DRILLING THE GULF OF CALIFORNIA

A Workshop Report

Ensenada B.C., Mexico

August 4-7, 1986

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PREFACE

A drilling workshop was held in Ensenada, Mexico August 5, 6, and 7, 1986 to define potential drilling objectives in the Gulf of California and adjacent areas of the eastern Pacific. Several individual sites, as well as, sites along transects were proposed with strong multiple scientific objectives. This document is an outgrowth of that workshop and summarizes the consensus of the attendees as to what those objectives were. This document was submitted as a summary proposal to the Ocean Drilling Program.

Of necessity, any program to drill in the region will require the full and meaningful participation of the Mexican scientific community. It was determined prior to the workshop that many Mexican scientists already had strong interests in a drilling program in the region. Therefore, it was decided to hold the workshop in Mexico in order to facilitate the participation of the Mexicans and allow them the opportunity to contribute at the earliest stages of planning. Several Mexican institutions were represented at the workshop. These included: the Direccion General de Oceanografia Naval (DGON), Mexico City; the Universidad Nacional Autonoma de Mexico (UNAM), Mexico City; the Centro de Investigacion Cientifica y de Educacion Superior (CICESE), Ensenada; the Instituto Oceanografico de Manzanillo (IOM), Manzanillo; the Universidad de Colima, Manzanillo; and the Escuela Superior de Ciencias Marinas, Ensenada.

Appended to the document is a list of workshop attendees and a list of drilling proponents. Proponents for drilling includes individuals who, although they were unable to attend the workshop, communicated there interests in drilling in the Gulf and/or surrounding region and who have contributed to this document.

Proposal to Ocean Drilling Program

DRILLING THE GULF OF CALIFORNIA

A Summary Drilling Proposal from the ODP Gulf of California Workshop

(GULFAC) Held in Ensenada, B.C. Mexico, August 4-7, 1986

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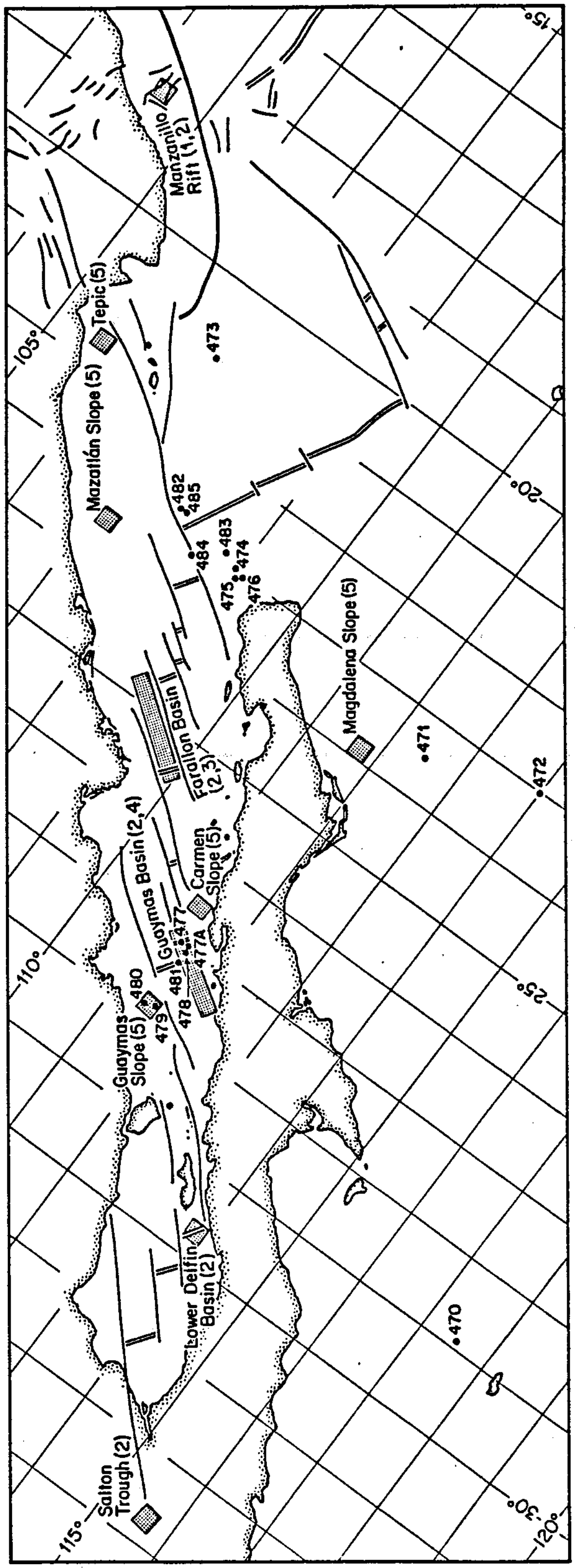
INTRODUCTION

The Gulf of California is an excellent example of a young rifted ocean basin; it has several unique features which make it an ideal environment for basement drilling. In the northern Gulf, the rise is broken into a series of small spreading centers offset by increasing frequent transform faults oriented obliquely to the axis of the Gulf (Figure 1). To the south, the spreading axis is considerably lengthened so that the Gulf represents a transition zone between a predominant transform environment to the north and a predominant spreading environment to the south. Axial spreading in the Gulf occurs at a full rate of about 6 cm per year.

Sedimentation rates are very high (>1 km/my) in the northern and central Gulf, due to a combination of massive terrigenous input, particularly from the Colorado River in the north, and high biological productivity with terrigenous input from Mexico, mainly in the central Gulf. The newly formed oceanic basement is formed here by intrusion into sediments rather than extrusion onto the seafloor. This type of oceanic crust may be common in young ocean basins formed by rifting of continental crust, and may therefore be characteristic of many passive margins.

Deep Sea Drilling Project (DSDP) Legs 64 and 65 were planned as a comprehensive interdisciplinary investigation of the Gulf of California by drilling. The primary goals were to investigate the opening history of the Gulf, the early evolution of a passive continental margin, the nature and history of a major upwelling system, and the nature of the hydrothermal systems in the Guaymas

Figure 1. Map of the Gulf and Peninsula of California including the Salton Trough region, showing the locations of the principal basins and the main tectonic features along with the locations of DSDP sites in the Gulf from Legs 63, 64 and 65 (sites 473-485). Site locations for the five objectives of this proposal are indicated by 1-5.


Salton Trough (2)
Lower Delfin Basin (2)
Guaymas Slope (5)
479
480
478
481
477
477A
Guaymas Basin (2,4)
Carmen Slope (5)
Farallon Basin (2,3)
Magdalena Slope (5)
471
472
470
475
476
474
483
484
482
485
Mazatlán Slope (5)
Tepic (5)
473
Manzanillo Rift (1,2)
105°
110°
115°
120°
15°
20°
25°
30°

Basin. Leg 65 was also designed to study the processes of crustal accretion along the relatively fast spreading East Pacific Rise, as compared with the slow spreading Mid-Atlantic Ridge.

The Gulf of California is the most suitable area to study continental rifting, since it has the greatest potential to develop into a true oceanic environment. Therefore, drilling results are of global importance for application to the contemporary and past geologic records.

The present proposal intends to broaden the investigations undertaken during these earlier DSDP cruises and extend their scope. It has five main objectives: (1) to explore early rifting in the Manzanillo Rift, (2) to complete transects along and across the Gulf of California, (3) to initiate geochemical studies in the Farallon Basin, (4) to thoroughly characterize the hydrothermal systems in the Guaymas Basin and (5) to expand the paleoceanographic and depositional history studies.

Information will be obtained on basins extending from oceanic to terrestrial depositional environments by carrying out the following drilling transects. Transects across basins (i.e. Guaymas and Farallon) and along the whole Gulf Province (i.e. Salton Sea to Manzanillo Rift) will address the aspects of thermal alteration of organic and inorganic matter, provenances and differences of these, the effects of thermal stress (lower temperatures than hydrothermal) and the consequences of oxicity levels of the depositional paleoenvironments (i.e. preservation of varved and organic-rich sediments). The Manzanillo Rift is an analogue to the early Gulf proper and represents an ideal area to access sediments representative of early continental rifting in a submarine realm.

The sediments are expected to have retained the organic and mineral indicators of the thermal history associated with this early rifting.

The geochemical studies are proposed to provide a comprehensive understanding of the hydrothermal systems in the Guaymas Basin and their influence on the overall Gulf Province from the various projected transects. Hydrothermal activity is presently occurring in the sediment-covered South Rift of Guaymas Basin, resulting in mineral diagenesis and catagenesis of immature organic matter with concomitant migration of the products in fluids. Previous drilling here terminated in greenschist facies. Seafloor exploration has only provided grab samples. Thus, additional drilling is aimed at penetrating into a seafloor hydrothermal mound group which will provide samples of the stockwork, and from deeper, and thus possibly higher, metamorphic facies (note high temperature drilling requirement). These results would then be applied to the understanding of other basins within the Gulf and worldwide in similar tectonic settings (i.e. Salton Sea, Delphin, Farallon and Manzanillo). The organic matter maturation and mineralization in such thermal systems will also be considered.

Sediments of the Gulf and of neighboring areas of the eastern Pacific also contain Neogene and Quaternary records of biological productivity and accumulations of high amounts of organic matter. These high resolution stratigraphic records are unique for several reasons. Biological communities off the western coast of Baja California Sur are at the border of transitional and tropical assemblages. This border fluctuates with changes in surface El Niño-type conditions. Under the same climatic controls in the

Gulf, communities appear to respond to different signals. Comparison of the paleoceanographic records of these two areas will help explain factors controlling their enhanced productivity and will complement similar records from the Peru Margin obtained by ODP Leg 112. Sediments accumulating in mid-water oxygen minima under these zones of high productivity contain unique information about paleoceanography and history of coastal upwelling systems and about the production and preservation of organic matter and the associated impacts of these high concentrations upon sediment geochemical properties.

FIRST OBJECTIVE:

DRILLING THE MANZANILLO RIFT (COLIMA)

Geophysical investigations have demonstrated that the Gulf of California was created by the shift of spreading from a ridge-ridge, intra-plate and purely oceanic setting to a continental site, landward of the active Middle America Trench. To occur, this process had to involve the extension of spreading from oceanic crust to continental crust, across a subduction zone.

That a structural proto-Gulf had been in existence for some time before spreading was initiated in the Gulf has been suggested by Allison (1964) and Gastil *et al*. (1972) who analyzed tectonic patterns and stratigraphic data. These careful field studies speculate that diffuse crustal extension and lateral translation occurred over a broad zone for a long time before the crust was rifted through and true seafloor spreading occurred.

A site has been identified where this process seems to be occurring at the present time. Allan (1981) and Luhr *et al*. (1985) suggest that an episode of continental rifting has formed a system of three intersecting grabens in the western Mexican volcanic belt (Figure 2). According to these authors, these grabens may mark the initial stage of a ridge-segment jump from the East Pacific Rise eastward, beneath continental crust. Since Pliocene time, small volumes of highly unusual, rift-related alkaline magmas have erupted in the Colima graben area. These occurred in close association with

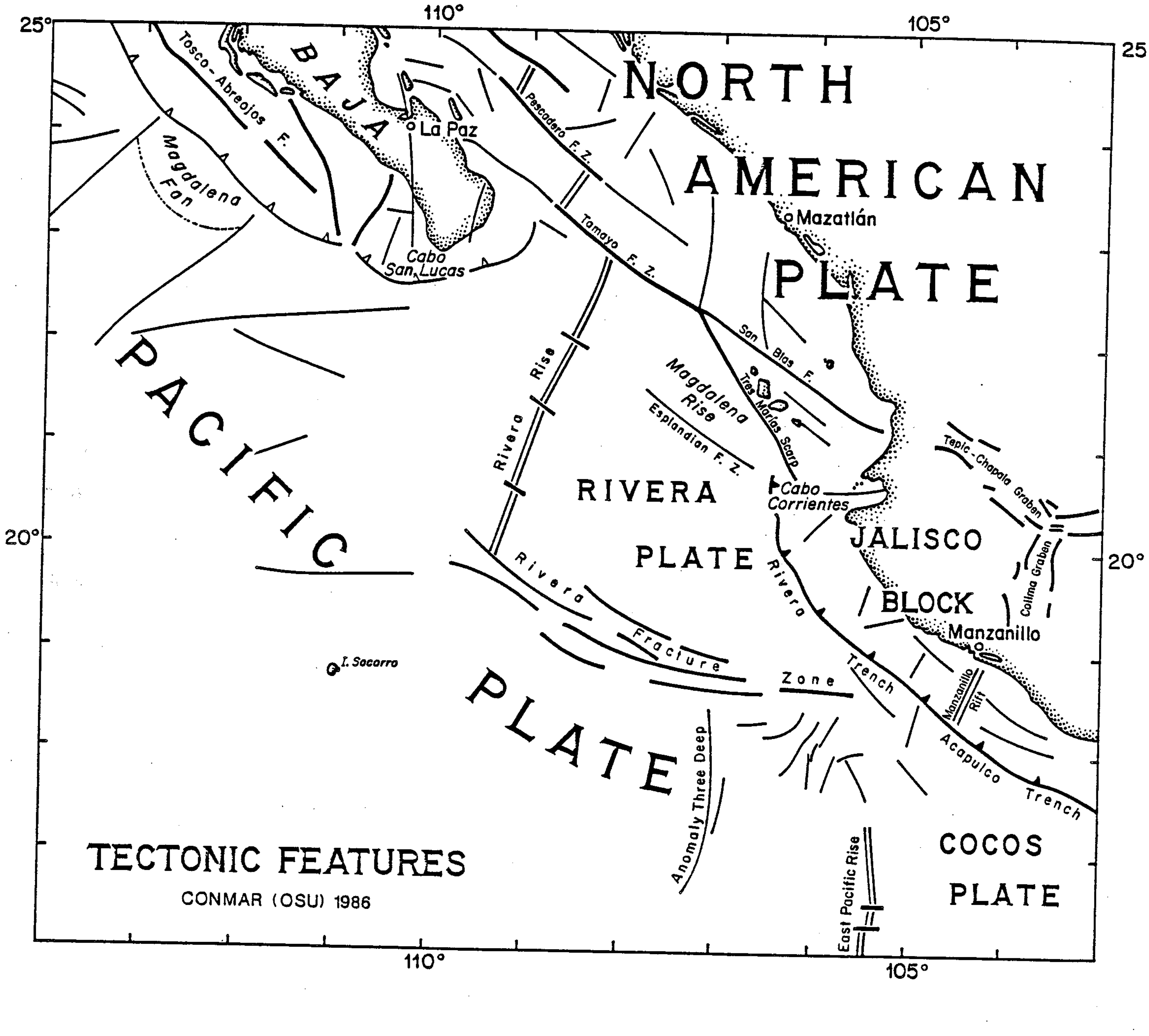


Figure 2. Principal tectonic features delineating the boundaries of the Jalisco Block.

the more abundant, subduction-related calc-alkaline magmas erupted from andesitic stratovolcanoes. The alkaline volcanic petrologic suites are similar to those found in the East African Rift.

Ness et al. (1981) and Ness and Lyle (1981), in order to account for a seafloor spreading rate imbalance identified in the mouth of the Gulf, proposed that some slow right-slip must be ocurring along the Trans Mexican Volcanic Belt, across the San Blas gravity minimum and into the Tamayo Fracture Zone. Stimulated by Allan's report (1981) on the Colima Graben, they concluded that it must be related to a set of gravity and bathymetric reentrants extending from the trench into the continental slope southwest of Manzanillo. In 1984, Ness conducted an ARGO-navigated gravity, bathymetry and magnetic survey of the area to better delineate the Manzanillo Rift. These onshore-offshore mapping efforts outlined the boundaries of the Jalisco Block. The bathymetry of the southern part of the region is shown in Figure 3. The Colima Trough and its offshore extension, the Manzanillo Rift, would be the modern equivalent of the proto-Gulf of California and as such would be ideal sites to study early rifting processes.

The outgoing track of Glomar Challenger, DSDP Leg 66, from Mazatlan to Sites 484-493, gives a good single-channel seismic reflection profile across this feature; it shows four fault-bound canyons (A, B, C, and D in Figure 4). "A" is partially filled with sediments, "B" is nearly completely filled, and "C" and "D" hardly at all. Other shallower channels are also observed that are probably purely erosional.

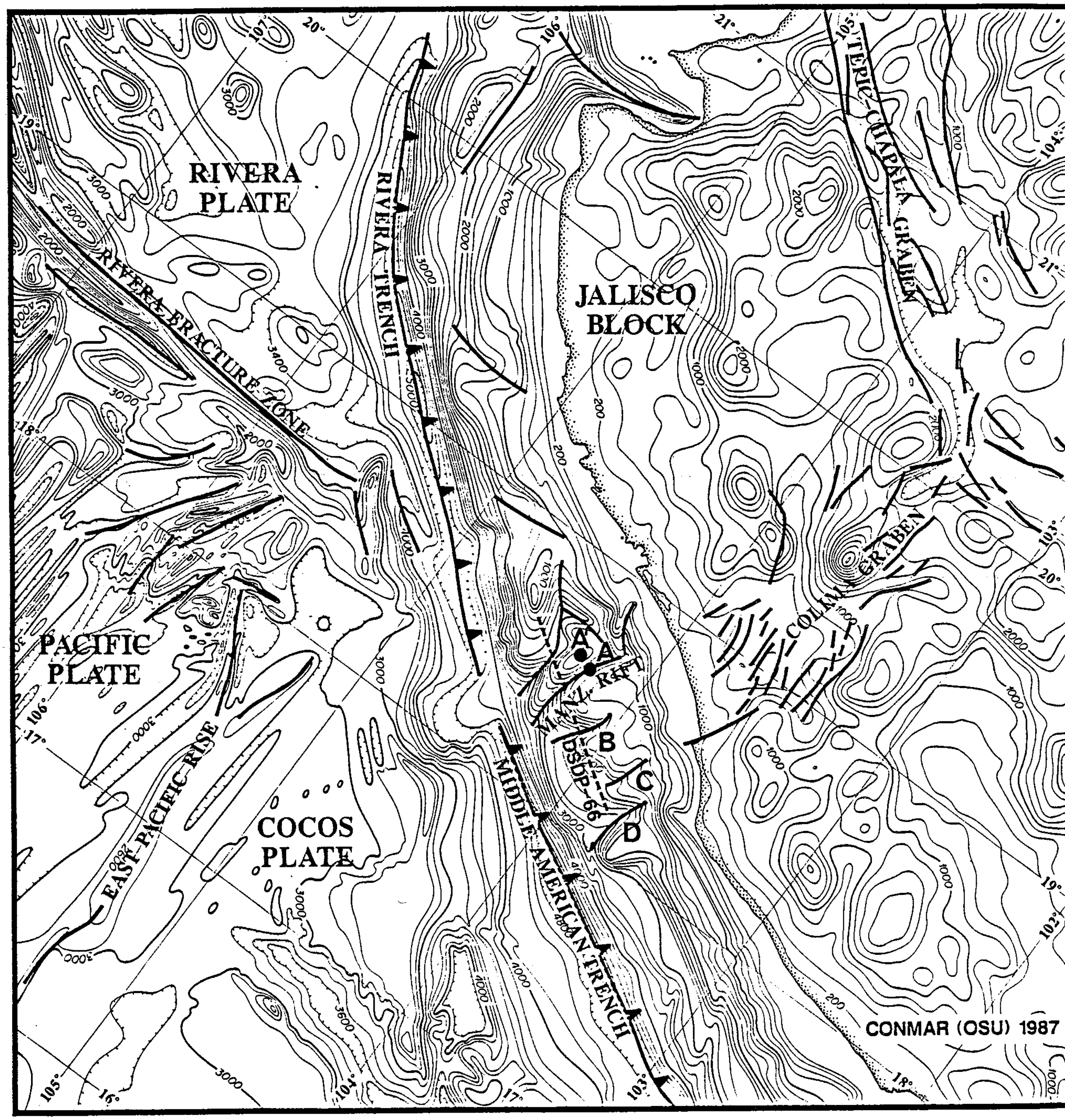


Figure 3. Bathymetric-topographic map of the First Objective area including the location of the seismic reflection profile shown in Figure 4. The map is excerpted from a set of larger maps compiled by the CONMAR Group at Oregon State University for publication by AAPG. Proposed drill sites are A and A'.

Figure 4. Single channel seismic reflection profile of DSDP Leg 66 (track on Fig. 3), showing the four grabens and rift (A-D). Proposed drill sites are A and A'.

