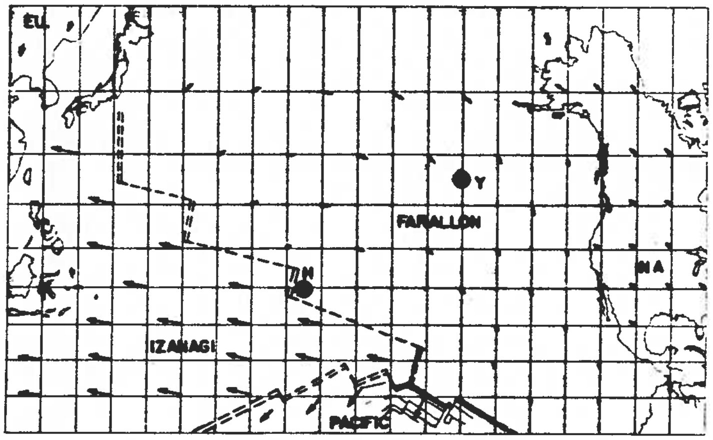
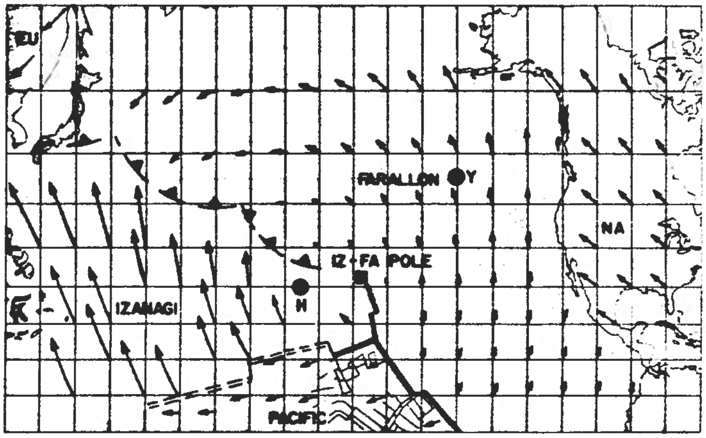
PRELIMINARY REPORT ON THE RESULTS AND RECOMMENDATIONS OF THE NORPAC CONFERENCE FOR ODP DRILLING IN THE NORTH PACIFIC-BERING SEA REGION

140 Ma (135-145)



110 Ma (100-115)



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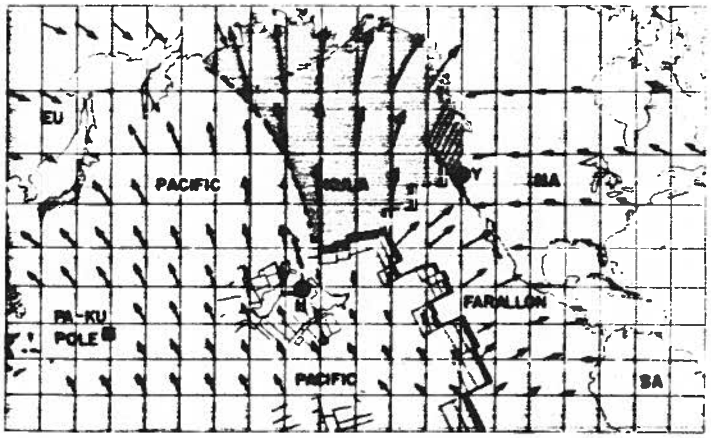
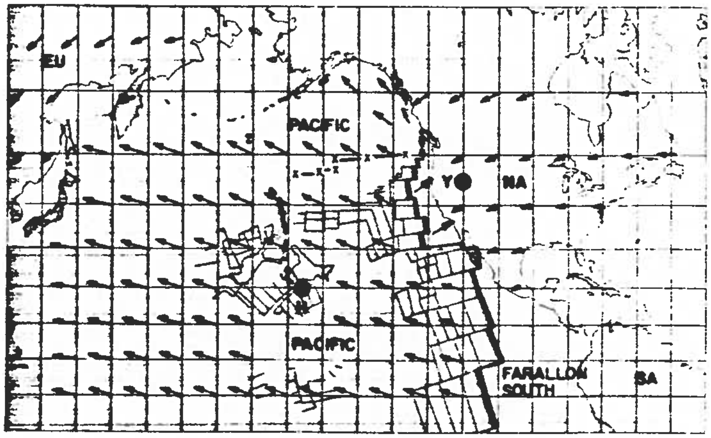


37 Ma (37-43)



JANUARY 15, 1986

PRELIMINARY REPORT ON THE RESULTS AND RECOMMENDATIONS OF THE NORPAC CONFERENCE FOR ODP DRILLING IN THE NORTH PACIFIC-BERING SEA REGION

CONTENT

----------------------------oOo----------------------------

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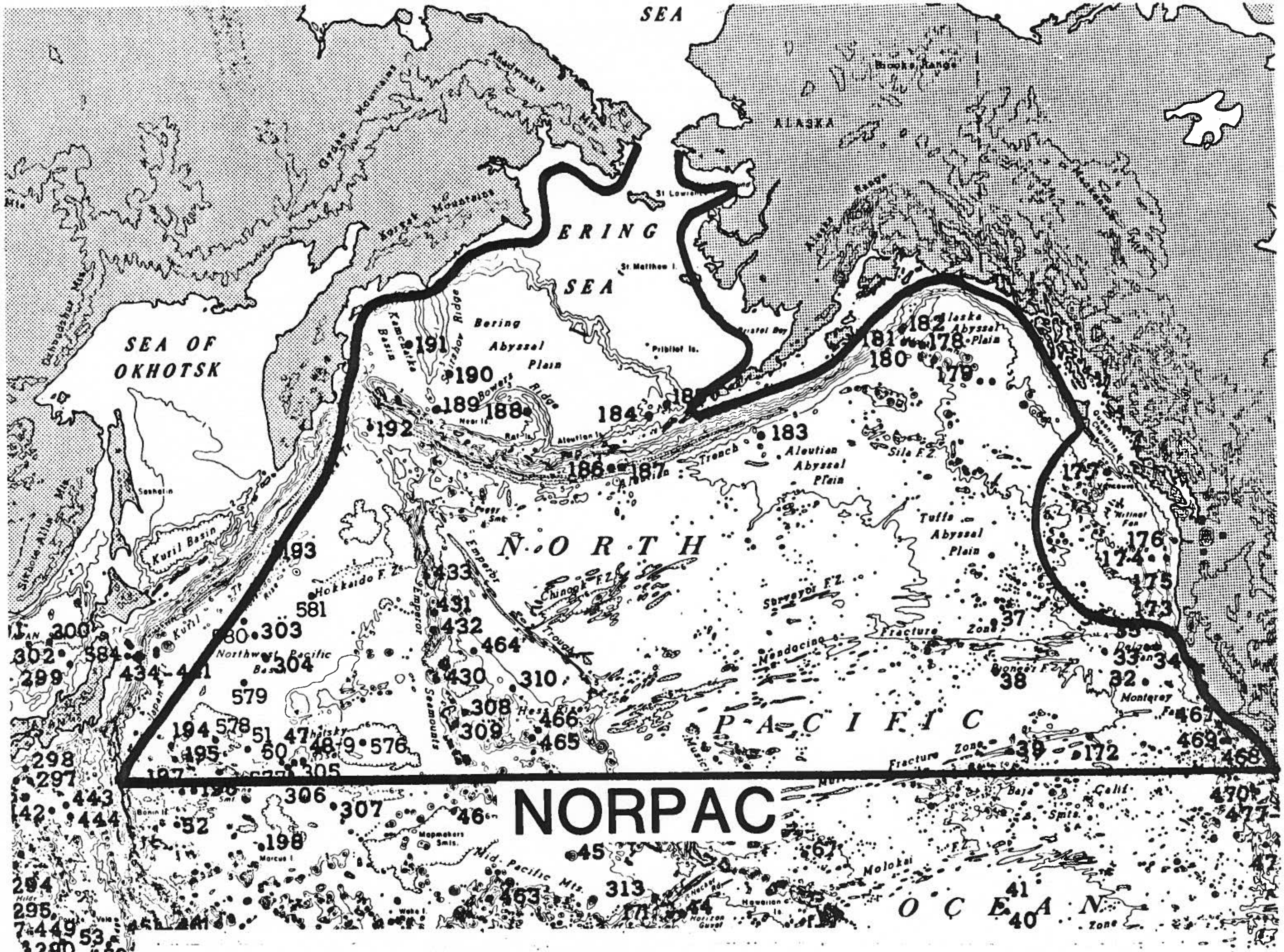

FIGURE 1. Index map, showing locations of DSDP hole sites--many drilled more than 20 years ago--of the NORPAC or north Pacific-Bering Sea region.

INTRODUCTION

PURPOSE OF NORPAC PLANNING CONFERENCE

The general purpose of ODP drilling in the north Pacific-Bering Sea region—NORPAC—is to gain by advanced drilling and subsurface sampling and recording techniques a great improvement in knowledge of its geologic record and evolution. The NORPAC Conference was therefore organized* so that knowledgeable scientists could gather and pool their information about important tectonic, igneous, depositional, and paleoenvironmental problems recorded in the NORPAC region, and how answers to them could be effectively pursued by a scientific drilling program of the JOIDES R/V *Resolution*. The JOIDES *Resolution* is scheduled to be in the NORPAC region toward the end of this decade.

The area of the Pacific-Bering Sea region considered at the NORPAC Conference is outlined on Figure 1. It extends northward as far as the Bering Strait, southward to roughly latitude 30°N, westward to the axis of the Kuril Trench, (but exclusive of the offshore Japan region), and eastward to the coast of North America (but exclusive of the INPAC area of the Juan de Fuca and adjacent seafloor and the Gulf of California).

DSDP sites occupied in this area—many of them drilled with the limited sampling technology and objectives of older *Glomar Challenger* legs, are shown on Figure 1. Notwithstanding the incompleteness of the data acquired at these sites, they nonetheless provide information critically important to guide potential ODP drilling and sampling by the JOIDES *Resolution*.

REASONS FOR NORPAC ODP DRILLING

The north Pacific region is a repository of igneous lithosphere and overlying sedimentary deposits that in part have reached this area by traveling thousands of km northward, including crossing the paleoequator (see cover). The northward moving sedimentary blanket alone contains an assembly of equatorial to high-latitude paleoclimatic and paleoceanographic events recorded over perhaps the past 150 m.y. During much of this time, prior to the opening of the Atlantic, the Pacific Basin was the Earth's largest marine repository of tropical and higher latitude sediment. Some of these deposits are thick and cap oceanic plateaus. There is a possibility that pelagic equatorial rocks of Early Cretaceous age underlie the Aleutian Basin of the Bering Sea.

The relatively thick (as much as 1.5 km) pelagic, hemipelagic, and terrigenous deposits lying immediately seaward and landward of north Pacific trenches (Kuril and Aleutian) record high latitude paleoceanographic and paleoclimatic events throughout much of Cenozoic time. The record of major boundary and bottom water currents, plate motions, and sediment dispersal patterns are preserved in these deposits. These same sequences contain a tephrochronology history of Pacific-rim volcanism, a further link to the history of plate-boundary tectonism.

Critical evidence bearing on the origin, demise, and total destruction of fast-moving Mesozoic-early-Tertiary oceanic plates (e.g. Kula, Chinook, Izanagi, North and South Farallon, Bering, the even more mythical Escondido, etc; see cover) that formerly occupied the north Pacific-Bering Sea area can be extracted from this region and its bordering continental margins. The history of these plates—why they formed, their absolute and relative movements, and why and how they died—is a record of lithospheric events of global significance. The origin and northward movement of the suspect tectonostratigraphic terranes embedded in north Pacific fold belts are a testament to the crust-building affects of these missing or defunct plates.

AUGUST 20-22, 1985*

Major plate-boundary processes can also be investigated along north Pacific rims. These include the record of displacement of tectonostratigraphic terranes that has been preserved in the sediment draping their seaward flanks, and the physical processes involved in creating and attaching a massive subduction complex to the rock framework of the Aleutian Arc and adjacent Alaskan crust. The subduction complex adjacent to the Aleutian Trench provides an unparalleled opportunity to examine in detail the process of subduction accretion—including those processes that determine the physical properties and diagenetic state of the accreting mass—along a plate boundary characterized by high sedimentation and convergence rates.

TECHNICAL RESULTS

KEY DRILLING AREAS

Drilling sites proposed to address different or similar scientific objectives crudely clustered themselves into about 10 operating areas. These areas, number from west to east and progressing northward are listed below and outlined on Figure 2:

Area (1) Shatsky-Hess Rises area (30-35°N, 155°E-175°W)
Area (2) Chinook Trough (43-45°N, 180-170°W)
Area (3) Central north Pacific (35-55°N, 170-150°W)
Area (4) California margin and vicinity (32-40°N, 130-120°W)
Area (5) Hokkaido Rise-Meiji-Obruchev Swell (45-52°N, 160-175°E)
Area (6) Aleutians Ridge (51-52°N, 175°E-172°W)
Area (7) Gulf of Alaska (50-57°N, 160-135°W
Area (8) Alaska Peninsula margin (53-57°N, 165-150°W)
Area (9) SE Alaska-Queen Charlotte margin (52-59°N, 145-130°W)
Area (10) Bering Sea Basin (52-60°N, 165°E-165°W)

OBJECTIVES AND ODP ADVISORY PANELS

Drilling objectives described at the Conference fell within 8 general categories of scientific interest. The number of drilling objectives falling within each category is listed below, and also keyed to the interest of appropriate JOIDES Advisory Panels:

Objective Category identified	Numberof Objectives	Relevant Advisory Panel
Tectonic	20	Tectonics and CEPAC.
Igneous Petrology	2	Tectonics, Lithosphere, and CEPAC
Sedimentary Processes	8	Sediments & Ocean History and CEPAC
Stratigraphy	4	Sediments & Ocean History and CEPAC
Alteration Processes	2	Sediments & Ocean History, Tectonics and CEPAC
Physical Properties	1	Sediments & Ocean History, Tectonics and CEPAC
Paleocean History	6	Sediments & Ocean History and CEPAC
Paleoclimatology	1	Sediments & Ocean History and CEPAC
	44	

NORPAC DRILLING AREAS

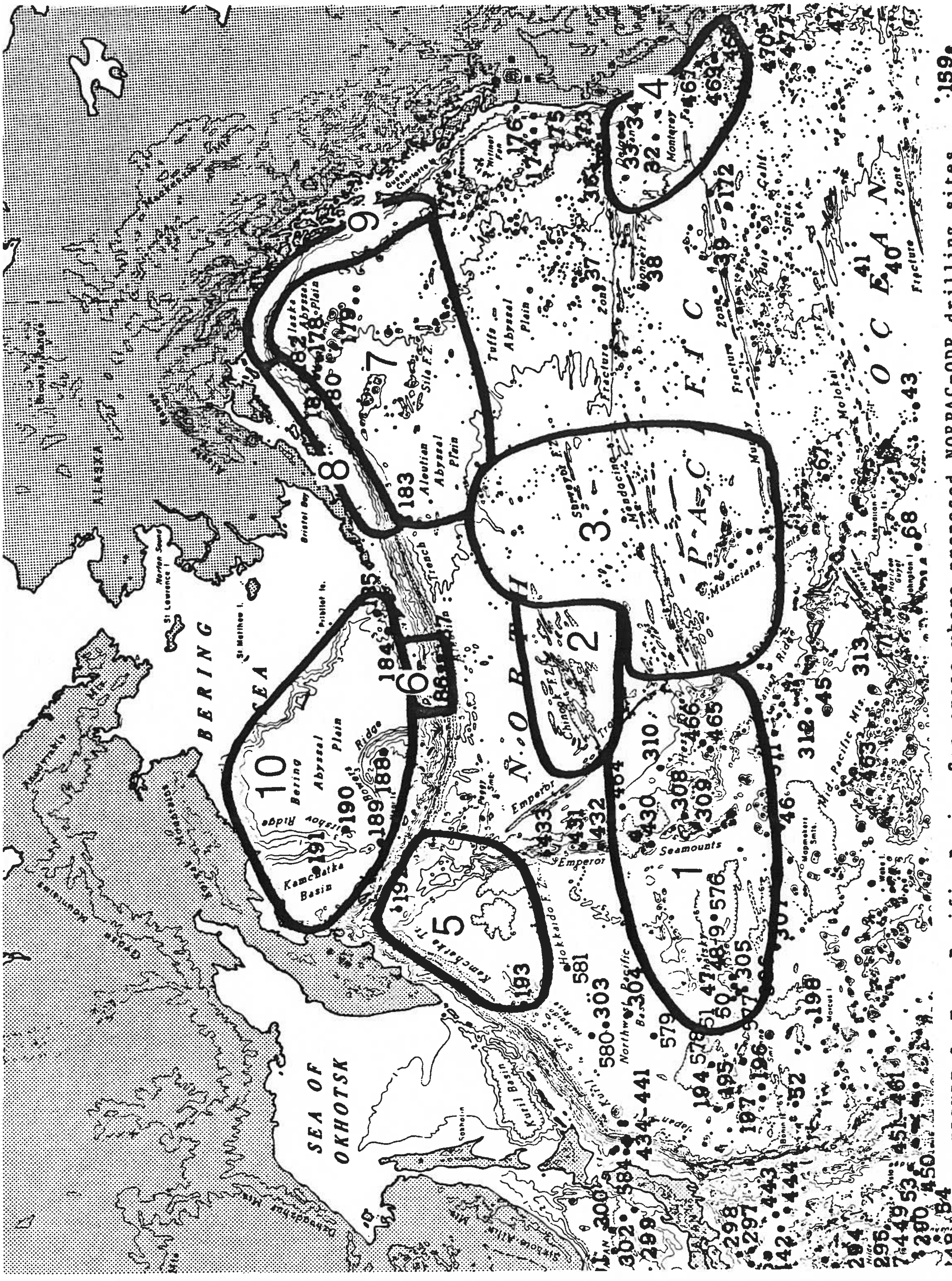

FIGURE 2. Ten, Pacific-Bering Sea areas where proposed NORPAC-ODP drilling sites clustered. Multipurpose objectives can be achieved at sites drilling in these areas.

PRELIMINARY RECOMMENDATIONS

Achievement of important NORPAC objectives, which are discussed below under SCIENTIFIC RESULTS, will require at least one drilling legs in most of the identified drilling areas (see Figure 2) Several of the objectives located in areas 9 (Queen Charlotte margin), 7 (Gulf of Alaska), and 4 (offshore California) are also identical to those recommended in the report of the INPAC Drilling Conference, which described drilling objective in the eastern Gulf of Alaska, Juan de Fuca Ridge, and Washington-Oregon-northern California region.

