REPORT OF THE
JOI-USSAC WORKSHOP ON
CRETACEOUS BLACK SHALES

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RATIONALE

Because of the intense interest in the Cretaceous (and Jurassic) "black shale" problem a workshop was proposed and organized primarily for U.S. participants. The problem of the origin of widespread depositional episodes of organic carbon in relatively deep-marine sequences is among the most perplexing problems facing the community of "paleoenvironmentalists", and because of its potential economic importance as well, the interdisciplinary workshop was held in Denver, CO from December 4-6, 1985. Because there is presently no focus on this problem within the JOIDES panel structure, the results and input of this workshop will be critical to the panels for targeting and prioritizing drill sites for the Ocean Drilling Program. Scheduling of ODP legs for the Atlantic is already completed for the first phase and there will be no opportunity for scheduling drill sites with black shale targets in the North Atlantic for the first two years of ODP. However, well-considered objectives will help to underscore the importance of drilling in this region on the next go-round. Indian Ocean and Pacific planning is underway for drilling in the first four to five years of ODP and we will need to focus on potential objectives important to black shales that exist there.

The synthesis and discussion of data from DSDP relating to the "black shale" problem and identification of key questions to be answered by further drilling and by multidisciplinary studies of core material (both DSDP and ODP) were the major purpose of the workshop. The highest priority regional and site-specific proposals as discussed and prioritized by the Workshop participants were also formulated and are attached to this document.

A group of individuals from the U.S. interested in the Black Shale Workshop responded to invitations and/or advertisements in EOS. The participants selected from this group (Sect. 6) spanned the wide variety of disciplines that we believe were necessary to satisfactorily address the topic. Most are recognized in their fields and have previously contributed to the "black shale" literature. Not all have worked directly on Cretaceous "black shale"; some were selected for their experience in investigations of modern marine sediments rich in organic carbon. We hoped in this way to encourage such cross-fertilization between studies of modern and ancient Corg-rich muds. The participants represented academic, industry and government interests. We also invited, at their expense, several representatives of other countries who are noted authorities on certain Cretaceous organic-carbon rich mudrocks. We hoped in this way to bolster U.S. community participation in generating drilling proposals and data syntheses while retaining an international perspective. Funding for the workshop was provided by the Joint Oceanographic Institutions-U.S. Science Advisory Committee (JOI-USSAC).

In general terms, the workshop participants strongly supported proposals to drill into and recover Cretaceous "black shales" in all major ocean basins, but with drilling designed to attack specific problems such as the paleodepth and timing of Cretaceous episodes of organic carbon preservation. These proposals represent a more mature phase of investigation that has developed as the result of studies of available core material in sites that were drilled largely for other reasons than to specifically address the "black shale" problem. We emphasize that studies of Holocene-Neogene environments in whic organic carbon-rich sedimetns have formed are also necessary for a better understanding of black shales in general. Therefore, workshop particpants expressed strong support for paleoenvironmental drilling transects along the Peru margin (trades-related upwelling) and Oman (Monsoonal upwelling) for example. A large part of discussion at the workshop also focussed on the efficacy of various analytical methods, and, particularly, the need for intensive interdisciplinary studies of "black shale" sequences.

THE BLACK SHALE PROBLEM

INTRODUCTION

A general overview of the Cretaceous "black shale" problem is provided in the following pages along with specific recommendations of the Workshop participants.

One of the early accomplishments of the Deep Sea Drilling Project (Leg 1) was the discovery of Cretaceous deep-water pelagic-hemipelagic organic-carbon rich mudrocks (so-called "black shale") in the North Atlantic Ocean basin (Heezen, Ewing et al., 1968; Lancelot et al., 1972, Leg 11). The recovery of these unusual lithotypes (relative to present-day sediment distribution in the ocean basins) then and during later DSDP legs in the North Atlantic (Legs 11, 14, 41, 43, 44, 47, 48, 51, 52, 53, 76, 77, 79, 80, 93, 95), South Atlantic (Legs 36, 39, 71, 75; e.g. McCoy and Zimmerman, 1977; Dean et al, 1984), Indian Ocean (26, 27), and Pacific Ocean (17, 31, 33, 61, 89) provided fuel for much speculation as to their origin. A number of stimulating early papers connected many of the deep-sea "black shale" occurrences in time and space with those cropping out on land as fairly discrete global events of varying duration (e.g. Schlanger and Jenkyns, 1976; Ryan and Cita, 1977; Thiede and Van Andel, 1977; Fischer and Arthur, 1977). Such a concept remains somewhat controversial because of the relatively poor stratigraphic resolution in many deep-water sequences as well as the very broad interval of the early and middle Cretaceous over which "black shales" occur. Nonetheless "oceanic anoxic events" (OAE's, Fig. 1: Schlanger and Jenkyns, 1976: also Arthur and Schlanger, 1979; Jenkyns, 1980) appear to be a valid concept (although see Waples, 1983, for contrary opinion). The carbon isotope record in Cretaceous marine pelagic carbonates (Scholle and Arthur, 1980), which presumably reflects global rates of organic carbon burial, corroborates evidence from the stratigraphic record of organic-carbon rich units (Schlanger and Jenkyns, 1976; Jenkyns, 1980). Major OAE's appear to correspond with general global sealevel highstands (Fig. 1). As such, OAE's may also have importance for understanding some sedimentary mineral deposits (e.g. Cannon and Force, 1983; Frakes and Bolton, 1984) as well as implications for hydrocarbon occurrences (Arthur and Schlanger, 1979; Tissot et al., 1980).

However, the origin and paleoceanographic implications of the black shale depositional episodes is poorly understood because the sedimentology and organic geochemistry of "black shale" sequences is quite complex and variable from region to region (e.g. Weissert, 1981).

By analogy with modern examples of organic-carbon-rich sediments at least three main variables could have been significant factors in the preservation of organic matter in ancient black shales:
(a) variation in the supply of both marine and terrigenous organic matter from surface productivity (pelagic settling, fecal pellets), fluvial discharge, redepositional processes and settling from slope and bottom nepheloid layers (e.g. Arthur, Dean, and Stow, 1984);
(b) variation in the rate of sedimentation and hence rate of burial of organic matter (e.g., Ibach, 1982; Habib, 1982)
(c) variation in bottom-water oxygenation within a midwater oxygen-minimum zone or throughout the basin as a result of oceanographic (e.g. changes in solubility of dissolved oxygen and/or change in rate of deep circulation) and climatic conditions (e.g. Fischer and Arthur, 1977; Schlanger and Jenkyns, 1976). Various authors have usually stressed the particular significance of one of these several variables from study of a black shale sequence in a particular locality or region, and have presented generalized or simplified models.

Basin deoxygenation and expansion and intensification of an oxygen-minimum layer and/or complete bottom-water anoxia (Fig. 2) have been proposed to explain the accumulation of the middle Cretaceous organic carbon-rich strata (e.g. Schlanger and Jenkyns, 1976; Ryan and Cita, 1977; Fischer and Arthur, 1977; Thiede and van Andel, 1977; Arthur and Schlanger, 1979; Berger, 1979; Thierstein, 1979). Both models require very low or no dissolved oxygen in part of the water column as a result of reduced advection of oxygenated water and (or) increased oxygen demand.

However, it is clear that more complex models are required, involving variations in rates of deep-circulation and sources of deep water (e.g. Wilde and Berry, 1982; Brass et al, 1982; Arthur and Natland, 1979) as well as changes in surface-water fertility and productivity (e.g. Roth, 1978; Bralower and Thierstein, 1985). Any models must take into account the following general characteristics of "black shale" sequences:

(1) the formation of many "black shales" under widespread poorly-oxygenated deep-water masses in some basins in the Atlantic and Tethys (Arthur and Dean, 1986; deGraciansky et al, 1982; Tucholke and Vogt, 1979, Jenkyns, 1980; Arthur and Premoli Silva, 1982) as evidenced by bioturbation characteristics and marine organic carbon enrichments in many mid-Cretaceous epicontinental sea, slop, and deep-sea sequences. A more limited extent of organic-rich facies is known from submarine highs in the Pacific basin (e.g. Dean, et al, 1981).

(2) the interbedding of organic-carbon-rich facies with organic-carbon-poor facies, in cycles with estimated periodicities that average 20,000 to 140,000 years (Dean et al., 1977; McCave, 1979; Arthur, 1979a; Dean et al., 1984), and with variable order of occurrence of the facies (McCave, 1979a; Stow and Dean, 1984);

(3) the variety of lithologies that are enriched in organic-carbon, including mudstones, marlstones, limestones, sandstones and radiolarites or diatomities, even within the same sequence, all of which have been loosely referred to as "black shales".

(4) the range of processes that may have been responsible for deposition of different black shales, including pelagic, hemipelagic (e.g. settling from nepheloid layer or other bottom-current associated deposition), turbiditic and other mass flow processes, and the fact that no one process is uniquely associated with any one of the associated facies (e.g. Arthur, Dean and Stow, 1984):

(5) the different types and degreee of preservation of organic matter and amounts of total organic carbon in black shales even within the same sequence. (Summerhayes, 1981; Herbin and Deroo, 1982; Habib, 1979; 1982).

THE NATURE OF THE PROBLEM

Without resorting to a detailed exposition of the "black shale problem" here (see recent reviews by Weissert, 1981; Summerhayes, 1981; and Arthur et al, 1984) we would like to outline some of the many remaining problem aspects in our understanding of Cretaceous "black shale" deposition. Many of the questions remain because of the following:

1) generally poor core recovery at many DSDP Sites (drilling disturbance; spot coring; physical property contrasts on a bed by bed basis such as in chert or shale-limestone lithologies)

2) few DSDP Sites were designed specifically to test "black shale" depositional models, i.e. recovery of "black shales" was ancillary to the main objectives.

3) many "black shale" sequences recovered in DSDP Sites were deposited below the carbonate compensation depth (CCD) and therefore stratigraphic resolution has been generally poor. And;

4) few detailed studies of well-exposed land sections have been completed, and organic geochemical studies of outcrop sections are commonly limited by weathering.

The problems can be separated as local or regional vs global in scope. The types of data required from each site (local scale) are:

(a) detailed biostratigrapy and faunal analysis integrated with sedimentologic studies;

(b) sedimentology with bed by bed details noting primary structures, color, degree of bioturbation, etc.

(c) detailed mineralogic, organic and inorganic geochemical studies integrated with sedimentological studies; the same beds should be sampled for all analyses as much as possible so that an assessment and understanding of the variabiliity in any one parameter relative to others can be achieved. Such coordinated multi-disciplinary studies have been completed on sequences in relatively few DSDP Sites (see, for example, Leg 75, Site 530 results in Meyers et al, 1984). These data, if properly collected, will contribute to solution of regional and global-scale problems.

Among some of the regional and global scale problems to be approached by further drilling and study of core material are the following:

1) The timing and distribution of black shale deposition-The exact timing of relative organic-carbon enrichments and the possible correlation within individual basins and from one ocean basin to another (Figs. 3,4,5). Is the concept of globally synchronous "oceanic anoxic events" valid or does such a principle only apply to the Cenomanian-Turonian event (e.g. Schlanger et.al., 1986; see Waples, 1983 for contrary view point)? What is the paleodepth range in each basin over which "black shales" were deposited (e.g. Fig. 6)? What relationship do widespread organic carbon-rich beds have to sea level, tectonic events, and global climate change (e.g. Arthur, Dean and Schlanger, 1985)?

2) The role of organic productivity vs. preservation (anoxia vs. sedimentation) rate in the origin of black shales - Are the two coupled in some way? Can we establish definitive criteria to distinguish between the two effects? In particular we need to evaluate the hypothesis that surface biologic productivity was low during much of Cretaceous black shale deposition in the North Atlantic (e.g. Roth, 1978; Roth and Bowdler, 1981; Bralower and Thierstein, 1984). We also need to examine the effects of changing sedimentation rate on Corg preservation (e.g. Muller and Suess, 1979; Ibach, 1982; Fig. 7).

3) The organic geochemistry of "black shales"-Can we distinguish sources and initial preservation of organic matter from the overprints of early and late diagenesis (Tissot et al., 1979) (Fig. 8)? What are the chemical (i.e. stable isotopic; organic compund structure) changes in organic matter in black shales during burial and how rapidly do they occur (e.g. Didyk et al, 1978)? What are the relative effects of time and temperature on organic maturation? (See numerous studies of organic geochemistry in Initial Reports Volumes of DSDP, as yet not well synthesized).

4) The inorganic geochemistry of black shales-What patterns of metal, phosphate, and sulfur enrichment are observed in black shales of differing depositional environment and organic contents (e.g. Brumsack, 1980; Dean, Arthur, Stow, 1984 Bralower and Thierstein, 1986). Can such information be used to interpret the origin of a given "black shale" unit in terms of deposition under an anoxic water column (e.g. Leventhal, 1982)? Do organic carbon-rich sediments provide the clue to the "dolomite problem" (e.g. Baker and Kastner, 1980). In other words, are "organic" dolomites ubiquitous and abundant in Cretaceous Corg-rich strata and are there specific geochemical settings in which they occur?

5) The global implications of widespread organic carbon depositional episodes-Can we understand the impacts and implications of organic carbon depositional episodes for the carbon cycle, pCO_2 and climate? What impact do such episodes have on ocean chemistry and isotopic compositions of carbonate and organic carbon (e.g. Scholle and Arthur, 1980; Dean, Arthur and Claypool, 1986), particularly on the geochemical cycles of trace elements and sulfur (e.g. Brumsack, 1980)? Are certain marine biotic extinction events related to so-called "Oceanic Anoxic Events? (e.g. Roth, 1979; Caron and Homewood, 1983; Arthur and Schlanger, 1979; Jenkyns, 1980)? Are certain stratiform mineral deposits (e.g. Cannon and Force 1983; Frakes and Bolton, 1984) and hydrocarbon reserves ultimately created by these episodes, if they indeed do exist?

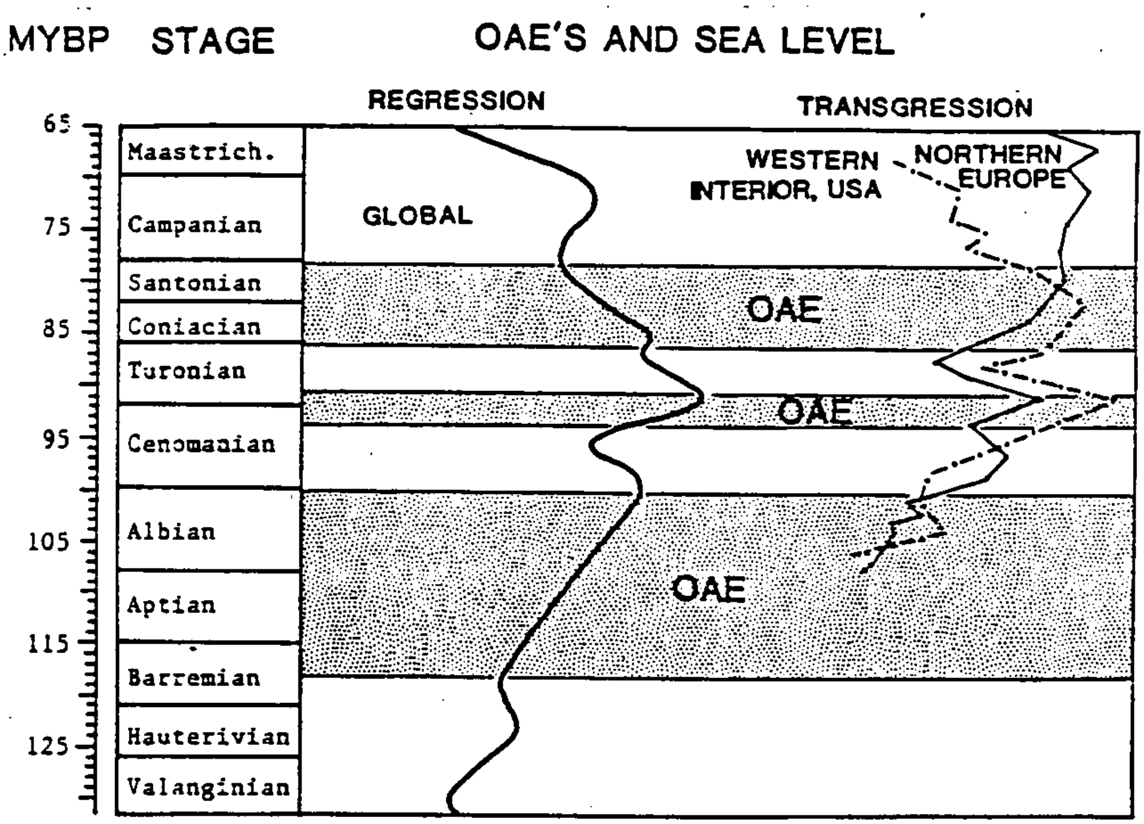


Figure 1: Timing of major Cretaceous "Oceanic Anoxic Events" (OAE's) defined by Schlanger and Jenkyns (1976) and their correspondance to Cretaceous sea level changes.

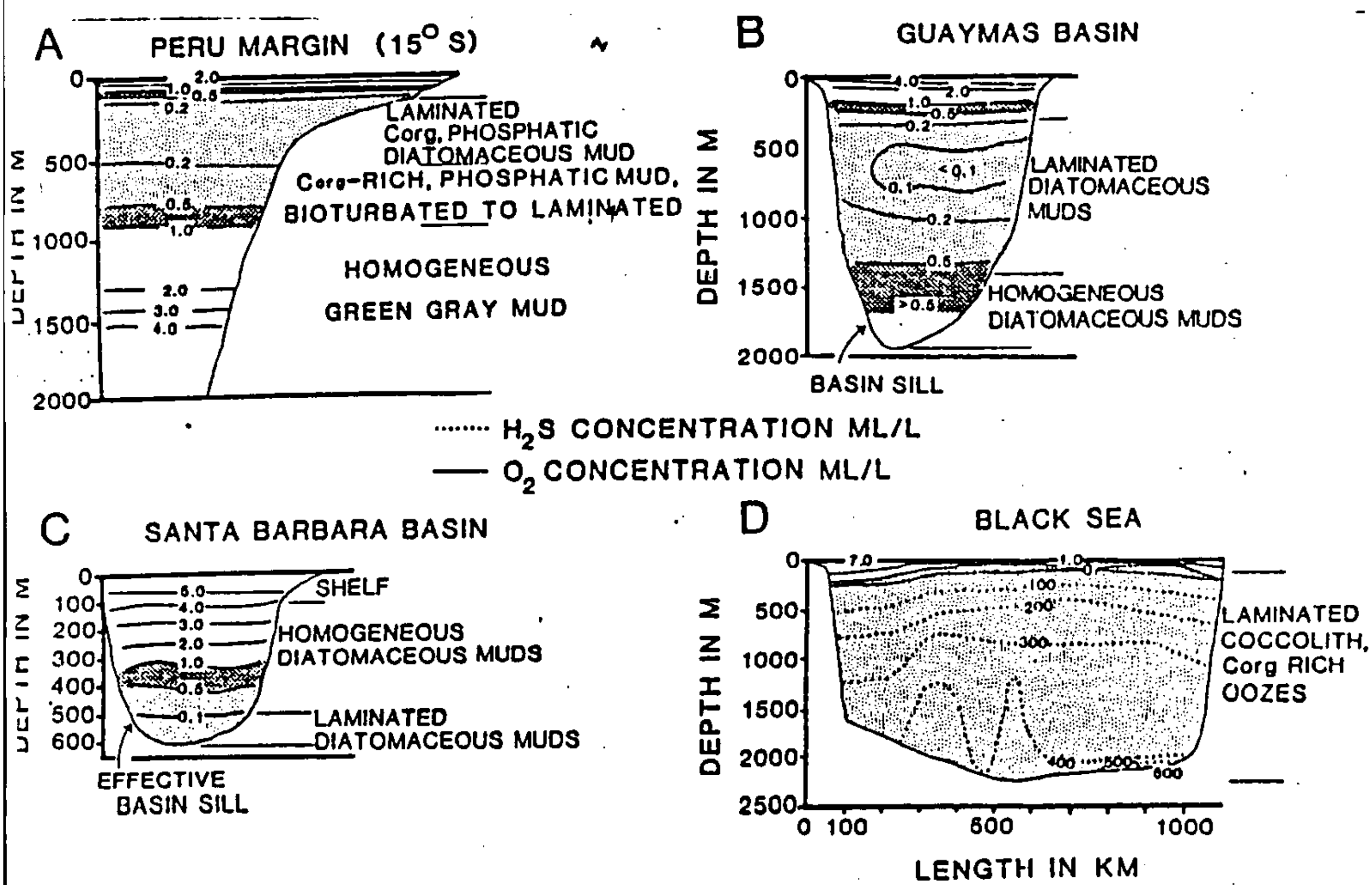


Figure 2: a) Variety of modern analogues that serve as models for basins in which ancient "black shales" are deposited (from Arthur et al., 1984)

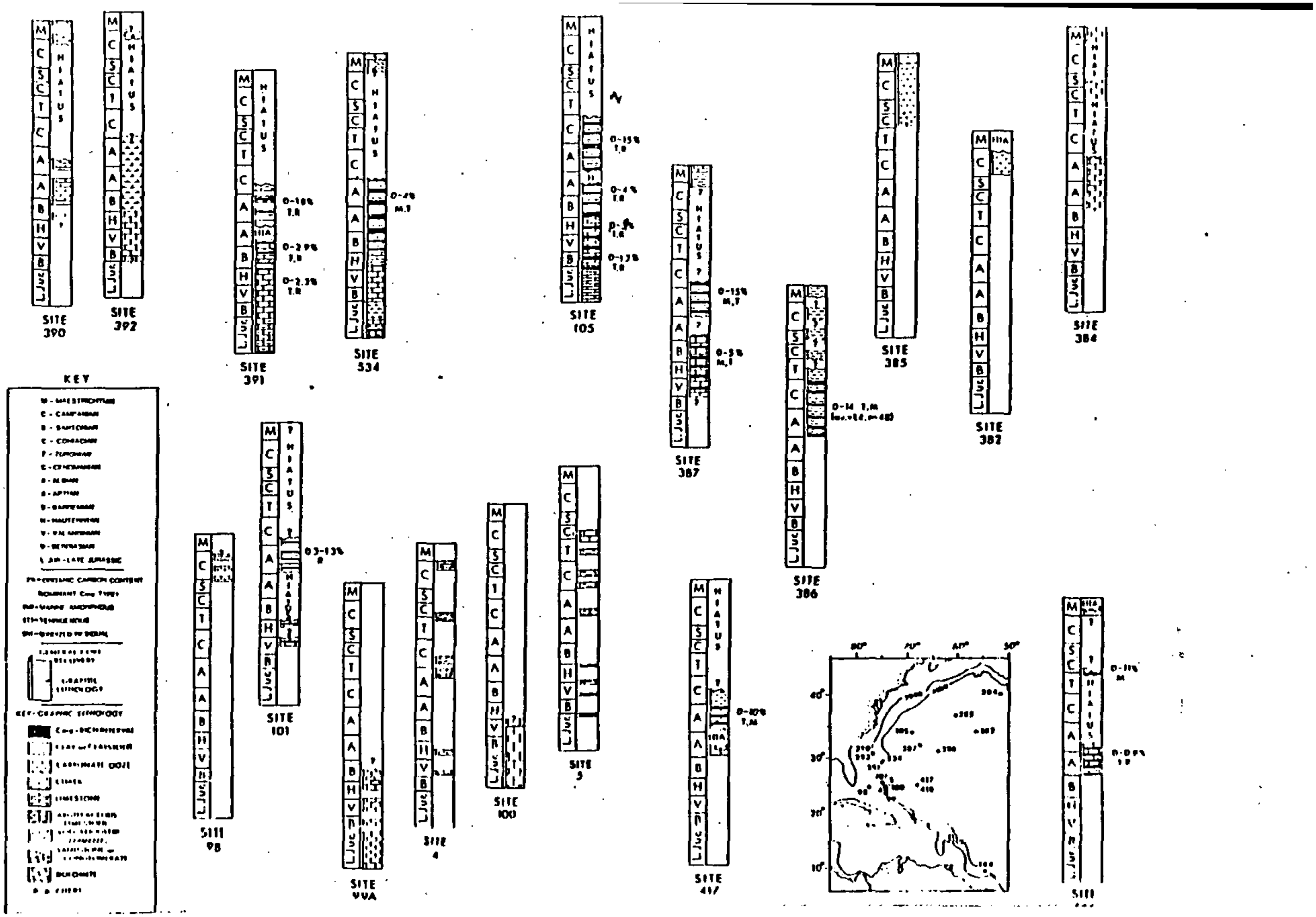


Figure 3: Age and lithology of Cretaceous strata from Western North Atlantic DSDP Sites showing intervals of "black shale" deposition (from Arthur et al., 1984)

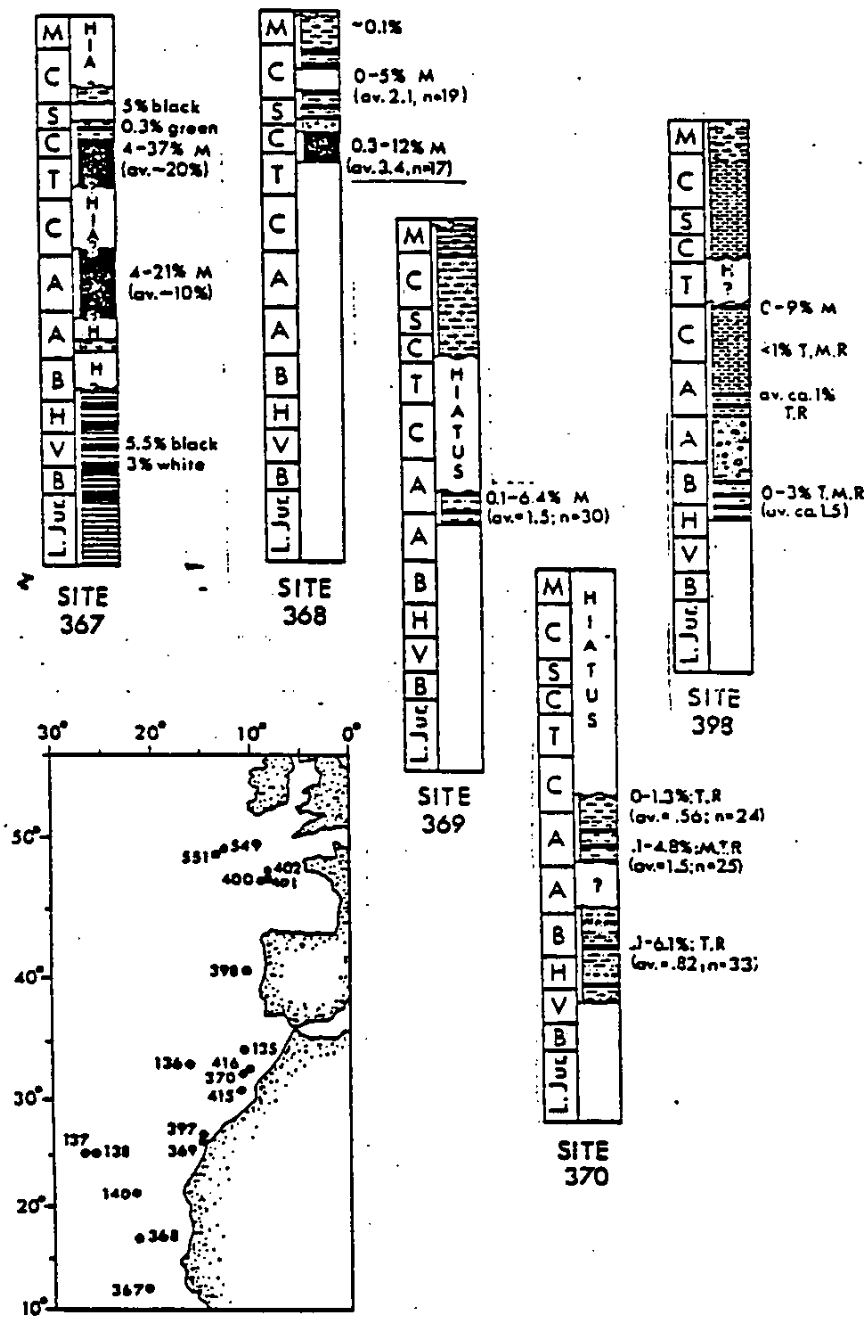


Figure 4: Age and lithology of Cretaceous strata from Eastern North Atlantic DSDP Sites showing intervals of "black shale" deposition (from Arthur et al., 1984).

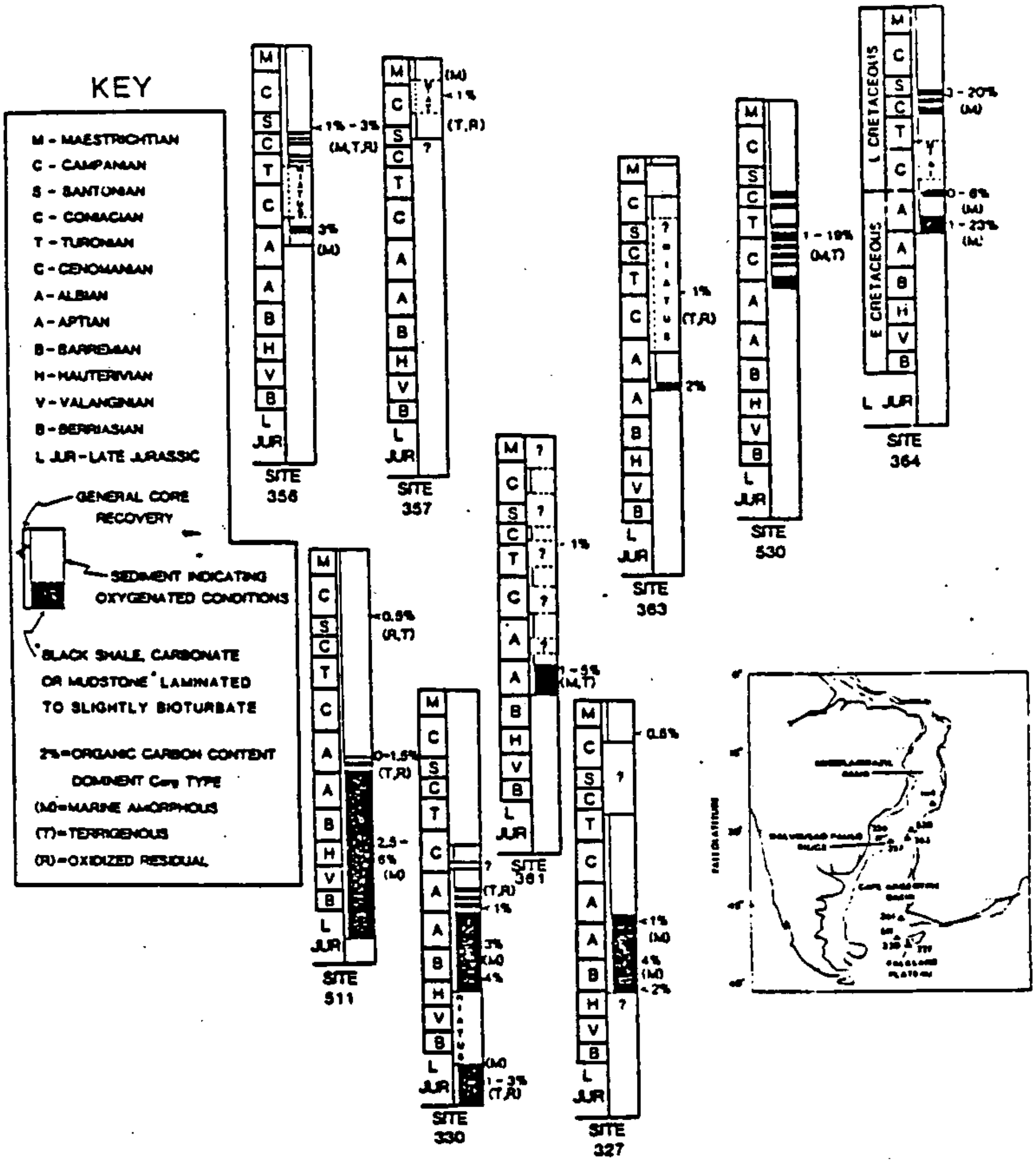
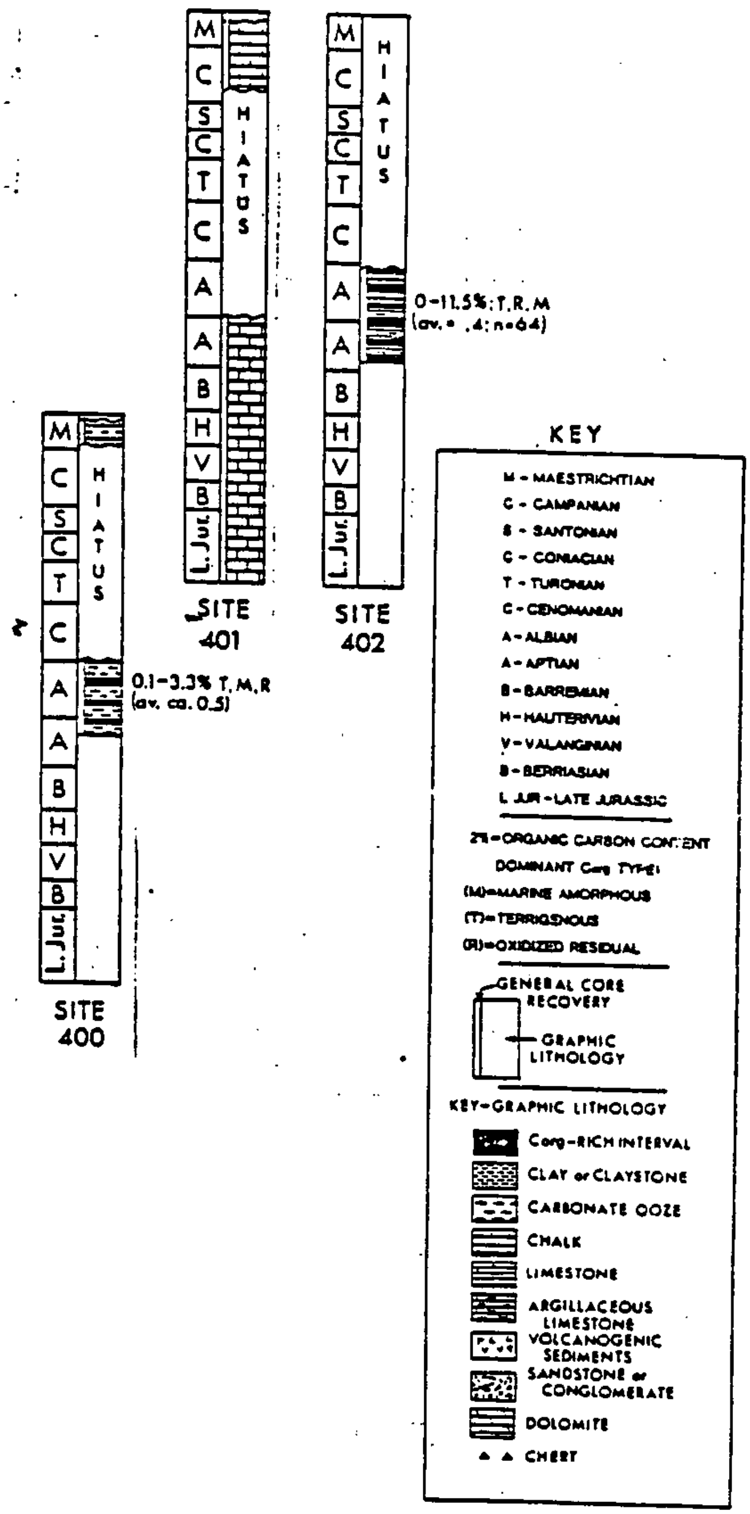


Figure 5: Age and lithology of South Atlantic DSDP Sites showing intervals of "black shale" deposition (from Dean et al., 1984).


M C S C T C A A B H V B L. Jur.
HIATUS
SITE 400
0.1-3.3% T,M,R (av. ca. 0.5)
SITE 401
SITE 402
0-11.5%: T,R,M (av. = .4; n=64)
KEY
M - MAESTRICHTIAN
C - CAMPANIAN
S - SANTONIAN
C - CONIACIAN
T - TURONIAN
C - CENOMANIAN
A - ALBIAN
A - APTIAN
B - BARREMIAN
H - HAUTERIVIAN
V - VALANGINIAN
B - BERRIASIAN
L. JUR - LATE JURASSIC
2% = ORGANIC CARBON CONTENT
DOMINANT Corg TYPE:
(M) = MARINE AMORPHOUS
(T) = TERRIGENOUS
(R) = OXIDIZED RESIDUAL
GENERAL CORE RECOVERY
GRAPHIC LITHOLOGY
KEY - GRAPHIC LITHOLOGY
Corg - RICH INTERVAL
CLAY or CLAYSTONE
CARBONATE OOZE
CHALK
LIMESTONE
ARGILLACEOUS LIMESTONE
VOLCANOGENIC SEDIMENTS
SANDSTONE or CONGLOMERATE
DOLOMITE
CHERT

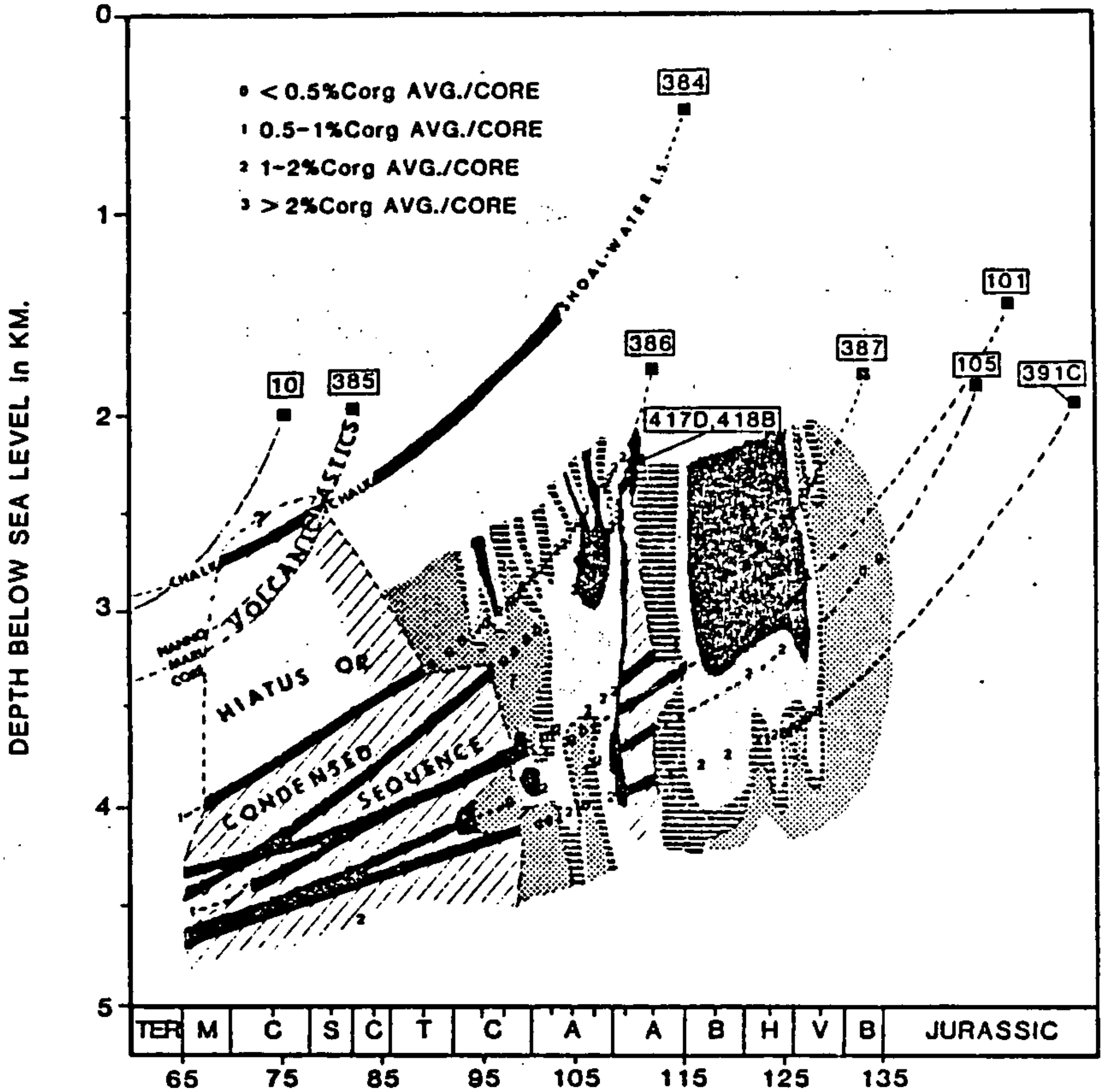


Figure 6: Paleodepth distribution of organic carbon contents for Western North Atlantic Cretaceous sediments from (Arthur and Dean, 1985).