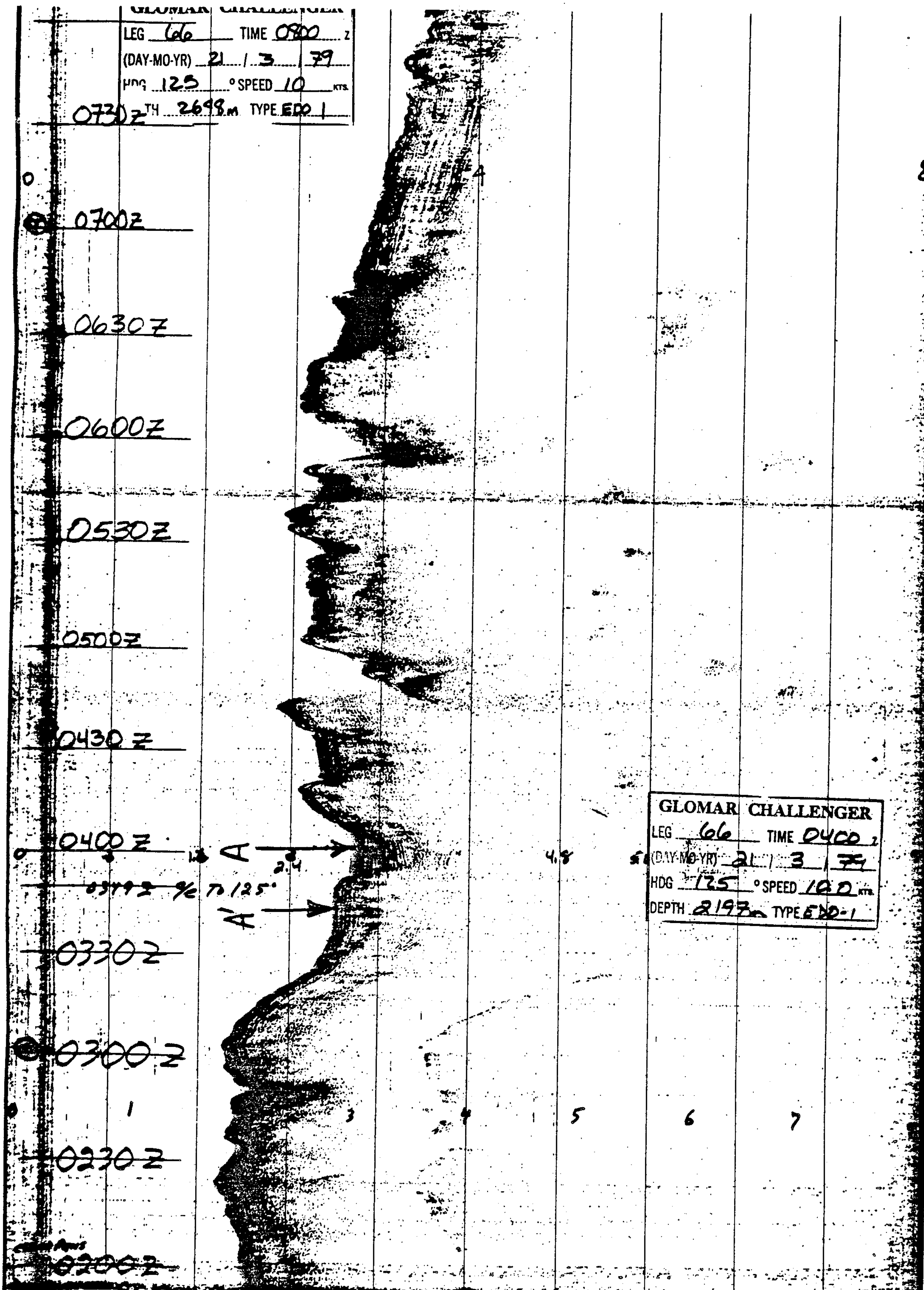

GLOMAR CHALLENGER
LEG 66 TIME 0800 Z
(DAY-MO-YR) 21 / 3 / 79
HDG 125 ° SPEED 10 KTS.
DEPTH 2698 m TYPE EDO 1
0730 Z
0700Z
0630Z
0600Z
0530Z
0500Z
0430 Z
0400 Z
A
A'
0349 Z c/c TO 125°
0330Z
0300Z
0230Z
0200Z
1
3
4
5
6
7
GLOMAR CHALLENGER
LEG 66 TIME 0400 Z
(DAY-MO-YR) 21 / 3 / 79
HDG 125 ° SPEED 10.0 KTS.
DEPTH 2197 m TYPE EDO-1

Figure 2 illustrates the tectonic setting at the present time and suggests that we are witnessing the early stages of a plate reorganization that would involve the creation of a micro-plate bound to the west by the Rivera segment of the East Pacific Rise and to the east by the Colima-Manzanillo Rift. Bounding transform faults to the north and south would be the Tamayo-San Blas-Tepic Faults and the Rivera transform fault. With time, the Rivera segment of the East Pacific Rise would probably fail, and the Colima-Manzanillo Trough would be the only active spreading ridge. Another consequence of this evolution would be abandonment of the Rivera Trench as a subduction zone. This tectonic setting is remarkably similar to that which prevailed at the time of rifting, just before the opening of the Gulf of California. In both cases, an active subduction zone fails, and an oceanic ridge starts spreading into a precursor rift. In the case of the Gulf of California, this sequence of events is inferred from the observation of 10 Ma marine deposits in the Gulf. Seafloor magnetic lineations near the tip of the Baja Peninsula place the initiation of spreading at ~3.5 Ma, although 6.5 Ma anomalies are found near the northern Rivera Trench at DSDP Site 473. In the Colima Trough, rifting is occurring now, and may have started as early as Pliocene in the northern graben (Allan and Carmichael, 1984).

We propose to drill two holes: one in the axis of the filled canyon "A", and one in the western wall of the same canyon. The two sedimentary sections would allow a comparison between the evolution of the two sides of one of the grabens in the Manzanillo Rift. In addition, it would provide access to the initial sediments deposited on an early rift. The study of the maturity of the organic matter in these sediments would provide data on the effective heat flow of early rifting before the onset of spreading. These results would couple with data from the Guaymas transects where both processes occurred.

SECOND OBJECTIVE:

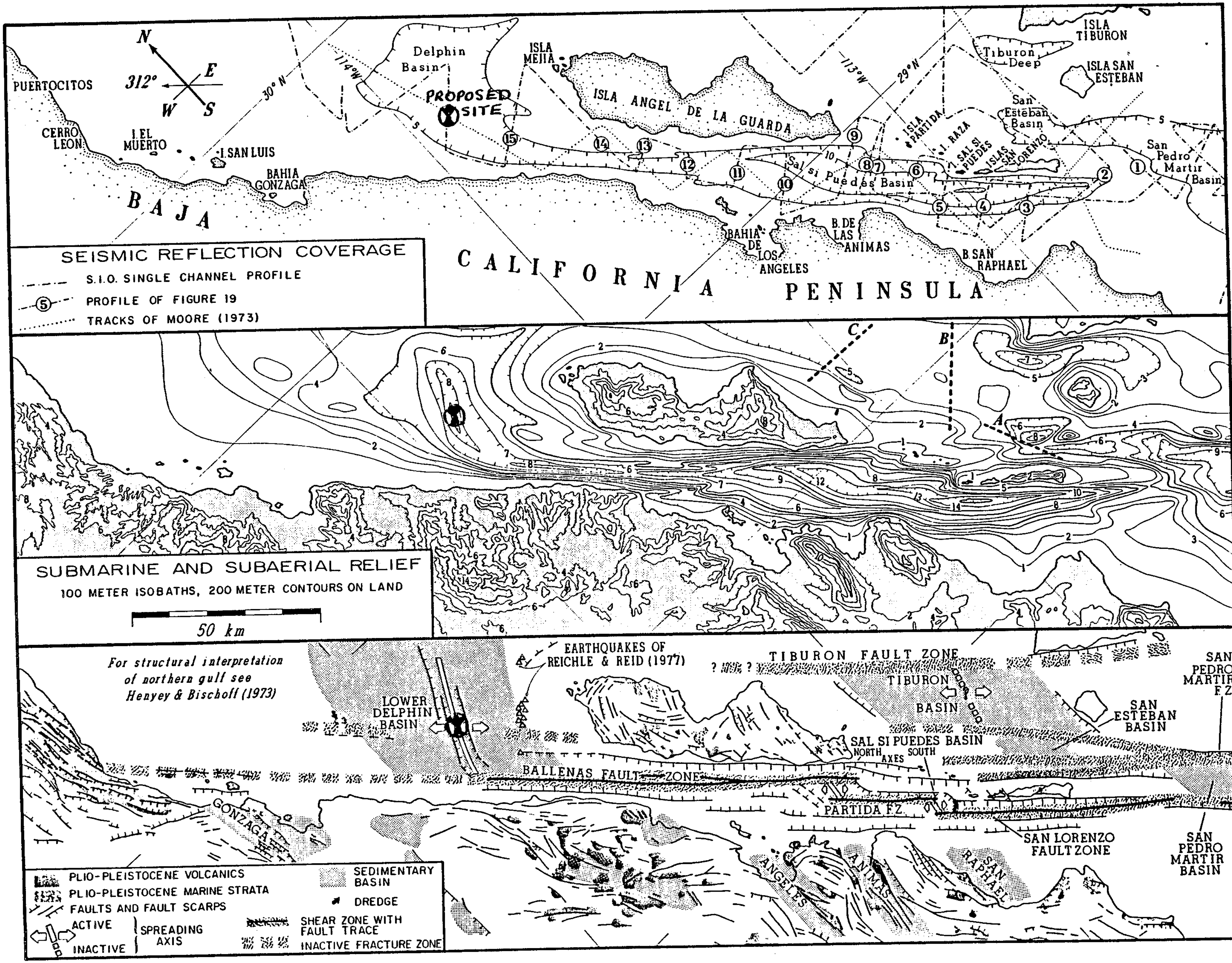
COMPLETION OF THE LONGITUDINAL TRANSECT ALONG THE GULF OF CALIFORNIA

Rationale:

Young oceanic crust accreted at early stages in the evolution of a sea-floor spreading system was drilled at the mouth of the Gulf and at Guaymas Basin in the central Gulf on DSDP Legs 64 and 65. Differences between these areas in volcanic and sedimentary stratigraphy, igneous petrology, and hydrothermal phenomena are caused mainly by differences in the amount and type of sediment deposited at the accreting plate boundary. A deep scientific drill hole for stratigraphic, petrologic, and geothermal studies has recently been drilled in the subaerial Salton Trough, where newly-accreted igneous rocks are deeply buried under the clastic sediments of the Colorado delta. We propose drilling single-bit holes at spreading centers in the southern and northern Gulf (Farallon Basin and Lower Delphin Basin, and including Manzanillo Rift) to complete a longitudinal profile of the Gulf province, allowing a more complete assessment of the effects of sedimentation on the emplacement and cooling of oceanic crust. The spreading centers are of differing ages, so sampling their igneous rocks will provide insights on the geochemical and petrological evolution of intercontinental spreading centers. Secondary objectives are sedimentological (studying the facies of narrow rhombochasms in marginal seas) and paleoclimatalogical (e.g., as recorded by fluctuations in sediment input from the Colorado River).

The spreading center in Lower Delphin Basin (Figure 5) appears from existing data to be structurally similar to those well surveyed in the Guaymas Basin. There is a 100-200 m deep and 3-5 km wide rift valley in a sediment plain. The sediment source and type is very different from Guaymas Basin:-Lower Delphin Basin is at the distal end of channels leading from the Colorado delta, so terrigenous sediments dominate over reactive organic-rich siliceous diatomaceous muds of the central Gulf. Although the Lower Delphin spreading-center trough is the best developed in the northern Gulf, it is also very young. Continental crust extends from Isla Angel de la Guarda to within 15 km of the spreading center, and on the other (northwest) flank, attenuated continental crust, with listric and antithetic faulting, is beautifully exposed on land around Puertocitos. At an estimated spreading rate of 50 m/10^3y, the width of newly accreted crust in Lower Delphin would have been formed within the past 1 my (earlier Pacific-North America spreading at this plate latitude was at a now extinct center in Tiburon Basin). The juxtapositon of well-exposed structures and igneous rocks from the rifting stages of crustal separation (on land around Puertocitos), and an accretionary axis at the earliest stage of spreading, makes this an excellent site to study stages of the Wilson cycle and passive margin development. It will be important to sample basaltic rock (none is exposed at the seabed) to determine the extent of continental "contamination" of the presumably tholeiitic magmas. A hydrothermal circulation with sea-water convection is predictable (though no good heat flow estimates are possible with short probes, because surface temperature gradients are too affected by bottom-water temperature changes); it will be important to compare

Figure 5. Location of Lower Delphin Basin and proposed drill site. (background data from a manuscript in preparation by Lonsdale).


SEISMIC REFLECTION COVERAGE
S.I.O. SINGLE CHANNEL PROFILE
PROFILE OF FIGURE 19
TRACKS OF MOORE (1973)
N
E
W
S
312°
PUERTOCITOS
CERRO LEON
I. EL MUERTO
I. SAN LUIS
BAHIA GONZAGA
BAJA CALIFORNIA PENINSULA
Delphin Basin
PROPOSED SITE
ISLA MEJIA
ISLA ANGEL DE LA GUARDA
ISLA PARTIDA
I. RAZA
I. SAL SI PUEDES
ISLAS SAN LORENZO
Sal si Puedes Basin
San Esteban Basin
Tiburon Deep
ISLA TIBURON
ISLA SAN ESTEBAN
San Pedro Martir Basin
BAHIA DE LOS ANGELES
B. DE LAS ANIMAS
B. SAN RAPHAEL
114°W
113°W
30° N
29° N
SUBMARINE AND SUBAERIAL RELIEF
100 METER ISOBATHS, 200 METER CONTOURS ON LAND
50 km
A
B
C
For structural interpretation of northern gulf see Henyey & Bischoff (1973)
EARTHQUAKES OF REICHLE & REID (1977)
LOWER DELPHIN BASIN
TIBURON FAULT ZONE
TIBURON BASIN
SAL SI PUEDES BASIN
NORTH AXES SOUTH
BALLENAS FAULT ZONE
PARTIDA F.Z.
SAN LORENZO FAULT ZONE
SAN ESTEBAN BASIN
SAN PEDRO MARTIR F.Z.
SAN PEDRO MARTIR BASIN
GONZAGA
ANGELES
ANIMAS
SAN RAPHAEL
PLIO-PLEISTOCENE VOLCANICS
PLIO-PLEISTOCENE MARINE STRATA
FAULTS AND FAULT SCARPS
ACTIVE
INACTIVE
SPREADING AXIS
SEDIMENTARY BASIN
DREDGE
SHEAR ZONE WITH FAULT TRACE
INACTIVE FRACTURE ZONE

the mineralogical, organic and inorganic geochemical, and ore-forming effects with those being investigated by deep drilling in Salton Trough (a recharging groundwater system).

The spreading center in Farallon Basin (Figure 6) has a structure more like sediment-smothered mid-ocean ridges (e.g. Gorda Rise) than the basins further north in the Gulf (e.g. at Guaymas). The spreading-center trough is an apparently rock-walled rift valley 15 km wide and more than 1 km deep, with a 5 km wide floor covered with turbidity currents from the Fuerte delta. Outcrops of fractured basement rocks at the rift walls should allow development of a recharging hydrothermal system intermediate between that of Guaymas Basin (no outcrop) and the East Pacific Rise crest (no sediment).

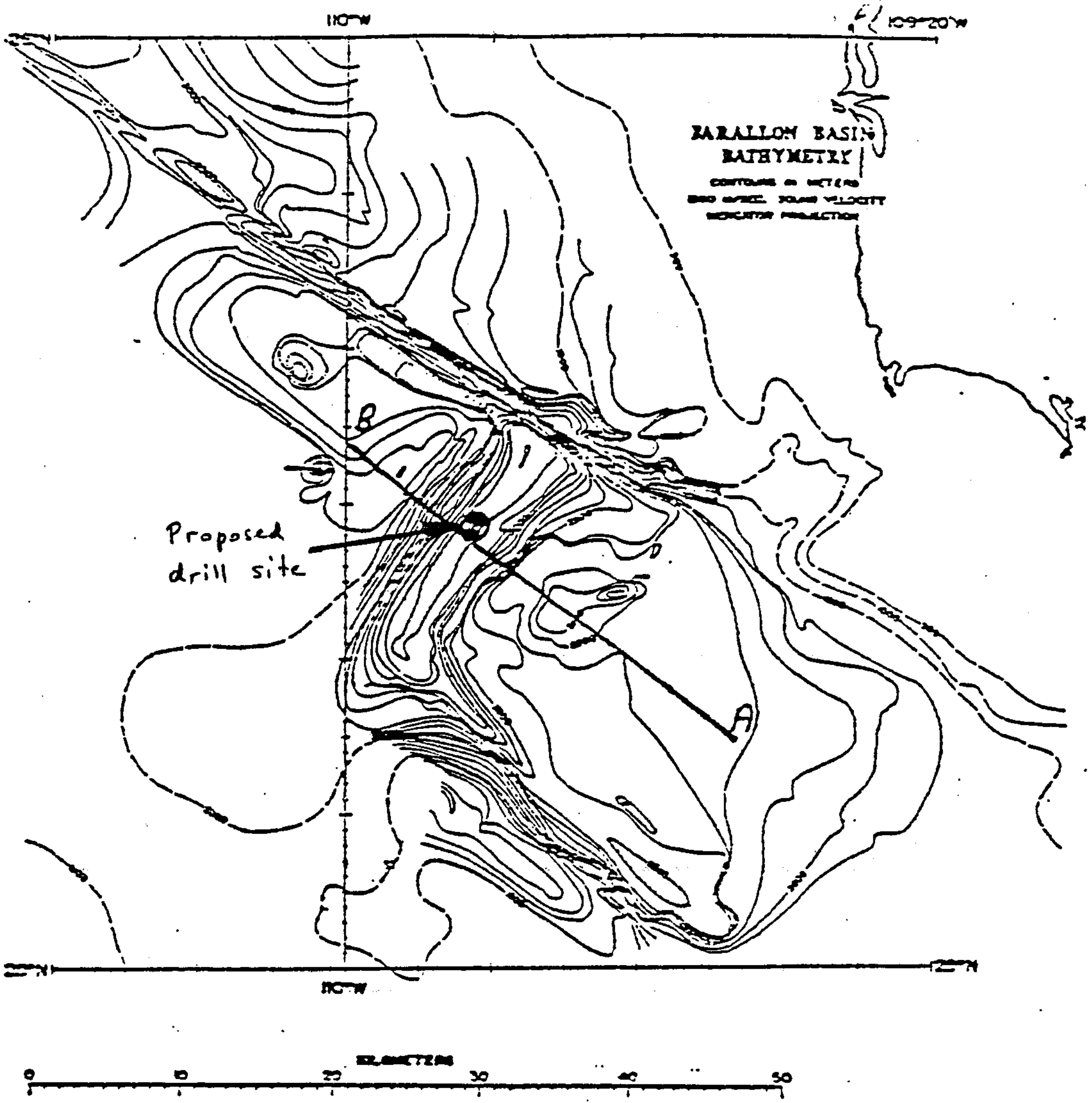
<u>Comparison with Salton Trough</u>: (M.A. McKibben, proponent)

The proposed ODP drilling in the Gulf of California provides a unique opportunity for studying the transition from the active spreading center of the East Pacific Rise to the "leaky" transform fault system of the San Andreas fault zone (Figure 7). This opportunity is based on the recent completion of deep drilling in the Salton Trough (Sass and Elders, 1987).

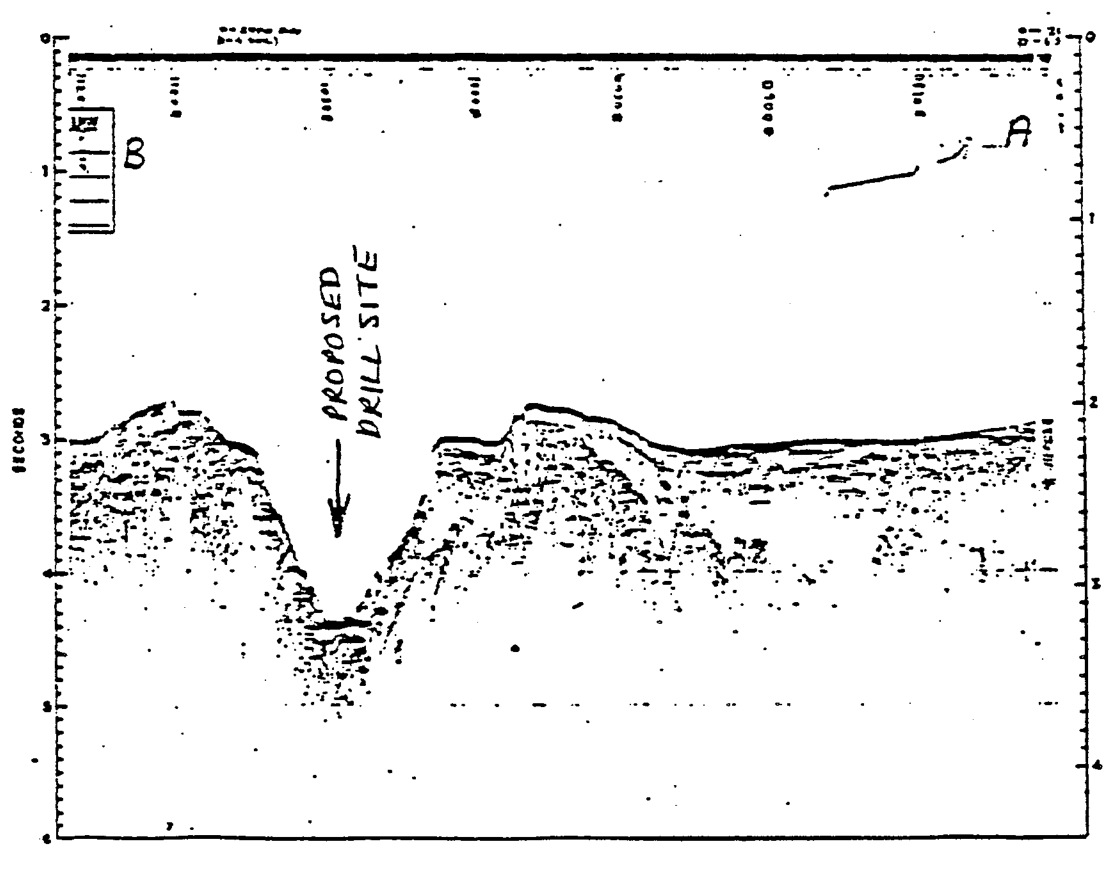
A comparative study of drill cores from the Salton Trough and Gulf of California hydrothermal systems has global significance, because it allows documentation of important changes in crustal petrogenesis, basin sedimentation, hydrothermal alteration and ore-formation along North America's most active and accessible rift zone.

Figure 6. Farallon Basin: (a) bathymetry and proposed drill site, and (b) seismic line (A-B).

a


110°W
109°20'W
FARALLON BASIN
BATHYMETRY
CONTOURS IN METERS
MERCATOR PROJECTION
B
Proposed
drill site
A
110°W
KILOMETERS
0
10
20
30
40
50

b


B
A
PROPOSED
DRILL SITE
SECONDS
KILOMETERS

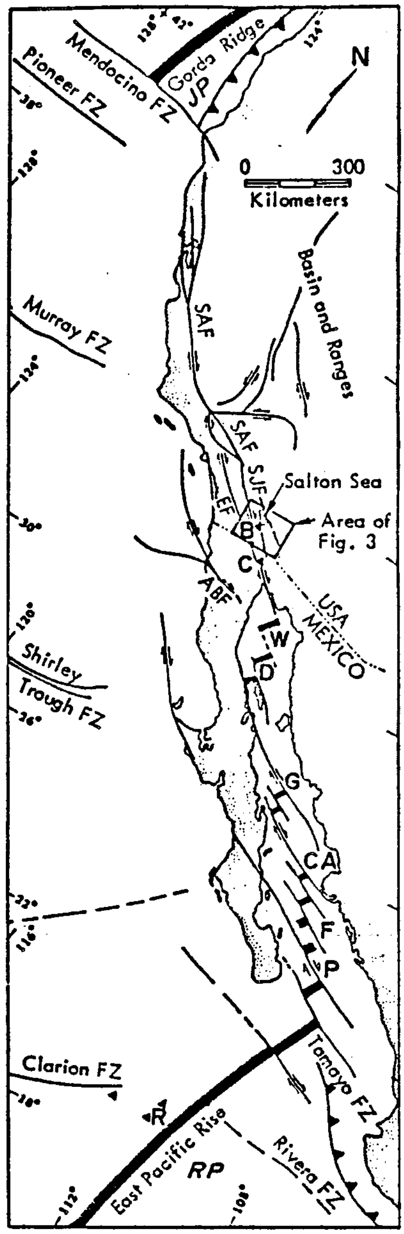


Figure 7. Gross tectonic environment of the Salton Trough. The Pacific Coast of North America is dominated by transform fault systems, which connect the Mendocino triple junction to the Rivera triple junction. Also shown are pull-apart basins between en echelon fault segments in the Gulf of California. Oceanic fracture zones (FZ) and continental faults (F) are solid black lines, dashed where uncertain. Other abbreviations: SAF - San Andreas Fault; EF - Elsinore Fault; SJF San Jacinto Fault; ABF - Agua Blanca Fault; JP - Juan de Fuca Plate; RP - Rivera Plate; W - Wagner Basin; D - Delphin Basin; G - Guaymas Basin; CA - Carmen Basin; F - Farallon Basin; P - Pescadero Basin; Δ - Holocene volcanoes; B - Salton Buttes; C - Cerro Prieto; and R - Revillagigedo. From Elders et al., 1972, Lawver and Williams, 1979, and Dickinson and Snyder, 1979.