We are mindful of the operational facts that the NORPAC region occupies an areas roughly 2000 nautical miles wide (north to south) and 5000 nm across, that drilling in the higher latitudes should take place between May and October, and that adequate ports north of about 50°N are few and widely separated.

Our preliminary judgement is that the minimally-desired achievement of first-order NORPAC objectives requires an 8-leg drilling program. This assessment includes consideration of the fact that drilling in the INPAC area will contribute to the attainment of NORPAC objectives.

SCIENTIFIC RESULTS

TECTONIC HISTORIES AND PROCESSES

Continental and Island-Arc Margins

Introduction

Insofar as the continental and island-arc margins of the north Pacific were concerned, discussions held at the NORPAC Conference focused on the need for subsurface information to:

(1) resolve key phases in their tectonic evolution and determine synchronuity—or lack of it—of these events with those that affected north Pacific oceanic plates, and

(2) clarify and more fully explore aspects of on-going plate-boundary processes that create the structural rims of oceans generally and, more specifically, the rock fabric of modern north Pacific and Bering Sea margins.

Tectonic History and Synchronicity

During the past 200 my relative northward movement between the margins of the North American plate and differentially moving north Pacific oceanic lithosphere has been as much as 10,000-15,000 km (Engebretson, Cox and Gordon, 1984, in press; see cover). This realization prompted most Conference attendees to suppose that the plate tectonic history of the oceanic north Pacific must be a dominant factor controlling the evolution of its margins—or vice versa (Figures 3, 4 and 5). Although it was not felt that the tectonic chicken-and-egg question could be fully resolved, drilling objectives keyed on:

(1) determining if synchronuity could be established between the times of major oceanic plate reorganization and the times of major ocean margin tectonic transitions: from subduction to transform or passive margin, or from the dominance of subduction erosion and sediment subduction to that of subduction accretion (Figure 4), and

(2) determining the movement histories of large sediment bodies—especially the terrigenous fans of the Gulf of Alaska and those bordering central and northern California—and the more massive tectonostratigraphic terranes transported along or adjacent to the transform margins of western North America (Figure 5).

Boundary Processes

Plate boundary processes continue to forge the structural fabric of modern north Pacific and Bering Sea margins. Greatest interests were shown in drilling objectives proposed to investigate geologic circumstances that:

(1) structurally fashion and attach large accretionary wedges to the landward slope of the Aleutian Trench (Figure 6),

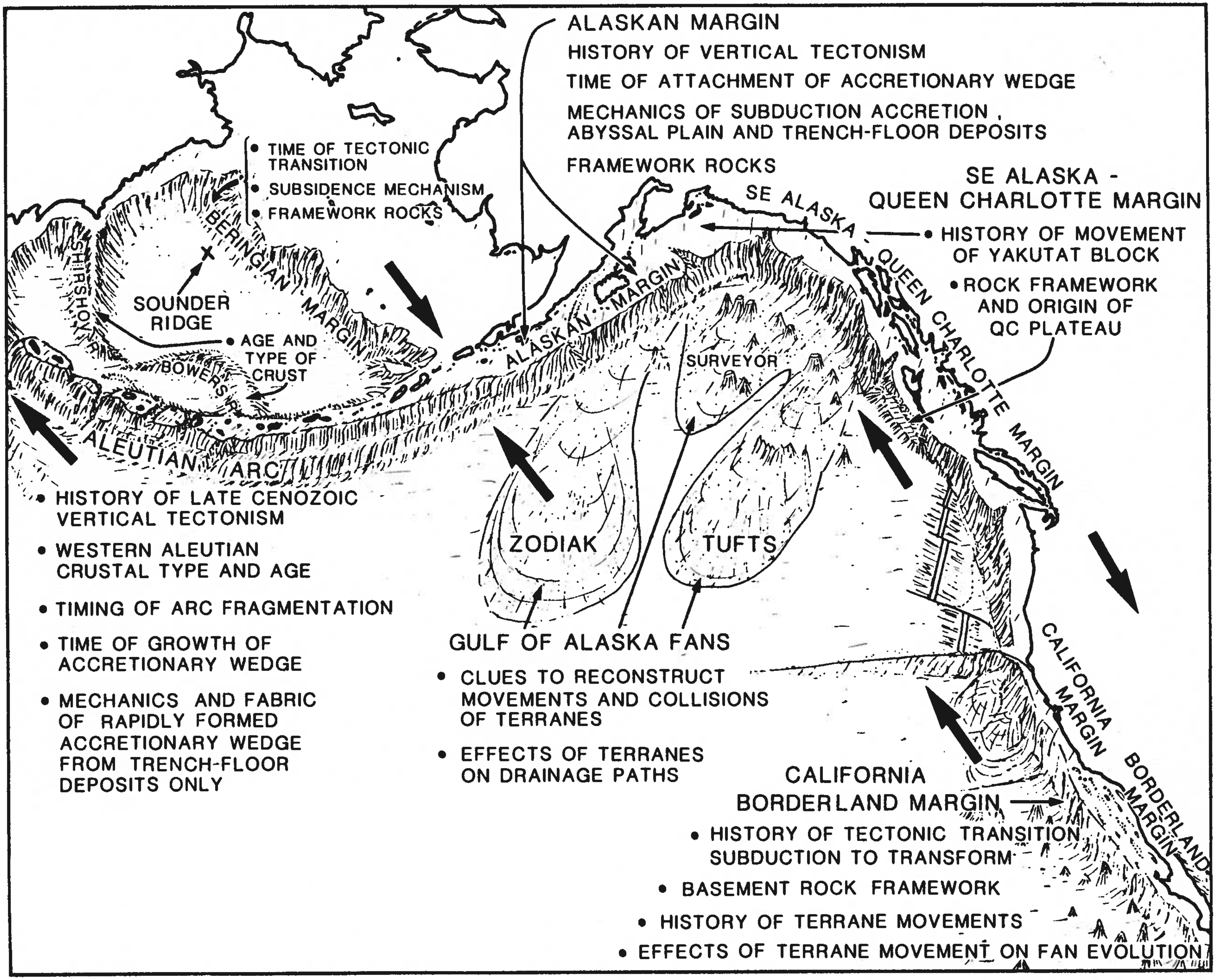

FIGURE 3. Generalized index map of NORPAC margins, Beringian margin to Baja California, with annotations describing major tectonic drilling objectives concerned with resolving past history and on-going processes.

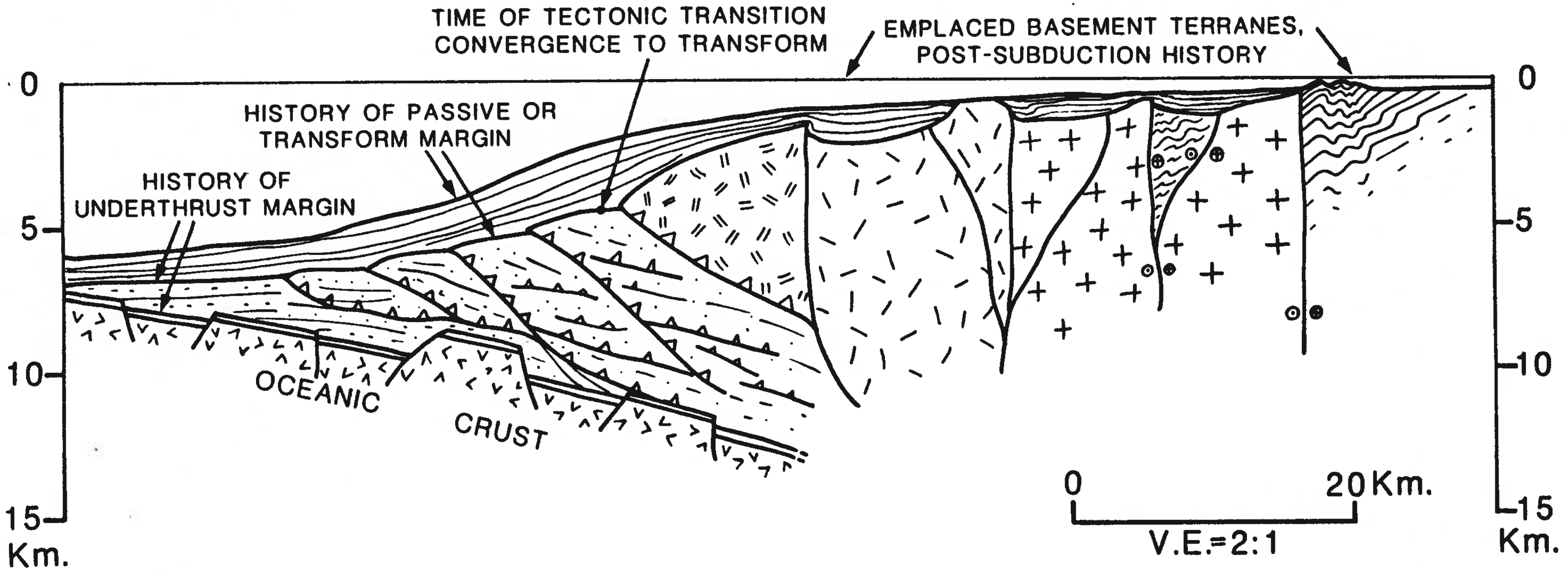

FIGURE 4. Idealized section showing structures of a continental or island-arc margin that has passed through a tectonic transition from an underthrust to a strike-slip plate-boundary setting. The Beringian margin of the Bering Sea and the Pacific's California margin are thought to record such a transition. Drilling to examine the sedimentary sequences and basement blocks of these margins has been recommended as essential to efforts to reconstruct their evolution, especially vis-a-vis the history of oceanic plates that have occupied parts of the Pacific in Mesozoic and Cenozoic time.

(2) condition the outbuilding of continental and island-arc margins by processes of subduction accretion,

(3) truncate the rock fabric of margins in the face of convergent settings,

(4) influence or cause vertical tectonism and related deformation of the outer shelf and slope structurally above the subduction zones (Figure 6),

(5) cause and control the timing and polarity of regional vertical tectonism along passive and transform margins, and

(6) seemingly cause regional synchronuity of neotectonic events recorded along Alaskan, Bering Sea, and western North American margins, despite great differences in contemporary tectonic setting.

Regional Discussions

Beringian Margin—Passive

Two dominant themes—that ought to be investigated by ODP drilling—emerged during the Conference concerning the tectonic history of the Beringian margin (area 10, Figure 2). This margin, about the length of California, stretches northwestward from the tip of the Alaska Peninsula to the vicinity of Cape Navarin, eastern Siberia (Figure 3):

(1) the time of tectonic transition from a presumed Mesozoic through early Tertiary setting of oblique strike-slip convergence with the Pacific's Kula plate, to that of the modern, nearly passive backarc setting (Figure 4), and

(2) the post-transition history—as a clue to the cause—of the vertical subsidence of the margin, especially in the vicinity of the Siberian coast and south of the Pribilof Islands, where industry data is available from outer shelf exploration wells (Figure 2).

It is important to realize that prior to the formation of the offshore Aleutian Island Arc, the Beringian margin was the Pacific's northern rim (Marlow and Cooper, 1983; Scholl, Vallier and Stevenson, in press). Thus the importance of dating the transition time is linked to determining the initial formation age of the Aleutian Arc, which has shielded the margin from direct interactions with northward moving oceanic lithosphere.

Although not strictly a tectonic problem of the Beringian continental margin, determining at least the minimum age of the adjacent crust of the Aleutian Basin is importantly needed to reconstruct the evolution of the entire north Pacific margin in Mesozoic and early Tertiary time (Scholl, Buffington and Marlow, 1975; Cooper, Scholl and Marlow, 1976; Ben-Avraham and Cooper, 1981). Hence drilling to determine the age of Sounder ridge, a sediment buried seamount in the Aleutian Basin seaward of the base of the margin (Cooper et al., 1979), was strongly recommended.

Interest was also expressed in more directly determining the crustal age, and origin and tectonic implications of Shirshov and Bowers Ridges (Cooper, Marlow, and Ben-Avraham, 1981; Ben-Avraham and Cooper, 1981), which extend away from the margins of the Bering Sea Basin and cordon it into three subbasins (Figure 3).

Since the time of tectonic transition—probably in Eocene time (Scholl, Vallier, and Stevenson, in press)—the Beringian margin has subsided 2-4 km, and very large outer shelf basins have

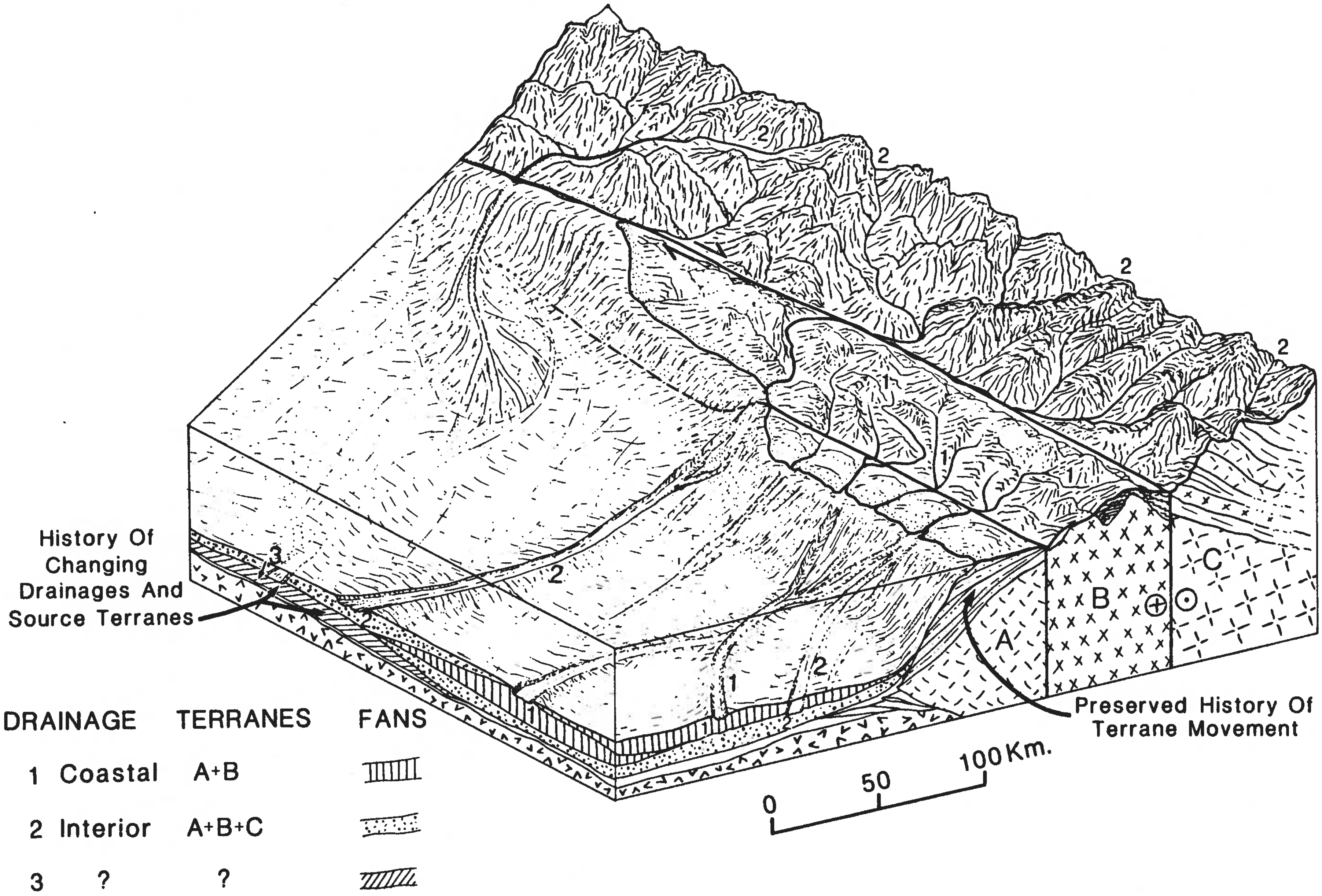

FIGURE 5. Cartoon sketch of a strike-slip margin showing relative movement of oceanic plate and attached terranes of continental crust relative to stable interior. History of movements of terranes, for example A, is preserved in sedimentary deposits underlying its continental slope. Evidence of changed or unchanged source regions for deep-sea fan deposits provides additional information bearing on terrane movements and potential consequent shifts in drainage outlets.

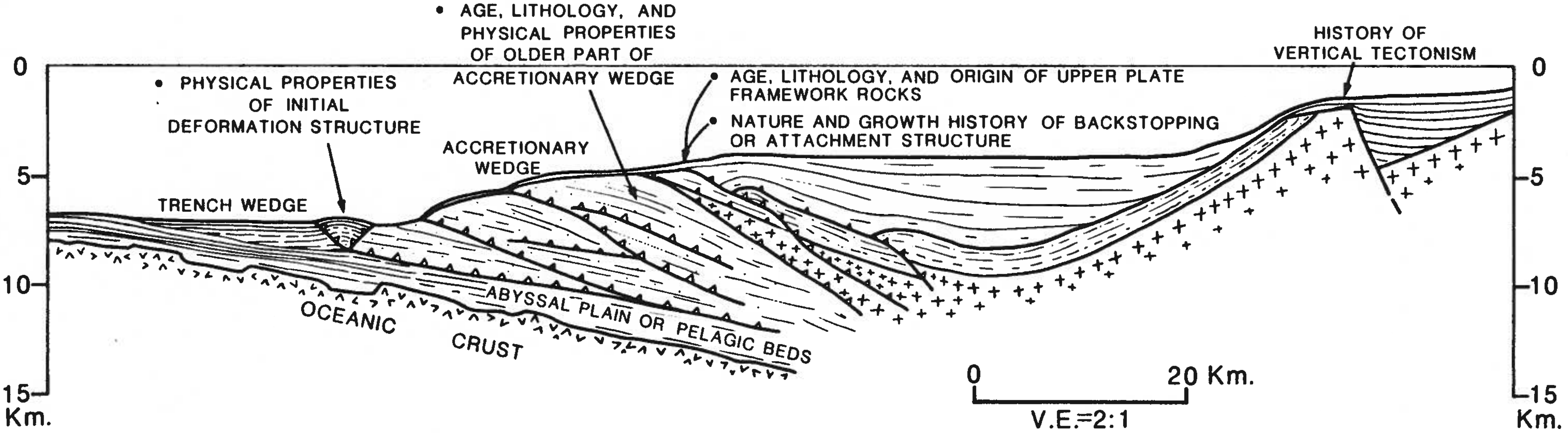

FIGURE 6. Cartoon sketch of accretionary wedge growing against, and being attached to, the older rock framework of a Pacific continental or island-arc margin. ODP sites were proposed to investigate the physical state of initial deformation structures, older ones higher on the landward trench slope, the age of the accretionary body, the nature and rock-types involved in the backstopping or attachment structure, and the effects of subduction accretion on the formation of up-slope basins and their vertical tectonism.

formed (Marlow and Cooper, 1980; Marlow et al., 1982) The cause of subsidence is unknown, although rifting along a transform margin is suspected (Marlow et al., 1982). But, important clues to this process can be acquired by sampling its sedimentary sequences, which must preserve evidence of its subsidence history.