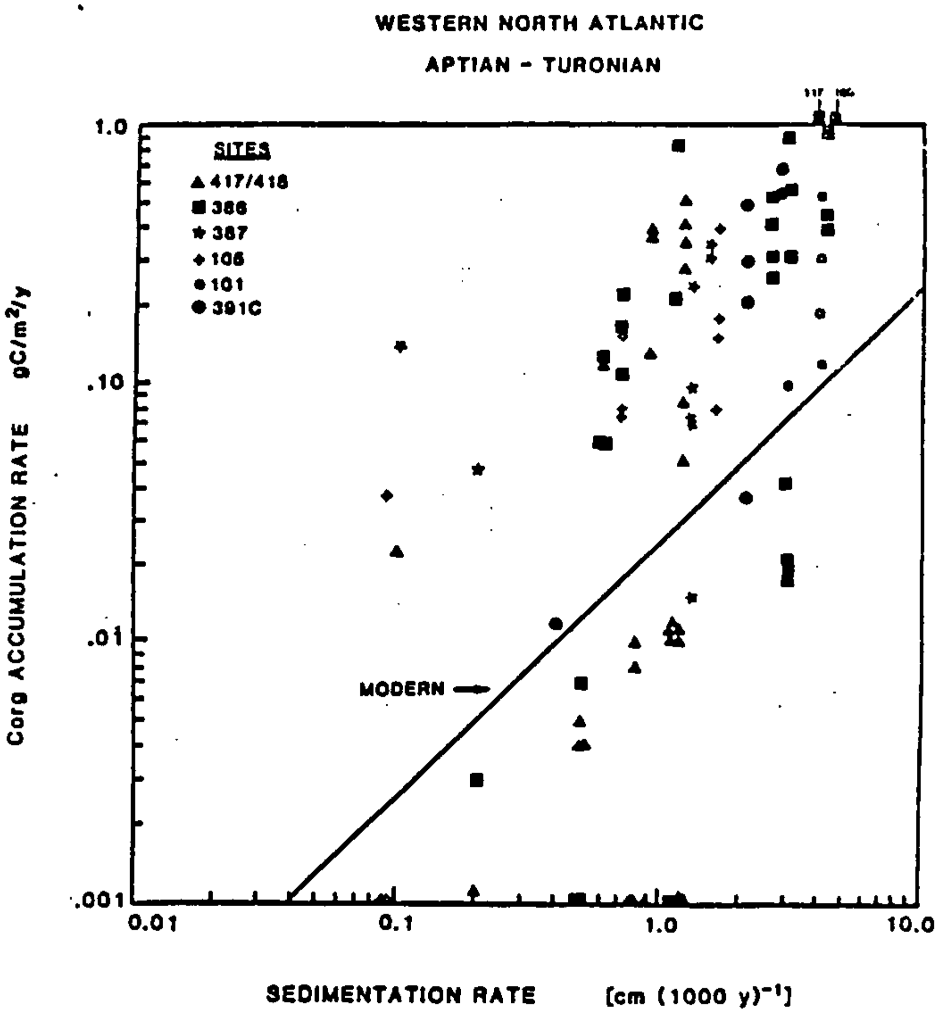


Figure 7: Plot of core by core averages of organic carbon accumulation rate vs sedimentation rate for selected Cretaceous Western North Atlantic DSDP drill sites (from Arthur and Dean, 1985). The line labelled "modern" is relationship predicted from Muller and Suess (1979) data if sedimentation rate is main control on Corg accumulation rate with average productivity. The spread of points above the line suggests enhanced preservation of Corg for some other reason than simply increasing burial rates.

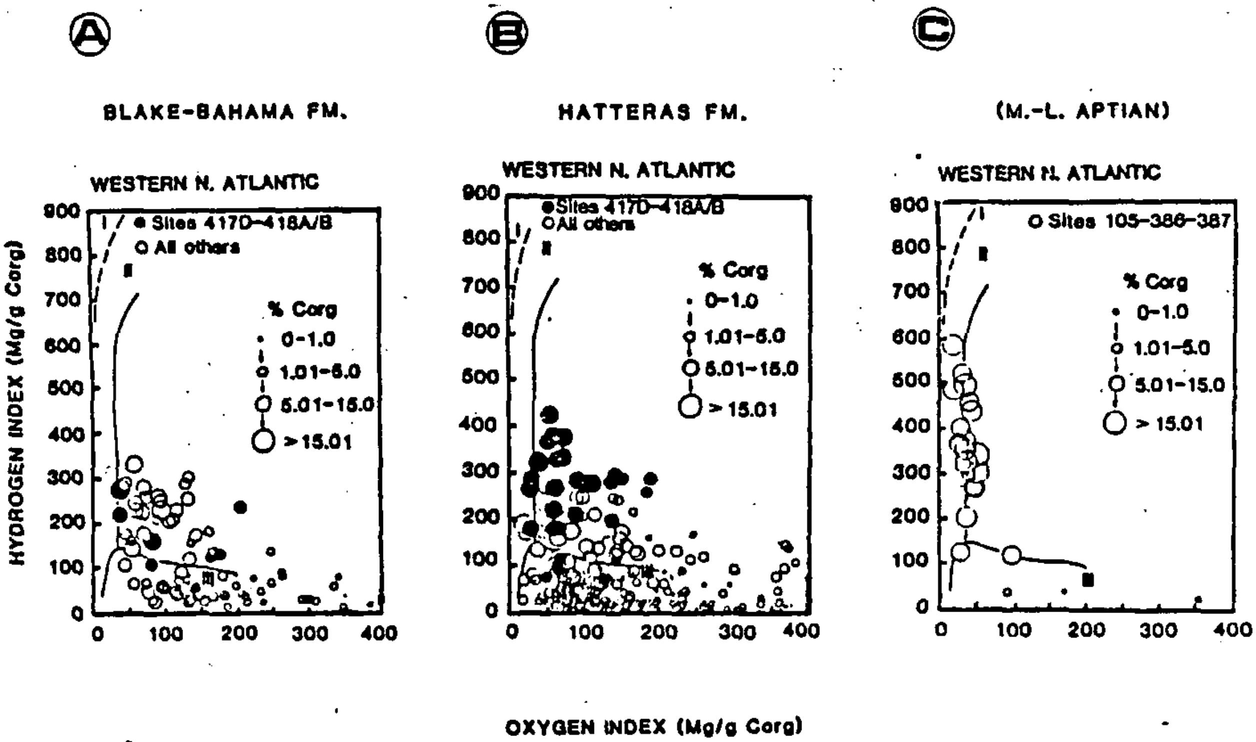


Figure 8: Pyrolysis data for Western North Atlantic Cretaceous DSDP cores (from Herbin and Deroo, 1982) that illustrate the combined effects of source and preservation signals on organic carbon compositions. The variations in Hydrogen Index for example, are very age dependant. Such data, however, are not easily interpreted.

REFERENCES

Arthur, M. A., 1979a, North Atlantic Cretaceous black shales: the record at Site 398 and a brief comparison with other occurrences, in Sibuet, J.-C., Ryan, W. B. F., et al., Initial Reports of the Deep Sea Drilling Project, v. 47, part 2: Washington (U.S. Government Printing Office), p. 719-751.

Arthur, M.A. and Dean, W.E., 1986, Cretaceous Paleoceanography: in Decade of North American Geology, Western North Atlantic Basin Synthesis Volume, B.E. Tucholke and P.R. Vogt, eds., Geol. Soc. Amer., in press.

Arthur, M. A., Dean, W. E., and Stow, D.A.V., 1984, Models for the deposition of Mesozoic-Cenozoic fine-grained organic-carbon-rich sediment in the deep sea: in Stow, D.A.V., and Piper, D., eds., Fine-Grained sediments: Geol. Soc. Lond. Spec. Publ., p. 527-562.

Arthur, M. A., and Natland, J. H., 1979, Carbonaceous sediments in North and South Atlantic: the role of salinity in stable stratification of early Cretaceous basins, in Talwani, M., Hay, W. W., and Ryan, W. B. F., eds., Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment: Washington, American Geophyscial Union, Maurice Ewing Series, v. 3, p. 297-344.

Arthur, M. A., and Premoli Silva, I., 1982, Development of widespread organic carbon-rich strata in the Mediterranean Tethys: in Schlanger, S. O., and Cita, M. B., eds., Nature and origin of Cretaceous carbon-rich facies: London, Academic Press, p. 7-54.

Arthur, M. A., and S. O. Schlanger, 1979, Cretaceous "Oceanic Anoxic Events" as causal factors in development of reef-reservoired oil fields: Bull. Am. Assoc. Petrol. Geol., v 63, p. 870-885.

Berger, W. H., 1979, Impact of Deep Sea Drilling on paleoceanography in Talwani, M., Hay, W. W., and Ryan, W. B. F., ed., Results of Deep Drilling in the Atlantic Ocean: Continental Margins and Paleoenvironment: American Geophysical Union, Maurice Ewing Series, v. 3, p. 297-344.

Bralower & Theirstein, 1984, Low productivity and slow deep-water circulation in mid-Cretaceous oceans: Geology, v.f 12, p. 614-618.

Bralower, T.J., and Thierstein, H. R., 1986, Organic carbon and metal accumulation rates in Holocene and mid-Cretaceous marine sediments: paleoceanographic significance, in Brooks, J., and Fleet, A., eds., Marine Petroleum Source Rocks, Geol. Soc. London Spec. Publ., in press.

Brass, G. W., Southam, J. R., and Peterson, W. H., 1982, Warm saline bottom water in the ancient ocean: Nature, v. 296 p. 620-623.

Brumsack, H. J., 1980, Geochemistry of Cretaceous Black shales from the Atlantic Ocean (DSDP Legs. 11, 14, 36, and 41): Chem Geol., v. 31, p. 1-25.

Cannon, W. F., and Force, E. R., 1983, Potential for high-grade shallow-marine Manganese deposits in North America: in W.C. Shanks, III, ed., Cameron Volume on Unconventional Mineral Deposits, Soc. Mining Engineers Publ., New York, p. 175-189.

Caron, M. and Homewood, P., 1983, Evolution of early planktic foraminifers: Mar. Micropaleont., v. 7, p. 453-462.

Dean, Arthur and Claypool, 1986, Depletion of ^{13}C in Cretaceous Marine organic matter: source, diagenetic, or environmental signal, Mar. Geol., V. 70, p. 119-157.

Dean, W. E., Arthur, M.A., and Stow, D. A. V., 1984, Origin and geochemistry of Cretaceous deep-sea black shales and multicolored claystones, with emphasis on Deep Sea Drilling Project Site 530, Southern Angola Basin: in Hay, W. W., Sibuet, J. C., et al., Initial Reports of the DSDP, v. 75, U.S. Government Printing Office, Washington p. 819-844.

Dean, W. E., Thiede, J., and Claypool, G. E., 1981, Origin of organic carbon-rich mid-Cretaceous limestones, Mid-Pacific Mountains and southern Hess-Rise, in Vallier, T., Theide, and others, Initial Reports of the DSDP, v. 62: Washington (U.S. Government Printing Office), p. 877-890.

Dean, W. E., Gardner, J. V., Jansa, L. F., Cepek, P., and Seibold, E., 1977, Cyclic sedimentation along the continental margin of northwest Africa, in Lancelot, Y., Seibold, E. et al., Initial Reports of the Deep Sea Drilling Project, v. 41: Washington (U.S. Government Printing Office), p. 965-986.

de Graciansky, P. C., Brosse, E., Deroo, G., Herbin, J.-P., Montadert, L., Muller, C., Sigal, J., and Schaaf, A., 1982, Les formations d'age Cretace de l'Atlantique Nord et leur matiere organique: paleogeographie et milieux de depot: Revue de l'Institut Francais du Petrole, v. 37, p. 275-337.

Didyk, B. M., Simoneit, B. R. T., Brassell, S. C., and Eglinton, G., 1978, Geochemical indicators of paleoenvironmental conditions of sedimentation: Nature, v. 272, p. 216-222.

Fischer, A. G., and Arthur, M. A., 1977, Secular variations in the pelagic realm: Spec. Publ. Soc. Econ. Paleont. Miner., v. 25, p. 19-50.

Frakes, L. A., and Bolton, B. R., 1984, Origin of manganese giants: sea-level change and anoxic-oxic history: Geology, v. 12, p. 83-86.

Habib, D., 1979, Sedimentary origin of North Atlantic Cretaceous palynofacies, in Talwani, M., Hay, W., and Ryan, W. B. F., eds, Deep drilling results in the Atlantic Ocean: continental margins and paleoenvironments: American Geophysical Union, Maurice Ewing Series, v. 3, p. 420-437.

Habib, 1983, Sedimentation-rate-dependent distribution of orgnaic matter int he North Atlantic Jurassic-Cretaceous, in Sheridan, R.E., Gradstein, F.M. and others, Init. Repts. of DSDP, V. 76, Washington, U.S. Government Printing Office, p. 781-794.

Ibach, Johnson, L.E., 1982, Relationship between sedimentation rate and total organic carbon content in ancient marine sediments: Amer. Assoc. Petrol. Geol. Bull., v. 66, p. 170-188.

Jenkyns, H. C., 1980, Cretaceous anoxic events: continents to oceans. Jour. Geol. Soc. Lond., v. 137, p. 171-188.

McCave, I. N., 1979, Depositional features of organic black and green mudstones at DSDP Sites 386 and 387, western North Atlantic, in Tucholke, B. E., Vogt, P. R., et al., Initial Reports of the Deep Sea Drilling Project, v. 43: Washington (U.S. Government Printing Office), p. 411-416.

McCoy, F. W., and Zimmerman, H. B., 1977, A history of sediment lithofacies in the South Atlantic Ocean, in Perch-Nielson, K., Supko, P., and others, Initial Reports of the DSDP, v. 39: Washington (U.S. Government Printing Office), p. 1047-1079.

Meyers, P. A., Brassell. S. C., and Huc, A. Y., 1984, Geochemistry of organic carbon in South Atlantic sediemtns from DSDP Leg 75, in Hay, W. W., Sibuet, J. C. et al., Initial Reports of DSDP, Leg 75: Washington (U. S. Govt. Print. Off.), p. 967-982.

Muller, P. S., and Suess, E., 1979, Productivity, sedimentation rate, and sedimentary organic carbon content in the oceans: Deep-Sea Research, v. 26, p. 1347-1362.

Roth, P. H., 1978, Cretaceous nannoplankton biostratigraphy and oceanography of the northwestern Atlantic Ocean, in Benson, W. E., Sheridan, R. E. et al., Initial Reports of the Deep Sea Drilling Project, v. 44: Washington (U.S. Government Printing Office), p. 731-752.

Roth, P.H., and Bowdler, J. L., 1981, Middle Cretaceous nannoplankton biogeography and oceanography of the Atlantic Ocean, in Warme, J. E., Douglas, R. G., and Winterer, E. L., eds., Deep-sea drilling: a decade of progress, Soc. Econ. Paleontol. Mineral. Spec. Publ. No. 31, p. 517-546.

Savrda, C.E. and Bottjer, D.J., 1986, Trace-fossill model for reconstruction of paleo-oxygenation in bottom waters, Geology, V. 14, p. 3-6.

Schlanger, S. O., Arthur, M. A., Jenkyns, H. C., and Scholle, P. A., 1986, The Cenomanian-Turonian oceanic anoxic event, I. Stratigraphy and distribution of organic carbon-rich beds and the marine S13C excursion, in Brooks, J., and Fleet, A., Marine Petroleum Source Rocks, Geol. Soc. Lond. Spec. Publ., in press.

Schlanger, S. ., and Jenkyns, H. C., 1976, Cretaceous oceanic anoxic events -- causes and consequences: Geologie en Mijnbouw, v. 55, p. 179-184.

Scholle, P. A., and Arthur, M. A., 1980, Carbon isotopic fluctuations in pelagic limestones; potential stratigraphic and petroleum exploration tool: American Association of Petroleum Geologists Bulletin, v. 643, p. 67-68.

Stow, D. A. V., and Dean, W. E., 1984, Middle Cretaceous Black Shales at Site 530 in the southeastern Angola Basin, in Hay, W. w., Sibuet, J. C. , and others, Init. Repts. Deep Sea Drilling Proj., V. 75: Washington (U.S. Govt. Print. Off.), p. 809-818.

Summerhayes, C. P., 1981, Organic facies of Middle Cretaceous black shales in deep North Atlantic: American Association of Petroleum Geolgoists Bulletin, v. 65, p. 2364-2380.

Thiede, J. and van Andel, T. H., 1977, The paleoenvironment of anaerobic sediments in the late Mesozoic South Atlantic Ocean: Earth and Planetary Science Letters, v. 33, p. 301-309.

Thierstein, H. R., 1979, Paleoceanographic implications of organic carbon and carbonate distribution in Mesozoic deep sea sediments, in Talwani, M., Hay, W. W., and Ryan, W. B. F., eds., Deep drilling results int he Atlantic Ocean: continental margins and paleoenvironment: Washington, American Geophysical Union, Maurice Ewing Series, v. 3, p. 249-274.

Tissot, B., Demaison, G., Masson, P., Delteil, J. R., and Combaz, A., 1980, Paleoenvironment and petroleum potential of middle Cretaceous black shales in Atlantic basins: American Association of Petroleum Geologists Bulletin, v. 64, p. 2051-2063.

Tissot, B. Deroo, G., and Herbin, J. P., 1979, Organic matter in Cretaceous sediments of the North Atlantic: contributions to sedimentology and paleogeography, in Talwani, M., Hay, W. W., and Ryan, W. B. F., eds., Deep drilling in the Atlantic Ocean: continental magins and paleoenviroment: American Geophysical Union, Maurice Ewing Series, v. 3, p. 362-374.

Tucholke, B. E., and Vogt, P. R., 1979, Western North Atlantic: sedimentary evolution and aspects of tectonic history, in Tucholke, B. E., Vogt, P. R., et al., Initial Reports of the Deep Sea Drilling Project, v. 43: Washington (U.S. Government Printing Office), p. 791-825.

Waples, D. W., 1983, Reappraisal of anoxia and organic richness, with emphasis on Cretaceous of North Atlantic: Am. Assoc. Petro. Geol. Bull., 67, p. 963-978.

Weissert, H., 1981, The environment of deposition of black shales in the Early Cretaceous: an ongoing controversy, in Warme, J. E., Douglas, R. G., and Winterer, E. L., eds., The Deep Sea Drilling Project: a decade of progress: Society of Economic Paleontologists and Mineralogists Special Publication 32, p. 547-560.

Wilde, P., and Berry, W. B. N., 1982, Progressive ventilation of the oceans -- potential for return to anoxic conditions in the post-Paleozoic, in Schlanger, S. O., and Cita, M. B.. eds., Nature and origin of Cretaceous carbon-rich facies: London, Academic Press, p. 209-224.

WORKSHOP ORGANIZATION

The workshop was organized around the first day of topical synthesis presentations by 6 participants, including ample time for questions and discussion of the problems presented. These presentations set the stage for the second day, which required participants to split up into topical working groups (see attached) for discussing the major problems in each field and outing recommendations for further study, either by special drilling or by analysis of existing and new core materials. On the third day the participants reassembled to present their recommendations to the group as a whole and for further discussion, amplification and prioritization of suggested drill sites.

The formal presentations were as follows:

Paleonenvironmental Models; an Holistic Approach (M. Arthur)

A Regional Perspective to Black Shale Paleoenvironments: The North Atlantic Example (B. Tucholke)

The Adequacy of the Biostratigraphic Record (W. Sliter)

The Importance of Organic Geochemistry in Black Shale Studies (P. Meyers)

Inorganic Geochemistry of Black Shales and Associated Strata; Can We Tell the Difference? (W. Dean)

Making Milankovitch More Manageable (Or Cycles in Black Shale Sequences) (A.G. Fischer)

THEMATIC WORKING GROUPS

I. Sedimentary Processes, Lithostratigraphy, Regional Problems

Rapporteur: D. Bottjer

Members:
- M. Arthur
- E. Barron
- L. Bonnell
- C. Byers
- A.G. Fischer
- T. Herbert
- J.P. Herbin
- J. Parrish
- S.O. Schlanger
- H. Zimmerman

II. Stratigraphic Problems and Paleoecologic Indicators

Rapporteur: P. Roth

Members:
- R. Diner
- D. Eicher
- E. Habib
- W. Hay
- E. Kauffman
- H. Schrader
- C. Savrda
- P. Scholle
- W. Sliter
- H. Thierstein

III. Organic/Inorganic Interactions and Geochemical Problems

Rapporteur: L.M. Pratt

Members:
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- D. Burdige
- H. Davis
- W.E. Dean
- K. Dunham
- K.C. Emeis
- K. Kvenvolden
- D.N. Lumsden
- P.A. Meyers
- R. Mitterer
- J. Morse
- G. Rau
- D.D. Sheu
- J.B. Risatti
- J. Rullkotter
- W. Sackett

Other Guests:
- G. Claypool
- J. Hatch
- H. Schrader
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Report of Thematic Working Group II

Stratigraphic problems and paleoecologic indicators

P.H. Roth, Rapporteur

1. Stratigraphy and Geochronology

1. 1. Biostratigraphy

Biostratigraphic control in many black shale sequences is insufficient. Only a combination of various fossil groups can provide the necessary resolution. Major fossil groups, their resolution and limitations are discussed below.

Planktonic foraminifera

A refined and relatively stable zonation based on this group has been established for the late Barremian to Maestrichtian. It can be applied globally although planktonic foraminifera are often sparce and poorly preserved in many black shale sequences; often these fossils do not withstand regular preparation procedures ("washing"). The use of thin sections is recommended in the part of the section where the forams can not be recovered as washed residues. The biostratigraphic resolution of planktonic foramifera is variable, 2 m.y. on average, 0.5 to 1.0 m.y. for particular intervals (e.g. the Cenomanian - Turonian boundary interval). Wheras mid-Cretaceous zonation is global, provinciality is established in Campanian time when tethyan and boreal assemblages were first apparent.

Calcareous nannofossils

Cretaceous zonations are well established and relatively stable. They can be used globally. Resolution is 2 to 3 m.y. on average, 1 m.y. for particular intervals (e.g. M. Albian). Calcareous nannofossils allow reliable biostratigraphic age assignments in sections that contain some carbonate (at least 10 to 20%). Nannofossils can now be recovered from highly lithified limestones by tapping rock fragments to dislodge coccoliths that can then be studied in the light microscope.

Dinoflagellates and Acritarchs

Dinoflagellates are mesoplanktonic and thus restricted to ocean margins and shallow plateaus. Acritarchs appears to be holoplanktonic but of minute size (2 to 8 μm) and thus need to be studied in the scanning electron microscope. Dinoflagellate zonations are refined for the Neocomian of the North Atlantic and Western Tethys. The Albian is still poorly zoned but improvements are possible. Dinoflagellates are excellent biostratigraphic markers in the organic-carbon rich parts of the section where calcareous plankton is often poorly preserved or absent. Thus, the dinoflagellates supplement calcareous plankton in high resolution biostratigraphy. Work on an integrated nannofossil and dinoflagellate zonation is in progress (Roth, Habib and Drugg). The biostratigraphic resolution of dinoflagellate zonations is about 2 m.y. Dinoflagellates and other palynomorphs are generally absent from highly oxidized lithologies.

Acritarchs have great potential. Zonation appears possible in mid-ocean areas because these forms are not mesoplanktonic. Future studies of this group appears highly promising but need to be done using the SEM due to their small size.

Pollen and Spores

These groups do not have much biostratigraphic value except locally. Fern spores are indicators of terrestrial influx of organic matter. Pollen are generally windblown and transported by currents. They do not show significant cyclic changes in the Cretaceous.

Radiolarians

Radiolarian zonations for the Cretaceous are still in the pioneer stage and improvements are still expected. Their occurrence in black shale sequences is spotty. Calcification is a serious problem in carbonate sequences. Radiolarians can be isolated from short sequences and may provide the only stratigraphic control. Biostratigraphic resolution is less than for Calcareous plankton and dinoflagellates.

Benthic foraminifera

In pre-Upper Baremian intervals, benthic foraminifera may provide some biostratigraphic control. Faunas are generally regional and species ranges may extend over a stage or more.

The following fossil groups occasionally provide some biostratigraphic control but are of limited use for global correllation or are very sparce:

ostracods, large benthic foraminifera, Calpionellids, aptichi, ammonites, bivalves and gastropods.

1. 2. Chemostratigraphy

Strontium isotope stratigraphy

A fairly well established Sr-isotope stratigraphy exists as far back as the Turonian; it could be extended farther back in time although the slope of the Sr-isotope trend flattens. Contamination from oceanic basaltic sources and continental sources is a problem. The method can be used on whole rock samples or individual carbonate fossils.

^{13}CStratigraphic

Major excursions in the Cenomanian-Turonian and Aptian-Albian are well documented. The method is promising in sections of uniform lithology. Diagenetic changes may alter $^{13}C/^{12}C$ ratios considerably in org C-rich strata.-

$^{13}C/^{12}C$ ratios in organic matter should be routinely determined in oceanic black shale sections.

Neodymium isotopes

Cyclic fluctuations in Nd isotope ratios may be used for stratigraphic correllation. Regional variations exist and the processes involved are poorly understood. The method should be tried in Cretaceous sections.

I. 3. Magnetostratigraphy

Magnetostratigraphy of Cretaceous sections is crucial for global correlation. Attempts should be made to establish magnetostratigraphies in the drilled section. Oriented cores are needed for the Pacific where inclinations are too low because all sections are from less than 20^{o} latitude. However, the Cretaceous quiet zone presents a major problem in resolution (mid-Aptian through Santonian)

I. 4. Recommendations

1. Establish a standard section in the Atlantic and Pacific where as many fossil groups can be studied in identical or very closely spaced samples. Such a standard section in the Atlantic should contain sufficient carbonate that planktonic foraminifer and nannofossils are preserved. The Atlantic section should be close enough to the margin and contain sufficient organic matter for dinoflagellate stratigraphy. The section should be as complete as possible and paleontological, ,sedimentological and geochemical studies should be integrated.

Recovery of a complete section in the Pacific poses major technical problems because of the presence of chert improvements in drill bit design and coring techniques are crucial for a successful recovery of adequate sections in the Pacific. High latitude sites are badly needed. Specific site recommendations are discussed in a following sections.

1.5. Stratigraphic resolution in the 20 k.y. to 400 ky range

Just about all known paleoceanographic processes operate at timescales of shorter duraation than biostratigraphic or magnetostratigraphic intervals. It is thus important that the duration of cycles is carefully calibrated in biostratigraphically well dated intervals (e.g. Cenomanian/Turonian boundary interval) or magnetostratigraphically well constrained intervals. Sedimentary or geochemical cycles can then be used for precision dating of paleoceanographic processes. Cycle-stratigraphics include: carbonate cycles, redox cycles etc.

Complete logging records could prove crucial for these attempts of very high resolution stratigraphy. Multiple holes at a particular site may be necessary to obtain complete records. Cycles should provide an "internal clock" if carefully tied to bio- and magnetostratigraphies. Reasonable estimates of sedimentation rates of various lithologies need to be used instead of average sedimentation rates.

1.6. Radiometric time scale

Discussions with Obradovich helped us gain a better understanding of Mesozoic geochronology. Glauconite dates are generally not trustworthy. Biostratigraphically well-constrained bentonites that can be dated radiometrically extend into the uppermost Albian. A reliable timescale exists for the late Cretaceous and the late Early Cretaceous down to the Aptian. Volcanic material is missing from the early middle Cretaceous (Aptian, Barremian) and early Cretaceous to late Traissic Attempts to date a Ryazanian (basal Cretaceous) Volcanic ash in the Speeton Section of England, and an uppermost Jurassic bentonite in the Great Valley Sequence of California are in progress. Reliable Jurassic radiometric dates are hard to come by. Radiometric dates of the upper Bajocian Carmel Formation will be forthcoming. Radiometric dates of igneous rocks in California (Kimmeridgian/Tithonian, Oxfordian in California are biostraigraphically not well constrained. Radiometric dating of basalts of Mesozoic age are confused by considerable alteration of these rocks. We need to search for volcanic ash beds (silicic) in the lower Cretaceous and Jurassic in order to improve the time scale.

2. Paleoecologic indicators

Fossils in Mesozoic sequences provide information on the following paleoenvironmental conditions

1. Paleo depth (mainly benthonic foraminifera)
2. Productivity
   Calcareous nannoplankton (some results); radiolarians, planktonic foraminifera and palynomorphs, yet untried.
3. Oxygenation of bottom waters
   trace fossils
   benthic foraminifera
4. Watermass stratification
   Foraminifera

2.1 Paleobathymetry

Benthonic foraminiferal assemblages can be used to establish paleodepth and to document downslop transport. In the Cretaceous the following environments can be determined:

Bathyal-slope-rise-abyssal environments. This appears only possible for the Aptian and younger interval. Redeposition can be documented and sources can be identified. Changes in dissolution can affect paleodepth estimates based on benthic foraminifera. The approach is by no means standardized. About 20 cc of sample material is needed and the finest fraction has to be studied as many forms are small. The most fruitful approach is an investigation of the foraminiferal assemblage from individual layers, in conjunction with sedimentological studies.
Good depth transects on the mid-Atlantic ridge flanks and down the flanks of Pacific Plateaus are needed. Areas where redeposition from shallow regions prevails are to be avoided.

2.2. Paleoproductivity
Considerable diagenetic overprinting puts some limitations on estimates of surface water productivity. Calcareous nannofossil assemblages indicative of upwelling and divergence regions have been identified for the middle Cretaceous. Cyclic changes in these high fertility indicators species have been found in selected black shale cycles. Closer sample spacing (i.e. more than one sample per lithology) appears desirable. Calcareous nannofossil assemblages are surprisingly robust and diagenetic changes (dissolution and overgrowth) have to be severe before the original signal is completely obliterated.
Quantitative studies of other surface plankton assemblages is encouraged in order to test models of changing surface water fertility.

Oxygenation of bottom waters and sediments

Besides sedimentological and geochemical criteria the benthic fauna (foraminifera) and trace fossil assemblages will contribute information on the degree of oxygenation of bottom waters.
Depth transects from mid to bottom water depths are needed. Characteristic foraminiferal assemblages and morphologic changes in particles species are known for recent dysaerobic environments. A major effort should be made to investigate Cretaceous benthic foraminifera as possible indicators of low oxygen concentration.
Trace fossils have been shown to be good indicators of oxygenation of the bottom and rare waters. An impoverishment of trace fossil assemblages is indicative of decreasing 0_2 - concentration, and have been fairly well documented for mid-Cretaceous Black Shale Cycles. Extensive X-radiography of core slabs is recommended for black shale cycles.

Water mass stratification

We are still fairly ignorant about the extent and degree of water mass stratification. Use of foraminifera to document water mass stratification needs testing in well placed depth transects. Preservational changes and redeposition may make such attempts very difficult.

Recommendations for improvements in the use of paleoenvironmental indicators

Combination of sedimentological, geochemical and paleontological studies of identical intervals including careful selection of samples and integration of results are crucial. Comparison of the eastern and Western Atlantic basin, low and high latitudes and Atlantic - Pacific comparisons are needed. Well selected depth and latitudinal transects will be important. Less "averaging", i.e. lamina by lamina studies of fossil assemblages of selected intervals are necessary to understand processes and changes. Good biogeographic data are a crucial first step.

3. Pre-middle Cretaceous black Shale sequences

Black shales of terrestrial and marine origin have been recovered from the Callovian of the Blake - Bahama Basin. Thus, black shale depositon extended back into at least the middle Jurassic in the oceanic realm. Additional Jurassic sequences should be drilled to prove that these Jurassic black shale sequences are not simply a local phenomenon. The Western North Atlantic appears to be the most promising area.

4. Desirable for drill sites

4.1. High latitude Sites

A. Weddell Sea, on M-anomalies to recover high latitude Cretaceous (lower to Middle Cretaceous) High latitude biostratigraphy, paleoceanographic conditions at high latitudes during mid-Cretaceous. Look for cycles.

B. Bering Sea
Similar objectives for Pacific. So far all Pacific mid-Cretaceous sections are tropical.

4.2. Indian Ocean
A site off the West Coast of Australia (Argo abyssal plain) would be useful and thus plans to drill these are supported by our group.

4.3. Pacific

Recovery of middle and lower Cretaceous in the Pacific has been very poor overall due to problems of recovery in chert-rich sections. A "standard" stratigraphic section is needed for the lower and middle Cretaceous Target areas such as the Western Pacific (Japanese M-anomaly lines ?) Shatsky Rise, deep basins without basalt flows (below km water - depth) as in the Gibest-Tuvalus Region.

A depth transect from the mid-water (O-minimum) to deep water paleodepths is needed. Drilling on the Shatsky rise in a region away from shallow seamounts (to avoid redeposition) or on paleodepths the flank of the Shatsky Rise is one possibility. A further possibly is the mid Pacific Mountains.

Atlantic

Western N. Atlantic
Depth transect on ridge crest flank between Sites 386 and 387. Look for watermass structure, extent of dysaerobic/anaerobic watermass, removed from overpowering continental margin effects.

Eastern N. Atlantic
Good "standard" stratigraphy hole for integrated stratigraphy, cyclicity study.
One hole in Northeastern N. Atlantic, near Spain (near Site 135)
One good hole section in the Sierra Leone rise area where marine production of organic matter was high, avoiding major fans (redeposition).
These two holes would also provide a N-S transect.

Report of Thematic Working Group I
Sedimentary Processes, Lithostratigraphy, Regional Problems

David J. Bottjer, Rapporteur

Objectives

Participants of this group agreed that the study of Cretaceous black shales has the ultimate goal of a better understanding of Cretaceous paleoceanography and paleoclimatology. To achieve this goal the following research questions were considered to be of top priority.
1) We need to better recognize patterns of Cretaceous anoxia in space and time - which are regional, which are worldwide, and when do these occur. To answer these questions more knowledge is needed of the geographic extent of Cretaceous black shales in the oceans and on land, and more detailed studies of paleontology and other correlation techniques are needed to establish the age of individual occurrences. In particular, more knowledge is needed on the "morphology" of each event, and on the pattern of successive events.
2) The group agreed that better methodologies for identifying in situ indicators of deposition in anoxic bottom-water environments were necessary. A more comprehensive understanding of "the meaning of laminations" and how biogenic structures can be used in core studies is necessary.
3) More work needs to be done on cyclically-bedded black shale sequences, to learn more about how Milankovitch cycles (periodic variations in the earth's orbit and consequent changes in solar radiation) influence their deposition.
4) Additional studies on younger black shale sequences should be pursued in order to learn more about the general dynamics of black shale deposition; the meaning of lamination, and the sources and preservation of organic matter.

In addition, this group believes that the implementation of several new technologies in examining the recovered cores would be helpful in gathering more and better sedimentological data.

Approaches

To better recognize patterns of Cretaceous black shale deposition in space and time, as well as the "morphology" of each interval or event of black shale depositon, additional drilling as part of ODP is necessary. The following targets for drilling were recommended.
1) One of the main questions that is fundamental to the study of these black shales is whether they are regional or worldwide events. Much is known about Cretaceous black shale distribution in the Atlantic and equatorial Pacific. However, the distribution of Cretaceous black shales at high latitudes is not well documented. The group proposed that one hole be drilled in the Bering Sea, one piece of trapped M-series aged crust which is the most promising area in the oceans that had a relatively high Cretaceous paleolatitude.
2) In order to better understand the "morphology" of Cretaceous black shales, the group decided that it would be highly worthwhile to drill a series of holes in areas where DSDP drilling has shown the presence of Cretaceous black shales. These would be drilled in different Cretaceous paleoceanographic settings, as transects covering a range of ocean paleoenvironments and paleodepths. The most important of these transects; and, indeed, the drilling objective that was given the highest priority by this group, is one that would pass from the continental margin to the deep-sea off of Northwest Africa. Such a transect would guarantee a better understanding of North Atlantic Cretaceous black shale depositional processes. Discussion led to the conclusion that as many as 8 holes could be included in this transect, combining already-drilled DSDP cores, cores taken as parts of other objectives, and cores drilled specifically to learn more about Cretaceous black shales.

3) A second transect that was considered highly desireable is one that starts in a Cretaceous epicontinental sea and traverses different paleoenvironments to the deep-sea. The best location for this transect is one from the Western Interior across the Texas Gulf Coastal Plain to the Gulf of Mexico. Western Interior and Texas data would come from land-based studies and the drilling results could be tied into black shale sequences known from Mexico and South America as well.
4) The occurrence of black shale deposition in equatorial areas of the Cretaceous Pacific has already been established. The group decided that another transect, to learn more about deposition of these Pacific black shales, was clearly warranted. In particular, a vertical transect through different paleoenvironments that were situated in the paleo-oxygen-minimum zone was thought to be highly desireable. The group decided that Shatsky Rise or the Mid-Pac Mountains would be the best place for such a transect, with the drilling of 4 holes sufficient to achieve this objective.
5) The group decided that more data was needed on the interrelationship between Cretaceous black shale deposition and the development of the connection between the North and South Atlantic. Therefore, we propose that 2-3 additional holes be drilled in the Northern South Atlantic to address this problem.
6) Extensive discussion centered on the further study of younger black shale deposits. In particular, it was believed that a core through the Pleistocene in Santa Barbara Basin off southern California would prove useful in understanding the dynamics of black shale depositon, due to a high sedimentation rate and the presence there of varving, which provides a built-in timekeeper. Other areas of more recent black shale deposition, which will or may receive ODP attention, and which are of much interest to this group were also discussed. These include: 1) Peru margin transect, where a number of HPC sites, to be determined, across the modern oxygen-minimum zone would be very important; 2) Oman margin transect, a series of HPC sites would be desireable, 2 on the margin and 2 one Owens's Ridge, to examine the record of productivity and monsoonal upwelling and development of an oxygen-minimum zone in the W. Indian Ocean; and 4) Namibia transect, a long piston core, as well as a series of short piston cores, are needed. The group endorsed continued study of all of these younger strata.
7) The group recommended that, for better recognition of strata deposited under anoxic conditions, ere should be a continued re-examination of already-collected DSDP cores as well as land-based sections. C. Savrda presented a trace fossil model for interpreting paleo-bottom-water oxygenation (Savrda and Bottjer, 1986) which may provide additional information on the nature of Cretaceous black shale strata. Others recommended that physical sedimentary structures, in particular the nature and origin of fine laminations, need further study. All agreed that more-detailed published descriptions of the new ODP cores will be needed.
8) Simple, but extremely useful, technological improvements were recommended for better examination of physcial and biogenic structures preserved in cores. These include: 1) continuous strip photography of cores; 2) continuous whole-core x-radiography; 3) digitizing cores directly from the slabbed surface or strip photos; 4) continuous video-taping of cores (as easily copied cassettes); and 5) channel sampling for chemical analyses.

Conclusions

In summary, the group believes that significant advances in the understanding of Cretaceous black shale deposition will be achieved if these research recommendations are implemented. Discussions with members of the other two workshop theme groups indicate that these recommendations are also concordant with many of the objectives of these other two groups, so that development of a broad integrated research program for Cretaceous black shales, for presentation to ODP, seems very feasible.

d-l) VAREC - Varve records of climate

In order to reach a better understanding of climate, climatic and oceanic oscillations must be studied over the entire frequency range from the l to the l0 year level. At present, a gap intervenes between the observational time scales of the meteorologist (l-l00 years) and those of the geologist (millions to billions). Some inroads are being made on this gap, on the high-frequency end by tree-ring studies, and on the low-frequency end by geological investigations extending down to the precessional (20,000 year) level. But the l,000-20,000 year interval remains essentially terra incognita.

A readable record for this time-level, containing a built-in time-keeper, exists in the form of varved deposits, in lake deposits, evaporites, and in hemipelagic depostis on continental margins. Particularly good records exist in some of the silled continental margin basins such as the Santa Barbara basin, which lie outside the normal range of turbidite sedimentation, but accumulate sediements with a high biogenic content at rates of l00-l,000 B (mm, ka) under anoxic conditions, thus excluding bioturbation and preserving a fine-scale seasonal record of events. In the Santa Barbara basin this record appears to extend back to 6,000 BP, and presumably various interglacial episodes when sea-levels were near their present stand led to older accumulations of the same sort. It seems not unreasonable to expect basins with deeper sill depths to have recorded lower sea-level times in the same way, and that Quaternary history may thus be extensively recorded in this detail, within the California borderland.

Studies by Soutar and others have shown that patterns of varve thickness over the last 200 years closely parallel California tree rings and the pattern of precipitation. Diatome floras on the other hand, presumed guides to temperature, showed unrelated patterns of variation. More general studies of the last 2,000 years revealed striking changes in the fish fauna, and in fish abundance. These are only some of the parameters available for study. Oxygen isotope studies of foraminifera should not only allow definitivties to the Quaternary pelagic isotope scale, but ought to reveal the isotopic history in far greater detail. They should also provide data on fertility changes. By these and other means it should be possible to obtain wholly new insights into the history of the California margin, and into the differences between glacial and interglacial regimes.

Report of Working Group III

Organic/Inorganic Interactions and Geochemical Problems

Lisa Pratt, Rapporteur

The following is a brief outline of the discussion and conclusions of the geochemistry subgroup of the Black Shale Workshop.

(1) Sedimentary constituents of black shales

a. Improved ability to discriminate between various sources of organic is needed. Integrated studies of split samples using elemental, pyrolysis, and optical methods of analysis would be most helpful. There is a need for geochemical profiles of endmember examples (e.g., coaly, algal, and bacterial). Lignin geochemical characterization should be more widely used as a source parameter.

b. Combined with geochemical analyses, there should be sedimentological studies of thin sections, polished sections, and acetate peels to identify mechanisms of transportation for organic and inorganic constituents. There should be improved descriptions of (1) extent of bioturbation, (2) small-scale sedimentary structures, (3) type of layering or lamination, and (4) pelletal forms.

c. New approaches are needed for estimations of paleoproductivity and sediment accumulation rates. What properties of ancient shales can be used to infer original input to the sediment?

d. There is a need for improved recognition and description of inorganic constitutents in fine-grained sediments using smear slides and X-ray diffraction of bulk, residue, and clay fractions. There should be comparisons of the inorganic constitutents of interbedded organic-rich and organic-lean lithologies.

e. Detailed studies are needed of modern organic matter and causes of the latitudinal changes in carbon isotope ratios of organic matter. Are these isotopic differences related to primary input or diagenesis and can this modern situation shed light on the Cretaceous values?

(2) Diagenetic alteration

a. New approaches are needed to study geomicrobiological cycles. Organic and inorganic indicators of microbiological activity in sediments should be studied. Quantification should be attempted of amounts of sedimented organic matter lost by gaseous migration of CO_2 and methane, and amounts transformed into bacterial biomass. There should be more studies of the nutrient value of various types of sedimented organic matter.

b. What factors control the formation and isotopic composition of pyrite? Studies are needed to determine if recycling of H_2S and monosulfides can be detected. There is a need for routine collection of sulfure content on both the bulk and pyrite fraction. What information can be obtained from studies of Fe-species, especially in interbedded red green, and black sequences.

c. More work is needed on sources, cycling, and the fate of nitrogen in ancient seas. New approaches are needed to discriminate between organic and inorganic pathways for nitrogen cycling. Data are needed on the nitrogen isotopic ratios and carbon isotopic ratios of single sample splits.

d. Preservation mechanisms and processes should receive more attention. What are the physical and chemical factors that limit microbiological recycling of organic matter in sediments?