Although the hydrothermal systems of the Salton Trough and the Gulf are part of the same rift system, they differ significantly in the nature of their basement, host sediments and hydrothermal fluids. The basement underlying the Salton Trough is thicker and of a more hybrid nature than the oceanic crust flooring the Gulf (Elders et al., 1972; Fuis et al., 1982). The sediments deposited in the Salton Trough are dominantly non-marine and include evaporites formed in the closed-basin environment of the northern trough. Sediments in the Gulf have a southwardly increasing component of organic-rich marine deposits. Fluids in the Salton Trough are evolved Colorado River water, with high salinities caused by evaporite dissolution. In contrast, the Gulf systems are dominated by seawater that interacts with basalt and sediments.

These lithologic and hydrologic changes along the rift system have profound effects on the development of hydrothermal systems, influencing hydrothermal alteration and ore forming processes. Comparative studies will greatly improve our understanding of the development and diversity of rift-basin sedimentation and hydrothermal systems along an active oceanic to continental transition. The proposed Delphin Basin, Guaymas Basin and Farallon Basin sites, when coupled with the Salton Sea and Cerro Prieto drilling, provide a unique, complete transect along the length of this transition. Such an opportunity for large-scale comparison of drilling results must be taken advantage of.

The Salton Trough and Cerro Prieto Systems:

Deposition of the Colorado River delta over the rift system has resulted in development of hydrothermal systems within a variety of sediment host rocks. The delta has effectively cut the rift system in half, yielding a closed-basin non-marine environment in the northern part of the Salton Trough. This closed-basin environment of the northern Trough has resulted in development of extremely saline brines derived from evaporation of Colorado River water and deep hydrothermal dissolution of evaporites (Elders, 1979; McKibben *et al.*, 1986; McKibben and Elders, 1985; White, 1981). The brines are metal-rich and deposit abundant sulfide-bearing veins in the hydrothermally-altered sediments at temperatures up to 365°C. The sediments are altered to relatively oxidized greenschist facies assemblages (Bird *et al.*, 1984; McKibben and Elders, 1985). Sulfide-bearing diabase intrusions were penetrated at the bottom of the recent deep Salton Sea hole. This occurrence of young sills in Plio-Pleistocene sediments is analogous to the Guaymas Basin occurrence, and warrants comparative study.

The Cerro Prieto system is located near the crest of the modern Colorado delta (Figure 7). In contrast to the relatively stagnant Salton Sea system, the hydrology of this system is much more laterally-open, with a well-defined hydrothermal plume and recharge and discharge zones (Figure 8, Elders *et al.*, 1984). There are no known evaporites present, and fluid salinity is low. Consequently, ore-formation in this system is very minor. The deltaic sediments are altered to a relatively reduced greenschist facies assemblage, the relatively open hydrology of Cerro Prieto is similar to the Gulf systems, although marine influences are absent.

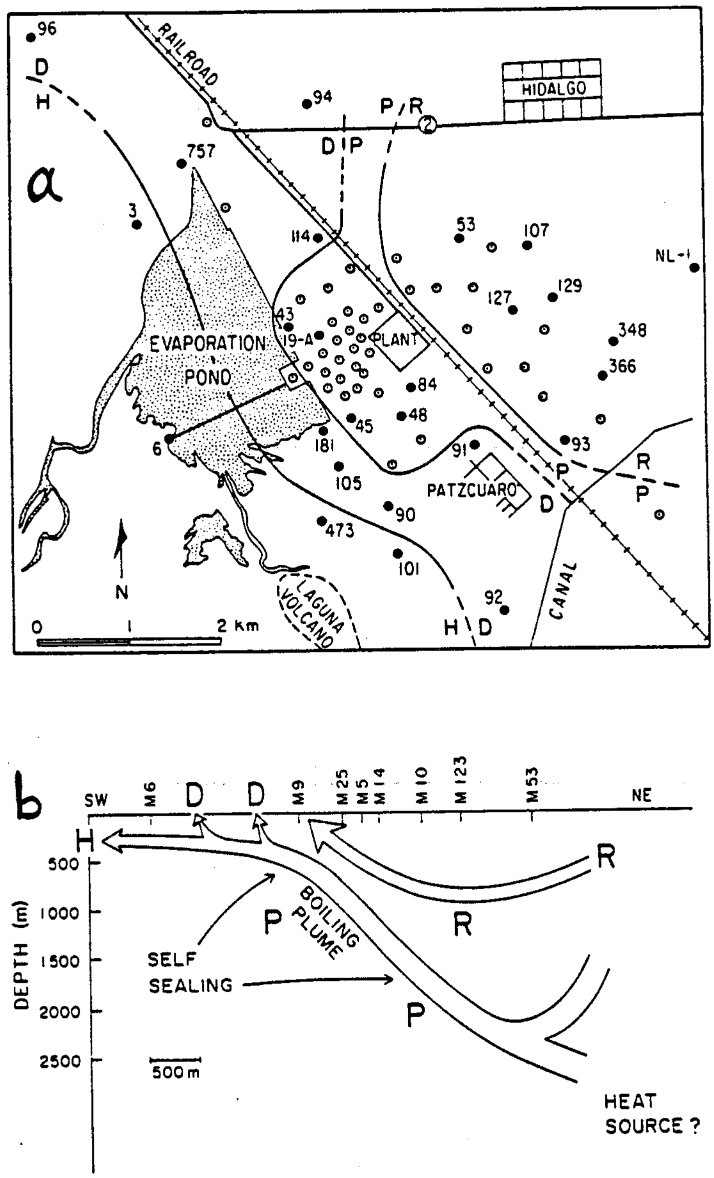


Figure 8. The Cerro Prieto geothermal field can be divided into regions with different patterns of mineral zones, characteristic of different flow regimes. R, Recharge zone; P, thermal plume; D, discharge zone; and H, horizontal flow zone.
(a) Open circles show well locations and filled circles are selected wells whose identifying numbers are shown.
(b) The proposed flow pattern at Cerro Prieto shown on a southwest to northeast profile from well M-6 to well M-53 (Elders et al., 1984).

We propose to compare the hydrothermal ore-forming processes occurring in these systems (Salton Trough to Farallon Basin transect). Evidently, abundant sulfides are found only in the Salton Sea and Guaymas Basin systems, with the former characterized by high salinity and the latter by high organic matter content. The nature of ore-formation in the Delphin and Farallon Basins is unknown, but presumably will be similar to Guaymas. In particular, the nature of stockwork and massive sulfide formation beneath the vent systems should be determined, for comparison with deep vein sulfides in the Salton Trough.

THIRD OBJECTIVE:

DRILL SITES IN THE FARALLON BASIN (TRANSECT SITES J1-J5)

Rationale:

Study of the Gulf of California will give us insight into two very important problems. The first is the initial rifting process of continental blocks and the evolution through time of the initial rifting. The second problem concerns the formation of terranes. Even though the Gulf of California is rifting obliquely to the North American plate margin, some of the basins are of sufficient width (i.e. greater than one crustal thickness, 40-50 km) that the thermal regime in the center of the rifted margin can be compared to a parallel-rifted Atlantic-type passive margin.

Roberts and Montadert (1979) summarized the thoughts and objectives of the passive margin panel of the DSDP. The passive margin panel considered three broad categories that could be investigated with drilling on rifted passive margins. These were: problems related to structural evolution; problems related to the genesis and evolution of sedimentary sequences; and geophysical aspects such as changing thermal regimes, gravity edge and magnetic slope anomalies and the composition of the diapiric structures observed on seismic reflection profiles. The evolution of passive margins was thought to involve four stages: (1) doming, (2) rifting, (3) onset of drifting sea-floor spreading and (4) subsequent post-rift evolution (Figure 9). While doming has been postulated on

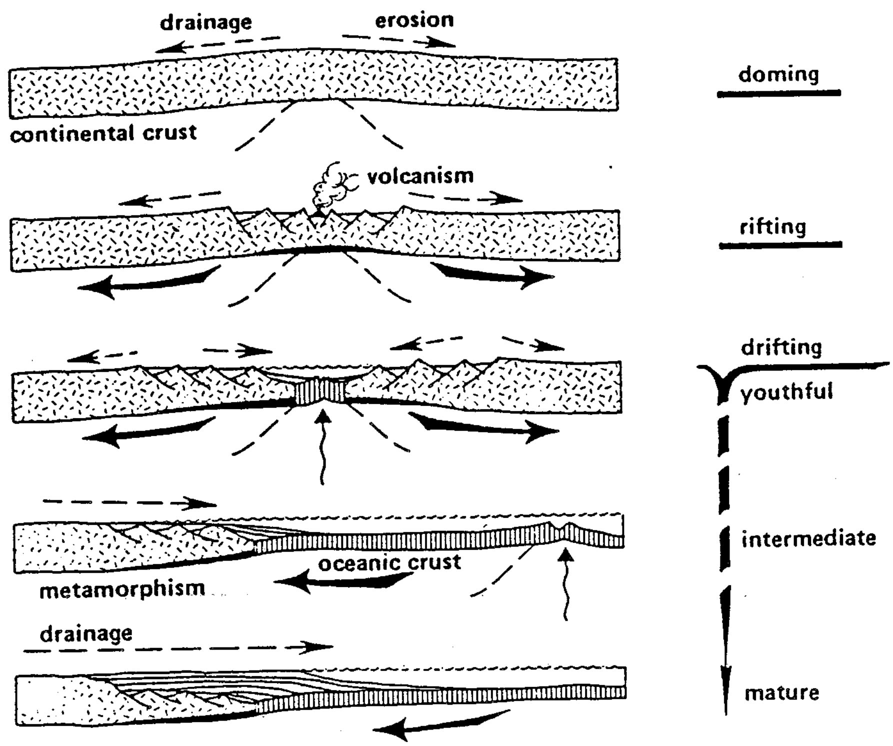


Figure 9. Model of formation and evolution of rift segments of passive continental margins, as adapted from many published sources (e.g. Curray, Moore et al., 1982).

the basis of uplift around the Red Sea and the East African Rift valley, it is now thought that it may not be a general characteristic of rifted margins.

On DSDP Leg 64 a transect of three holes was drilled at the tip of the Baja California Peninsula to investigate the oceanic continental transition (Holes 474A, 475 and 476; Curray, Moore et al., 1982). The first hole bottomed in pillow basalts and intercalated sills with the lowermost unit being a massive basalt flow which was interpreted as oceanic basement. Holes 475 and 476 were drilled on the lower continental slope with Hole 475 being stopped by a conglomerate of predominantly metamorphic cobbles. Hole 476 penetrated the conglomerate and bottomed in weathered granite. Hole 476 was not more than 10 kilometers from the oceanic crust found at Hole 474. The weathered granite and the deposition of the conglomerate both appear to have occurred subaerially. It appears that subsidence, accompanied or even preceded the first block faulting (the rifting stage) and occurred before sea-floor spreading and thus the present phase of opening of the Gulf began (Curray, Moore et al., 1982). There is certainly no evidence to suggest doming occurred prior to seafloor spreading. The structure of the margin near the mouth of the Gulf tip derived from Holes 474A, 475 and 476 suggests that it is dominated by horst-and-graben and rotational listric faulting.

The Gulf of California varies from the nearly normal ocean-continent boundary at the mouth of the Gulf to a super-mature, sediment filled continental rift at the northern boundary. During the rifting stage, the basic structural framework of the margin is determined by the pattern of rifting and preexisting zones of structural weakness. Within the rift according to Curray, Moore et al. (1982), basic and alkaline intrusive rocks may be intercalcated with and thickly covered by contemporaneous, coarse, clastic, continental sediments. During the rifting stage, if uplift and doming did not occur and an abundant terrigenous sediment supply is available then even during the early stages of formation of the young ocean basin, it will be filled with terrigeneous sediments as rapidly as opening occurs. This has clearly occurred in the northern Gulf of California in the Salton Trough and probably also occurred during the initial phases of rifting in the central and southern Gulf of California.

Consequently, the Gulf of California presents an excellent opportunity to study the variation from normal rifted passive margins to well-sediments ('super-mature') rifting margins (see Figure 10). Leg 64 has already drilled the normal rifted margin at the mouth of the Gulf so we are proposing two additional profiles for comparison. In Farallon Basin (this section) seafloor spreading is occurring at a nearly normal and unsedimented spreading center. In Guaymas Basin (Fourth Objective: Basin and Margin Transect) seafloor spreading is occurring at two troughs that are fully sedimented. Leg 64 drilling in Guaymas Basin did not find pillow basalts and intercalated sills on oceanic crust. Instead sills that had intruded into the overlying sediment were found with baked contacts both above and below. In Hole 474 at the mouth of the Gulf at a normal rifted margin, the overlying sills were extrusive and had been extruded as much as a million years after initial rifting.

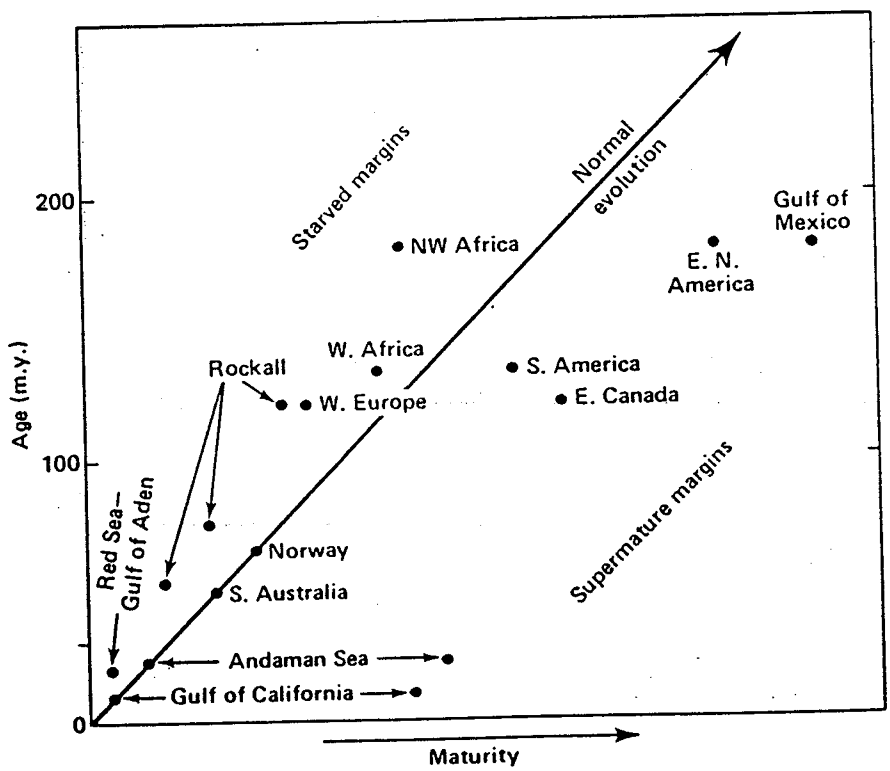


Figure 10. Relationship between age and maturity of passive continental margins (Curray, Moore et al., 1982).

In Guaymas Basin exceptionally high heat flow has been found (up to 3.0 W/m^2) (Lonsdale and Becker, 1985) which is clearly indicative of an insulated seafloor spreading center. The very high heat flow is associated with black smokers that also release higher order hydrocarbons. The exceptionally high conductive heat flow is thought to occur above a cap that traps hydrothermal circulation beneath it (Lawver and Williams, 1979). In contrast, the meager heat flow data from Farallon Basin seems to indicate that a great deal of convective heat loss occurs at the spreading axis. The highest conductive heat flow (Figure 11) was measured to the south of the central depression with only four relatively low heat flow values recorded in the central trough.

In Guaymas Basin, the southern trough is covered with at least 268 m (Hole 477A) of diatomaceous ooze, dolerite sills and hydrothermally altered and indurated diatomaceous turbidites ranging from clay and claystone to sandy siltstone and silty sandstone. In the northern trough (Hole 481A) at least 384 m of olive-brown muddy diatom ooze and turbidites, megaturbidites, sandstones, chert and dolerite sills, and mudflows, overlie 142 m of alternating laminated and bioturbated hemipelagic muddy diatomaceous ooze. Early work on the Galapagos spreading center (Williams et al., 1974) estimated that open hydrothermal circulation systems are essentially closed off when the sediment thickness reached about 100-200 m on crust about 9 x 10^5 years in age. In the southern and northern troughs of the Guaymas Basin the hydrothermal circulation systems can be considered as 'closed', due to the thick sedimentary cover. The intrusive sills act as an effective local cap rock probably producing multi-layered hydrothermal systems. At a few places, vents occur through the sills

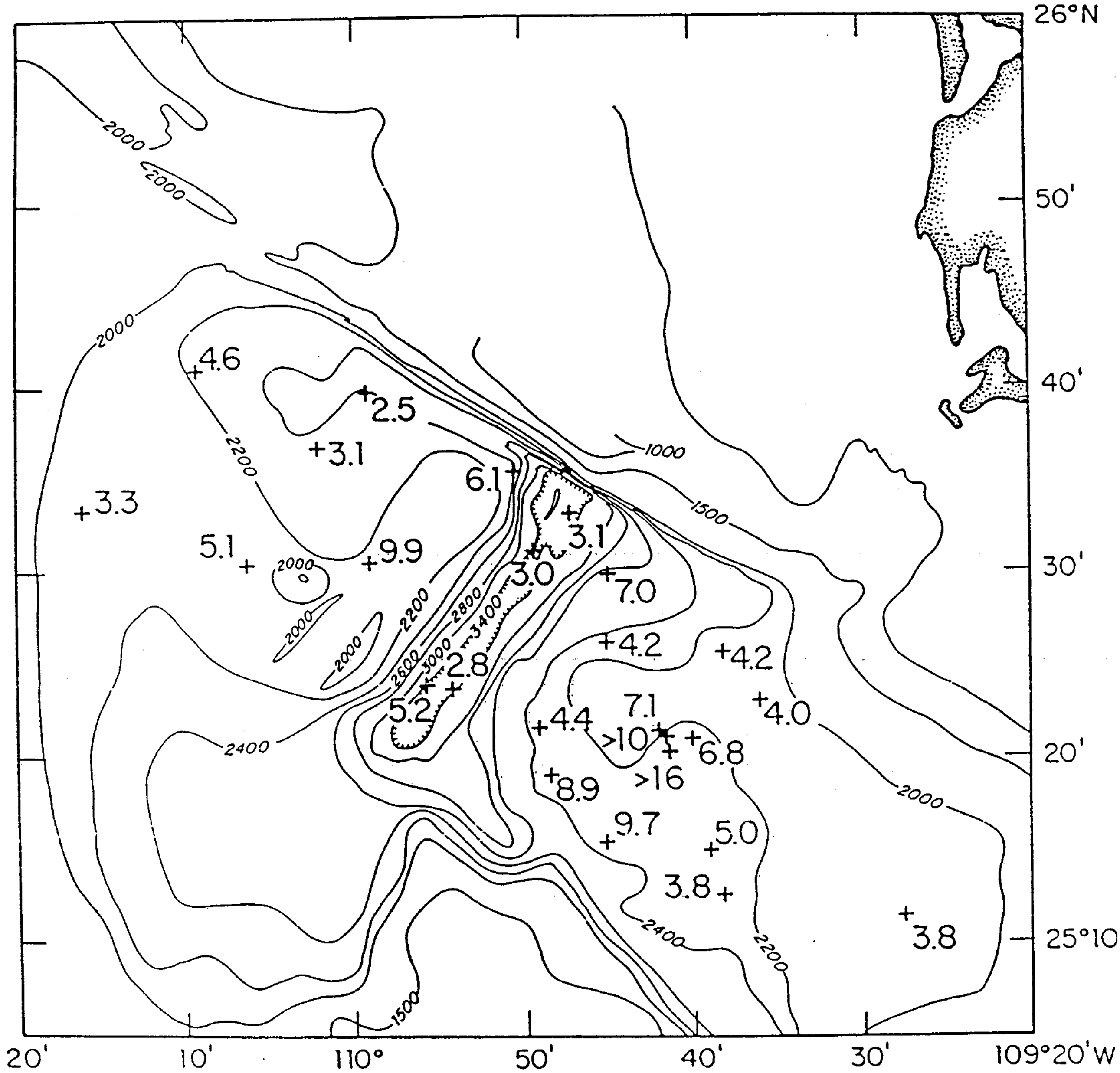
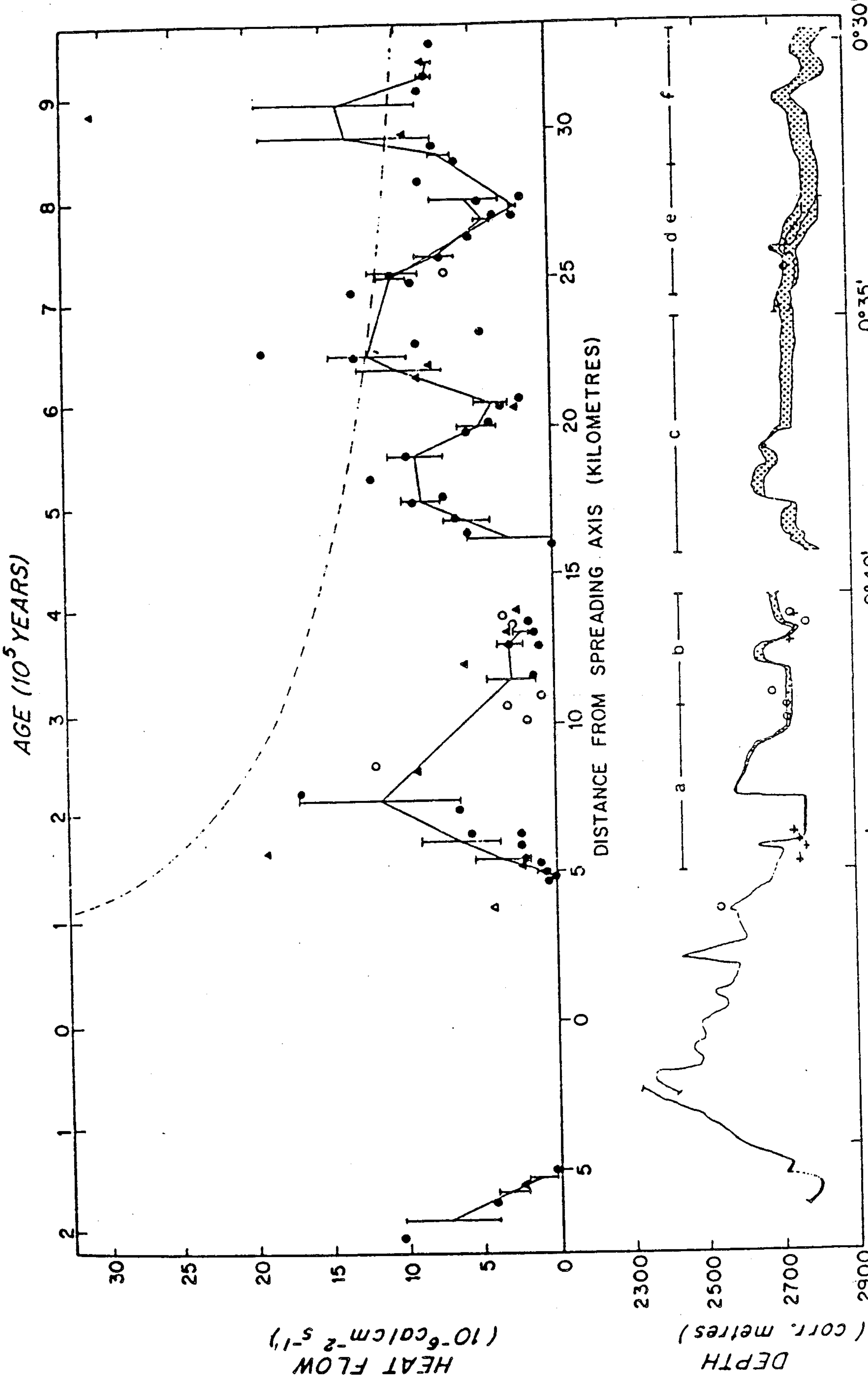


Figure 11. Farallon Basin heat flow data (Lawver and Williams 1979) units are in $\mu cal/cm^2$-sec.

and produce the spectacular seafloor features observed in the southern rift (Lonsdale and Becker, 1985). In contrast, at the Galapagos spreading center (Figure 12) a large percentage of the heat is lost by open hydrothermal circulation on crust younger than 1 my (Williams et al., 1974). Williams and von Herzen (1974) estimate that more than 50% of the lithospheric cooling occurs before the seafloor is 2 my old. If Guaymas Basin has lost heat primarily through conductive heat transfer from a mostly closed hydrothermal system with very limited axial convective activity, then it may be quite some time before the normal crustal topography might be formed. The crustal zone of the Galapagos spreading center is dominated by faulted blocks tilted outward with scarps facing the crest (Klitgord and Mudie, 1974). Scarps on blocks 0.25 my old are offset an average of about 100 m, whereas those in 1.0 my old crust have an offset of only 50 m. In Guaymas Basin such blocks have not been seen but the rapid post-glacial turbiditic sedimentation may have hidden such tilted blocks. On the other hand, the hydrothermal system in the Guaymas Basin may cause the young crust to cool much more slowly and tilted blocks may not occur. The formations of the central troughs in both the Guaymas and Farallon Basins need to be explained. Although the spreading rate implies an age of only 50,000 years for the 3 km wide central rift in Guaymas Basin, the seismic correlation together with the youth and thermal histories of the encountered intrusive units demonstrate that the process of intrusion of magma into rapidly deposited sediments is not limited to the 3 km width of the present troughs (Curray, Moore et al., 1982).

