59. EVOLUTION OF PASSIVE RIFTED MARGINS — PERSPECTIVE AND RETROSPECTIVE OF DSDP LEG 48

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INTRODUCTION

The sites drilled during DSDP Leg 48 on the margins of the Bay of Biscay and Rockall Plateau were designed to address several of the fundamental problems of passive margin geology formulated by the Passive Margin Panel of JOIDES (Curray et al., in press). To formulate these problems, the panel developed highly generalized and conceptual models of passive margin evolution. Passive margins were thus considered to have formed principally by rifting, and their present structure and stratigraphy to result from a variety of successive and contemporaneous processes, in part a function of changing climate and ocean circulation. From the available geological and geophysical data, and by comparison with present-day analogs likely to be representative of earlier stages in margin evolution, a perspective of passive margin evolution was developed within which the drilling objectives could be reviewed in more detail. One highly schematic model is shown in Figure 1. Conceptually, the evolution included the following phases: (1) rifting, (2) onset of spreading, i.e., the separation of continental crust and the accretion of oceanic crust, and (3) the post-rift evolution including subsidence of the rifted margin and shaping by sedimentary and tectonic processes. The principal drilling objectives included a study of the transition from rifting to spreading, the nature of post-rift subsidence and the role of margin paleoenvironments in fashioning the sedimentary record of passive margins. A detailed account of the philosophy and objectives of passive margin drilling is given in the introductory chapter (Roberts and Montadert, this volume).

Discussion of candidate margins in the light of this model and drilling objectives encompassed thickly sedimented or mature margins and thinly sedimented, starved margins on a world-wide basis. Logistics and the excellent examples of mature and starved margins in the North Atlantic and Gulf of California ultimately focused the drilling program in these areas.

Many of the more ambitious, though clearly desirable, objectives requiring deep penetration on mature margins could not be met within the capability of *Glomar Challenger*. However, many of the deep objectives desired on mature margins could be reached on starved margins, although some paleoenvironment targets could still be reached by shallow holes on mature margins. Further, a few well studied drilling transects based on thorough regional and site-specific geological and geophysical data were felt likely to yield valuable results rather than an inevitably diffuse worldwide program of passive margin drilling. The transects would also provide important background data and objectives for a subsequent deep drilling program. The sediment starved margins of the northeast Atlantic offered several prime sites requiring only shallow penetration to sample pre-, syn-, and post-rift sediments and to thereby examine the transition from rifting to spreading, the subsidence history, and the influence of changing paleoenvironments on margin stratigraphy. During DSDP Leg 47A, sites were drilled to investigate the slope and rise unconformities off northwest Africa (Ryan, von Rad, et al., in press), and the deep structure of the slope off Galicia was examined at Site 398 drilled during Leg 47B (Ryan, Sibuet, et al., in press). The principal objectives of Leg 48 were to compare the structural and stratigraphic evolution of the Biscay and Rockall margins (Figures 2,3) that contrasted in both age and structural style. Detailed accounts of individual site objectives are presented in the site chapters of this volume.

RIFTING AND SUBSIDENCE

The most widely used models of rifting are based on actualistic analogs such as the East African rift (Falvey, 1972; Fuchs, 1974; Neugebauer, 1978; Burke and Whiteman, 1972) system and Rhine graben. In these models, upwarping or doming of the crust, incipient volcanic activity, formation of faults with increasing volcanic activity followed by subsidence of the grabens are considered to be stages in the rifting process. Rifts are also considered to form on domal uplifts developed in response to hypothetical mantle plumes (Burke and Whiteman, 1972). Crustal attenuation is partly attributed to subaerial uplift and erosion coupled to some ill-defined sub-crustal process.