(3) Influence of deeper burial and heat flow

a. There is a need to improve our ability to recognize early changes in thermal maturation (i.e., before the onset of peak petroleum production). Organic and inorganic species sensitive to heating in the 30^{o} to 80^{o} C temperature range should be studied.

b. New studies of deep-sea cores are needed to look for evidence of mineral dissolution and reprecipitation resulting from organic acids and CO_2. It would be very useful to obtain deeper samples of pore waters than are curently sampled, for the purpose of gathering data on concentrations of organic acids in deep-sea settings that are not subject to the influence of meteoric waters.

PACIFIC OCEAN

SITE PROPOSALS

PALEOCEANOGRAPHIC CONTROLS ON THE DEPOSITION OF ORGANIC CARBON-RICH BLACK SHALES IN THE ANCESTRAL PACIFIC; A PROPOSAL FOR A DRILLING TRANSECT ON THE SHATSKY RISE

Objectives

Three sites to be drilled on the Shatsky Rise during a single ODP Leg are proposed in order to:

1) Define the time-stratigraphic distribution of organic carbon-rich strata in a low-paleolatitude setting and correlate these strata with well-documented carbon-rich black shale sequences that were deposited during middle and Late Cretaceous "Oceanic Anoxic Events" in major ocean basins as well as in cratonic seas.

2) Obtain sufficient core material to study the sedimentology, chemistry and paleontology of these strata so as to determine the sources of the carbon, the relative importance of carbon preservation vs surface water productivity, the effect of volcanism on the sedimentary environment and the roles of bathymetry and climate in the development of upwelling conditions that could enhance the production and deposition of marine organic carbon.

3) Define the paleodepth of deposition of these carbon-rich strata so as to establish the upper and lower bounds of Cretaceous oxygen-deficient water masses and determine the degree of oxygen deficiency that prevailed during deposition in order to understand the temporal and spatial history of the development of oxygen-minimum zones in the ancestral Pacific Cretaceous Ocean.

4) Further our understanding of the role of black shale deposition in the global carbon cycle and the hydrocarbon resource potential of marine black shales.

Relationship Of This Proposal To COSOD Recommendations and ODP Planning Efforts

The 1981 report of the Conference on Scientific Ocean Drilling (COSOD) listed 12 top priority objectives that "..should be attacked with scientific ocean drilling and related programs in the next decade." This proposal addresses objective no. 7: Sedimentation in Oxygen-Deficient Oceans--aimed at obtaining answers to the question, "What are the ocean circulation, paleoclimate, and potential hydrocarbon characteristics associated with black shale deposits?".

Further, this proposal is based on recommendations developed at the Workshop on Cretaceous Black Shales, held at Denver, Colorado on December 3-6, which was aimed at producing drilling plans to address the questions surrounding the paleoceanography of black shale deposition. A companion proposal for drilling black shale sequences in the Atlantic is also being submitted as a result of this workshop.

The proponents of this proposal, for the community represented at the workshop, are:

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Background and Scientific Rationale

A striking result of the DSDP-IPOD program was the discovery that widespread deposits of organic carbon-rich shales are characteristic of Cretaceous sequences in the major ocean basins. These sediments contain up to 20+% TOC in the form of both marine and terrestrially derived organic carbon, are generally dark-gray to black, laminated and lacking in a normal, diverse benthic fauna. Their lithology and chemistry indicate deposition in oxygen-deficient water masses. Although the "black shale" facies has been long recognized in the geological record and their development ascribed to anoxic basin conditions, it was not until outcrop studies, inspired by the DSDP-IPOD results, showed that exposed Cretaceous sections also contained anomalously abundant black shales that the geological community realised that Cretaceous organic carbon-rich strata were concentrated in restricted stratigraphic intervals. As shown by Schlanger and Jenkyns (1976), Fischer and Arthur (1977), Ryan and Cita (1977) and Thiede and van Andel (1977) the periods of enhanced black shale deposition cluster in the Barremian-Albian, Late Cenomanian-Early Turonian and Santonian-Coniacian stages. Schlanger and Jenkyns (1976) denoted these intervals of black shale deposition as "Oceanic Anoxic Events" (OAE). Scholle and Arthur (1980) pointed out that pelagic carbonates deposited during these OAE's are enriched in ^{13}C and proposed that this geochemical signal was the result of the burial of ^{12}C in the carbon-rich black shales and that the failure of the oceanic waters to reoxidise this carbon, in contrast to present-day conditions of well-oxygenated oceans, led to an increase in the ^{13}C content of the oceanic reservoir; the calcite precipitated by forams and nannoplankton then reflect the high ^{13}C levels in the surface water. As shown on Figure 1, $\Delta^{13}C$ peaks in Cretaceous strata coincide with the OAE's postulated by Schlanger and Jenkyns (1976) and can be used to model carbon storage rates as seen on Figure 2.

Outcrop studies (Schlanger, et al., in press; Arthur, et al., in press) have shown that these OAE's are global in extent; in particular the Cenomanian-Turonian OAE has been documented (Figure 3). It is now evident that these OAE's record times when significant parts of the oceanic water masses were largely deoxygenated. Models proposed to account for these severe oxygen deficiences include the development of expanded and intensified O_2-minimum zones due to sluggish circulation in an ice-free world and the development of salinity stratification during transgressions due to the export of warm, saline waters from widespread epicontinental seas.

A complication in developing paleoceanographic models to account for these OAE's lies in the differences between Atlantic and Pacific occurrences of black shale sequences. In the early opening Atlantic the formation of isolated basins and major turbidite inputs of terrestrial carbon led to the formation of widespread but temporally diffuse black shale units. However in the Pacific (Figures 4,5 and 6; Table 1) carbonaceous strata are restricted to locations on paleo-bathymetric highs such as the Shatsky and Hess Rises and the Manihiki Plateau. A single exception is the occurrence of a thin black shale in the deep Mariana Cretaceous Basin cored at Site 585 (Moberly, Schlanger, et al., 1986); this unit was deposited as a minor turbidite derived from the mid-water slopes of a nearby seamount. Along the western margin of North America, intervals of mid-Cretaceous bituminous limestone are tectonically incorporated in accretion complexes. Presumably derived from sediments that capped Cretaceous seamounts and plateaus, these bituminous intervals are contained within sequences of micritic pelagic limestone (Sliter, 1984). The bituminous intervals are now dated as older than middle Aptian or 115 Ma (Tarduno and others, 1985). Several inferences that relate to this proposal are drawn from these occurrences.

1. Oceanic reconstructions based on paleomagnetics and plate models for the North Pacific place the site of deposition of the limestone blocks near San Francisco on the Farallon Plate between 19° and 25°N (Tarduno and others, 1985). Presumably formed on the eastern flank of the Pacific-Farallon ridge axis, these occurrences indicate that oxygen-deficient water extended throughout a wide region of the Cretaceous Pacific Ocean and was not restricted to bathymetric highs west of the Pacific-Farallon ridge.

2. Dating of the carbon-rich limestone as older than middle Aptian correlates these deposits with those from Shatsky Rise, Mid-Pacific Mountains and the Manihiki Plateau (Figure 5).

3. These older anoxic deposits predate Albian and Cenomanian black shale sequences on Shatsky Rise and Hess Rise (Figure 6) and indicate that one or more anoxic events predate the Cenomanian-Turonian event in the Pacific Ocean.

Studies to date by Schlanger et al. (in press) and Arthur et al. (in press) show that the O_2-minimum zone model developed from the Pacific data can be applied to explain European shelf black shale deposition during the Cenomanian-Turonian OAE (Figure 7). The backtracking of the Pacific occurrences by Thiede et al.(1982) also suggest that the these carbonaceous sediments were deposited in mid-water depths.

This proposal calls for the drilling of a paleodepth transect across Shatsky Rise in order to obtain complete sections of the Cretaceous carbon-rich strata representative of both the Barremian-Albian and Cenomanian-Turonian OAE's in order to define both the timing and extent of Cretaceous O_2-minimum zones.

Previous Drilling on the Shatsky Rise and Future Prospects

By virtue of its elevation above the surrounding deep sea floor and its paleo-path across a wide latitude range during its ~140 m.y. history Shatsky Rise has been a drilling target on several DSDP and IPOD Legs.

On Leg 6 (Fischer, et al., 1971) Sites 47,48,49 and 50 (Figures 8,9,10) were drilled. Sites 47 and 48 atop the Rise reached Maastrichtian cherty chalk and at Sites 49 and 50 in deep water on the western flank Tithonian cherty chalk was reached. On Leg 32 (Larson and Moberly, 1975) Sites 305 and 306 were occupied (Figure 11) and succeeded in recovering organic carbon-rich sediments of both Cenomanian and Barremian-Aptian ages that were deposited at paleodepths of from 1000 to 2000 meters. These holes, which penetrated strata of Valanginian (Site 305) and Berriasian (Site 306) ages also showed that all of the stages during which OAE's took place are represented in the sections atop the Rise. The most recent attempt at drilling on Shatsky took place on Leg 86 when Site 577 was occupied. Drilling was terminated shortly after the K/T boundary was crossed.

Thus Shatsky Rise carries on it the stratigraphic targets needed for recovery of sediments from the desired Cretaceous stages. Further the paleodepth history of the rise shows that a transect to determine the geometry of the Cretaceous O_2-minimum zones is a feasible objective. Drilling on Shatsky Rise is preferred over other Pacific sites for these reasons:

1. The Cretaceous section is known to contain several pre-Cenomanian-Turonian intervals of carbon-rich sediments.

2. The sediments consist of micritic pelagic limestone and marls and are not diluted with shallow-water derived material or volcanogenic sediments as are those of Hess Rise, Mid-Pacific Mountains or the Manihiki Plateau.

3. The sediments are well suited for paleomagnetic study for the above reasons. The Cretaceous Long Normal Polarity Chron presently represents a 'blind' spot in Pacific basin plate motion models based on marine magnetic anomalies. Some models have relied on a continuity of spreading, assuming a linear spreading rate between chrons M0 and 33r. Complications, however, are clearly present as shown by the mismatch of spreading rates obtained north and south of the Mendocino Fracture Zone where an easily dated carbonate record extending over the entire Cretaceous quiet zone could be obtained. Previous paleomagnetic analysis of similar sediments from onland sections (Alvarez and Lowrie, 1984) and preliminary analysis of carbonates from oceanic rises south of the Mendocino Fracture Zone (Hammond et al. in Andrews et al., 1975; Sayre in Thiede et al., 1981) documents the fidelity of magnetic inclination data contained in such sediments. Paleomagnetic data in the form of an inclination versus time curve could place valuable constraints on Late Cretaceous spreading rates and the evolution of the Pacific-Farallon-Izanagi triple junction.

The proponents realise that previous drilling efforts have been severely hampered by the limitations of drilling equipment aboard Challenger in dealing with cherty sections. We assume that by ca. 1991 we will have the capability of drilling cherty Cretaceous strata.

Proposed Drilling Program on Shatsky Rise

The transect proposed builds on earlier results described above. One site, SHAT-1, is atop the Rise between Sites 305 and 306 and two sites, SHAT-2 and 3, are in intermediate water depths and located between Sites 305 and 49 and 50. Locations of the proposed sites and available seismic profiles are shown on Figures 8,9,10 and 11.SHAT-1 is located so as to spud into exposed Eocene-Late Cretaceous sediments and sample the Cretaceous to the Valanginian strata cored at Site 305. At Site 306 10m of Quaternary overlay Cenomanian-Albian strata;

erosion of the Rise section west of Site 305 allows us to pick the optimum location for avoiding drilling through the Cenozoic strata that caps the Cretaceous at Site 305. SHAT-2 and 3 are located to sample the Cretaceous section which overlies the Tithonian cored at the deeper water Sites 49 and 50. As shown on Figure 6 Sites 305 and 306 were in water depths of from 1000 to 2000m during much of the Cretaceous; SHAT-2 and 3 would have been in significantly deeper water during the Barremian-Albian and Cenomanian-Turonian OAE's.

Details of the proposed sites are given in the attached ODP Site Proposal Forms.

References

Andrews, J. E. and Packham, G., et al., Initial Reports of the DSDP, v. 30, U.S. Gov't. Printing Office, Washington, DC, 1975.

Arthur, M. A., Dean, W. E., Schlanger, S. O., Variations in the global carbon cycle during the Cretaceous related to climate, volcanism, and changes in atmospheric CO2, Geophysical Monograph 32, Amer. Geophys. Union, 504-529, 1985.

Arthur, M. A., S. O. Schlanger, H. C. Jenkyns, The Cenomanian-Turonian Oceanic Anoxic Event, II. Paleoceanographic controls, Geol. Soc. London Spec. Pub., in press.

Engebretson, D. C., Cox, A., and Gordon, R. G., Relative motions between oceanic plates of the Pacific Basin, J. Geophys. Res., 89, 10291-10310, 1984.

Fischer, A. G. and Arthur, M. A., Secular variations in the pelagic realm, Spec. Pub. Soc. Econ. Paleo. Min., 25, 19-50, 1977.

Fischer, A. G., et al., Initial Reports of the DSDP, v. 6, U.S. Gov't. Printing Office, Washington, DC, 1971.

Larson, R. L., and Moberly, R., et al., Initial Reports of the DSDP, v. 32, U.S. Gov't. Printing Office, Washington, DC, 1975.

Moberly, R. M., and Schlanger, S. O., et al., Initial Reports of the DSDP, v. 89, U.S. Gov't. Printing Office, Washington, DC, 1986.

Ryan, W. B. F., and Cita, M.-B., Ignorance concerning episodes of ocean-wide stagnation, Marine Geol., 23, 197-215, 1977.

Schlanger, S. O. and Jenkyns, H. C., Cretaceous oceanic anoxic events: Causes and consequences, Geol. en Mijn., 55, 179-184, 1976.

Schlanger, S. O., M. A. Arthur, H. C. Jenkyns and P. A. Scholle, The Cenomanian-Turonian Oceanic Anoxic Event, I. Stratigraphy of organic carbon-rich beds and the marine $\delta^{13}C$ excursion, Geol. Soc. London Spec. Pub., in press, 1986.

Schlanger, S. O., and Jackson, E. D., et al., Initial Reports of the DSDP, v. 33, U.S. Gov't. Printing Office, Washington, DC, 1976.

Scholle, P. A., and Arthur, M. A., Carbon isotope fluctuations in pelagic limestones: potential stratigraphic and exploration tool, Amer. Assoc. Petrol. Geol. Bull., 64, 67-87, 1980.

Tarduno, J. A., McWilliams, M., Debiche, M. G., Sliter, W. V., and Blake, M. C. Jr., Franciscan Complex Calera limestones: Accreted remnants of Farallon Plate ocean plateaus, Nature, 317, 345-347, 1985.

Tarduno, J. A., McWilliams, M., Sliter, W. V., Cook, H., Blake, M. C. Jr., and Premoli Silva, I., Southern hemisphere origin of the Cretaceous Laytonville Limestone, Science, in press, 1986.

Thiede, J., and Vallier, T. L., Initial Reports of the DSDP, v. 62, U.S. Gov't. Printing Office, Washington, DC, 1981.

Thiede, J., and van Andel, T. H., The paleoenvironment of anaerobic sediments int he Late Mesozoic south Atlantic ocean, Earth Planet. Sci. Lett., 33, 301-309, 1977.

Thiede, J., Dean, W. E., Claypool, G. E., Oxygen deficient depositional environments in the mid-Cretaceous tropical and subtropical Pacific Ocean, in S. O. Schlanger and M. B. Cita, Nature and Origin of Cretaceous Carbon-Rich Facies, Academic Press, pp. 79-100, 1982.

Winterer, E. L. and Metzler, C. V., Origin and subsidence of guyots in Mid-Pacific Mountains, J. Geophys. Res., 89, 9969-9979, 1984.

Winterer, E. L., and Ewing, J. I., et al., Initial Reports of the DSDP, v. 17, U.S. Gov't. Printing Office, Washington, DC, 1973.

Table 1. Location, present water depth, lithology, age and estimated paleodepth of deposition of mid-Cretaceous organic carbon-rich deposits in the tropical and subtropical central Pacific Ocean. The information has been compiled from data published in the site reports of the Initial Report volumes of the Deep-Sea Drilling Project (see text for references).

Location	*Latitude*	*Longitude*	*Water depth*	*Lithology of organic carbon-rich strata*	*Age of organic carbon-rich strata (m.y. B.P.)*	*Estimated depth of deposition (m)*
Site 171 (Leg 17, Mid-Pacific Mountains, Horizon Guyot)[1]	19°07.9′N	169°27.6′W	2295	Laminated calcareous volcanic sandstone	Turonian (86–88)	400–800
Site 305 (Leg 32, Shatsky Rise)[2]	32°00.1′N	157°51.0′E	2903	Carbonaceous zeolitic pelagic shale	Cenomanian (98–100)	1000–2000
Site 306 (Leg 32, Shatsky Rise)	31°52.0′N	157°38.7′E	3399	Carbonaceous silicified radiolarian shale	Aptian–Barremian (~115)	1000–2000
Site 310 (Leg 32, Hess Rise)[3]	36°52.1′N	176°54.1′E	3516	Laminated carbonaceous pelagic shale	Albian–Cenomanian (~100)	1000–2000
Site 317 (Leg 33, Manihiki Plateau)[4]	11°00.1′S	162°15.8′W	2625	Volcanic sandstone	> Barremian (> 120)	300–1000
Site 463 (Leg 62, Mid-Pacific Mountains)	21°21.0′N	174°40.1′E	2525	Laminated silicified limestone with volcanic ash	Early Aptian (112–113)	500–1500
Site 465 (Leg 62, Hess Rise)	33°49.2′N	178°55.1′E	2161	Laminated limestone with volcanic ash	Late Aptian–Early Cenomanian (98–103)	500
Site 466 (Leg 62, Hess Rise)	34°11.5′N	179°15.3′E	2665	Laminated limestone with volcanic ash	Late Aptian–Early Cenomanian (98–103)	500–1000

[1] Based on 2 samples (2.8% and 2.3% C_{org}).
[2] One horizon only.
[3] One fragment in core catcher (no C_{org} data).
[4] One sample (28.7% C_{org}).

(From Thiede et al., 1982)

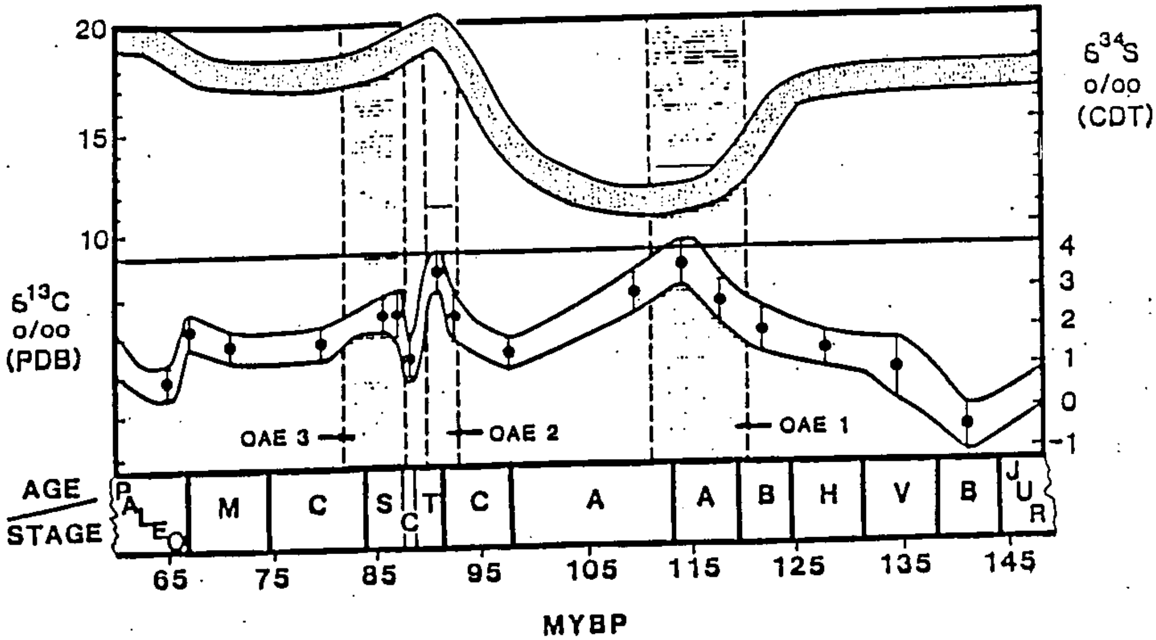


Figure 1. Cretaceous $\Delta^{13}C$ values plotted against stratigraphic stage and related to OAE's (from Arthur, Dean and Schlanger, 1985).

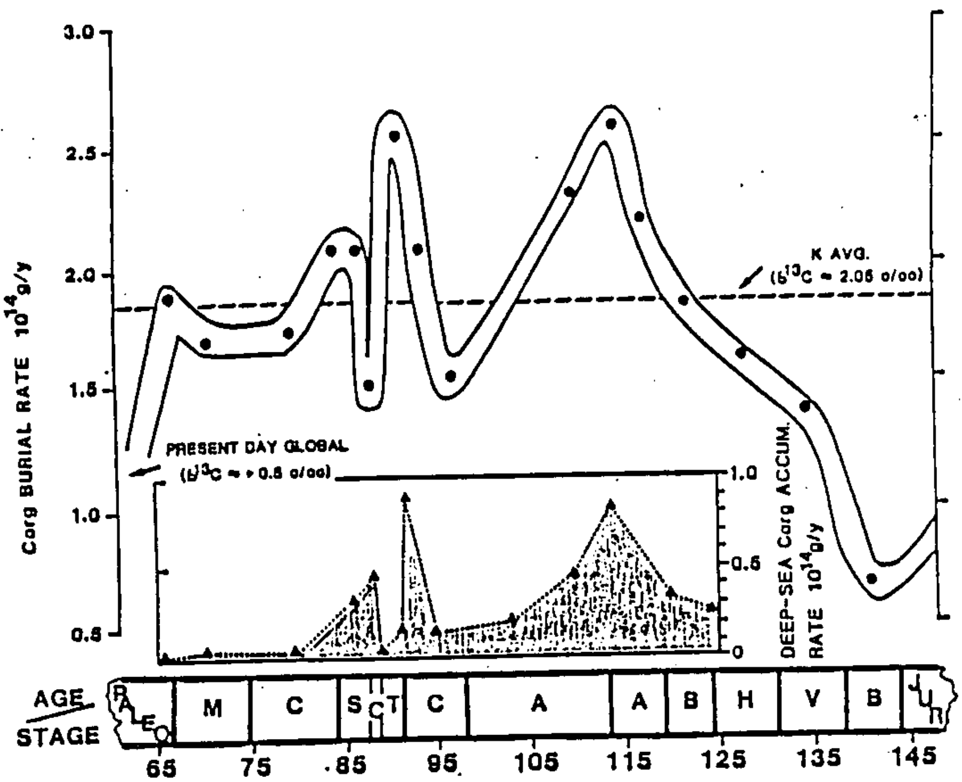


Figure 2. Organic carbon burial rates during Cretaceous time (from Arthur, Dean and Schlanger, 1985).

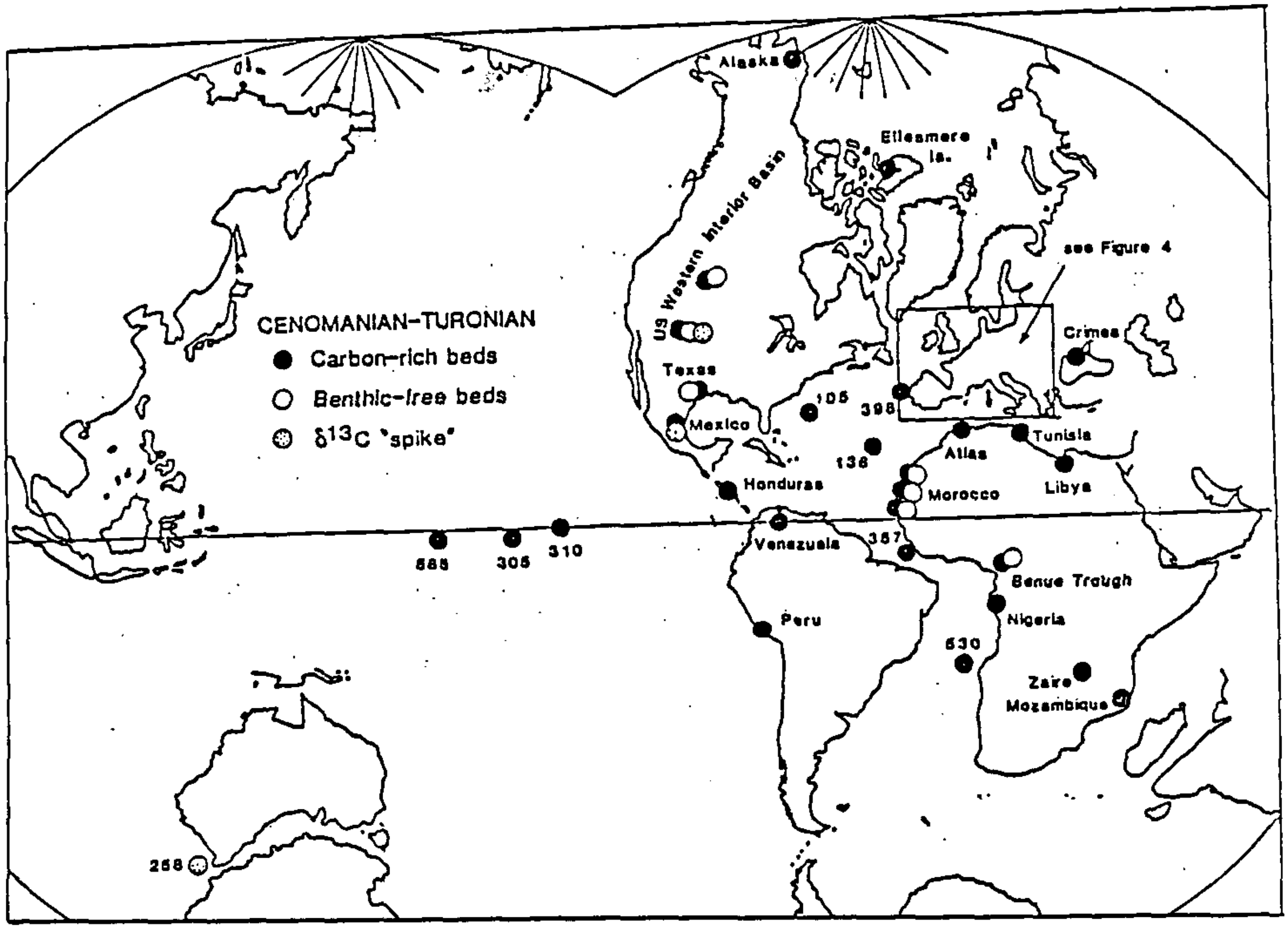


Figure 3. Global distribution of Cenomanian-Turonian strata that were deposited in the O_2-minimum zone (from Schlanger et al., 1986).

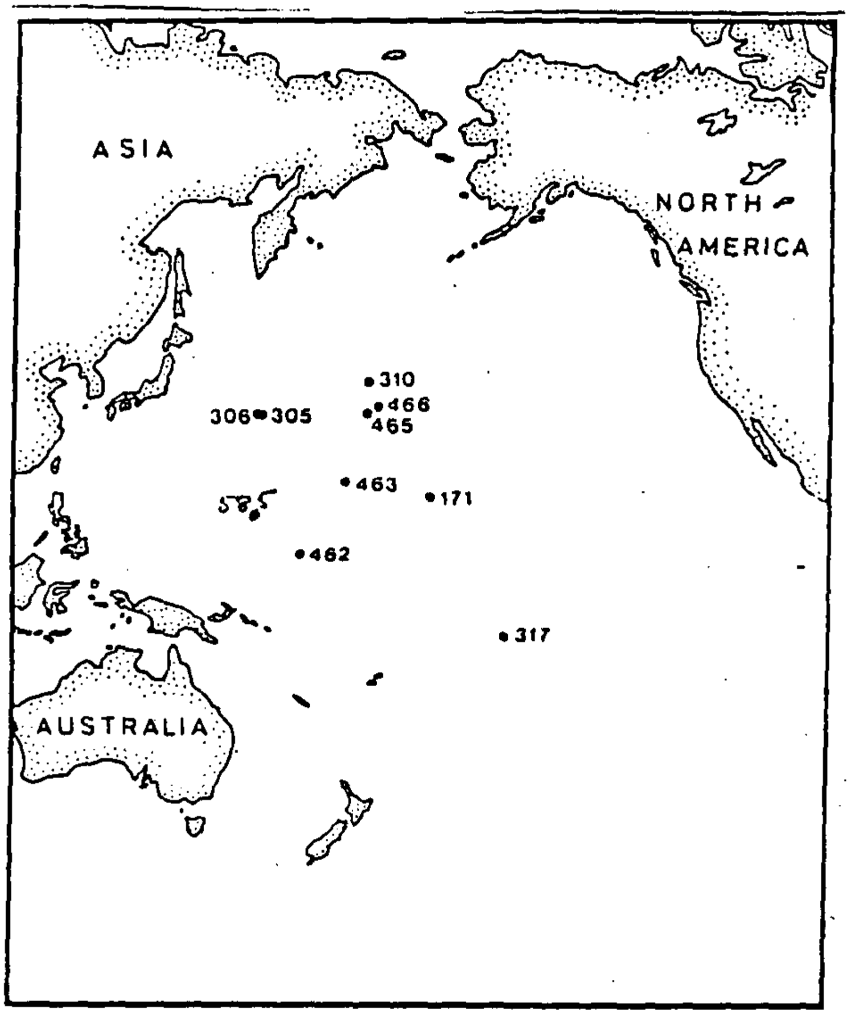


Figure 4. Locations of Pacific Basin drill sites at which Cretaceous black shales have been encountered.

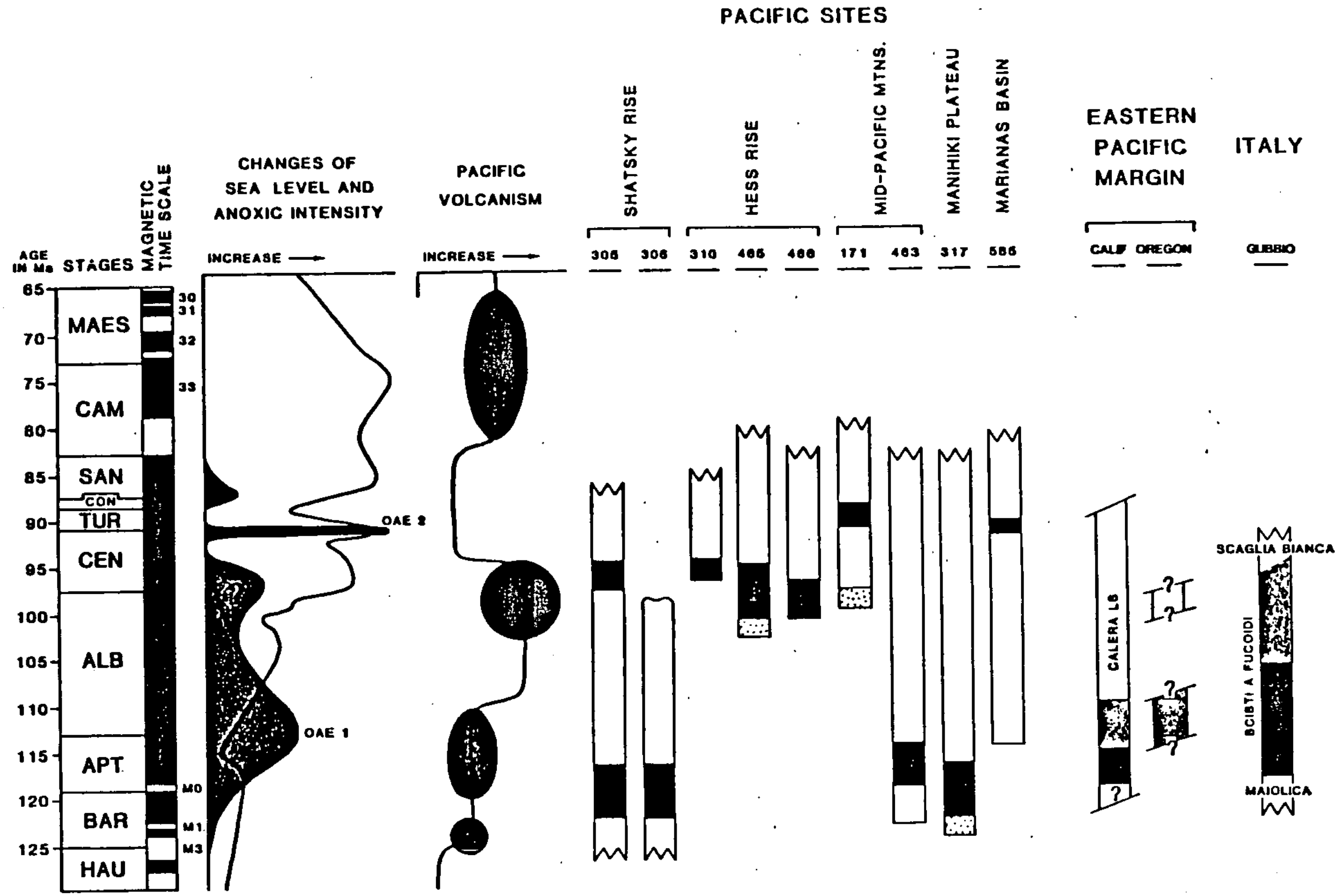


Figure 5. Pacific Basin black shale horizons related to eastern Pacific margin occurrences and Oceanic Anoxic Events.

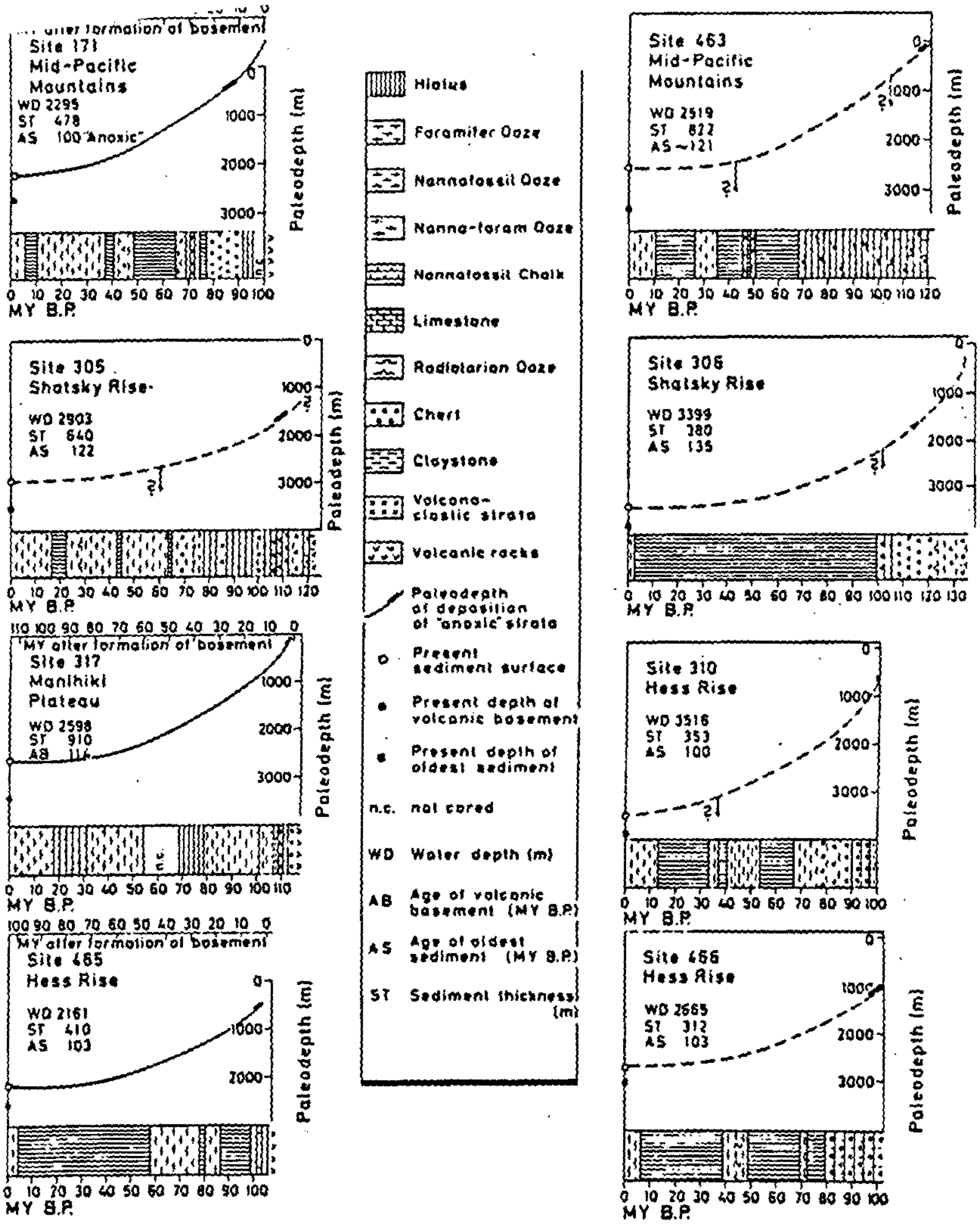


Figure 6. Reconstructions of the depth of deposition of central Pacific drill sites where organic carbon-rich mid-Cretaceous strata have been observed (from Thiede et al., 1982).

ARGO ABYSSAL PLAIN ODP SITE 1A

on Shell line N207

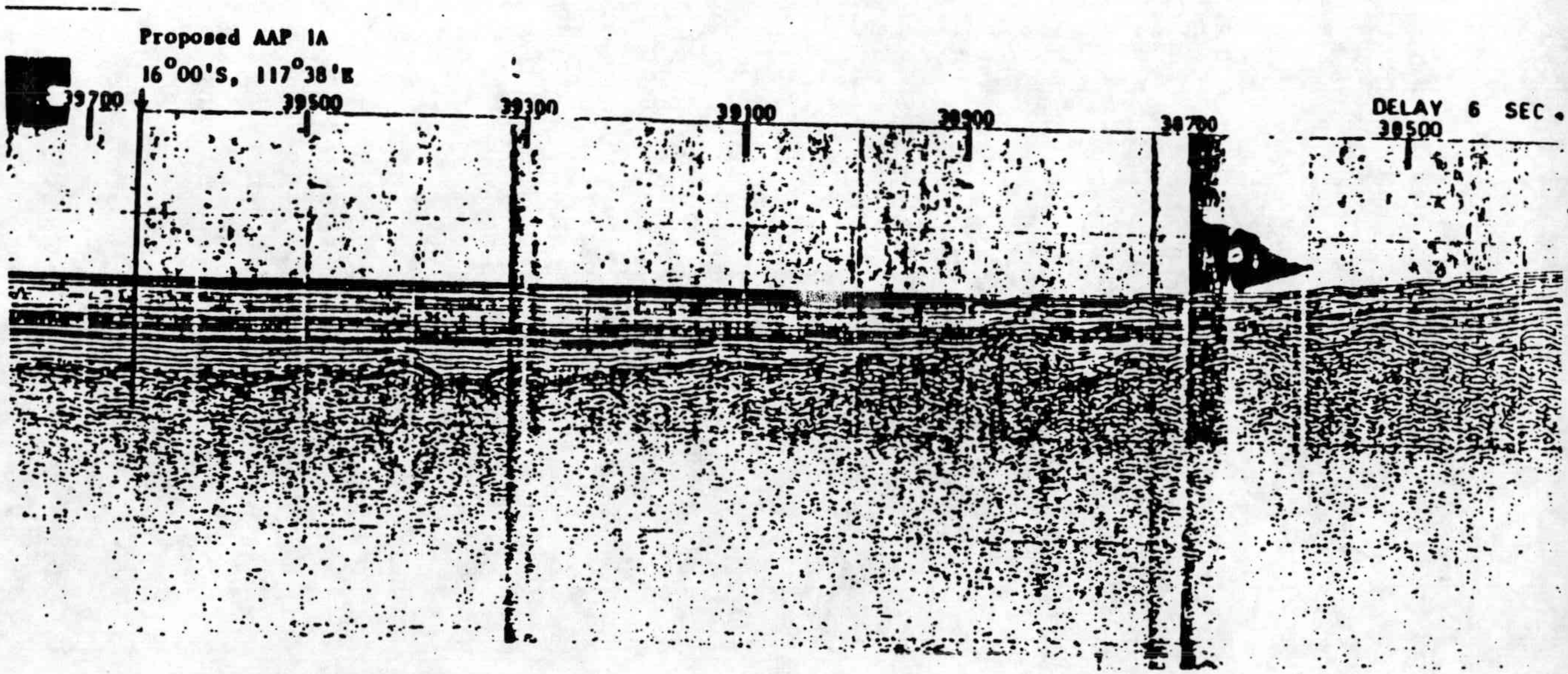


Fig. 67. Argo Abyssal Plain Site AAP1A on Shell line N207

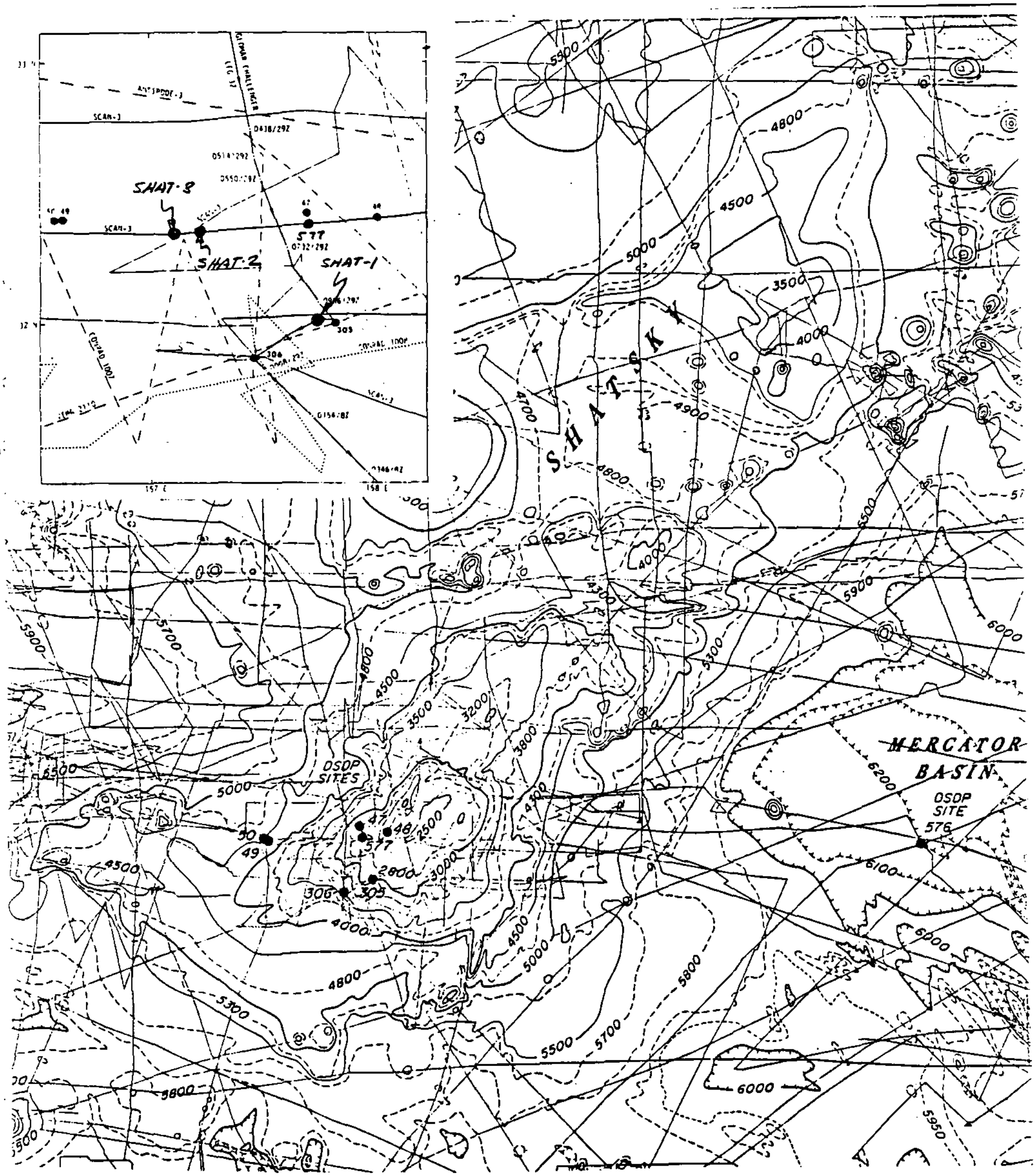


Figure 8. Bathymetric chart of Shatsky Rise showing sites drilled to date. Inset shows locations of proposed sites and tracks of seismic lines.