Figure 12. Heat-flow data, topography and sediment thickness (stippled pattern) from the 4 profiles shown by dashed lines in Figure 10 (projected north-south). The vertical exaggeration is 12.5:1. Closed circles are individual heat-flow values which were within 2 km of profile. Crosses represent depth of heat-flow measurement deviating 20 m or more from the plotted topography. Triangles indicate minimum values of heat-flow. Open circles and triangles represent heat-flow stations more than 2 km away from the profile track. The circle with a cross in it is station 62. It is discussed in the text and is not used in the averages. The dashed line is the theoretical heat-flow (from Sclater and Francheteau 1970) for an 85 km thick lithosphere, 1250°C on its lower boundary, an internal heat generation of 2.0 x 10^{-10} cal cm^{-3} s^{-1} and an average thermal conductivity of 6.9 x 10^{-3} cal cm^{-1} s^{-1} °C^{-1}. The solid lines connect averages of the measured heat flow values (vertical bars are ± standard error) averaged over 2 km intervals every 1 km along a profile.


AGE (10^5 YEARS)
HEAT FLOW
(10^-6 cal cm^-2 s^-1)
DEPTH
(corr. metres)
DISTANCE FROM SPREADING AXIS (KILOMETRES)
a
b
c
d e
f
0°30'
0°35'
0°40'
0°45'
0°50' N

Terrane Formation:

Terranes accreted to continental shields seem to be more common than originally thought. If the major plate motions remain as they are presently occurring, then the Baja California Peninsula will eventually become part of Alaska. Passive margins take at least three different forms. The first and most important is the Atlantic-type passive margin where rifting occurs parallel to the break-up boundary. The second which may be a subset of the first is the Red Sea type margin where rifting is occurring parallel to the margin but it is possible that rifting may fail since the Arabian plate is colliding with the Eurasian plate. The third type of passive margin is the oblique rift.

Numerous terranes are now recognized in Alaska (Jones et al., 1982). In addition to the terranes, there are massive sulfide deposits such as the one near Shellabarger Pass in the Alaska Range (Reed and Eberlein, 1972). It is interesting to compare the description of the Shellabarger Pass massive sulfide deposit with that of the Boleo copper district deposits near Santa Rosalia.

Reed and Eberlein (1972) describe the Shellabarger Pass deposits as:

> Copper- and zinc-bearing sulfide deposits near Shellabarger Pass occur mainly as replacement bodies in a north-trending structural trough of marine sedimentary and mafic volcanic rocks of probably Triassic and (or) Jurassic age. The lower part of the sequence is interbedded chert, dolomite, siltstone, shale, volcanic graywacke, basaltic aquagene tuff, sedimentary breccia, and conglomerate.

These rocks are overlain by submarine basaltic pillow flows and subordinate interbedded agglomerate, flow breccia, and tuff. This eugeosynclinal assemblage is believed to rest unconformably upon sedimentary rocks of Paleozoic age.

...The deposits are of three general types: (1) lenticular massive sulfide bodies, (2) sulfide minerals that replace carbonate-rich beds, and (3) fracture fillings, mainly in chert and siltstone. Types 2 and 3 are of relatively minor importance.

While Wilson and Rocha (1955) describe the Boleo copper deposits as:

The oldest rock, exposed only in small erosional windows, is a quartz monzonite, which has been considered to be either of Cretaceous or pre-Cretaceous age. This is overlain unconformably by the Comondu volcanics, of middle (?) and late Miocene age, which are probably at least 500 m thick, consisting of andesitic and basaltic flows, sills, tuff, breccia, agglomerate, conglomerate, and tuffaceous sandstone, all the sediments being of nonmarine origin. Facies changes indicate that the sediments were derived from the present site of the Gulf of California.

Overlying the Comondu with profound unconformity is the lower Pliocene Boleo formation, which is the host rock to the copper deposits. This formation consists mainly of interbedded tuff and tuffaceous conglomerate of latitic to andesitic composition, together with a local nonmarine basal conglomerate, a fairly persistent basal marine limestone, thick layers of gypsum, and a few lenses of fossiliferous sandstone. Its thickness ranges from 50 to 250 m and averages 140 m.

By drilling the Farallon Basin and Guaymas Basin transects, and by comparing them to the transect at the mouth of the Gulf we may be able to learn about the variations along a rifted passive margin. In the Gulf of California we know that metalliferous deposits have been found at Santa Rosalia, along the outer edge of Bahia de Concepcion (McFall, 1968) and at other places. If we could correlate the massive sulfide deposit locations with their tectonic evolution and with respect to their age and spacing along the terrane edge, it is possible to then go look for such locations along terrane boundaries in Alaska.

Farallon Basin Transect:

The Farallon Basin is characterized by an 800 m deep central depression. The northeast edge of the basin is well-delineated by an active transform fault that connects the central trough with an active spreading center in the Carmen Basin. While the seismic reflection profile across Guaymas Basin shows an essentially flat lying basement (see Figure 13), the seismic reflection profile across Farallon Basin (Figure 14) shows possible tilted blocks similar to the Galapagos spreading center.

At the Galapagos spreading center, the measured heat flow seems to cyclically approach the theoretical curve for conductive heat loss (Figure 12). The wavelength seems to be about 5 to 10 km. In Farallon Basin, high heat flow was found about 10 km north of the

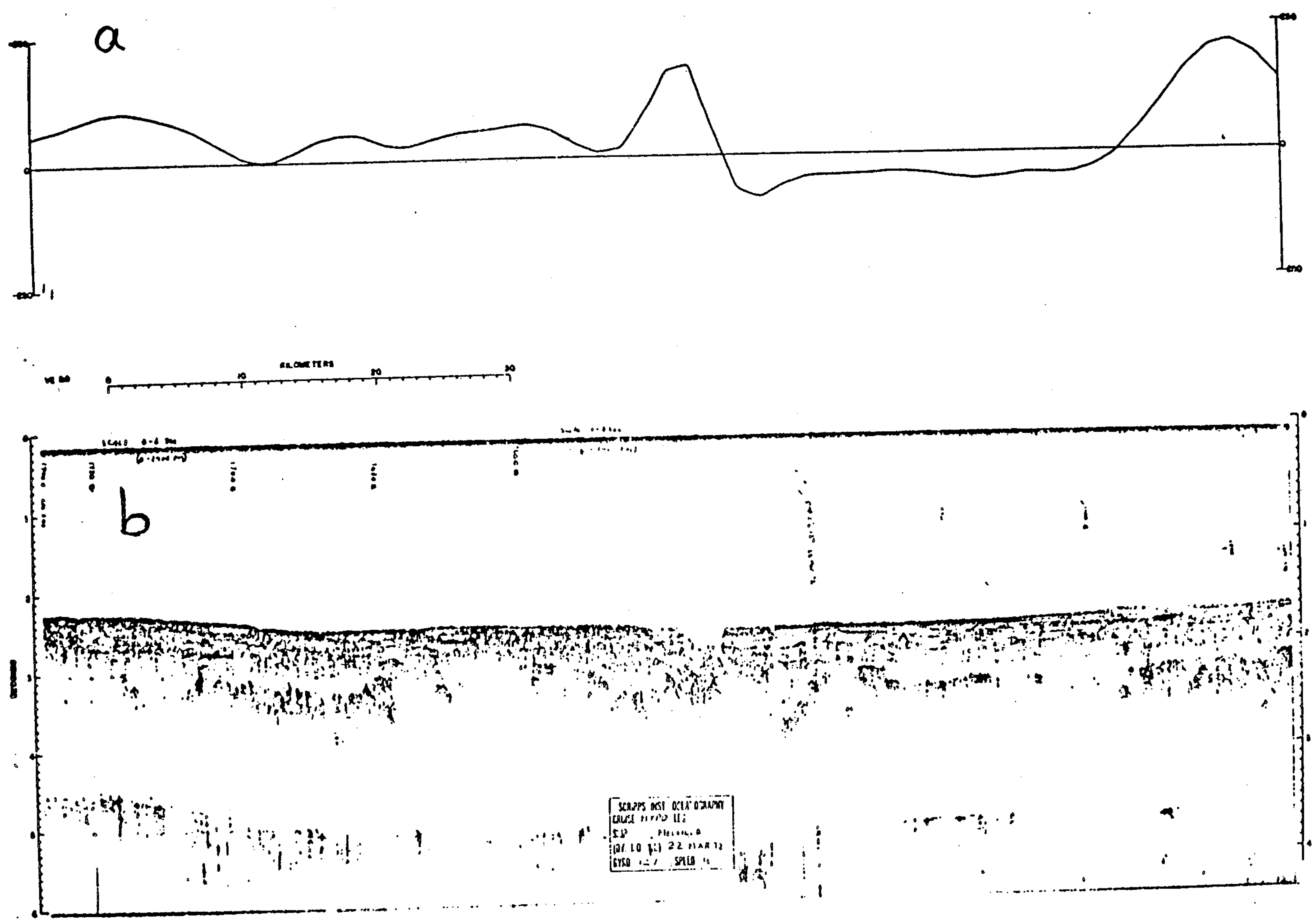
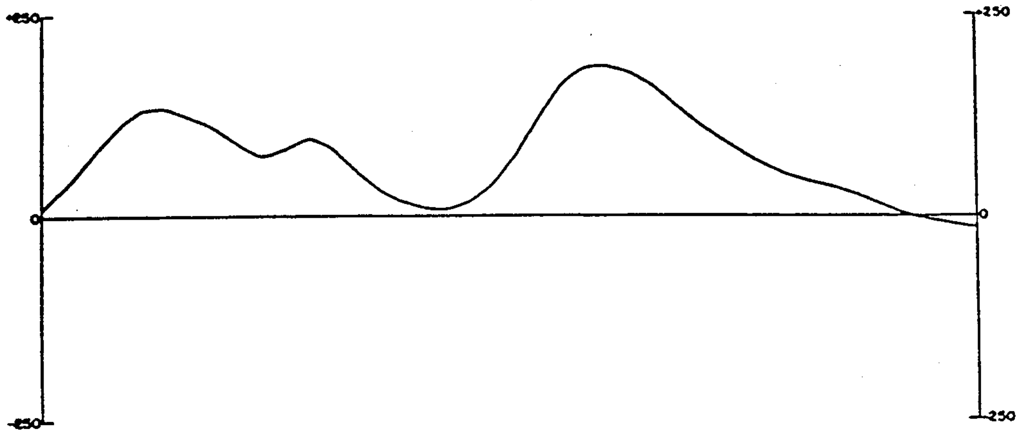


Figure 13. Guaymas Basin: (a) Magnetics profile--200 per inch, and (b) single channel seismic profile (Sharman, 1976).



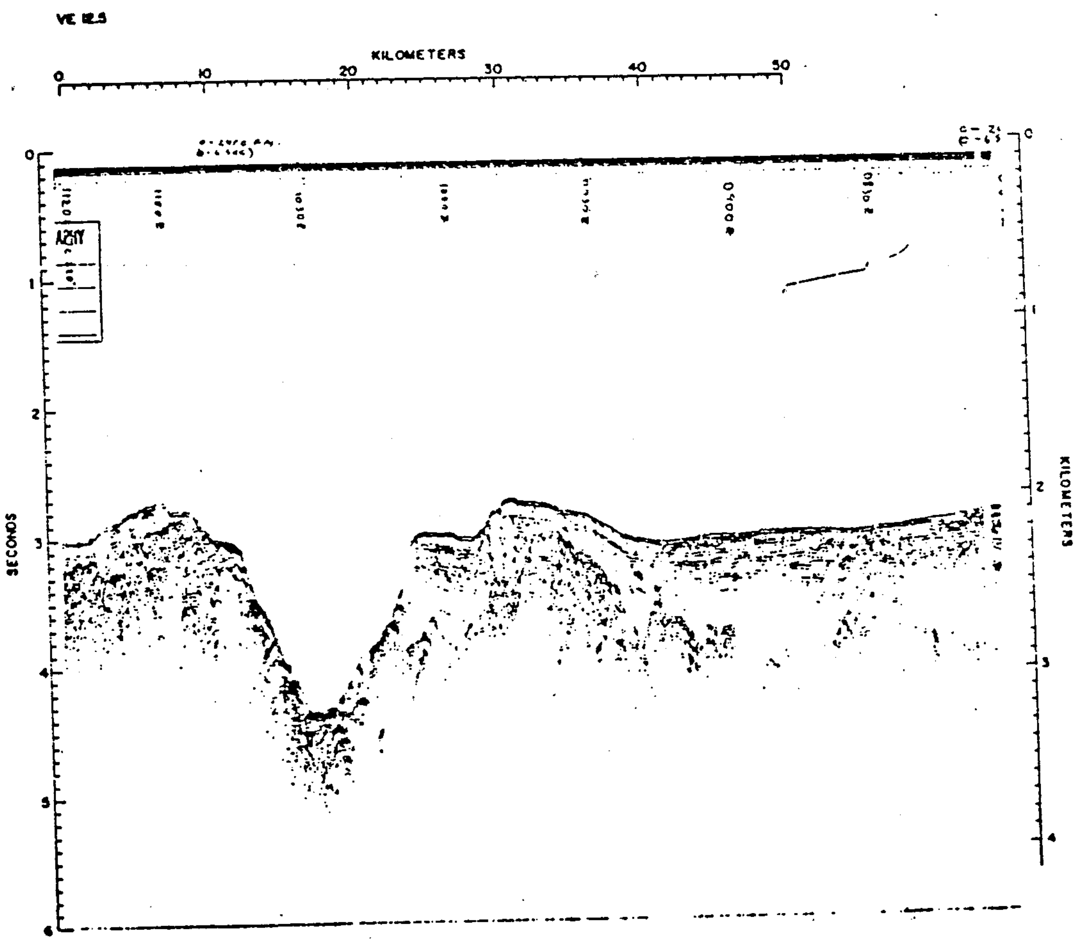


Figure 14. Central Farallon Basin: (a) magnetics profile, and (b) single-channel seismic profile (Sharman, 1976).

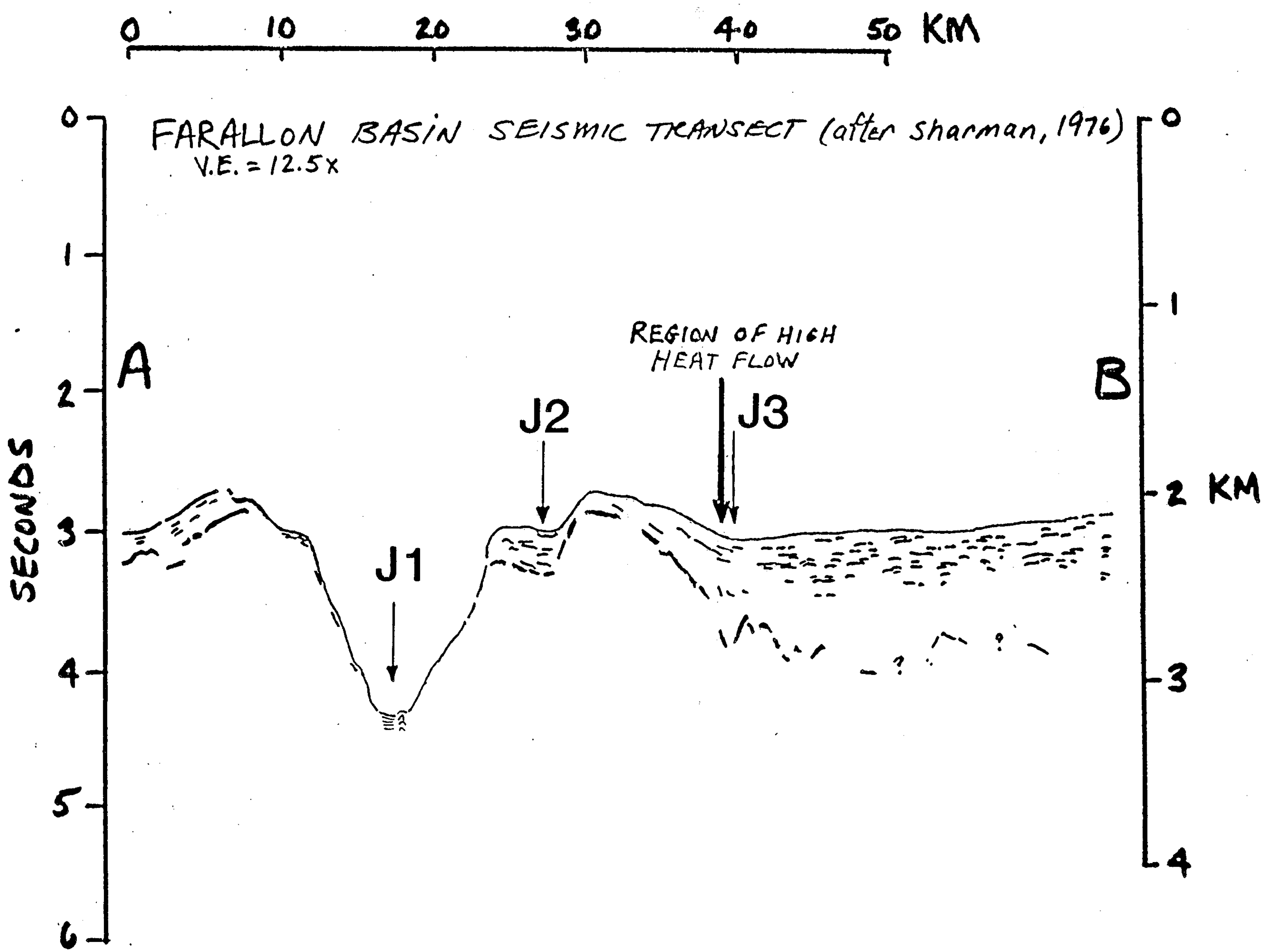


Figure 14(c). Line drawing of SCS line shown in (b) with proposed sites J1 through J3.

deep and 20 km south of the central deep. Additional heat flow measurements will certainly delineate any cyclical nature of the heat flow measured. It does appear that the wavelength in Farallon Basin is longer than at the Galapagos. In Guaymas Basin, the only very high heat flow was found at the central trough, so it may happen that increased sediment cover causes longer wavelength hydrothermal circulation.

Objectives:

With a good multi-channel seismic reflection survey of Farallon Basin we would hope to map the extent of the underlying true oceanic basement. Farallon Basin at present exhibits what we think is a thinly covered central rift with possible outwardly tilted blocks not dissimilar to standard oceanic spreading centers. Since the few heat flow values in Farallon Basin are similar to what was found on the Galapagos spreading center with low values in the center and higher values in the well sedimented regions we would expect nearly normal oceanic crust with evidence of pillow basalts and glassy rims in the central trough. As sites are drilled away from the central rift a transition should be found from the nearly normal oceanic crust at the central trough to a region dominated by intrusive sills similar to present-day Guaymas Basin.

Another objective of great interest is the sediment geochemistry and hydrothermal alteration that has produced such excitement from the Guaymas Basin results (Gieskes *et al*., 1982a,b; Kastner, 1982; Simoneit and Lonsdale, 1982; Simoneit, 1985). If a large amount of the heat which is normally lost due to open hydrothermal circulation is retained in Guaymas Basin and produces the formation of petroleum hydrocarbons, then Farallon Basin may show a transition between the nearly normal sediment maturation found at such places as the Galapagos spreading center and the hydrocarbon-rich Guaymas Basin.

Since there is clearly a continuum resulting in hydrocarbon formation with respect to time and temperature, we should see it in Farallon Basin. The increase in both time and temperature as the distance from the Farallon Basin increases would be observed in drill sites J1 through J3. If the conductive heat flow maximum actually coincides with site J3 then a gradual decrease in the rate of organic matter maturation and hydrocrbon generation might be observed at sites J4 and J5.

