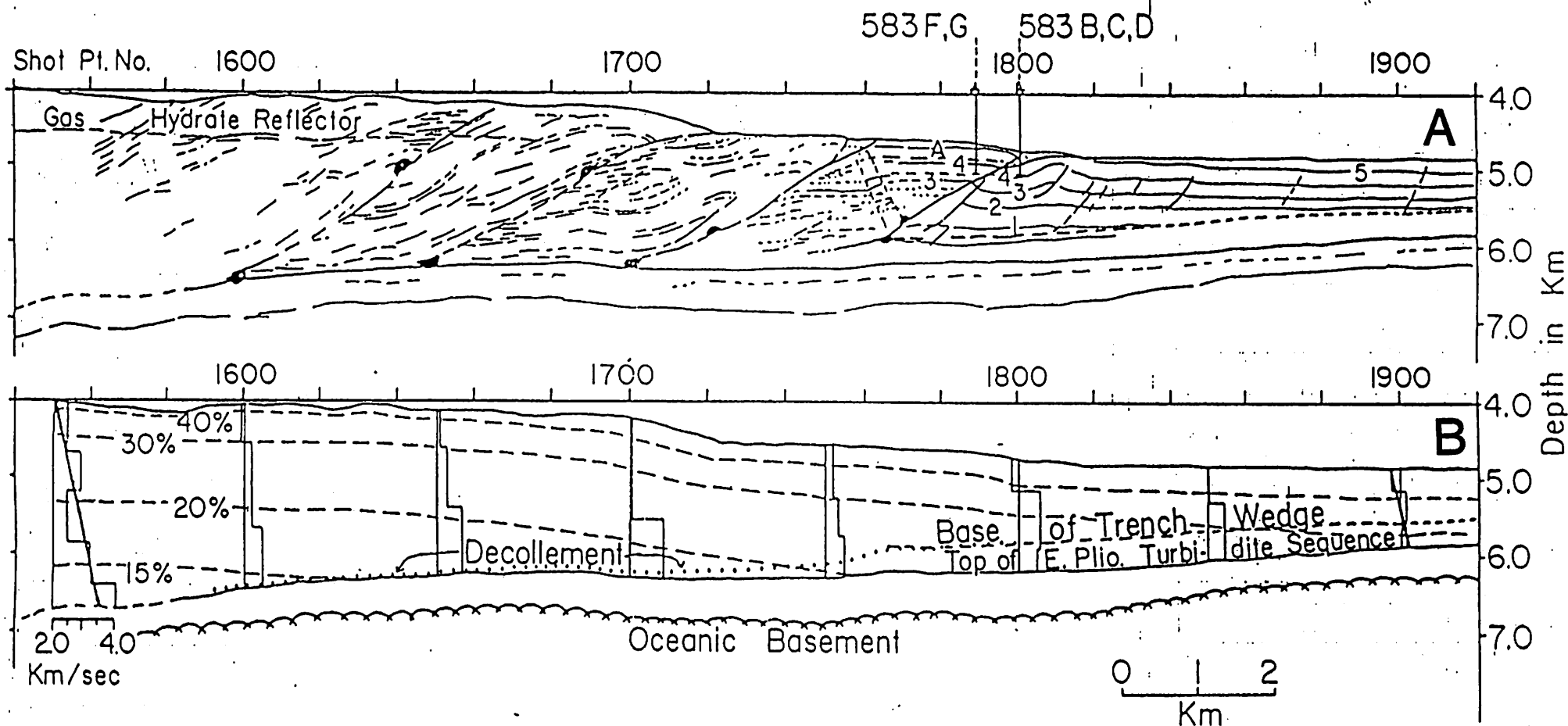


Figure 4. A. Interpretive depth section across the toe of the Nankai accretionary prism, from seismic profile 55-3-1 (Nasu et al., 1982). The displaced half circles represent estimates of offset along major thrust faults. B. Interval velocities (from Nasu et al., 1982); linear velocity gradients, derived from interval velocities, refraction velocities (Yoshii et al., 1973), and drilling results; and porosities, converted from velocities using relationships of Hamilton (1978), across the prism toe. (From Karig, in press.)

response to a 'trajectory' any given portion of the margin may take (e.g., subducted, offscraped, underplated). They believe that dewatering occurs in both a diffuse manner as well as along shear zones. They believe the sediments along the basal decollement should be strongly dewatered, and in general, that there are not high-water content sediments deep within the prism as suggested by von Huene and Lee (1983) and Cloos and Shreve (1984) due to the efficiency of shear dewatering.

Proposed Research

We propose to use an expanding spread profile (ESP) technique in the Nankai Trough to define the physical property variations and their relationship to deformation and subduction processes. The ESP technique will provide high resolution velocity information by incorporating high temporal and spatial frequencies with an adequate receiving aperture (Stoffa and Buhl, 1979). A detailed knowledge of seismic traveltime trajectories will allow inferences to be made about material propagation velocity and the physical properties. To derive interval velocities from homogeneous and gradient layers, it is desirable to record both pre-critical reflections and post-critical reflections and refractions. Because of the usually great depth of water in trenches, this requires a long surface receiving aperture or moving both source and receiver to the seafloor. Although it is possible to acquire wide angle reflection/refraction data at the surface on a continuous basis (Buhl et al., 1982, NAT study group, 1985), point measurements that derive detailed information at only one geographic location are often adequate. Constant offset profiles (COP's) are not appropriate if we desire very detailed velocities in complex tectonic environments. While the effects of ray-path variations through complex structure can be approximated during modeling, the structure cannot be completely compensated for when there are near offset gaps. Spatially focused Common Mid Point ESP's, on the other hand, can greatly simplify the geometry corrections necessary in complex structural settings (Diebold and Stoffa, 1981; Stoffa, 1985). We will describe the field program and address the problems of spatial aliasing, resolution and data processing procedures in later sections.

Specific Objectives

Accurate characterization of the deformational processes and history within the lower slope regions of active convergent margins requires a detailed knowledge of sediment physical properties such as seismic velocity, porosity, density, water content and fluid pressures. Proper structural interpretations can only be made on seismic sections that have been converted from time to depth using accurate seismic velocities.

Our overall objectives are to obtain: (1) estimates of the in situ sediment physical properties across the toe of the Nankai Trough inner slope; and (2) a three-dimensional picture of this region for detailed structural analysis. These objectives will be attained by collecting a series of vertical velocity profiles and high-resolution seismic reflection lines across this region. The velocity data will be inverted to obtain estimates of porosity, density, water content and fluid pressure, and will be used to convert the seismic grid to depth. Analysis of these data will allow a measure of the link between mechanical properties, physical proper-

ties, and deformational processes with increasing cumulative strain.

In order to accomplish the overall objectives listed above, the following detailed objectives must be attained:

A. Characterization of the physical properties in cross section across the Nankai Trough lower slope.

- define the compaction/dewatering trajectories within the subducting/accreting seismic-stratigraphic units
- track 'input' volumes beginning from the location of the first ESP 5 km seaward of Site 582

B. Determine the location of fluid flow zones and their sources.

- determine whether fault reflections and polarities are consistent with fluid flow. Determine whether porosities in the zones are high or low.
- define the variation in reflectivity/polarity/velocity along the fault zone.
- determine whether the thrust ramps track back to the seismic decollement.
- define the relationship between reflectivity and source.
- examine the fault zones for incidence of high pore pressure.

C. Investigate the nature of the decollement and subducted sediments.

- determine whether the zone is of high or low porosity and determine how porosity varies along its seismically imaged length.
- track the subducting Shikoku basin sediments to determine if they are being thickened at depth.
- examine evidence for elevated fluid pressures, determine the thickness of these zones and their lateral extent and possible stratigraphic control.

D. Investigate the nature of the gas-hydrate reflection.

- define the vertical concentration gradient.
- determine if gas hydrates are concentrated only near the BSR.
- examine evidence for fluid trapping beneath the BSR.
- estimate the drilling safety problems associated with the BSR.

Methods

Conventional Velocity Estimates. Conventional MCS surface seismic acquisition methods are not adequate for our high resolution purposes. Some other alternatives are possible but we believe the ESP technique is superior. For instance, it would be desirable to employ a deeply towed source and a deeply towed multichannel receiving array, but one is not currently available with the appropriate source bandwidth and power. NORDA is developing a deeply towed multichannel reflection system for use in mapping the upper 500 m of sediments. Although the potential is promising (see Fagot et al., 1983), this system's low source level and narrow bandwidth limits its usefulness to our problem. Ocean bottom receivers (OBS and OBH instruments) are another alternative since they offer the distinct advan-

tage of a fixed receiver location (Dao and Purdy, 1983; Purdy et al., 1985). However, many OBS's do not have appropriate system response at recording frequencies as high as 250 Hz. The biggest problem with OBS's are their limited recording capabilities at 1 ms sample rates. To achieve appropriate data density, we would require each OBS to record closely spaced shots out to at least 10 km. The amount of data storage required is beyond the capabilities of OBS's known to us.

The source-receiver offsets required for both surface and ocean-bottom instruments to sample adequately the sedimentary section is shown in Figure 5. This illustration is idealistic and does not take into account velocity discontinuities and velocity gradient reversals well known in sedimentary sections, but it is a useful guide in judging the aperture required for bottom and surface measurements. The ray parameter versus range plots indicate the offset required to observe a turning ray from the gradient zone for different water depths. Events before a ray parameter of .285 sec/km (a velocity of 3.5 km/sec) are reflection contributions from the discontinuity under the gradient zone. In 4 km of water, a turning ray (refraction) from within the gradient zone with a velocity of 2.5 km/sec would be observed at source-receiver offsets of 10 km for the 1(km/sec)/km gradient. By moving only the receiver to the sea floor, we remove only one part of the water column travel path from the ranges required to observe this event. In this example, we would reduce the offsets required for an OBS to about 7 km, only a modest improvement. A surface ESP which acquires data with a source-receiver offset to about 10 km will observe most of the refraction events we require from within the sedimentary gradient zone. However, we propose to collect data to 20 km range to assure observation of all arrivals.

High Resolution ESP's. We believe that surface wide angle reflection/refraction ESP measurements can solve the problem of velocity-depth resolution for sedimentary sequences in the deep water. At the same time the high resolution data set will provide significant estimates within the sedimentary section of reflection coefficients and attenuation as a function of offset and angle of incidence. Also, commonly observed converted shear waves may be exploited to estimate significant properties of the sediments, including Poisson's ratio, which should allow a more quantitative evaluation of porosity, density and potentially fluid pressures.

ESP measurements have proved useful in deriving detailed crustal velocity-depth structures; see, for example Stoffa and Buhl (1979), Mutter et al (1983), NAT Study Group (1985), Diebold and Stoffa (1981). Previously, these profiles were obtained with low frequency sources (air guns or explosives) designed to observe deep arrivals using receiving arrays with conventional group spacings. The pass band for faithful recording was 6 to 60 Hz. We propose to scale this type of seismic measurement appropriately to the problem of deriving detailed velocity depth measurements for the sediments overlying oceanic basement in deep water areas.

First, we will replace the low frequency source with two 400 cubic inch water guns. According to Hutchinson's (1984) far-field source comparison, the 400 cubic inch water gun is approximately equivalent in total energy to a 530 cubic inch Bolt 1500c air gun fitted with a wave shape kit. Is there enough energy to be observed at 15 to 20 km? The 400 cubic inch gun has been used successfully in a JOI site survey off the U.S. east coast

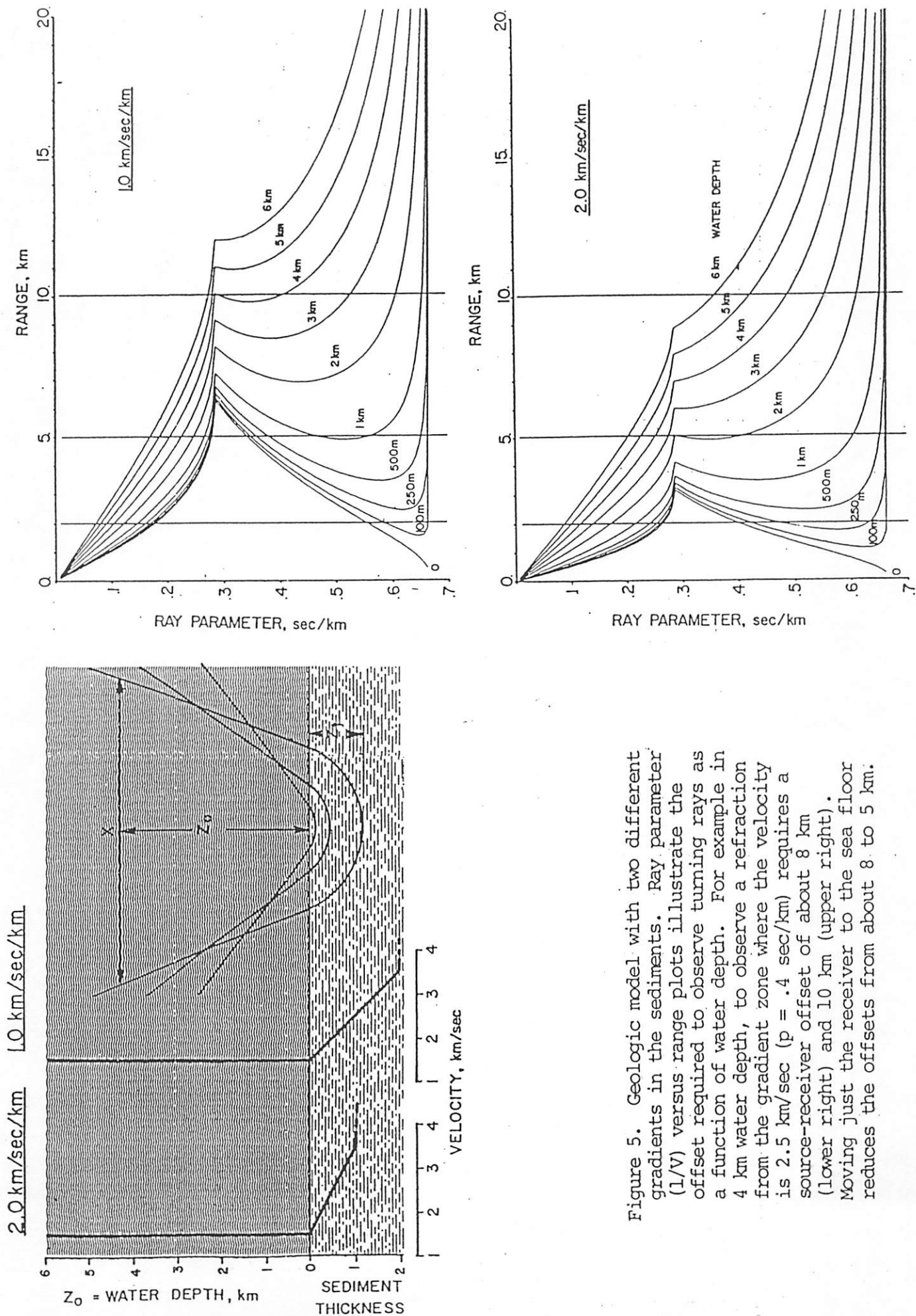


Figure 5. Geologic model with two different gradients in the sediments. Ray parameter ($1/V$) versus range plots illustrate the offset required to observe turning rays as a function of water depth. For example in 4 km water depth, to observe a refraction from the gradient zone where the velocity is 2.5 km/sec ($p = .4 \text{ sec/km}$) requires a source-receiver offset of about 8 km (lower right) and 10 km (upper right). Moving just the receiver to the sea floor reduces the offsets from about 8 to 5 km.

in shooting to sonobuoys. Two smaller 80 cubic inch water guns shooting to a sonobuoy recorded significant reflection and refraction energy out to the limit of the recording range of 10 km in water depths of 5,500 m, which is deeper than the Nankai Trough (Figure 6a). Thus we expect that the source of two 400 cubic inch water guns and 8-fold multiplicity of data will provide adequate signal levels. We will have air guns available as a back-up should they be required.

The bandwidth of the 400 cubic inch water guns is reported by Hutchinson (1984) to have -6 db points at 20 Hz and 120 Hz in the band recorded during the experiment of 8 to 128 Hz. Hutchinson (1984) also reports that about half of the energy is above 70 Hz. The manufacturer's specifications in the 0 to 500 Hz band indicate that the -6 db points are about 15 Hz and 220 Hz. Thus we believe this source has significant energy at least to 200 Hz. However, will the high frequencies exist 15 to 20 km from the source? Attenuation is difficult to measure reliably and/or predict, and most attempts to do so are unconvincing. Figure 6b is an example of ESP data collected as part of the North Atlantic Transect program. These data were acquired with a 2640 cubic inch tuned air gun array designed to optimize the 6-40 Hz seismic band. The data were digitized at 4 msec, so the anti-alias filter begins to fall off at 72 db per octave at 62.5 Hz. The active group length was 30 m. The display has been band-passed from 72-125 Hz well within the fall off region of the anti-alias filter. Reasonable high frequency signals still exist at offsets of 20 km in the display even for this array.