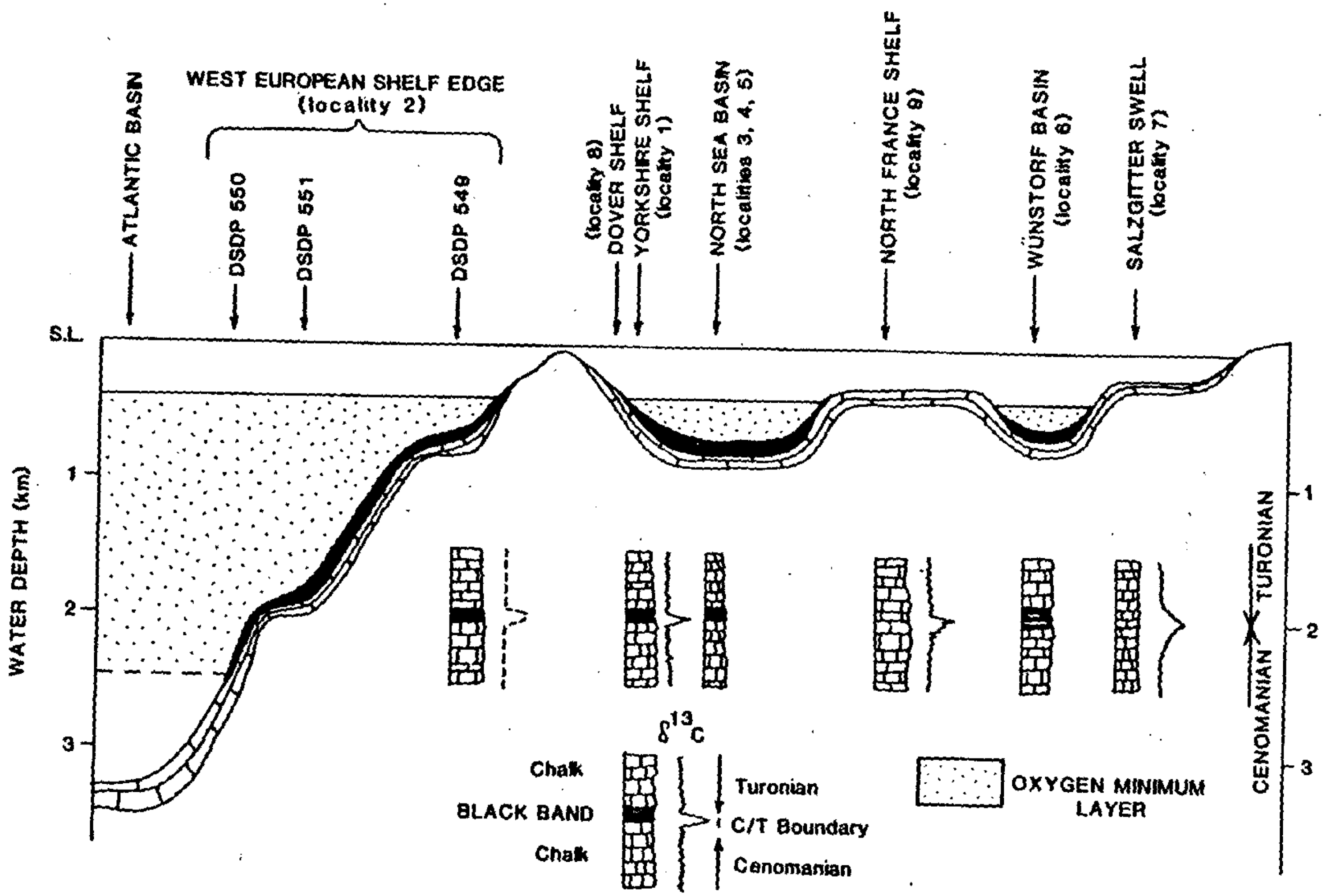


Figure 7. Schematic cross-section across the west European shelf during the Cenomanian-Turonian OAE showing the extent and thickness of the oxygen minimum layer (from Schlanger et al., 1985).

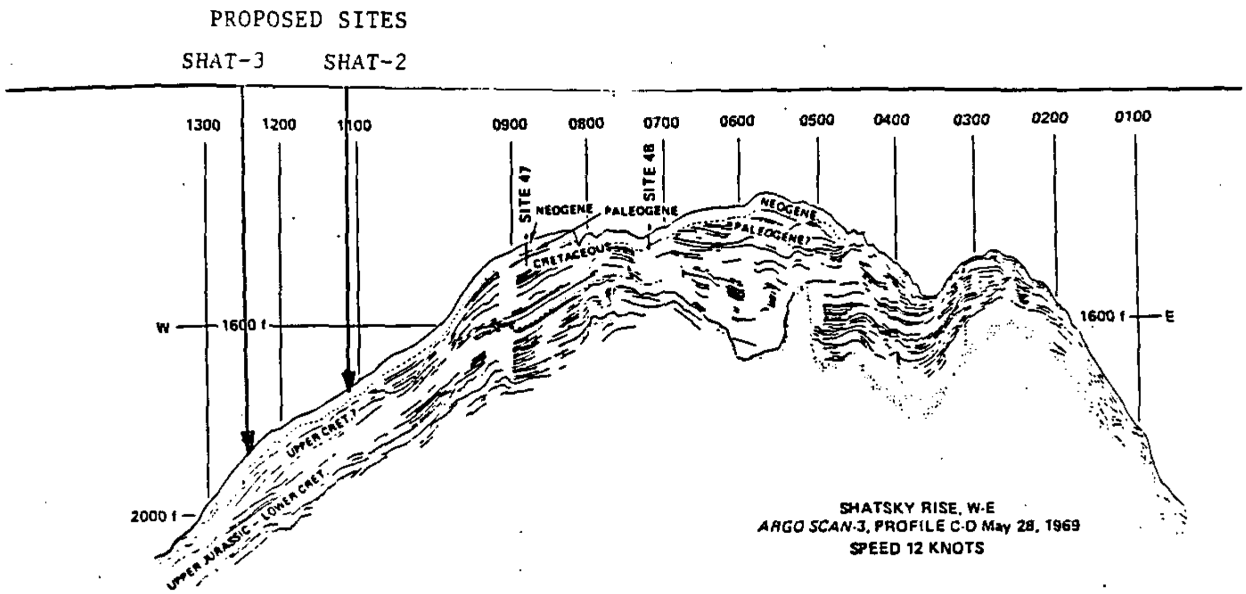


Figure 9. Seismic profile of Shatsky Rise showing proposed sites SHAT-2 and SHAT-3.

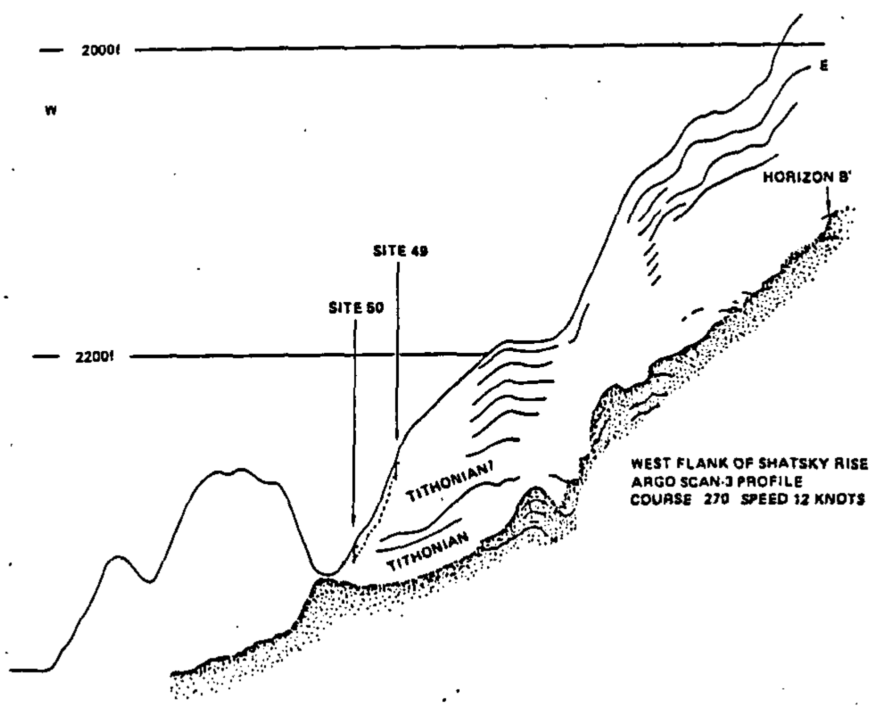


Figure 10. Seismic profile interpretation at Sites 49 and 50.

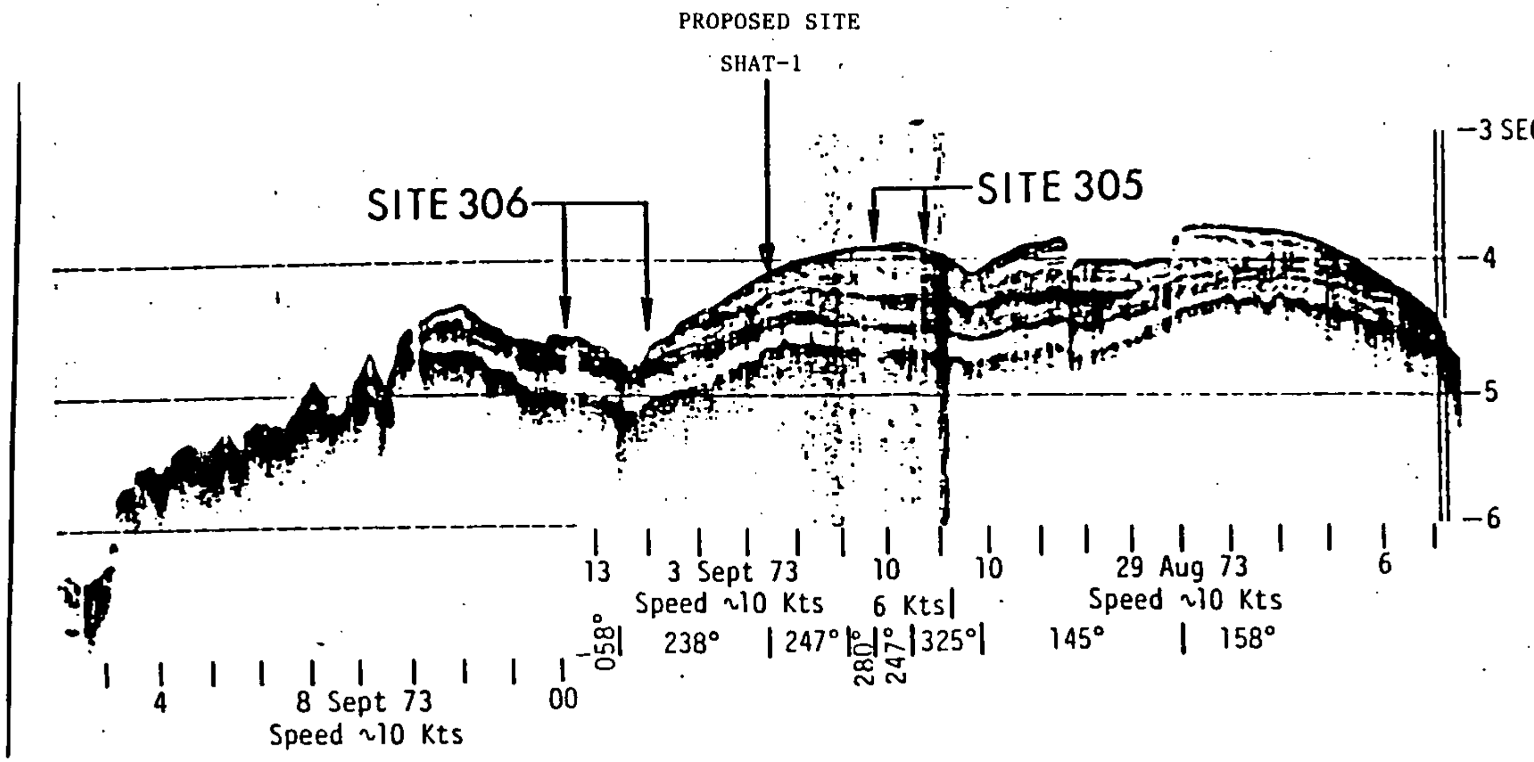


Figure 11. Seismic profile through Sites 305 and 306 showing proposed site SHAT-1.

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

Proposed Site: SHAT-1
(see also SHAT-2 and SHAT-3)

General Area: SHATSKY RISE, W. Pacific
Position: 32°N, 157°5o'E
Alternate Site:

General Objective: Paleoceanography of organic carbon-rich black shales of Cretaceous age.

Thematic Panel interest: SOHP
Regional Panel interest: CEPAC

Specific Objectives: Penetrate and core strata of latest Jurassic to latest Cretaceous age deposited on a paleobathymetric high in order to:
1) Study the sedimentology, geochemistry and paleontology of Cretaceous black shales deposited during Oceanic Anoxic Events,
2) Determine the paleoceanographic conditions that control deposition and preservation of organic carbon-rich sediments in an open ocean setting.

Background Information:
Regional Data:
Seismic profiles: SCAN-3, VEMA 2110, CONRAD 1007, CONRAD 1008, GC 32, GC 6

Other data: Drilling results from Sites 47, 48, 49, 50, 305, 306, 577

Site Survey Data - Conducted by:
Date:
Main results:

Operational Considerations

Water Depth: (m) 3100 Sed. Thickness: (m) 700 Total penetration: (m) 800 (w/ basalt)

HPC ____ Double HPC ____ Rotary Drill X Single Bit X Reentry ____

Nature of sediments/rock anticipated: Cretaceous chalk, cherty chalk-limestone, black shale, over basalt

Weather conditions/window: Not critical

Territorial jurisdiction: International waters

Other:

Special requirements (Staffing, instrumentation, etc.)

Organic geochemistry, Mesozoic paleontology

Proponent:

S. O. Schlanger
Dept. Geological Sciences
Northwestern University
Evanston, IL 60201

W. V. Sliter
U. S. Geological Survey
Menlo Park, CA 94025

Date submitted to JOIDES Office:

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

Proposed Site: SHAT-2
(see also SHAT-1 and SHAT-3)

General Area: SHATSKY RISE; W. Pacific
Position: 32°25'N; 157[12;E
Alternate Site:

General Objective: Paleoceanography of organic carbon-rich black shales of Cretaceous age.

Thematic Panel interest: SOHP
Regional Panel interest: CEPAC

Specific Objectives: Penetrate and core strata of Cretaceous age deposited in a mid- to deep-water setting in order to:

1) Study the sedimentology, geochemistry and paleontology of black shales deposited during Oceanic Anoxic Events,
2) Determine the paleoceanographic conditions that control deposition and preservation of organic carbon-rich sediments in an open ocean setting.

Background Information:

Regional Data:

Seismic profiles: SCAN 3, CONRAD 1007, GC 6

Other data: Drilling results from Sites 47, 48, 49, 50, 305, 306, 577

Site Survey Data - Conducted by:

Date:

Main results:

Operational Considerations

Water Depth: (m) 3500 Sed. Thickness: (m) 700 Total penetration: (m) 800 (w/ basalt)

HPC ____ Double HPC ____ Rotary Drill _X_ Single Bit _X_ Reentry ____

Nature of sediments/rock anticipated: Cretaceous chalk, clay, cherty chalk-limestone, black shale, over basalt.

Weather conditions/window: Not critical

Territorial jurisdiction: International waters

Other:

Special requirements (Staffing, instrumentation, etc.)

Organic geochemistry, Mesozoic paleontology

Proponent:
S. O. Schlanger
Dept. Geological Sciences
Northwestern University
Evanston, IL 60201

Date submitted to JOIDES Office:
W. V. Sliter
U. S. Geological Survey
Menlo Park, CA 94025

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

roposed Site: SHAT-3
(see also SHAT-1 and SHAT-2)

General Objective: Paleoceanography of organic carbon-rich black shales of Cretaceous age.

ieneral Area: SHATSKY RISE, W. Pacific
'osition: 32°25'N, 157°5'E
ulternate Site:

Thematic Panel interest: SOHP
Regional Panel interest: CEPAC

pecific Objectives: Penetrate and core strata of Cretaceous age deposited in a mid- to deep-water setting in order to:
1) Study the sedimentology, geochemistry and paleontology of black shales deposited during Oceanic Anoxic Events,
2) Determine the paleoceanographic conditions that control deposition and preservation of organic carbon-rich sediments in an open ocean setting.

ackground Information:
Regional Data:
Seismic profiles: SCAN 3, CONRAD 1007, GC 6

Other data: Drilling results from Sites 47, 48, 49, 50, 305, 305, 577

Site Survey Data - Conducted by:
Date:
Main results:

Operational Considerations

Water Depth: (m) 3700 **Sed. Thickness: (m)** 700 **Total penetration: (m)** 800 (w/ basalt)

HPC ____ Double HPC ____ Rotary Drill X Single Bit X Reentry ____

Nature of sediments/rock anticipated: Cretaceous chalk, cherty chalk-limestone, black shale, over basalt

Weather conditions/window: Not critical

Territorial jurisdiction: International waters

Other:

Special requirements (Staffing, instrumentation, etc.)

Organic geochemistry, Mesozoic paleontology

Proponent:

S. O. Schlanger
Dept. Geological Sciences
Northwestern University
Evanston, IL 60201

W. V. Sliter
U. S. Geological Survey
Menlo Park, CA 94025

Date submitted to JOIDES Office:

Attachment 3

Bering Sea

Bering Sea Deep Hole

One of the more perplexing problems to be attacked by ODP drilling is that of the evolution of late Mesozoic through Paleogene paleoclimates at high paleolatitudes. At present we lack any record of the high northern latitudes in the Cretaceous-Paleogene Pacific except for the few fragments of record that are lodged in allocthonous terrains along the accreted margins of the north Pacific Ocean basin. These accreted terrains are tantalizing pieces of the puzzle but woefully inadequate for the purposes of paleoceanographic research because most of them have been tectonically disturbed, deeply buried and diagenetically altered, and many cannot be adequately located in terms of paleolatitude and paleodepth. Part of the Bering Sea may be underlain by crust as old as Chron M13 (early Cretaceous) belonging to the now largely subducted Kula Plate, which was probably formed at paleolatitudes at least as high as 20°N. Drilling in the Bering Sea may therefore provide us with a higher northern paleolatitude locality with which to examine the record of pelagic sedimentation in the Cretaceous-Paleogene. We have few opportunities to obtain relatively high paleolatitude records of this type, and such data are badly needed in order to evaluate prevailing concepts of the Cretaceous and early Paleogene as warm, equable, ice-free times as well as to examine possible exchange of water masses with the Arctic Ocean through time. In addition, such a hole would possibly give us an idea of the areal extent of mid-Cretaceous black shale deposition, an objective considered high priority by a recent USSAC-sponsored workshop on the black shale problem; the present distribution of DSDP drillholes in the Pacific Basin does not adequately constrain models for the deposition of organic-carbon rich strata during the mid-Cretaceous, and it has been suggested that black shale deposition in the Pacific was only related to equatorial upwelling, high productivity and expansion and intensification of the midwater oxygen-minimum zone there. It is considered high priority to test such models.

We support two recent proposals (182/E and 195/E) which essentially have endorsed a site on Sounder Ridge (see Figs. 1 and 2) in the Bering Sea that was originally proposed by the PAC-A-BERS group (1981) /for drilling during DSDP. The proposed site would be located on the axis of Sounder Ridge which is a probable Cretaceous submarine high that would be optimal for carbonate preservation and avoids the thick middle to late Tertiary clastic sequences that cover much of the deep Bering Sea. The Sounder Ridge lies on crust thought to be Chron M9 in age

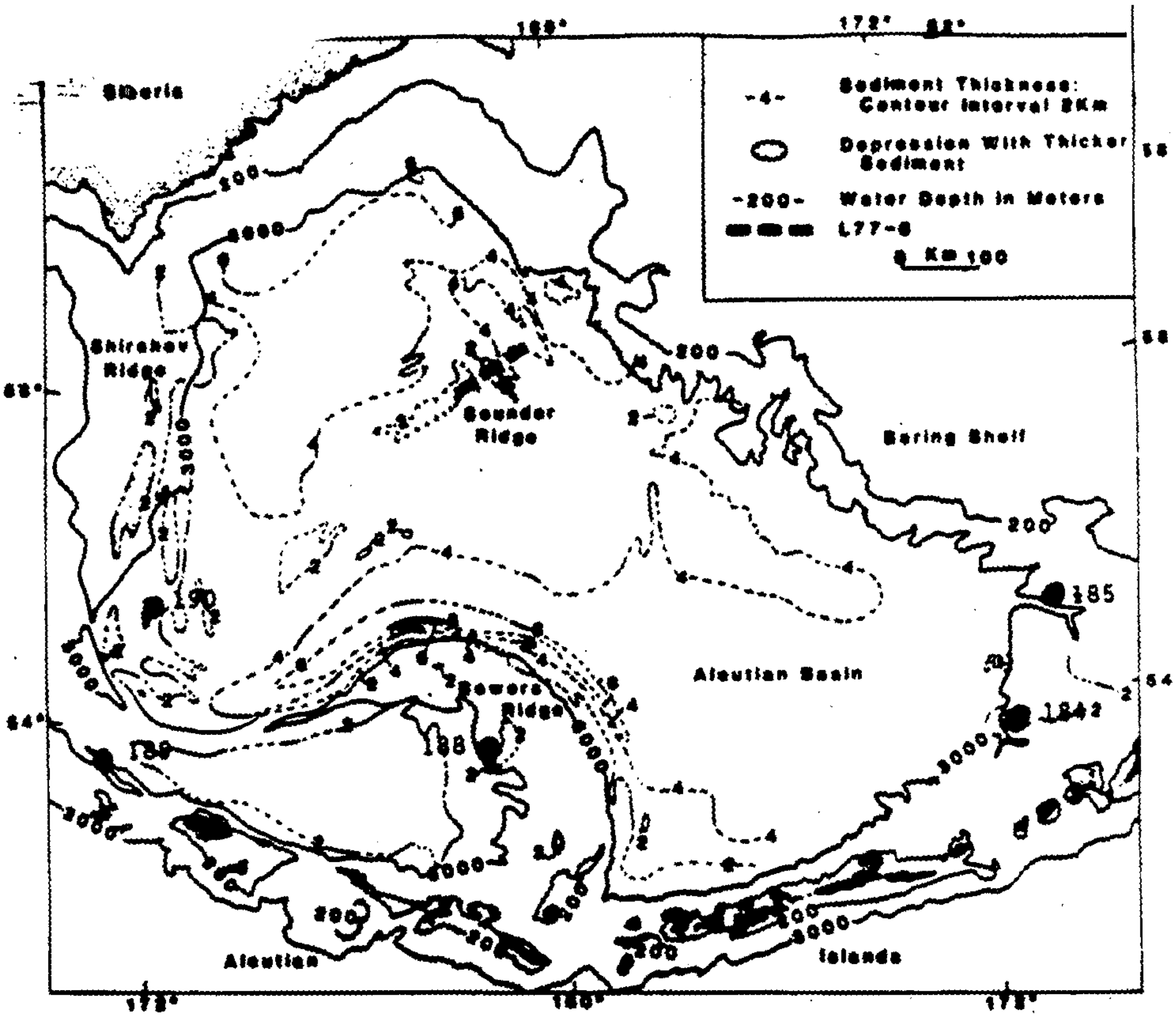


FIGURE 1. Bathymetry and sediment isopach map of Bering Sea basins and Aleutian arc. DSDP sites indicated by large dots.

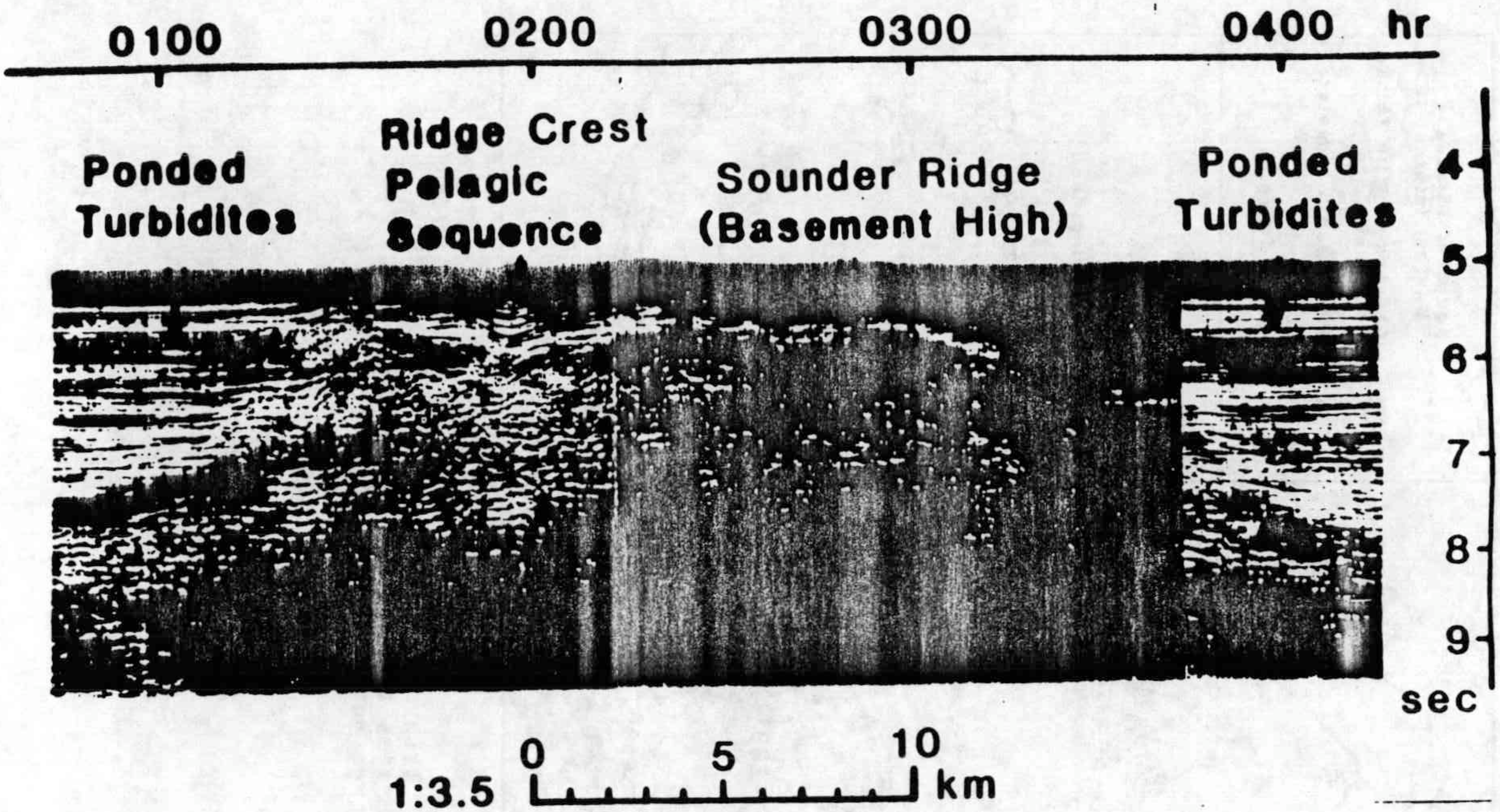


FIGURE 2. Seismic reflection profile across Sounder Ridge.
Figure provided by D. Scholl, U.S.G.S.

ODP SITE PROPOSAL SUMMARY FORM

(Submit 5 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site: BR-1: Sounder Ridge

General Objective: Mesozoic Plate Motion History and Environment of Pacific

General Area: Bering Sea

Position: 58°10'N, 177°48'E

Alternate Sites:

Thematic Panel interest: Tectonics, SOHP

Regional Panel interest: CEP-RP

Specific Objectives:

(1) To establish "Kula" plate stratigraphy and Mesozoic paleoenvironment and plate motion

(2) To examine the hypothesis of trapped marginal ocean

Background Information:

Regional Data:

Seismic profiles: Multichannel Lines by U.S. Geol. Survey

Other data:

Site Survey Data - Conducted by: U.S. Geol. Survey

Date:

Main results:

Operational Considerations

Water Depth: (m) 3,800 Sed. Thickness (m) 1,200 Total penetration: (m) 1,300

HPC X Double HPC ____ Rotary Drill X Single Bit ____ Reentry X

Nature of sediments/rock anticipated: Hemeipelagic clay, Chert, Basalt

Weather conditions/window: Summer

Territorial jurisdiction:

Other:

Special requirements (Staffing, instrumentation, etc.)

Proponent:

Asahiko Taira (Ocean Res. Inst., Univ. of Tokyo)

Constance Sancetta (LDGO)

Pac-A-Bers (D. Scholl, USGS, Menlo Park)

Date submitted to JOIDES Office: Aug. 8, 19

ATLANTIC OCEAN

SITE PROPOSALS

BLACK SHALE DEPOSITION IN THE PELAGIC REALM (N ATLANTIC)

(Contributed by Brian E. Tucholke)

Cretaceous black shales in the North Atlantic record two primary signals. One is an oceanographic (pelagic) signal that reflects variations in properties and productivity of the overlying water column. The second is a "terrestrial" signal that is determined largely by lateral injection of sediments and controlled by eustatic and relative sea-level changes, near-margin current activity, sediment mass movements, and so on. In order to understand the oceanographic conditions that favored deposition of black shales, without having to deal with the often confusing "terrestrial" signal, it is imperative to core the sediments in an area where lateral injection of sediment was absent or at least minimized.

In this respect the best locality for study is the flanks of the Cretaceous Mid-Atlantic Ridge, which were elevated and consequently above the zone of influence of terrestrial debris entering the deep ocean from the continental margins. The primary difficulty with drilling these locations is in finding low-gradient areas where local turbidity currents and other sediment mass movements have not complicated the signal.

In the North Atlantic, the requirements of elevated seafloor and low seafloor gradient are best met on the Madeira-Tore Rise (MTR) and the J-Anomaly (JAR) Ridge (Figures 1, 2). These are paired aseismic ridges that were formed in late Hauterivian to early Aptian time at the crest of the Mid-Atlantic Ridge; at least parts of the ridge were formed at and near sea level (Tucholke and Ludwig, 1982). Of the two ridges, the Madeira-Tore Rise appears to be a better drilling target based on presently available data. It has lower gradients and a relatively uniform Cretaceous sedimentary cover (Figure 1, bottom).

In contrast, the J-Anomaly Ridge has relatively steep gradients in its northern part (Figure 1, top), and its southern part is covered by turbidites of the Sohm Abyssal Plain (Figure 1, center); the sandy turbidites could pose technical difficulties in drilling, as they did at DSDP Site 383 (Leg 43).

The advantages of drilling the Madeira-Tore Rise to study the Cretaceous black shales in partcular, and Cretaceous oceanographic conditions in general, are several:

1) The rise had a total vertical relief of one to several kilometers, depending on specific location along strike. Consequently, various parts of the rise probably were above, at, and below the CCD during the episode of black shale deposition in the mid-Cretaceous (Figure 3). It is important to understand the position and evolution of this oceanographic boundary.

2) The rise probably lay near the northern boundary of the circum-global current through the Tethys, North Atlantic, and Indo-Pacific in Cretaceous time (Figure 2). Thus the relation of black-shale deposition to fluctuations in productivity patterns associated with this surface current could be studied.

3) The Cretaceous sedimentary section probably is relatively uniform in thickness (Figure 3), mostly unaffected by local mass sediments movements, isolated from terrestrial sediment sources, and easily accessible to coring (small overburden).

The optimum drilling strategy would be a transect of drillsites across the east and/or west flanks of the rise (Figure 3). This transect would sample mid-Cretaceous sediments both above the contemporary CCD (carbonates) and below (black shales). It would sample the nature of the sedimentary transition at the CCD and the vertical movement of the CCD in time. With high-resolution seismic reflection profiling, it would also allow study of whether seismic reflectors follow time lines in the sedimentary section, or whether they follow facies boundaries (carbonate-shale transitions). Presently available data are not adequate to precisely specify the optimum drillsite locations on the Madeira-Tore Rise. Site surveys with high-resolution seismic reflection will be necessary.

If drilled, the Madeira-Tore Rise also offers several other important opportunities for study:

1) It has been postulated that the JAR-MTR system was formed by southward flow of magma along the Mid-Atlantic Ridge crest and away from a hot spot between Iberia and the Grand Banks (Tucholke and Ludwig, 1982). Both the JAR and MTR also exhibit the high-amplitude (~1000 nT) "J-Anomaly", which is thought to result from anomalous magnetization of crust between anomalies M0 and M1 (Rabinowitz et al., 1979). Geochemical studies of the MTR basalts could test these hypotheses.
2) It is known from reef debris recovered at a drillsite (384) on the J-Anomaly Ridge that at least parts of the JAR-MTR were at and above sea level in the Aptian. The elevation and subsidence history of these paired ridges would be greatly elucidated by drilling.
3) The west flank of the MTR exhibits a well developed sedimentary drift, probably deposited beginning in Oligocene time (Figure 3). Study of core stratigraphy and seismic stratigraphy of this sequence would help greatly to understand the history of bottom-water circulation in the eastern North Atlantic.
4) The MTR probably was uplifted in the Neogene; it is now roughly 2 km shallower than the JAR, and this region (e.g. Madeira Is.) is known to have been affected by volcanism beginning in the middle to late Miocene. Sedimentary parameters such as carbonate content could be used to study the history of uplift of the rise.

Figure 1 - Profiles 1 and 2 are crossings of the J-Anomaly Ridge in the western North Atlantic. Profile at bottom (~200 km long) crosses the Madeira-Tore Rise 70 km north of Madeira. Vertical scale is in seconds reflection time. Locations of magnetic anomalies M-0, M -2 and M-4 are shown.

Figure 2 - Reconstruction of North Atlantic at magnetic anomaly M-0 (Aptian), from Tucholke and Ludwig (1982). Contours are present basement depth (km) west of spreading axis and present bathymetry (km) east of axis. Note juxtaposition of JAR and MTR. A Barremian-Aptian reef was cored at DSDP Site 384 on the JAR. Bold arrows show general pattern of east-to-west circumglobal surface currents through the Tethys and North Atlantic in Aptian time.

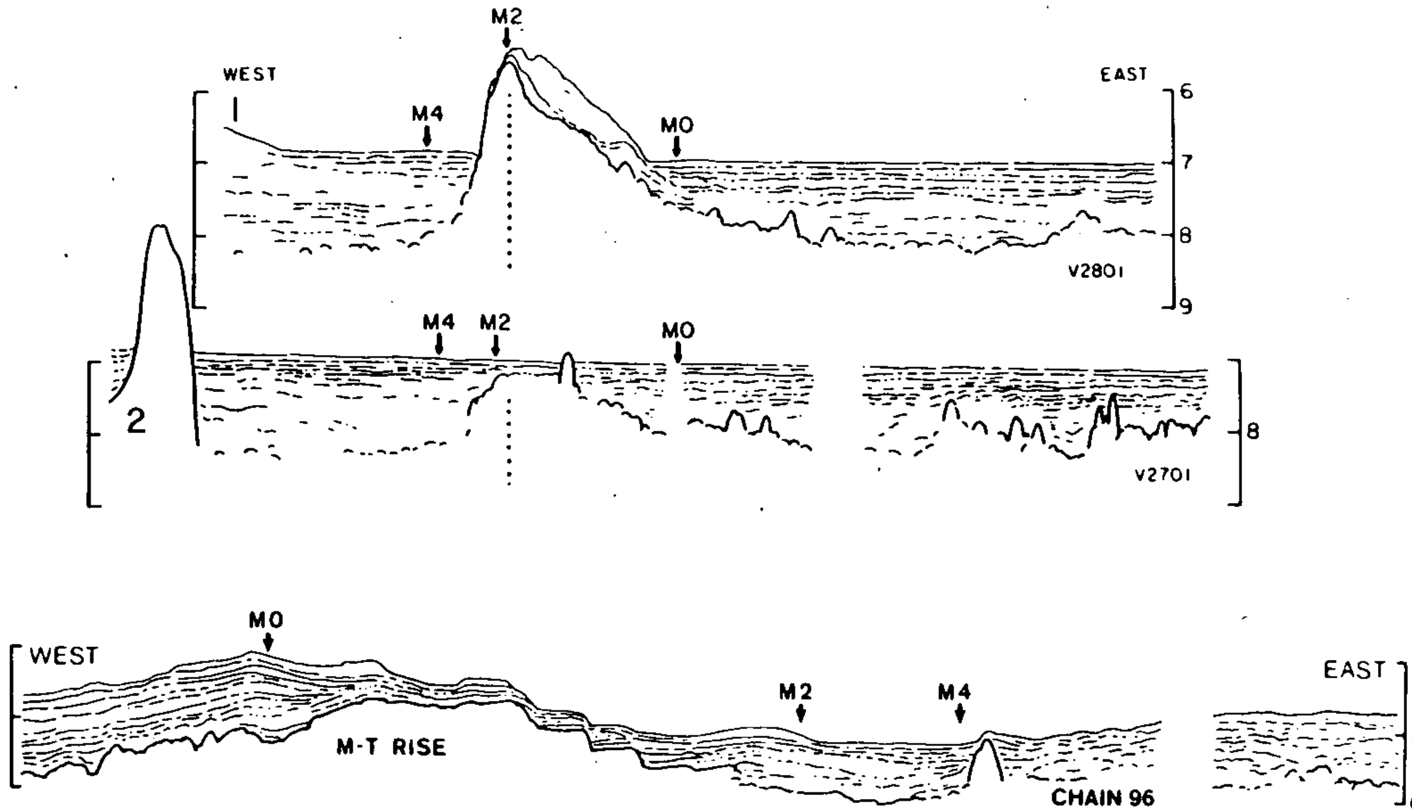
Figure 3 - Top: Schematic cross section of MTR, with high vertical exaggeration, showing approximate distribution of time-stratigraphic intervals. Distri- bution of calcareous versus shaley sediments is generalized, but is based on documented rise of CCD in Barremian time (Horizon β) and a shallow CCD at an assumed relatively constant depth in late Aptian-Turonian time. Vertical lines show potential drillsite transect sampling black shales, carbonates, and history of CCD fluctuations in this pelagic realm.

Bottom: Seismic reflection profile as in Figure 1, with bold line approximately dividing Mesozoic and Cenozoic sedimentary sections. Depths are in seconds reflection time.

REFERENCES

Rabinowitz, P.E., S. Cande and D.E. Hayes. The J Anomaly in the central North Atlantic Ocean. Initial Rept. Deep Sea Drilling Project, v. 43, p. 879-885, 1979.