Sites (Figure 15):

J1: This site should be drilled in the center of the Farallon Trough located halfway between the active transform faults. It is virtually the same as the site proposed in the Second Objective: Gulf Transect, but moved slightly so that it is in line with this proposed transect and to be more nearly in the basin center. Drilling should be on nearly zero-aged crust but the difference in sediment coverage between this site and Hole 477A implies that nearly normal oceanic crust may be found here that might show a significant amount of open system hydrothermal circulation. This site should have less than 0.05 sec of sediment according to Einsele and Niemitz (1982) and moderately low conductive heat flow (Lawver and Williams, 1979). It is estimated that there may be up to 80-100 m of sediment cover based on the single channel seismic profile of Sharman (1976). It should be very easy to reach oceanic basement and it should be

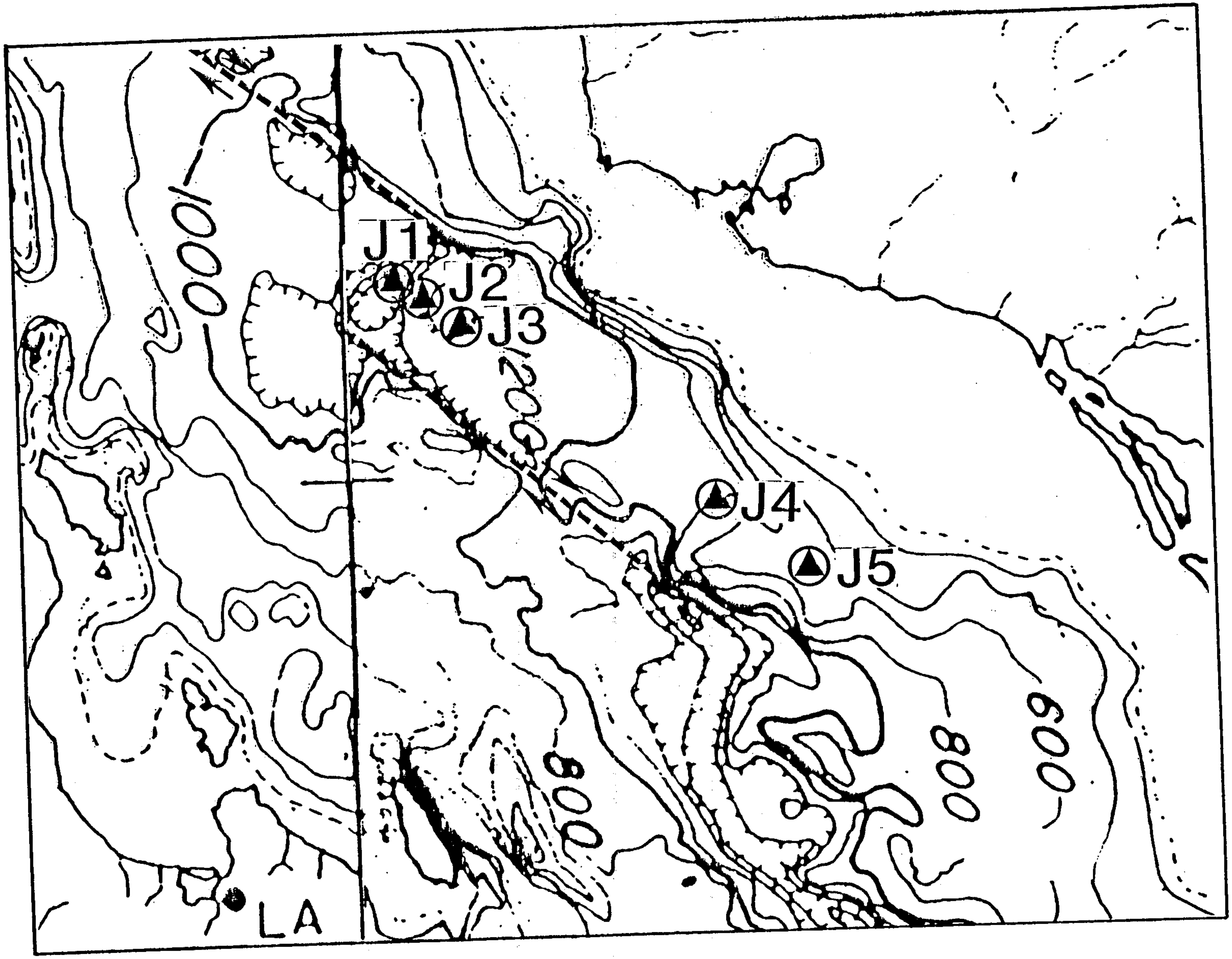


Figure 15. Location map of sites J1 to J5.

simple to determine if the crust is indeed zero-age. The water depth is 3200 m and the bottom of the Farallon trough appears to be less than 2 km across.

J2: This site is suggested for a point midway between the zero-age crust location and the site on the highest heat flow anomaly. The highest heat flow is located near a bathymetric high of 1864 m (Sharman, 1976) which may be a very recent intrusion. J2 is located on what may be an outwardly tilted block with as much as 0.6 sec of sediments on it. It is located about 10 km from Site J1 and if normal symmetrical seafloor spreading has taken place then the age of the crust should be less than 300,000 years. While 3 km/my for a sedimentation rate seems high, it is not too much greater than that found by Bruland (1974) in Guaymas Basin.

J3: This site was chosen to coincide with the highest heat flow measured in Farallon Basin (>0.65 W/m^2). This heat flow may in fact be much higher, because the instrument measuring the thermal gradient was completely off-scale on all thermistors. What appears to be the basement reflector rises to within 0.1 sec of the surface about 15 km from the central trough. If this is the basement, then it either represents a recent intrusion or it is indicative of a tilted block.

If symmetrical seafloor spreading has occurred here, then the age of the oceanic crust might be expected to be 700,000 years old. The Parson and Sclater (1977) heat flow versus age curve would suggest a conductive heat flow from a closed hydrothermal system of 0.6 W/m^2. Our previous heat flow value of >0.65 W/m^2 would indicate secondary intrusive activity consistent with the nearby bathymetric high. Drilling of this site should determine if an initially rifted passive margin spreads symmetrically once true oceanic crust is produced, or whether jumped spreading centers persist long after oceanic crust has formed. Seismic refraction results (Phillips, 1964) indicate reasonably normal oceanic crust as far north as Carmen Basin between the Farallon and Guaymas Basins. Penetration of basement will reveal the nature of the hydrothermal system operating on what may be 0.7 my crust.

J4: Located 90 km from the central trough, this site was chosen since it should be on crust about 3 my. There is very little sediment thickness data available although Einsele and Niemitz (1982) indicate about 0.3 sec of sediments. If the initial rifting of Farallon Basin was covered with young sediments, then a sediment column with multiple intrusive sills may be found below the hemipelagic sediment cover. The apparent basement at 0.3 sec (Einsele and Niemitz, 1982) may in fact be the transition to intercalated sills and sediments. The water depth would be about 1500 m.

J5: The last site is chosen on what may be the rifted continental margin about 120 km from the central Farallon Trough. The site is chosen in about 1000 m of water on what may be rifted and stretched continental crust. The sediment thickness according to Einsele and Niemitz (1982) is about 0.2 sec but again that may be only the sediment cover over the intercalated sills and sediments overlying the stretched continental crust.

FOURTH OBJECTIVE:

DRILLING OF TRANSECT IN GUAYMAS BASIN AND SLOPE

Drilling during Leg 64 (Curray et al., 1982; Gieskes et al., 1982a,b; Kastner, 1982; Simoneit et al., 1984) has revealed that hydrothermal activity in this young ocean basin, which is characterized by very high sedimentation rates, is of quite a different nature than open ocean hydrothermal systems. Though drilling during Leg 64 did reveal important information on the nature of the hydrothermal system, there is a need to more thoroughly characterize this regime, as well as its relation to the Boleo deposits at Santa Rosalia, presently exposed on land in Baja California. For this purpose it will be of importance to characterize in greater detail the nature of the hydrothermal systems operative in the Southern Trough of the Guaymas Basin (Gieskes et al., 1982a,b; Kastner, 1982; Lonsdale and Becker, 1985), not only with respect to the extent of sill induced hydrothermal systems, but in particular with respect to the nature of the deep seated hydrothermal system. It has been postulated (Bowers et al., 1985) that below the depths penetrated during Leg 64 in Hole 477A, hydrothermal deposits may occur. Drilling in this area would then provide a unique opportunity to study ore genesis that has been postulated for many important ore deposits associated with early rifting processes.

Of further importance will be the extension of drilling a transect from the Guaymas Basin towards the terranes on Baja California, where the Boleo deposits are found in Santa Rosalia.

Associated with these studies will be the detailed study of organic matter maturation and provenance in this area. This will complement the mineralogical temperature reconstructions as the organic matter undergoes catagenesis over a 100-350°C temperature window. In addition, the study of the migration of the hydrothermal petroleum products will aid in the elucidation of the pathways of fluid movement.

For these reasons we propose a drill site transect in the Guaymas Basin to meet the following objectives:

A) A detailed study of the physical (hydraulical) and chemical nature of the hydrothermal systems in the Southern Trough of Guaymas Basin; and

B) A basin-slope transect to study continental rifting and terrane formation.

A) Hydrothermal Drilling

Introduction:

Previous drilling in the Guaymas Basin during DSDP Leg 64 served to delineate two types of hydrothermal systems (Einsele et al., 1980; Kastner, 1982; Gieskes et al., 1982; Simoneit et al., 1984): one associated with sill intrusions at relatively shallow depths (e.g. Site 481), and one associated with hydrothermal circulation to greater depths, closer to a relatively permanent heat source. In the latter system, active recharge involving overlying seawater occurs, which subsequently undergoes changes in chemical composition of the dissolved solids, reflecting interactions with basalts and sediments at high temperatures (Site 477).

Subsequent detailed studies of seismic profiles, obtained with deep-tow, of heat flow distributions and of hydrothermal deposits visited by the diving vessel ALVIN in early 1982 and in August 1985, have helped to formulate a more encompassing model for the nature of hydrothermal systems operative in the Southern Trough (Lonsdale and Becker, 1985). Studies of the major elements and trace metal composition of hydrothermal waters emanating from vents on the sea-floor (Von Damm, 1983; Von Damm et al., 1985), as well as of pore waters of Site 477 (Gieskes et al., 1982b), have led to the suggestion that deposition of base metal ores may occur at greater depths (Bowers et al., 1985).

Objectives:

For this purpose, and also to delineate the nature of the hydrothermal plumbing system, we propose to deepen the penetration of Site 477: (a) if high temperature drilling technology is not available, drill to as deep a depth as possible, and (b) if this technology is available, we propose to drill a single bit hole to bit destruction.

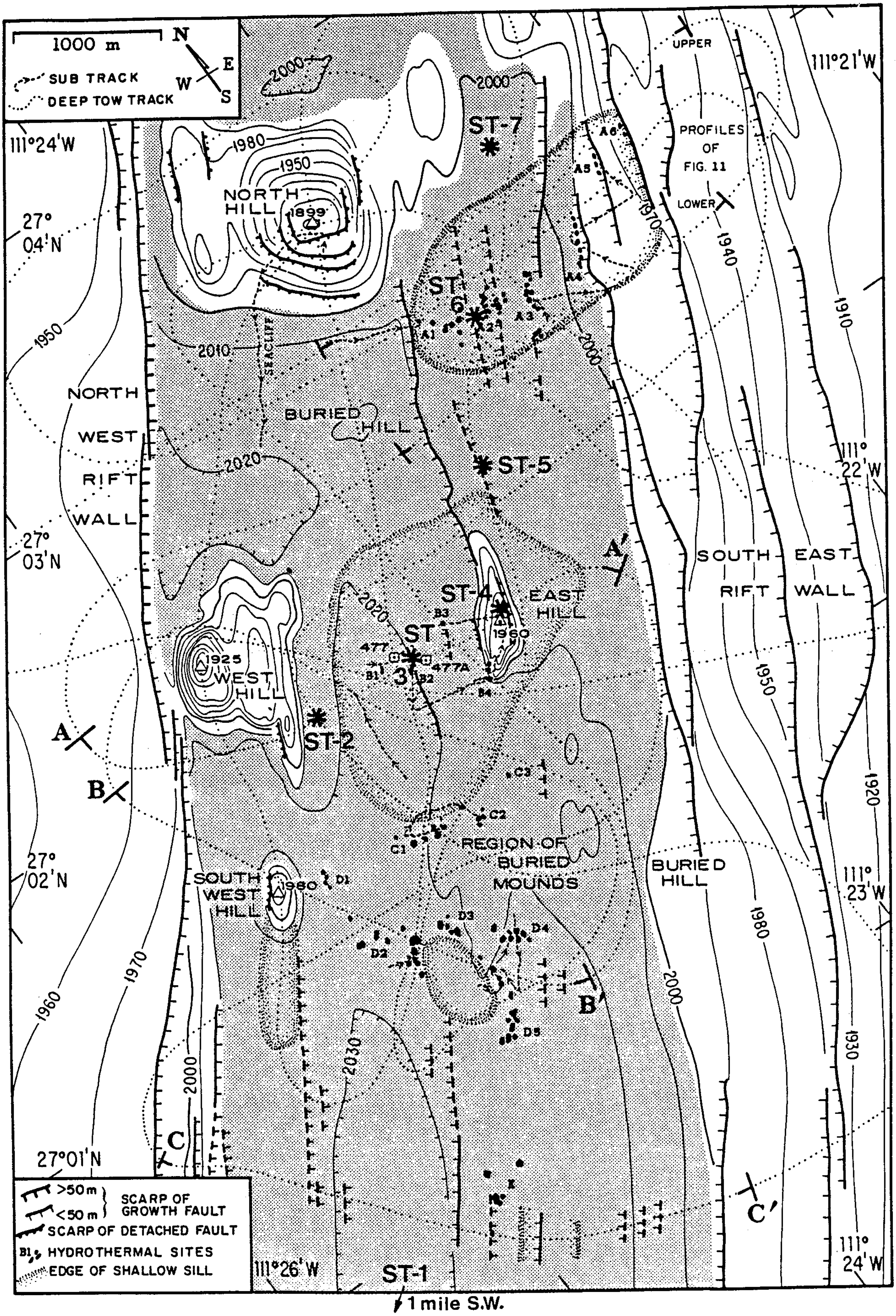
An additional problem of great interest is the production of hydrocarbons under hydrothermal conditions in this area. Though a complete sequence of petroleum products has been detected in the Guaymas Basin sediments and hydrothermal fluids (Simoneit and Lonsdale, 1982; Simoneit, 1983, 1984, 1985; Simoneit et al., 1984), sampling versus subbottom depth has been sparse, and the seabed mounds have only been sampled surficially. The data on the molecular compositions and kinetics of the compound interconversions of the hydrothermal petroleums generally fit with laboratory (hydrous pyrolysis) and basin studies. However, the cumulative mixtures of low (e.g. cholestene) to high (e.g. PAH-pyrene) temperature alteration products in the seabed mounds preclude accurate kinetic interpretation. This can only be alleviated by drilling with good sample recovery, permitting the analyses of these compounds spread over the migration path away from the thermal sources in the sediments. Such results can then be correlated with more accurate temperature scales, and additionally, the migration behavior of the various organic compound classes can be delineated for the hydrothermal fluids. The amounts of these hydrocarbons are small enough not to constitute a danger to drilling operations, as was demonstrated during Leg 64.

The proposed transect should yield valuable information on the distribution, production, and migration of hydrocarbons in relation to heat sources and hydrothermal circulation systems. In addition it will yield valuable information on the extent of hydrothermal activity in the deeper sediment layers of the Southern Trough of Guaymas Basin.

<u>Proposed Site Locations</u>:

The proposed transect is described in Figure 16. Only a very deep penetration of Site 477 would require new drilling technology (high temperature). Seismic profiles along lines A-A', B-B', and C-C' are given in Figure 17.

Figure 16. Bathymetry and shallow structure of the surveyed part of the Southern Trough of Guaymas Basin, based on deep-tow sonar records (125 kHz and 4 kHz profiles, and side-scan). DSDP Sites 477 and 477A are at the center of the mapped area. Depths assume a 1500 m/sec sonic velocity, used throughout this paper. Stippling shows extent of the relatively undeformed turbidite pond on the rift floor. Profiles along tracks labeled A-A', B-B', and C-C' are in Figure 17. Some "fault scarps" are steps in incompetent sediment; they are shown as solid lines where their trace was mapped by side-scan sonar, and as dashed lines where the trend of buried scarps was interpolated between subbottom profiles or inferred. The terminology adopted for superficial hydrothermal phenomena is that precipitated <u>deposits</u> (e.g., columns, spires, mounds) coalesce into <u>sites</u>, operationally defined as discrete side-scan targets. The proposed drill sites are indicated as ST 1 to ST 7 (ST 1 is about 1 mile southwest).


1000 m
N
E
W
S
SUB TRACK
DEEP TOW TRACK
111°24'W
111°21'W
UPPER
PROFILES OF FIG. 11
LOWER
2000
1980
1950
NORTH HILL
1899
ST-7
A6
A5
A4
1970
1940
27° 04'N
ST 6
A1
A2
A3
1910
1950
2010
SEACLIFF
2000
NORTH WEST RIFT WALL
BURIED HILL
2020
ST-5
111° 22'W
27° 03'N
A'
SOUTH EAST RIFT WALL
ST-4
EAST HILL
B3
2020
1960
477
477A
ST 3
B1
B2
B4
1925
WEST HILL
ST-2
A
B
1950
C3
C2
C1
REGION OF BURIED MOUNDS
27° 02'N
SOUTH WEST HILL
1960
D1
BURIED HILL
111° 23'W
D3
D4
D2
1920
1980
B
2000
1970
1960
D5
2030
2000
1930
C
27°01'N
C'
>50 m
<50 m
SCARP OF GROWTH FAULT
SCARP OF DETACHED FAULT
B1 HYDROTHERMAL SITES
EDGE OF SHALLOW SILL
111°26'W
ST-1
111° 24'W
1 mile S.W.

Site ST1 is ~1 mile southwest of the site indicated in Figure 16-this site will establish whether recharge to the hydrothermal systems to the northern part of the Southern Trough occurs in this area of relative low heat flow. Also in this area there is little evidence for shallow sill intrusions.

Site ST2 is in an area of relatively low heat flow (Figure 18) and could detect a shallow recharge system.

Site ST3 will coincide with Site 477 and should attempt to drill into the hydrothermal deposit discovered between DSDP Holes 477 and 477A (Figure 17).

Site ST4 will drill East Hill and establish the nature of the intrusion that appears to constitute this hill (c.f., line A-A', Figures 16 and 17).

Site ST5, like Site ST3, is in the area of relatively low heat flow, and is in the zone separating the central sill and north sill (Figure 18).

Alternate sites could be located at Site ST6 in the middle of north sill and the northern hydrothermal vent field (Figure 18), and at Site ST7 to the north of this sill. The latter hole could also be drilled in the vicinity of ALVIN dive Site 1168, i.e., in an area where a developing hydrothermal system was detected (Lonsdale and Becker, 1985).

Background Information

The study area is in no need for further site survey work -- a combination of Leg 64 DSDP site survey, deep-tow and DSV ALVIN work (c.f., Introduction above) has led to the proposed sites.

Figure 17. Near-bottom, 4 kHz profiles across the Southern Trough, located on Figure 16. Asterisks along vehicle track indicate passage through hydrothermal plumes. Inset at right is an enlargement of the central part of profile A-A', showing correlation with drilling results (the profile crosses the site of DSDP 477A; DSDP 477 is projected 100 m onto this line). Note the persistent reflector sequence in the upper turbidite pond and abrupt variations in acoustic penetration of the underlying intruded sequence. Several apparently buried mounds are known from concurrent side-scan to be artifacts produced by side-echoes from outcropping deposits.

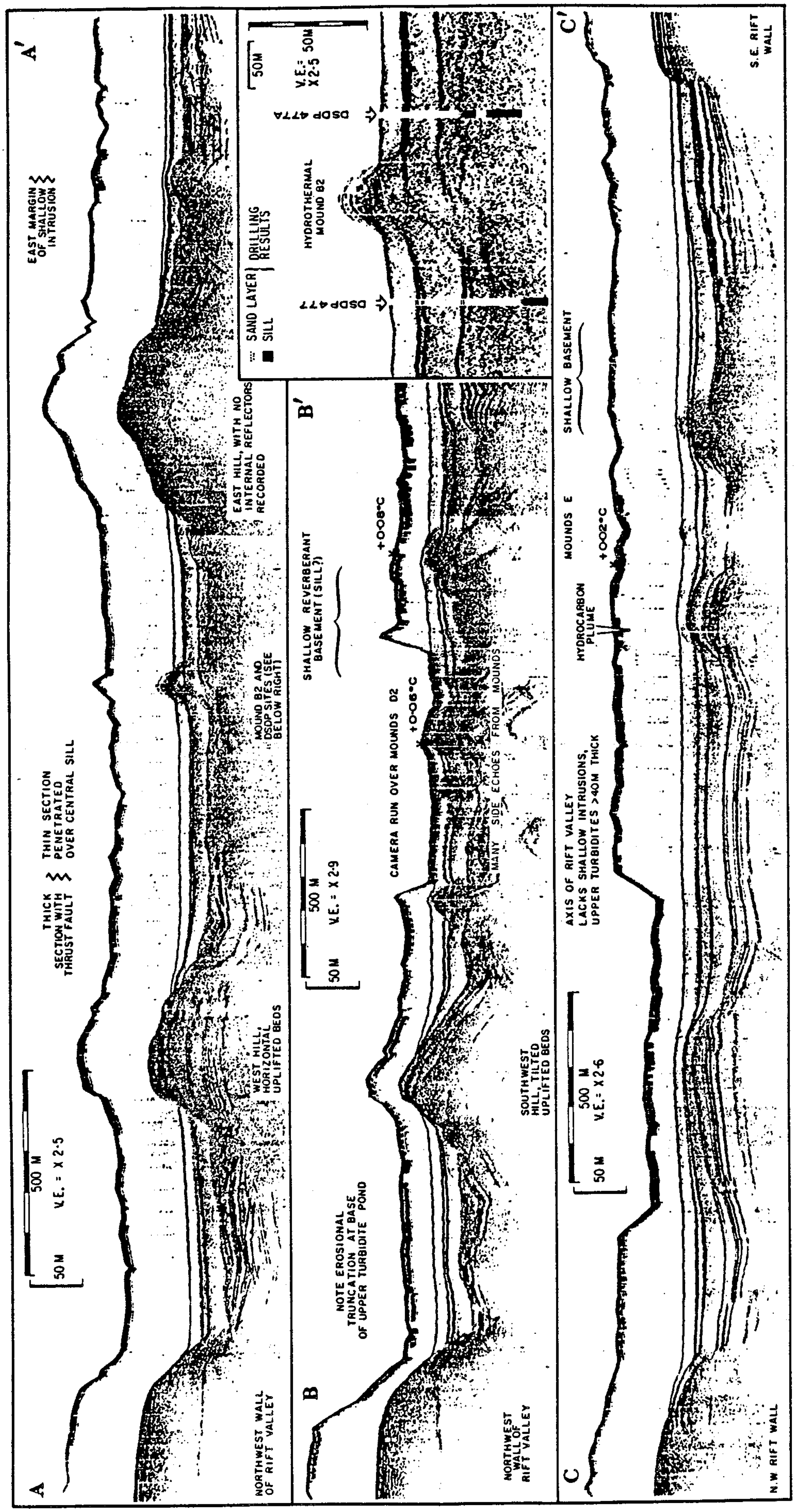
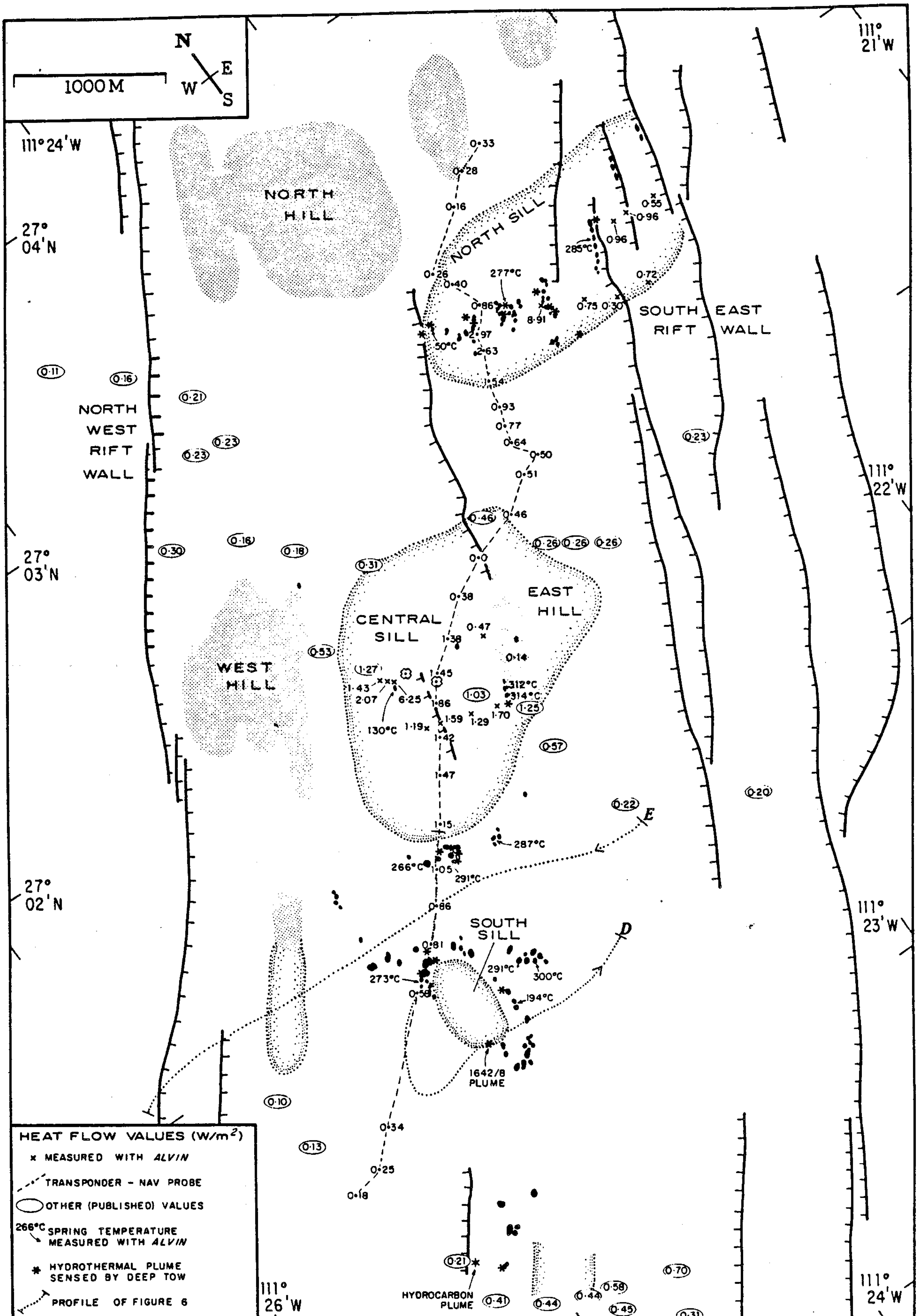