Second, we will employ a University of Texas surface multichannel array of 48, 12.5 m groups for a total length of 600 m. This will guarantee faithful recording (i.e., less than 10 dB of attenuation) for most post-critical seismic arrivals having angles of incidence less than 70° and frequencies less than about 100 Hz, (Figure 7). Frequencies out to 200 Hz will be preserved for pre-critical reflection arrivals whose angles of incidence are less than about 30° .

Spatial aliasing will occur for frequencies above 100 Hz and phase velocities less than 2.5 km/sec because of the 12.5 m group interval. Although this is an important design consideration, we do not consider it a serious limitation. It is true that all frequencies above 100 Hz will be aliased for phase velocities less than 2.5 km/sec using the 12.5 m group spacing. This is of little practical concern. It does not imply that frequencies above 100 Hz will be useless during data analysis. Figure 8 illustrates the aliasing phenomena for a 100 Hz sine wave and a phase velocity of 2.5 km/sec for the proposed group interval of 12.5 m. Clearly, the aliased phase velocities of .833 and -2.5 km/sec would not be interpreted as phase velocities of interest by a geophysicist familiar with sedimentary velocity structures and the fact that the arrivals being interpreted are reflections and/or refractions. On the top of Figure 8 is a 100 Hz wavelet superimposed on the same phase velocity event. This is obviously more typical of the data we expect to acquire than the data on the bottom. As the pulse becomes more broad-band in frequency, the time duration of the pulse will become shorter and the interpreters ability to "pick" the event because of the higher temporal resolution will improve.

The process of "picking" seismic traveltimes is inherently non-linear. Stoffa et al. (1981) showed how aliasing can be significantly reduced in

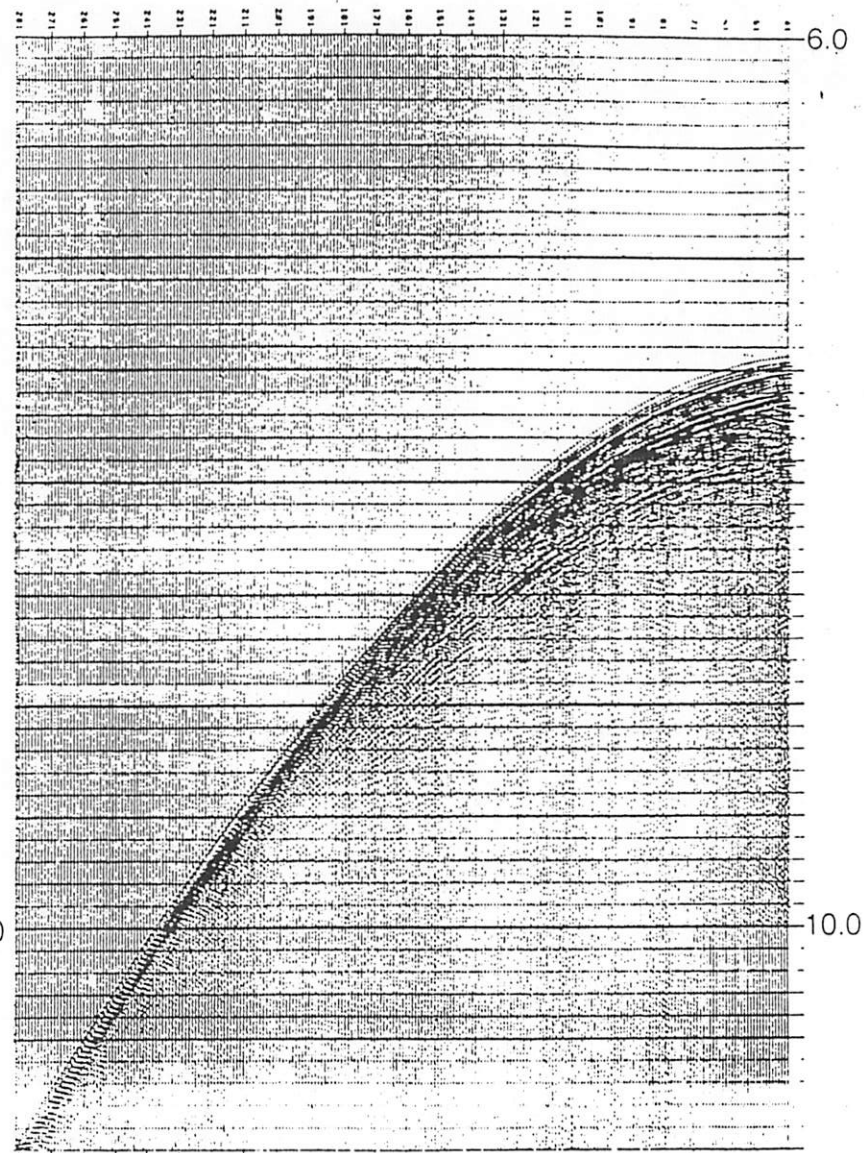


Figure 6a. Illustration of power of two 80 cubic inch water guns. This is example of data from a military sonobuoy with a total range of 10 km. Section on left was filtered 3 to 100 Hz, the right 30 to 100 Hz. No time-varying gain has been applied. Note bottom reflections on high frequency bandpass and refractor (5.6 km/s) in the low pass sections, respectively. Water depth is about 5500 m. Thus we expect a 400 cubic inch water gun should provide sufficient energy out to 20 km, particularly with the eight fold multiplicity of data we will record with 48-channel array.

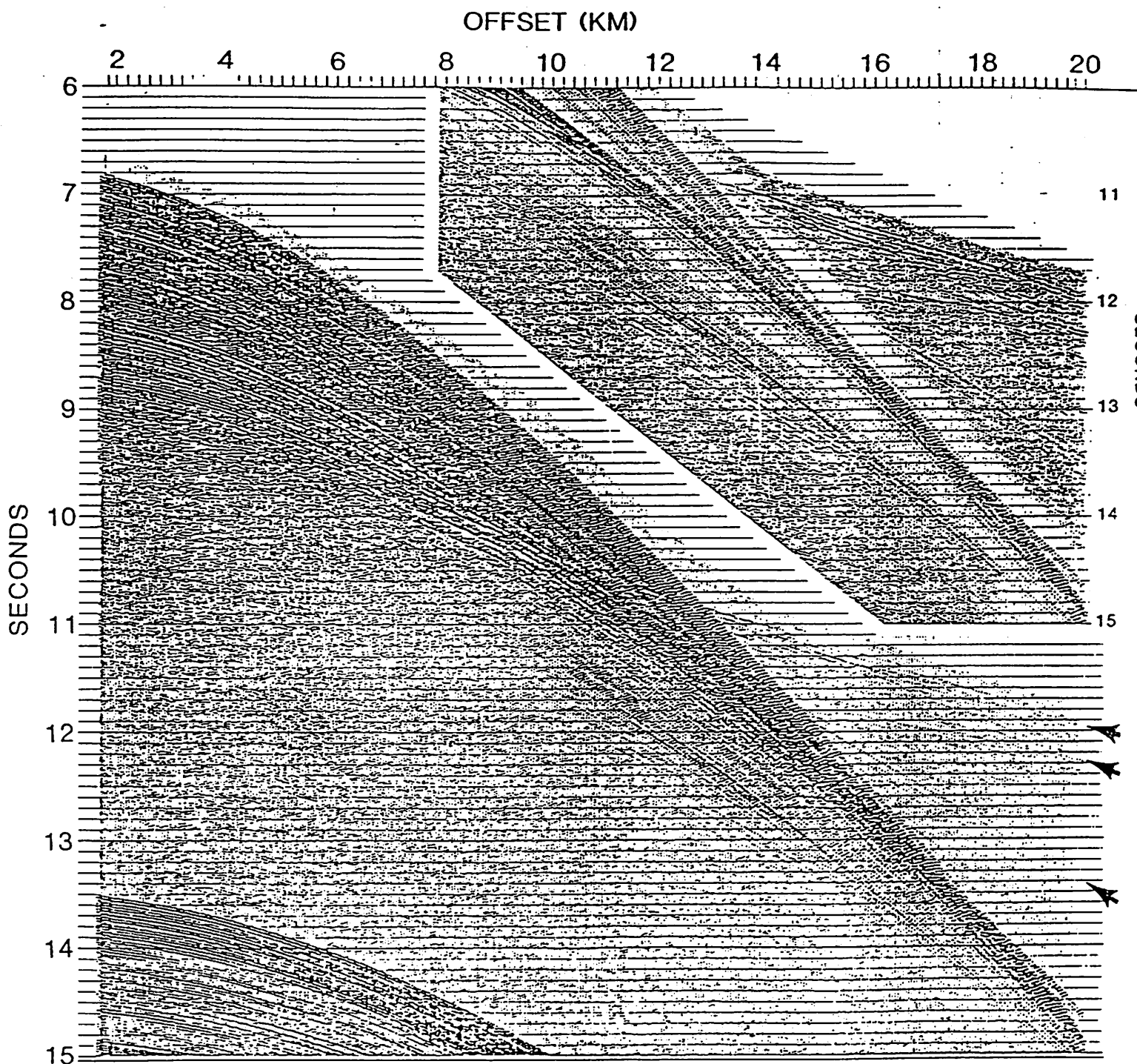
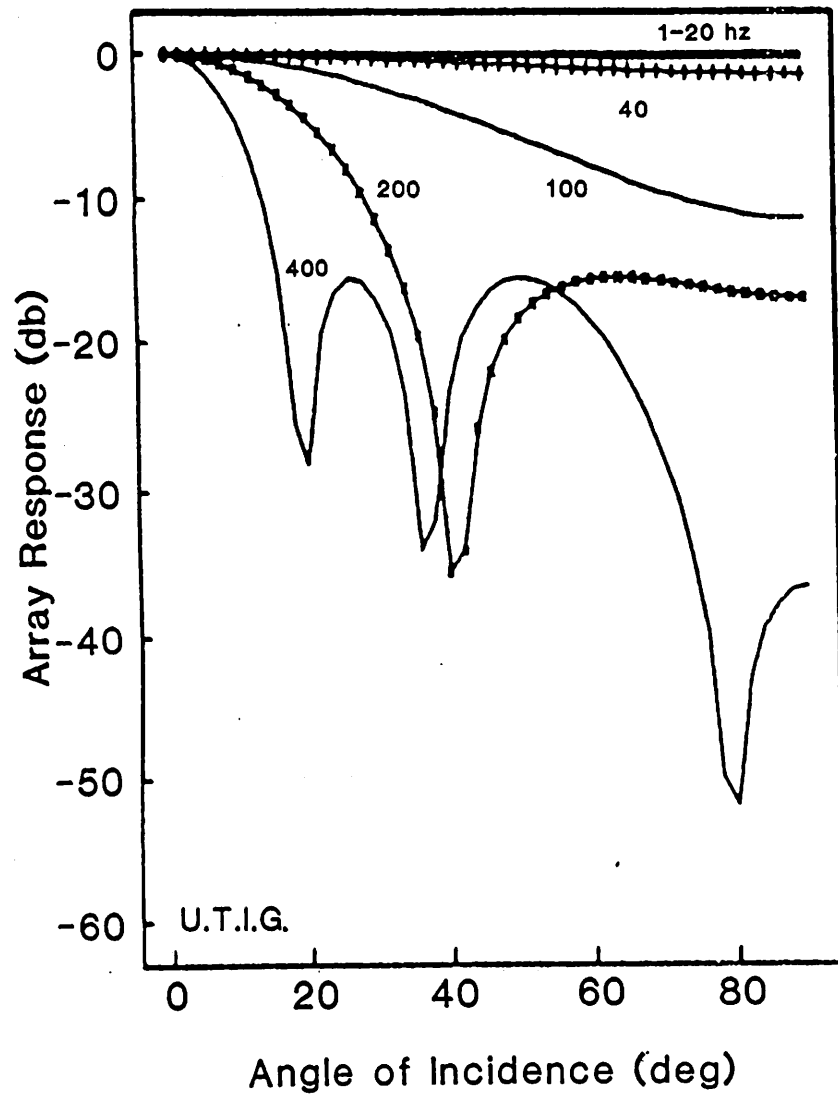


Figure 6b. Band pass filtered, 72-125 Hz, true amplitude display of an ESP collected during the NAT program with a tuned, 6-40 Hz, air gun array with anti-alias filters set at 62.5 Hz and with a 72 db per octave slope. Even in the band 72-125 Hz, significant arrivals (arrows) are observed out to 20 km range. This illustration implies that attenuation is not a limitation. Inset is close-up in the range 8 to 20 km with a one second window AGC. This illustrates that higher frequencies are observed at large ranges.

Angular Response of Seismic Array



Frequency Response of Seismic Array

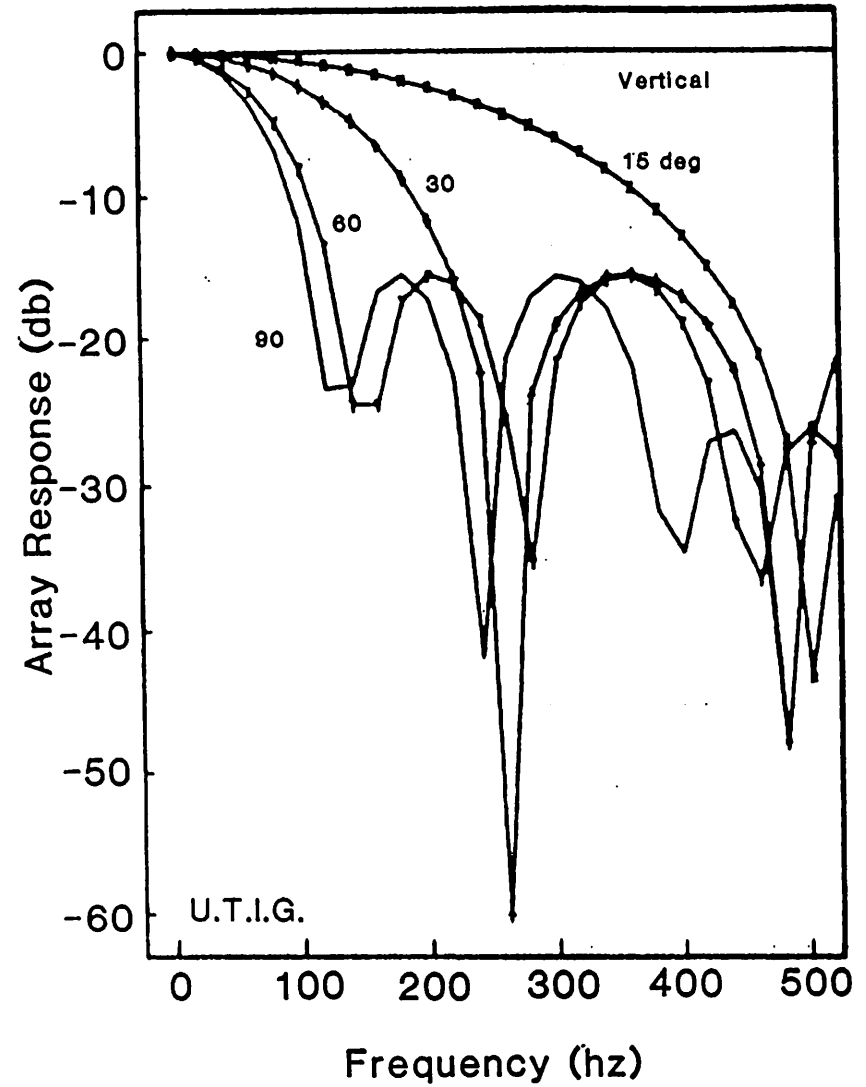


Figure 7. Array response of the UT 12.5m group interval streamer.