The Leg 48 results and the regional seismic data provide several new constraints on the environment and crustal attenuation during rifting (Montadert et al., this volume). In the Bay of Biscay, subaerial uplift is not evident; seismic profiles show no evidence of erosion before or during rifting on the outer part of the margin adjacent to the axis of the rift system. Drilling results also show that water depths at the end of rifting were 2000 meters (Montadert, Roberts, et al., this volume). The seismic data and the existence of deep water Aptian marine beds imply that the rifting was not preceded by, nor associated with, subaerial uplift or relief. Formation of the first ocean crust took place in 2000 meters water depths. These observations contrast markedly with the high altitude of the East African rift and subaerial accretion of ocean crust in the Afar depression.

The seismic profiles (Figure 4) show that structure of the rifted margin consists of a series of tilted and rotated fault

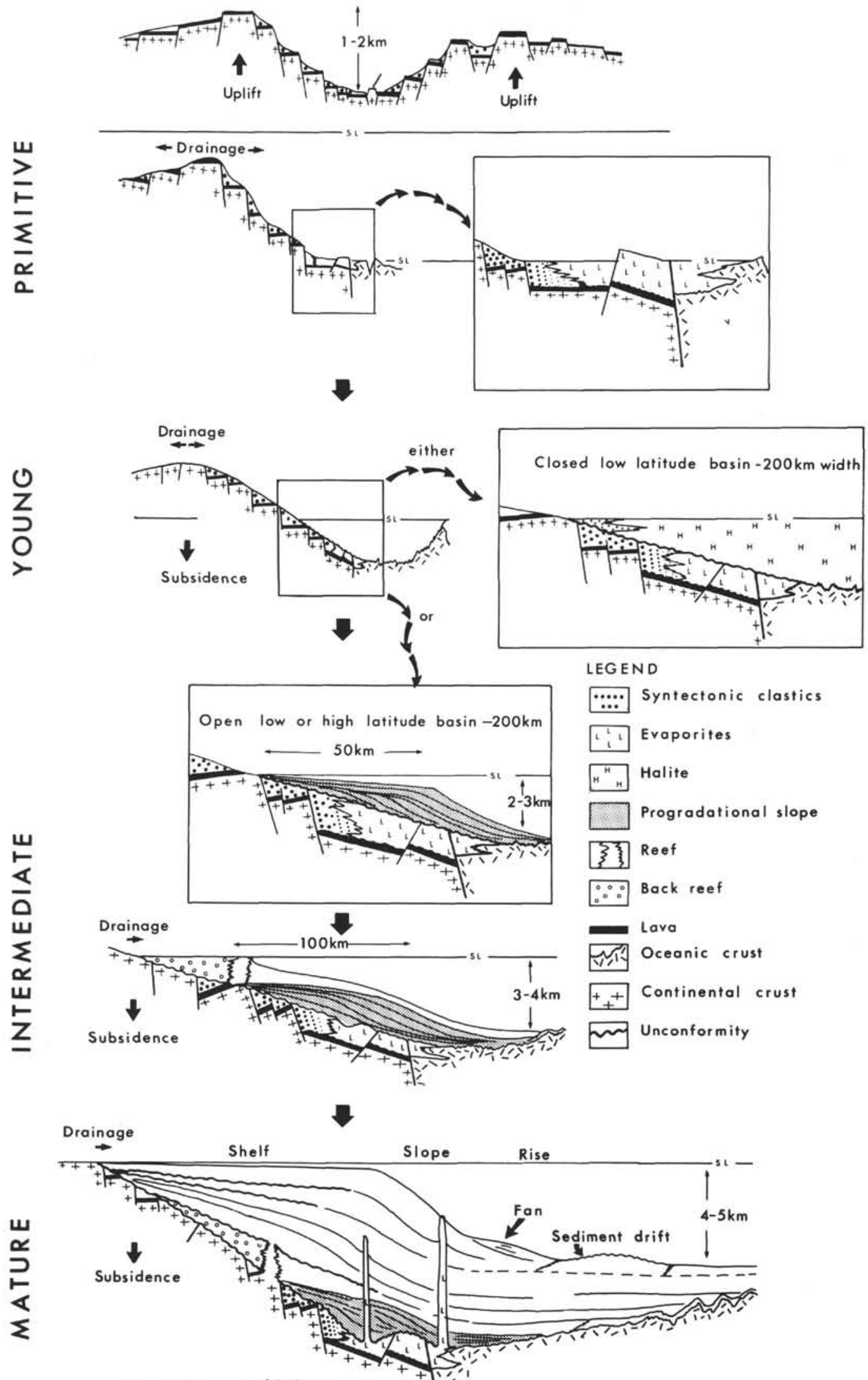

Figure 1. *Schematic model of the evolution of passive rifted margins (from Roberts and Caston, 1975).*

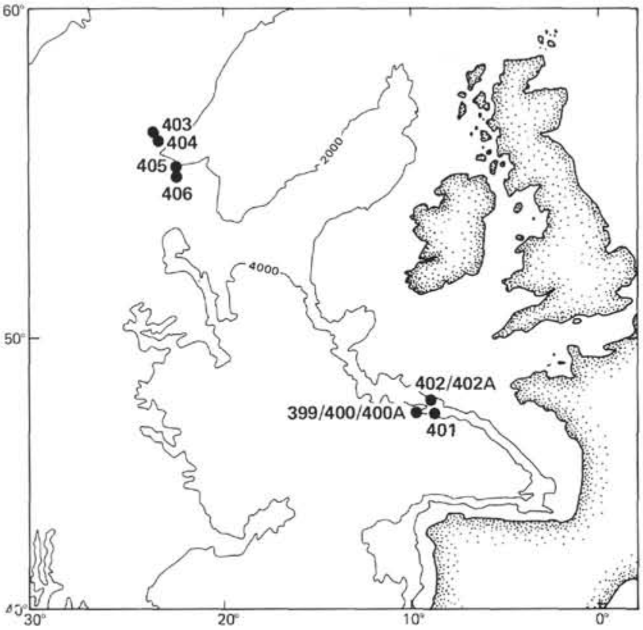

Figure 2. *Location of Leg 48 sites.*

blocks the polarity of which is consistently down toward the rift axis (Montadert et al., this volume). The lystric faults bounding the fault blocks curve and flatten with depth indicating that extensional faulting is confined to the upper part of the crust (Avedik et al., this volume). Crustal thinning of 24 km across the margin cannot be accounted for alone by the observed extensional faulting in the upper crust. The termination of the lystric faults with depth (Figure 4) is considered to mark a transition in the rheological properties of the crust from brittle above to ductile below. Flow within the ductile layer during rifting is considered to accommodate the balance of crustal thinning. The observations in Biscay best support a model of rift valley formation by subsidence of a crustal wedge due to normal faulting under tension of the brittle upper layer with compensatory flow or thinning taking place in a lower ductile layer (Bolt, 1971; Artemjev and Artyushkov, 1971; Montadert et al., this volume). Heat flow data for the Biscay margin (Foucher et al., this volume) can only be interpreted in terms of thinning of the ductile lower part of the crust and not in terms of phase changes or intrusions.