A
A′
NORTHWEST WALL OF RIFT VALLEY
50 M
500 M
V.E. = X 2·5
WEST HILL, HORIZONTAL UPLIFTED BEDS
THICK SECTION WITH THRUST FAULT
THIN SECTION PENETRATED OVER CENTRAL SILL
MOUND B2 AND DSDP SITES (SEE BELOW RIGHT)
EAST HILL, WITH NO INTERNAL REFLECTORS RECORDED
EAST MARGIN OF SHALLOW INTRUSION
B
B′
NORTHWEST WALL OF RIFT VALLEY
NOTE EROSIONAL TRUNCATION AT BASE OF UPPER TURBIDITE POND
SOUTHWEST HILL, TILTED UPLIFTED BEDS
50 M
500 M
V.E. = X 2·9
CAMERA RUN OVER MOUNDS D2
MANY SIDE ECHOES FROM MOUNDS
+0·06°C
SHALLOW REVERBERANT BASEMENT (SILL?)
+0·08°C
SAND LAYER
SILL
DRILLING RESULTS
DSDP 477
HYDROTHERMAL MOUND B2
DSDP 477A
50M
V.E.: X2·5 50M
C
C′
N.W RIFT WALL
50 M
500 M
V.E. = X 2·6
AXIS OF RIFT VALLEY LACKS SHALLOW INTRUSIONS, UPPER TURBIDITES >40M THICK
HYDROCARBON PLUME
MOUNDS E
+0·02°C
SHALLOW BASEMENT
S.E. RIFT WALL

Figure 18. Hydrothermal plume locations, calculated conductive heat flow, and selected vent temperatures. Plumes are along the deep-tow tracks of Figure 17. Heat flow values are all based on best fits of measured gradients to a linear, non-convective model. Spring temperatures are those measured in natural and artificial orifices after destruction of any diffusing or sealing caps.


1000 M
N
E
W
S
NORTH HILL
NORTH SILL
SOUTH EAST RIFT WALL
NORTH WEST RIFT WALL
CENTRAL SILL
EAST HILL
WEST HILL
SOUTH SILL
1642/8 PLUME
HYDROCARBON PLUME
111° 24' W
111° 21' W
111° 22' W
111° 23' W
111° 24' W
111° 26' W
27° 04' N
27° 03' N
27° 02' N
277°C
285°C
50°C
312°C
314°C
130°C
287°C
266°C
291°C
273°C
300°C
194°C
HEAT FLOW VALUES (W/m²)
MEASURED WITH ALVIN
TRANSPONDER - NAV PROBE
OTHER (PUBLISHED) VALUES
266°C SPRING TEMPERATURE MEASURED WITH ALVIN
HYDROTHERMAL PLUME SENSED BY DEEP TOW
PROFILE OF FIGURE 6

(18)

Drilling Requirements

All sites can use single bit holes. For 5-7 sites, we estimate 3-4 weeks of drilling in the Southern Trough -- steaming time should be minimal.

A potential of high temperature drilling will be particularly useful for Site 477 (ST3), as this site will meet temperatures above 300°C.

Logging

Logging of the holes, especially those penetrating sill intrusions would be very helpful, as was shown in Sites 477 and 481 of DSDP Leg 64.

Safety Problems

Leg 64 showed that all the Guaymas Site hydrocarbons exist in the upper part of the sediment column and that hydrothermal generation of hydrocarbons occurs at depth. However, when temperatures reach >300°C, hydrocarbons do not appear to be a problem, all organic carbon has been converted to hydrocarbons, which have migrated away, and native (amorphous) carbon at lower temperatures. Generally, hot vents with waters >300°C do not show evidence of oil during ALVIN dives.

B) Guaymas Basin-Slope Transect and Terranes

Introduction:

The Gulf of California represents the best extant example of the initial stage of continental rifting to form a young ocean basin. The interaction of oblique transform plate motion, rapid accumulation of organic muds, and extremely high heat flow indicative of hydrothermal circulation infer an outstanding natural laboratory for studying early rifting with concomitant sedimentological and geochemical consequences analogous to the initial stages of the opening of the Mesozoic North Atlantic or the Late Cretaceous Labrador Sea.

Within the Gulf, the Guaymas Basin (Figure 19) is a microcosm exhibiting all the aforementioned characteristics: sea-floor spreading, rapid sedimentation, and high heat flow. Yet, although extensively surveyed, studied, and drilled, the Guaymas Basin has not been approached as a model for young ocean basin rifting. We propose a transect of sites with the primary objective to seek a fundamental understanding of early rifting processes: tectonic, sedimentological, and geochemical.

Rationale:

DSDP Leg 64 drilling established the Guaymas Basin "basement" as intercalated diabase sills and hydrothermally altered diatomaceous muds. Heat flow values (Figures 18 and 20) of 2-9 W/m^2 (Lonsdale and Becker, 1985; Lawver and Williams, 1979) lend credence to the notion of dual hydrothermal systems; one associated with the intruding sills, the other at greater depth and, presumably, near a more permanent heat source (Kastner, 1982). Metal sulfide-rich hydrothermal mounds in the basin (Lonsdale et al., 1980) and the Pliocene Boleo stratiform copper deposits (Wilson and Rocha, 1955)

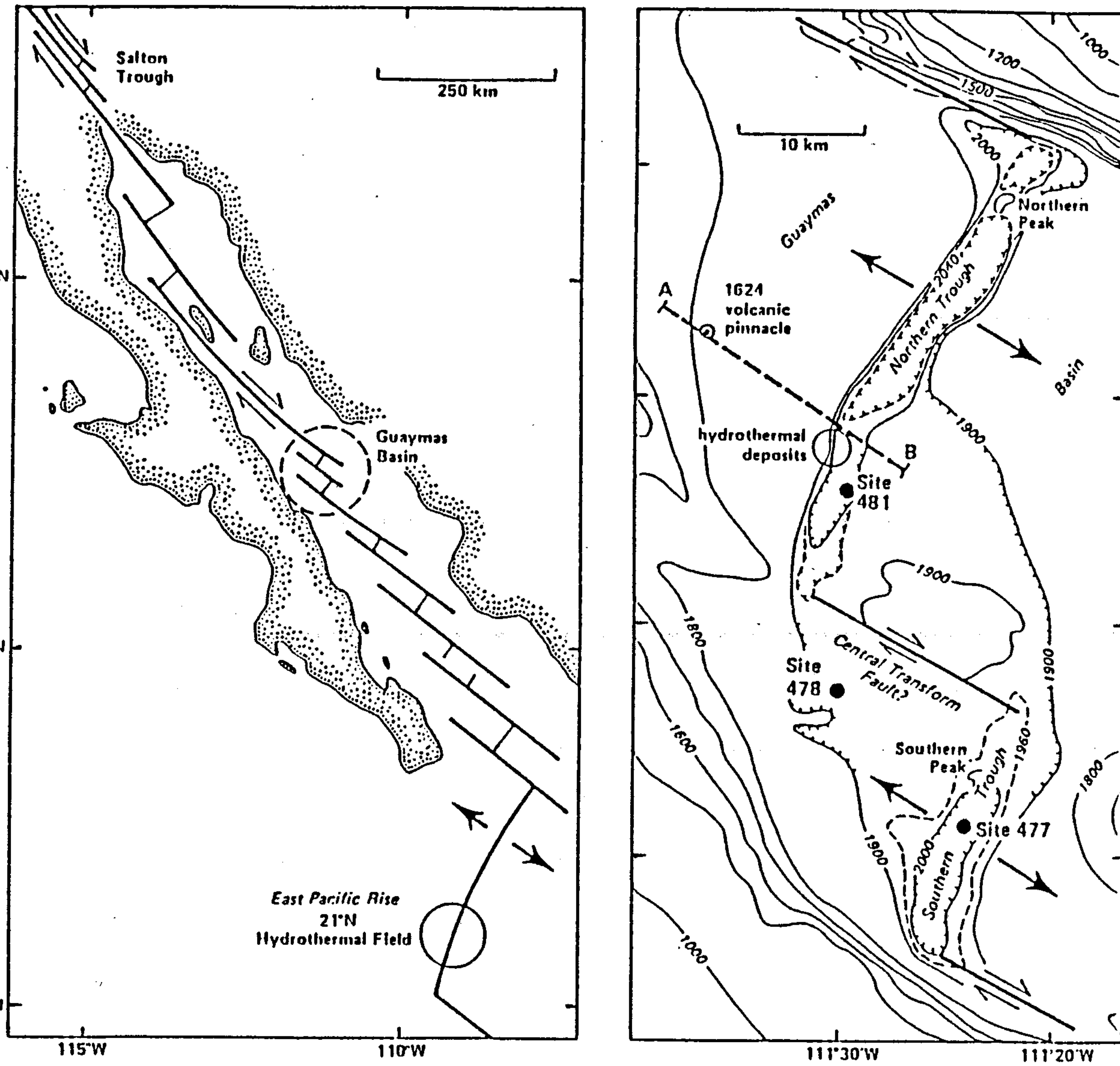


Figure 19. Guaymas Basin with DSDP sites and hydrothermal deposits (from Lonsdale et al., 1980).

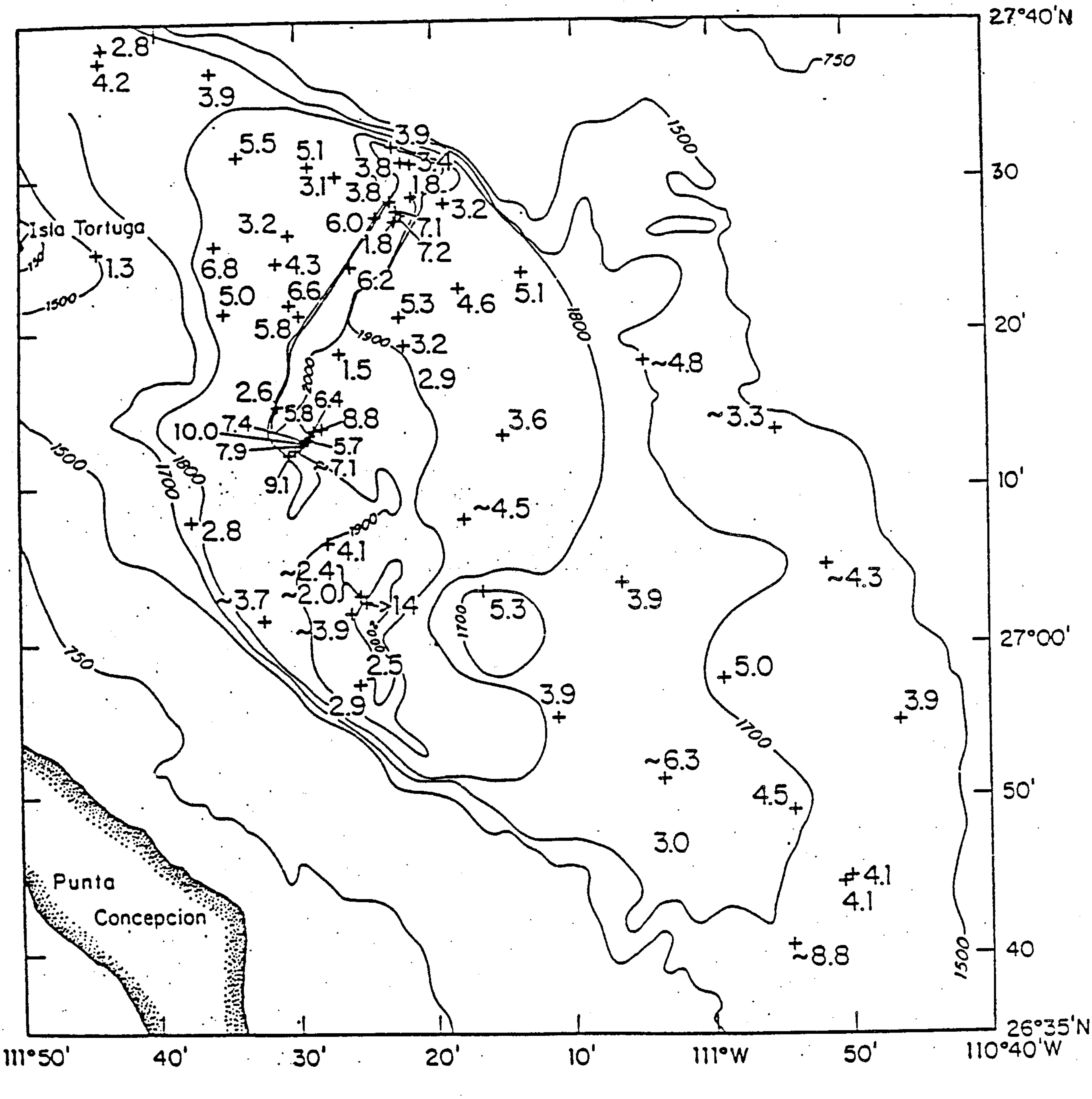


Figure 20. Guaymas basin heat flow data (Lawver and Williams, 1979), units are in $\mu cal/cm^2$-sec.

near Santa Rosalia, Baja California, appear to be tectonically related and infer long-lived, though probably episodic, hydrothermal circulation as sill intrusion occurs in the basin spreading centers and hydrothermal fluids escape along active faults (Figure 21) (Einsele, 1982).

The region is an area of extremely high biological productivity due to upwelling. This produces a pronounced, but not geologically permanent, oxygen minimum zone. Sedimentation rates of greater than 1 km/my have been measured for the predominantly diatomaceous muds (Calvert, 1966). The circulation of hydrothermal fluids through organic muds has produced unusual results. Mature hydrocarbon deposits within the metal-rich mounds (Simoneit and Lonsdale, 1982; Simoneit, 1983, 1984, 1985) and acoustically-sensed hydrocarbon plumes (Lonsdale, 1985; Merewether et al., 1985) observed during submersible and deep-tow studies suggest rapid maturation processes.

Free-air gravity anomaly analysis of the Gulf (Figure 22) by Harrison and Mathur (1964), and recently confirmed by Ness and Couch (unpublished data, 1986), suggests a gradational contact between oceanic and continental crust along the northwest flank of the southern Guaymas Basin trough. Stretched continental crust and/or diabase sills intruded into continental margin may be present.

Objectives:

Further Guaymas Basin study by drilling, therefore, provides an opportunity to address three globally significant objectives:

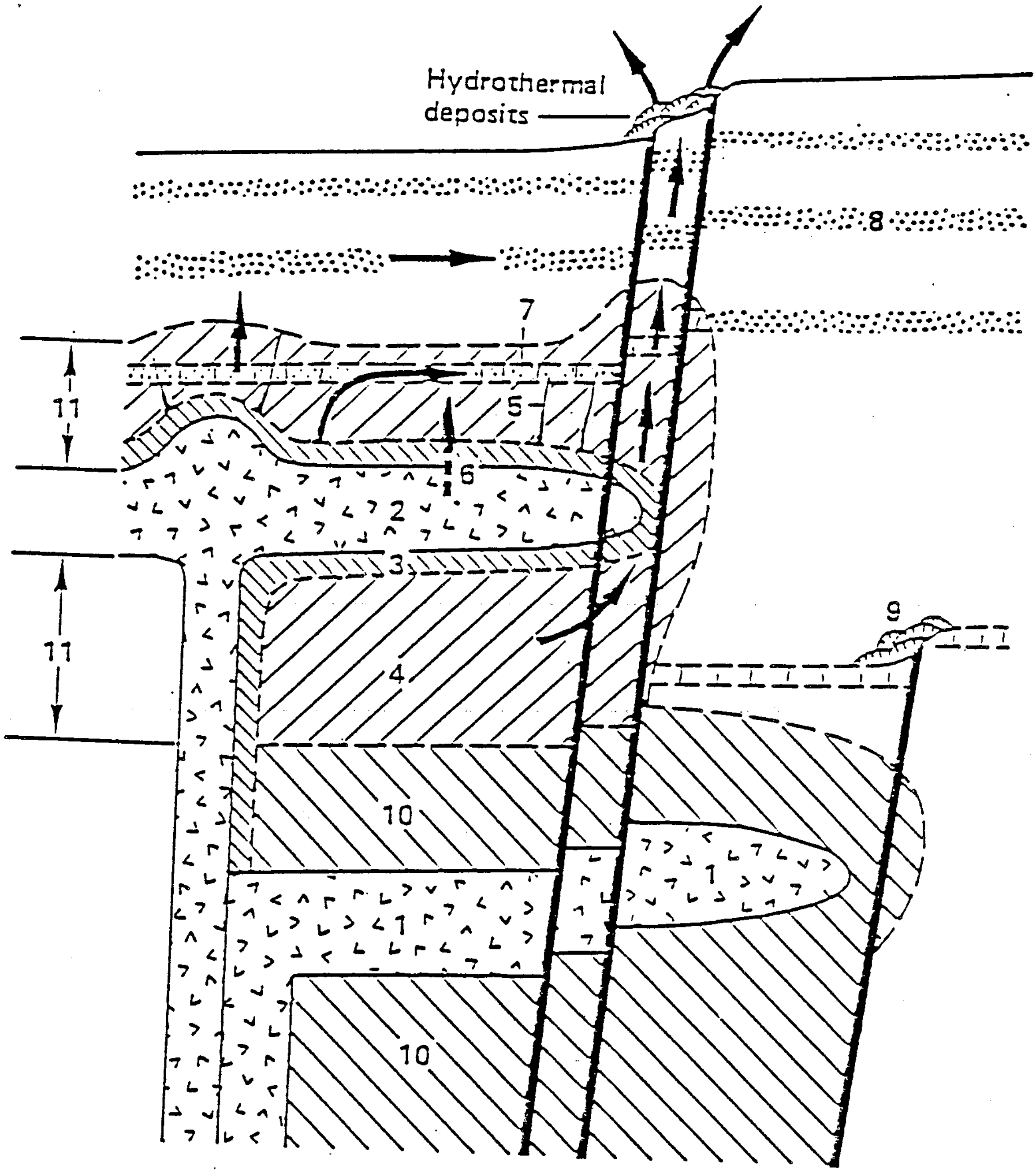


Figure 21. Schematic of diabase sill and dike intrusion into high porosity diatomaceous sediments with accompanying expulsion of hydrothermal fluids to form hydrothermal deposits along active faults: 1-older lower sill, 2-young uppermost sill, 3-possible steam zone, 4-zone of sill reduced porosity, 5-shrinkage cracks acting as vents for steam escape, 6-chemical exchange from magma to sediments, 7-permeable layer lithified during pore water flow, 8-non-indurated sand turbidites, 9-buried hydrothermal deposit, 10-precompaction by older sill, 11-zones of water loss.