Tucholke, B.E. and W.J. Ludwig. Structure and Origin of the J Anomaly Ridge, Western North Atlantic Ocean. Journal of Geophysical Research, v. 87, p. 9389-9407, 1982.



WEST
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2
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M-T RISE
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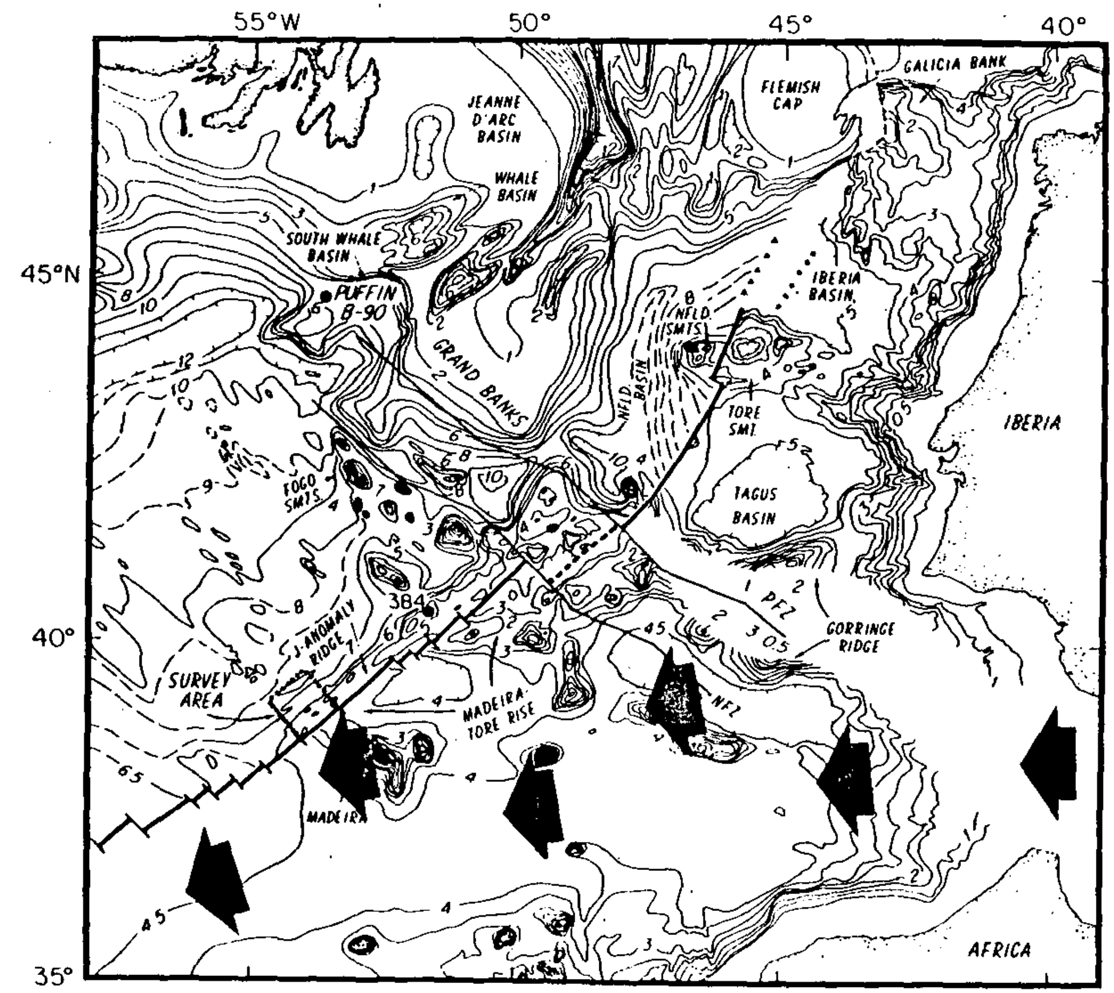
55°W
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35°
GALICIA BANK
FLEMISH CAP
JEANNE D'ARC BASIN
WHALE BASIN
SOUTH WHALE BASIN
PUFFIN B-90
GRAND BANKS
IBERIA BASIN
NFLD. SMTS.
NFLD. BASIN
TORE SMT.
TAGUS BASIN
IBERIA
FOGO SMTS.
384
J-ANOMALY RIDGE
SURVEY AREA
MADEIRA-TORE RISE
MADEIRA
PFZ
GORRINGE RIDGE
NFZ
AFRICA

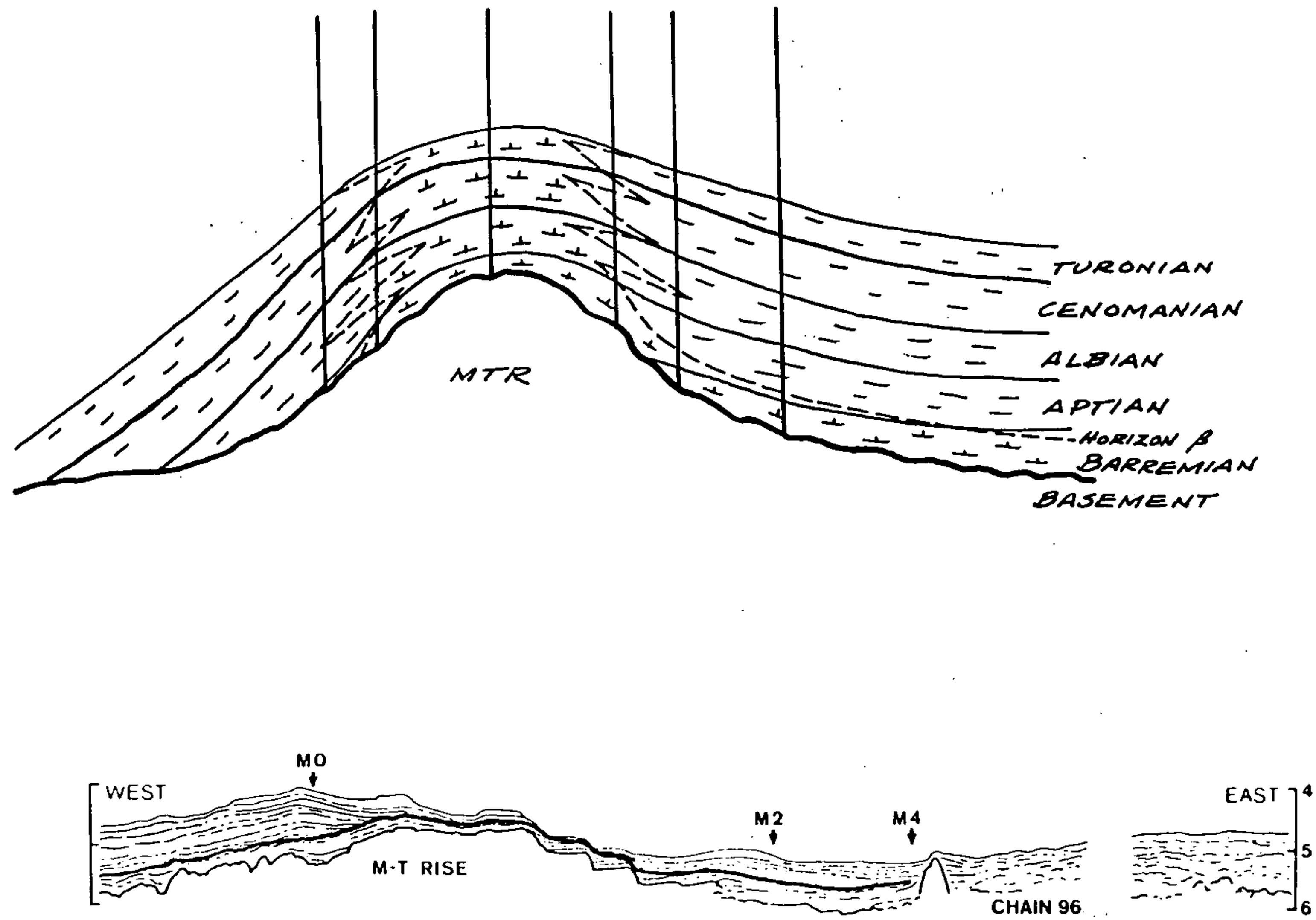
TURONIAN
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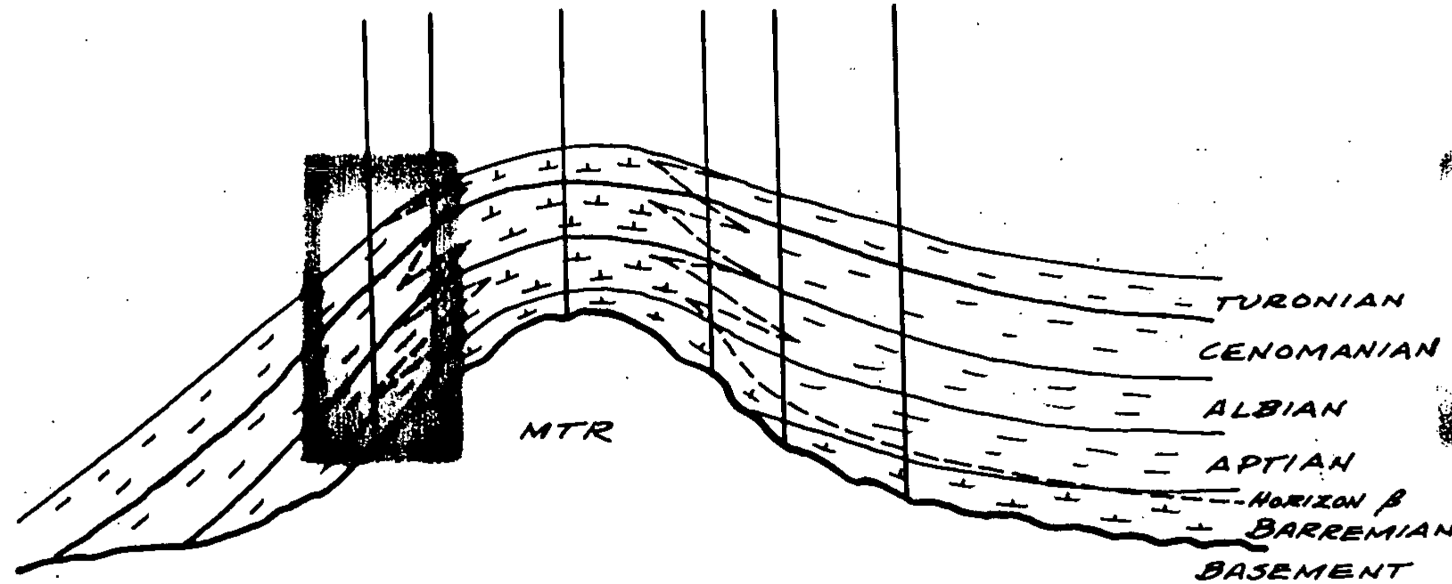
Fig 3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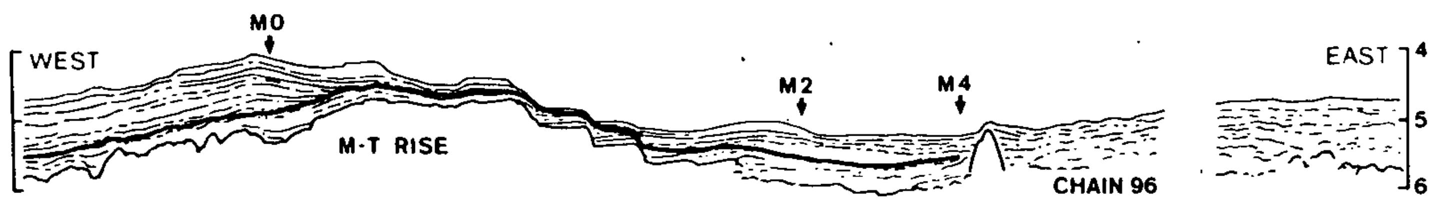
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Site Proposals (NW AFRICAN MARGIN)

Introduction

One of the most spectacular results to come from DSDP is the discovery of widespread organic-rich sediments of Cretaceous age. Like all such discoveries, this one has raised more questions than it has answered. These questions include the following:

(1) What is the nature and meaning of the cyclicity observed in many of these units?

(2) What is the origin of the organic matter?

(3) Under what conditions were the organic-rich sediments deposited?

(4) If the organic-rich sediments were deposited in an anoxic zone, what was the lateral and horizontal extent of that zone and what does its geometry tell us about circulation?

(5) How extensive is each black shale bed and what does the geometry of the beds tell us about circulation?

We propose future drilling to answer some of these questions. This drilling is best undertaken as a series of sites in transect roughly perpendicular to the continental margin. Although knowledge of the margin-parallel dimensions of the organic-rich sediments would be interesting to have, in a sense, we already have this knowledge. Knowledge of the margin-perpendicular dimensions is much less certain.

Objectives

The overall objective for the four proposed sites is to allow for the detailed study of Cretaceous black shales in the eastern North Atlantic. Study of these rocks beyond previous work (e.g., Tissot et al., 1979; Dean et al., 1977) is necessary to answer the questions listed above. We have chosen Northwest Africa as the best place to carry out such a study for the following reasons:

(1) Previous drilling, especially DSDP Leg 41, has revealed that extensive Cretaceous black shales are present along the Northwest African margin, reducing the possibility of failure to penetrate them. We are trying to avoid further reconnaissance work because such work will not answer the questions posed.

(2) Work on previous cores (e.g., Site 367) provides a good baseline for these studies, as evidenced by the abundant publications, but has left the questions listed above unanswered.

(3) The post-Cretaceous wedge of margin sediments is narrow and thin off Northwest Africa relative to other margins where a study of Cretaceous black shales might be contemplated. This is important to the selection of sites for a margin-perpendicular transect, as the "window" of seafloor where Cretaceous rocks are neither too deep to penetrate (beneath younger cover) nor absent (on seafloor too young) can be quite narrow.

(4) The continental geology of Cretaceous rocks is well-exposed and well-studied (e.g., papers in von Rad et al., 1982), permitting much more extensive regional correlations and facies studies.

General considerations in site selection

Three regions might be suitable for the proposed transect, near Site 367

(Submit 6 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site: Site 1A	General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition.
General Area: off Cap Verde, Senegal Position: 11°37'N, 19°2'W Alternate Site:	Thematic Panel interest: organic geochemistry Regional Panel interest: Atlantic

Specific Objectives: This is the nearest-shore site of the proposed transect. Nearer shore, Cretaceous sediments are probably buried too deep for drilling. A shoreward limit to some of the Cretaceous black shale beds may be expected here, permitting study of the nearshore side of the black shale depositional system.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles: to be provided by MAA; slumping appears to be minimal in this region

Other data: Site 367 cores included a long section of Cretaceous black shale that exhibits cyclicity, organic-rich horizons. Chert drilled at Site 367 did not create great difficulties with drilling other than to force more continuous drilling, which is consistent with the objectives of this proposal.

Site Specific Survey Data:

Seismic profiles: see attached

Other Data:

Operational Considerations:

Water Depth: (m) 4500 Sed. Thickness: (m) gt 1500 Tot. penetration: (m) 1500

HPC _____ Double HPC _____ Rotary Drill _____ Single Bit _____ Reentry _____

Nature of sediments/rock anticipated: clay, chert layers, silicified limestone, limestone, shale

Weather conditions/window: good year-round

Territorial jurisdiction: outside 200 mile limit off Senegal

Other:

Special Requirements (staffing, instrumentation, etc.):

3 organic geochemists, lithostratigrapher with experience in black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish Address & phone number: 303-236-5775 U.S. Geological Survey, MS 971 Denver Federal Center Denver, CO 80225-0046 U.S.A.	FOR OFFICE USE: Date received: Classification no.: Panel allocation:

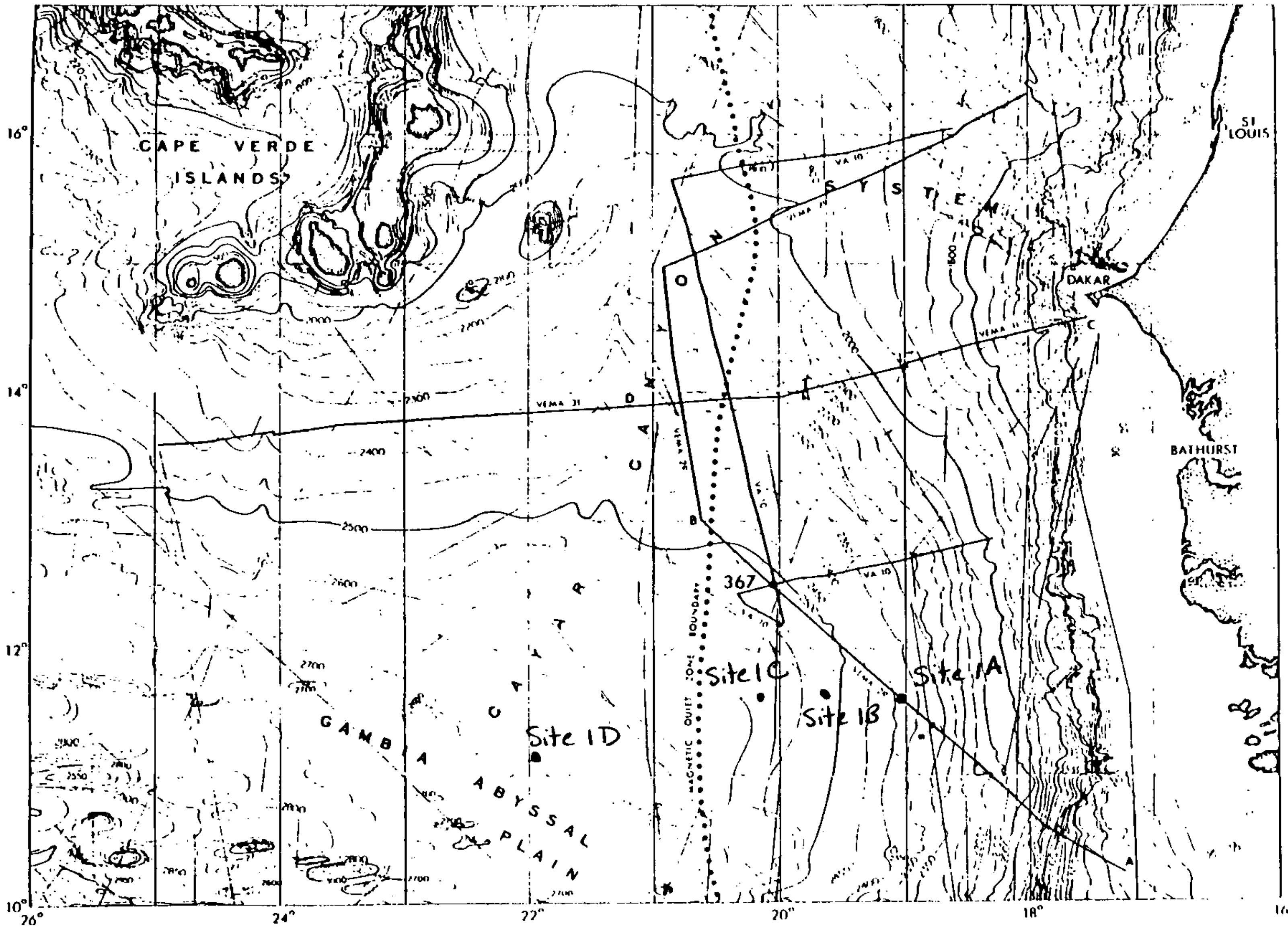

Figure 1. *General location of Site 367 in the Cape Verde Basin. Bathymetry from Jacobi and Hayes (in preparation); Magnetic Quiet Zone boundary from Hayes and Rabinowitz (1975).*

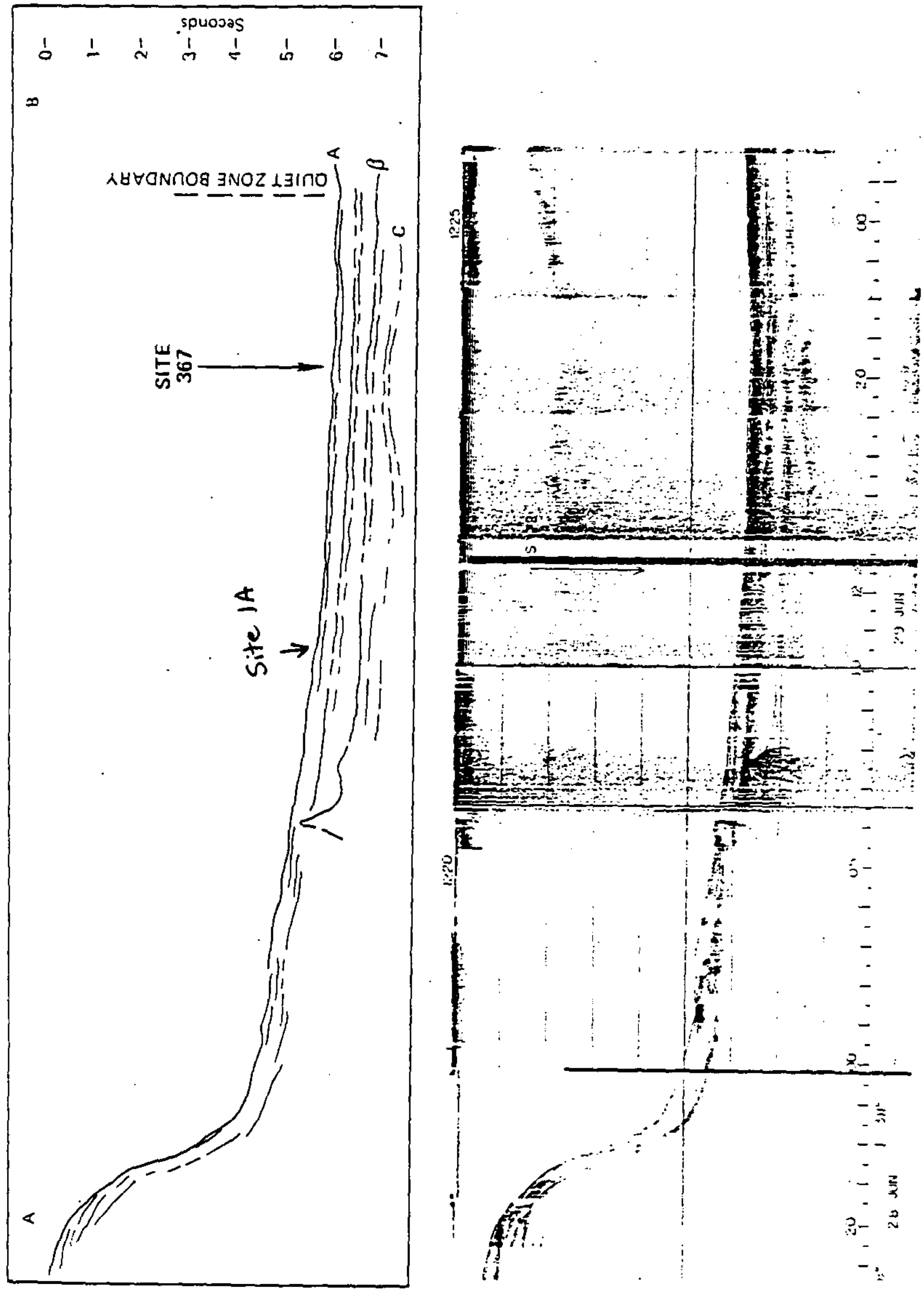

Figure [illegible]. Lamont Doherty Geological Observatory Vema [illegible] seismic profile from the Cape Verde Basin (see location on Figure 1).

ODP SITE PROPOSAL SUMMARY FORM
(Submit 6 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site: Site 1B General Area: off Cap Verde, Senegal Position: 11°37' N, 19°40'W Alternate Site:	General Objective: Continuously core Cretaceous black shales for studyof their geometry, geochemistry, and environment of deposition. Thematic Panel interest: organic geochemistry Regional Panel interest: Atlantic

Specific Objectives: *Site chosen to be approximately in same bathymetric position as Site* 367. Drilling will permit not only confirmation of Site 367 stratigraphy (particularly upper part) but also provide data on the margin-parallel distribution and continuity of the Cretaceous black shale units found at Site 367.

Background Information (indicate status of data as outlined in the Guidelines):
Regional Geophysical Data:
Seismic profiles:

Other data:

Site Specific Survey Data:
Seismic profiles:

Other Data:

Operational Considerations:

Water Depth: (m) 4770 Sed. Thickness: (m) gt 1200 Tot. penetration: (m) 1150 (prj.)

HPC ____ Double HPC ____ Rotary Drill ____ Single Bit ____ Reentry ____

Nature of sediments/rock anticipated: clay, chert layers, silicified limestone, limestone, shale

Weather conditions/window: good year-round

Territorial jurisdiction: outside 200 mile limit off Senegal

Other:

Special Requirements (staffing, instrumentation, etc.):
3 organic geochemists, lithostratigrapher familiar with black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish Address & phone number: 303-236-5775 U.S. Geological Survey, MS 971 Denver Federal Center Denver, CO 80225-0046 U.S.A.	FOR OFFICE USE: Date received: Classification no.: Panel allocation:

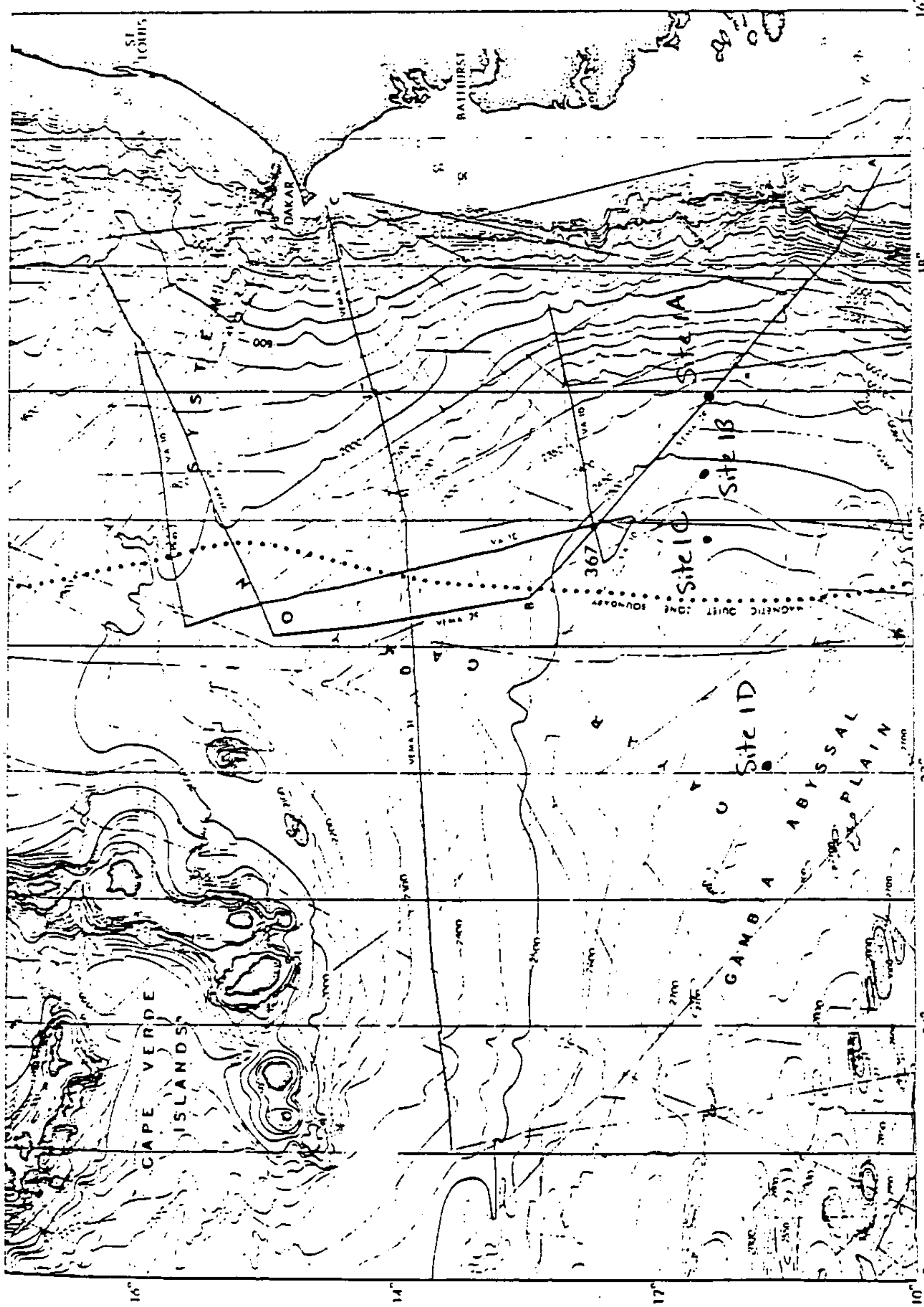

Figure 1. General location of Site 367 in the Cape Verde Basin. Bathymetry from Jacobi and Hayes (in preparation). Magnetic Quiet Zone boundary from Hayes and Rabinowitz (1975).

(Submit 6 copies of mature proposals, 3 copies of preliminary proposals)

›sed Site: Site 1C (see attached map) General Area: off Cap Verde, Senegal Position: 11°37'N, 20°10'W Alternate Site:	General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition. Thematic Panel interest: organic geochemistry Regional Panel interest: Atlantic

Specific Objectives: Site chosen because it is the same distance from the magnetic quiet zone boundary as Site 367 and therefore probably has basement that is approximately the same age. This facilitates comparison with Site 367 stratigraphy, particularly lower part, and additional margin-parallel data on distribution of the black shales, as well as the margin-perpendicular data that is the object of this transect.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

Other data:

Site Specific Survey Data:

Seismic profiles:

Other Data:

Operational Considerations:

Water Depth: (m) 4890 Sed. Thickness: (m) ________ Tot. penetration: (m) ________

HPC _____ Double HPC _____ Rotary Drill _____ Single Bit _____ Reentry _____

Nature of sediments/rock anticipated: clay, chert layers, silicified limestone, limestone, shale

Weather conditions/window: good year-round

Territorial jurisdiction: outside 200-mile limit off Senegal

Other:

Special Requirements (staffing, instrumentation, etc.):
3 organic geochemists, lithostratigrapher familiar with black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish Address & phone number: 303-236-5775 U.S. Geological Survey, MS 971 Denver Federal Center Denver, CO 80225-0046 U.S.A.	FOR OFFICE USE: Date received: Classification no.: Panel allocation:

in the Cape Verde Basin, near Site 369 off Cape Bojador, and near Site 140 west of Cap Blanc. None of these sites showed evidence of slumping, as did sites in the Moroccan Basin (e.g., Site 370; Kelts and Arthur, 1981). Site 367 did show some evidence of turbidites in the Cretaceous rocks (Kelts and Arthur, 1981), reducing its desirability for this study. Site 369 did not have turbidites, but lies off the Spanish Sahara, which might prove politically problematic(?). In addition, drilling at this site was terminated owing to the high gas content of the sediments. Finally, parts of the Lower Cretaceous are truncated by unconformities; this extends as far south as 25°N (von Rad, Ryan, et al., 1979; Ranke et al., 1982). Site 140 also did not have turbidites in the sections drilled, but only Late Maestrichtian sediments were penetrated, so evaluating the suitability of this region is more difficult. A straightforward extrapolation from Site 367 suggests that at least 1500 meters penetration would be required to drill the Cretaceous completely at Site 140. On the other hand, Late Cretaceous black sediments were drilled at Site 138 in only 422 meters, so a transect starting with Site 140 and extending toward Sites 137 and 138 (the region of which is also being recommended as part of this proposed leg) might serve the purposes of this study. In general, a gap between the slope and the lower part of the rise may have to be accepted for this study. In all places, sedimentation in the upper part of the rise was greatest and the Cretaceous sediments, therefore, buried deepest. For example, in ~2100m of water shoreward of Site 139, the top of the Cretaceous is about 1000m below the sea floor (von Rad and Wissmann, 1982).

<u>References</u>

Dean, W.E., Gardner, J.V., Jansa, L.F., Cepek, P., and Seibold, E., 1977. Cyclic sedimentation along the continental margin of Northwest Africa. IN Lancelot, T., Seibold, E., et al., Initial Reports of the Deep Sea Drilling Project, v. 41, p. 965-986.

Kelts, K., and Arthur, M.A., 1981. Turbidites after ten years of deep-sea drilling — wringing out the mop? IN Warme, J.E., Douglas, R.G., and Winterer, E.L., eds., The Deep Sea Drilling Project: A Decade of Progress. Society of Economic Paleontologists and Mineralogists Special Publication No. 32, p. 91-128.

Ranke, U., von Rad, U., and Wissmann, G., 1982. Stratigraphy, facies and tectonic development of the on- and offshore Aaiun-Tarfaya Basin — a review. IN von Rad, U., Hinz, K., Sarnthein, M., and Seibold, E., eds., Geology of the Northwest African Continental Margin. Berlin, Springer-Verlag, p. 86-105.

Tissot, B., Deroo, G., and Herbin, J.P., 1979. Organic matter in Cretaceous sediments of the North Atlantic: contribution to sedimentology and paleogeography. IN Talwani, M., Hay, W.W., and Ryan, W.B.F., eds., Deep drilling results in the Atlantic Ocean: Continental Margins and Paleoenvironment. Washington, American Geophysical Union, p. 312-374.

von Rad, U., Ryan, W.B.F., et al., 1979. Site 397. IN von Rad, U., Ryan, W.B.F., et al., Initial Reports of the Deep Sea Drilling Project, v. 46, Part 1, p. 17-217.

von Rad, U., and Wissmann, G., 1982. Cretaceous-Cenozoic history of the West Saharan continental margin (NW Africa): Development, destruction and gravitational sedimentation. IN von Rad, U., Hinz, K., Sarnthein, M., and Seibold, E., eds., Geology of the Northwest African Continental Margin. Berlin, Springer-Verlag, p. 106-131.

von Rad, U., Hinz, K., Sarnthein, M., and Seibold, E., eds., Geology of the Northwest African Continental Margin. Berlin, Springer-Verlag, 703 p.

Wissmann, G., 1982. Stratigraphy and structural features of the continental margin basin of Senegal and Mauritania. IN von Rad, U., Hinz, K., Sarnthein, M., and Seibold, E., eds., Geology of the Northwest African Continental Margin. Berlin, Springer-Verlag, p. 160-181.

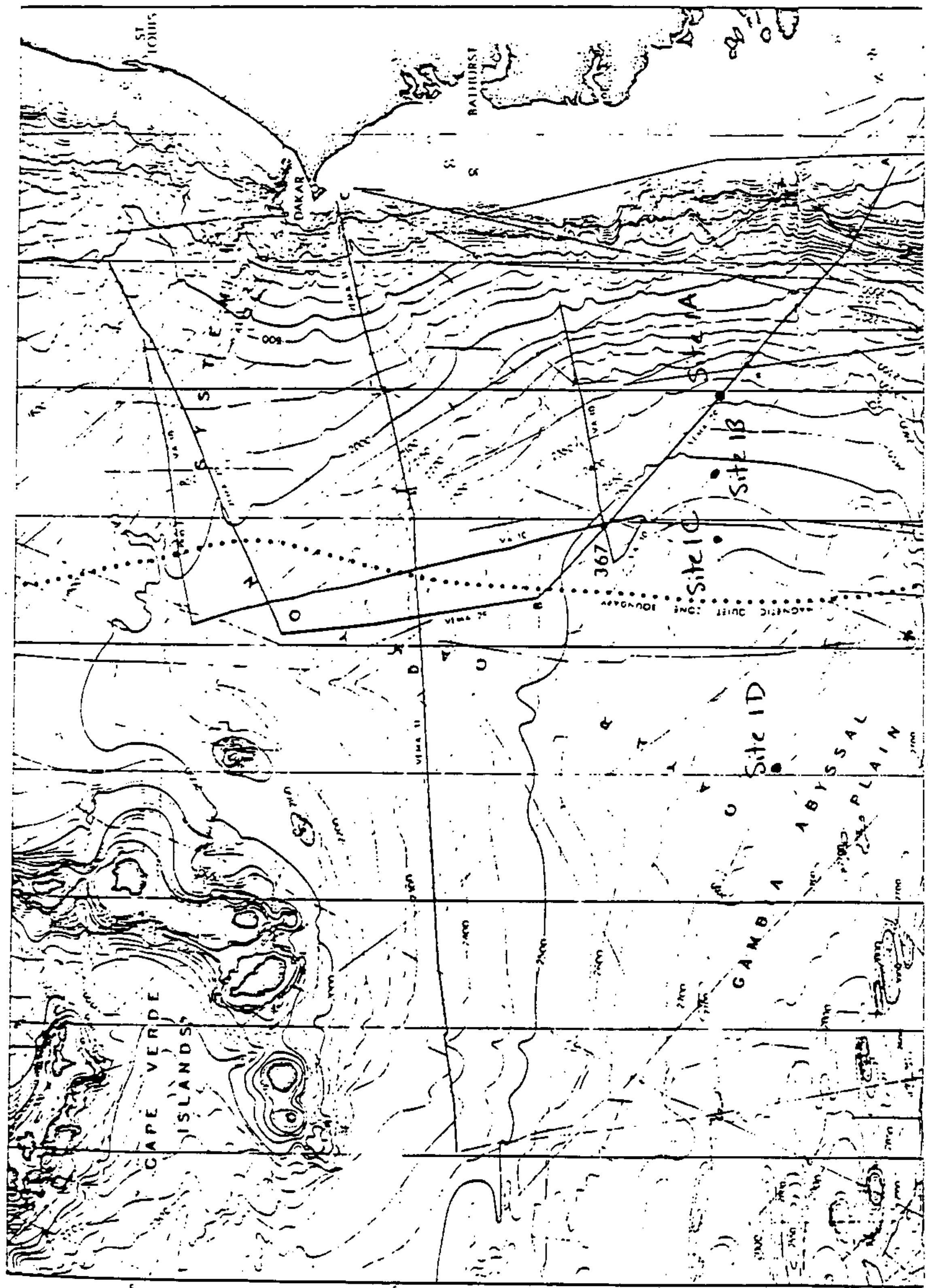

Figure 1. General location of Site 367 in the Cape Verde Basin. Bathymetry from Jacobi and Hayes (in preparation). Magnetic Quiet Zone boundary from Hayes and Rabinowitz (1975).

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Proposed Site:

Site 1D (see attached map_

General Area: off Cap Verde, Senegal
Position: 11°10'N, 21°57'W
Alternate Site:

General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition.

Thematic Panel interest: organic geochemistry
Regional Panel interest: Atlantic

Specific Objectives: Site chosen as farthest offshore site in proposed transect. Expect seaward limit of some of the Cretaceous black shale beds at this depth. This site also lies about halfway between Site 1C and sites to be proposed for the abyssal plain in terms of bathymetry.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

Other data:

Site Specific Survey Data:

Seismic profiles:

Other Data:

Operational Considerations:

Water Depth: (m) 6000 Sed. Thickness: (m) ________ Tot. penetration: (m) ________

HPC _____ Double HPC _____ Rotary Drill _____ Single Bit _____ Reentry _____

Nature of sediments/rock anticipated: clay, limestone, chert layers, silicified limestone, shale

Weather conditions/window: good year-round

Territorial jurisdiction: outside 200-mile limit off Senegal

Other:

Special Requirements (staffing, instrumentation, etc.):
3 organic geochemists, lithostratigrapher familiar with black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish
Address & phone
number: 303-236-5775
U.S. Geological Survey, M.S. 971
Denver Federal Center
Denver, CO 80225-0046 U.S.A.

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Proposed Site:
Site 2A

General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition.

General Area: off Cap Blanc, Mauritania
Position: 20°30'N, 18°45'W
Alternate Site:

Thematic Panel interest: organic geochemistry
Regional Panel interest: Atlantic

Specific Objectives: Site chosen because the Paleocene-Cretaceous boundary is quite close to the surface on this slope, in a slope anticline (see sections from Wissmann, 1982). Thus this site would provide an unusually nearshore view of the Cretaceous black shales in this transect. Drilling at this site may provide more information about the black shale geometry than did Site 369 because this is closer to the ancient upwelling and main black shale deposition evident in Site 367, although this could be preservation.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

Other data:

Site Specific Survey Data:

Seismic profiles: See profile C in the figure from Wissmann (1982).

Other Data: Site 369 was on a similar slope anticline to the north and did penetrate Cretaceous rocks. Although drilling at that site had to be terminated owing to an increasing gas content, valuable information was obtained about the distribution of Cretaceous rocks and unconformities therein.

Operational Considerations:

Water Depth: (m) 2400 Sed. Thickness: (m) gt 1500 Tot. penetration: (m) 1000?

HPC _____ Double HPC _____ Rotary Drill _____ Single Bit _____ Reentry _____

Nature of sediments/rock anticipated: clay or limestone, possibly cherty in some horizons

Weather conditions/window: good year-round

Territorial jurisdiction: Mauritania

Other:

Special Requirements (staffing, instrumentation, etc.):
3 organic geochemists, lithostratigrapher with background in black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish
Address & phone number: 303-236-5775
U.S. Geological Survey, MS 971
Denver Federal Center
Denver, CO 80225-0046 U.S.A.