Aleutian Margin—Active Oblique Convergence

ODP drilling along the Aleutian Arc (especially in the vicinity of area 6, Figure 2), a Cenozoic magmatic pile with an attached accretionary wedge (Scholl, Vallier, and Stevenson, 1983), was proposed to investigate tectonic questions and processes concerned with:

(1) determining when it's late Cenozoic history of accelerated subsidence and framework fragmentation began, and whether these events are coeval with similar ones recorded on the Alaskan margin to the east, and whether they are related to predicted late Cenozoic changes in age of crust underthrusting the arc and direction and speed of convergence,

(2) determining the age of a massive accretionary wedge, its attachment structure (backstop structure) to the arc, and the temporal relation of the wedge to the formation of the very large forearc basin of the Aleutian Terrace (Figure 6), and

(3) determining the growth history, physical state, and tectonic fabric of the upper part of a massive accretionary wedge that is forming along a rapidly converging plate boundary thickly (2-4 km) sedimented by trench-floor deposition (Figure 6).

An important aspect of determining the age—and related structural style—of the accretionary wedge concerns testing the notion that the subduction complex is a late Cenozoic structure only added to the arc when the glaciated drainages of the Gulf of Alaska flooded the trench with turbidite deposits toward the end of Miocene time (McCarthy and Scholl, 1985). Thus late Cenozoic tectonism along the Aleutian forearc may be related to sedimentation rather than changes in the kinematics of convergence.

Alaskan Margin—Active Normal Convergence

ODP drilling along the southern or Pacific margin of Alaska (Figure 3, and area 8, Figure 2) were proposed to investigate regional tectonic problems concerned with determining or clarifying:

(1) the late Cenozoic history of vertical tectonism (Figure 6) on the margin relative to subduction of the Farallon-Pacific spreading ridge, increased rates during Eocene underthrusting, and the later collision and partial subduction of the Yakutat Block (von Huene et al., 1985a),

(2) the structure and rock fabric of the upper continental slope along key sectors that are parts of other transect-related crustal studies and on-land drilling (von Huene et al., 1985b,

(3) the age and attachment structure—to older crustal rocks—of the Alaskan accretionary wedge, and the age of the erosional episode that preceded the present phase of subduction accretion (von Huene, 1983), and

(4) the physical properties of the strata involved in early-stage accretionary structures, especially downhole porosity, pressure, and material-strength measurements (Shin and Wang, 1985; Figure 6).

Because the geometry of early-formed deformational structures in the growing accretion wedge have been clearly resolved on research-level processed multichannel reflection profiles (von Huene et al., 1983; Figure 6), it is possible to deduce the strength and physical state of the deforming strata. But in-situ measurements are critically needed not only to verify these deductions, but also to test and calibrate theoretical models describing the physical state of sedimentary sequences being conveyed into the subduction zone.

Eastern Gulf of Alaska-Queen Charlotte Margin—Active Transform

Conference attendees, aware that the clumping of large crustal blocks—tectonostratigraphic terranes—had constructed much of the rock fabric of southern Alaska and the connecting coastal ranges of British Columbia (Howell et al., 1985; area 9, Figure 2), requested drilling to investigate:

(1) the history of movement of the Yakutat block (Figure 3), which, along its trailing edge or continental slope, preserves a lower, middle, and upper Tertiary section recording it northward passage and collision with Alaska (Keller et al., 1984; Figure 5), and

(2) the lithology and sedimentary history of the large fans of the Gulf of Alaska, in particular Zodiac fan and the Baranof fan complex that includes Surveyor and Tufts Fans (Stevenson, Scholl, and Vallier, 1983), and

(3) the rock composition and history of origin and movement of the Queen Charlotte Terrace (Figure 3; Yorath et al., 1985), a terrane of probable continental apron deposits or subduction complex that is presently underway toward Alaska and potential collision with the Yakutat block.

It is important to emphasize that the large "oceanic fans"/ of the Gulf of Alaska—Zodiac fan, Surveyor fan, and Baranof fan complex—which were, or are, nourished by source regions landward of SE Alaska-Queen Charlotte transform boundary, shared much of the same relative motion as the fragments of crustal terranes. Thus, exceptionally important clues regarding their movement, and their effects on modulating sources feeding the offshore fans, are contained in the Eocene through Holocene terrigenous deposits underlying the gulf's abyssal plains (von Huene et al., 1985a; Figure 5).

California Margin and Borderland—Complex Transform Margin

The California margin (area 4, Figure 2) was converted from a dominantly convergent to a complex transform boundary in early Tertiary time (Atwater, 1970; Biddle and Seely, 1983; Figure 4). Thus most of the tectonically oriented drilling objectives proposed for this margin concerned addressing:

(1) the timing of the tectonic transition—especially the northward transit of the Mendocino triple junction—in key areas along the central California margin, and

(2) the identification of basement rock types, and the lithostratigraphic terranes they represent, at a number of northern, central, and borderland sites.

It should be emphasized that identifying the rock character of tectonically distinct basement terranes underlying sediment-buried parts of the margin will provide information critical to reconstructing its structural evolution (Howell et al., 1985), especially, during its transform-boundary history. Part of the history and effects of the northward translating terranes is recorded in the sedimentary masses of the large central and northern California deep-sea fans, in particular the Monterey and Delgada Fans. Because they would provide important clues to the tectonic evolution of the California margin, drilling sites were proposed to determine the age and time-varying composition of these fans.

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North Pacific and Bering Sea Basins

Introduction

Oceanic crust of the north Pacific offers a history of plate tectonics for the past 180 million years (Engebretson, Cox and Gordon, 1984). Any and all hope for deciphering the importance of oceanic-continental plate interactions in the geologic development of western North America and eastern Eurasia depends critically on future high-quality observations from this area. Alone, the northern Pacific plate holds the record of the origin and displacement of ancient plates that occupied this region throughout the Mesozoic and Cenozoic eras (Woods and Davies, 1982; Rea and Dixon, 1983. Although dominated by subduction at the margins, every conceivable style of plate boundary has probably operated along the rims of the north Pacific. Moreover, processes involved in the development of oceanic crust at the spreading centers can be studied within this oceanic realm.

Recent advancements in understanding the growth of continents through the accretion of allochthonous terranes are also closely linked to the displacement histories of oceanic plates (Howell et al., 1985). The discovery of acceptable scenarios for the origin and travel of allochthonous terranes depends heavily on the ability to model plate interactions within the Pacific basin. Former oceanic plates of the basin provide the transport system necessary to account for thousands of kilometers of movement of terranes relative to the continents (Engebretson, Cox and Gordon, in press). Possibly the best studied oceanic-continental orogen of the world is the western North America Cordillera and its tectonic evolution has been influenced, if not controlled, by the interaction of oceanic plates that were once adjacent to the Pacific plate. Our greatest hope for a better understanding of orogenic processes in western North America and eastern Eurasia lies in the northern regions of the Pacific plate. We outline in this section some of the most important areas of the north Pacific that require data obtainable only through drilling.

Tectonic Evolution

Figures 7 through 10 show preliminary reconstructions of the North Pacific at selected times. Paleopositions of the North American, Eurasian, and Pacific plates were obtained from hotspot tracks and the record of seafloor spreading in the north Atlantic (Engebretson, Cox and Gordon, 1984, in press). The locations of oceanic plate boundaries were derived solely from magnetic isochrons and fracture zones presently preserved on the Pacific plate. Any attempts to reconstruct tectonic histories within the Pacific basin depend almost entirely on understanding the ages and geometries of hotspot tracks, fracture zones, and magnetic isochrons found on the Pacific plate today.

Drilling Objective: Ages of Magnetic Anomalies

A critical factor in deciphering important episodes in the tectonic history of all ocean basins is knowing accurately the true ages of reversals of the Earth's magnetic field. Relatively few basement ages are available to tie the magnetic reversal sequence to absolute ages. Thus, any drill hole that penetrates into basement, especially within area 7 of Figure 2, will provide vital information for correlations using the magnetic time scale.

Drilling Objective: Hawaiian-Emperor Seamount Chain

The north Pacific hosts what is probably the most complete hotspot track in the world. The Hawaiian-Emperor chain contains a record of displacement over the hotspot reference frame from the present back to the Late Cretaceous. Two major questions are resolvable through drilling. One is concerned with the paleo-latitudinal stability of this hotspot for the past 75 million years. A drill hole near the bend in the chain (approximately 43 Ma, area 1 of Figure 2) and one near the northern end (approximately 75 Ma, area 5 of Figure 2) in conjunction with paleomagnetic determinations and radiometric ages should answer this question. A second study could be directed toward understanding the origin of the hotspot. The location of the hotspot at 80 Ma ("H" of Figure 9) indicates the close proximity of the Pacific-Kula ridge. If this hotspot was generated at the Pacific-Kula ridge, then a drill hole on one of the northernmost seamounts and one in the crust nearby would show nearly the same ages. Careful choice of the seamount could also establish the validity of extending the Emperor trend further back in time.

Drilling Objective: Plate Geometries Within the Cretaceous Normal Superchron (119 to 83 Ma)

The absence of reversals in the Earth's magnetic field between 120 and 80 Ma has led to a "blind spot" in understanding the tectonic evolution of the northern Pacific. Drill holes within areas 1, 2, 3, and 5 of Figure 2 are appropriate for addressing this important time interval. Recently, several authors have proposed a variety of plate geometries and spreading histories for the Superchron (for example, Woods and Davies, 1982; Rea and Dixon, 1983; J. Mammerickx and G Sharman, personal communications, 1985). Figures 9 and 10 show what is probably an oversimplified scenario. Additional plates and alternative geometries probably existed within this time interval and the only hope for resolving the nature and timing of plate motions and geometries lies in data obtainable from drill holes. Major reorganizations occurred in the Pacific basin and along its margins within the Cretaceous Superchron so any new information will contribute significantly to these questions.

Drilling Objective: Origin, Travel, and Arrival of the Bering Sea Plate

It has been postulated that the Bering Sea plate (area 10 of Figure 2) originated far to the south of its present position in the Early Cretaceous, travelled northward, and was accreted to North America in the early Tertiary (Scholl, Buffington, and Marlow, 1975; Cooper, Scholl, and Marlow, 1976; Ben-Avraham and Cooper, 1981). Poorly-preserved magnetic isochrons within the Aleutian Basin of the Bering Sea Basin should be drilled in order to establish their true ages and paleolatitudes. Such information would provide key data for unravelling not only the history of the Bering Sea plate but also that of the Beringian margin (Figure 3) and the timing of the inception of subduction beneath the Aleutian Arc. If the basin's sedimentary sequence is too thick (typically $>$ 3 km) to reach igneous crust, then at least its minimum age should be determined by drilling to the igneous top of one or more buried seamounts—for example, Sounder Ridge (Figure 3).

Drilling Objective: Geometry and Timing of Plates in the Late Cretaceous and Early Tertiary

About 80 Ma (Figure 9) major reorganizations took place in the north Pacific (Woods and Davies, 1982; Rea and Dixon, 1983). These reorganizations included the birth and death of spreading centers and probable changes in the motion of all of the interacting plates. Drill holes within areas 2 and 3 of Figure 2 will provide essential information for this time interval. Coincident with these reorganizations are a series of tectonic changes recorded in the geologic record along the western margin of North America. Important questions concerning both the relative motions of plates and the locations of plate boundaries remain for the tectonic evolution of the north Pacific. Paleomagnetic data from terranes within the Pacific rim suggest large-scale transport during this interval. Carefully selected drill holes within areas 2 and 3 of Figure 2 will help establish plate geometries and spreading histories for comparison with geologic evidence found on the continents.

At about 56 Ma (Figure 8) the relevant plates of the northeast Pacific basin were the Pacific, Farallon (possibly as several plates) and Kula. Magnetic isochron data from area 7 of Figure 2 has indicated a possible acceleration of Pacific-Kula spreading at about chron 25 (56 Ma). A drill hole is needed within the "T" shaped anomaly (see Figure 7, just south of the Aleutian Arc) to substantiate or refute the claim of rapid movement of the Kula plate (Engebretson, Cox and Gordon, 1984). This rapid Pacific-Kula motion results in very fast and oblique convergence of the Kula plate along western North America. If true, this period of accelerated velocities may account for the far-travelled nature of many allochthonous terranes now found in the Circum-Pacific margins.

Summary

The north Pacific supplies a laboratory for studying possible correlations between tectonic events in the oceanic realm and those along plate margins. Our most important hope for accurate reconstructions of oceanic and continental plates resides in an understanding of the evolution of the Pacific plate and the remnant fragments of others. The only direct record of oceanic plate geometries along western North America and eastern Eurasia during the Mesozoic and Cenozoic exists within the north Pacific. We, therefore, need new data obtainable only through ocean drilling.

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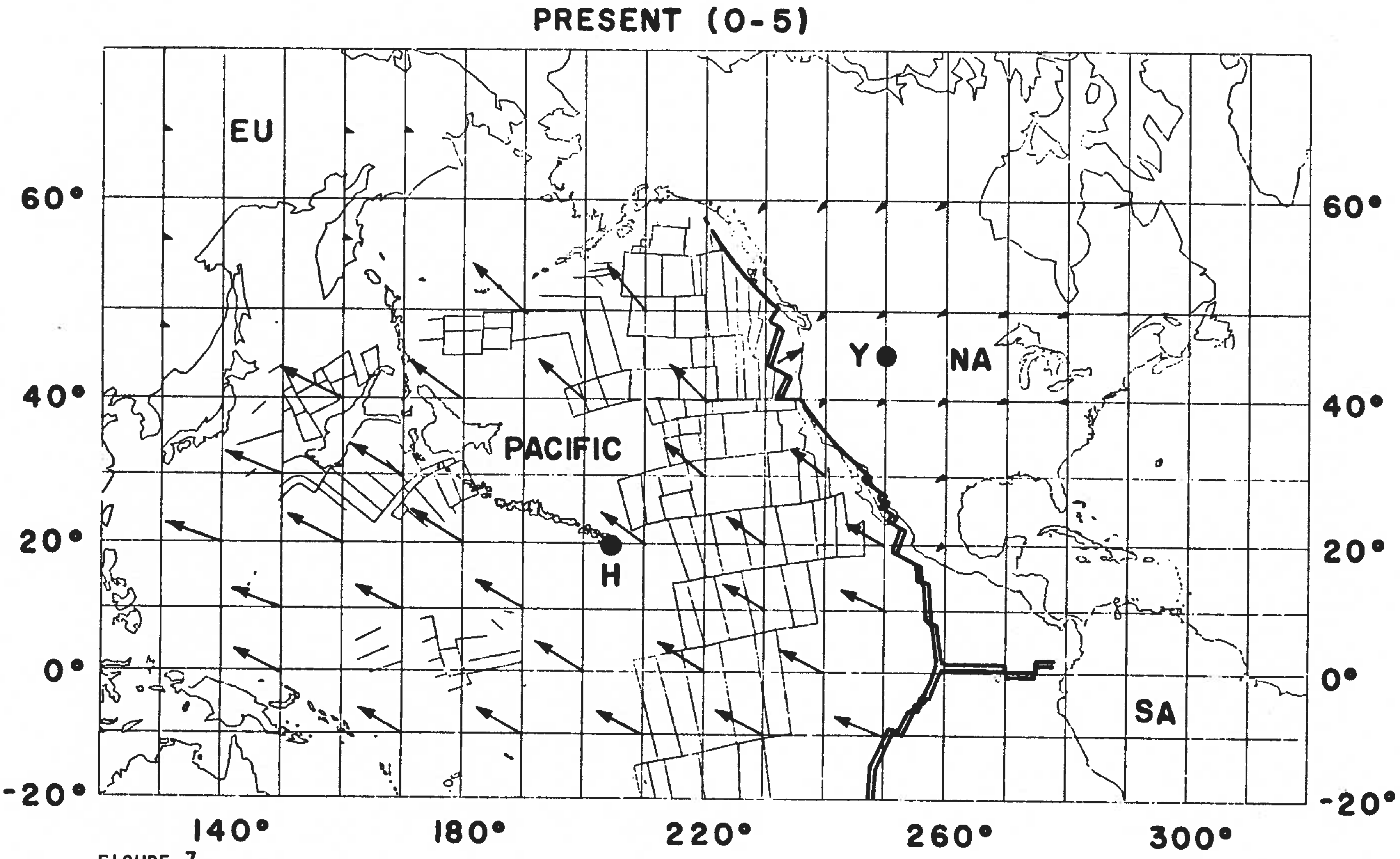
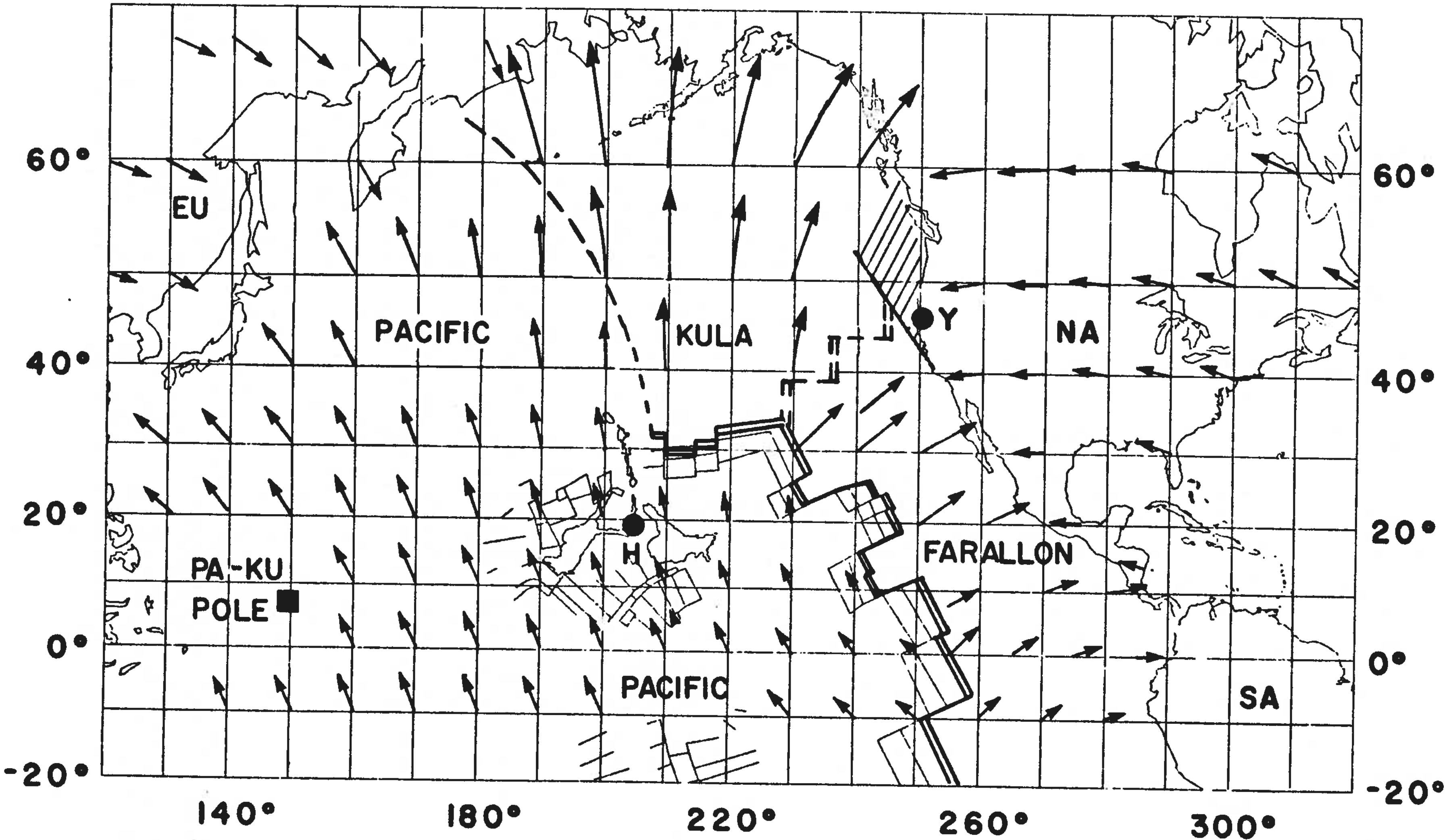
FIGURES 7-10. Reconstructions in fixed hotspot reference frame. Double heavy lines: ridge boundaries between oceanic plates (dashed where inferred). Single heavy lines: transform boundaries (dashed where inferred). Arrows: motion of plates through a 10 m.y. time interval appropriate for the times shown in parentheses. Dots: locations of Yellowstone (Y) and Hawaiian (H) hotspots, assumed fixed. Diagonal shading: lithosphere that may have been Farallon or Kula plate. Barbed area: inferred island arcs—solid barbs when active; open barbs when inactive. Squares: location of Euler stage poles. SA: South American plate. EU: Eurasian plate. NA: North American plate.