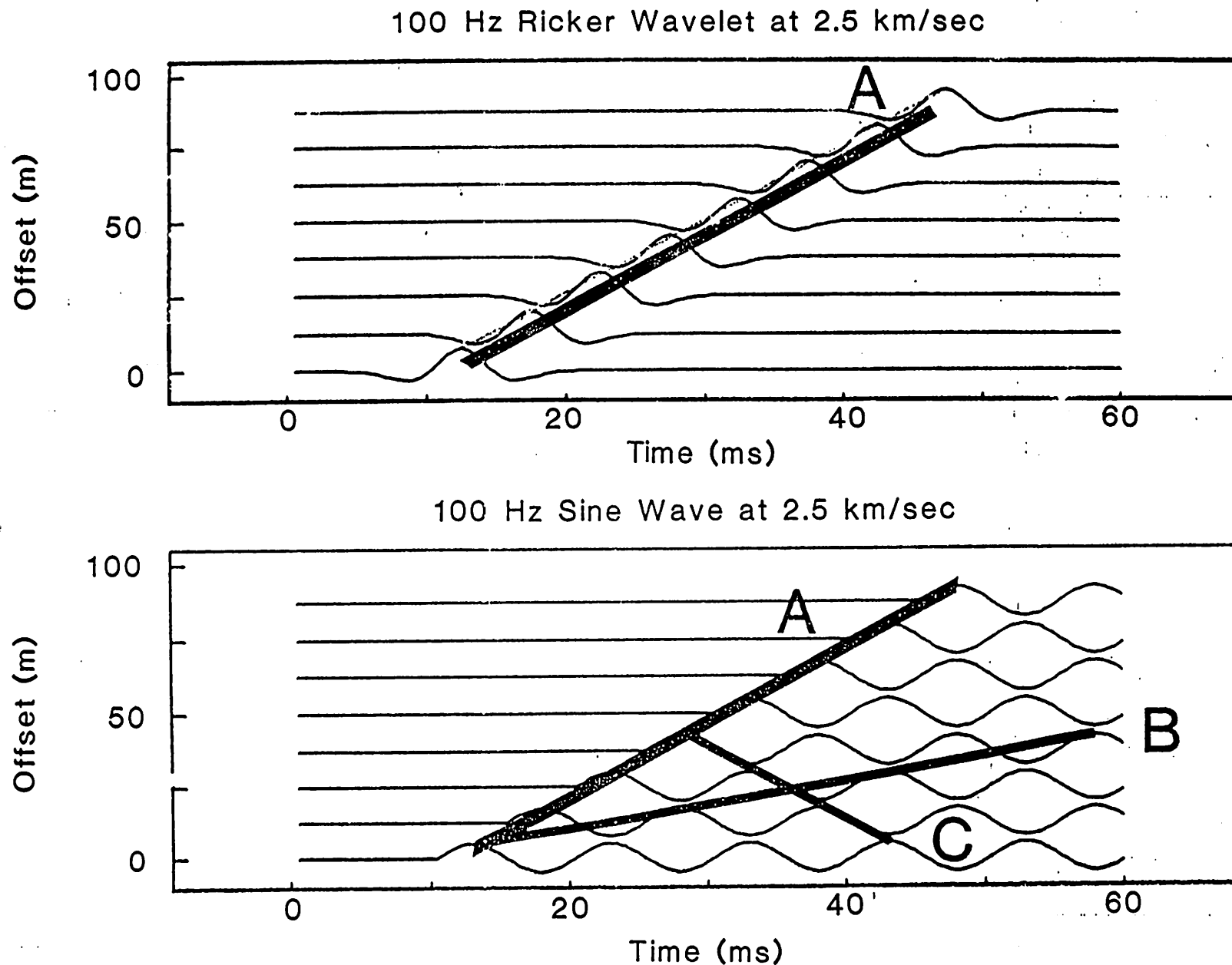


Figure 8. Spatial aliasing in a sinusoidal wavefield (lower), compared with the wavefield of typical seismograms (upper). The true velocity of 2.5 km/sec is marked "A". Two aliased velocities are marked "B" and "C" on the lower diagram; "B" = 0.833 km/sec, and "C" = -2.5 km/sec. Neither "B" nor "C" would have been interpreted mistakenly in any practical seismic situation. The upper diagram shows how the temporal resolution of the typical seismic wavelet leads to an unambiguous measure of the velocity.

the tau-p transform using a non-linear weighting based on semblance, a coherency measure. Stoffa et al. (1981) also showed that this process works well even where many reflection/refraction events cross over and severely interfere. In a theoretical study of elastic modelling, Wenzel et al. (1981) used this same non-linear technique of semblance weighting and were able to generate seismically accurate broadband 0-125 Hz seismic waveforms with a ray parameter sampling that was a factor of 8 coarser than required by theoretical calculations. Thus, in most interpretation applications, aliasing is not the practical limitation.

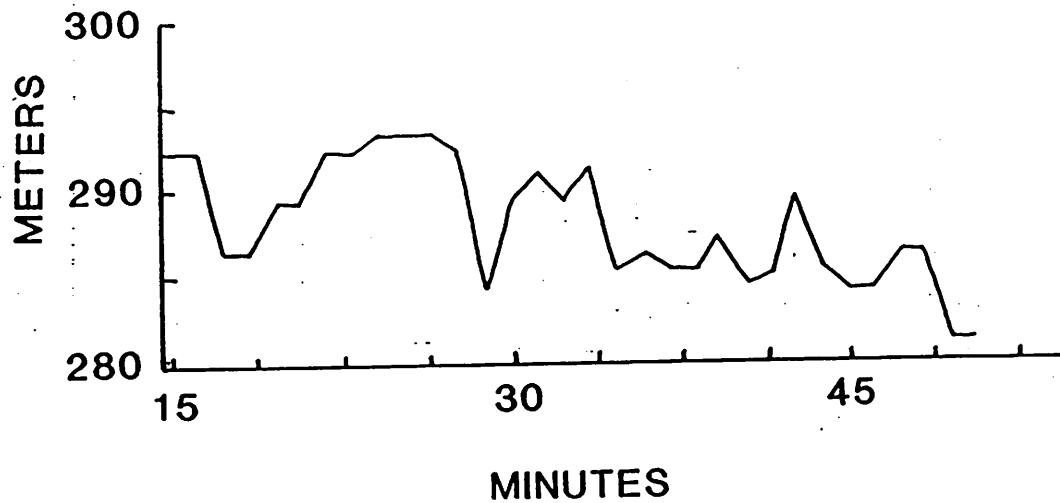
Third, we will use a range navigation system to provide accurate source-receiver distance measurements and either a GPS translocation system or Syledis-type shorebased navigation for common mid-point location. To illustrate the uncertainties in location, Figure 9 shows the type of shot to shot variability we experience in a Gulf of Mexico ESP program. The figure displays the changes in distance between shots. The 30 minutes of data displayed correspond to source-receiver offsets of 5 to 15 km. Although the mini-ranger derived distances between shots does vary, it does so relatively slowly with maximum variations of about 10 m between shots. The mean value is 287 m with standard deviation of 3.8 m indicating that the ships are able to maintain the required separation speed. If the ships were not able to maintain the common midpoint because they were unable to maintain a constant separation rate, we would expect a non-zero mean indicating a trend in the rate of separation. In this profile the mean is -.3 m with a standard deviation of 3 m indicating that the ships did nearly maintain a constant separation rate over this time interval. Of course, we are only evaluating the distance variability between ships. The geographic midpoint based on Loran C for this same example, varied 18 m along the track. We will use Syledis shore stations for absolute ship positioning to about 10 m. We are also considering a GPS translocation method which should provide 1 m accuracy in post-processing, but is limited to only part of each day.

Fourth, each ship will depart from the Common Mid Point at 4 kts. With a shot interval of about 18 seconds, a 600 m array and 8 kts (14.8 km/hour) total effective ship separation rate, we will acquire about 8 seismograms for each 12.5 m source-receiver offset (16 sec recording, 1 ms sample rate). The digital recording system has ample dynamic range and a recording sample rate of 1 ms guarantees that all frequencies less than 250 Hz will be recorded faithfully with no system attenuation (Appendix 1). Thus our goal of achieving a faithful high resolution digital representation of the seismic wavefield is nearly achieved.

We believe by employing the 400 cubic inch water gun source, a 1 ms sampling rate, and an active group length of 12.5 m, we should be able to generate and then record sufficient high frequency, high signal-to-noise seismic data to obtain the resolution and penetration we require. We will obtain:

- 1) Adequate source and system response for 6-250 Hz without significant attenuation for reflection events.
- 2) Adequate spatial sampling. The array employs 12.5 m active groups. Events with horizontal phase velocities of 2500 m/sec and greater will not be aliased below 100 Hz.

DISTANCE BETWEEN SHOTS



CHANGE OF DISTANCE BETWEEN SHOTS

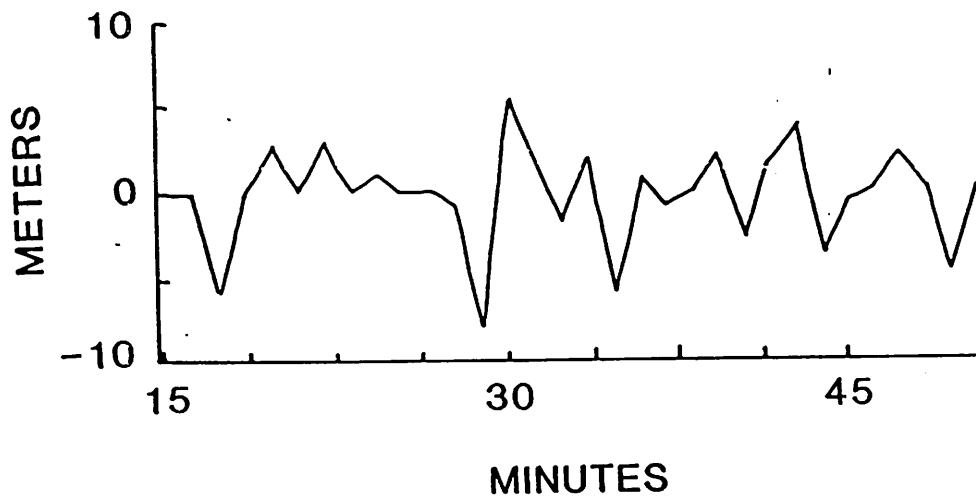


Figure 9. Top is a display of the distance between shots as derived from Miniranger during a recent two-ship ESP in the Gulf of Mexico. The time window shown corresponds to source-receiver offsets of 5 to 15 km. The change in the distance between shots for Miniranger data, lower. The shot-to-shot variability is less than 10 m and the mean value is small indicating that the ships were able to separate at a nearly identical rate maintaining the common mid-point.

- 3) Significant spatial redundancy for signal to noise enhancement. This will be useful during the tau-p transform when each individual seismogram will be combined. This data will not be binned (vertically stacked) as in previous lower frequency profiles. The resolution will be preserved by correcting each trace recorded with the proper time-shift during the transform.
- 4) Sufficient source-receiver offsets (20 km) for targets at depths less than 7 km. That is a 3 to 1 aperture to target depth ratio.

To fully utilize this system's performance, we prefer that the structure to be as simple as possible. Thus, careful site selection by evaluating the existing seismic and Sea Beam bathymetric data available will be required. If complications in structure are encountered, the redundancy of the source-receiver data acquired and the temporal bandwidth employed will make it possible to accurately exploit iterative forward travel time modeling analysis methods for 2-D structures.

Data Analyses Techniques and Resolution

As an example of the resolution required, we will consider the detection of an overpressured zone on the basis of resolution of the velocity structure in this zone. This zone would probably be relatively thin, on the order of 50 ms, requiring high temporal resolution to discriminate between reflections from the top and bottom of the zone. Also, sufficient source receiver offsets are needed so that adequate normal moveout will be available to discriminate between the possible velocities. The analysis methods will include transformation of the ESP data to the domain of intercept time and horizontal ray parameter using either the high frequency approximation for the Bessel function (Wenzel et al., 1982) or using the exact transformation (Tygel and Hubral, 1985). Either integral transform will maintain the original frequency content of the data with no attenuation of high frequencies, which is not the case for a simple slant stack. Once in the tau-p domain, the question of source-receiver offset and sufficient normal moveout can be rephrased in terms of the maximum ray parameters that will be observed for the tau-p reflection trajectories of interest. Simple ray tracing of the structure expected at DSDP site 583 indicates that ray parameters of at least .5 sec/km should be recorded in a typical ESP for the horizons of interest.

Since the analysis will be done directly in the tau-p domain, stacking velocities and/or RMS velocities do not need to be defined before deriving estimates of the interval velocity. Rather, using the method of Schultz (1982) and/or the tau-p normal moveout of Stoffa et al. (1981) the interval velocity can be directly determined by analysis of the vertical delay time differences in the tau-p trajectories. In our analysis of the ESP data, we will employ all of the standard tau-p velocity analysis methods to derive the overall velocity depth structure. But, because we are particularly interested in the velocity of a thin zone and its lateral variation, we will investigate an addition to the existing methods that will make it possible to accurately define the velocity of this zone independent of the overlying structure. As we describe this method, we will also illustrate the type of velocity resolution we expect for the field parameters we plan

to employ.

All tau-p velocity analysis methods are based on inverting the tau-p travel time equation:

$$\tau_n(p) = \sum_{j=1}^N \Delta\tau_j(o) (1-p^2 v_j^2)^{1/2} \quad (1)$$

to find the two-way normal times, $\Delta\tau_{oj}$, and the velocities v_j . All methods must proceed in a top down fashion, deriving first the overlying structure, and then removing the effect of this structure in the vertical delay time data for each ray parameter. In this manner, the individual vertical delay time contributions, $\Delta\tau_j(p)$, are successively isolated.

Shultz (1982) proposed that once the overlying structure was known, the effect of it could be removed by doing a tau-p normal moveout correction (Stoffa et al., 1981), and then finding the best fit single ellipse for the next reflection event using semblance or another coherency measure. Alternatively, it is also possible to 'pick' the upper reflection curve and then do a static shift to remove the effect of the overlying structure. The accuracy of either method is a trade between our knowledge of the overlying structure, tau-p normal moveout method, or our ability to pick the overlying reflection event. Our final velocity resolution of the underlying layer will depend critically on our ability to horizontally align this upper event so that the next reflection event will truly have an elliptical tau-p trajectory.

Basically, in either method, equation 1 is solved for $\Delta\tau_j(p)$:

$$\Delta\tau_j(p) = \tau_j(p) - \tau_{j-1}(p) = \Delta\tau_j(o) (1-p^2 v_j^2)^{1/2}$$

here, $\tau_j(p)$ are the reflection vertical delay times observed and $\tau_{j-1}(p)$ are the vertical delay times that are either predicted from the estimates of the velocity structure (tau-p normal moveout), or the times picked on the previous reflection event. In our case, for the detailed study of the thin zone, we propose to align the overlying event horizontally and do a trial and error computer search for $\Delta\tau_{oj}$ and v_j using semblance. Figure 10 illustrates schematically how the tau-p data would appear after the earlier reflection event has been perfectly aligned and for a reflection from a zone with a velocity of 1.6 km/sec and a two-way normal time of 50 ms. Ricker wavelets of 5, 10, 20 and 40 ms duration (peak frequencies of 160, 80, 40 and 20 Hz) are used to simulate variations in possible source wavelet resolution. Additive random noise of 50% (peak-to-peak) was also included. For our proposed field configuration, we would expect a source duration of about 10 ms or less.

Two problems need to be addressed. Is the temporal resolution and the tau-p moveout available sufficient to resolve the velocity of the 50 ms layer to a reasonable accuracy? Can we really align the upper event correctly so that timing errors are not introduced that will degrade the potential velocity resolution?