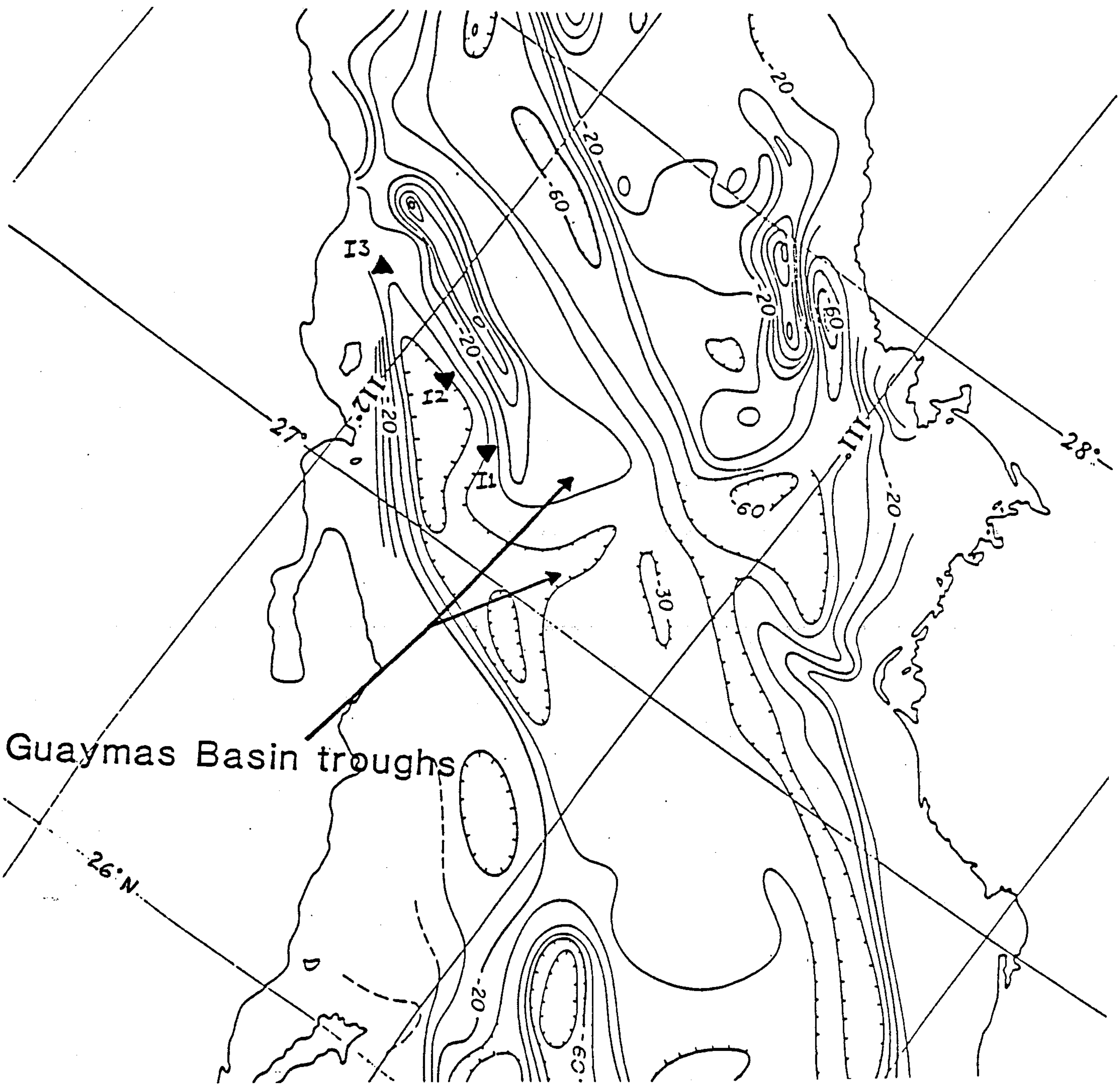


Figure 22. Free-air gravity anomalies of the Guaymas Basin region (after Ness and Couch, 1986, in press). Site locations are approximate.

a. Early Rifting Processes

The conditions prevalent in the Guaymas Basin -- diabase dike and sill intrusion into rapidly accumulating, high porosity biogenic muds - may be a common process in the initial rifting stages of presently mature ocean basins. The persistence of Jurassic-through-Late Cretaceous black shale facies in the Atlantic (Thiede and van Andel, 1977; Schlanger and Jenkyns, 1976; Arthur, 1979) can be cited as evidence of a paleoenvironment similar to the Gulf of California today. If this analogy holds, the Guaymas Basin is an excellent location for revealing the nature of early rifting processes. Basement in the Guaymas Basin is easily reachable with current drilling technologies (i.e. without riser), whereas thick sediment cover on mature ocean basin flanks frequently make basement unapproachable. Moreover, the potential for a series of sites will allow more precise characterization of the nature of the oceanic-continental transition. The question still remains as to whether initial rifting involves continental crustal thinning, sill and dike intrusion of continental crust, or both.

b. Organic Matter Maturation and Petroleum Genesis

The interaction of organic-rich sediment and high heat flow in the Southern Guaymas Trough have produced extensive evidence of mature hydrocarbons (Simoneit, 1983, 1984, 1985; Simoneit *et al*., 1984). The rate of organic matter maturation must be extremely rapid to be forming on zero-age crust. Additional drilling away from the rift zone should add significantly to our understanding of the time-temperature relationship in organic matter maturation, petroleum generation, and migration. While sediment thicknesses are less in the Guaymas Basin than would be found on mature continental margins, the extreme heat flow appears to have matured the organic matter much more rapidly, preserving the continuum from high initial heating through gradual cooling as the continental margin is approached. One would expect increased maturation with depth in each site as well. It remains problematic as to whether sediments deposited on continental crust will contain mature organic matter or hydrocarbons. There may be no maturation if initial rifting does not "superheat" the sediments. However, since such high heat flow exists in the active rift zones today, the notion that even slope sediments were heated during initial rifting is plausible. As evidence supporting regional heating, a rapid increase in isopentane below 270 m was reported at DSDP Site 479 (Guaymas Basin slope) (Simoneit, 1982).

c. Submarine Exhalative Metallogenesis and Accreted Terranes

The idea of accreted terranes proposed by such researchers as Jones et al. (1982) and Tempelman-Kluit (1979) suggests that rifting of a comparatively narrow strip of continental crust such as Baja California and the western edge of California is not unique. The close proximity of the stratiform Boleo copper deposit to the active transform fault bounding the southern end of the southern Guaymas trough suggests a genetic relationship between it and the hydrothermal chimneys and mounds found in the trough. If so, then the Guaymas and Boleo sites may be geologically young analogs of ore deposits and depositional processes present in Mesozoic terranes of Alaska, British Columbia, and northern California. Our proposed sites afford the opportunity to document hydrothermal metallogenesis from present to Late Pliocene time.

Proposed Plan:

We propose a transect of three holes (Figure 23) in the northwest flank of the Guaymas Basin southern trough. These sites should significantly augment the information available from DSDP Holes 477, 477A in the Southern Trough rift zone and Site 478, approximately 12 km to the northwest. This proposal assumes that Site 477 will be reoccupied and deepened and/or additional sites will be drilled in the Southern Trough roughly perpendicular to our proposed transect (see sites ST2 to ST4 - Guaymas Trough hydrothermal transect).

Site I-1: Northwest flank of southern Guaymas Basin approximately half-way between Site 478 and the gradational contact between oceanic and continental crust suggested by Harrison and Mathur's (1964) gravity data. From previous site surveys (Moore et al., 1978; Sharman, 1976), a thin layer of sediment (Figures 24 and 25) overlies approximately 1.25 my crust, assuming a full spreading rate of approximately 56 km/my. This site should be far enough away from the very highest heat flow zones to begin to see time-temperature effects in the hydrocarbon maturation process. It will be relatively easy to reach basement as extensive sills are not expected, in order to ascertain the nature of the oceanic crust. An accurate crustal date should be obtainable from biostratigraphy in the absence of reliable magnetic anomaly signature correlations. This information will confirm or deny the presently accepted

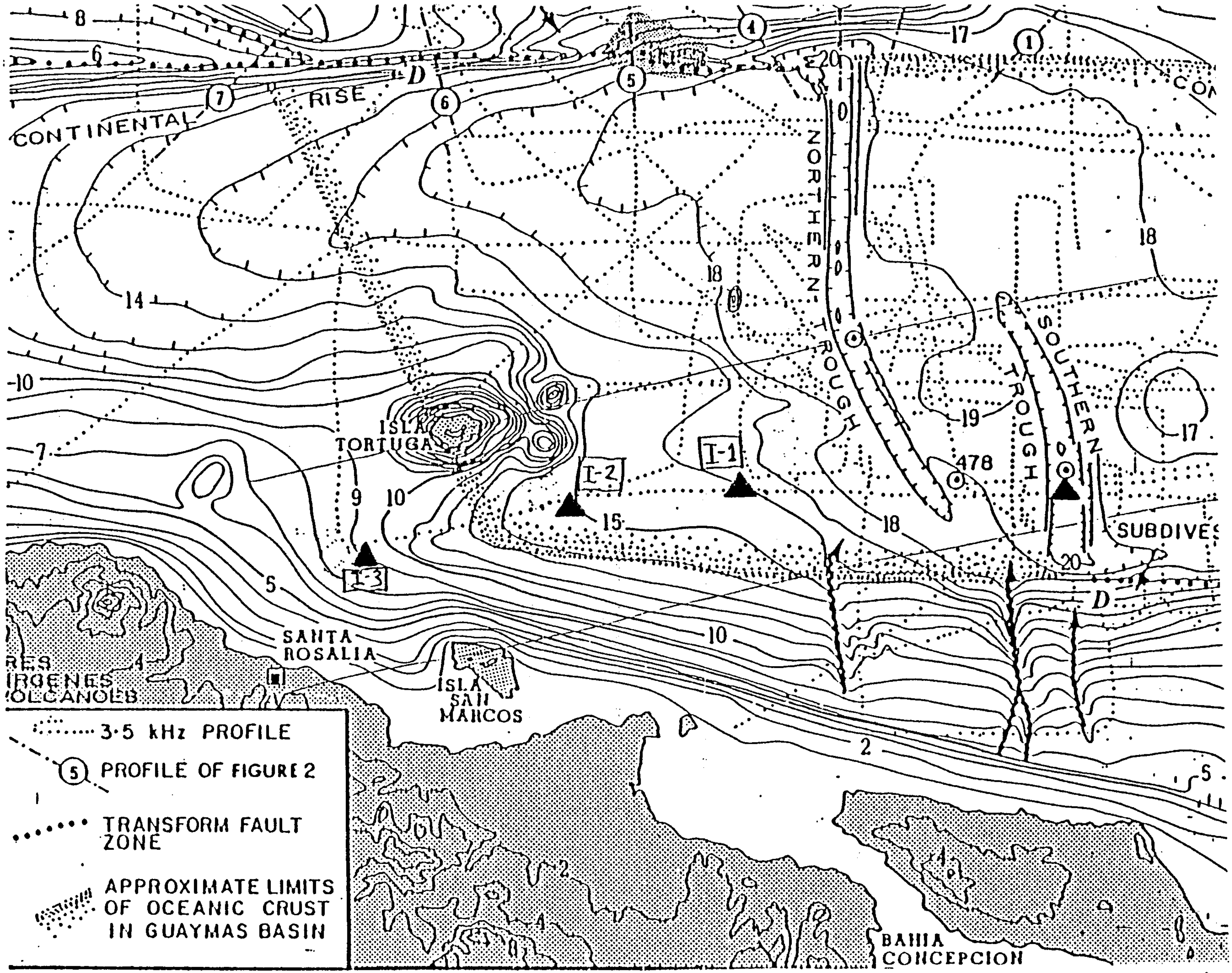


Figure 23. Proposed drill sites for Guaymas Transect (I sites are indicated by solid triangles, map after Lonsdale, 1985).

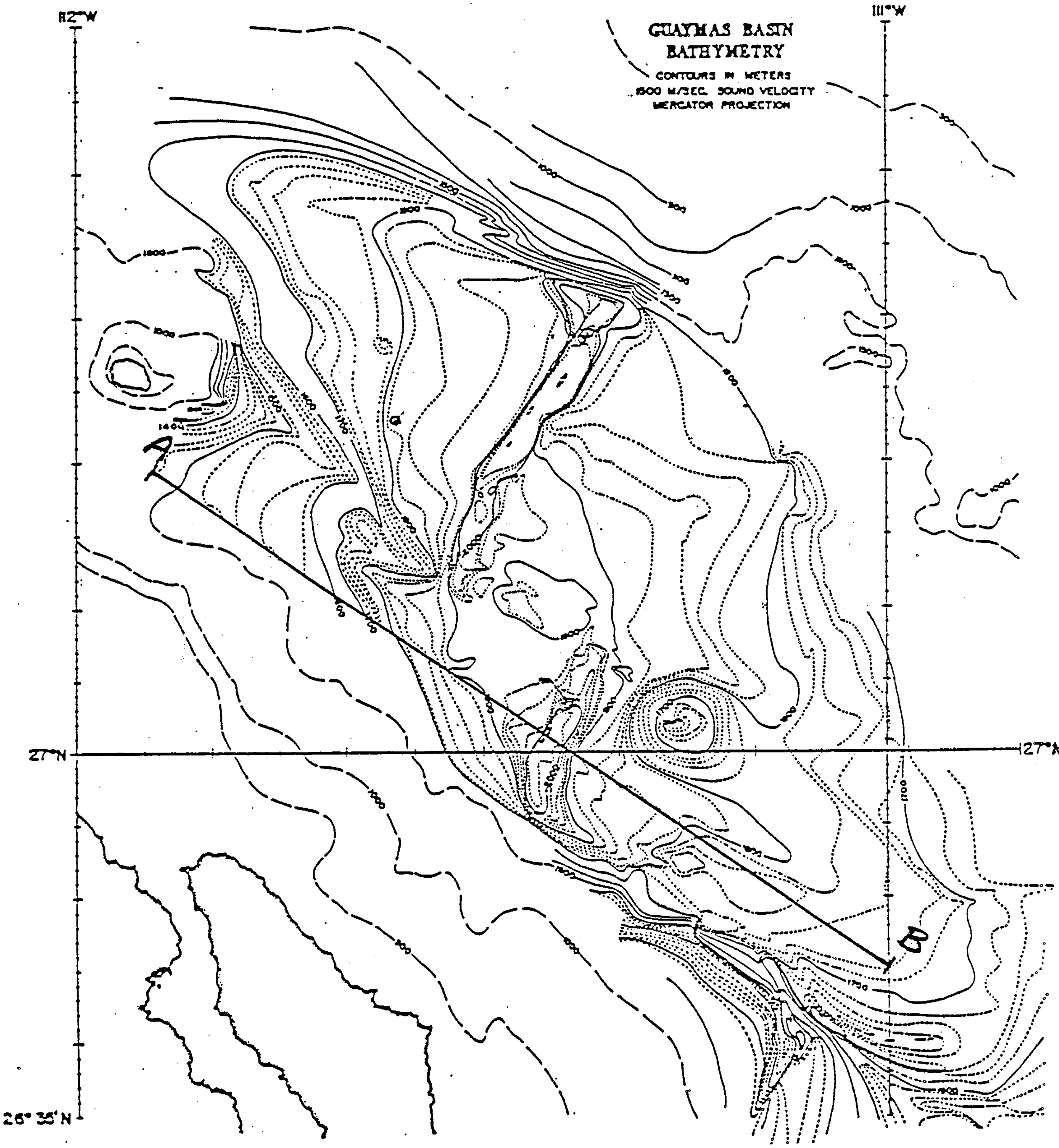


Figure 24. Bathymetry (meters) of the Guaymas Basin (after Sharman, 1976). (Profile line A-B shown in Figure 25).

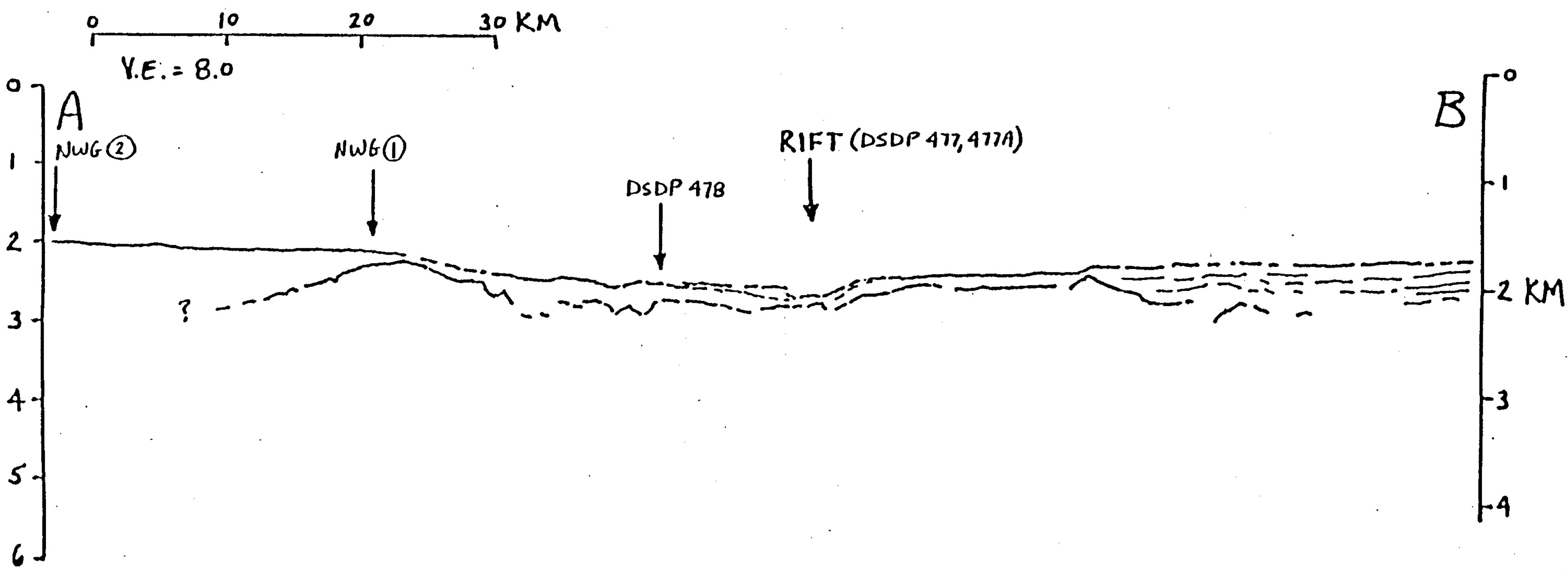


Figure 25. Guaymas Basin seismic transect (after Sharman, 1976).

spreading rate for the Guaymas Basin and add to the overall picture for the timing of the opening of the Gulf. Penetration of basement will also reveal the nature of the hydrothermal system (if any) operating approximately 1.25 Ma.

Site I-2: South of Isla Tortuga between the bounding southern Guaymas Trough transforms, near the inferred ocean-continent contact. There is relatively little detailed information available on this area of the basin. Sharman's (1976) single channel seismic profile (Figure 25) suggests that the sediment thickness increases as the continental slope is approached. The importance of this site lies in its proximity to the inferred ocean-continent contact, as the primary objective would be to ascertain the nature of the ocean-continent transition from the oceanic point-of-view. Petrologic studies would establish the character of the first upwelled oceanic basalts in the initial opening of the Guaymas Basin, as near-oldest crust (approx. 2.15 my) should be penetrated. The position of this site, therefore, will be critical and should be thoroughly site-surveyed prior to drilling. As with Site I-1, the time-temperature correlation of hydrocarbon maturation, confirmation of spreading rates, and nature of hydrothermal systems will also be examined.

Site I-3: Continental slope half-way between Isla Tortuga and Santa Rosalia, Baja California. This site completes the objectives of the transect by providing information on the continental-oceanic crust transition from the continental point-of-view. Is the continental crust stretched during rifting? Is sediment loading the cause of the stretching and subsidence, or do diabase sills intrude and subside the continental crust during the initial rifting stage? Does initial rifting and heat flow affect sediments on continental crust? We should see the final step in the organic matter maturation and petroleum genesis process with the thickest, oldest, and, possibly, the first superheated sediments being drilled. Was there hydrothermal circulation at initial rifting, and, if so, how did it affect the continental rocks and sediments thereon? What exactly is the relationship of the Boleo deposit to the Guaymas Basin hydrothermal system, and what does it tell us about the genesis of ore deposits emplaced into what are now ancient accreted terranes?

In addition, this site is well situated for paleoceanographic studies of the evolution of the oxygen minimum zone in the Gulf (see sites G1-3 - Gulf paleoceanography studies). As such, the site is located under a high biological upwelling zone produced when winds blow from the southeast. In addition to our objectives, this site would serve as a counterpoint to the well-established upwelling along the Mexican mainland, best exemplified by DSDP Site 480.

FIFTH OBJECTIVE:

PALEOCEANOGRAPHY AND DEPOSITIONAL HISTORY

Introduction:

The Gulf of California constitutes a unique marginal sea and a natural laboratory for understanding the interplay between paleoceanographic, climatic, biologic, and tectonic processes governing the sedimentary evolution and depositional history characterizing juvenile oceans. Previous DSDP drilling together with older dredges and cores and analysis of limited onshore exposures of Neogene marine sequences around the Gulf margin have clearly demonstrated that Gulf sediments contain a detailed record of the tectonic and paleoceanographic development of this young ocean (e.g. Allison, 1964; Curray et al., 1982; Gastil et al., 1979; Ingle, 1974; Moore, 1973). These deposits are marked by the initial deposition of non-marine red beds, evaporites, and volcaniclastic material, subsequent widespread deposition of pelagic laminated muds under anoxic conditions, and the evolution of both terrigenous siliciclastic and carbonate depositional facies--a stratigraphy clearly analogous to that commonly associated with the early evolution of Paleozoic and Mesozoic oceans, most notably the early low latitude Atlantic (e.g. Arthur, 1979; Berger and von Rad, 1972; Thiede and van Andel, 1977). Consequently, a major aim of the proposed ODP drilling in the Gulf of California is to detail the nature of the paleoceanographic development of the sea with a special effort devoted to floral, faunal, and isotopic analysis of Quaternary surface and deep circulation, evolution of intermediate water anoxia, and the role of faunal and watermass interchange with the adjacent open Pacific Ocean.