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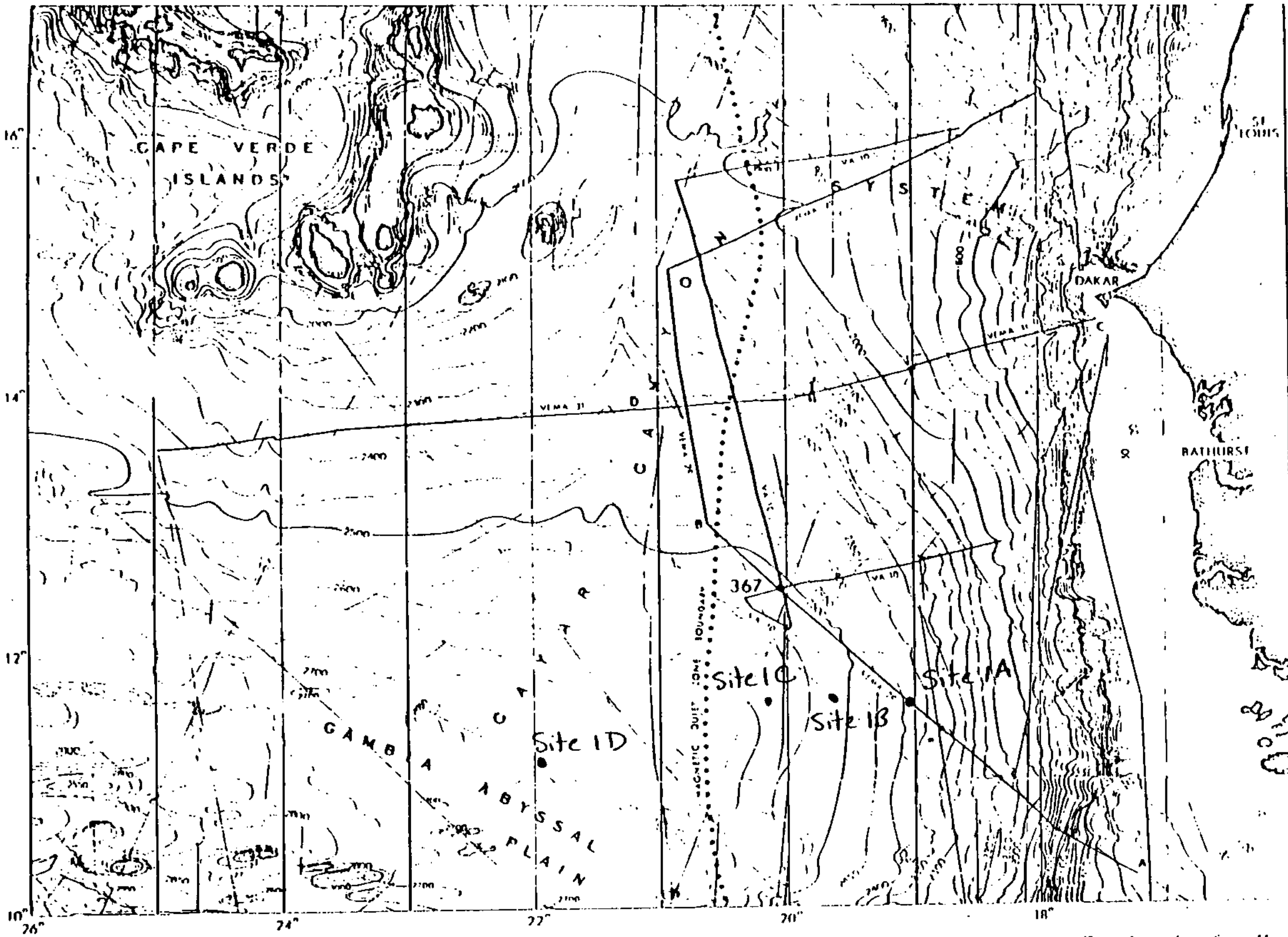

Figure 1. *General location of Site 367 in the Cape Verde Basin. Bathymetry from Jacobi and Hayes (in preparation); Magnetic Quiet Zone boundary from Hayes and Rabinowitz (1975).*

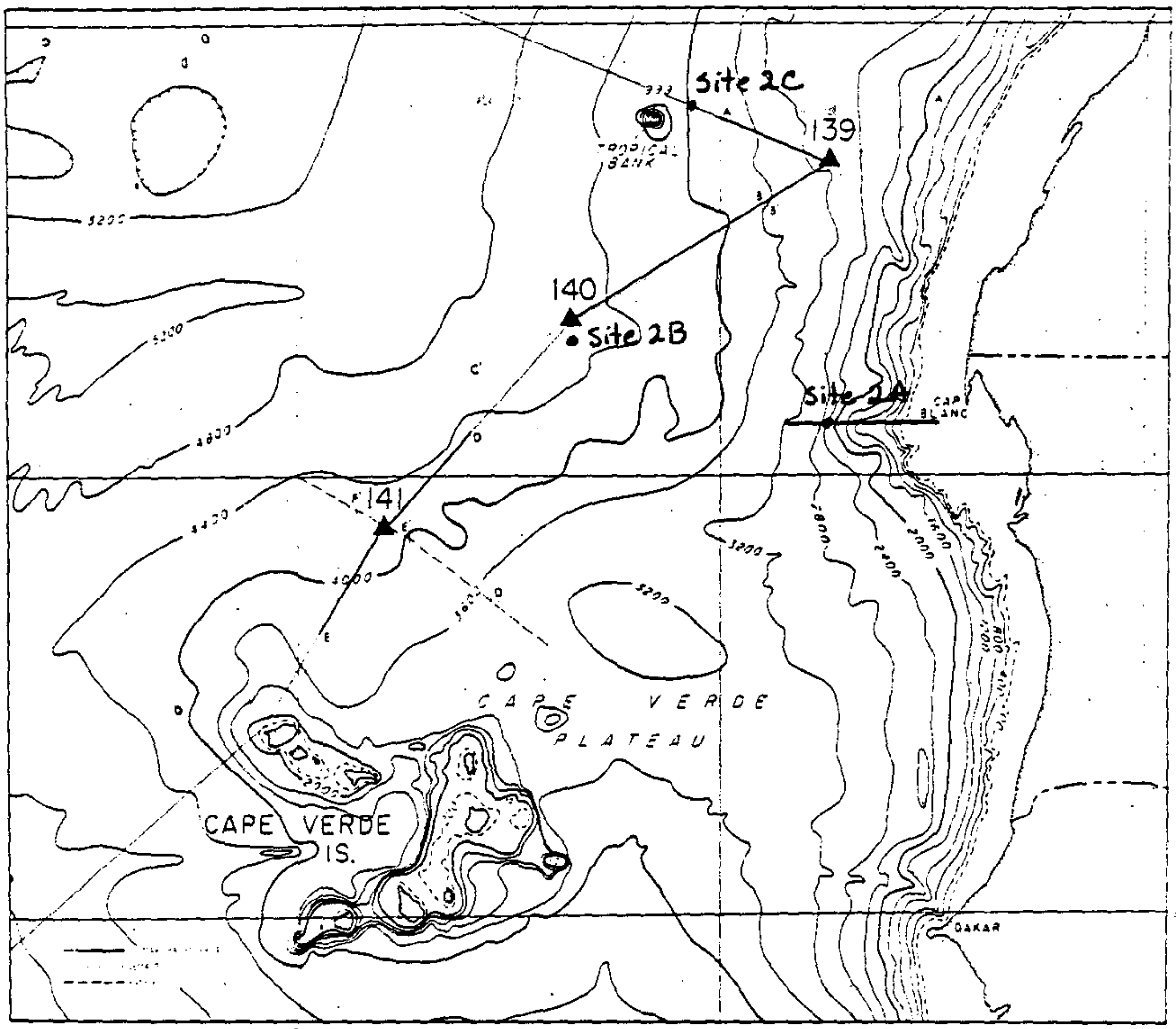

Figure 1. *Location map of Sites 139, 140, 141. Contours in corrected meters from Uchupi (1971). Letters indicate seismic profiles shown in Chapter 6, Figure 2 and Chapter 8, Figure 1.*

Seismic line off Cap Blanc from Wissmann, 1982 (see attached)

indicative of Paleocene to Upper Campanian occur in 140-7 and 8. Radiolaria from 140-8 indicate a Maestrichtian age.

Foraminifera

The Pliocene foraminiferal fauna of Core 1 is of the normal pelagic type. The two following cores (140A-1, 140-2) of Miocene age apparently contain a large proportion of displaced forms. This is especially true for 140A-1, where typical shallow water fossils such as *Ammonia beccarii*, Pararotalia, Elphidium, barnacle plates, and larger mollusk shells, are associated with common planktonic foraminifera. The benthonic association of 140-2 lived probably in somewhat deeper water; it is very similar to that of Core 5 in Site 139. Of the lower cores in Site 140, only Cores 7 and 8 contain some foraminifera. These are of the agglutinated type and most probably indicate deep water below the calcium carbonate compensation level. A Paleocene to Late Campanian age for these two cores is indicated by the presence of *Rzehakina epigonalata*.

Nannoplankton

Core 1 contains rich assemblages of Late Pliocene age. The common occurrence of the four rayed *Discoaster tamalis* in this core is characteristic for the lowermost part of the *Discoaster brouweri* zone. Core 2 yields only etched assemblages of Early Miocene age. *Sphenolithus heteromorphus* and *S. belemnos* occur together with *Helicopontosphaera ampliaperta* throughout the core. Cores 3 through 8 lack calcareous nannoplankton. Core 1 of Hole 140A recovered Middle Miocene nannofossils in a poor state of preservation. Core 2 of Hole 140A does not contain any nannoplankton.

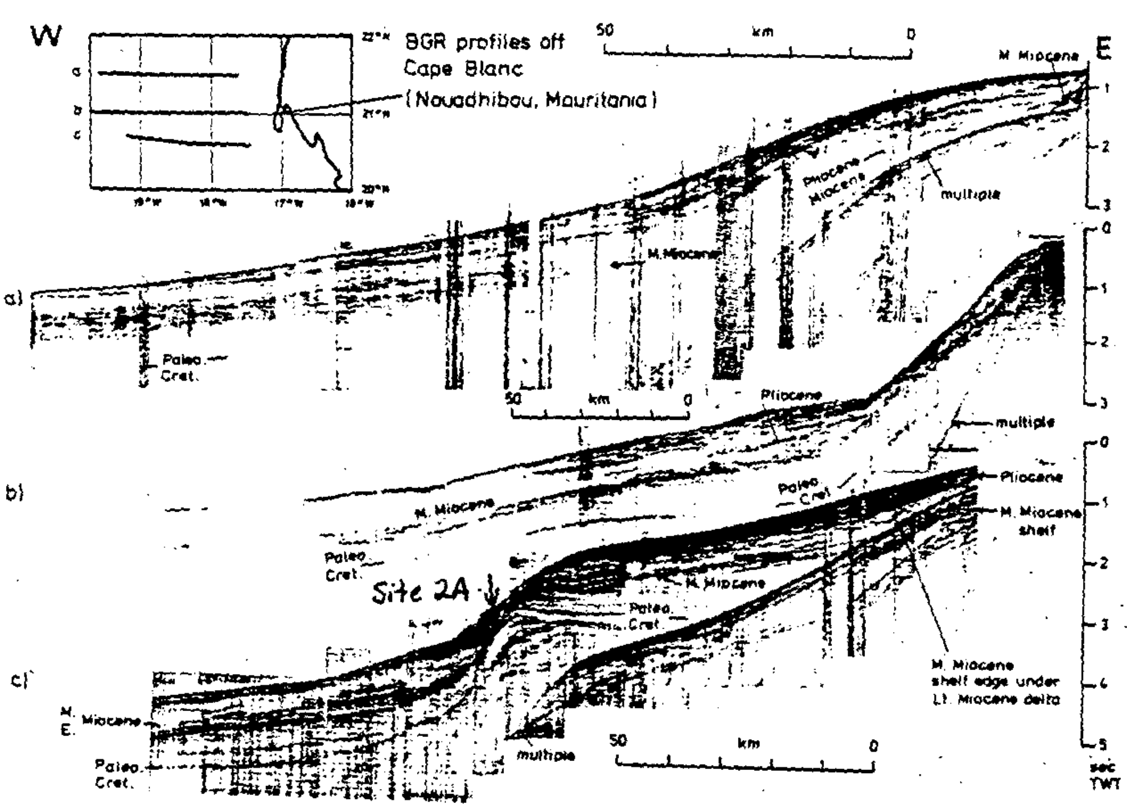

Fig. [illegible] Seismic reflection profiles off Cape Blanc

Acknowledgements

The author wants to thank Dr. J.S. Watkins for providing the Gulf oil company seismic profile 25-1. The profile is shown with the author's interpretation as a line drawing in Fig. 8 of this paper.

Drs. von Rad and Hinz critically read and improved drafts of this paper.

REFERENCES

Aymé JM (1965) The Senegal salt basin. In: Salt basins around Africa. London Inst Petroleum: 83-90

Bertrand H, Prioton JM (1975) Les dolerites marocaines et l'ouverture de l'Atlantique, Etude pétrologique et geochimique. Dissertation Université Claude Bernard-Lyon

Blot C, Crenn Y, Rechenmann J (1962) Eléments apportées par la gravimétrie à la connaissance de la tectonique profonde du Sénégal. Comptes rendus 254: 1131-1133

Cantagrel J-M, Lappartient J-R, Tessier F (1976) Nouvelles données géochronologique sur le volcanisme ouest-africain. 4ème Réun ann Sci Terre, Paris, 13-16 avril 1976: p 93

Castelain J (1965) Apercu stratigraphique et micropaléontologique du bassin du Sénégal, historique de la découverte paléontologique. BRGM Mémoire n 32, Colloque International de Micropaléontologie (Dakar, 6-11 mai 1963): 135-161

from Wissmann, 1982

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Proposed Site: Site 2B General Area: near Site 140 Position: 21°45'N, 21°48'W Alternate Site:	General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition. Thematic Panel interest: organic geochemistry Regional Panel interest: Atlantic

Specific Objectives: Site chosen to complete penetration of Upper Cretaceous.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

Other data:

Site Specific Survey Data:

Seismic profiles: Profile from Leg 14 volume.

Other Data: Drilling at Site 140 only penetrated Maestrichtian rocks. However, Cretaceous black shales in Site 138 indicate the presence of these sediments in older rocks.

Operational Considerations:

Water Depth: (m) 4500 Sed. Thickness: (m) gt 1600 Tot. penetration: (m) 1600

HPC ____ Double HPC ____ Rotary Drill ____ Single Bit ____ Reentry ____

Nature of sediments/rock anticipated: clay, limestone, shale, possible cherty layers

Weather conditions/window: good year round

Territorial jurisdiction: outside 200-mile limit, Western Sahara

Other:

Special Requirements (staffing, instrumentation, etc.):
3 organic geochemists, lithostratigrapher familiar with black shale (esp. upwelling) deposits

Proponent: Judith Totman Parrish Address & phone number: 303-236-5775 U.S. Geological Survey, MS 971 Denver Federal Center Denver, CO 80225-0046 U.S.A.	FOR OFFICE USE: Date received: Classification no.: Panel allocation:

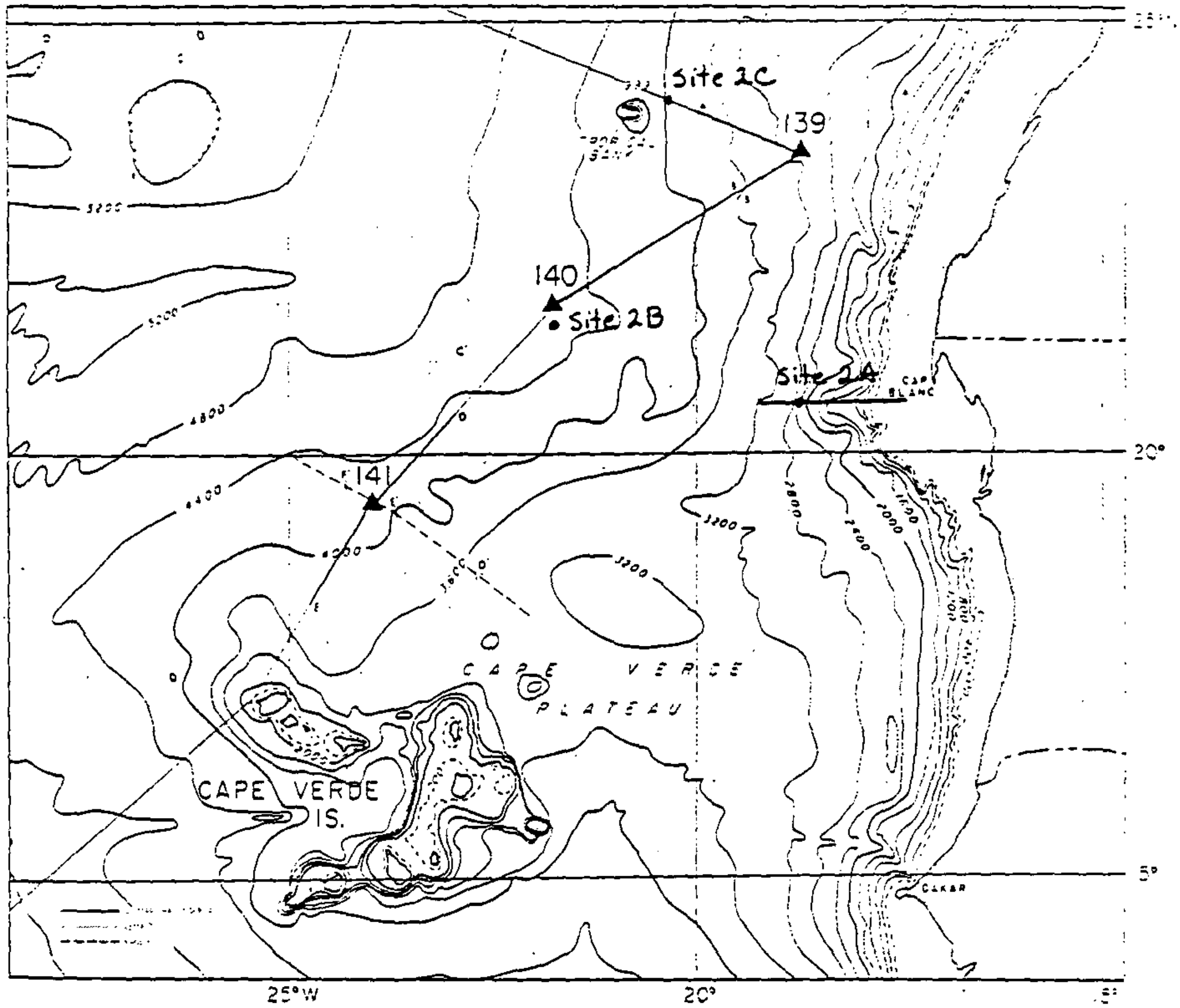

Figure 1. *Location map of Sites 139, 140, 141. Contours in corrected meters from Uchupi (1971). Letters indicate seismic profiles shown in Chapter 6, Figure 2 and Chapter 8, Figure 1.* Seismic line off Cap Blanc from Wissmann, 1982 (see attached)

indicative of Paleocene to Upper Campanian occur in 140-7 and 8. Radiolaria from 140-8 indicate a Maestrichtian age.

Foraminifera

The Pliocene foraminiferal fauna of Core 1 is of the normal pelagic type. The two following cores (140A-1, 140-2) of Miocene age apparently contain a large proportion of displaced forms. This is especially true for 140A-1, where typical shallow water fossils such as *Ammonia beccarii*, Pararotalia, Elphidium, barnacle plates, and larger mollusk shells, are associated with common planktonic foraminifera. The benthonic association of 140-2 lived probably in somewhat deeper water; it is very similar to that of Core 5 in Site 139. Of the lower cores in Site 140, only Cores 7 and 8 contain some foraminifera. These are of the agglutinated type and most probably indicate deep water below the calcium carbonate compensation level. A Paleocene to Late Campanian age for these two cores is indicated by the presence of *Rzehakina epigonalata*.

Nannoplankton

Core 1 contains rich assemblages of Late Pliocene age. The common occurrence of the four rayed *Discoaster tamalis* in this core is characteristic for the lowermost part of the *Discoaster brouweri* zone. Core 2 yields only etched assemblages of Early Miocene age. *Sphenolithus heteromorphus* and *S. belemnos* occur together with *Helicopontosphaera ampliaperta* throughout the core. Cores 3 through 8 lack calcareous nannoplankton. Core 1 of Hole 140A recovered Middle Miocene nannofossils in a poor state of preservation. Core 2 of Hole 140A does not contain any nannoplankton.

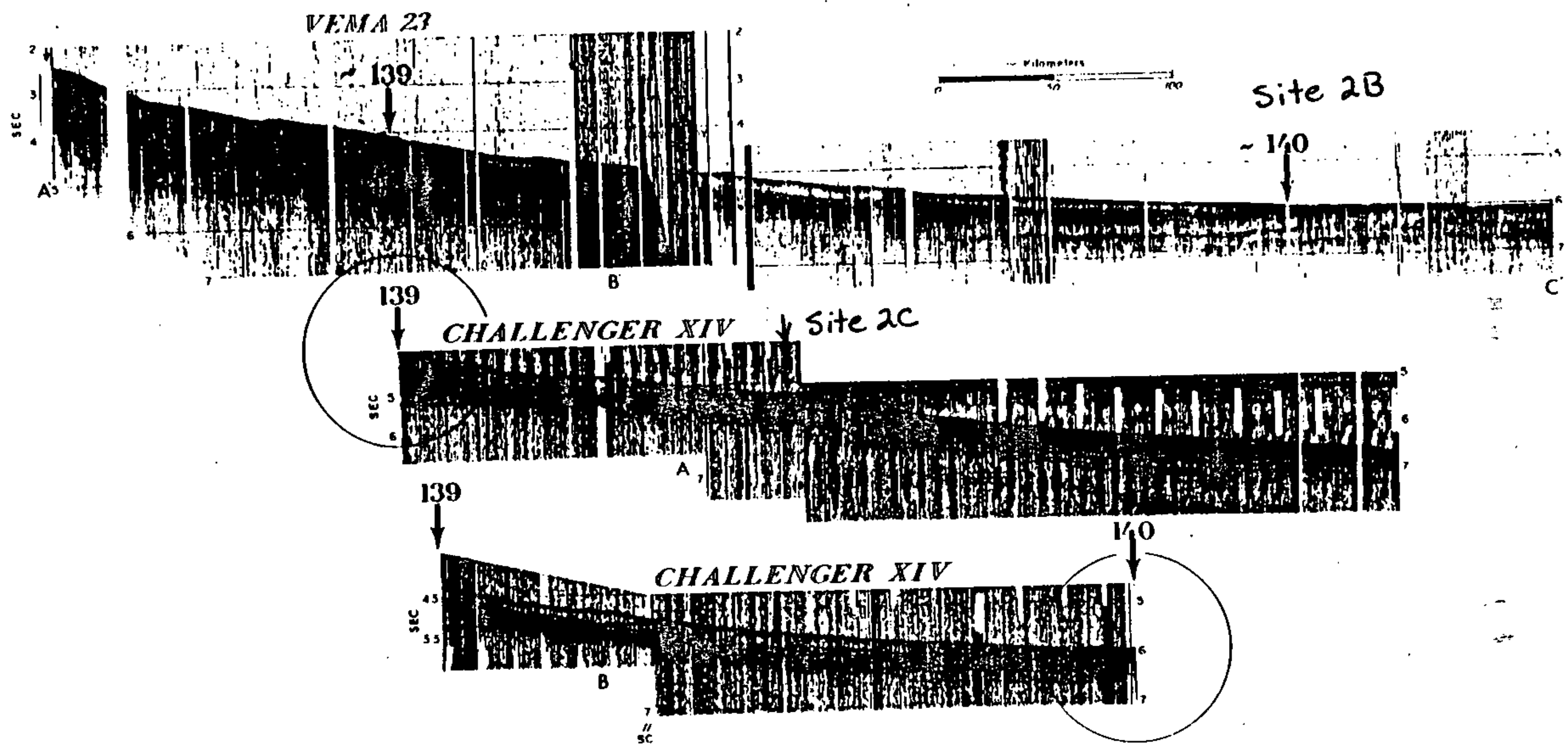

Figure 2. *Seismic reflection records in the vicinity of Sites 139 and 140. Location of profiles shown in Figure 1 and in Chapter 7, Figure 1. Note there is a change on the vertical scale near point B on the* Challenger *profile. The* Vema *profile is from unpublished Lamont Doherty Geological Observatory data (J. Ewing, pers. comm.).*

ODP SITE PROPOSAL SUMMARY FORM
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Proposed Site:

Site 2C

General Area: NW of Cap Blanc, Mauritania
Position: 24°5'N, 20°25'W
Alternate Site:

General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition.

Thematic Panel interest: organic geochemistry
Regional Panel interest: Atlantic

Specific Objectives: Intermediate in bathymetry between proposed Site 2A and Site 140. This site also is offset slightly parallel to the continental margin, providing some margin-parallel data on the distribution of the black shales.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

Other data:

Site Specific Survey Data:

Seismic profiles: Profiles from Leg 14 volume. Seismic data indicates that the thick wedge of young sediments that predominated in drilling in Site 139 pinches out just upslope from this proposed site

Other Data:

Operational Considerations:

Water Depth: (m) 4000 Sed. Thickness: (m) gt 1500 Tot. penetration: (m) 1500?

HPC ____ Double HPC ____ Rotary Drill ____ Single Bit ____ Reentry ____

Nature of sediments/rock anticipated: clay, limestone, some cherty layers, shale

Weather conditions/window: good year-round

Territorial jurisdiction: outside 200-mile limit, Western Sahara

Other:

Special Requirements (staffing, instrumentation, etc.):
3 organic geochemists, lithostratigrapher with experience in black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish
Address & phone number: 303-236-5775
U.S. Geological Survey, MS 971
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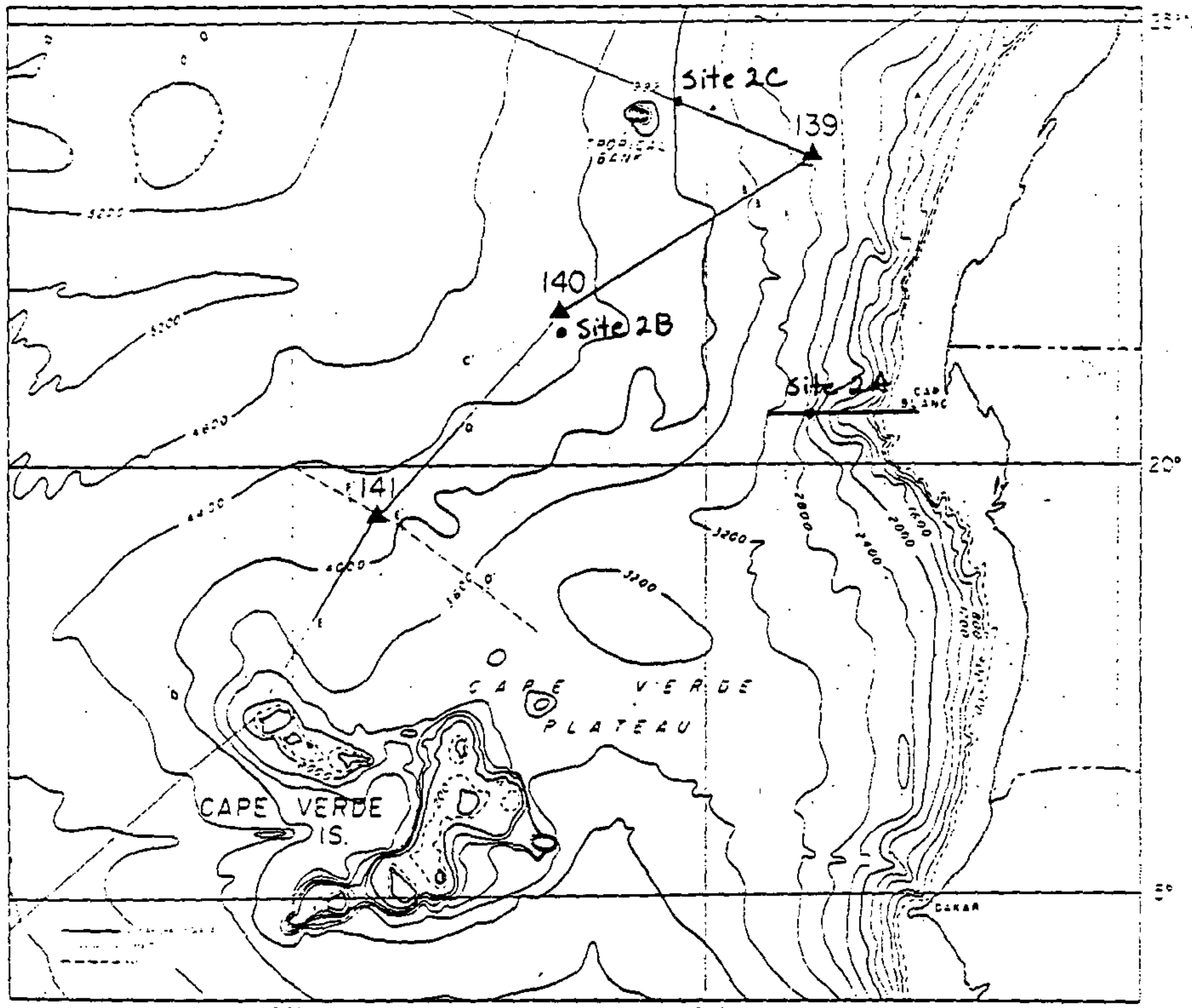


Figure 1. *Location map of Sites 139, 140, 141. Contours in corrected meters from Uchupi (1971). Letters indicate seismic profiles shown in Chapter 6, Figure 2 and Chapter 8, Figure 1.* Seismic line off Cap Blanc from Wissmann, 1982 (see attached)

indicative of Paleocene to Upper Campanian occur in 140-7 and 8. Radiolaria from 140-8 indicate a Maestrichtian age.

Foraminifera

The Pliocene foraminiferal fauna of Core 1 is of the normal pelagic type. The two following cores (140A-1, 140-2) of Miocene age apparently contain a large proportion of displaced forms. This is especially true for 140A-1, where typical shallow water fossils such as *Ammonia beccarii*, Pararotalia, Elphidium, barnacle plates, and larger mollusk shells, are associated with common planktonic foraminifera. The benthonic association of 140-2 lived probably in somewhat deeper water; it is very similar to that of Core 5 in Site 139. Of the lower cores in Site 140, only Cores 7 and 8 contain some foraminifera. These are of the agglutinated type and most probably indicate deep water below the calcium carbonate compensation level. A Paleocene to Late Campanian age for these two cores is indicated by the presence of *Rzehakina epigonalata*.

Nannoplankton

Core 1 contains rich assemblages of Late Pliocene age. The common occurrence of the four rayed *Discoaster tamalis* in this core is characteristic for the lowermost part of the *Discoaster brouweri* zone. Core 2 yields only etched assemblages of Early Miocene age. *Sphenolithus heteromorphus* and *S. belemnos* occur together with *Helicopontosphaera ampliaperta* throughout the core. Cores 3 through 8 lack calcareous nannoplankton. Core 1 of Hole 140A recovered Middle Miocene nannofossils in a poor state of preservation. Core 2 of Hole 140A does not contain any nannoplankton.

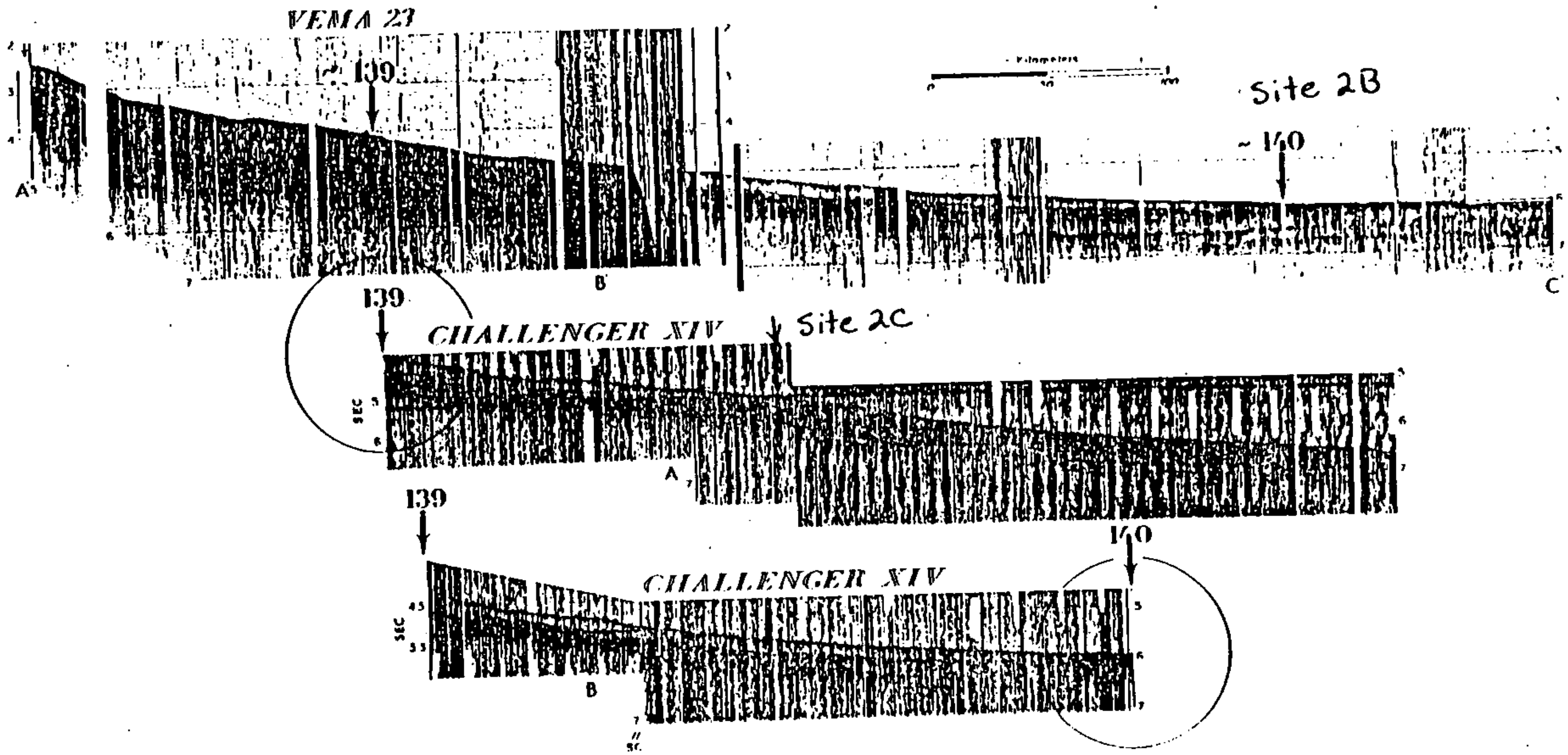


Figure 2. *Seismic reflection records in the vicinity of Sites 139 and 140. Location of profiles shown in Figure 1 and in Chapter 7, Figure 1. Note there is a change on the vertical scale near point B on the* Challenger *profile. The* Vema *profile is from unpublished Lamont Doherty Geological Observatory data (J. Ewing, pers. comm.).*

(Submit 6 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site: Site 2D General Area: NW of Cap Blanc, Mauritania Position: 25°30'N, 24°19'W Alternate Site:	General Objective: Continuously core Cretaceous black shales for study of their geometry, geochemistry, and environment of deposition. Thematic Panel interest: organic geochemistry Regional Panel interest: Atlantic

Specific Objectives: Site is deepest of proposed transect and therefore should provide data on the seaward side of the black shale depositional system. It is also intermediate in depth between Sites 140 and 138. Stratigraphy should be correlatable to Site 138, which will be part of this study (proposed separately). Basin for proposed site is deeper than that at Site 138, possibly resulting in a more expanded section.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

Other data:

Site Specific Survey Data:

Seismic profiles: Profile from Leg 14 volume

Other Data: Cretaceous black shales were penetrated at Site 138 and basement reached at about 437 m below the sea floor. The Cretaceous sediments were Upper Cretaceous; the deeper basin at the proposed site may contain slightly older rocks.

Operational Considerations:

Water Depth: (m) 5000 Sed. Thickness: (m) 1000 Tot. penetration: (m) 1000

HPC ____ Double HPC ____ Rotary Drill ____ Single Bit ____ Reentry ____

Nature of sediments/rock anticipated: clay, dolomite, siltstone, chert

Weather conditions/window: good year round

Territorial jurisdiction: outside 200-mile limit, Western Sahara

Other:

Special Requirements (staffing, instrumentation, etc.):

3 organic geochemists, lithostratigrapher familiar with black shale (especially upwelling) deposits

Proponent: Judith Totman Parrish Address & phone number: 303-236-5775 U.S. Geological Survey, MS 971 Denver Federal Center Denver CO 80225-0046 U.S.A.	FOR OFFICE USE: Date received: Classification no.: Panel allocation:

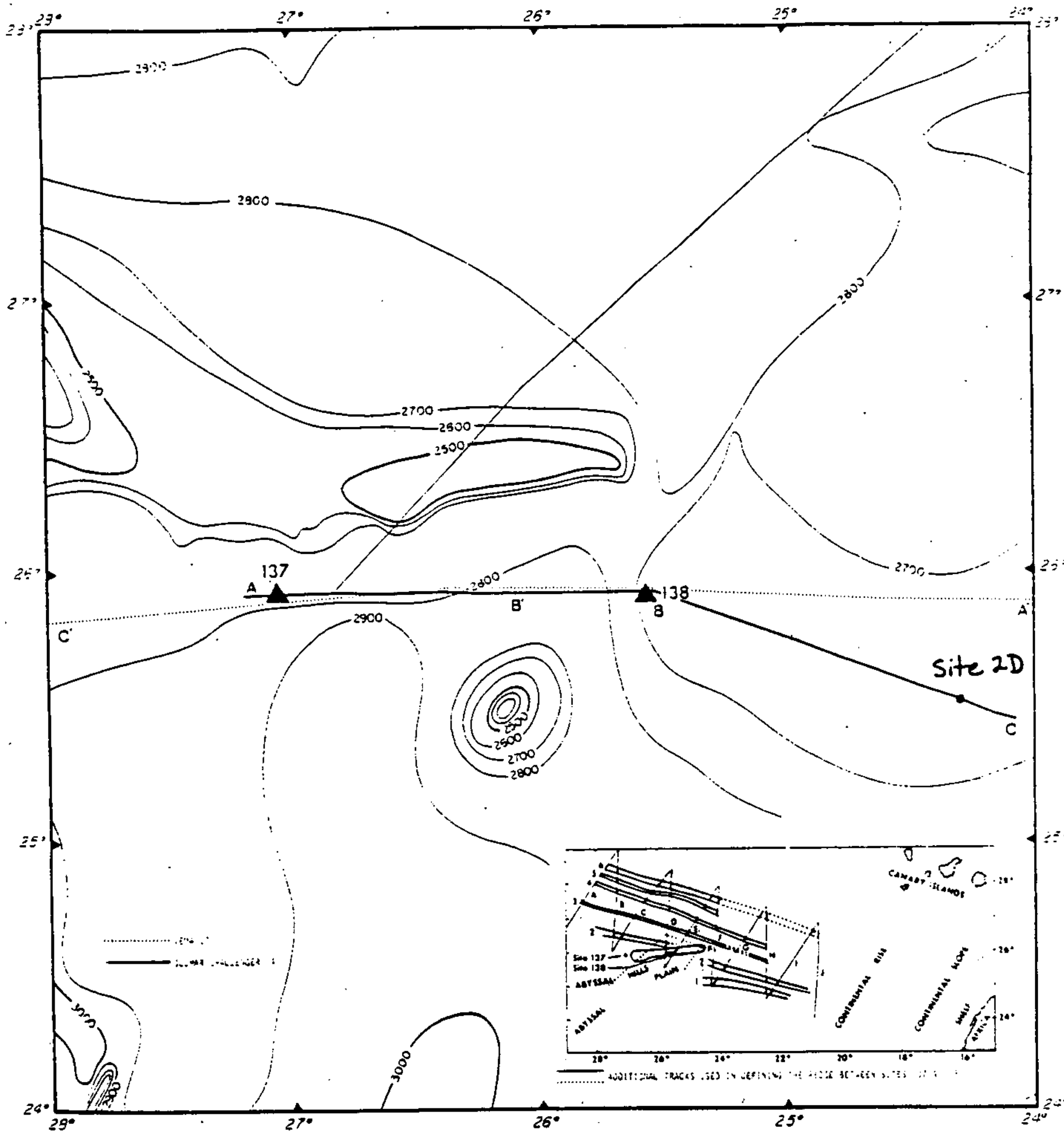


Figure 1. *Location map for Sites 137 and 138. Contours are in nominal fathoms taken from U.S. Naval Oceanographic Office B.C. Chart 0305N; contours are considered subject to major revision. Recent work of Lattimore* et. al., *(1971) is schematically summarized in the inset. Letters serve to key profiles in Figure 2.*

At Site 12 of Leg 2 (DSDP), about 300 km to the south, a thick sequence of magnesium-rich clay (palygorskite-sepiolite) was recovered. This mineral is sometimes associated with evaporite deposits. A secondary objective was to investigate the areal extent of the palygorskite and to study its mode of formation in the deep ocean environment.

Seismic Reflection Data:	*Vema 27*	*Challenger*
Intermediate Reflector	0.15 sec	0.15 sec
Basement Reflector	0.29 sec	0.30-0.40 sec

The drilling and coring records are given in Table 1 and Figure 4.