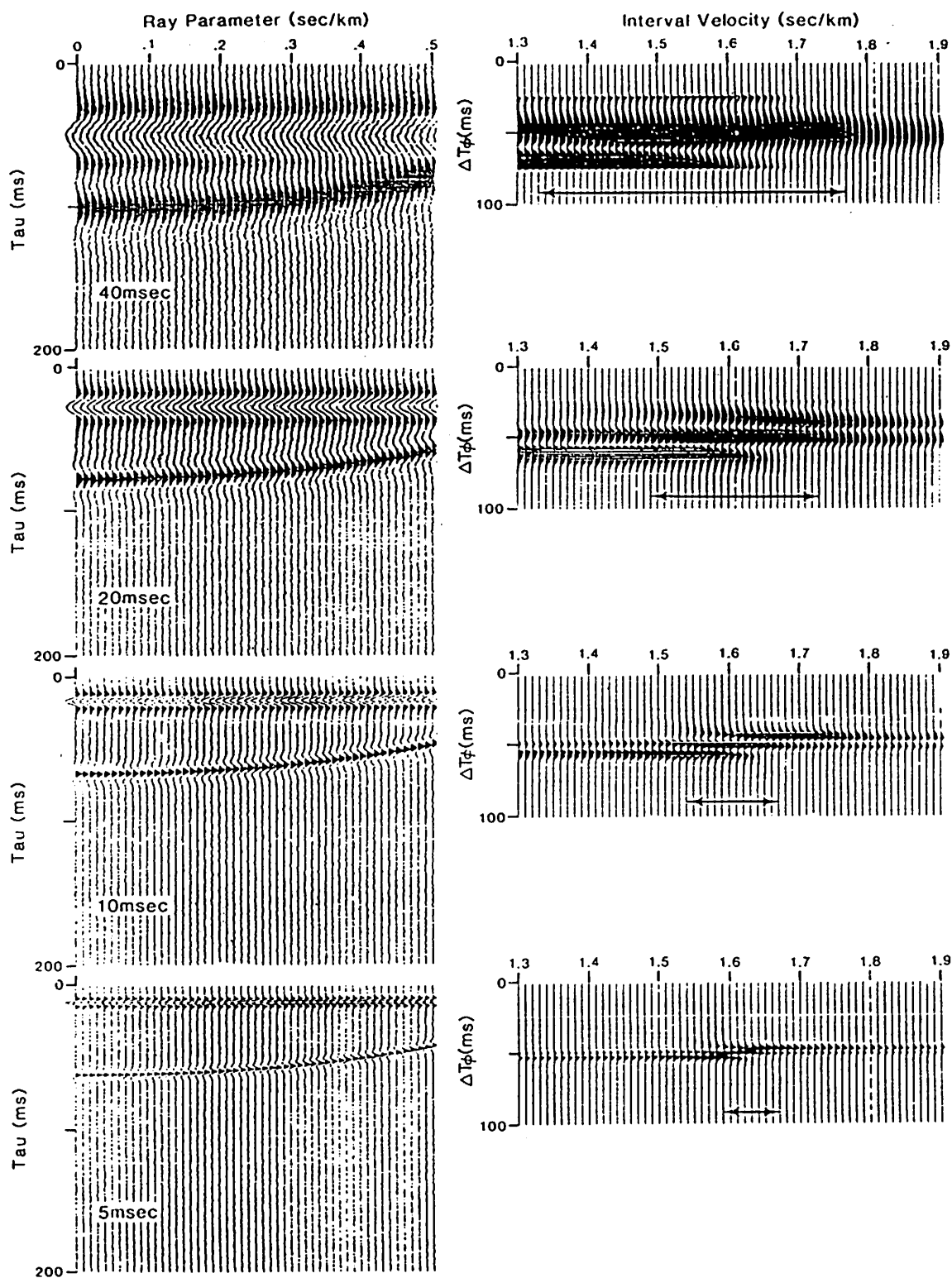


Figure 10. Tau-p data and semblance interval velocity scans for a 50 ms zone with a velocity of 1.6 km/s. The reflection from the top of the zone has been corrected so that it is horizontally aligned, i.e., there is no tau-p movement with increasing ray parameter. 40, 20, 10 and 5 ms Ricker source wavelets are shown and additive noise of 50% was used to simulate a real data situation. Because this analysis is done in tau-p directly, we can measure the interval velocity directly from the difference in the vertical delay times. In the semblance velocity scans, we see good interval velocity resolution for the 5, 10 and even 20 ms wavelet cases. The arrows on the velocity scan indicate the velocities where the semblance values are 80% of the maximum value. Half of this range, then represents a measure of the uncertainty. For example, for the 10 msec wavelet, the range is .13 km/sec indicating an uncertainty of ± 0.065 km/sec. (Although not clear in this display, the 80% level is easy to define by scanning the actual semblance data. Also, the choice of 80% is arbitrary, but clearly a 20% decrease in semblance is readily recognized.)

The first problem of theoretical velocity resolution for bandlimited, limited aperture data was addressed in detail by Stoffa et al. (1982). Here, we present a simple demonstration of the practical aspects of this problem. If the data are perfectly aligned and semblance is computed, the result would be similar to that shown in Figure 10. For the wavelets of 20 ms or less there is no problem in resolving the velocity of the event using as a limit the velocities where the semblance values are 80% of the maximum. This indicates a velocity resolution of ± 12 km/sec for the 20 ms wavelet. In the 10 ms wavelet case, the velocity resolution is .065 km/sec. This simple demonstration indicates that we should be able to derive the velocity information we require with sufficient accuracy (e.g. $\pm 5\%$) if we can horizontally align the reflection event above the zone of interest.

Rather than 'pick' the upper reflection, or rely on our knowledge of the overlying velocity structure to align the upper reflection, we will define a tau-p window that includes only the two reflection events we require. Next, we will compute the autocorrelation function of the windowed tau-p seismograms. Because we are really interested in only the differences between the reflection vertical delay times as a function of ray parameter, the autocorrelation is a natural choice. This is because each of the autocorrelation functions will contain an event at the lag, $\Delta\tau_j(p)$ associated with the difference between the upper and lower reflection events. Also, we have now automatically aligned the $\Delta\tau_j(p)$ data and removed any static time delays caused by the definition of the window, (see Figure 11). In actual practice, there will be other events in the data window such as multiples from the overlying layers. These should not present a problem because we will manually interpret the coherency data and the contributions due to other events will be ignored in the final interpretation. Figure 11 shows schematically an example of windowed tau-p data where static shifts and obvious errors in defining the window are present. A small residual elliptical normal moveout is also present in the overlying reflection event. Figure 11 (middle) shows the resulting autocorrelation functions. The reflection event for the second layer now appears as a contribution to the autocorrelation function at the lag of the interval vertical delay time between the two reflection events. Figure 11 (right) shows the semblance data obtained from analysis of the autocorrelation functions. It shows that the velocity is correctly recovered and that the resolution is comparable to that obtained using the original data when it is perfectly aligned.

In practice, we will use an interactive graphics terminal to display the original tau-p data. We can then carefully define our analysis window so that our upper reflection, or marker horizon, is the event against which all relative times will be measured by the autocorrelation function lags. Other functions, e.g., the even part of the complex cepstrum (Stoffa et al., 1974) can also be used and might further improve our temporal and hence velocity resolution. In any case, careful analysis of the tau-p data that is derived from each ESP should result in sufficient velocity resolution, i.e., $\leq 10\%$ to solve the problems posed.

After analysis of seismic travel times, we plan to refine our models using seismic amplitudes in both the X-T and tau-p domain (see Wenzel et al., 1982). This part of the study will be particularly important for gaining additional information on the material properties including in situ

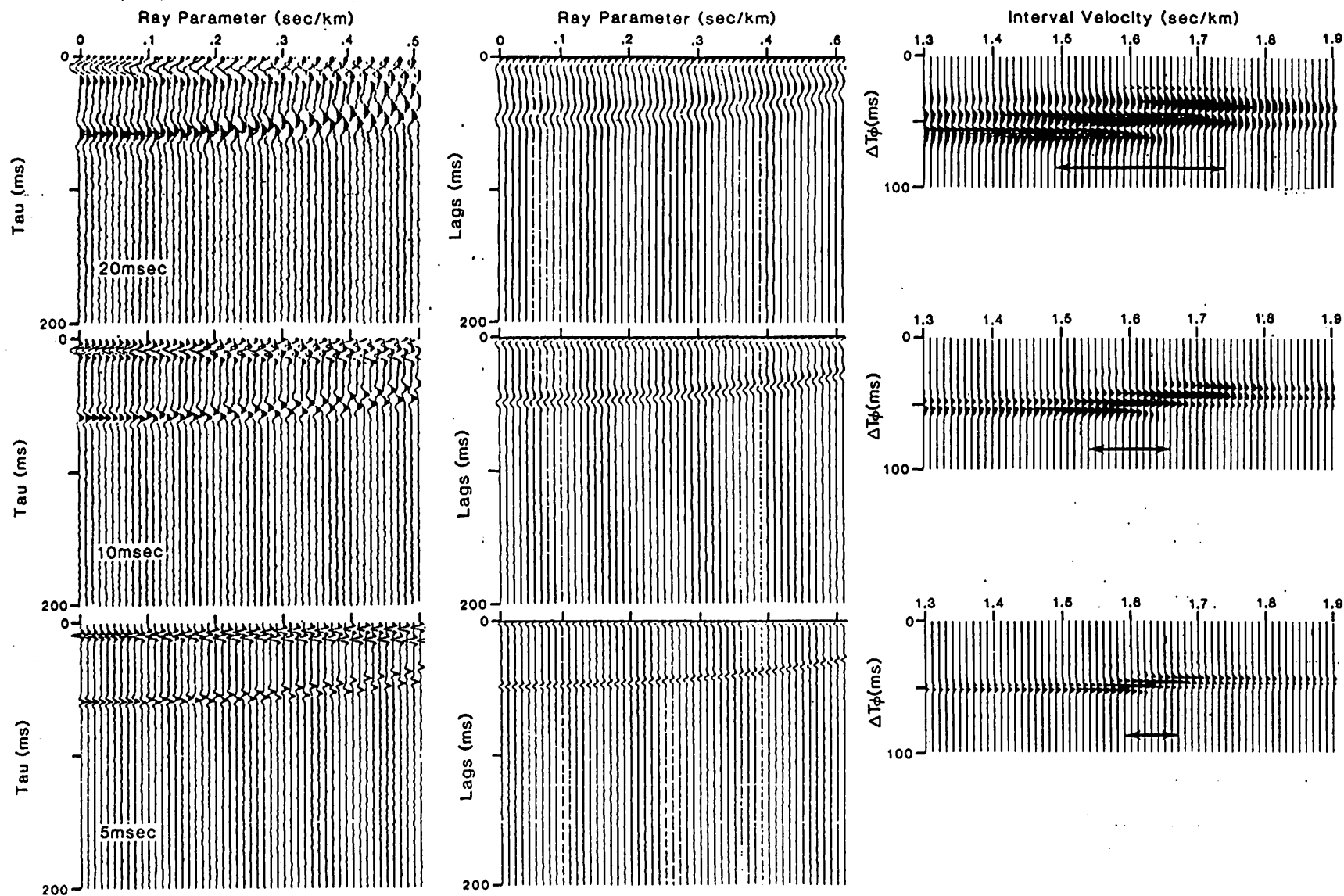


Figure 11. Left: Tau-p data with arbitrary time shifts and residual elliptical moveout. This data is used to illustrate that timing errors in the alignment of the tau-p reflection data can be eliminated by using the auto correlation function of the tau-p window which contains the two reflection events of interest. Since the autocorrelation function will have a peak at the lag associated with the time difference between the two reflection events, all the static absolute time errors are removed. Elliptical semblance interval velocity analysis (right) can now be used just as in the case of the original data where the upper event was horizontally aligned. The resulting interval velocity resolution is equivalent to that of Figure 10. In real data applications, care must be taken in defining the analysis window to guarantee that only two primary reflection events will be present. Of course, multiples from overlying layers may also be in the window, but these can be manually eliminated in the interpretation of the semblance data.

density and porosity by employing forward modeling techniques. Work already in progress at the University of Texas on elastic reflection amplitude variation with offset for two phase elastic media is being carried out with industry funding of project SEER under the supervision of Milo Backus. The results of that effort will greatly enhance our ability to refine our material property estimates using full waveform elastic modeling. This inversion approach is usually iterative and the computation time is long on conventional computers. Now the University of Texas has a Cray XMP which will make it possible to compute large numbers of trial models rapidly and at low cost. Also, access to this type of computation power make it possible to apply direct inversion methods based on offset dependent elastic waveform modeling. The resolution and redundancy of the data we plan to acquire coupled with 'inexpensive' access to a high speed super computer make it possible to consider implementing this type of inversion procedure.

The 48-channel MCS data will be routinely processed through 24-fold stack. We will use the far-field water gun source signature recorded during ESP work for wavelet processing of the MCS data. Velocity information from the ESPs will be used for migration and depth conversion.

Summary

Our experimental design should allow detection of even weak velocity gradients and all significant velocity reversals. These velocity profiles can then be used to derive the porosity structure as well as to provide evidence of the fluid state. For inversion of the velocity data we will use the methods of Hamilton (1978) for terrigenous sediments with modifications by Bray and Karig (1985), who paid particular attention to the Leg 87 results. We will refine these estimates by iterative forward elastic waveform modeling that uses the variations in reflection response with angle of incidence.

The kinds of data we will have to answer the specific questions outlined earlier are of the following type:

1. Twenty vertical velocity-depth functions of high resolution for inversion to porosity, density and water content. The spatial location of these functions will allow us to determine lateral variations in physical properties.
2. MCS ties to the velocity depth functions for lateral correlation of specific stratigraphic zones and structures.
3. True dip and strike of major structures by utilizing the detailed MCS grid of three dip lines spaced at 5 km and twenty lines shot normal to the dip lines along the ESP lines, combined with the velocity-depth functions to correct the reflection geometry for the velocity variations.
4. Reflection polarity data.
5. Amplitudes of reflections and their variations for both normal incidence MCS and wide offsets.

6. Forward elastic waveform modeling for estimates of porosity, density.

7. Use of converted shear waves, when observed, for estimates of Poisson's ratio for quantitative estimate of porosity, density and fluid content.

Plan of Work

We will collect 20 ESP's parallel to structure in the lower slope region of the Nankai Trough (Figure 12). These will be recorded with a 48-channel, 12.5 m group array. We will record the 48 channels for 16 sec at a 1 ms sample rate.

We will also collect 24-fold, 12.5 m bin CDP data along each of these lines with the 48 channel streamer, recording for 9 sec at a 1 ms sample rate. Finally we will collect three 50 km, 24-fold CDP dip lines to tie to the ESP lines. We will also collect conventional magnetics, 3.5 kHz echo sounder, miniranger and Syledis or GPS navigation data with translocation.

Thus we will collect 20 ESP's of 20 km each for 400 km, and
20 CDP lines of 20 km each for 400 km, and
3 CDP lines of 50 km each for 150 km.

The logistics for this program are not as difficult as it might seem. The Japanese will supply the shooting ship for ESP's, while we will supply the receiving ship. We are proposing the simplest and presently least expensive scheme by using the R/V Fred H. Moore (Appendix 1). However, we could conduct this program off the R/V Conrad, R/V Moana Wave or R/V Washington in that order with increasing logistical efforts. If the Conrad obtains a short group space streamer and realtime demultiplexing capabilities, it would at least be as suitable for this program. Realtime demultiplexing and high density tape drives become an issue because of the high sample rates and number of channels we will be recording.

We recently learned that the Moore will be acquiring a 96-trace, 33.6 m or 16.3 m group space streamer. We have not had time to evaluate the possibility of using this streamer instead of the proposed 12.5 m interval streamer. The advantage is 96 vs. 48-trace and the disadvantage is the 16.3 m group spacing vs. 12.5 m. We plan to evaluate this trade-off before a final decision is made on streamers. The recording system is a 102 channel GUS seismic system with realtime demultiplexing to 6250 BPI tape which will undergo seatrials in late May, 1986. Realtime navigation will be with various rental equipment discussed earlier and integrated into the existing data loggers on the Moore and Tansei Maru. The water gun sources will be rented by the Japanese for the ESP's and shifted to the Moore for the MCS work.

We are proposing a 14 day cruise from Yokohama to Yokohama. We are allocating 10 days for the work which includes 4 days of contingency time for the inherent delays in two-ship work and higher downtime for navigation problems.

The basic ship operations schedule is as follows:

Receiving Ship <u>R/V MOORE</u>	<u>Days</u>	Shooting Ship <u>R/V TANSEI-MARU</u>	<u>Days</u>
Transit to Operations Area	2.0	Transit to Operations Area	2.0
ESP & MCS Collection	10.0	ESP Shooting	8.0
Transit to Port	2.0	Transit to Port	2.0
Total Days	14.0		12.0

Japanese-United States Cooperation

The Ocean Research Institute of the University of Tokyo has expressed significant interest in this program (Appendix 2). Asahiko Taira, head of the marine geology and geophysics group at ORI, is ready to commit his resources to this proposed project. Taira has been involved for years in studies of sedimentation in the Shimanto Belt, recently participated in the Japan-French diving program in the Nankai Trough, and is the proponent for an ODP drilling leg in the area. Kiyoshi Suyehiro, an ORI marine geophysicist, will also be involved in the program. ORI will: (1) provide all data needed for planning purposes (Taira has already supplied all the Sea Beam data in the area); (2) provide up to two weeks of ship time on the R/V Tansei Maru (Appendix 3) in Fall, 1987; and (3) rent the water gun sound sources, along with special navigation equipment such as minirangers and GPS receivers (estimated to total about \$50,000). ORI will also provide technical and scientific support in the post-cruise stages of the program. We expect to have at least one ORI post-doc work on the ESP processing at UT. We also expect significant cooperation with JAPEX, the Japanese oil company that has extensive MCS data in the region. Yutaka Aoki has expressed interest in working with us, and will send a JAPEX employee, Taku Kawanaka, to Tulsa University to study for an M.S. in geophysics. We hope to use the JAPEX Syledis navigation system for free or at a reduced charge.