PRESENT (0-5)

FIGURE 7



56 Ma (56-61)

FIGURE 8

80 Ma (74-85)

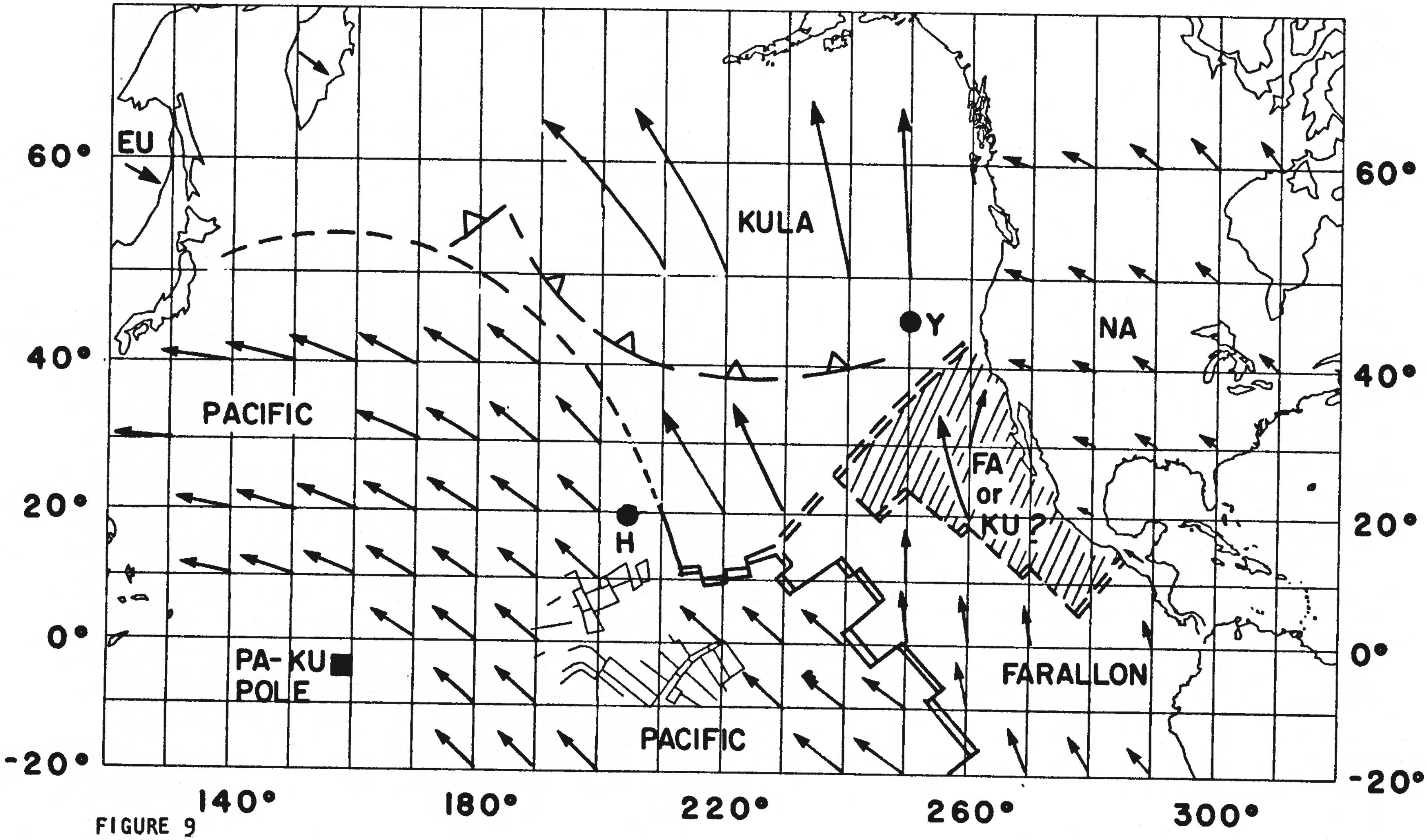


FIGURE 9

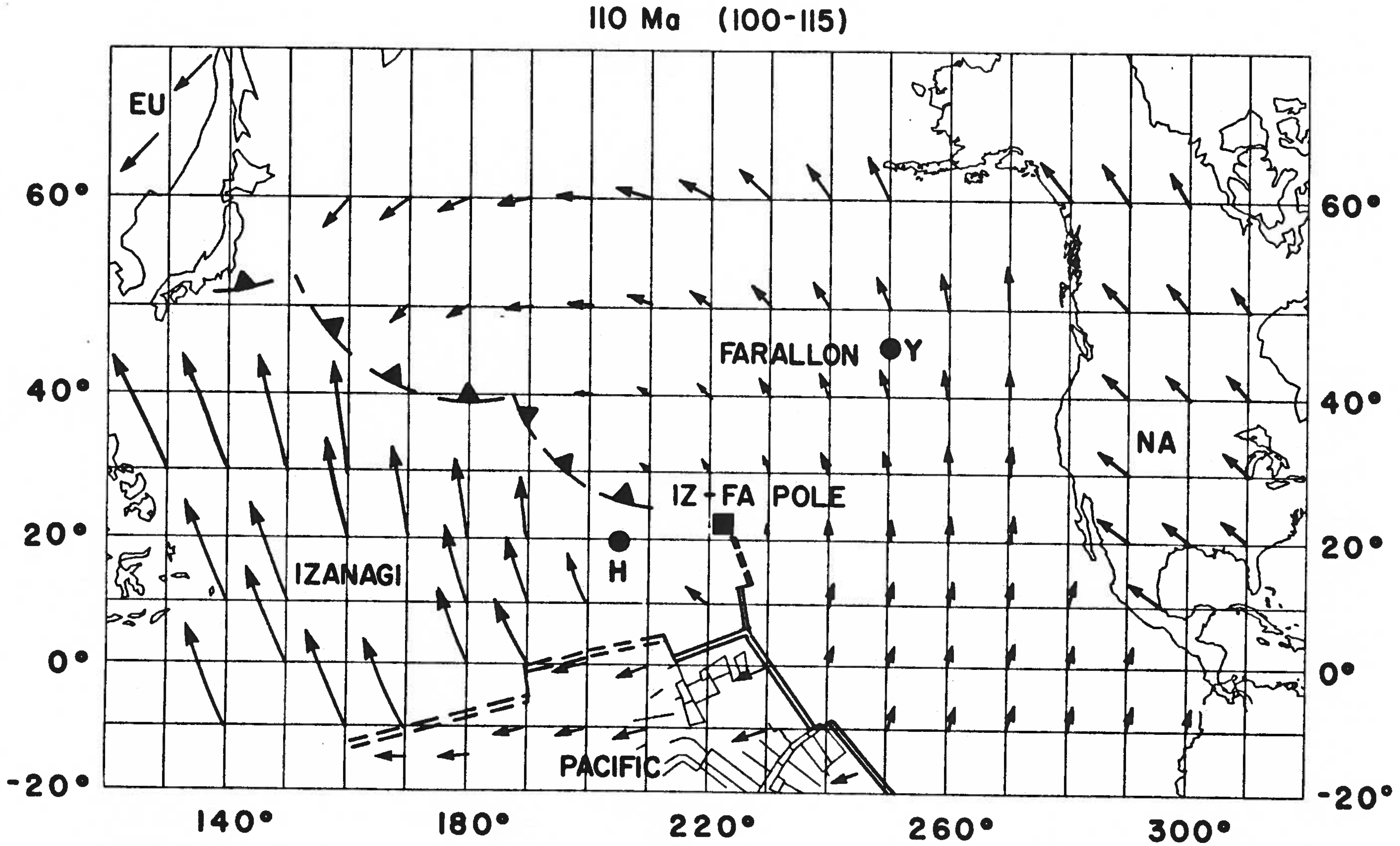

110 Ma (100-115)
EU
FARALLON
Y
NA
IZ-FA POLE
H
IZANAGI
PACIFIC
60°
40°
20°
0°
-20°
140°
180°
220°
260°
300°

FIGURE 1Q

DEPOSITIONAL HISTORIES AND PROCESSES

Ocean Basins and Margins Histories

Introduction

Mesozoic and Cenozoic sediments blanketing the North Pacific Ocean and Bering Sea contain an unparalleled record of ocean history in a region encompassing almost one third of the global ocean. Despite the obvious importance of this record for our understanding of both regional and global events, it remains largely unexplored and little understood due to (1) the surprisingly small number of previous deep sea drilling sites relative to the immense size of the region (Figure 1) and (2) the largely discontinuous and disturbed nature of early DSDP drilling and associated poor core recovery. Indeed, only three sites (173, 183, and 192) out of all sites drilled during DSDP legs 6, 18, 19, 32, 55, and 56/57 were continuously cored, a situation only recently reversed with HPC drilling during IPOD Leg 86 in the equatorial Pacific.

Thus, what little is known of sediment and ocean history in the north Pacific has been pieced together from a decidedly fragmentary record skewed toward sites atop seamounts and along the eastern Pacific margin (Figure 1). Virtually the entire central North Pacific and the bulk of the Bering Sea lie undrilled. Despite this state of affairs, analysis of older DSDP sequences, correlative onshore continental margin sequences, and available seismic reflection records have provided tantalizing glimpses of the dynamic paleoceanographic and depositional histories available in this region.

For instance, DSDP sites in the eastern north Pacific and beneath the North Pacific Front have revealed excellent Pliocene and Pleistocene histories which detail the onset of Northern Hemisphere glaciation, glacial cycles, and associated sea level fluctuations including expanded records of these events in the thick wedges of terrigenous debris that sit astride the continental margins. Early drilling has also illustrated that virtually no middle Miocene or Oligocene sediments are preserved over much of the deep north Pacific indicating major changes in deep water character and circulation during these periods (Figure 11). In contrast, DSDP sites along the California margin penetrated thick middle and upper Miocene diatomaceous and siliceous facies correlative with the much studied and widespread Monterey Formation onshore; this limited information nonetheless greatly improved correlation of oceanic and margin biostratigraphies and sediment history.

Fragmentary records of older Eocene sediments and Oligo-Miocene chalks have been recovered from the northwest Pacific and Gulf of Alaska indicating the presence of an extensive high latitude Paleogene record in this region. In addition, dredged sediments from the Gulf of Alaska have revealed the presence of subtropical faunas in juxtaposition with coeval, cool high latitude faunas suggesting a complex micrterrane story only drilling can clarify. Of paramount importance, the Paleogene record in this region will allow recovery of mid and high latitude biostratigraphic reference sections and direct faunal evidence of surface and deep circulation prior to separation of the Bering Sea and north Pacific Basins by the Aleutian magmatic arc.

Early drilling targets in the north Pacific included the Mesozoic sediments atop the Shatsky and Hess Rises and the Emperor Seamount chain. These sites indeed yielded mid Cretaceous through Cenozoic sequences including the Cretaceous/Tertiary boundary along with evidence of northward plate motion during this period. However, a truly well preserved Cretaceous biostratigraphic reference section has yet to be drilled in a bona fide pelagic setting despite the fact that Lower, middle, and Upper Cretaceous sediments are known to be present in the northwestern Pacific. The notorious cherts on Shatsky Rise have repeatedly foiled attempts to recover the Lower Cretaceous sediments in this area and volcanogenic debris on the flanks of Hess Rise have yielded valuable but diluted Cretaceous faunal recorded there. What is needed are true pelagic

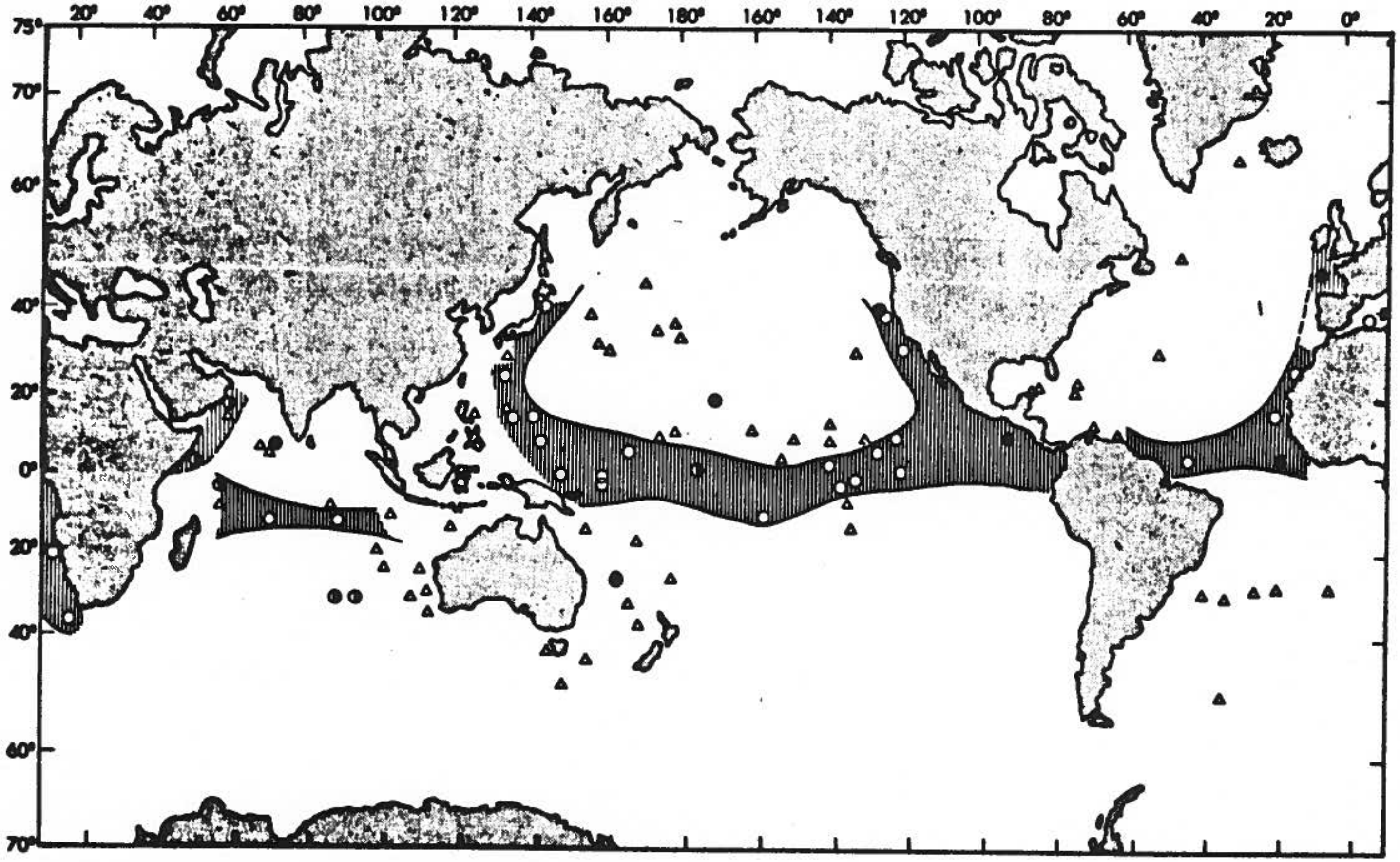


Figure 11. Distribution of mid Miocene hiatus NH-2 (16-15 Ma) of Keller and Barron (1983) in the world ocean. Note that triangles represent deep sea drilling sites where sediment of this age is missing whereas stippled areas represent areas where mid Miocene high productivity facies are present. Carbonate dissolution and erosion of these sediments in the central North Pacific imply major changes in deep water mass character and circulation in this region during this period. Alternately, the simultaneous appearance of mid Miocene diatomaceous muds along the margins of the North Pacific including the Monterey Formation of California, signal a change in surface circulation and upwelling in these regions. Figure from Keller and Barron (1983).