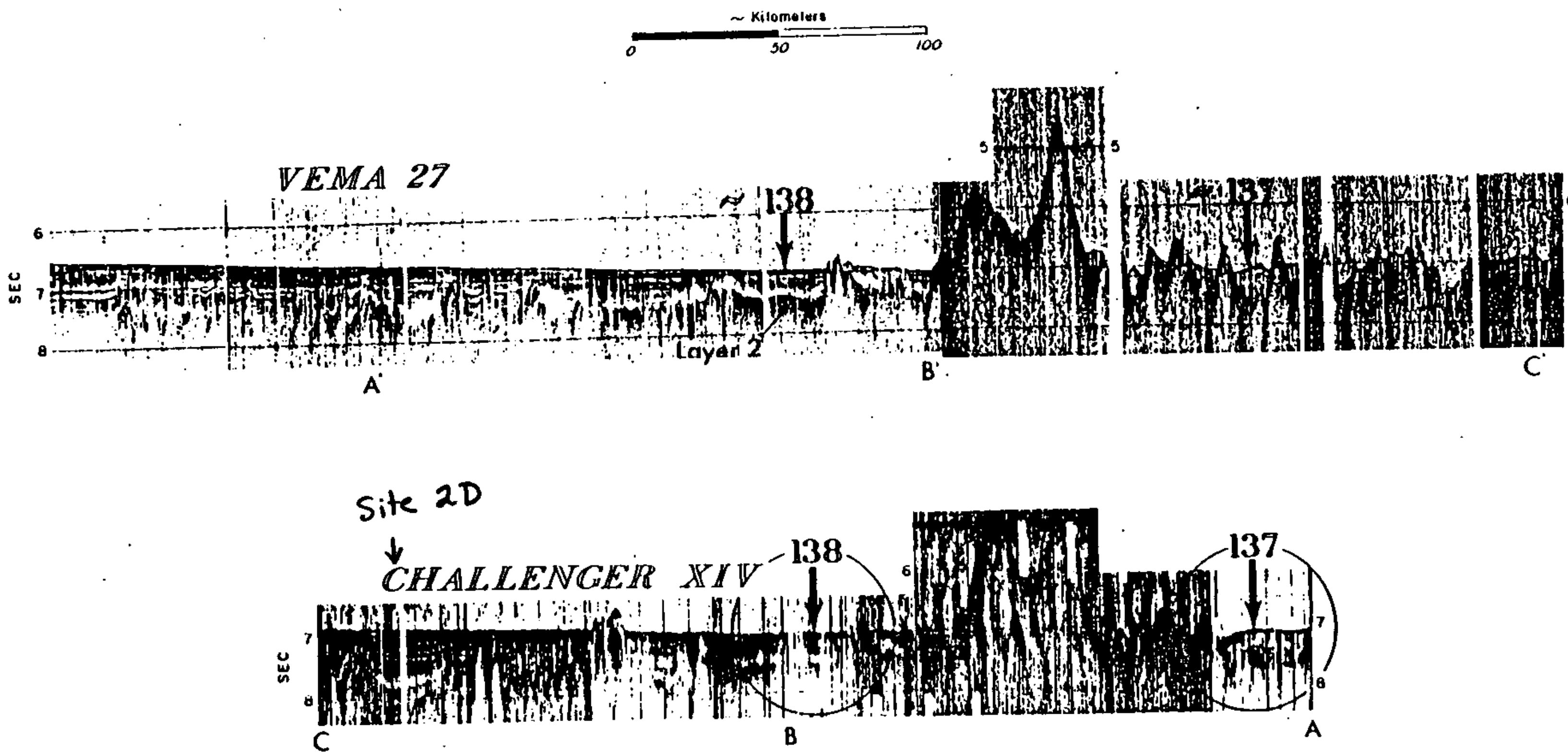


Figure 2. *Seismic reflection profiles in the vicinity of Sites 137 and 138. Location of profiles shown in Figure 1. The* Vema *record is from unpublished Lamont Doherty Geological Observatory data (J. Ewing, pers. comm.).*

ODP SITE PROPOSAL SUMMARY FORM

(Submit 6 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site: **General Area:** Gulf of Guinea **Position:** 00°52.5'N, 03°49'E **Alternate Site:** 00°45'N; 03°28.5'E	**General Objective:** Cretaceous paleoceanography of the Equatorial Atlantic **Thematic Panel interest:** Sediments/OH **Regional Panel interest:** Atlantic

Specific Objectives:

1. The conditions of Black Shale deposition in early ocean basins;
2. Establishment of the sequence of paleoceanographic events associated with the opening of the Equatorial Atlantic passage.
3. Subsidence history on a sheared continental margin.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data:

Seismic profiles:

A II 75 - Leg 2, Line 66 (Feb. 25, 1973); on file at ODP Data Bank (LDGO).

Other data:

Site Specific Survey Data:

Seismic profiles:

Other Data:

Operational Considerations:

Water Depth: (m) 4200 **Sed. Thickness: (m)** 12-1500 **Tot. penetration: (m)** 12-1500

HPC ____ **Double HPC** X **Rotary Drill** X **Single Bit** ____ **Reentry** Probable

Nature of sediments/rock anticipated: Distal turbidities/hemipelagic overlying Calcareous-pelagic

Weather conditions/window: No problem

Territorial jurisdiction: Nigeria-Economic Zone

Other:

Special Requirements (staffing, instrumentation, etc.):

Proponent: H.B. Zimmerman **Address & phone number:** Geology Dept.-Union College Schenectady, NY 12308 518/370-6310 J.P. Herbin Institut Francais du Petrole Geologie et Geochimie B.P. 311 92506 Rueil Malmaison FRANCE	**FOR OFFICE USE:** **Date received:** **Classification no.:** **Panel allocation:**

PROPOSAL FOR ODP DRILLING - GULF OF GUINEA

Herman B. Zimmerman
Jean Paul Herbin

Introduction

This proposal originated from discussions at the Workshop on Cretaceous Black Shales sponsored by JOI-USSAC (December, 1985; Denver, CO). The workshop addressed the problem of the origin of widespread depositional episodes of organic carbon in deep-marine sediments. The Gulf of Guinea was suggested as a key region to address this problem as well as other related questions concerning the Cretaceous Atlantic and the joining of the North and South Atlantic Oceans.

The sites proposed here form an eastern continuation of the equatorial traverse proposed previously by J. P. Herbin ("Paleocommunication between the North and South Atlantic Seas during the Cretaceous: formation of the Atlantic Ocean"). The objectives of these sites are similar - principally an increased understanding of black shale deposition and the dynamics of anoxic paleoenvironments; but also a more detailed understanding of the history of the African-South American separation.

Geologic Background

Regional movement at the African-South American plate boundary occurs along a series of offset, side-stepping faults (Figure 1). This en echelon structural pattern is expressed, in its early stages, as localized zones of extension (pull-apart sedimentary basins) and compression (local uplifts). Although the width of the basins is controlled by the separation of the master faults, the long dimension is controlled by the minor horsts and graben trending obliquely to the fracture zones (Figure 2; Mitchell and Reading, 1986). It is likely that the earliest sediments recording the joining of the North and South Atlantic Oceans have been deposited in this series of pull-apart basins associated with the shear between the separating continents.

The regional history of the Cretaceous equatorial Atlantic may be determined, in part, from the sediments of the marginal basins of equatorial and western Africa (Figure 3; Franks and Nairn, 1973; Machens, 1973). The establishment within the Gabon/Angola Basin of normal oceanic conditions follows the termination of evaporitic deposition; in the Guinea Basin, large accumulations of evaporites are apparently absent and a normal marine sequence follows directly on Jurassic-early Cretaceous continental, lacustrine, and lagoonal sediments. The marine history of the Gulf of Guinea commences in the Albian with sedimentation in two marginal basins: one in the region of the present-day Ivory Coast, the other in southern Nigeria. Both basins must have been connected to the open sea (Figure 4). Although surface water exchange between the North and South Atlantic Oceans had certainly been initiated by the late Albian (Reyment and Tait, 1972; Zimmerman, et al., in press), deeper exchange continued to develop through the Cenomanian.

The Albian marine/paralic sediments of the Ivory Coast marginal basins are known only from borings and exceed 2600m in thickness. They contain at least some black shales and are "rich in organic matter" (Machens, 1973). Further to the east in Nigeria, marine sedimentation began in the lower middle Albian (Reyment, 1965). Overlying sediments in the marginal basin record a rather complete late Cretaceous-Cenozoic sequence, with only Oligocene sediments missing. In both basins the Cenomanian sediments are characterized by a regressive-clastic character. The climax transgression occurs in the Turonian with a clear Tethys-Atlantic connection in the Benue Trough; this transcontinental linkage, established in the early Turonian, lasted into the Mastrichtian.

Objectives

The Gulf of Guinea is a unique area as a drilling target because of the varied objectives that may be addressed by drilling.

1. The conditions of black shale deposition. If Cretaceous evaporites were not deposited in the area of the Gulf of Guinea, their absence was probably a response to the basin's equatorial position under

high precipitation (Burke, 1975). The series of equatorial basins from the Gulf of Guinea to the Monrovia Basin, under moderate productivity and a low salinity cap provides an attractive area to test the basinal (Black Sea) model of organic deposition (e.g. Zimmerman, et al., in press).

2. The opening of the Atlantic in the Gulf of Guinea sector was dominated by transform motion associated with the large equatorial fracture zones. The Gulf of Guinea is the classic example of a sheared continental margin. Models of sheared margin subsidence and evolution have yet to be tested, even by reconnaissance scientific ocean drilling.

3. Establish the sequence of events associated with the mid-Cretaceous transgression and the opening of the equatorial Atlantic. Connection of the North and South Atlantic first occurred in late Albian time, but was probably limited to shallow exchange. Deeper connection may not have occurred until the Cenomanian and may have been responsible for the Cenomanian hiatus so widespread throughout the Atlantic. Dating and characterization of the mid-Cretaceous sediments in these basins will serve to further constrain our estimates of the timing and relationship of these tectonic and oceanographic events, both locally as well as their more distant consequences.

Proposed Site

In order to accomplish these objectives, we propose a drilling site located in the Gulf of Guinea, southwest of the Niger Cone (Figures 6 and 7). The lower continental margin and ocean basins in the area of the Cameroon bight are deeply buried and generally beyond current drilling range. To the west, however, the sediment section is thinner and the Mesozoic section and basement within range of the JOIDES Resolution.

The proposed drilling site is located on the southwestern side of a small basin to the south of the Charcot Fracture Zone, at approximately 01° N, 04° E. The basin may be found on seismic line Atlantis II 75, Leg 2, line 66 (between 0230 - 0930Z, Feb. 25, 1973); water depth is 4100m, and the sediment thickness is 1.2 - 1.5 stwt. Correlation with other seismic lines to the north (Figure 6), suggest that this is a pull-apart basin trending to the northwest - an orientation which is oblique to the regional shear. The basement highs of the basin margin resemble a series of normal faults with a northwest trend, roughly corresponding to the expected extension orientation associated with the regional shear. Age of basement is expected to be latest Albian.

We have tentatively identified the specific target location at: 00°52.5'N, 03°49'E. An alternative target, under a somewhat thinner sediment section, is located in the basin just to the west at 00°45'N, 03°28.5'E.

Although the targets are quite deep, we have an excellent chance of recovering a full record early equatorial/oceanographic events, the Cenomanian-Turonian black shale episode, and later oceanographic history in this region. The basin identified strikes a workable compromise between the geologic/oceanographic objectives of this investigation and the drilling capability currently available.

Proposed Site Survey

In order to more fully document the geological framework of the proposed site and to identify other potential drilling targets with similar objectives, we require more complete site survey information in the Gulf of Guinea. Objectives for this site survey should be:

1. the region immediately surrounding the proposed site above to better define the basin shape and its relationship to the surrounding horsts and fracture zones;

2. the area to the west - between the proposed site and site F (4^{o}N, 2^{o}W) in the Herbin drilling proposal. Although in sliding to the west we will lessen the influence of the Niger Cone and thin the sediment section, we will also shift to an area with somewhat younger basement age.

References

Burke, K., 1975. Atlantic evaporites formed by evaporation of water spilled from Pacific, Tethyan, and Southern Oceans; Geology, p. 613-616.

Franks,s. and Nairn, A.E.M., 1973. The equatorial marginal basins of West Africa; in Nairn, A.E.M. and Stehli, F.G. (eds.), The Ocean Basins and Margins, v. 1, p. 301-350.

Machens, E., 1973. The geologic history of the marginal basins along the north shore of the Gulf of Guinea; in Nairn, A.E.M. and Stehli, F.G. (eds.), The Ocean Basins and Margins, v. 1, p. 351-390.

Mitchell, A.H.G. and Reading, H.G.,1986. Sedimentation and tectonics; in Reading, H.G. (ed.), Sedimentary Environments and Facies, 2nd Ed., Blackwell Scientific Pub., London, p. 471-519.

Reyment, R.A., 1965. Aspects of the geology of Nigeria; Ibadan Univ. Press, 145p.

Reyment, R.A. and Tait, E.A., 1972. Biostratigraphical dating of the early history of the South Atlantic Ocean; Phil. Trans. Roy. Soc. London, Ser. B., v.264, p. 55-95.

Zimmerman, H.B., Boersma, A., and McCoy, F.W., in press. Carbonaceous sediment and paleoenvironment of the Cretaceous South Atlantic Ocean; in Brooks, J. and Fleet, A. (eds.), Marine Petroleum Source Rocks, Spec. Pub., Geol. Soc. London.

Figure Captions

Figure 1 - Fracture Zone trends in the equatorial South Atlantic; from SEASAT data (S. Cande, per comm.).

Figure 2 - Extensional "pull-apart" sedimentary basins produced in dextral shear regime (from Mitchell and Reading, 1986).

Figure 3 - Index map of the marginal sedimentary basins on the coast of the Gulf of Guinea (from Machens, 1973).

Figure 4 - Paleogeographic history of the marginal basins of equatorial Africa during the Cretaceous (from Machens, 1973).

Figure 5 - Synthetic flow lines for the South Atlantic with magnetic anomalies identified (S. Cande, per comm.).

Figure 6 - Index map for the proposed drilling site; track lines for Atlantis II; dashed box indicates the position of the profile of Figure 7.

Figure 7 - Seismic profile for the proposed drilling site in "pull-apart" basin associated with sheared margin.

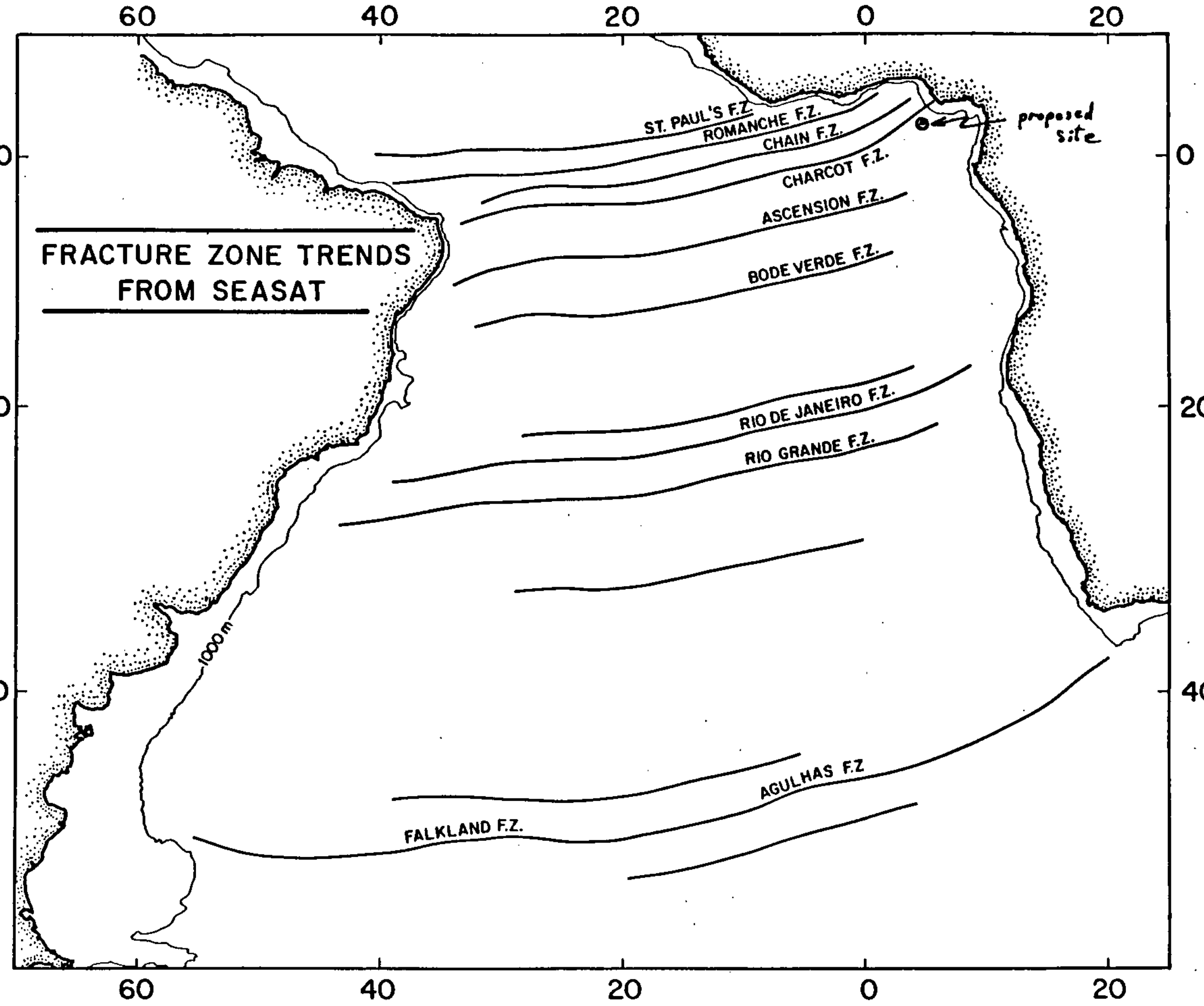

FRACTURE ZONE TRENDS
FROM SEASAT
ST. PAUL'S F.Z.
ROMANCHE F.Z.
CHAIN F.Z.
CHARCOT F.Z.
ASCENSION F.Z.
BODE VERDE F.Z.
RIO DE JANEIRO F.Z.
RIO GRANDE F.Z.
AGULHAS F.Z
FALKLAND F.Z.
1000 m
proposed site
60
40
20
0
20
40

Figure 1

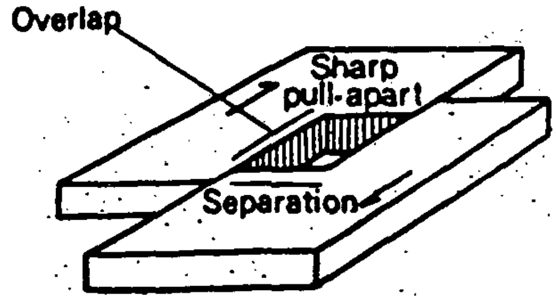


Figure 2

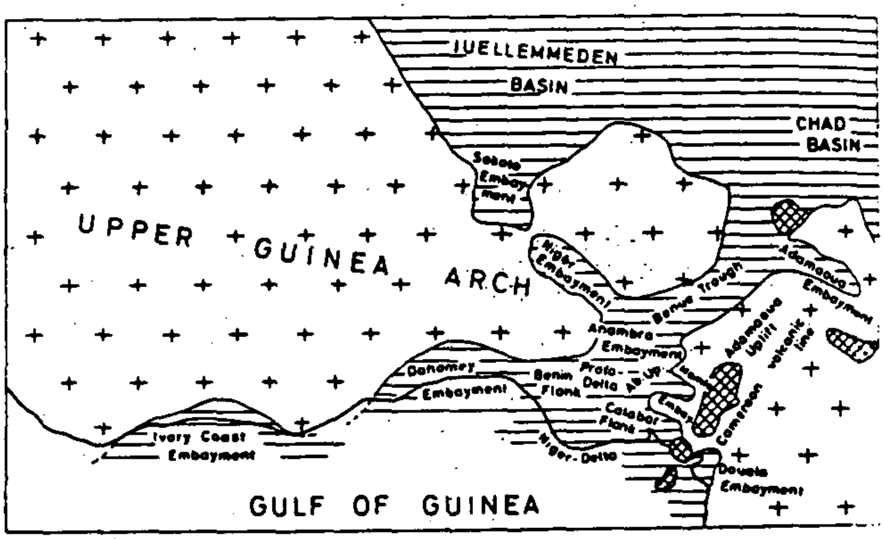
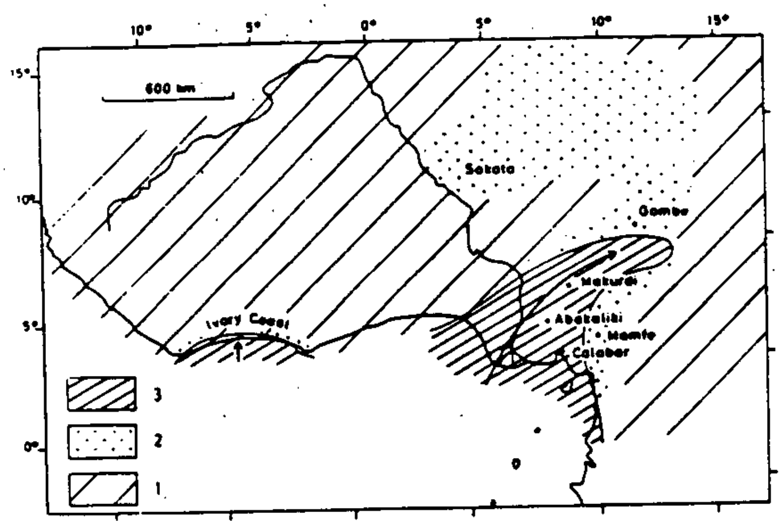
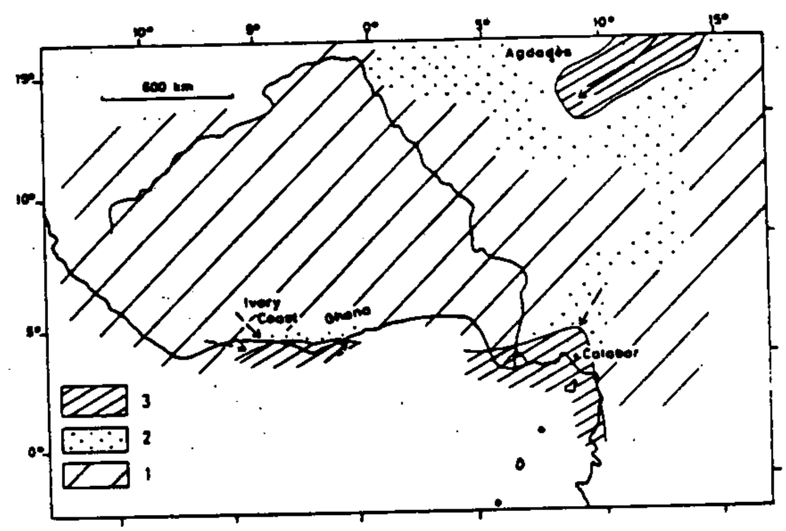


Figure 3

Figure 4



A. Paleogeographic sketch of the Middle and Upper Albian



B. Paleogeographic sketch of the Cenomanian

(3) marine zone.

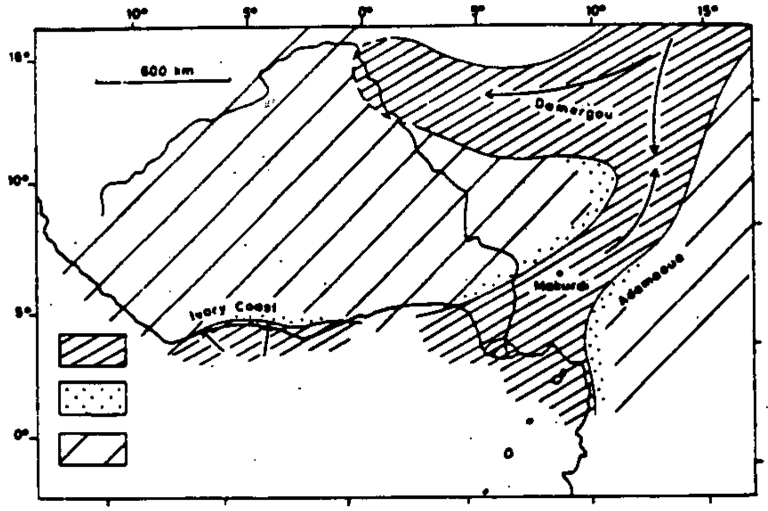
(2) region of continental sedimentation

(1) the continental area undergoing erosion;

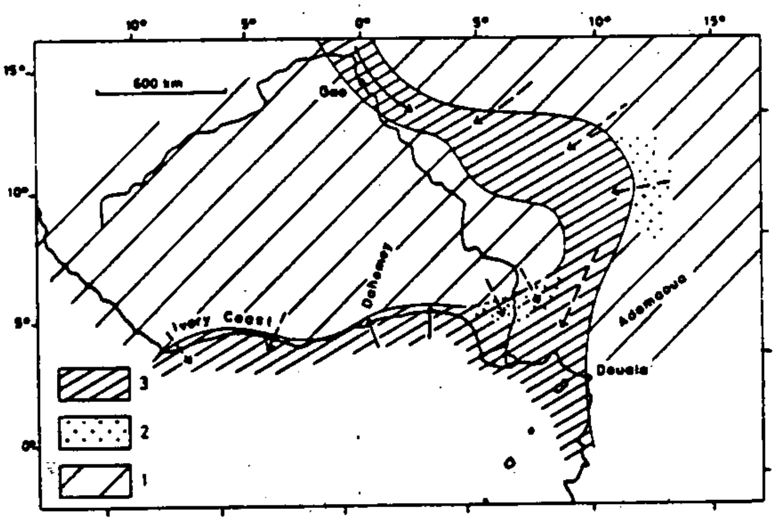
Arrows indicate transgression

dashed arrows indicate regression.

Figure 4, con



C. Paleogeographic sketch of the Turonian



D. Paleogeographic sketch of the lower-middle Maestrichtian

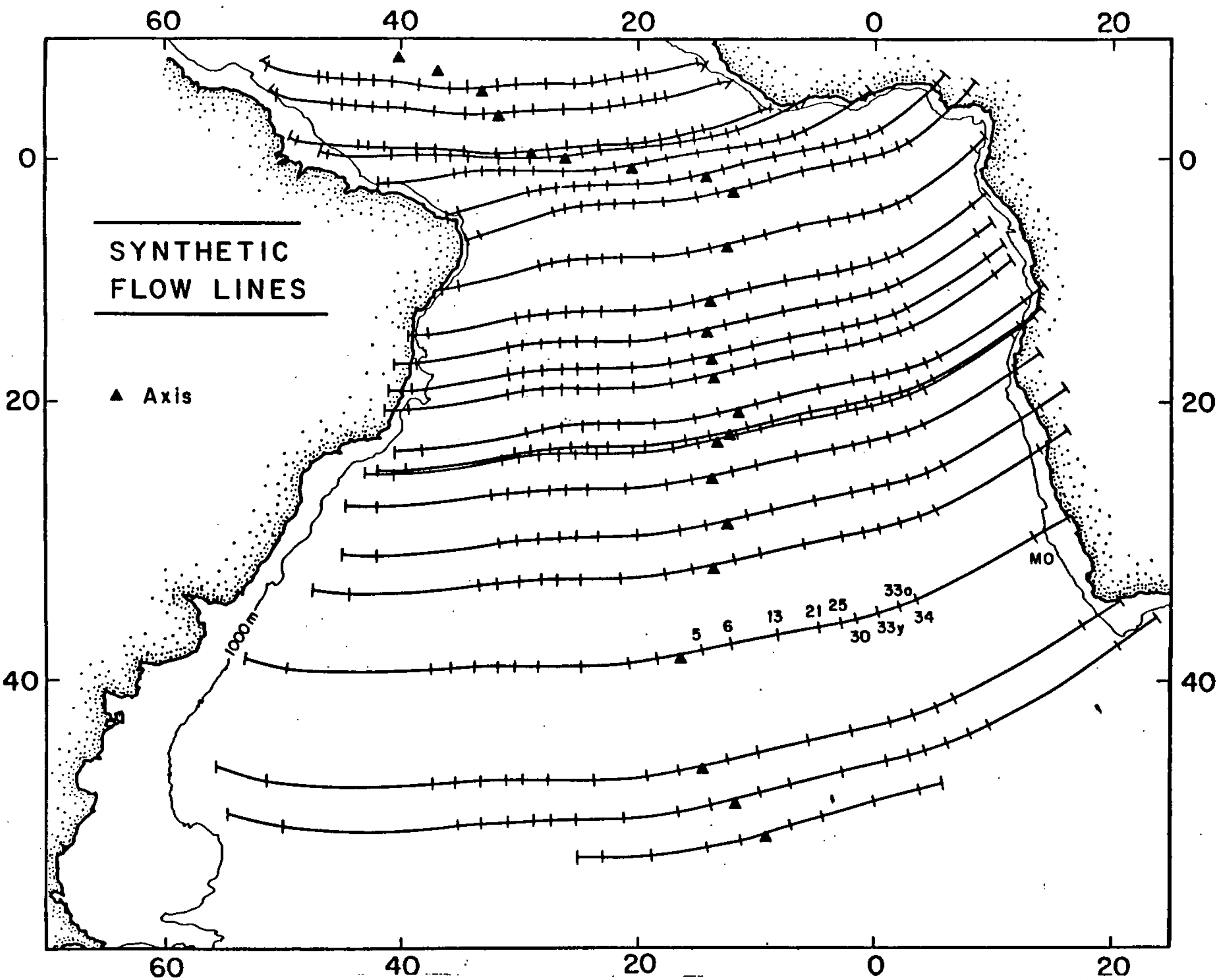
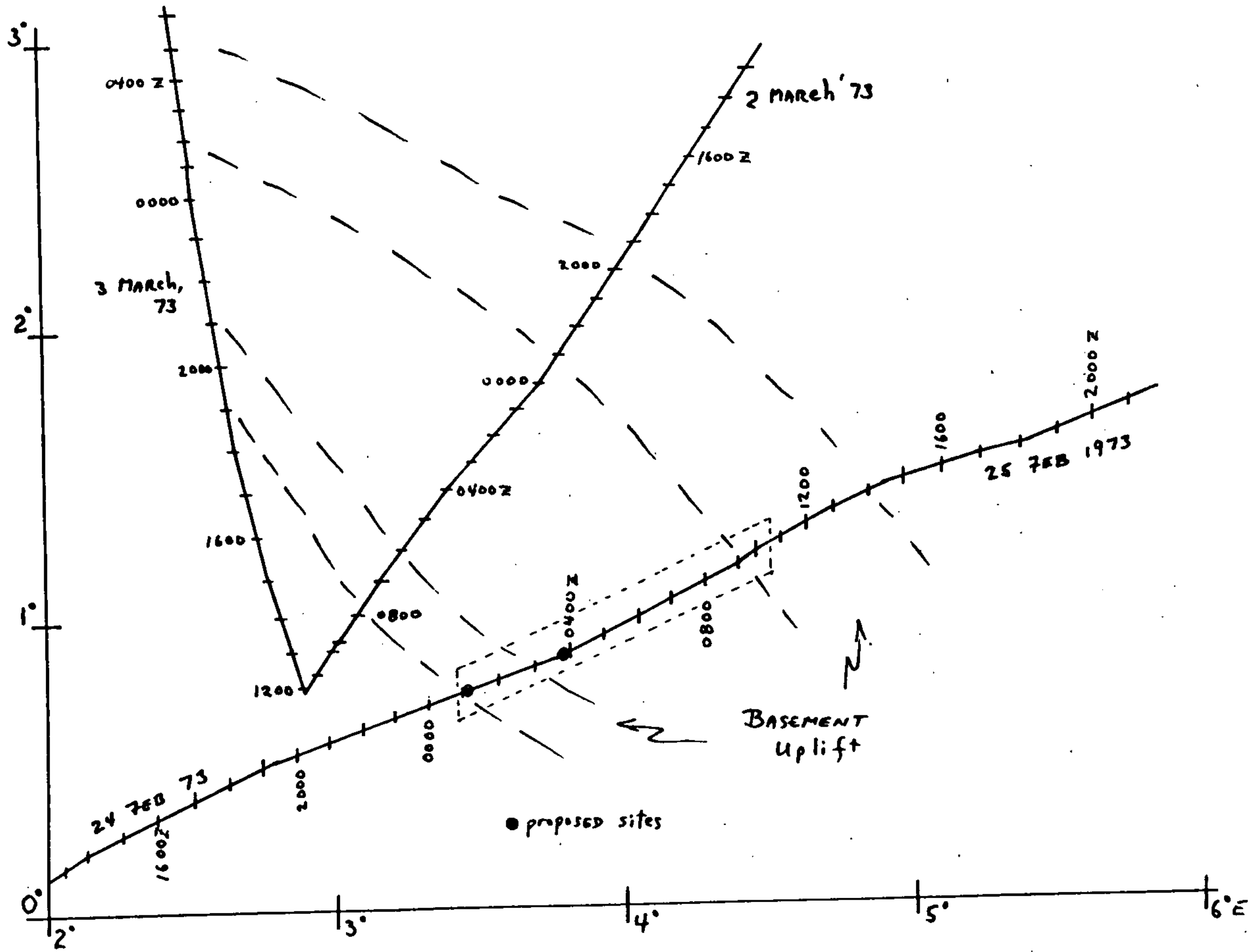


Fig. 9. Synthetic flowlines for the South Atlantic derived from a new set of stage poles. The stage poles were determined from the SEASAT fracture zone trends and all of the available marine

Figure 5



2 MARCH '73
1600 Z
2000
0000
0400 Z
0800
1200
3 MARCH, 73
0400 Z
0000
2000
1600
1200
25 FEB 1973
2000 Z
1600
1200
0800
0400 Z
0000
2000
24 FEB 73
1600 Z
BASEMENT Uplift
proposed sites
3°
2°
1°
0°
2°
3°
4°
5°
6°E

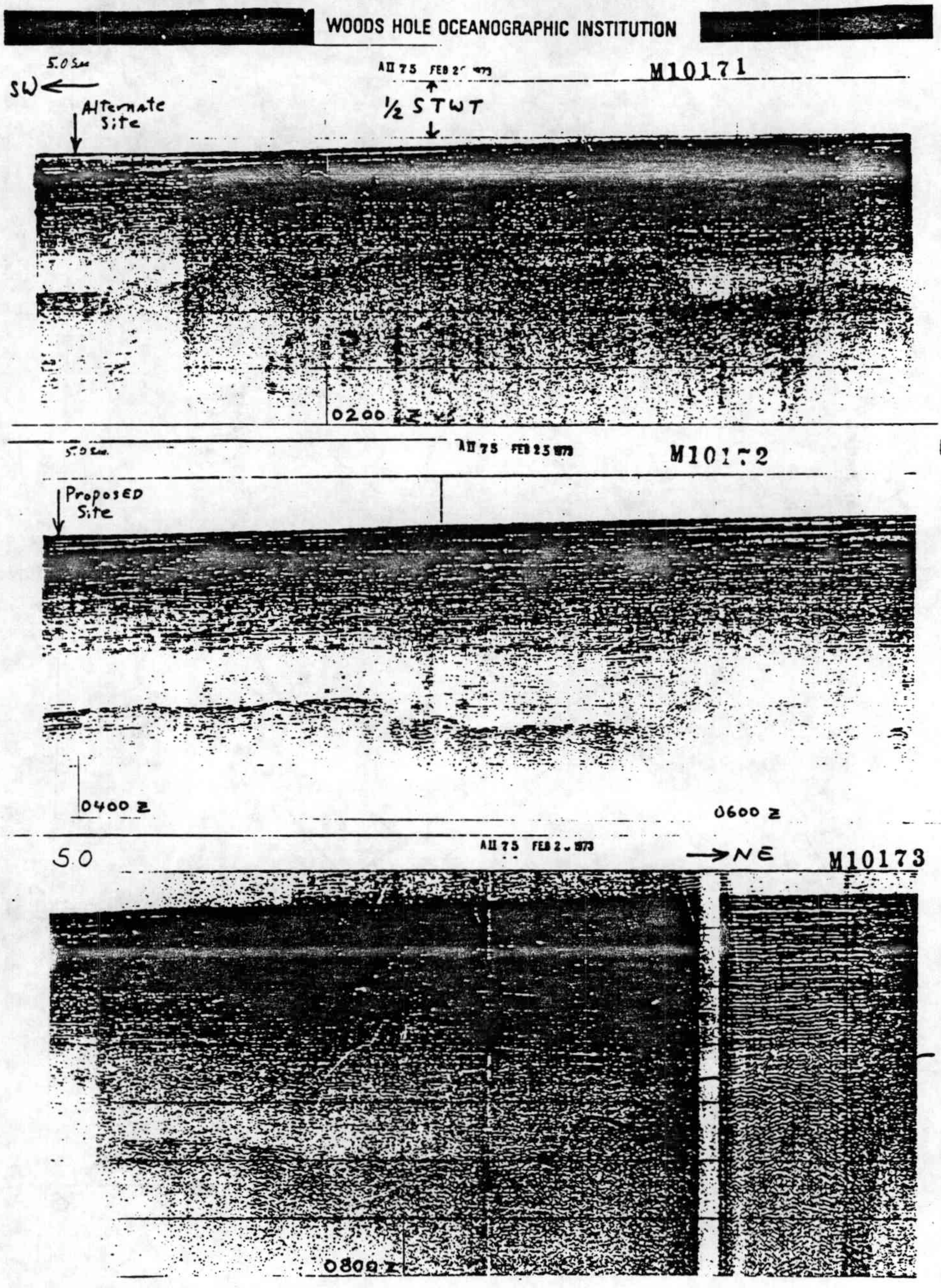

WOODS HOLE OCEANOGRAPHIC INSTITUTION
M10171
SW
Alternate Site
½ STWT
0200 Z
M10172
Proposed Site
0400 Z
0600 Z
5.0
NE
M10173
0800 Z

Figure 7

MODERN ENVIRONMENTS

(VAREC PROPOSAL)

d-l) VAREC - Varve records of climate

In order to reach a better understanding of climate, climatic and oceanic oscillations must be studied over the entire frequency range from the l to the l0 year level. At present, a gap intervenes between the observational time scales of the meteorologist (l-l00 years) and those of the geologist (millions to billions). Some inroads are being made on this gap, on the high-frequency end by tree-ring studies, and on the low-frequency end by geological investigations extending down to the precessional (20,000 year) level. But the 1,000-20,000 year interval remains essentially terra incognita.

A readable record for this time-level, containing a built-in time-keeper, exists in the form of varved deposits, in lake deposits, evaporites, and in hemipelagic depostis on continental margins. Particularly good records exist in some of the silled continental margin basins such as the Santa Barbara basin, which lie outside the normal range of turbidite sedimentation, but accumulate sediements with a high biogenic content at rates of l00-1,000 B (mm, ka) under anoxic conditions, thus excluding bioturbation and preserving a fine-scale seasonal record of events. In the Santa Barbara basin this record appears to extend back to 6,000 BP, and presumably various interglacial episodes when sea-levels were near their present stand led to older accumulations of the same sort. It seems not unreasonable to expect basins with deeper sill depths to have recorded lower sea-level times in the same way, and that Quaternary history may thus be extensively recorded in this detail, within the California borderland.

Studies by Soutar and others have shown that patterns of varve thickness over the last 200 years closely parallel California tree rings and the pattern of precipitation. Diatome floras on the other hand, presumed guides to temperature, showed unrelated patterns of variation. More general studies of the last 2,000 years revealed striking changes in the fish fauna, and in fish abundance. These are only some of the parameters available for study. Oxygen isotope studies of foraminifera should not only allow definitivties to the Quaternary pelagic isotope scale, but ought to reveal the isotopic history in far greater detail. They should also provide data on fertility changes. By these and other means it should be possible to obtain wholly new insights into the history of the California margin, and into the differences between glacial and interglacial regimes.

INDIAN OCEAN

SITE PROPOSALS

ATTACHMENT 1

Western Somali Basin

SOMALI BASIN DEEP HOLE

A deep site in the Somali Basin is considered an extremely important objective by SOHP in order to examine the Late Jurassic through Recent history of sedimentation along the east African margin, and for investigation of the seismic-stratigraphic signature of relative sea level changes. The site is recommended to be located on or near seafloor of Chron M25 age (Callovian-Oxfordian), giving us another sequence on nearly the oldest Jurassic crust in the Indian Ocean. The site would be a conjugate to the proposed high priority Exmouth Plateau-Argo Abyssal Plain transect (AAP-1 is located on anomaly M25), and would allow us to contrast the depositional history, margin subsidence patterns, sea level changes and paleoceanography of a thickly sedimented margin (Somalia) versus a starved passive margin (NW. Australia) of the same age. In addition, the formation of the Somali Basin probably allowed the first major exchange of water masses between the high latitude southern Ocean-South Atlantic and equatorial Tethys through the late Jurassic and early Cretaceous.

A) Questions to resolve through deep drilling:
1. Timing of rifting of Madagascar and separation from Africa and initial development of a narrow longitudinal seaway; subsidence and first deep-water exchange with southern ocean.
2. "Oldest" Tethyan crust preserved intact (with perhaps exception of northern Somali Basin).
3. Problem of gateways, ammonite evolution and faunal exchange between high and low latitudes; possible intensified deep circulation in mid-Cretaceous (inferred from seismic records).
4. Site of accumulation of sediment lost from Africa during Cretaceous rifting and uplift of South Atlantic margin.
5. Constrain age and volumes of evaporites in deep basin along margin.
6. Climatic evolution of east Africa and timing of east African uplift (in Neogene).
7. Premonsoonal climates of the western Indian Ocean region
8. Black shale events (are they manifested there and what is their character) of the Jurassic and Cretaceous.

B) Global Objectives:
1. East-west tilt of Africa during rifting and opening of S. Atlantic Ocean; applicability of Vail onlap-offlap curve (comparison with NW Australian margin which has different freeboard history but roughly the same paleolatitude.
2. Mid-latitude (equatorial) long-term climate record.
3. Reference section for Indus cone--tectonics vs. sea level effects on sediment supply

Requirements for location

1. Crustal age, anomaly M25.
2. Off thick evaporites, but at or close to feather edge of evaporite strata to enable dating and seismic correlation.
3. Total sediment thickness of no more than about 2.5 km to allow penetration and recovery during normal-length drilling leg; water depth of less than 4.5 km--total depth to basement of less than 7 km. We would argue that such a test of the drilling platform should be made; we do not yet know whether drilling to depths greater than 1.5 km is feasible, and the opportunity to test the Resolution's capabilities should be made early in the program because many more such deep-drilling proposals will be made.
4. Oblique seismic experiment and complete logging.
5. Case deeply to improve hole conditions and likelihood of reaching basement ?