The Japanese are also planning an OBS refraction program in conjunction with, and possibly overlapping, this program to look at the deeper structure of the prism farther from the deformation front.

Relevance to the Ocean Drilling Program

Our proposed investigations will serve to enhance the effectiveness of proposed ODP drilling in the Nankai Trough by providing critical data necessary for optimum site location and regional physical properties information needed to place drilling results into a regional context. Although the Nankai Trough is already one of the best surveyed subduction zones, existing data were not collected for the purpose of supporting the physical properties hole that has been proposed for the area (Appendix 4). Thus, the data provide valuable information on the regional structural setting of the area, but do not provide information that are relevant to a physical properties hole.

The location for a site to be drilled to understand physical properties must be chosen based on a detailed knowledge of lithologies and param-

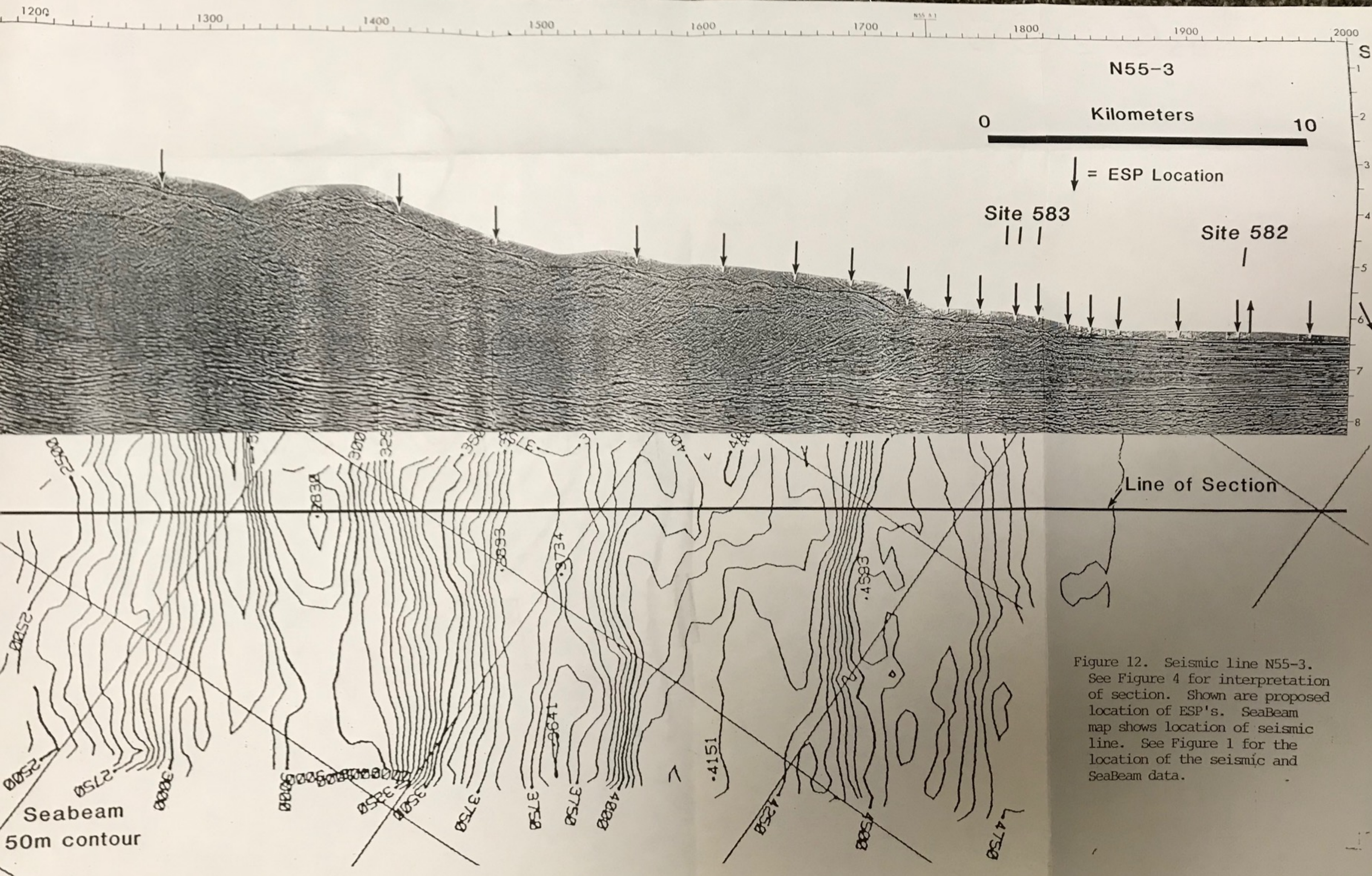


Figure 12. Seismic line N55-3. See Figure 4 for interpretation of section. Shown are proposed location of ESP's. SeaBeam map shows location of seismic line. See Figure 1 for the location of the seismic and SeaBeam data.

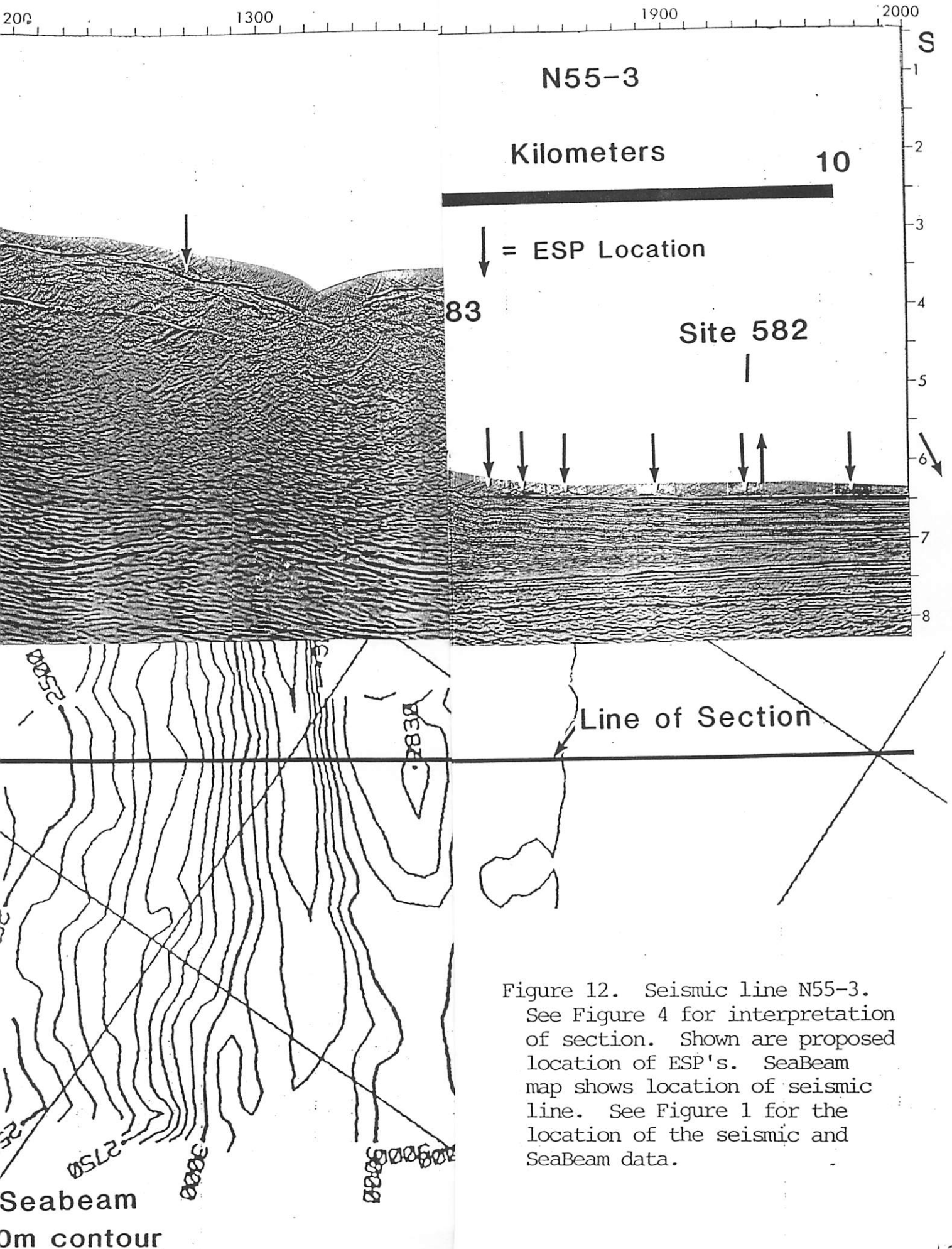


Figure 12. Seismic line N55-3. See Figure 4 for interpretation of section. Shown are proposed location of ESP's. SeaBeam map shows location of seismic line. See Figure 1 for the location of the seismic and SeaBeam data.

eters such as P-wave velocities. Existing seismic reflection and DSDP data yield sufficient lithologic information, but only gross velocity information that can be used to infer physical properties parameters. Our field program will yield a high density of velocity measurements that will be useful for inferring lateral variations in porosity and pore pressure. This will then allow the best possible site to be chosen for drilling. So little is actually known about the material properties in the toe of slope region, yet most models make specific inference about these properties and how they are responsible for the developing structures. It may be that the seismic program, independent of drilling, will be able to provide insights which will either further improve drilling siting/results or suggest new strategies to resolve the state of natural properties and their relationship to active margin processes.

An adequate regional knowledge of seismic velocities will allow extrapolation of ODP results from the small area around the drill hole through a much larger area. Calibrating a regional seismic data set with one or two ODP holes will allow meaningful interpretations of velocity variations across structures to be made.

Long-term ODP Goals

The COSOD document outlines a number of specific subduction zone problems that will be addressed by our investigation. The document recognizes that quantitative modeling of the mechanics of subduction zones requires an understanding of the degree of lithification and the fluid pressures in the subducted sediments. The following specific questions cited in the document are relevant to our proposed work.

- (1) How are pore pressures distributed in a subduction zone?
- (2) Do faults enhance dewatering by providing high-permeability pathways or hinder dewatering by disrupting the beds?
- (3) How does migration of pore fluid relate to diagenesis of subducted sediment and to changes in physical properties?
- (4) How does pore pressure influence tectonism in subduction zones?

The document proposes that in addition to obtaining porosity and permeability data from deep drilling, detailed seismic reflection studies are needed.

Role of Investigators

The field program will be designed and conducted by Stoffa, Moore, Shipley and Karig. All have had extensive experience with marine programs. Shipley, Moore and Karig have had significant involvement in active margin work, with Karig the co-chief scientist on the two DSDP drilling legs in this area. Stoffa has designed and participated in several conventional ESP projects and, along with Douze will provide the signal processing expertise.

To make best use of the facilities (and minimize costs) the processing

will be split between the University of Texas (UT) and Tulsa University (TU), as has been the case in earlier joint programs between Shipley and Moore. The MCS data will be sorted and processed in a normal fashion, including pre- and post-stack migration as necessary, at Tulsa University. The navigation reduction and sorting of the ESP data will be conducted at the University of Texas. Parts of these partially processed ESP data will then be jointly processed at Texas, Tulsa and Japan. UT is budgeting on the assumption it will do about 75% of the ESP data reduction, the rest at Tulsa and ORI. Suyehiro and/or students will spend time at UT and TU. Karig has the most experience in studying physical properties at active margins and in complementary laboratory experiments and will lead in this area. Moore, Shipley and Karig will work jointly on structural interpretation. All the American investigators have worked before in various combinations and we expect that our differing expertises and experiences will provide needed synergism to this program. Because of the nature of the program, significant travel will be required by all of the principles.

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University of Texas Budget Discussion

Science Budget Discussion

T. Shipley and P. Stoffa, as the University of Texas principal investigators, will participate in the field program in year one and will coordinate the seagoing program. M. Weiderspahn, our programmer/engineer will be responsible for interfacing the navigation/logging equipment on both the ships, and will be responsible for the cruise and post-cruise ESP navigation reduction. D. Dean is the senior data processor and will be in the seagoing party and will be involved in day-to-day coordination with the graduate students at TU, UT and with requirements of ORI investigators. The graduate student will be partially responsible for data processing as well as development of signal processing procedures as part of his/her thesis.

The equipment purchase is for a transportable personal computer for use by Shipley on trips at sea, in Japan and for office related word processing and other minor computational jobs appropriate to a personal computer. The University of Texas has declined to purchase any such equipment for Shipley.

Travel is for the most part self-explanatory. The pre-cruise planning trip either by Windisch or Wiederspahn is necessary to coordinate the navigation and shot instant equipment and procedures.

The computer costs for ESP processing are based on the equivalent processing cost of MCS data but multiplied by two for the iterative nature of the processing and the fact that little data compression by stacking will occur. The standard MCS processing of 24-fold, 4 ms, 12 sec records is about \$40/nm. This cost only covers computation services which includes operator salaries, supplies and maintenance. We could not come up with a more rational approach at estimating these costs. The costs do represent only processing 75% of ESP data, the rest to be completed at ORI and TU. TU will also be responsible for the MCS processing.

The reduction of the range data and Syledis or GPS translocation data will require substantial effort. We have processed data from other ESP projects but still expect some program development will be necessary. Experience has shown that the data set will require substantial editing and reprocessing.

Time is also requested on the UT Cray-XMP for interactive full waveform elastic modeling. UT charges have not been set yet so this is only an estimate.

Lease payments on UT budgets are the difference between on-campus and off-campus overhead rates and is used to pay the lease of the off-campus building that houses the Institute. This arrangement has the approval of funding agencies.

Science Operations Cost Center Budget

The Science Operations Cost Center sets rates for maintenance and services for seagoing projects conducted on the R/V FRED H. MOORE. The MOORE is not covered by technician grant support from NSF. Should it become so, some technician salaries and related travel would be deducted from this budget.

Windisch is in charge of technical services. Griffiths, Roper and McPherson are electronics engineers and technicians. Roberts is an engineer in charge of the shipboard science equipment. Fabres-Cordero and Percy are airgun and streamer technicians. Ganey is in charge of the data archive library and standard underway data reduction. Her salary covers the majority of the cost associated with producing standard data for NGDC. Griffiths, McPherson, Roper, Fabres-Cordero, and Percy will participate on the cruise either on the MOORE or TANSEI-MARU.

The equipment purchases are for the two-ship controlling of shot timing needed for the ESP work. Griffiths and Wiederspahn will integrate the system with ship data logging systems.

The refurbishment of the streamer is related to the cost of rejacketing the 6-100 m active sections and placing 48 transformers in the streamer for compatibility with existing recording systems.

Other costs are standard charges for maintenance of the systems. Note that the streamer charge includes maintenance for the streamer, birds, towing hardware and winches. I have requested that this charge be reduced since we are already charging the streamer refurbishment to this proposal. The issue is still under negotiation at UT.

One way air fare is requested for technical rotations.

Lease payments on UT budgets are the difference between on-campus and off-campus overhead rates and is used to pay the lease of the off-campus building that houses the Institute. This arrangement has the approval of funding agencies.