Cretaceous sequences—given plate constructs these sorts of records are likely available in the northwesternmost Pacific and in the Bering Sea. Potential Cretaceous targets also include sites aimed at addressing Late Cretaceous plate reorganization including the birth of the Kula and Chinook plates with associated pelagic sequences likely yielding an improved Cretaceous biostratigraphy.

Our current notions regarding the evolution of the Bering Sea have largely been derived from dredges and cores taken by the USGS and limited drilling during DSDP Leg 19 in 1971. These scanty data, along with more recent seismic reflection records and COST wells, indicate that Cretaceous, Paleogene, and Neogene sequences can likely be penetrated in the Bering Sea providing here-to-fore unavailable paleoceanographic and depositional records of this sea as it became tectonically isolated from the Pacific. It is fair to say that there is no higher priority among paleoceanographic and biostratigraphic workers today than recovery of high latitude faunal records and the Bering Sea constitutes a prime target in this regard. Thus, NORPAC's interest and enthusiasm for drilling in the Bering Sea cannot be overstated with our special concerns focused on the age and evolution of the Aleutian Arc and its effect on north Pacific surface and deep circulation, divergent evolution of Bering Sea and Pacific faunas and floras, potential evidence of older Arctic climatic history, and recovery of high latitude biostratigraphic reference sections.

Drilling Objectives

The NORPAC workshop identified four major ocean and sediment history objectives to be achieved by drilling in the north Pacific Ocean and the Bering Sea. These included: (1) development of biostratigraphic reference sections, (2) evidence bearing on paleoclimates, (3) paleoceanographic history and evolution of the north Pacific, and (4) tectonic history of macro- and microterranes of the north Pacific.

Significantly, the first three of these objectives overlap with those identified by the INPAC working group concerned with drilling in the northern Pacific Ocean-Juan de Fuca Ridge area; cooperative discussions between these two groups are in progress with the aim of coordinating drilling proposals in this area. Drilling objectives include the following:

Development of Biostratigraphic Reference Sections

1. Middle and high latitude Neogene, Paleogene, and Cretaceous sequences.
2. paleomagnetic stratigraphy of pelagic and margin sequences.

Biostratigraphic reference sections are the backbone of ocean history in that they provide a time frame into which climatic, tectonic, and ocean circulation events can be placed (Figure 11). A major NORPAC goal involves selection and drilling of a series of Mesozoic and Cenozoic reference sites across mid and high latitudes in areas of pelagic sedimentation. Although these sites will ideally include sediments deposited above the CCD we also envision recovery of key sequences in areas of red clay deposition for the purpose of determining the eolian history known to be housed in these sediments.

At present, north Pacific biostratigraphy is the least well established in any major ocean basin due primarily to the absence of continuously cored drilling sites. In fact, only DSDP Site 173 off Cape Mendocino, California, was continuously cored through the Miocene. This site con-

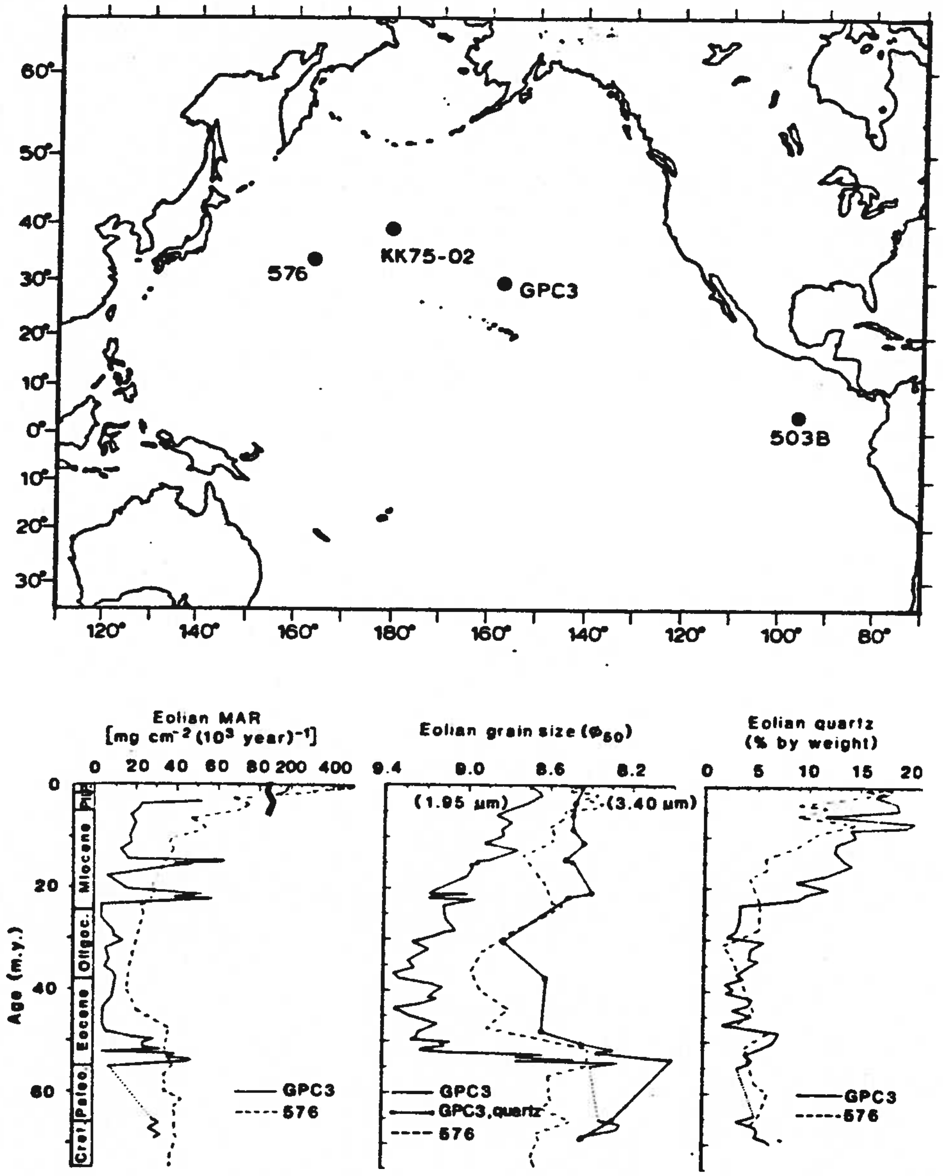


Figure 12. Mass accumulation rates of dust grains, variations in grain size distribution, and variations in the percent of eolian quartz in the Cretaceous to Recent red clay sequence of core GP33 from the central North Pacific. Analysis of wind borne detritus offers a new paleoclimatic tool and a means of assessing the history of atmospheric circulation and variations in climate of source areas in the North Pacific. NORPAC goals include drilling in red clay areas to extract this record. Figure from Rea, Leinen, and Janecek (1985).

tinues to serve as the key middle latitude reference section for the Neogene of the north Pacific despite poor recovery and major gaps in coverage. Of special concern to NORPAC is the fact that no middle Cenozoic through Mesozoic reference sections exist north of 30°N latitude in the Pacific. As a consequence, the paleoceanographic and paleoclimatic histories of this vast region remain essentially unknown.

The absence of well-established biostratigraphic and paleoceanographic histories also adversely affects interpretation of the tectonic history of the north Pacific region. Prior to about 45 Ma the accumulating pelagic blanket was carried rapidly northward with Pacific plate motion. Thus, the early Tertiary biostratigraphic record preserves a history of northward passage beneath increasingly higher latitudes and hence cooler surface waters. This aspect of the biostratigraphic record has already played a role in interpreting the history of microterranes in the Gulf of Alaska region and we anticipate more detailed records will enhance our ability to pinpoint plate motion in time and space. As noted earlier, Cretaceous biostratigraphies are also lacking in this region and we are committed to identifying likely sites for recovery of Lower, mid, and Upper Cretaceous sequences in both the north Pacific and Bering Sea. Although plate history dictates that much of the Cretaceous record in this region was originally deposited at lower latitudes, it remains a key objective and one necessary for proper analysis of Pacific history.

Evidence of Paleoclimate

1. Milankovich cycles of Pliocene and Pleistocene and perhaps older sediments.

2. Onset of northern hemisphere glaciation including onset of ice rafting and detailed analysis of ice rafted facies as a test of computer models of ice-cap growth and decay.

3. Early Tertiary climate at mid and high latitudes with indirect evidence of Arctic Sea history from Bering Sea sediments.

4. Cretaceous equatorial and mid latitude climate from northernmost Pacific and Bering Sea deposits.

5. Evidence of fertility changes and carbonate dissolution.

6. Fluctuations in the CCD.

7. Onset and history of bottom water formation in the northern Pacific.

8. Cretaceous-Cenozoic history of eolian/atmospheric phenomena as recorded in red clay sequences of the deep Pacific.

The most detailed studies of Cenozoic paleoclimate to date have been concentrated in the Southern Hemisphere and concerned with the development of circum-Antarctic circulation and the history of Antarctic glaciation. Much less is known about the climatic development of the Northern Hemisphere and initiation of glaciation in the Arctic region. Indeed, no detailed climatic studies have been completed on either high latitude north Pacific or Bering Sea sediments. Sedimentary sequences in these areas contain key information bearing on the history of both oceanic and atmospheric circulation of this region including direct evidence of the onset of glaciation and details of glacial cycles. It is far from clear when initial glaciation occurred in the Alaskan region, with controversial drop stones identified in Miocene marine sequences in the Gulf of Alaska region. Recovery of Neogene and Paleogene sediments in the north Pacific will provide both lithologic and faunal evidence bearing on these sorts of questions and allow a climatic record

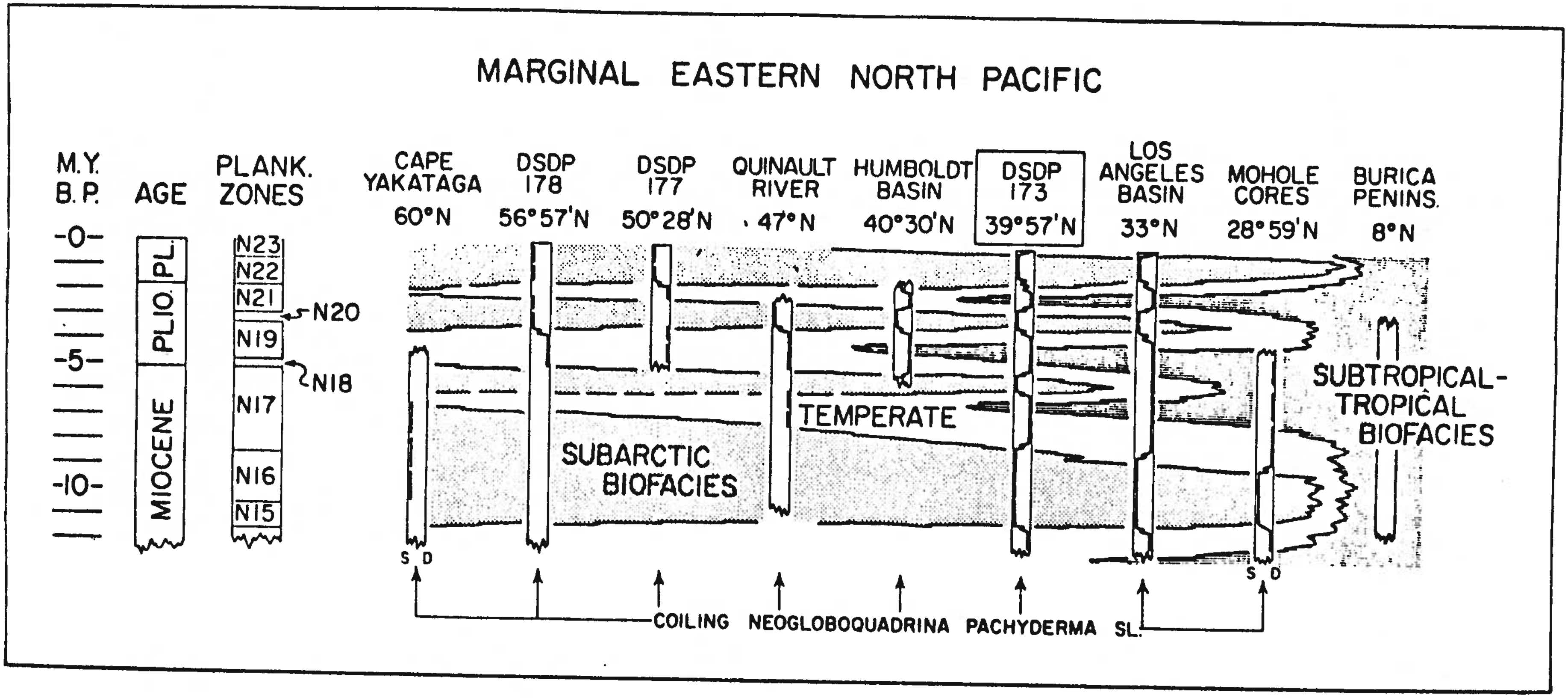


Figure 13. Schematic representation of major late Neogene oscillations of temperature sensative planktonic foraminiferal biofacies within the California Current system and adjacent Alaskan Gyre. Exclusively sinistral populations of *Neogloboquadrina pachyderma* are interpreted as evidence of surface temperatures lower than 10^{o}C whereas dextral populations are though to represent temperatures higher than 15^{o}C. Proposed NORPAC and INPAC drilling includes sites aimed at enhacing this record and the associated records of primary productivity and upwelling along this margin. Figure from Ingle (1981).

to be established for this region of the Northern Hemisphere.

In addition, faunal and isotopic analysis of Cenozoic sediments from this region will allow variations in the thermal gradient between high and low latitudes of the Pacific region to be more accurately assessed, leading to greatly improved models of both ocean and atmospheric circulation. Finally, study of deep pelagic sequences will allow development of the Cretaceous and Cenozoic history of eolian/atmospheric phenomena in this region through detailed study of clay mineralogy and facies. Although red clay sequences lack normal fossil age control, ichnolith stratigraphy and magnetostratigraphy will allow dating and correlation of these sequences enhancing their value for both paleoclimate and paleoceanographic analysis (Figure 12).

Paleoceanographic History and Evolution of the North Pacific

1. History of oceanic circulation in the north Pacific.

2. Fluctuations and history of the California Current system.

3. Variations in upwelling and primary productivity.

4. Development and variations in the Cretaceous and Cenozoic oxygen minima.

5. History of surface and deep water communication between the Bering Sea and north Pacific.

6. Cretaceous and early Cenozoic paleoenvironments and faunal provinces.

7. Possible relationships between evolution of the planktic and benthic communities and major paleoclimatic, paleoceanographic, volcanic, and tectonic events.

8. Evidence of catastrophic extinctions in mid and high latitudes over the Cretaceous/Tertiary boundary.

9. Ocean paleochemistry and history of hydrothermal activity and links to spreading rate changes and plate reorganizations.

10. Tephrochronolgy and depositional patterns of volcanic events in time and space.

Reconstruction of the history of deep and surface circulation in the North Pacific and Bering Sea is a primary NORPAC goal and of special importance to interpretation of climatic history in this region. Available evidence from both the deep sea and onshore sequences illustrates that Cretaceous and Cenozoic faunal patterns in this region reflect major variations in water mass character and circulation. Faunal analyses of key biostratigraphic reference sections will provide evidence bearing on changes in surface productivity and upwelling, evolution of both planktic and benthic microfossil groups, and relationships between major variations in biofacies and paleoceanographic events dictated by climatic evolution and tectonic control of ocean gateways. The closing of the Indonesian Seaway in mid Miocene time and the Isthmus of Panama in Pliocene time may well be reflected in north Pacific faunal variations. Similarly, the history of separation of the north Pacific Ocean and the Bering Sea should be clearly recorded in sediments on either side of this major barrier with implications for major changes in both surface and deep water circulation in this region.

Early DSDP sites in the eastern north Pacific have provided preliminary evidence of significant variations in the history of the California Current involving major north-south adjustments of surface isotherms over 20 degrees of latitude (Figure 13). Continuous coring under the track of this current should provide a truly detailed picture of these events along with a equivalent record of upwelling and primary productivity along this margin. These same sequences will allow scrutiny of evolutionary patterns of both calcareous and siliceous plankton on a region characterized by laboratory-like circulation patterns throughout the Cenozoic.

Paleogene and Cretaceous paleoceanographic history of the north Pacific is currently obscure but available data suggest that distinct faunal provinces existed implying major water mass control of these patterns. Faunal and isotopic analysis of NORPAC sites will increase our understanding of both surface and deep circulation during this period. Moreover, sites will be sought which will allow evaluation of the expansion and evolution of the intermediate water oxygen minimum in this region during Cretaceous and Cenozoic time with the possibility of detailed paleoceanographic analysis of laminated sequences should they be recovered. Finally, questions regarding the causal nature of mass extinctions may be approached in this region. For instance, is there a cause-effect relationship among sea floor hydrothermal activity, tectonic pulses, climatic changes, major episodes of volcanism, circulation changes, and mass extinctions? Related questions involve whether there are additional records of iridium enrichment at the Cretaceous/Tertiary boundary other than at sites 465 and 577.

Tectonic History of Macro- and Microterranes of the North Pacific

1. Faunal and stratigraphic evidence of microterranes.
2. Tracing of northward motion of terranes based on faunal assemblages.

It has been recently recognized that a complex set of microterranes have been subducted and accreted on their northward migration along the transform margins of California, Oregon, Washington, British Columbia, and the Gulf of Alaska (Figures 4 and 5). Remnants of at least some of these terranes (e.g., the Yakutat block; Figure 3) appear to be still present in the eastern Gulf of Alaska as demonstrated by dredged tropical faunas of Eocene age juxtaposed with coeval cooler water faunas. Drilling in this area will allow this history to be clarified with the added bonus of establishing both Neogene and possibly Paleogene biostratigraphic reference sections. Other terranes in adjacent areas are also viable targets with potential drilling sites identified by both the INPAC and NORPAC working groups. Clearly, drilling in these terranes will yield data of immediate value to both tectonic and depositional analysis of these crustal segments and to paleoceanographic reconstructions of the northeastern Pacific.