The optimal location is near but to northeast of DSDP Site 241 (see Figs. 1-4; sequence is probably too thick at Site 241). Examination of available seismic and other data (source: M. Coffin, 1985, PhD Dissertation, LDGO) (see attached Figures) suggests that if further site surveys are not possible, an alternate Site along multichannel Line 81 (Figs. 5 and 7), but probably on anomaly M23 (Oxfordian-Kimmeridgian) crust meets the sequence thickness-water depth criteria above.

ODP SITE PROPOSAL SUMMARY FORM

(Submit 6 copies of mature proposals, 3 copies of preliminary proposals)

Proposed Site: Somali Basin DST-1

General Area: W. Somali Basin
Position: 0°40'S 47°S 'E (approx.)
Alternate Site: (Old DSDP 241)

General Objective: Jurassic through Quaternary sedimentation, sea level changes and seismic stratigraphic history of a sedimented passive margin; paleocirculation black shales, African tectonic history.

Thematic Panel interest: SOHP, TECP
Regional Panel interest: IOP

Specific Objectives: To obtain continuous stratigraphic sequences of Jurasic through Recent age to understand tectonic history of Africa, paleocirculation between Tethys and southern Ocean, paleoclimatic history, and to date age of crust at inferred anomaly M25.

Background Information (indicate status of data as outlined in the Guidelines):

Regional Geophysical Data: Numerous boreholes (see Coffin, 1985, Ph.D. Dissert., LDGO)
Seismic profiles: on margins of Somalia, Tanzania, Madagascan; gravity and magnetics.
Single channel oversite, but regional net of multichannel lines just to South over much of Somali Basin.
Other data:

Site Specific Survey Data:
Seismic profiles:
Single channel line, but Site Surveys needed; need multichannel data across site with link to existing net.
Other Data:

Operational Considerations:

Water Depth: (m) ca 4300 Sed. Thickness: (m) ca 2500 Tot. penetration: (m) 2600

HPC ____ Double HPC X Rotary Drill X Single Bit ____ Reentry X

Nature of sediments/rock anticipated: Shales, carbonates, some lithified sand and silt in Jurassic-Cretaceous.

Weather conditions/window: Monsoons not too strong; sea conditions fair most of year.

Territorial jurisdiction: Somalia

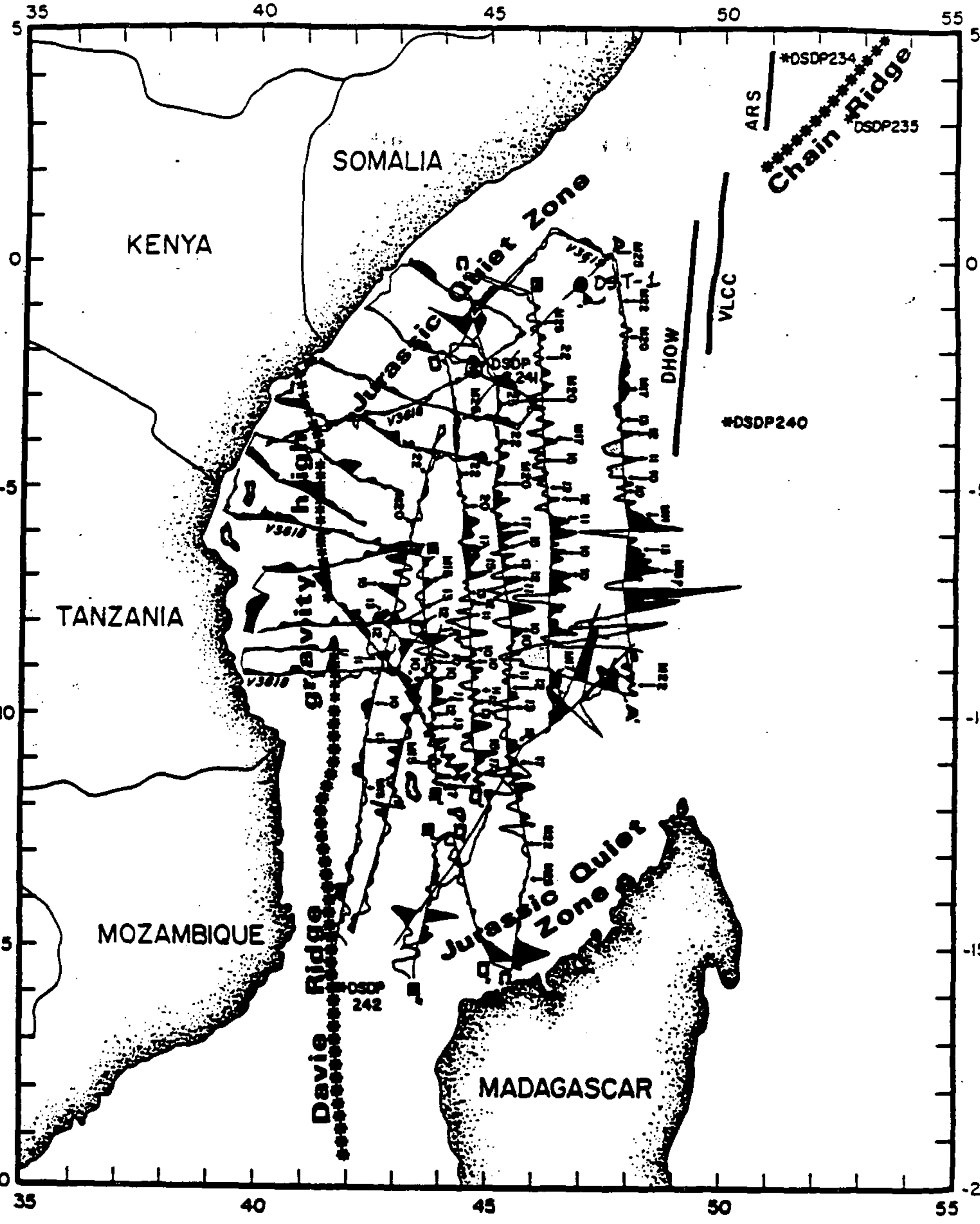
Other:

Special Requirements (staffing, instrumentation, etc.):

Need oblique seismic experiment; casing of upper part of hole; complete logging.

Proponent: SOHP, M. Coffin
Address & phone number: (M. Arthur; GSO/URI;401-792-6867)

FOR OFFICE USE:
Date received:
Classification no.:
Panel allocation:



SOMALIA
KENYA
TANZANIA
MOZAMBIQUE
MADAGASCAR
Jurassic Quiet Zone
Jurassic Quiet Zone
Davie Ridge
gravity high
Chain Ridge
ARS
VLCC
DHOW
DSDP234
DSDP235
DSDP240
DSDP 241
DSDP 242
DST-1
V3618
35
40
45
50
55
5
0
-5
-10
-15
-20

Figure 1

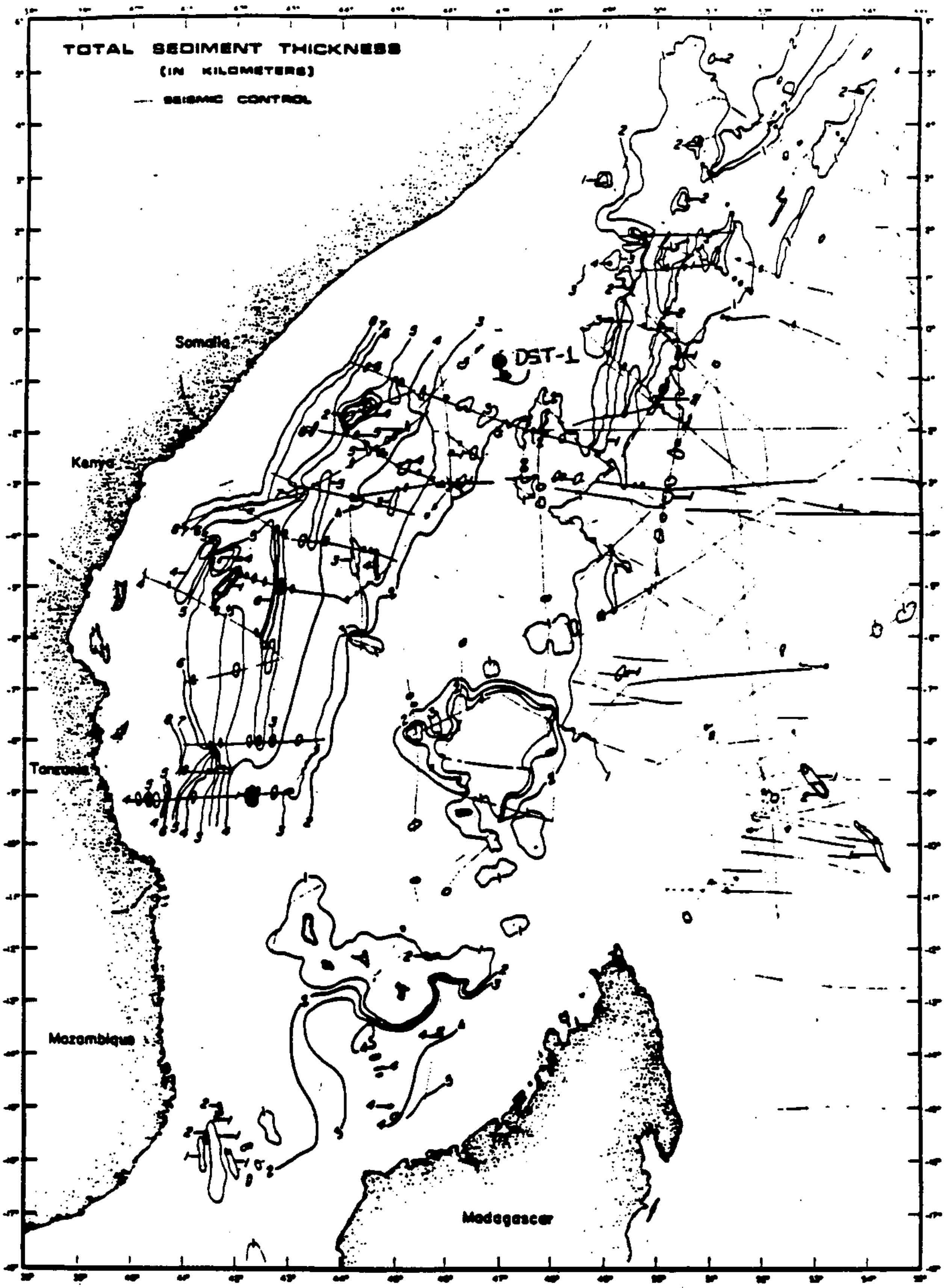

TOTAL SEDIMENT THICKNESS
(IN KILOMETERS)
SEISMIC CONTROL
Somalia
Kenya
Tanzania
Mozambique
Madagascar
DST-1

Figure 2

ODP SITE PROPOSAL SUMMARY FORM

Proposed Site: AAP1A, ARGO ABYSSAL PLAIN (Figs. 65, 67)

General Area: SE Argo Abyssal Plain
Position: 16°S; 117°38'E
Alternate Site: AAP1
16°00'S, 114°45'E

General Objective:
Nature of sediment and mid-Jurassic oceanic basement: early rifting history of NW Australian passive margins.
Thematic Panel interest: LITHP, SOHP, TECP
Regional Panel interest: IO-RP

Specific Objectives:

- The nature and exact age of oceanic basement in one of the world's oldest oceanic basins.
- Age and lithofacies of the overlying three seismic sequences, widespread on Argo Abyssal Plain - questions of oceanic circulation with relation to climate and configuration of land masses, and variation of facies with eustasy and tectonics.

Background Information:

Regional Data:
Seismic profiles: On Shell profiles N207 and N208; BMR and Atlantis II lines in area.
Other data: BMR and Atlantis II mangetics and gravity data.

Site Survey Data - Conducted by:
Date: Could be included in BMR multichannel seismic survey of Exmouth
Main results: Plateau in early 1986

Operational Considerations

Water Depth: (m) 5700 **Sed. Thickness: (m)** 1250 **Total penetration: (m)** 1350

HPC 300 **Double HPC** ____ **Rotary Drill** 1050 **Single Bit** ____ **Reentry** ?

Nature of sediments/rock anticipated: 400m Cz and Late Cretaceous ooze; 250m mid-Cretaceous claystone; 600m Late Jurassic and E. Cretaceous claystone; 100m mid-Jurassic oceanic crust.
Weather conditions/window: Good, except November to March when cyclones.

Territorial jurisdiction: Australian

Other: Thinner sequence could be drilled elsewhere on N207 or N208 (oldest sequence ca. 300m thick), but oldest sediments might be younger.

Special requirements (Staffing, instrumentation, etc.)

Proponents: Ulrich von Rad and Neville Exon
undesanstalt fuer Geowissenschaften und Rohstoffe
Bureau of Mineral Resouces
G P O Box 378

Date submitted to JOIDES Office:

<u>Suggested sites</u>: Proposed sites AAP1 (alternate AAP1A) are shown on Fig. 65. Multichannel site surveys could be run by BMR in early 1986. The holes proposed are :

AAP1 : 16°00'S, 114°45'E; total penetration 800m (600m of sediment + 100m of oceanic crust), drilling time: 12 days.

AAP1A: 16°00'S, 117°38'E; total penetration 1350m (1250m sediment + 100m oceanic crust).

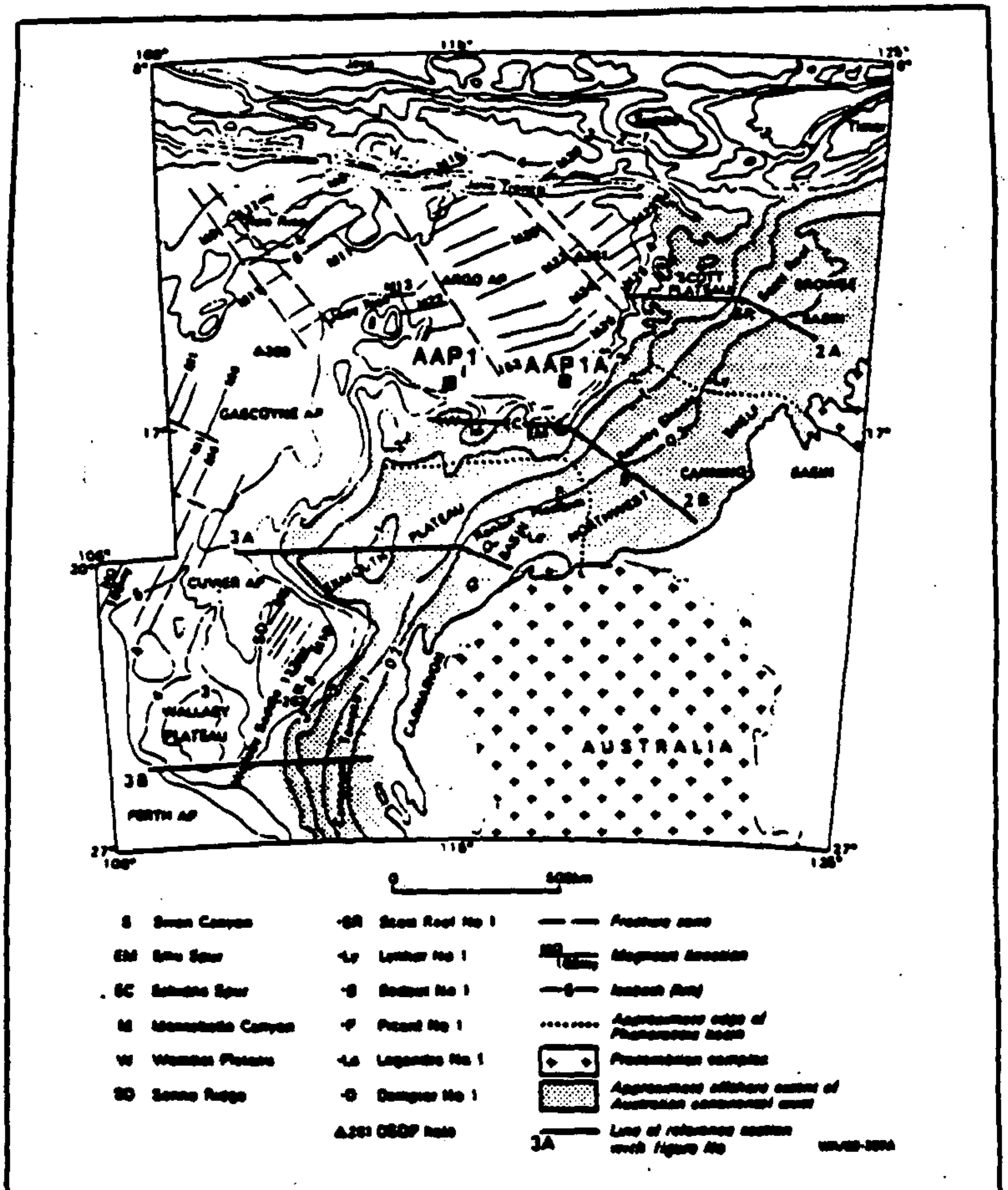


Figure 65. Regional and tectonic setting of the Scott, Exmouth and Wallaby Plateaus off northwest Australia, showing general [illegible] and selected commercial shelf wells. Bathymetry after Falvey and Veevers (1974) and Veevers and Cotterill (1978); magnetic lineations after Heirtzler et al (1978) and Larson et al (1979) [illegible] reference sections (Figures [illegible])

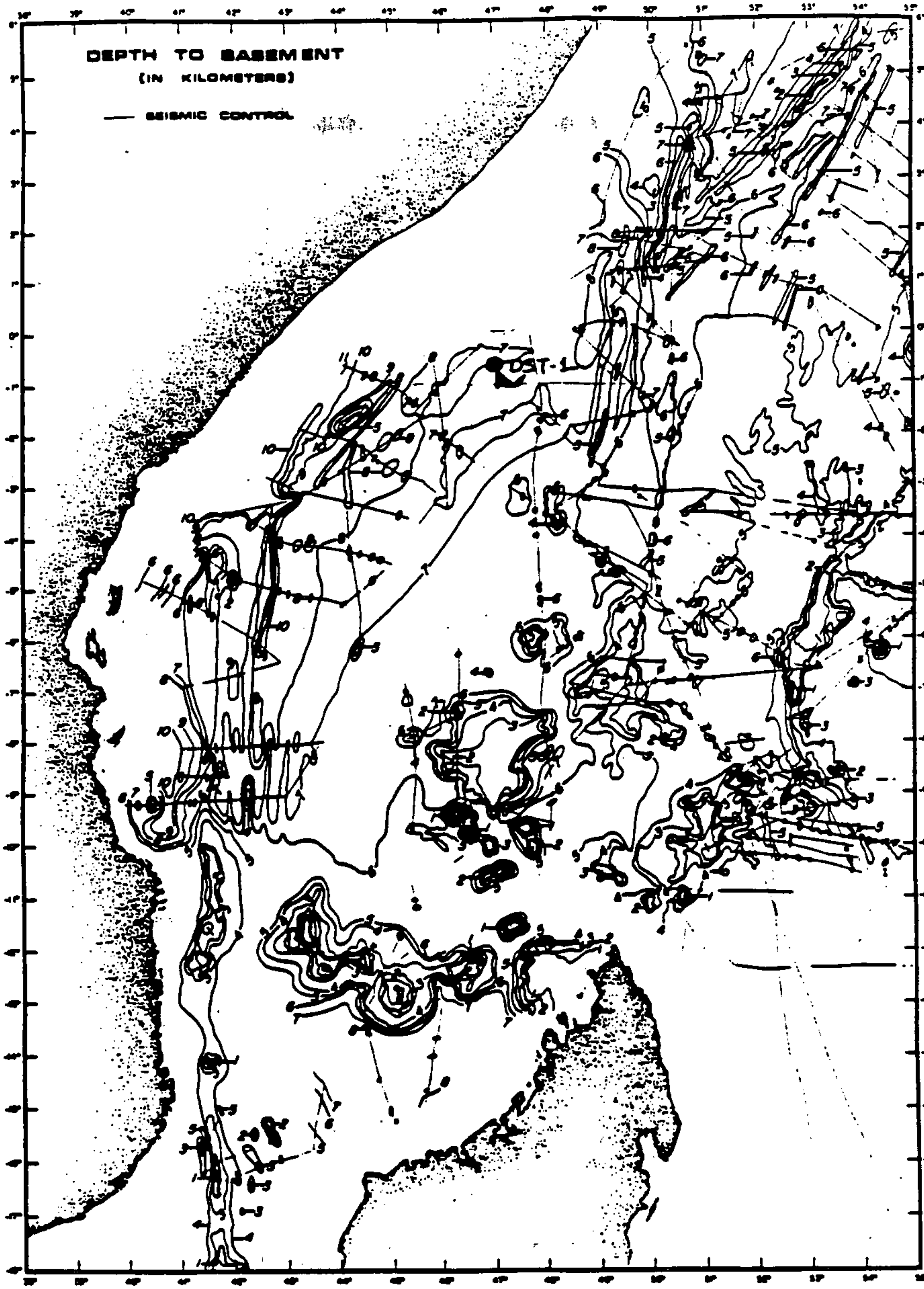


Figure 3

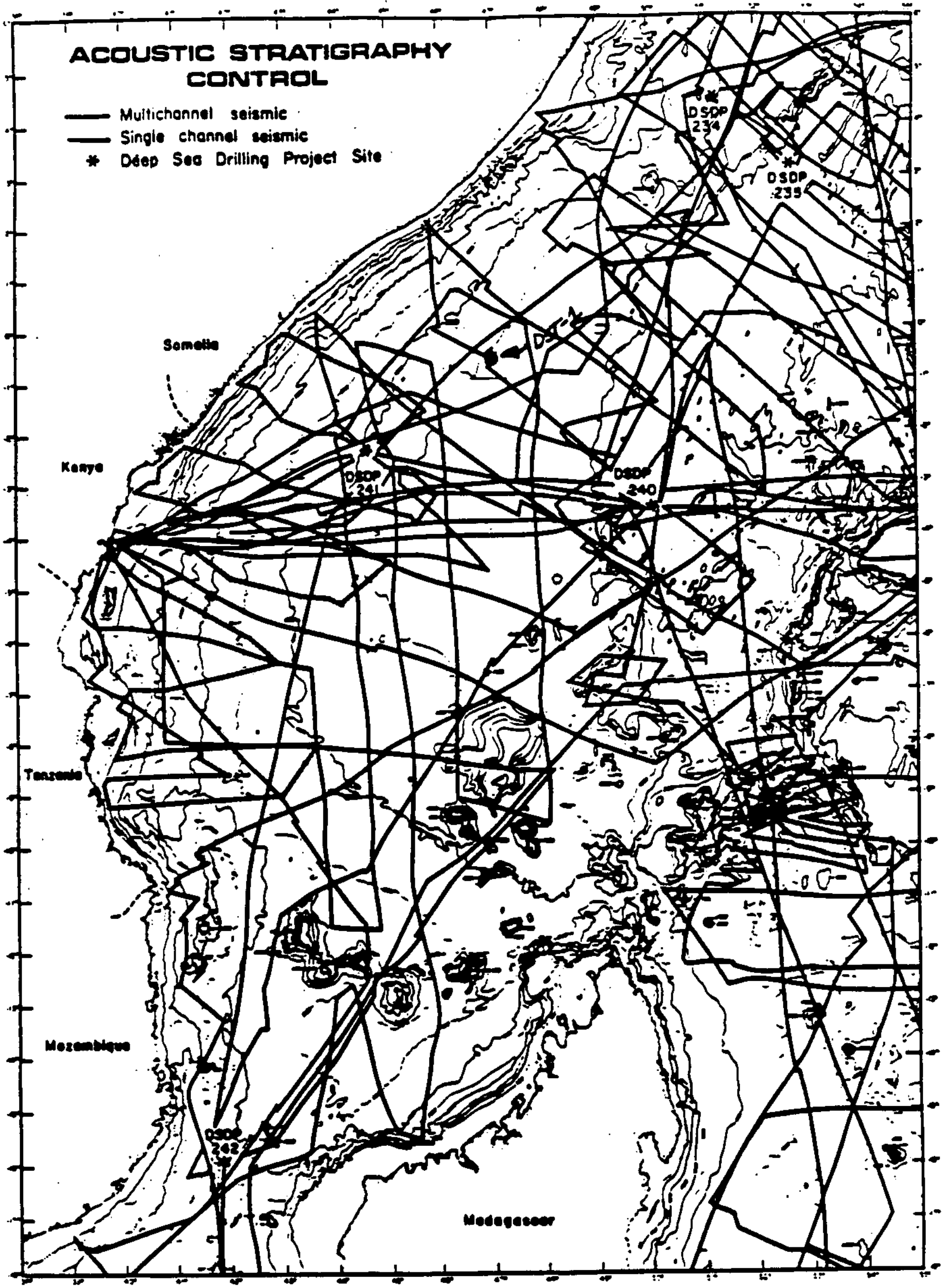

ACOUSTIC STRATIGRAPHY CONTROL
Multichannel seismic
Single channel seismic
Deep Sea Drilling Project Site
DSDP 234
DSDP 235
Somalia
Kenya
DSDP 241
DSDP 240
Tanzania
Mozambique
DSDP 242
Madagascar

Figure 4.

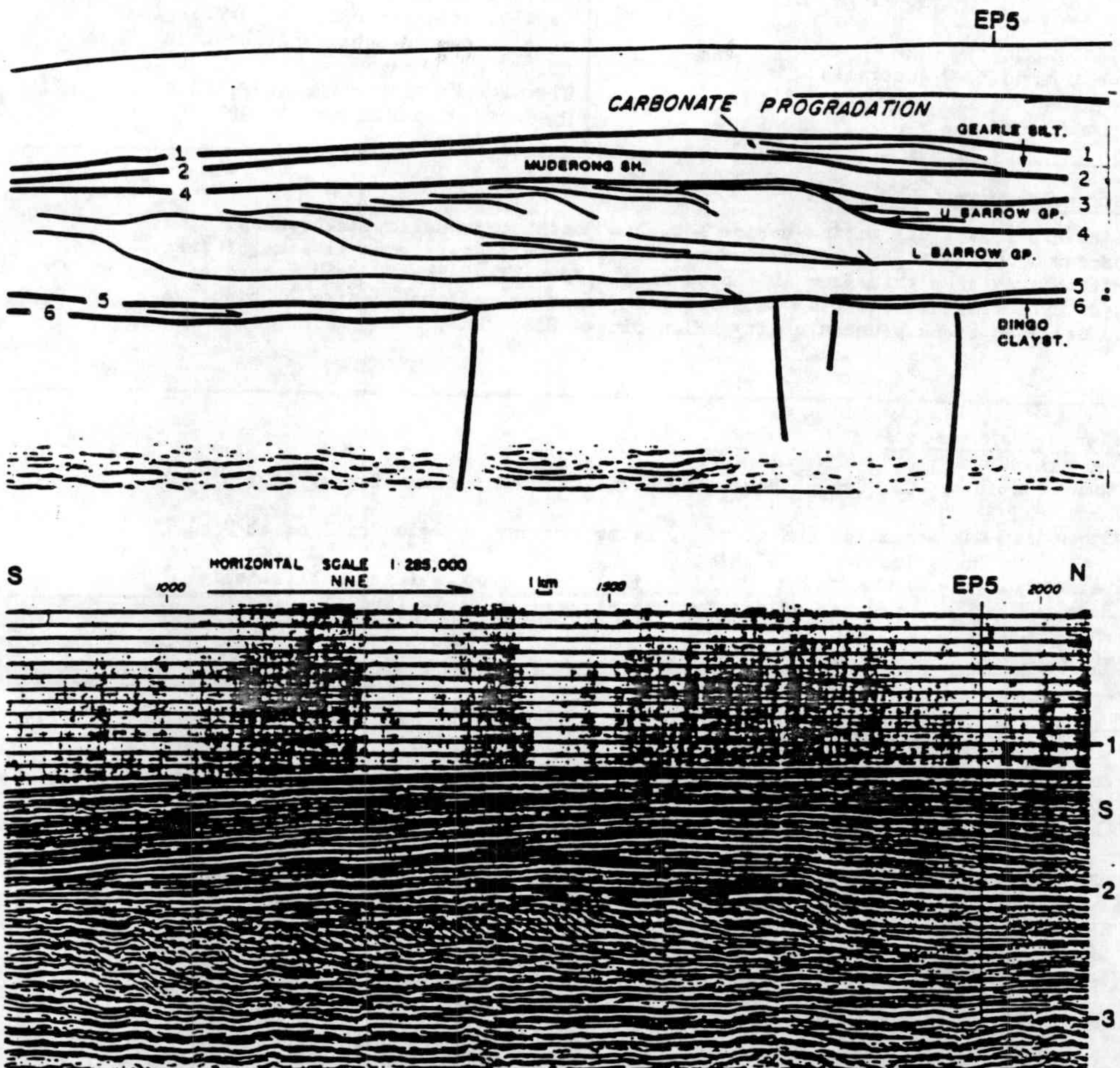


Fig. 81. Location of site EP5

ODP SITE PROPOSAL SUMMARY FORM

Proposed Site: EP5, CENTRAL EXMOUTH PLATEAU
(Figs. 72-76, 81)

General Area: NW Australia
Position: 20°15'S, 113°12'E
Alternate Site:

General Objective:
Late Jurassic to Late Cretaceous sea levels. Sedimentological expression of rifting and subsidence history

Thematic Panel interest: SOHP, TECP
Regional Panel interest: IO-RP

Specific Objectives:

Site has a marginal marine-marine sequence dating from Callovian breakup. Barrow Group delta becomes sediment-starved in Late Cretaceous as some of area rifted away on a transform in second margin formation phase. Good record of sea level fluctuations from Late Jurassic on in delta front facies. Objective to drill to breakup unconformity below Dingo Claystone.

Background Information:

Regional Data:
Seismic profiles: GSI Group Shoot line WA76-20. BMR 6-channel.

Other data: BMR magnetics and gravity, later company seismic drilling at Investigator 1 (20°18'S, 113°E)

Site Survey Data - Conducted by: Could be included in BMR multichannel seismic
Date: survey of the Exmouth Plateau in early 1986.
Main results:

Operational Considerations

Water Depth: (m) 900m   Sed. Thickness: (m) >5km   Total penetration: (m) 2000

HPC ____   Double HPC ____   Rotary Drill Yes   Single Bit ____   Reentry Yes

Nature of sediments/rock anticipated: Cenozoic oozes and chalks 600m, Late Cretaceous chalk and limestone 350m, Early Cretaceous shale 500m, Early Cretaceous-Late Turonian shale and sands 550m.

Weather conditions/window: Good, possible cyclones November-March.

Territorial jurisdiction: Australian

Other:

Special requirements (Staffing, instrumentation, etc.)

Because of the delta front facies safety panel may require riser.

Proponent: G H Packham & J B Keene
Ocean Sciences Institute
University of Sydney
SYDNEY N.S.W. 2006

Date submitted to JOIDES Office:

Attachment 2

Exmouth Plateau - Argo Abyssal Plain

(from Site Proposals Australasian Region
Consortium for Ocean Geosciences Publ. No. 2)

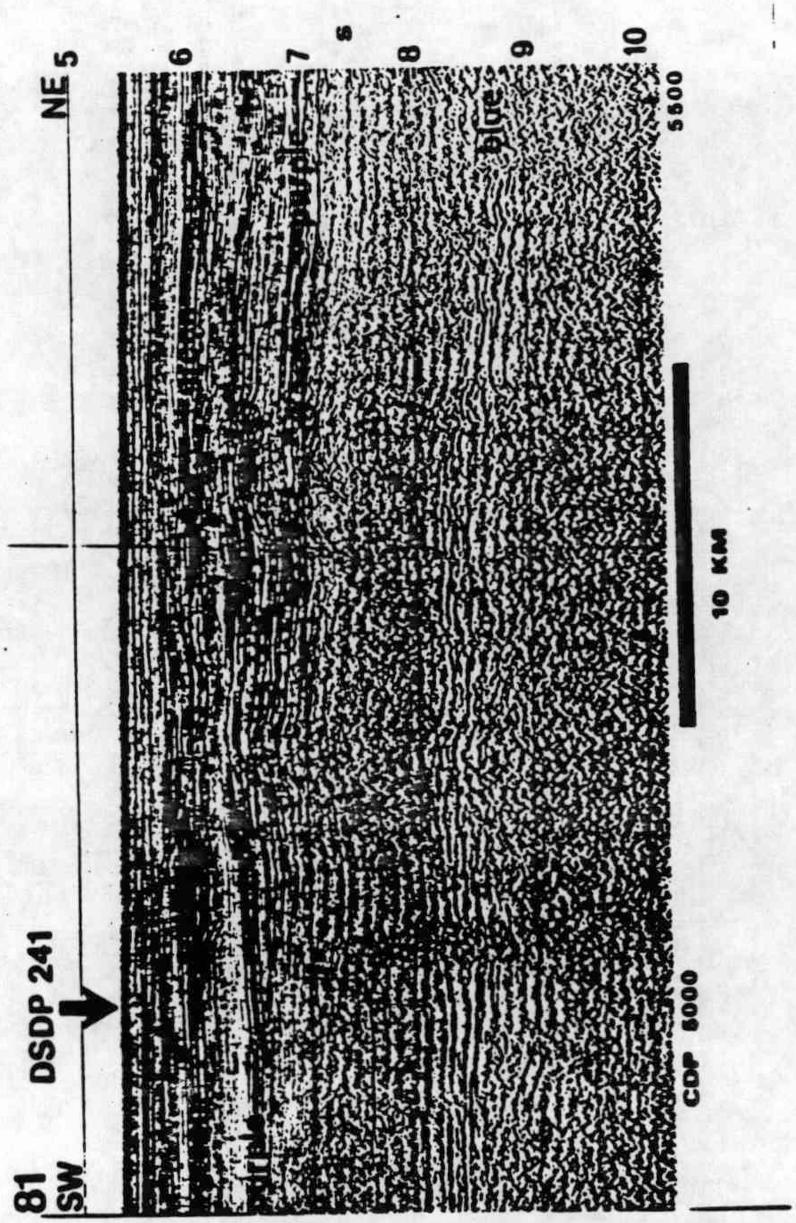


Figure 7a

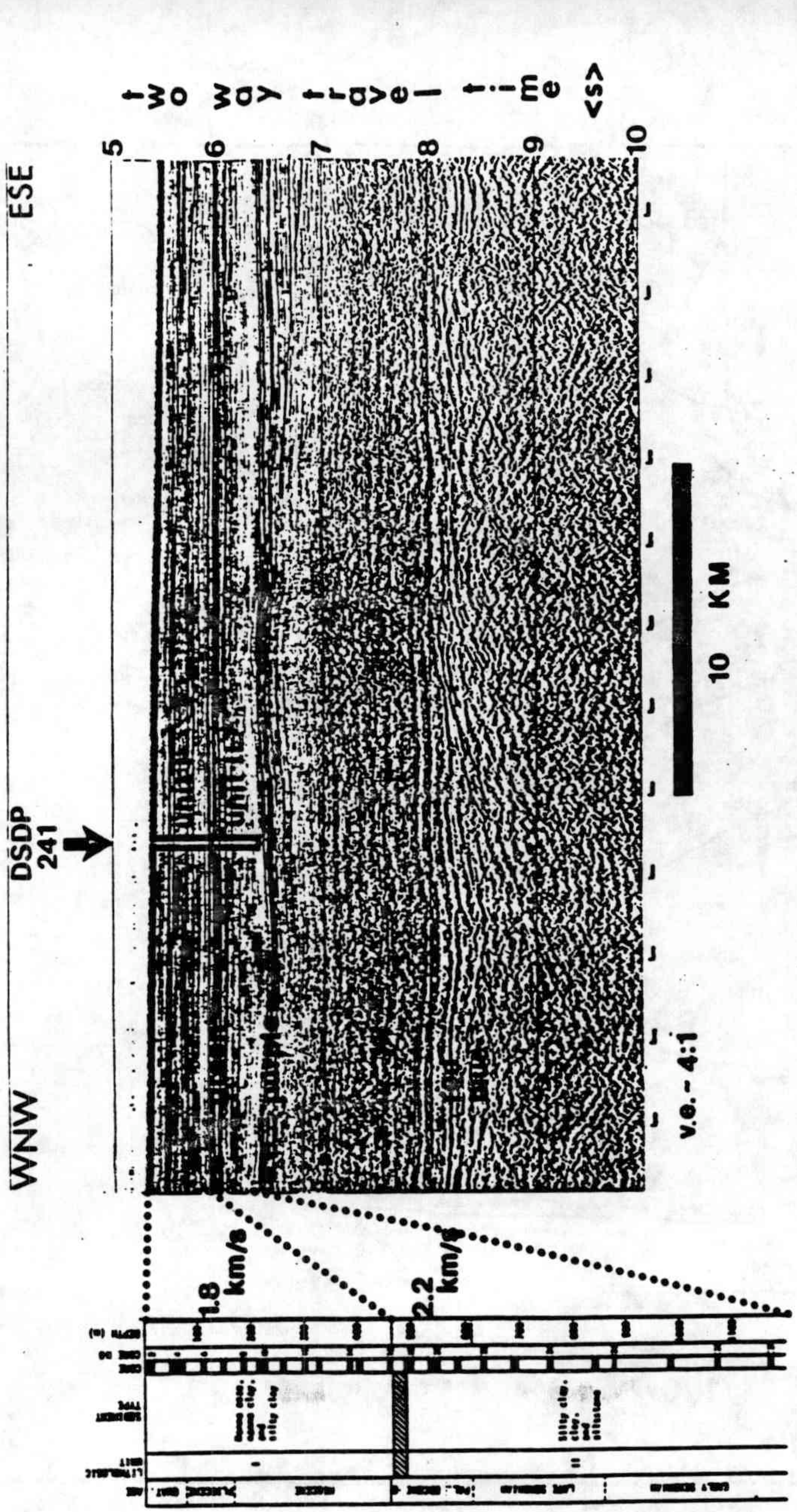

WNW
ESE
DSDP
241
two way travel time (s)
5
6
7
8
9
10
10 KM
v.e. - 4:1
1.8
km/s
2.2
km/s

Figure 6?

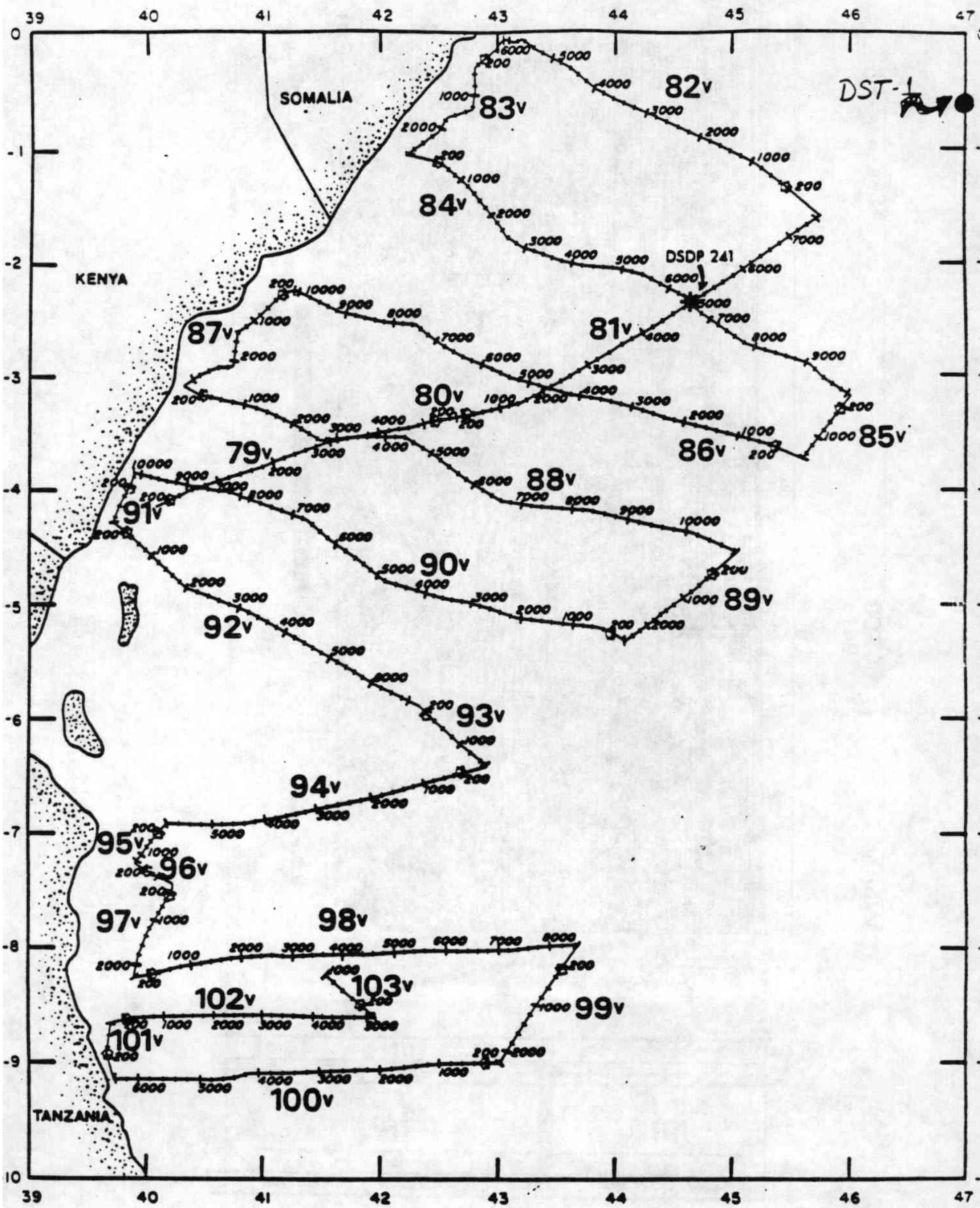

SOMALIA
KENYA
TANZANIA
DSDP 241
79v
80v
81v
82v
83v
84v
85v
86v
87v
88v
89v
90v
91v
92v
93v
94v
95v
96v
97v
98v
99v
100v
101v
102v
103v
DST-1

Figure 5