RESEARCH SUPPORT

THOMAS H. SHIPLEY

CURRENT SUPPORT

<u>Agency and Contract/Grant Number</u>	<u>Title of Project</u>	<u>Months on Project</u>	<u>Total Award</u>	<u>Period of Support</u>
NSF OCE-8511385	Detailed Investigation of Subduction Processes in the Middle America Trench (with G. Moore & B. Lewis)	4.0	\$110,020	1/15/86-1/14/87
		2.0		1/15/87-1/14/88
NSF OCE-8511364	Three dimensional seismic imaging of an accretionary wedge: Costa Rica (with M. Backus, P. Stoffa, & E. Silver)	0.5	\$1,036,283	3/1/86-8/31/86
		3.0		9/1/86-8/31/87
		3.5		9/1/87-8/31/88
		3.0		9/1/88-8/31/89

PAUL STOFFA

NSF OCE-8511364	Three dimensional seismic imaging of an accretionary wedge: Costa Rica (with M. Backus, T. Shipley, & E. Silver)	0	\$1,036,283	3/1/86-8/31/86
		1.0		9/1/86-8/31/87
		2.0		9/1/87-8/31/88
		1.0		9/1/88-8/31/89

R/V FRED MOORE SHIP TIME REQUEST

TO Bill Mitchell	and/or	UNOLS OFFICE <input type="checkbox"/>	UNOLS Office, V/B-15 University of Washington Seattle, WA 98195
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SHIP REQUESTED (if no specific ship, leave blank) MOORE (or CONRAD)
--

PRINCIPAL SHIP USE <input checked="" type="checkbox"/>	(where project will be chief use of ship) (on a shared or not-to- interfere basis)
ANCILLARY SHIP USE <input type="checkbox"/>	

PURPOSE (project title and brief outline of scientific objective) Japan-U.S. cooperative study of the relationship between sediment physical properties and subduction processes in the Nankai Trough Two-ship expanding spread profiling in the Nankai Trough

CHIEF INVESTIGATOR (name, title, address, tele. no.) T. Shipley, UTIG, Austin, TX 78751 (512) 458-5358 G. F. Moore, Univ. Tulsa, Tulsa, OK 74104 (918) 592-6000 Ext. 3090	OTHER SCIENTISTS INVOLVED P. Stoffa, UTIG; D. Karig, Cornell; A. Taira, ORI, Univ. Tokyo; K. Suyehiro, Chiba Univ., Chiba TOTAL NUMBER OF SHIPBOARD PARTY 15
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PROJECT REQUIREMENTS

SHIP REQUIREMENT (large, small & why) Medium to large, MCS	MINIMUM NUMBER OF SHIP DAYS NEEDED 14
SHIPBOARD EQUIPMENT NEEDED MCS system	OPTIMUM INCLUSIVE DATES Summer '87
SPECIALIZED FACILITIES OR INSTRUMENTS REQUIRED 12.5 m group streamer, Ray dist, Syledis	ACCEPTABLE ALTERNATIVES *
SUPPORTING PERSONNEL NEEDED (technicians) Navigation, electronics	AREA OF OPERATIONS (attach page size track chart) Near 32°N, 134°E Nankai Trough
EXPLOSIVES CARRIED NO	UNDERWAY and/or STATION REQUIREMENTS (attach sampling plan if available) *Two ship program requires joint scheduling with R/V TANSEI-MARU
RADIOACTIVE MATERIAL NO	

FUNDING STATUS

FUNDED			NOT-FUNDED	
FUNDING AGENCY			PROPOSAL SUBMITTED <input type="checkbox"/>	
GRANT NO:			WILL BE SUBMITTED <input checked="" type="checkbox"/> TO: NSF MG&G/ODP	
AMOUNT OR ANNUAL RATE			DATE: 1 June 1986	AMOUNT REQUESTED: --
BEGIN. DATE	DURATION		NEW PROPOSAL X or	RENEWAL OF GRANT NO:

OTHER SHIPS, LABS, AGENCIES TO WHOM REQUESTS HAVE BEEN SUBMITTED

DATE OF REQUEST April 10, 1986

SUBMITTED BY (name, title, address, tele. no. if different from chief investigator)
SIGNATURE <i>T Shipley</i>
APPROVED BY (department chairman or lab. director)

R/V FRED H. MOORE

ANTICIPATED GEOPHYSICAL CAPABILITY FOR 1987

We are at present upgrading the seismic instrumentation aboard R/V FRED H. MOORE in order to bring our MCS capability more into parity with the offshore exploration industry. Originally a gift from Mobil Oil Corp. to the University of Texas Marine Science Institute, R/V MOORE has been carrying out marine geophysical surveys for the University since 1978. MOORE's data acquisition systems have been supplemented at various times through additional gifts of equipment and investment of institutional funds. However, a recent donation of modern seismic equipment from Chevron Oil Corporation precipitated a move to raise R/V MOORE's entire MCS capability to the standards of industry. Efforts to supplement our standard sound sources with tuned subarrays of air guns are now underway. Navigation, quality control, and data logging are also being integrated for 3-D seismics and other types of more sophisticated geological and geophysical research.

We expect R/V MOORE's upgrade to be complete by early 1987. A description of her anticipated geophysical equipment and capability is as follows:

Seismic Sound Sources

1 x 80 in³ SSI Model S-80 water gun
2 x 2000 in³ Bolt 800c air guns
2 x 1,065 in³ tuned subarrays, six guns per array, 60, 78, 108, 150, 240*, and 429* in³ guns ea.

Deep Crustal Source Configuration:

Volume 6,130 in³; 2 x 2,000 in³ guns plus 2 x 1,065 in³ subarrays
Output 80 bar-meters p-p @ 20 ft depth, 0-128 Hz
Bandwidth + 8 dB 3-110Hz, P/B 6:1

High Resolution Source Configuration:

Volume 2 x 1,065 in³ subarrays at 2000 psi
Output 50 bar-meters p-p, 0-128 Hz.
Bandwidth +3 dB 8-80 Hz; P/B = 7:1.

Refraction source configuration:

Volume 2 x 2,000 in³ guns
Output 30 bar-meters p-p. 0-128 Hz.

Available Sources:

20 x 1,900c airguns
4 x 1,500c airguns
2 x 800c airguns

Fire control:

* Litton LRS-100

Air Compressors

2 x Gardner Denver rotary screw; 600 scfm @ 100 psi ea.
2 x Gardner Denver MDY Boosters; 1,500 scfm @ 2,000 psi ea.

Total air system capacity of 1,200 scfm at 2,000 psi will fire
2,130 in³ source at 7 sec pop rate or 6,200 source every 20
sec.

Seismic Receiving Array

Litton 96 trace streamer:

3,200 m with 30 m groups, 33 1/3 m group interval, 40
phones/group
1,600 m with 16 2/3 m group interval, 20 phones/group
16 auxiliary channels for:
depth transducers
waterbreak detectors
magnetic heading sensors
depth controllers
QC testing
Transformer coupled groups
Group sensitivity -208 dB re 1v/uPa,
Group response - 3 dB, 2 Hz - 1 kHz

Streamer QC

• Kalamos M4 fault locator
Gulf leakage/pulse tester for amplitude, phase and frequency
response of individual groups.
* Depth control and compasses
Syntron RCL-3 cable levelers with depth and wing angle
data feedback
Syntron RCU8310 remote compass system

Seismic Recording System

GUS 4200 Marine system

112 data channels; 1, 2, or 4 ms sampling rate
Automatic gain ranging in 6 dB steps, 0-90 dB range
Individual DC & AC balance controls and RF filters at each
amplifier input

Recording filters:

Low cut @ out, 5, 10, 15 or 20 Hz
High cut @ 220, 110, 140 or 86.5 Hz

GUS CDX MK 4 Dual Demultiplexing System

Capacity 8 seconds @ 1 ms, 16 seconds @ 2 ms, 32 seconds @ 4 ms for 96 traces
Four STC 9 track/6250 bpi tape drives for demultiplexed recording
in SEG-D format (2 1/2 byte binary exponent method) with
extended and external headers).

Full logic QC for tape I/O.

Dot scope for continuous monitoring of streamer noise.

Recording of airgun array signature on full gain ranging auxiliary
channel and video monitor.

SIE model ERC-10C monitor camera.

EPC single-trace profiler with independent selection of any trace.

Sonobuoy refraction receiver. Sonobuoy data recorded on full gain
ranging auxiliary channels.

Onboard testing and analysis of total streamer/recording system response
using pulse testers in streamer.

Data Logging

PDP 11/34 based data logger records auxiliary input from navigation
sources, streamer position sensors and other peripherals as required on
1/2 in 9-track tape @ 1,600 bpi, and formats data as appropriate for
inclusion in seismic tape headers.

Navigation

Data Sources:

- Gyro compass
- * Doppler log
- Transit Satellite
- Loran C
- * GPS
- * Streamer compasses

On-line computation and plotting* of ship position and streamer
location.

Seismic QC

Offline playback of seismic tapes through Cipher dual density tape
drive & PDP 11/34 based computer system for header checks,
seismic data quality monitoring and limited offline seismic
data processing.

General purpose Computing

* On-board MicroVax and 9-track 1,600 bpi tape drives.

Auxiliary Systems

Bell BGM-2 gravimeter
2 x Varian magnetometers
3.5 and 12 kHz echo sounders

* indicates equipment to be purchased

OCEAN RESEARCH INSTITUTE

UNIVERSITY OF TOKYO

1-15-1, MINAMIDAI, NAKANO-KU,
TOKYO 164 JAPAN.
TEL. (03) 376-1251

April 23, 1986

Dr. Thomas H. Shipley
Institute for Geophysics
The University of Texas at Austin
4920 North I.H. 35
Austin
Texas 78751-2789

Dear Dr. Shipley;

After discussing with you about our co-operation project on two-ship seismic experiments in the Nankai accretionary prism, I feel, from both scientific and logistic points of view, that this project should be very exciting and realistic. First, scientifically, the detailed seismic velocity information of active accretionary prism is a crucial factor for the understanding of evolution of accretionary prism. There is a significant gap in correlating the structure between acoustically imaged trench accretionary prism and on-land examples. The detailed velocity information is probably the most important data to fulfil this gap. The Nankai trough is the best area to study this because :

- 1) multichannel seismic data show one of the best and clearest images of accretionary process of trench turbidites.
- 2) there are substantial geologic and geophysical informations including DSDP drilling and submersible diving data.
- 3) active porefluid circulation which probably is responsible for lithification processed and thrust tectonics is evident from anomalously high heat flow and vent ecosystem.

Logistically, we can provide a shooting ship, R/V Tansei-Maru of Ocean Research Institute (51m, 470t) whose ship time and schedule can be easily adjusted according to your receiving ship schedule. Also as seismology is one of our strongest academic fields, this will be a great opportunity to develop a cooperative processing and analytical work of seismic data between two countries. I have organized a list of scientists who show a great enthusiasm for this project.

OCEAN RESEARCH INSTITUTE

UNIVERSITY OF TOKYO

1-15-1, MINAMIDAI, NAKANO-KU,
TOKYO 164 JAPAN.
TEL. (03) 376-1251

Again I strongly believe that this project has great scientific merits and we are very interested in this.

Sincerely yours,

A handwritten signature in cursive script, reading "Asahiko Taira". The signature is fluid and elegant, with a long horizontal stroke at the end.

Asahiko Taira

AT/ai

LIST OF JAPANESE PARTICIPANTS

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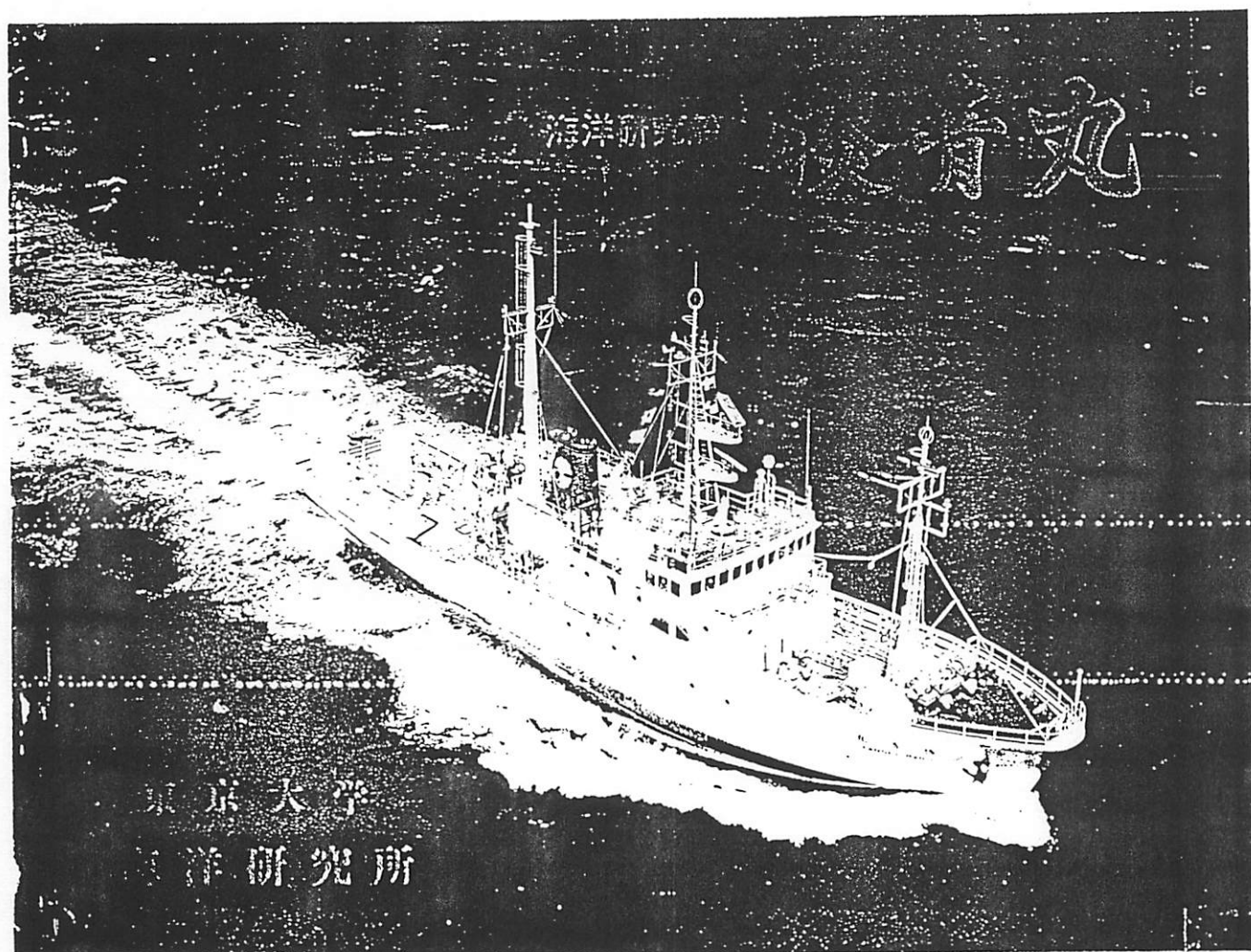
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船体部要目 Particulars

本船は、日本近海において海洋に関する物理学、化学、生物学、地質学、気象学、水産学等の各分野における基礎研究を行うことを目的とする海洋研究船である。

全 長	Length (o.a.)	51.00m
垂 線 間 長	Length (h.p.)	45.00m
幅 員 (型)	Breadth (mld.)	9.20m
深 さ (型)	Depth (mld.)	4.20m
計画満載喫水 (型)	Designed Draft (mld.)	3.70m
夏季満載喫水	Summer Draft (ext.)	4.30m
総 ト ン 数	Gross Tonnage	469.84T
純 ト ン 数	Net Tonnage	125.24T
航 行 区 域		第三種航路制限
試運転最大速力	Max. Trial Speed	14.61knots
航 海 速 力	Service Speed	(主機出力85%, 15%a.m.) 12knots
航 程 距 離	Cruising Range	(航海速力12knotsにて) 6200 nautical miles

要目 Machinery Particulars

主機の主機、減速機および可変ピッチプロペラは機関制御室および操縦台からリモコン操縦が可能である。

本船の研究観測作業時には、長時間にわたる低負荷運転が行われることを考慮して低負荷運転を施行した主機関による2機1軸システムを採用すると共に主機駆動発電機を装備し、省エネルギー化を図っている。

発電機は機関制御室からの遠隔操縦装置および自動起動装置を装備している。

これらの各機関の圧力、温度等の諸データを自動的に監視し、記録し、警報を行うためのモニターおよびCRTが装備されている。また研究活動や船室の居住性向上のために、主機、減速機や発電機関の防振、防音にも特に留意されている。

主 機 関	Main Engine	6 DSM-22N (マ イ ハツ) 2機1軸 750ps × 720rpm × 2台
主 発 電 機	Main Generator	
原 動 機	Prime Mover	6 PKT 6-16 (マ イ ハツ) 360ps × 1,200rpm × 2台

乗 組 員	Complement (乗員8, 総員14)	23名
研 究 員	Scientists (調査員1, 研究員10)	11名
積 載 容 量	Capacity	
清 水 タンク	Fresh Water (兼用タンクを含む)	119.0m ³
バラストタンク	Ballast Water	16.7m ³
燃料油タンク	Fuel Oil	162.2m ³
潤滑油タンク	Lubricating Oil	8.3m ³
研 究 室	Research Laboratory	
トライ研究室		約21m ²
セミドライ研究室		約20m ²
ウェット研究室		約12m ²
観測ウインチ	Winches	4台
起倒式ガントリー	Gantry	1台
中折式クレーン	THH Crane	1台
回転ダビット	Radial Davit	1台
ピストンコアラー用ダビット	Davit for Piston Corer	1台
作業艇	Work Boat (6人乗)	1隻
空調装置		全船内冷暖房一式

発 電 機	Generator	300KVA (240KW) × 2台 (神 鋼 電機)
補助発電機	Aux. Generator	300KVA (240KW) × 1台 (主機駆動) (神 鋼 電機)
可変ピッチプロペラ	Controllable Pitch Propeller	2,650ps × 4翼 × 1台 (カ ー ン)
バックスロウ	Back Thruster	TC-20MN (カ ー ン)
空 調 装 置	Air Conditioner	970ps × 4翼C.P.P. × 538rpm × 1台 (日 新 興 業)
		居住区(上甲板室)パッケージ型7.5KW × 1台 居住区(上甲板下室)パッケージ型3.7KW × 1台 研 究 室 パッケージ型3.7KW × 1台 機関制御室 パッケージ型2.2KW × 1台
汚物処理装置	Sewage Treatment	エプソビクトTF-40型 (互 光 製 作 所) 40人用
データロガー	Data Logger	JMC-SMS-2 (日本無線電機) (サーベス社)