Continental Margins

Major sedimentologic objectives to be addressed through margin drilling in the NORPAC region involve three basic and related topics; (1) development of distinct lithostratigraphies on migratory transform terranes along the Pacific coast of North America, (2) detailed analyses of the depositional architecture, facies, and evolution of small submarine fans commonly filling Paleogene and Neogene marginal basins in this region, and (3) scrutiny of silica-diagenesis and related petrologic boundaries and thermal histories of marginal basins containing thick biogenic silica deposits (diatomaceous muds).

Proposed NORPAC and INPAC drilling in the Gulf of Alaska and along the margins of British Columbia, Washington, Oregon, and California is aimed at documenting the tectonic and depositional evolution of both active and complex transform margin segments involving northward migration, subduction and accretion of discrete crustal slices as the margin evolved from a collision margin to transform margin in Neogene time (Figure 4). Unique biostratigraphies and lithostratigraphies are now known to characterize each crustal segment or tectonostratigraphic terrane. The stratigraphic sequence accumulated on each terrane together with paleomagnetic evidence within these sequences hold the keys to delineating the timing and trajectories of these crustal blocks. The stratigraphies atop each segment also contain direct faunal and lithostratigraphic evidence of the vertical motion and eustatic events experienced by each terrane emphasizing the importance of stratigraphic and faunal analyses of these sequences.

Tectonic objectives of these studies are described in elsewhere in this report, but is important to emphasize here that the development of the depositional records themselves is worthy of special attention in that repeated progradational cycles of shelf and slope sedimentation characterize each phase of terrane history. Thus, we propose to analyze the manner in which these repetitive facies patterns evolve in this tectonic setting and attempt to judge the impact of regional and global paleoceanographic, paleoclimatic, and eustatic events on local margin stratigraphies relative to the signatures imposed by transform tectonics. Work to date emphasizes the importance of Neogene eustatic events in regulating fan development in individual marginal basins but the patterns seen involve even more complex associations. For example, Miocene diatomites are a characteristic lithologic facies in the majority of Neogene basins along this margin including the Bering Sea. Clearly, the tectonic evolution of each basin or margin segment was overprinted by regional oceanographic and eustatic controls which were responsible for widespread starvation of individual margin segments allowing relatively undiluted biogenic (diatoms) sediment to form this distinctive regional facies. In turn, increased productivity of diatoms appears to be linked to late Miocene climatic cooling in this region with mid Miocene deposits a mix of calcareous nannoplankton and siliceous diatomaceous debris reflecting warmer climate during this latter period. Thus, the paleoceanographic and paleoclimatic events in the north Pacific had a direct bearing on not only the nature of lithofacies characterizing individual margin histories, but also their subsequent diagenetic evolution from poorly consolidated diatomites to dense and bittle cherts forming fractured petroleum reservoirs and bottom simulating reflectors (BSR) in various parts of this region.

An example of a combined sedimentologic and stratigraphic analysis of a specific margin segment is illustrated in the Monterey Fan area off central California. NORPAC workers propose to drill a 3-hole transect across this major fan in order to sample and analyze the history of proximal, medial, and distal fan facies and in addition determine the age of a key seismic unconformities to determine the timing of cessation of subduction in this area and the initiation of transform motion (Figure 4).

In fact the lack of documentation of deep sea fan evolution in the modern ocean as opposed to the intense study of smaller scale features in fossil fans exposed onshore has led to an impasse in the application of current models of fan deposition and evolution. In effect, a major problem exists in relating insights gained via outcrop study to observations on fan evolution obtained primarily from acoustic records of large modern deep sea fans compounded by a disparate scale between these features. As described in the following section, in recognition of this circumstance, NORPAC workers propose that Navy Fan off southern California forms an ideal target to investigate the details of fan evolution and facies in a tectonically confined setting analogous to many of the marginal basins around the Pacific rim and elsewhere.

A third sedimentologic objective is the analysis of the diagenetic transformation of biogenic opal (diatomites) to opal-CT (porcelanite) to microcrystalline quartz (chert) at depth in many basins along the margin of the northeastern Pacific and Bering Sea. So-called bottom simulating reflectors (BSRs) have long plagued seismic reflection surveys in this region and many are interpreted to represent thermally induced changes in siliceous muds representing the diagenetic alteration of opal-A (diatomaceous muds) to opal-CT (porcelanite) or chert. NORPAC drilling in both the Bering Sea and Pacific continental margin will penetrate thick diatomaceous Neogene sequences and allow in situ measurement of temperature and chemical parameters at these phase-change boundaries. These measurements will not only aid interpretation of the diagenetic process proper but will also provide quantitative data of significance for interpretation of deformed sequences and creation of fractured shale petroleum reservoirs.

Clastic Sedimentation

Introduction

Three major sedimentologic themes arising from the NORPAC conference should be addressed by ODP drilling. The first is a detailed assessment of sedimentary cyclicity and lithofacies within various sub-environments of a single submarine fan. The second issue involves the documentation of facies relations within the Aleutian Trench, Aleutian forearc, and the abyssal plains of the Gulf of Alaska. We stress here that sedimentologic data from the Aleutians represent only one element of multi-disciplinary transects designed to constrain the timing of regional depositional/tectonic events and document the effects of tectonic accretion on such parameters as physical properties, structural fabrics, and sediment diagenesis. A final problem involves hemipelagic sedimentation in the vicinity of Meiji sediment tongue, which occupies the northwestern corner of the Pacific Basin.

Navy Fan

In spite of many years of research on modern submarine fans, surprisingly little is known about actual sedimentary cycles and lithofacies associations. Models of fan growth and morphology are based primarily upon seismic-reflection and sonar data (e.g., Figure 14; Normark, 1978). Direct comparisons between different fans show a tremendous amount of morphologic diversity (Stow et al., 1983,1984); this is because fan geometries are influenced by a host of factors including sediment texture, rate of sediment influx, spacing of sediment delivery points, basin morphology, and tectonic setting (crustal type, structure, etc.). Moreover, major changes in depositional systems can occur as a consequence of tectonic events and/or changes in the position of sea level. Perhaps the most important conclusion of recent years is that multiple fan models are mandatory (just as they are, for example, with fluvial or deltaic facies). Unfortunately, this diversity means that limited and random sampling will not provide much useful information about fan-forming processes. Instead, a detailed and comprehensive drilling program is most certainly required.

Because submarine fans remain poorly sampled, data sets derived from ancient turbidite sequences cannot be correlated directly with their inferred modern analogs. Semantic arguments abound because of attempts to relate surficial morphologic features (such as suprafan bulges) to vertical cycles or lithofacies associations (e.g., Nilsen, 1980; Normark, 1980; Walker, 1978, 1980). The problem is compounded by the tremendous differences in scale between certain morphologic elements (such as major channels) and typical exposures in the rock record. In fact, most outcrop features are small enough to be beyond the resolution of modern marine remote-sensing techniques. Typical interpretations of sub-environments within ancient turbidite sequences are based upon vertical cycles measuring 10s to 100s of meters in thickness (Mutti and Ricci Lucchi, 1972; Walker, 1978). For example, thinning-upward cycles are attributed to channel migration or abandonment; similarly, progradation of sand lobes is thought to cause thickening-upward trends (Figure 15). It is important to note, however, that most cores from modern fans penetrate 5 m or less below the substrate and that *continuous* sections of appropriate dimensions have never been

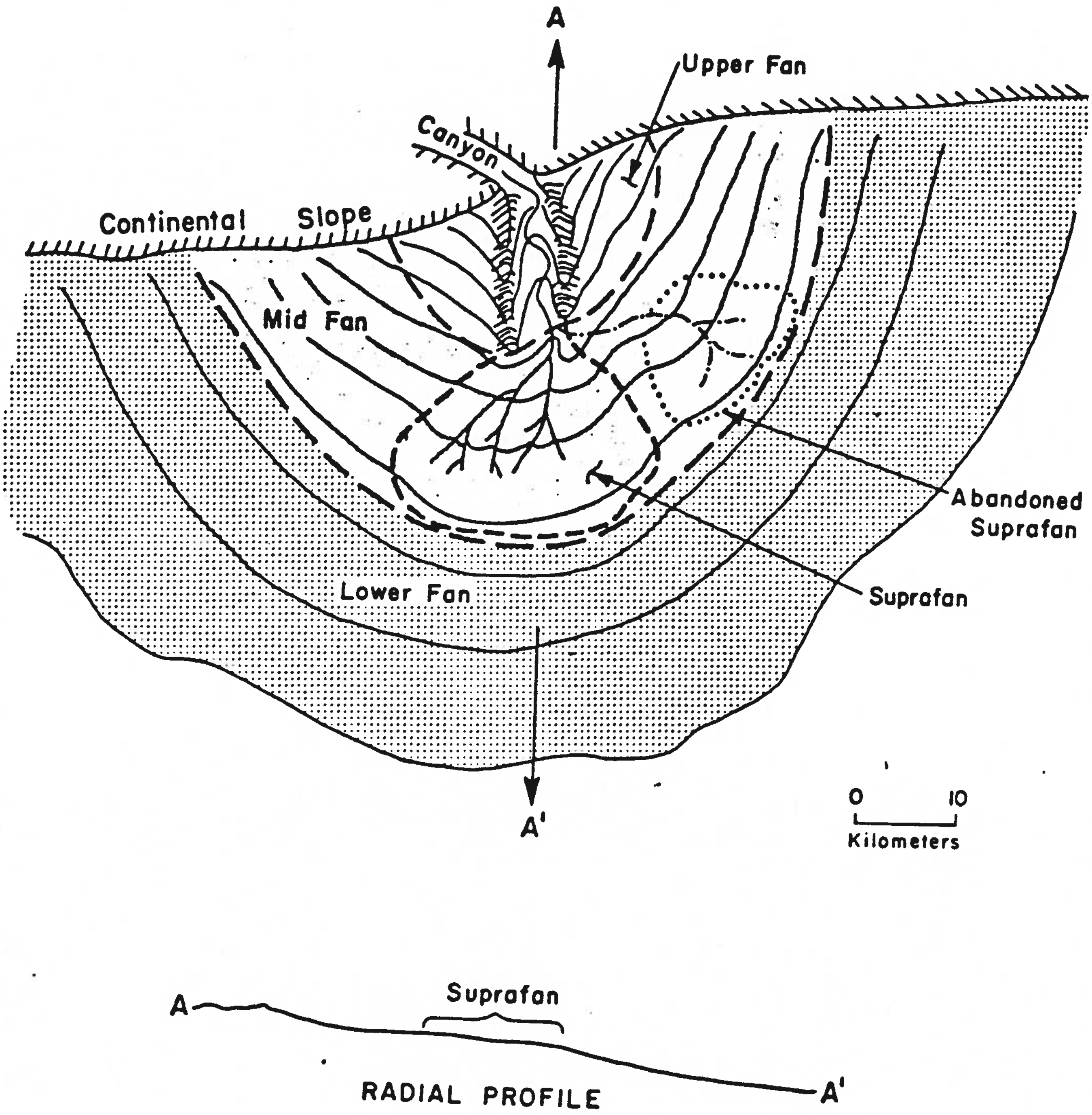


FIGURE 14. Schematic representation of model for growth of submarine fans (from Normark, 1978). This model emphasizes active and abandoned depositional lobes termed suprafans.

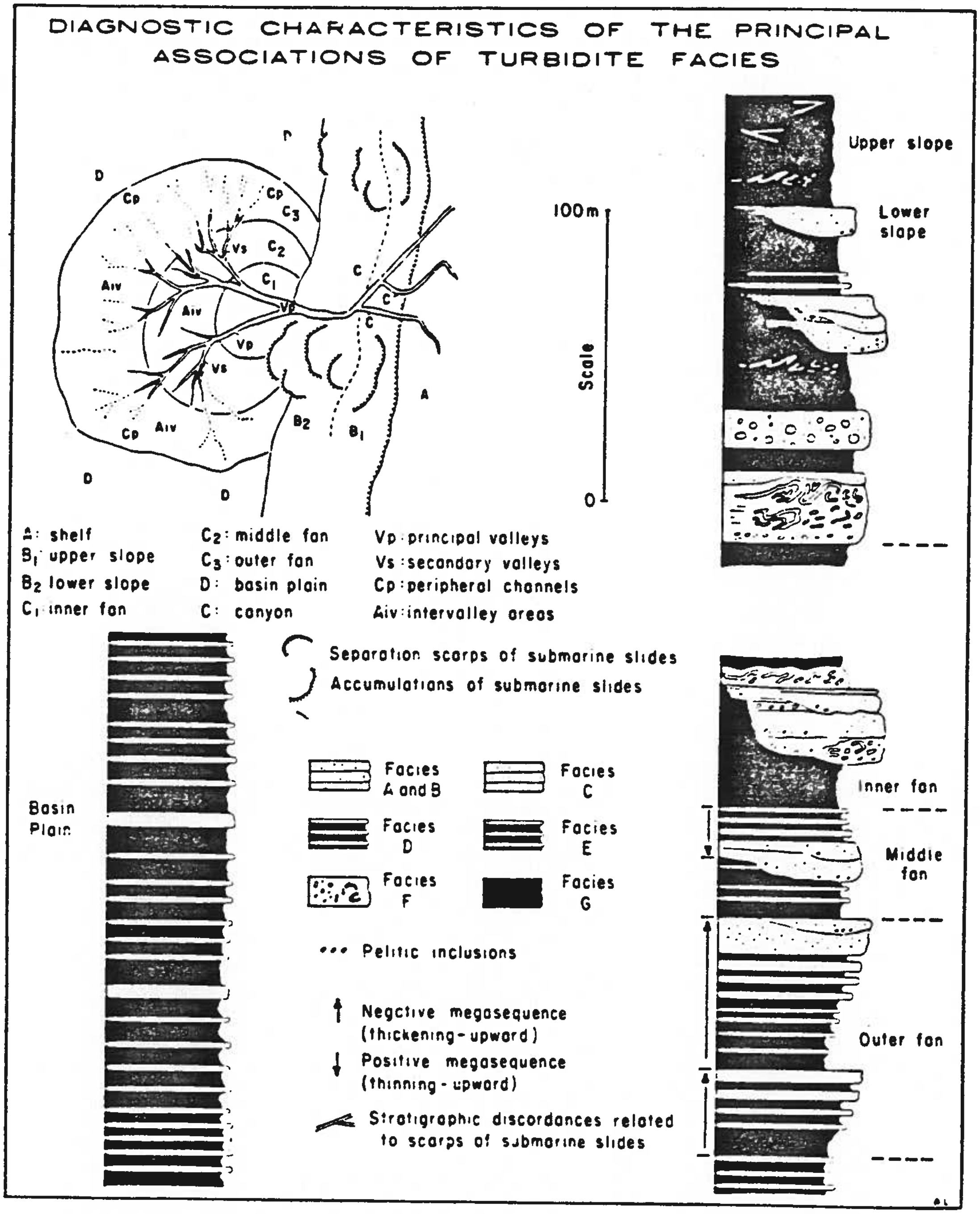


FIGURE 15 . Environmental model and stratigraphic sections representative of the principal associations of turbidite facies (from Mutti and Ricci Lucchi, 1972). The validity of this model requires testing by drilling and continuous coring of corresponding sub-environments on Navy Fan, located offshore southern California.

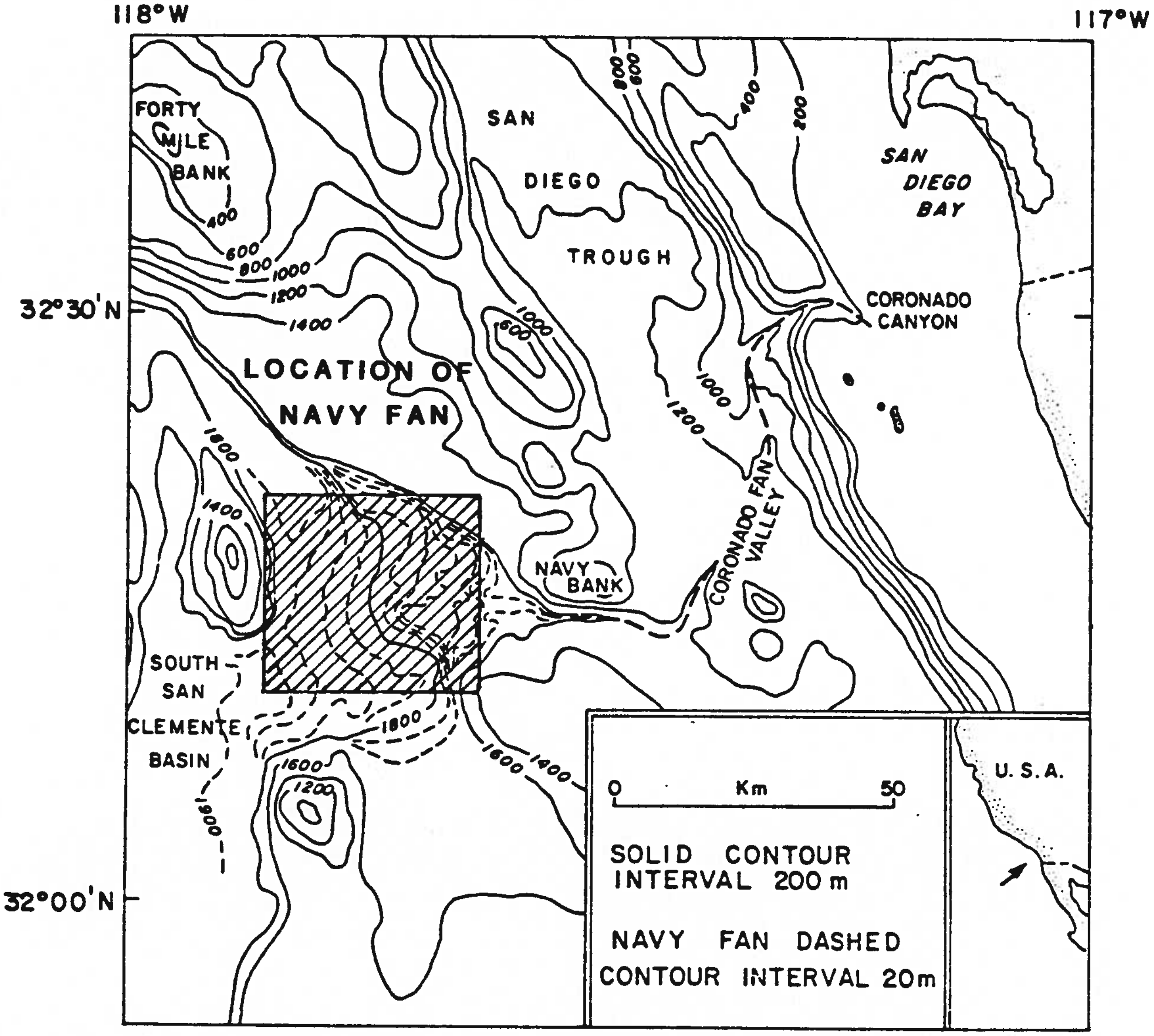


FIGURE 16 . Location map of Navy Fan. Bathymetry in meters. Details of the fan morphology are illustrated in Figure IV-4.