In contrast, a substantial subaerial relief was created on southwest Rockall by the end of rifting (Roberts et al., this volume). Volcanism, largely absent in Biscay, was important (Harrison et al., this volume). Tilted and rotated fault blocks with a consistent polarity toward the rift axis are absent and a horst and graben structure is more apparent in a regional sense (Figure 5, in back pocket). Lystric faults have not been observed although this may reflect the limited resolution of seismic technique in the underlying Precambrian basement. The first oceanic crust accreted in water depths of less than 800 meters. Gravity models indicate crustal thinning of about 16 km between Hatton Bank and the continent/ocean boundary (Scrutton, 1972). It is striking (but may not be more than coincidence) that the total subaerial and submarine relief of about 2000 meters at Rockall at the end of rifting is not dissimilar to that observed in Biscay. Although it seems plausible that the crustal attenuation in both Biscay and Rockall took place by a combination of brittle fracture and ductile flow, the mechanism responsible for the development of submarine and subaerial relief, respectively, remains obscure. In Biscay, Galicia, and Aquitaine, the development of a deep water rifted basin may be related to rifting of pre-existing epicontinental basin, perhaps thinned in response to earlier rifting episodes and sediment loading. Rifting between Greenland and Rockall took place within a Precambrian craton situated near the Iceland-Faeroes hot spot. The contrast in structural style may reflect the response of the craton to rifting, and the subaerial altitude, higher lithosphere temperatures due to the nearby hot spot. The implication of the results from Biscay and Rockall that a thick shallow water marine clastic section need not be a ubiquitous feature of early margin sedimentation may carry important economic consequences.

The altitude of the rift axis at the end of rifting also bears on the first accretion of ocean crust in these primitive basins. In Biscay, the transition between the continent and the first ocean crust which accreted in 2000 meters water depths is sharp (Montadert, Roberts, et al., this volume). The ocean crust close to the continent/ocean boundary has a typical oceanic structure, and the basement is typically irregular and strongly diffracting, contrasting with the adjoining fault blocks. The isostatically corrected basement depth of about 5500 meters is not substantially different from the depth predicted by the age versus depth curve for the ocean crust (Le Pichon et al., 1977). To the west of Rockall, however, the transition between the ocean crust and oceanic crust is less clear (Roberts et al., this volume). Although a structural high is developed along the boundary as identified by magnetic anomalies, a prominent reflector of anomaly-24 age (Roberts et al., this volume; Hailwood et al., this volume) can be traced onto the adjoining ocean crust where it merges with the strong flat-lying "basement." In contrast to the Bay of Biscay, the oceanic "basement" is underlain by discontinuous reflectors that can be followed as far west as anomaly 21-22 (Figure 5). Closely comparable features observed to the west of the Vøring Plateau and in the Lofoten Basin have been enigmatic (Hinz, personal communication, 1976). The Leg 48 results suggest that the layered structure and low refraction velocities arise from accretion of ocean crust in shallow water depths contemporaneously with rapid sedimentation. The flat-lying character of the basement may also reflect voluminous eruption of lava flows due to proximity to the Iceland hot spot. It should also be noted that the Iceland Basin has remained anomalously shallow throughout most of its history and was probably subaerial on the flanks of the Iceland-Faeroes Ridge (Talwani, Udintsev, et al., 1976). Haigh (1973) has attributed the shallow depth to higher lithospheric temperatures. Accretion of oceanic crust in shallow depth is also indicated for the adjacent older margin between Fangorn and Lorien Banks (Roberts et al., this volume).

These data suggest that there may be important differences in the nature of the continent/ocean boundary at passive margins formed under these conditions that are worthy of further investigation by both drilling and geophysical survey.