電気部要目 Electrical Particulars

本船の電気機器は研究船としての特性を考慮し、給電の連続性、電源品質の確保、研究機器への適正かつ十分な給電計画、研究観測作業のための円滑な連絡が行える通信系統、密度の高い観測仕事の施行、および将来の増設計画への対応性等に留意して整備されている。

電源装置 Electric Power Equipments

主発電機 Main Generator 300KVA (240KW) AC450V

3φ 60Hz 2台(神鋼電機)

補助発電機 Aux. Generator 300KVA (240KW) AC450V

3φ 60Hz 1台(神鋼電機)

静止形精密電源装置 Static Precision Power System

10KVA AC100V

60Hz 1台(神鋼電機)

受電用陸上電源 Shore Connection Facility

AC440V 60Hz 1式(東洋電業)

変圧器 Transformer 450/105V 25KVA 3台

(協電製作所)

450/225V 15KVA 3台

(協電製作所)

航海装置 Navigation Equipments

反映式磁気コンパス Magnetic Compass 1台(東京計器)

電気式操舵装置 Steering Control 1式(東京計器)

電磁ロジ Electro-Magnetic Log 1台(北崎電機)

ジャイロコンパス Gyro Compass 1式(東京計器)

風向風速計 Anemometer & Anemoscope 1台(光電電気)

ドップラー式速度計 Doppler Speed Meter 1式(古野電気)

無線方位測定機 Radio Direction Finder 2台(光電製作所)

レーダー及び衝突予防装置 Radar & Rayex 2台(レイセオン)

音響測深機 Echo Sounder 1式(海上電機)

自記海水温度計 Seawater Thermorecorder 1台(村山電機)

監視用テレビ装置 Industrial Television 2式(ゼネラル)

ハイブリッド航法装置 Hybrid Navigation System

(P. 1)

レシーバー部

衛星航法受信部 NNSS 1式 HN 1107 R (北崎電機)

デカ受信部 Deca Receiver 1式 MS 3A (協電)

デカプロセッサ部 Deca Processor 1式 DP 80 (協電)

ラング受信部 Loran-C Receiver 1式 LIC-80 (協電)

ラング航法部 Loran-C R/R Unit 1式 (協電)

ラングA受信部 Loran-A Receiver 1式 SAL-1A (協電)

ルビジウム周波数標準器 Rubidium Frequency Standard 1式 FRT-II (古野電気)

ドップラー速度計 Doppler Speed Meter 1式 CI-20 (古野電気)

中央処理装置部

中央処理装置 Computer System 1台 PANAFACOM U-1100 (協電)

固定ディスク装置 Disk Unit 1台 6080C (協電)

CVCF電源部 CVCF Power Supply 2台 FLA-500 FHX (イトロニクス)

磁気テープ装置 Magnetic Tape 1台 7028A (協電)

CRTディスプレイ CRT Display Terminal 1台 FACOM 9410 (協電)

出力部

プリンタ Printer 1台 MP-130 (山崎精治)

X-Yプロッタ X-Y Plotter 1台 WX-4637 (西通測器)

CRTカラープロッタ CRT Color Plotter 1台 TU-047 (光電製作所)

制御器 Controller 1台 (協電)

遠隔表示器 Remote Display Unit 3台 9-CRT (協電)

イベントマーク Event Mark Junction 1台 (協電)

無線装置 Radio Equipments

500W送信機 500W Transmitter 1台 NSD 1585 (日本無線)

125W送信機 125W Transmitter 1台 NSD 1135G (日本無線)

75W補助送信機 Reserve Transmitter 1台 NSD 1175N (日本無線)

全波受信機 All Wave Receiver 2台 NRD 721 NDH 73 (日本無線)

補助全波受信機 All Wave Reserve Receiver 1台 NRD 721 NDH 73 (日本無線)

ライフボート用携帯無線機 Liferaft Portable Radio Equipment JSL-5 (日本無線)

ファクシミリ Radio Facsimile 2台 JAX-29HAP (日本無線)

受信機 JAX-12V (日本無線)

自動電信解読印字装置 Tele Writer 1式 DCR-550F (パナソニック)

国際VHF無線電話機 International VHF Radio Telephone JIV-227 (日本無線)

緊急自動受信機 Auto Alarm Receiver 2台 JXA-15A (日本無線)

JXA-8A (日本無線)

船舶電話 Ships Telephone 1台 (船舶通信)

共通式電話装置 Common Battery Telephone System 1式 NQW (日本無線)

自動交換電話装置 Automatic Exchange Telephone System 1式 NCF-733A (日本無線)

船内指令装置 Public Addressing System 1式 NVA-1051-AT (日本無線)

テレトーク装置 Tele-Talk System 1式 NVA-1303J-48 (日本無線)

水晶時計 Electric Clock 1式 QC-6M2-N (協電)

船内研究設備 Research Equipments

PDR	Precision Depth Recorder 式
	型式 NS-74	(日本電気)
	周波数 12KHz	
	測深範囲 8,000m	
魚群探知機 I	Fish Finder I 式
	型式 FE-1804F	(古野電気)
	周波数 28KHz	
	測深範囲 5,200m	
魚群探知機 II	Fish Finder II 式
	型式 FQ-50	(古野電気)
	周波数 50KHz - 200KHz	
	測深範囲 1,860m (50KHz) - 630m (200KHz)	
スキャニングソナー	Scanning Sonar 式
	型式 CS-70	(古野電気)
	周波数 75KHz	
	探知範囲 0~800m	
気象・海象観測装置	Marine meteorological Observation System 式
		(太陽社)
CEK	Geomagnetic Electro Kinetograph 式
	型式 埋蔵式電磁海流計	(本地郷)
CTD	Conductivity Temperature Depth Recorder 式
	型式 ニール・ブラウンMark III B (ニール・ブラウン社)	
エアガンコンプレッサー	Compressor for Air Gun	1台
	型式 YQ3-45 Y型4気筒単動3段圧縮	
	吐出圧力 120kg/cm ²	
	吐出量 1.8m ³ /min	(加地鉄工所)

APPENDIX 4

A Proposal for an ODP Hole Dedicated to the
Physical Properties, Mechanical State, and
Structural Fabric of Deforming Sediments
in Accretionary Prisms

Daniel E. Karig

Department of Geological Sciences

Cornell University

Ithaca, New York 14853

August 30, 1985

Statement of Problem

A number of problems now impeding the understanding of accretionary processes at convergent plate margins center on the inter-relationships among the physical properties of the sediments undergoing deformation, the mechanical state at which deformation occurs and the resultant structural fabric. For example, it is accepted that accreted sediments dewater anomalously rapidly, but does the attendant drop in porosity occur rapidly at the toe of the prism (Carson, 1977; Fowler et al., in prep.) or more gradually across the prism (Bray and Karig, 1985)? Does this water escape by normal intergranular permeability vertically or horizontally (e.g., Westbrook and Smith, 1983), or might it rely on fracture permeability in fault zones? Fault zones have been suggested to be avenues of fluid escape by some (e.g., Cloos, 1984; Bray and Karig, 1985), but the data are ambivalent as to whether these are zones of high (Aoki et al., in press) or low (Karig, in press) porosity and pore pressure. Fluid pore pressures are clearly very important in controlling mechanical state, but these have not yet been quantified nor related to structural setting.

Most workers would agree that the mechanical response of these sediments can be approximated by the Coulomb criterion, $\tau = C + \mu\sigma_n$, but there is very little agreement as to the co-efficients of cohesion (C) and friction (μ), or as to the relationship of these to physical properties such as porosity. The value of μ at fracture is related to the orientation of the failure surface with respect to σ . Small scale fracture surfaces have been recognized in DSDP cores, together with other structural fabric elements, but little thought has been given to using these as criteria for the mechanical state.

The structural fabric of accreted sediments has spawned many arguments, but most concern the interpretation of structural setting from the resultant fabric. What do brittle and ductile responses imply? Where do the different fabrics observed in emergent accretionary prisms develop? Arguments concerning all these problems are a bit sterile without the quantitative control offered by in-situ observation and measurements.

Proposal

I am proposing an ODP hole in the toe of an accretionary prism dedicated to the measurement of porosity, permeability, pore pressure, and structural fabric as functions of depth and location relative to one of the major imbricate thrust faults. Although several possible sites could be suggested, a site near DSDP hole 583G in the Nankai Trough is felt to have the best qualifications for a number of reasons.

Probably the most important consideration is that such a site should be part of a very simple and very well known mechanical system. At this early stage of understanding, quantification of the mechanical behavior of these deforming sediments will require simple and well-posed boundary conditions and gradients for the relevant variables (porosity, stress, strain, temperature, fluid pressure, etc.). It would be extremely difficult or impossible to estimate field characteristics in a complexly deformed zone of highly variable strata. Instead a setting, with minor folding, and a single simple thrust in a uniform sediment section ought to be sought.

The structural framework near Site 583 is extremely well known, from a very well imaged seismic profile and from earlier drilling. It is one of the few, if not only, accessible locations where one of the imbricate faults is a clear, strong impedance surface, implying a high contrast in porosity with

respect to the wall rock. The large scale structure of this area is a relatively simple ramp and hanging wall anticline. The strata involved are a relatively uniform sequence of sandstone and mudstones, the finer grained of which provide the most sensitive and best understood material response to stress and strain. Certainly these terrigenous clastics are to be preferred to biogenic carbonates for such studies, because they are typical of subduction complexes and because they are mechanically "better behaved".

The necessary background studies for any such hole have already been undertaken at the Nankai site. Extensive site surveys, with single and multichannel seismic profiles, and seabeam swath mapping have been done as described more fully in the proposal of Taira et al. (submitted to ODP). Possible hydrocarbon leakage up the fault and trapping beneath a gas hydrate have been disproven by Holes 583C, D, and E. Hole stability in these strata was documented by Holes 298, and 583F and G. Although the deepest of these penetrated only 650m, the core recovery and cohesiveness of core was very good below depths of 350 or 400 m. There is always the possibility of very poor stability in the major fault zone, but Hole 298 successfully penetrated another imbricate thrust also with a strong impedance contrast. In all these deep holes we observed interesting structural features (kinks, deformation bands, shear fractures, folds), but in none was the fault zone itself tested. Hole 298 was spot cored and at Site 583 we were forced to stop above the fault because of problems other than geological (bit release, major fatigue problem on rig, and a typhoon). Moreover, the tools and priorities necessary to achieve the proposed objectives were not available on these earlier legs.

I am proposing a hole about 1000 m deep, to penetrate the frontal imbricate thrust at a depth of near 600 m. This hole could be drilled directly to 350 m without significant loss of information, because of earlier work. Depending on the tools to be used, the hole might be either single entry or re-entry. A re-entry cone with several hundred meters of casing would undoubtedly reduce the sloughing problems encountered in the shallow low-cohesion clastics. This in turn would greatly enhance the logging and bottom hole probe conditions as well as to provide a long term bottom site for on-going experimentation.

Specific objectives and measurements that I visualize for the site would include:

1. Physical Properties. Porosity, permeability, acoustic velocity (both V_p and V_s), and thermal conductivity would be measured, both in-situ, through the logging program, and in the lab on core samples. Redundancy in methodology will provide data on "rebound", and on the scale effect on the property. For example the difference between in-situ and sample porosity is a measure of fracture porosity.
2. Mechanical State. The orientation and magnitude of stress would be obtained by study of fracture patterns and by triaxial tests on cores (the latter would also provide data on cohesion and internal friction). A second source of information concerning stress could come from break-out geometry and fracture patterns observed in the bore hole by the sonic televiewer, if the hole conditions are similar to or better than those observed near the bottom of Hole 298.

3. Fluid Conditions. Pore fluid pressures and rates of flows would be sought by bottom hole pore-pressure probes and by indirect methods. These latter include logging relationships, the porosity-stress equilibrium (Karig, in press), the distribution of temperature and heat flow, and the chemical gradients in pore waters.

4. Long Term Measurement. Although I do not have any ideas yet for long term experiments using this hole, Taira et al. (submitted) have proposed such a station, which could be used for studies of local seismicity, velocity structure, and long term strain measurements.

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*****ODP SITE PROPOSAL SUMMARY FORM*****
(Submit 5 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site:
Toe of Accretionary Prism

General Objective: To quantify and interrelate the physical properties, mechanical state, and structural fabric of deforming sediments in accretionary prisms

General Area: Nankai Trough
Position: 31°50.2'N, 133°51.2'E (S.P. 1784)
Alternate Site: on Profile N55-3-1

Thematic Panel interest: Tectonics
Regional Panel interest: Western Pacific

Specific Objectives: (see text for details)

1. Lab and in-situ physical properties (including Temp)
2. In-situ pore pressure and permeability
3. Lab and in-situ fracture patterns and structural fabric
4. Mechanical state (stress and strength) - using both lab and in-situ techniques

Background Information:

Regional Data:

Seismic profiles: Primary control Japex N-55-3-1; also JNOC Line L, and a grid of ORI single channel lines

Other data:

Seabeam survey by LePichon/ORI

Site Survey Data - Conducted by: G.S.J., O.R.I., CNEXO (Kaiko project)

Date:

Main results: Although no specific site survey has been conducted, extensive studies during the past few years have delineated the geologic & geophysical parameters very well. See Leggett et al., in press, DSDP Init. Repts., v. 87

Operational Considerations

Water Depth: (m) 4850 Sed. Thickness: (m) 2000 m Total penetration: (m) 1000

HPC _____ Double HPC _____ Rotary Drill x Single Bit x Reentry ?? see text

Nature of sediments/rock anticipated: Clastic sediments, sand to clay, moderately stable

Weather conditions/window: Typhoon season is mid-summer to early winter

Territorial jurisdiction: Japan

Other:

Special requirements (Staffing, instrumentation, etc.) Additional structural geologists and physical mechanical properties specialists. We can cut out paleontologists, minimize sedimentologists (already done). Need all logging staff; bore hole televiewer, packer and/or down hole casing (through fault). Possible surface casing if deemed necessary for hole stability. We also would need authorization for extensive total core (over)

Proponent:

Daniel E. Karig
2124 Snee Hall
Department of Geological Sciences
Cornell University
Ithaca, New York 14853

Date submitted to JOIDES Office:

January 14, 1985

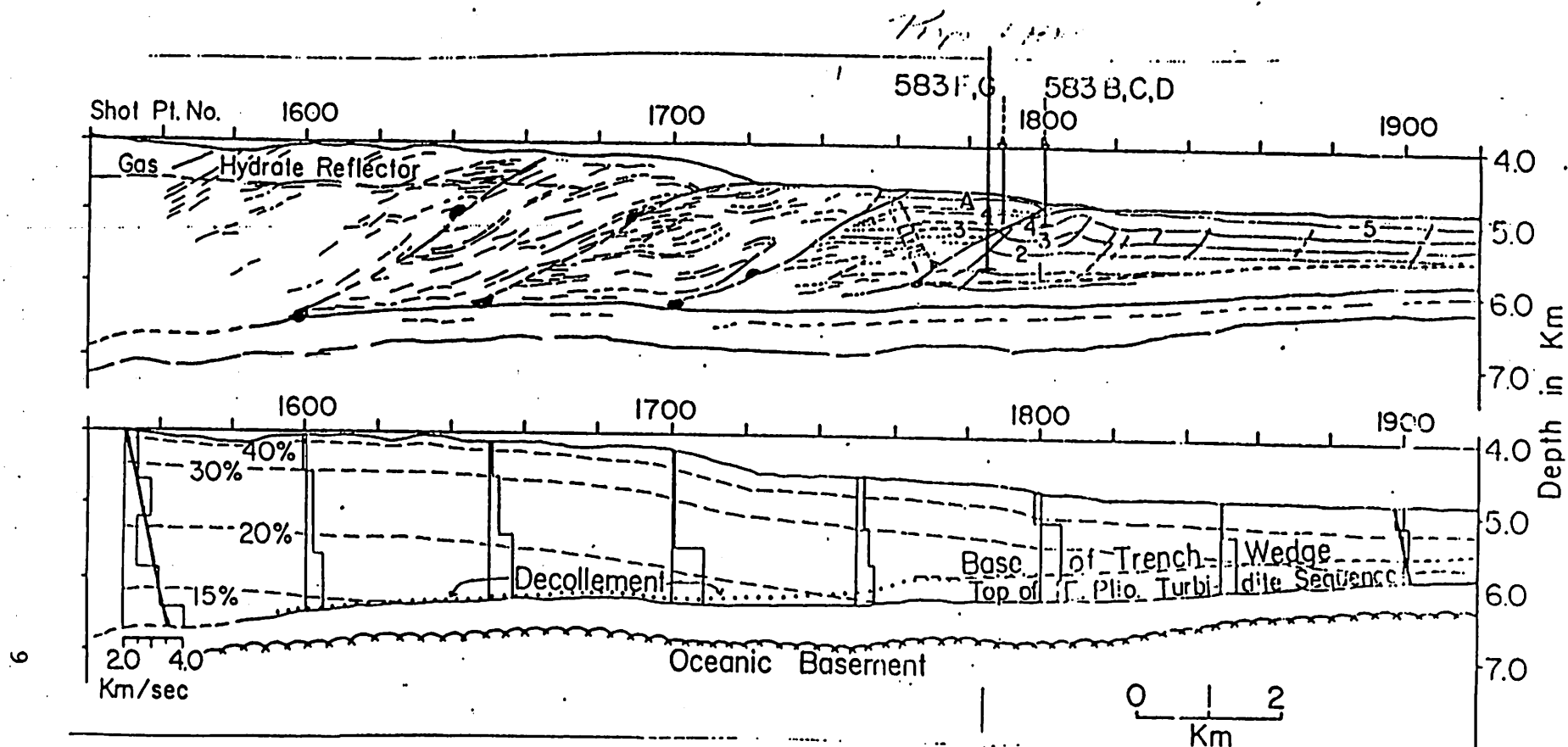


Fig. . A. Interpretive depth section across the toe of the Nankai accretionary prism, from seismic profile 55-3-1 (Nasu et al., 1982). The displaced half circles represent estimates of offset along major thrust faults. The labeled reflectors are the same as shown in Fig. 2. B. Interval velocities (from Nasu et al., 1982); linear velocity gradients, derived from interval velocities, refraction velocities (Yoshii et al., 1973), and drilling results; and porosities, converted from velocities using relationships of Hamilton (1978), across the prism toe.