The value of the Gulf of California as a sensitive monitor of both global and provincial climatic and paleoceanographic events is enhanced by (1) its latitudinal position which encompasses the dynamic boundary between the temperate-subtropical and equatorial-tropical systems of the eastern North Pacific (Figure 26) and (2) the widespread deposition of organic-rich varved diatomaceous muds throughout the Gulf during Miocene, Pliocene, and Pleistocene time as a product of climatically driven upwelling, primary productivity, and the development of intense mid-water oxygen minima (Calvert, 1964; Ingle, 1981). The varved sequences which characterize the Gulf depositional record (Figures 27 and 28) in fact offer multiple opportunities to scrutinize paleoceanographic and depositional history on an unparalleled spectrum of time scales including inter-annual and decadal scales as demonstrated by initial studies of the pioneering advanced (hydraulic) piston core (APC) recovered on DSDP Leg 64 (Kelts and Niemitz, 1982). These unusual sediments, deposited in anoxic slope and basinal settings, contain rich assemblages of both siliceous and calcareous plankton and offer the possibility of developing a truly high resolution stratigraphy for the Quaternary as well as a portion of the Pliocene and Miocene (e.g. Baumgartner et al., 1985; Molina-Cruz, in press). The relatively high rates of sediment accumulation within the Gulf dictate that these records are also much expanded in comparison with equivalent but telescoped records from deep sea sites in the Central and North Pacific. In addition, the Gulf of California penetrates a

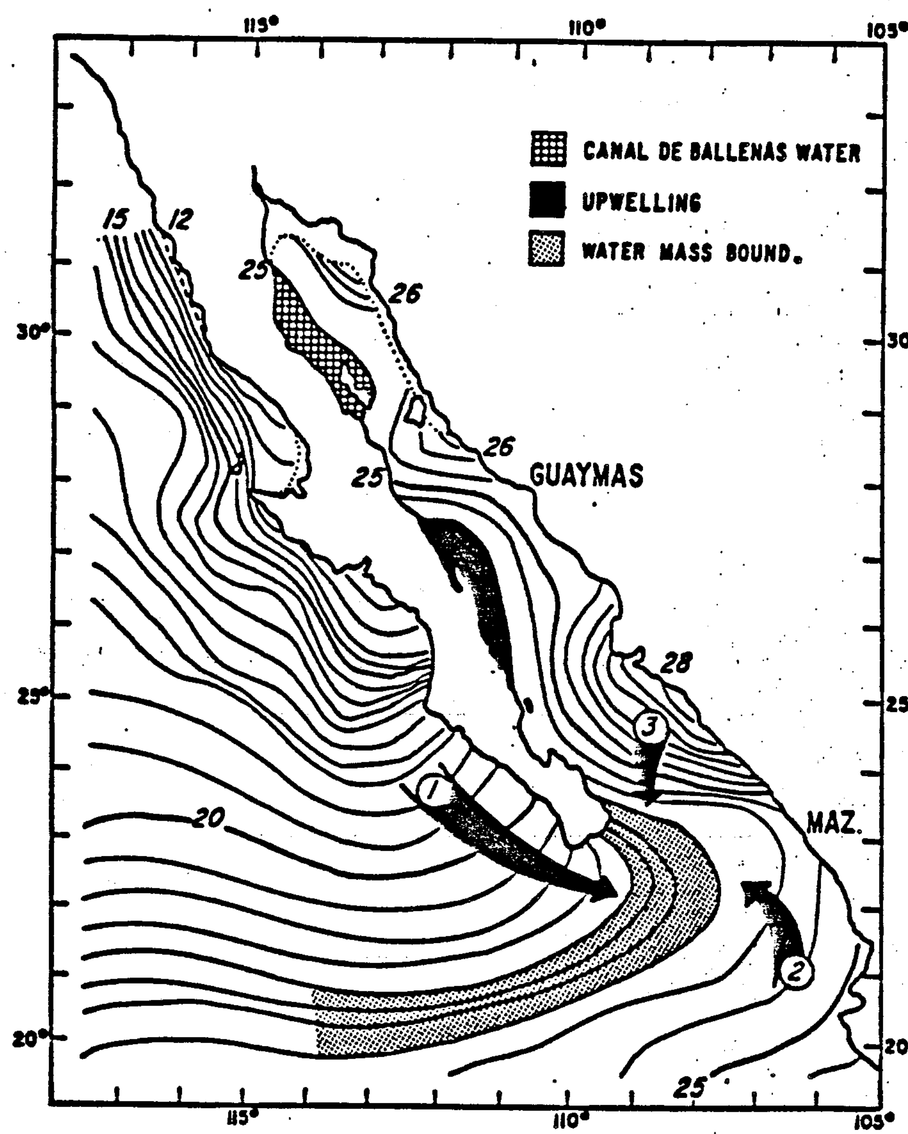


Figure 26. Location of major surface water masses, isotherms (°C), and area of summer upwelling within the modern Gulf of California (after Molina-Cruz, in press). Numbered arrows illustrate the triple front developed within the gulf mouth area between the distal California Current (1), North Equatorial Water (2), and Gulf water (3). The area of upwelling expands during the winter and spring months to include the entire central gulf region with most intense upwelling located along the eastern gulf margin--a pattern induced by seasonal wind patterns and gulf configuration. Because the Gulf of California sits astride the dynamic ocean-atmosphere boundary between tropical and temperate systems it has acted as a sensative monitor of both global and regional paleoceanographic and climatic events through the late Neogene and Quaternary.

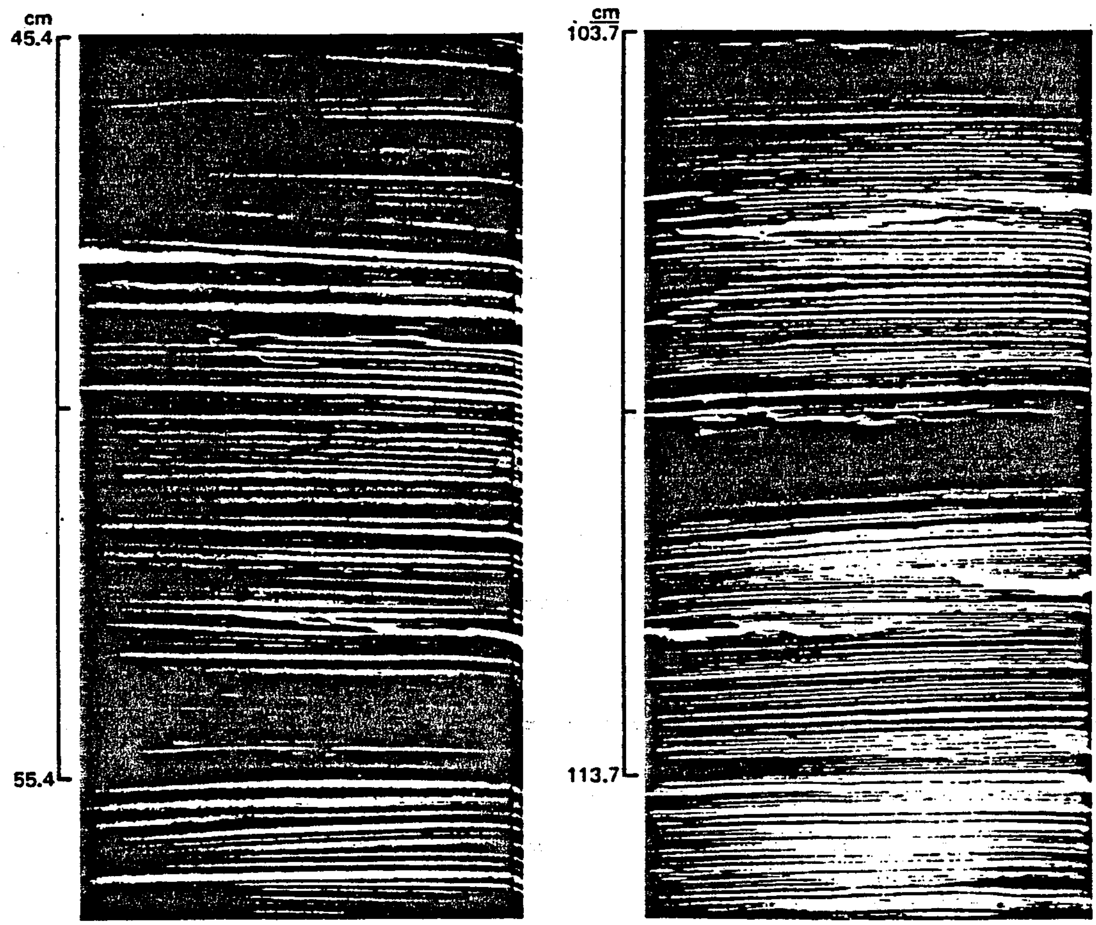


Figure 27. Slab radiographs illustrating the exceptional preservation of laminated diatomaceous sediments within the anoxic-suboxic oxygen-minimum slope facies at Site 480, Guaymas Basin, Gulf of California. Submillimeter laminations represent seasonal varves and annual records of upwelling marked by periodic variations in the flux of siliceous and calcareous plankton and terrigenous suspensates to the basin slope. Proposed ODP sites within the Gulf of California and in the Soledad Basin on the adjacent Pacific margin are aimed at recovery of a complete Quaternary record within similar varved sequences known to be present throughout the late Neogene development of the gulf. Figure modified from Soutar, Johnson, Taylor, and Baumgartner (1982).

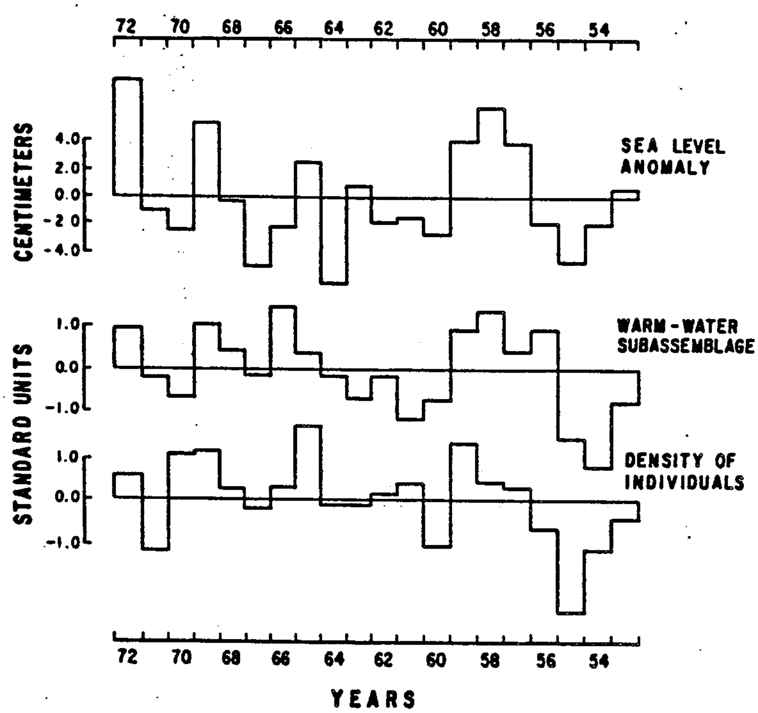


Figure 28. Example of the sensativity of climatic-paleoceanographic signals within a laminated oxygen minimum zone (OMZ) sequence from the Guaymas Basin, Gulf of California (modified from Baumgartner, Ferreira-Bartrina, and Schrader, 1985). The diagram represents a comparison of; (1) a warm-water biogeographic index developed from quantitative analysis of siliceous plankton within laminated diatomaceous muds recovered by box core from the slope of Guaymas Basin within varves representing the years 1953 through 1972, (2) densities of siliceous plankton tests within varves, and (3) Gulf of California sea-level anomalies plotted as twelve-month averages for the years 1953 through 1972. Positive sea-level anomalies are assumed to represent proxy indicators of El Niño periods within the gulf and eastern Pacific region. Peaks in the warm-water biogeographic index clearly record the El Niño events along with evidence of variations in productivity within the varved diatomaceous sequence illustrating the potential of proposed ODP sites in the Gulf of California to yield an equally sensative but long term Quaternary record of marginal sea response to global and regional climatic, paleoceanographic, and eustatic extremes.

continental interior and thus contains an integrated record of both continental and oceanic responses to climatic and paleoceanographic events in this region (Schrader and Baumgartner, 1983). Although initial studies of laminated deposits from DSDP Leg 64 have illustrated their power to resolve seasonal details of climate, water mass, and plankton history, a lack of accurate dating and correlation have limited their use to date in developing a synoptic view of Gulf paleoceanographic evolution--a major aim of ODP drilling in 1990.

Objectives:

Proposed paleoceanographic goals for ODP drilling in the Gulf of California include: (1) recovery and analysis of a complete high resolution Quaternary climatic and biostratigraphic record within the varved anoxic facies of the Guaymas Basin; (2) a longitudinal transect of upper slope sites from the mid to southern Gulf aimed at understanding the long term dynamics of mid-water oxygen minima, primary productivity, and provenance of pelagic and terrigenous materials forming these deposits; (3) analysis of interannual, decadal, secular, and longer term climatic and paleoceanographic patterns within the Gulf including expressions of regional events of special importance such as the El Niño-Southern Oscillation phenomenon (e.g. Baumgartner and Christensen, 1985); (4) analysis of the Neogene evolution of surface, intermediate, and deep water circulation from early rifting to fully developed marginal sea and analysis of the relative impact of global climatic and eustatic events versus local tectonic regulation of circulation and sediment distribution and provenance; and (5) correlation and comparison of Gulf Quaternary and late Neogene history with events in the adjacent open Pacific including the history of frontal systems associated with the distal California Current, North Equatorial Current, and Gulf water proper (Figure 26).

Proposed Drilling Sites:

Paleoceanographic discussions at the GULFAC workshop yielded an initial set of eight proposed drilling sites with prime ocean history goals (Area G, see Figure 29) to be addressed through APC coring of varved anoxic slope facies. In addition, paleoceanographic and sediment history objectives were identified for all other proposed sites with the overall goal of recovering as broad a view of Quaternary and Neogene events as possible both within the Gulf proper and in the critical Gulf-mouth and Pacific Margin areas.

The eight Area G sites are collectively aimed at obtaining a high resolution record of Quaternary paleoceanography of the central and southern Gulf and the adjacent Pacific margin off Baja California over the past 500,000 to 1,000,000 years. Principal scientific objectives at these sites include: (1) recovery of as complete a Quaternary sequence of varved seidments as possible within plankton-rich anoxic slope facies; (2) establishment of a master Quaternary geochronology and biochronology within these sequences via plankton biostratigraphy, analysis of stable isotopes in benthic and planktonic foraminifera, and correlation of climatic signals with well established Quaternary sequences in the open Pacific; (3) analysis of the history of Pleistocene and Holocene climatic variation within the central and southern Gulf and adjacent continental and oceanic areas through quantitative study of both marine and terrestrial microfossils and sediments; (4) sampling of

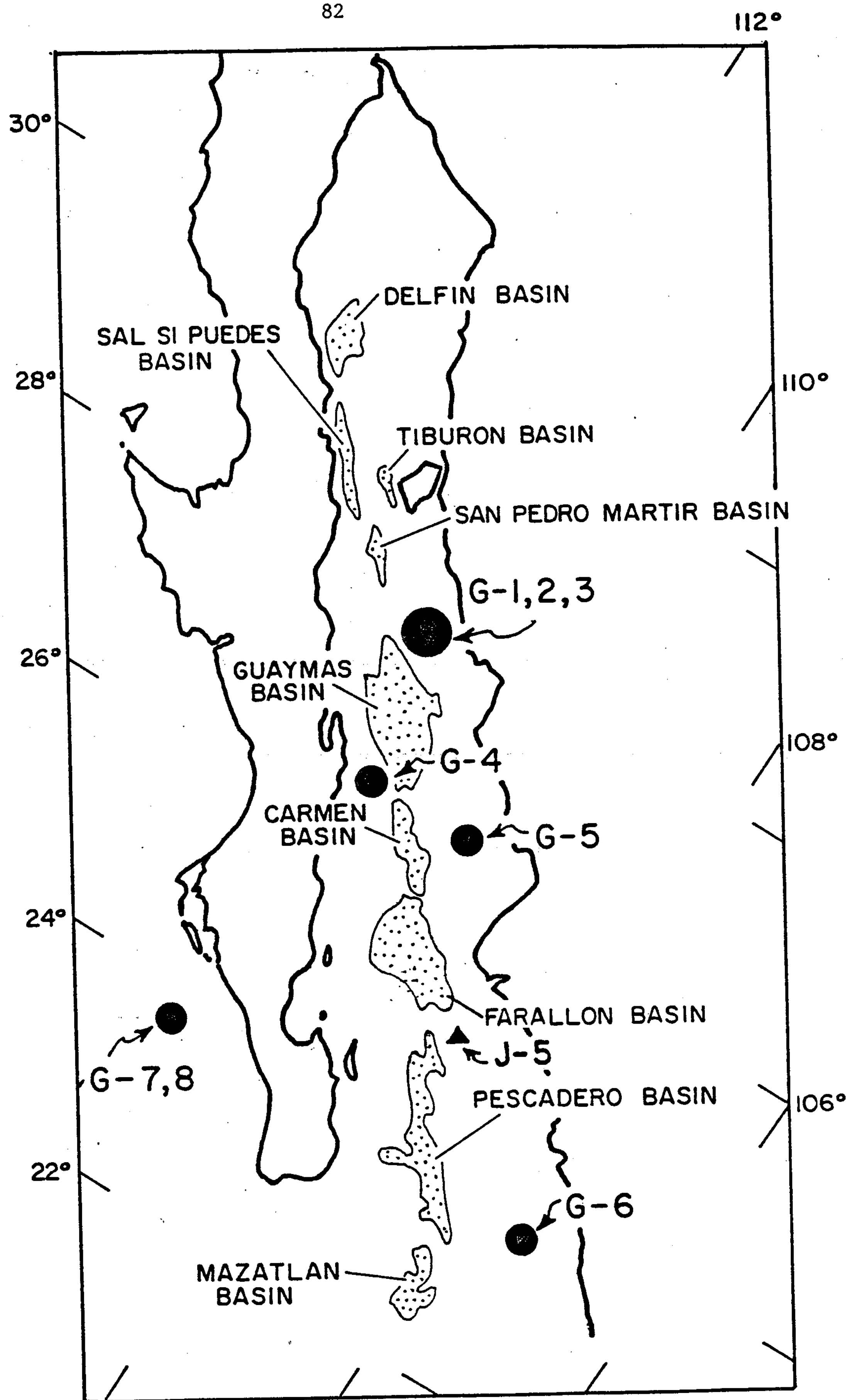


Figure 29. Location map of proposed Area G ocean history sites in the Gulf of California and adjacent Pacific margin. Proposed Site J-5 has dual tectonic and ocean history objectives.

sediment records representing contrasting upwelling and surface water regimes both in the Gulf and adjacent Pacific Ocean (Figure 28); (5) ultra high resolution (e.g. interannual and decadal) biostratigraphic and isotopic analysis of major climatic transitions within the Quaternary as recorded in anoxic varved facies; (6) quantitative analysis of variation in rates of sediment accumulation, provenance of pelagic and terrestrial sediments, as well as variations in organic geochemistry within varved sequences; (7) examine evidence for changes in the intensity and distribution of the mid-water oxygen minimum related to glacial-interglacial climatic transitions; and (8) synthesize sedimentation history as analog to conditions of continental breakup and formation of young ocean basins.

Sites G1, 2 and 3 form an APC profile across the oxygen minimum zone of the eastern slope of the Guaymas Basin in the vicinity of DSDP Site 480 drilled on Leg 64. Sites G4, 5 and 6 represent a longitudinal transect of APC sites located within the core of the oxygen minimum zone along the eastern and western slopes of the southern Gulf of California. Importantly, we anticipate that sites G4 and G6 will provide carbonate-rich records suitable for analysis of stable isotopes ($\delta^{18}O$, $\delta^{13}C$) along with adequate siliceous material. Alternately, sites G1, 2, 3 and 5 are expected to contain well preserved siliceous plankton but marginal carbonate records. Cross correlation of these varved sequences by means of isotopic, microfossil, and lithostratigraphic analysis will ultimately yield a three-dimensional picture of both surface and intermediate water dynamics through periods of climatic maxima and minima; including high resolution evidence of variations in plankton composition, dominant water masses, rates of primary productivity, and relative penetration and mixing of Pacific and Gulf water masses. Analysis of varve character, composition, and organic geochemistry together with analysis of ecologically significant benthic foraminifera will be used to estimate variations in the intensity and dimensions of mid-water oxygen minima through major climatic and seasonal cycles and as a means of assessing the effects of variations in eustatic sea level on sediment and water mass history.

Proposed sites G7 and G8 in the Soledad Basin area off the southern margin of Baja California constitute a critical component in our proposed analysis of Gulf paleoceanography, although they lie outside the Gulf proper. Site G7 is expected to recover a varved Quaternary sequence in the central area of the Soledad Basin, a depression known to represent an anoxic subsill environment similar to the much studied Santa Barbara Basin off southern California. Site G8 is located over a basement high in this same area and is aimed at both recovery of an APC Quaternary record as well as a basement sample. APC coring at Site G7 will provide a high resolution varved record of Quaternary events within the distal portion of the California Current including evidence of the timing and magnitude of north-south oscillations of the mixing zone between this current and tropical equatorial water to the south. Correlation and comparison of this record with equivalent Gulf records and,in turn, with well calibrated Quaternary sequences from the equatorial and northern Pacific will allow a full evaluation of the similarities, differences, and interdependencies in Quaternary behavior of the open Pacific with that of the Gulf of California--a synoptic view of long term ocean and marginal sea behavior currently unavailable but much needed.

SITE SELECTION STRATEGY FOR PALEOCEANOGRAPHIC APC'S:

Eastern Guaymas Slope Transect (G-1, G-2, G-3)

The eastern Guaymas slope represents the highest biogenic sedimentation in the Gulf of California, providing a rich history of siliceous phytoplankton productivity and an expanded high-resolution proxy record of Late Quaternary climatic variability. As shown by analysis of Leg 64 pollen, the adjacent continental source provides a terrestrial record highly sensitive to climatic fluctuation between present day semi-arid and cooler, less arid glacial conditions.

An important discovery from Hole 480 is the presence of massive homogeneous zones which interrupt the high-resolution varve record. This poses a problem for continuous dating of the sequence by varve count. The homogeneous zones appear to coincide with glacial conditions and may be the result of lowering of sea level and consequent displacement of the oxygen minimum. Alternative explanations include local weakening of the oxygen minimum due to lowered productivity; a southward contraction of the Eastern Tropical Pacific oxygen minimum; or a significant increase in terrigenous influx to the slope due to lowering of sea level. A transect of three sites across the present oxygen minimum should resolve the origin of the homogeneous zones and may provide material to reconstruct a continuous sequence of varved sediments throughout the Late Quaternary.

Western Carmen Slope Site (G-4)

In contrast to the eastern Guaymas slope sites, which lie beneath a strong winter-spring coastal upwelling regime, the western Carmen slope is located within a less intense summer upwelling regime with lower diatom sedimentation and correspondingly greater representation of radiolarian and carbonate microfossils. In addition the Baja California source provides a significantly lower terrigenous influx. This site should provide a clear oxygen isotope stratigraphy as well as radiolarian, foraminiferal and nannoplankton records to tie to the diatom stratigraphy of the eastern Guaymas slope.

Eastern Slope Longitudinal Transect (G-2, G-5, G-6)

These three sites are located along a strong latitudinal eco-climatic gradient with increasing precipitation and terrigenous influx, an increasingly tropical pollen record and diminishing diatom production, reflecting increasing oceanic and tropical influence to the south. Examination of the contemporaneous records at these sites will allow us to reconstruct the lateral movement of this important environmental boundary through time and to thoroughly define the response of both the oceanic and terrestrial ecosystems to climatic change. The site furthest south should contain adequate carbonate content for oxygen isotope stratigraphy to provide a time framework to correlate with the floral and faunal stratigraphy which can be extended to site G-2 on the Guaymas slope. Note site G-5 objectives could be met at equivalent site J-5.

Soledad Basin (G-7 and G-8)

The Soledad Basin (i.e. Magdalena Slope, Figure 1) is located near the present northern boundary of the transition or mixing zone between the California Current and the North Equatorial Current System and lies within the oxygen minimum zone impinging against the open Pacific Coast of Baja California Sur. Alternately the location of the Mazatlan slope site (G-6) is near the present southern boundary of this major oceanic transition. Sites G-7 and G-8 should be relatively enriched in carbonate and yield a good oxygen isotope record with which to correlate to the well established carbonate and isotopic stratigraphy of the low latitude Pacific, as well as with carbonate-rich ODP sites within the Gulf of California (e.g. sites G-4 and G-6).

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