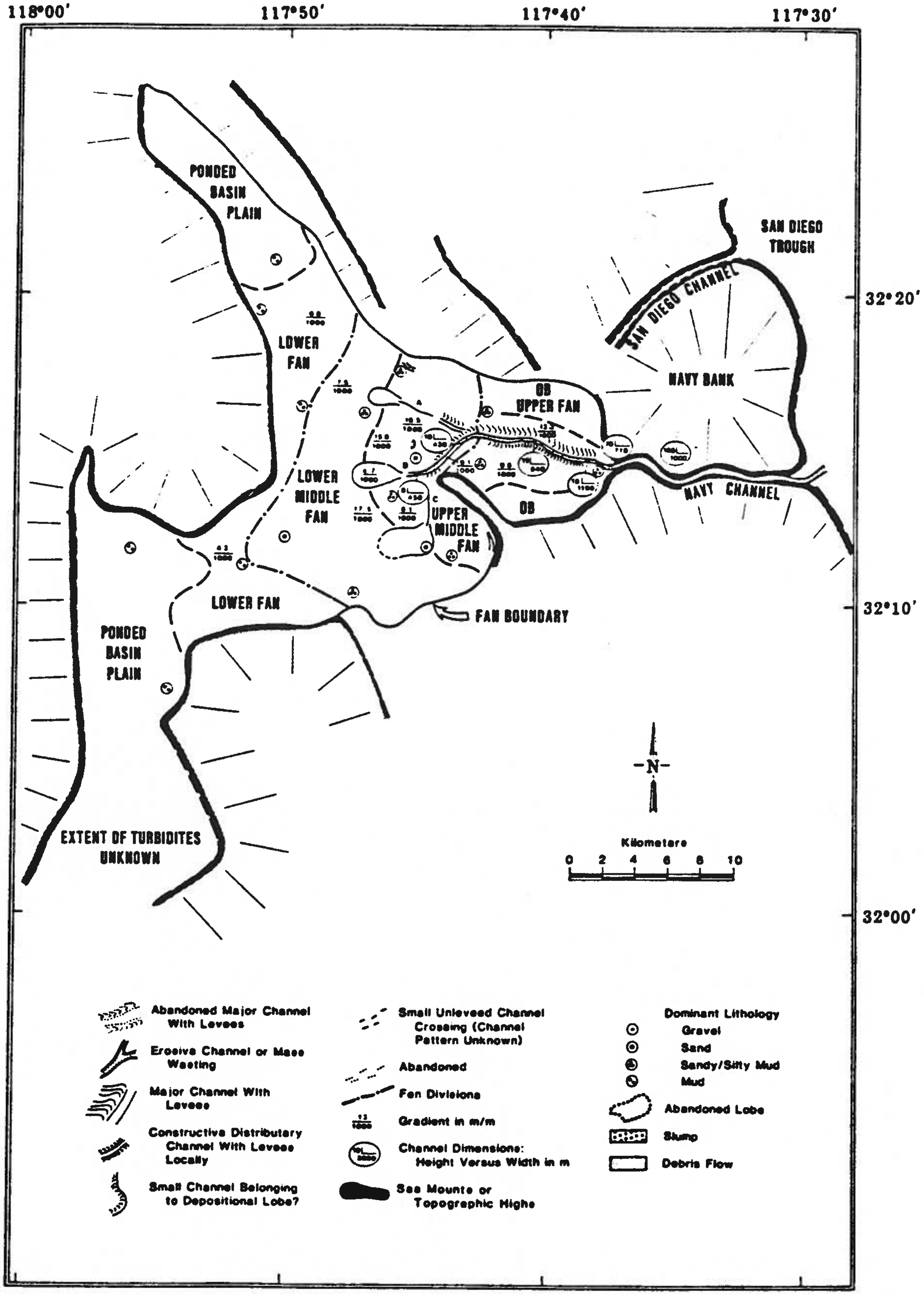


FIGURE 17 . Schematic representation of Navy Fan showing morphologic divisions, channel pattern, channel dimensions, fan-surface gradients, dominant lithologies, and basin configuration (from Normark and Piper, 1983/1984).

drilled on modern fans to test the validity of these widely accepted models.

Leg 96 of the Deep Sea Drilling Project drilled several holes in the Mississippi Fan. This effort, however, failed to satisfy the objective of providing a suitable modern analog for ancient turbidite sequences. First of all, continuous coring was not maintained during Leg 96. Secondly, Mississippi Fan is located along a passive continental margin above oceanic crust; it is also a delta-fed turbidite system. In contrast, most examples from the rock record are associated with tectonic (active) margins and continental or accretionary crust; such systems generally are fed by submarine canyons rather than deltas. Consequently, even if recovery during Leg 96 had been better, it still would not serve as an appropriate analog for the rock record. We believe the Ocean Drilling Program should provide type reference sections for modern deep-water turbidites that would allow sedimentary geologists to take advantage of data derived from analyses of rock sequences. The global appeal for such a program cannot be overstressed, as virtually all geologists working with deep-marine strata will benefit from the results.

We believe the most appropriate laboratory for a comprehensive study of submarine-fan facies is Navy Fan, which is late Pleistocene in age and located in the California borderland off San Diego (Figure 16). Water depth within this region of fan sedimentation ranges from 1700 m to 1920 m. It is essential to select a small, well-surveyed fan in a geologic setting that is well understood. Navy Fan has been surveyed extensively using conventional single-channel seismic and near-bottom deep-tow instruments. Consequently, the fine-scale mesotopographic relief (i.e., 2-3 m vertical, 10-20 m across) on the fan surface is well known (Normark et al., 1979). In addition, more than 100 shallow-penetration cores (7 m or less) have been collected, and gross sediment character has been correlated with acoustic facies (Piper and Normark, 1983; Normark and Piper, 1983/1984). Because of its location (32°N), Navy Fan can be drilled during winter months when more northerly sites in the Pacific are affected by adverse weather.

In order to document the stratigraphic nature of Navy Fan properly, we propose seven nonreentry holes be drilled and cored continuously using HPC techniques. The drill sites will be closely spaced and should include the following sub-environments: upper-fan constructional (proximal) levee, upper-fan distal overbank, upper middle-fan distributary channel, lower middle-fan sand lobe, channel-lobe transition, lower fan, and the basin plain (see Figure 17). The maximum thickness of Navy Fan is on the order of 0.5 sec two-way travel time, and most sections range from 0.2-0.3 sec (Smith and Normark, 1976). This means that nearly the entire fan stratigraphy can be recovered by drilling only 200-300 meters. Moreover, it should be possible to evaluate the effects of Pleistocene fluctuations of sea level at each drilling site. Retention of core and prevention of hole collapse during drilling of sand-rich sections may depend upon the development of improved core catchers or vibracore tools; we hope these technological advances will be given high priority by ODP over the next several years in order to assure a successful drilling program.

Aleutian Transects

Several fundamental sedimentologic issues need to be addressed within the Aleutian forearc region (Figure 18). One of the most intriguing topics is the thick wedge of sediment associated with the Aleutian Trench (Figure 19). The trench-fill in the central Aleutians approaches 4000 meters in thickness, and the rate of sedimentation there may be as high as 7 km/my (Scholl et al., 1982a, 1982b); yet, the source of this material remains inconclusive. Thin sand layers cored from the uppermost 5 m of sediment display both Aleutian-Arc and Gulf-of-Alaska petrographic affinities (Figure 20), so it is clear that both transverse flows and axial flows have made contributions to the trench wedge (Underwood, 1986). The relative importance of each delivery route remains undocumented, however, as does the overall proportion of sand to mud. Evidently, unconfined turbidity currents bearing volcaniclastic sand did cross the mid-slope Aleutian Terrace and continue down the lower slope to the trench floor (Underwood, 1986), but whether or not such

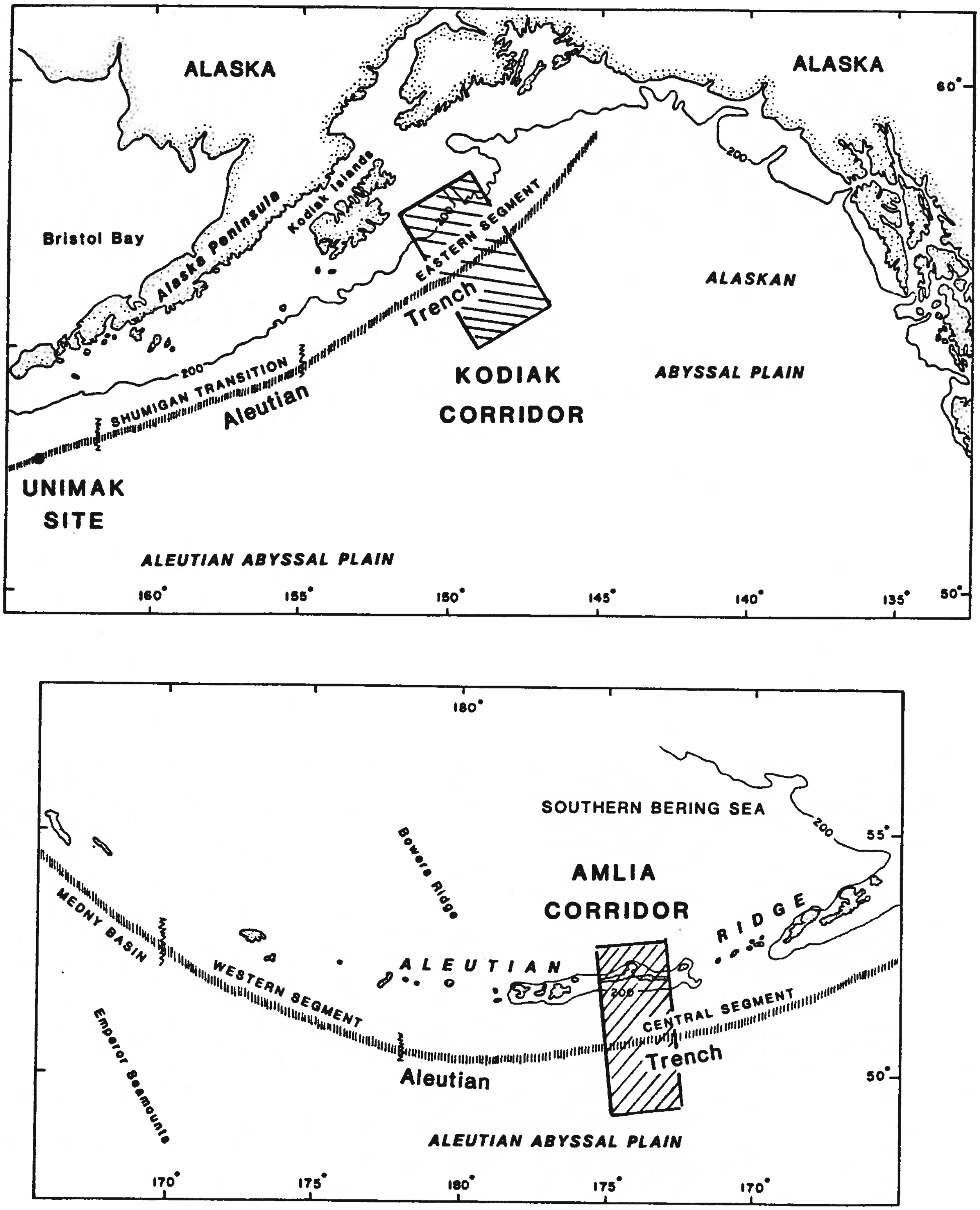


FIGURE 18 . Maps showing the location of the Aleutian Trench and forearc. Sites for principal sedimentologic objectives include the Kodiak corridor, a trench-floor site south of Unimak Island, and the Amlia/Atka corridor. See text for further discussion.

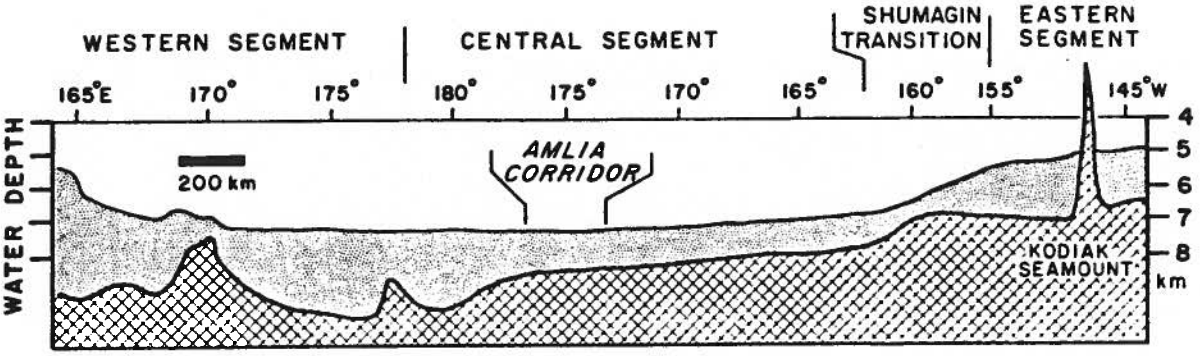


FIGURE 19 Axial profile for the Aleutian Trench (modified from Scholl, 1974). Sediment types above igneous basement are undifferentiated. Approximate locations of proposed drilling sites are as follows: 149°W (Kodiak corridor), 163°W (Unimak site), and 175°W (Amlia corridor).

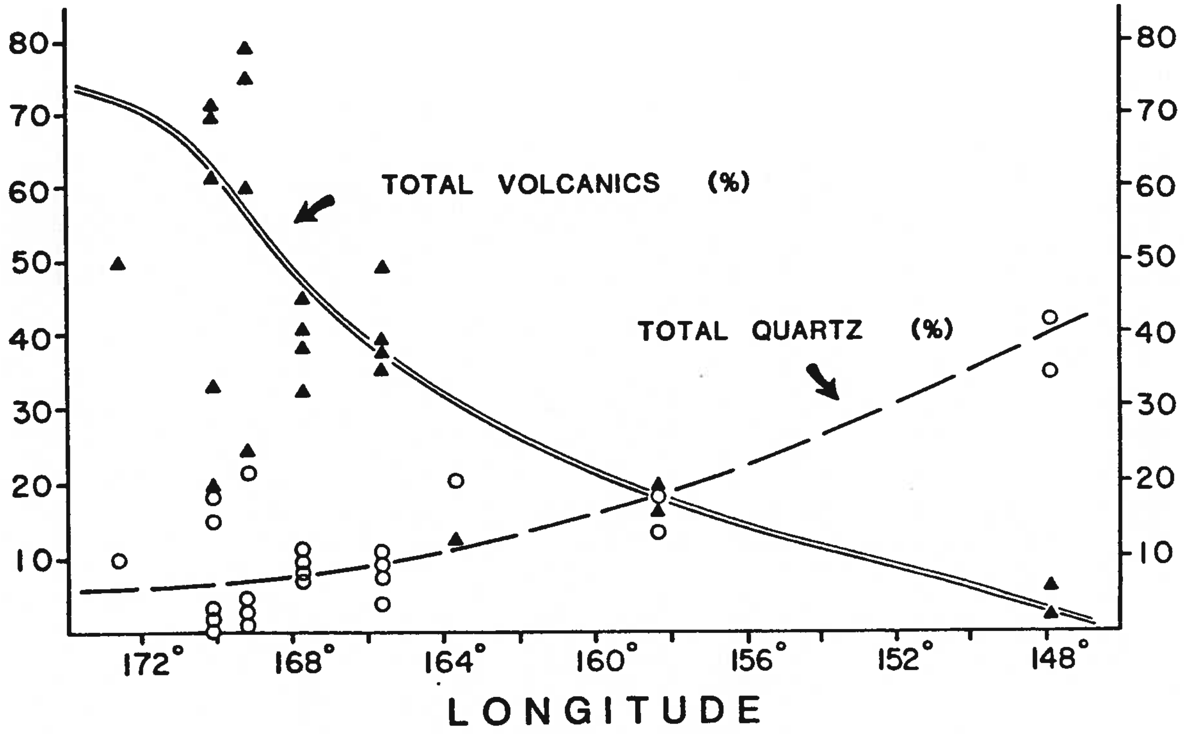


FIGURE 20 . Longitudinal variations in sand composition within the Aleutian Trench, based upon sand layers recovered by piston coring. Most sands deposited west of 165°W are dominated by volcaniclastic debris derived from the central Aleutian magmatic arc, but axial flows have also transported materials from the Gulf of Alaska. Open circles = mono-quartz + poly-quartz; solid triangles = volcanic rock fragments + glass shards. From Underwood (1986).