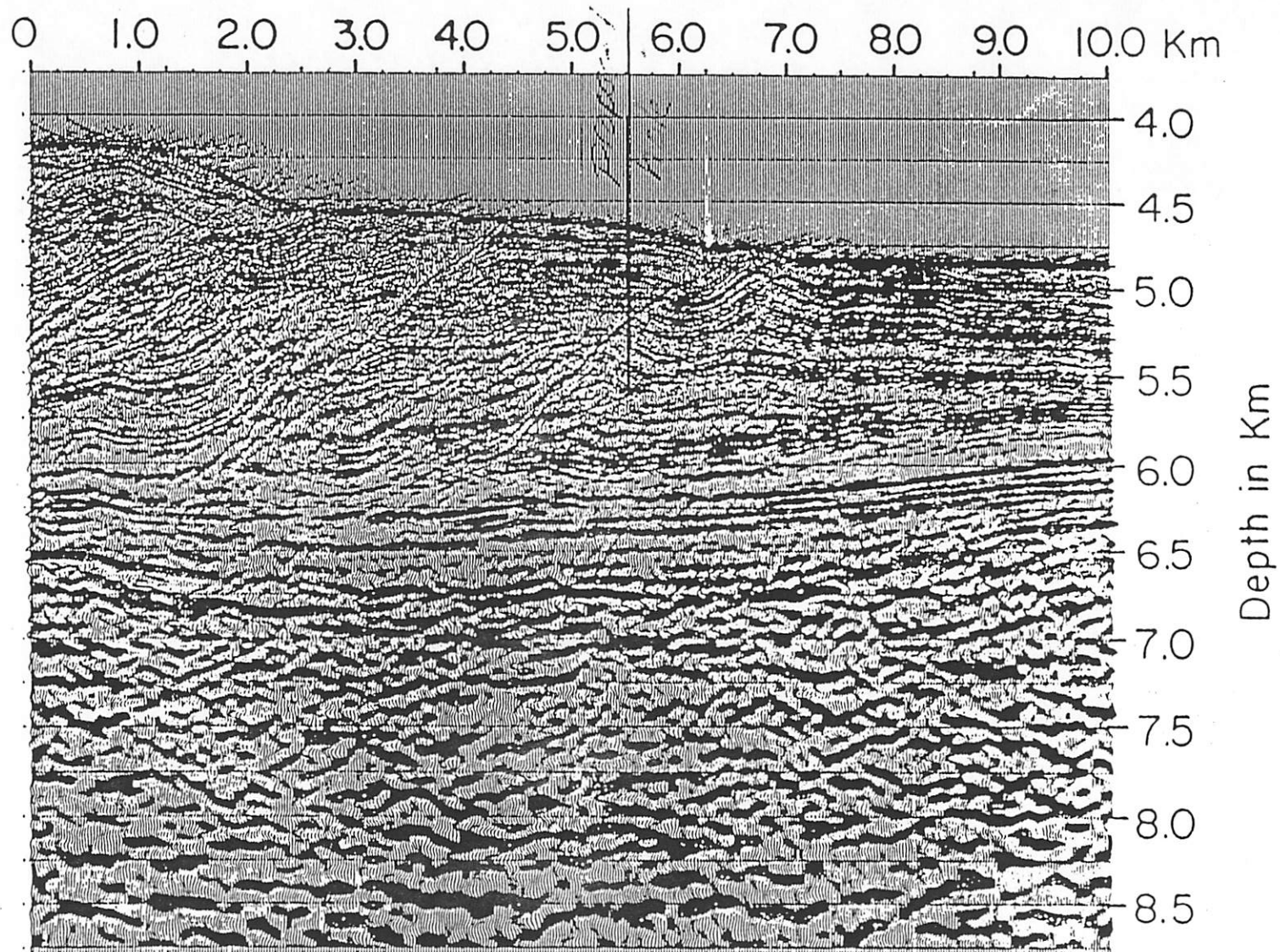
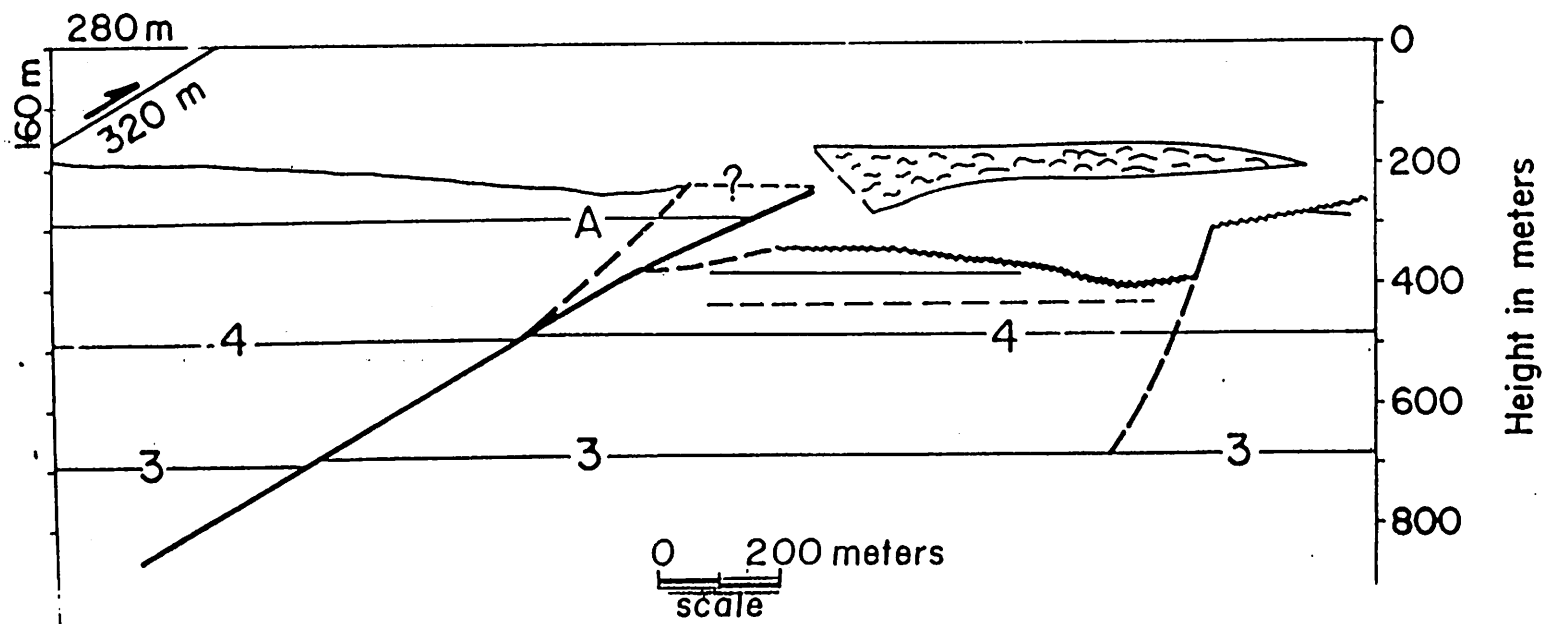
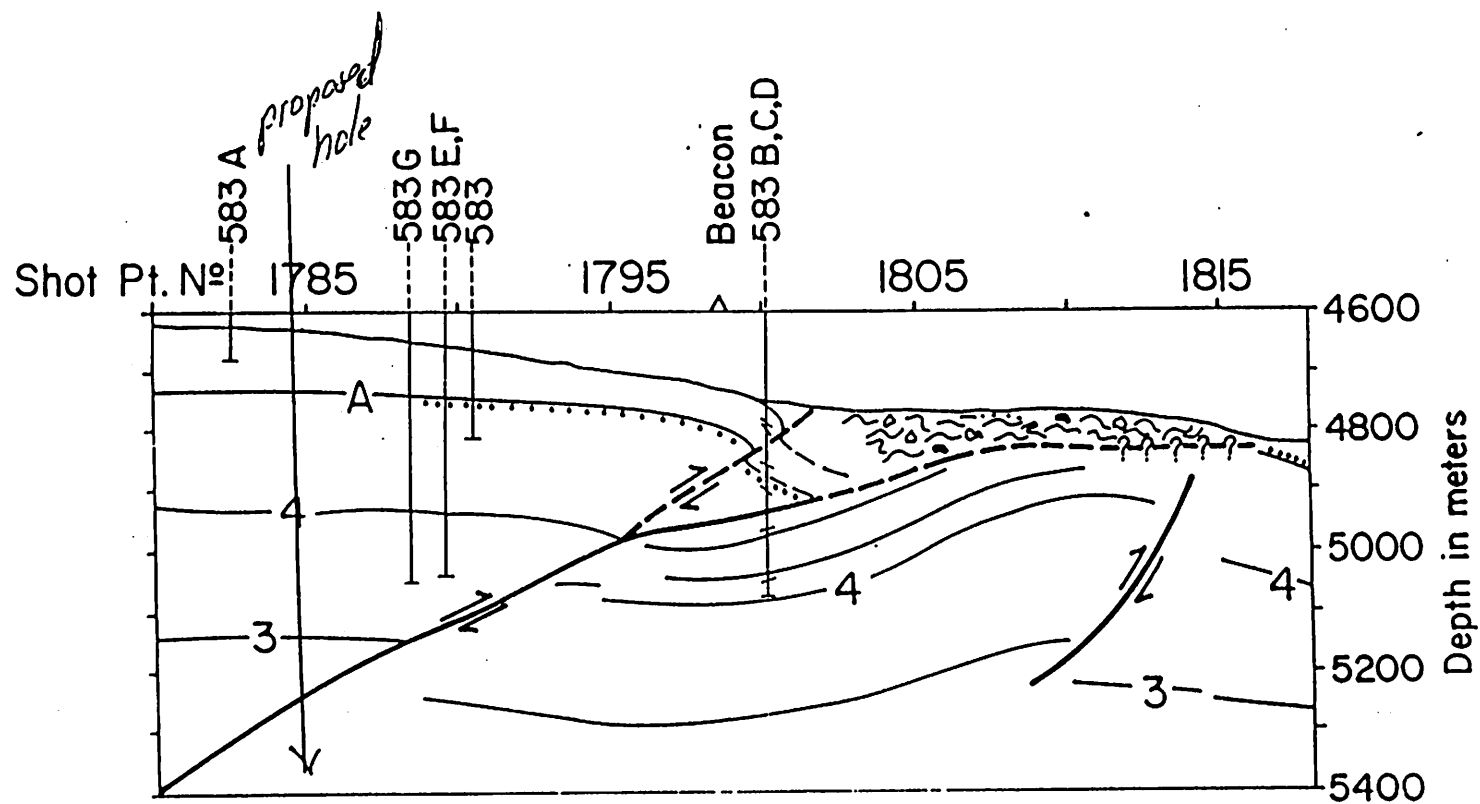
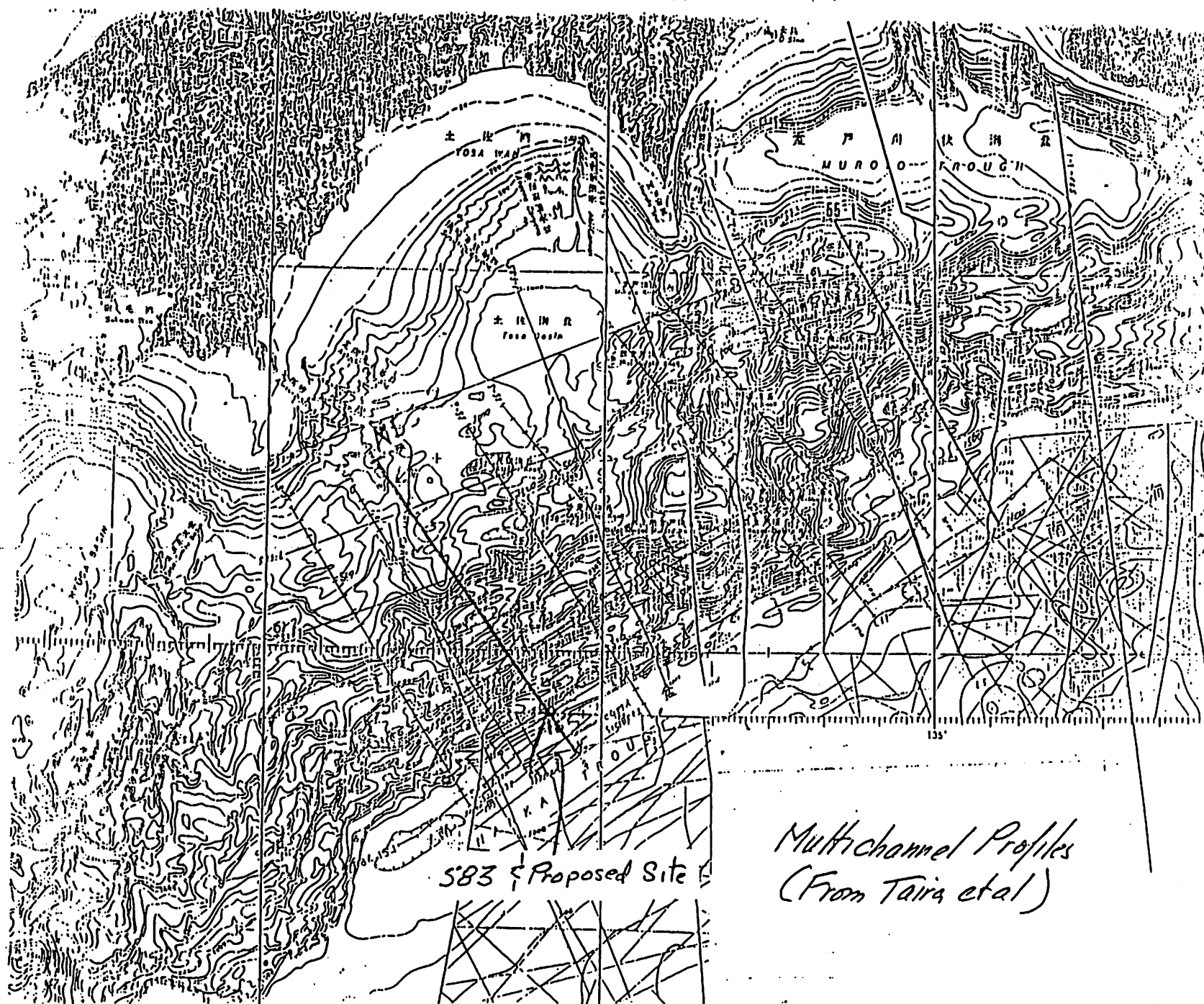


Fig 2





*Multichannel Profiles
(From Taira et al)*