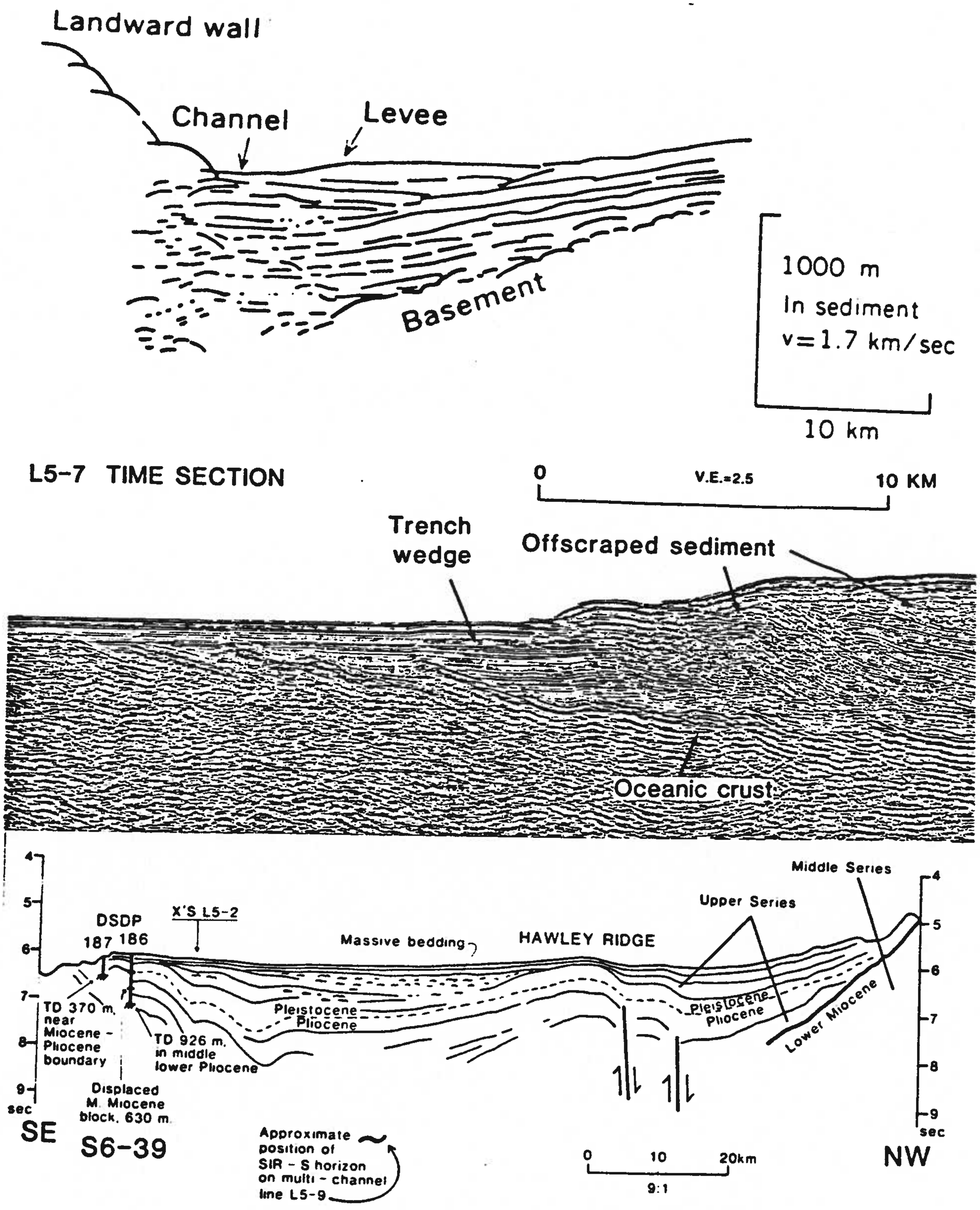


FIGURE 21 Line drawings and seismic reflection profiles from the Aleutian Trench and forearc. Top profile shows the axial channel in the eastern Aleutian Trench (from von Huene, 1974); central trench segment (middle profile) is not channelized (from McCarthy and Scholl, 1985). Oblique crossing of Atka Basin (bottom profile) also shows no evidence of channelized flow (from Scholl et al., 1982a).

flows dominated in pre-Holocene time cannot be evaluated unless coring penetrates several hundred meters below the substrate.

Ideally, multiple drilling sites can be spaced along the length of the Aleutian Trench to test for both longitudinal and temporal variations in sediment composition. One site should be located within the Amlia corridor south of the intraoceanic portion of the Aleutian magmatic arc. The maximum water depth within this area is roughly 7300 m, but this is nearly 1000 m above the limit for ODP drilling. At least two sites should be drilled farther east, one off Unimak Island and one within the Kodiak corridor (Figure 18). Water depths for these sites range from 6900 m to less than 5000 m, respectively. Collectively, these sites can test for sediment influx from the island arc, the Alaska Peninsula, and the Alaska mainland.

In addition to questions of sediment dispersal, the Aleutian forearc region offers a variety of depositional geometries, and there are several apparent transport mechanisms. For example, thick turbidite sequences within forearc basins (e.g., Atka Basin) show no evidence of channelized flow on seismic-reflection profiles (Figure 16). Instead, turbidite ramps have developed at the expense of submarine fans. This style of deposition has been inferred in several ancient turbidite sequences (e.g., Heller and Dickinson, 1985), but modern examples remain poorly documented. DSDP Sites 186/187 were drilled along the seaward margin of Atka Basin, but at least one ODP site (with continuous HPC coring for several 100 m) should be located within the central portion of the basin in order to document proximal sedimentary facies and processes. Realistically, two or three holes must be spaced across the basin in order to accurately define facies changes; because so little is known about forearc turbidite ramps, we believe the necessary time commitment is justified. Moreover, sites in Atka Basin will undoubtedly yield valuable information pertaining to the evolution of the adjacent magmatic arc.

Depositional geometries within trenches are known to vary considerably (e.g., Underwood and Bachman, 1982), although the precise reasons for these changes remain unclear. For example, the Aleutian Trench wedge in the Gulf of Alaska displays an axial channel (von Huene, 1974), but the central trench segment is not channelized (Figure 21). The Kodiak segment represents an ideal setting for multiple-site drilling and continuous HPC coring of a trench channel; holes should be located, for example, on the landward margin, the channel axis, and the seaward overbank region, with sub-bottom penetration restricted to perhaps 100-200 meters. When combined with data from additional sites located farther to the west (e.g., Unimak site, Amlia/Atka corridor), it should be possible to identify the parameters which dictate the transition from channelized flow to sheet flow. At the same time, all of the trench sites will obviously serve the purpose of sediment-provenance investigations. Perhaps one hole should penetrate through the contact between the trench wedge and underlying abyssal-plain sediments, but deep penetration is not vital at all sites.

Another sedimentologic theme involves multi-disciplinary transects across the width of the Aleutian accretionary system. In order to quantify variations in sedimentation and tectonics along strike, at least two forearc transects should be planned, one in the Gulf of Alaska (Kodiak region) and another within the Amlia/Atka corridor (Figure 18). There is a fundamental distinction between these two corridors, because one is a convergent continental margin and the other is intraoceanic. Both areas have benefited from the recent acquisition of CDP seismic-reflection data (Scholl et al., 1982a; von Huene, 1979; McCarthy and Scholl, 1985), but very little coring has been achieved since DSDP Legs 18 and 19.

Among other things, we hope to investigate the effects of subduction-accretion on the development of structural fabrics, changes in physical properties, heat flow and fluid flow within the accretionary prism, sediment diagenesis, and pore-water chemistry. Contrasts between accreted strata and overlying slope/slope-basin sequences also require documentation. In order to achieve these goals, however, reference sections *must* be recovered from incoming sediment bodies located seaward of the deformation front (Figure 22). Included in this package of "reference"

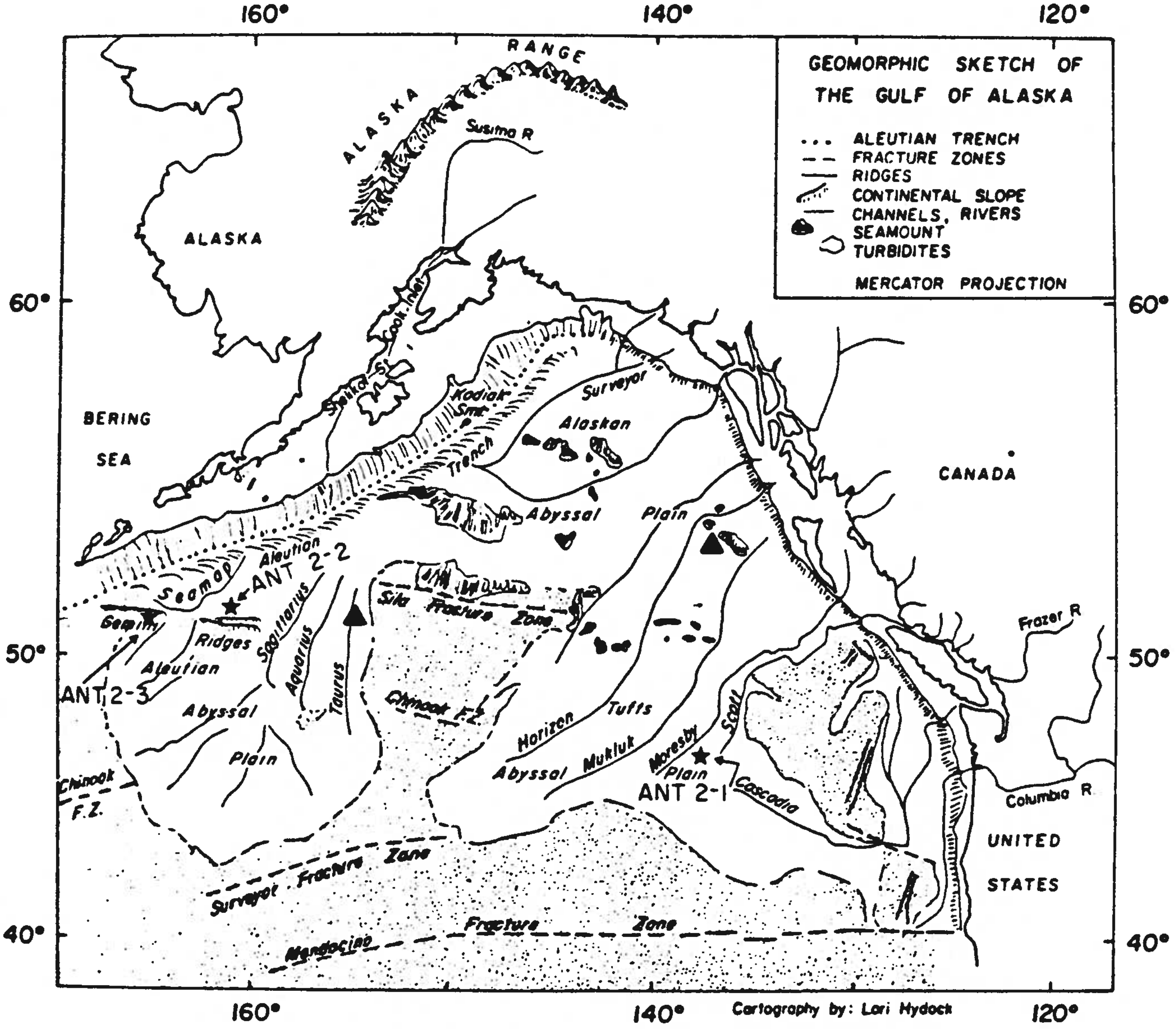
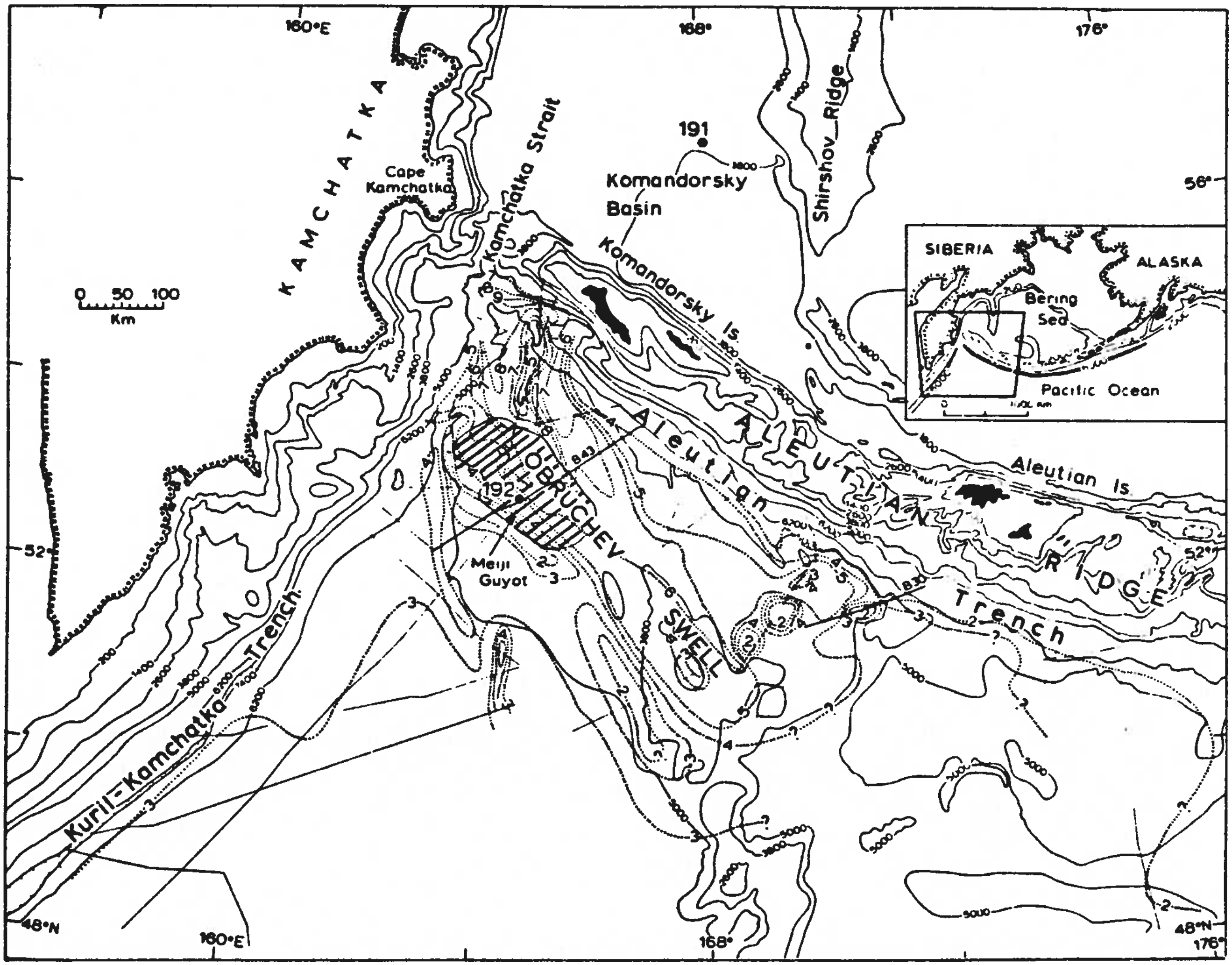


FIGURE 22 Map showing principal morphologic elements of the abyssal plains of the North Pacific (from Mammerickx, 1970). One site adjacent to Taurus channel (Zodiac fan) and one site between Mukluk and Horizon channels (Baranof fan) would address a multitude of sedimentologic issues. See text for further discussion.



FIGURF 23 Map showing the location of Meiji sediment tongue on the northwestern arm of Obruchev Swell. The origin of hemipelagic muds at this locality remains controversial but could probably be resolved by a single ODP drilling site. Tectonic and biostratigraphic objectives that could be addressed at the same site are outlined in the text.

sediment are the relict (Eocene-Oligocene) channels of Zodiac fan (Aleutian Abyssal Plain), Neogene-Recent sequences associated with Surveyor, Mukluk, Horizon, and related channels (Alaska and Tufts Abyssal Plains), and, of course, the Quaternary trench wedge (see Hamilton, 1967; Mammerickx, 1970; Stewart, 1976; Stevenson et al., 1983). Potential drilling sites located seaward of the trench will also yield samples of interest to the following studies: (1) fan/channel facies and genesis, (2) the long-term evolution of the Aleutian magmatic arc (e.g., tephrochronology, volcanic-ash geochemistry), (3) potential effects of glaciation/sea-level fluctuation on abyssal sedimentation, (4) high-latitude biostratigraphic reference sections, and (5) tectonic implications of temporal changes in sediment composition/provenance. If properly located, one abyssal site could sample sediments originating from more than one channel system (e.g., between Horizon and Mukluk channels). The Zodiac fan site should be drilled next to the youngest fan channel (Taurus) to determine the timing of fan cessation and to allow direct comparison with older sediments recovered at DSDP Site 183 (Stewart, 1976).

Meiji Sediment Tongue

The Meiji sediment tongue is an elongate, mud-dominated sedimentary body in the northwestern corner of the Pacific (Figure 23). Past studies of the sediment cored at DSDP Site 192 indicate that the tongue began to form in earliest Miocene time and that most of its clay-sized terrigenous debris originated in eastern Siberia (Scholl, et al., 1977). Controversy exists, however, over the agent of sediment transport. Scholl and others (1977) linked the transport pattern to surface currents, whereas Mammerickx (1985) concluded that deep thermohaline currents were responsible for suspended sediments transport. Because of extremely poor drilling recoveries at Site 192, one additional ODP hole is required to resolve this question.

Penetration to igneous basement on Obruchev Swell could also help satisfy tectonic objectives associated with the inferred age-progression of the Emperor seamount chain (and hotspot stability); documentation of crustal age in the Cretaceous superchron is also required to test implications of spreading ridge jumps, origin of Hokkaido and Chinook Troughs, and origin and areal extent of the Kula plate. Finally, this site could also help establish a much-needed high-latitude Cenozoic biostratigraphic reference section.

Summary

The sedimentologic objectives which should be addressed by ODP drilling in the North Pacific are as follows:

(1) *Navy Fan* - minimum of five holes with continuous HPC coring to sub-bottom depths of 200-300 meters; maximum of seven holes.

Purpose - to quantify stratigraphic sequences within various sub-environments of a submarine fan for direct comparison with rock record.

(2) *Aleutian Trench* - three holes across the width of Kodiak the segment (where axial channel is developed); one hole offshore Unimak Island; one hole offshore Amlia/Adak Islands. All holes require continuous HPC coring, but maximum sub-bottom depths are flexible.

Purposes - to establish reference sections for transects involving deformation and diagenesis within the Aleutian accretionary prism; to resolve questions involving sediment provenance and dispersal (particularly the distinction between transverse and axial flows); to determine the factors which control the transition from channelized flow to sheet flow.

(3) *Atka Basin* - two or three holes across the width of this prominent forearc basin in the central Aleutians; continuous HPC coring to depths of 200-300 meters, with perhaps one deeper hole.

Purposes - to document the parameters which favor the development of a non-channeled turbidite ramp instead of a submarine fan; to document proximal-to-distal changes in lithofacies; to document temporal changes in sediment influx from the Aleutian magmatic arc.

(4) *Abyssal Plains* - one hole on Baranof fan (Mukluk/Horizon channels); one hole on Zodiac fan (Taurus channel).

Purposes - to provide additional reference sections for Aleutian forearc transects; to constrain timing of specific depositional events on the abyssal plain (e.g., cessation of growth of Zodiac fan).

(5) *Meiji Tongue* - one hole; continuous HPC coring.

Purpose - to resolve the roles of surface currents and deep thermo-haline currents in the delivery of suspended sediment.

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