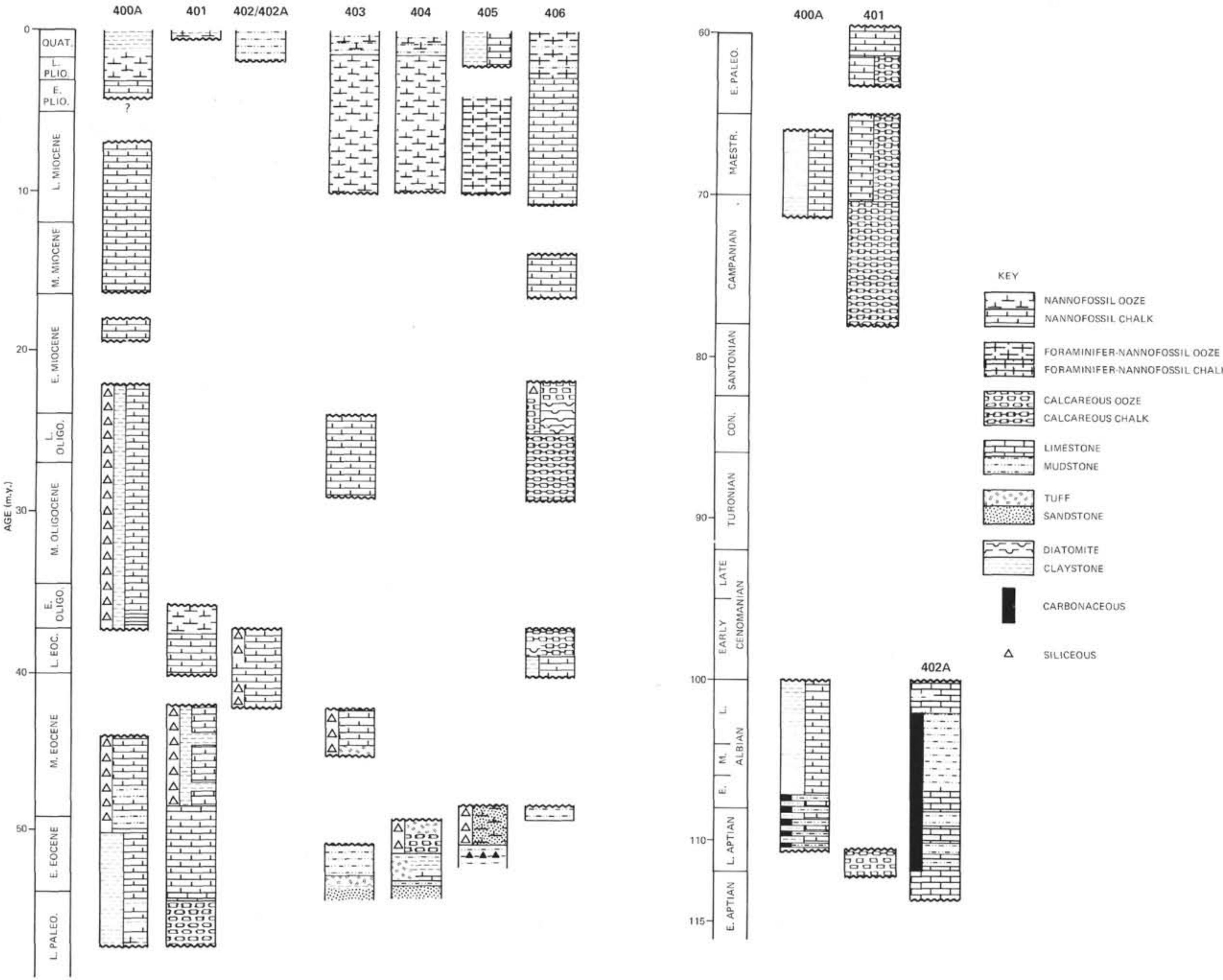

Figure 3. *Summary stratigraphy of Leg 48 sites.*

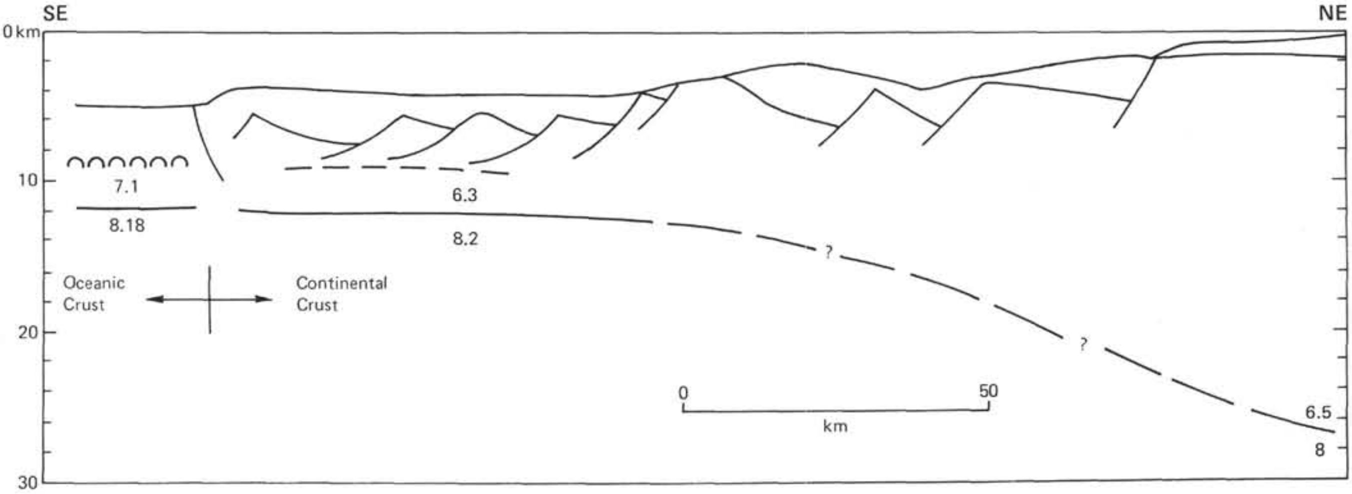

Figure 4. *Schematic structure section across the north margin of Biscay based on seismic reflection and refraction data (Montadert et al., this volume, Avedik et al., this volume).*

Regional subsidence of passive margins beginning at the onset of spreading is now a widely recognized phenomenon. In Biscay, post-rift subsidence of 2300 meters is indicated by shallow water Aptian/Albian sediments and of 2700 meters in Rockall (Site 404). In both cases, the subsidence was not accomplished by faulting because the post-rift sediments are only rarely affected by faults. The post-rift subsidence took place largely by oceanward tilting of the margin without decoupling of the continental and oceanic crust (Montadert, Roberts, et al., 1977; Montadert et al., this volume, Roberts et al., this volume).

The most widely accepted mechanism of post-rift subsidence is thermal contraction of the lithosphere initiated as the heat source migrates away from the margin at the onset of spreading (Sleep, 1971). The exponential decrease in subsidence with time has been considered to be similar to that deduced for the ocean crust. In both Biscay and Rockall, the subsidence data show that the present altitude of a point on the margin depends upon its initial altitude whether above or below sea level (Montadert, Roberts, et al., 1977). The subsidence curves show that the subsidence increases progressively from the shelf toward the deep ocean (Montadert et al., this volume) (Figure 6). Subsidence of the thinned continental crust adjacent to the continent/ocean boundary is greatest and most similar to that of the oceanic crust, affirming coupling between continent and ocean, whereas that of the thick crust beneath the shelf is least and most different. The magnitude of the subsidence seems related most closely to distance from continent/ocean boundary and/or crustal thickness. Although the paleobathymetric data are imprecise, they do not contradict an exponential form of subsidence. Spatial variations in the post-rift subsidence may be at least a partial function of crustal attenuation produced by thinning of the ductile layer during rifting.

TRANSFORM BOUNDARIES

The results obtained from Sites 403 to 406 provide several constraints on the history of vertical movements along transform faults at passive margins. Such faults are considered to mark offsets in the rift axis and to remain active until the trailing edges of the continent separate. Their often large relief has been attributed to decoupling between continent and ocean both during and after transcurrent motion. The transform fault off west Rockall was initiated at about 76 m.y. (Roberts, 1975). Epibathyal depths in middle Eocene time (Murray, this volume) indicate a large part of the transform scarp was subaerial and the seismic profiles suggest a total relief of 2.6 km of which at least 1.6 km were subaerial (Roberts et al., this volume). Consistent paleodepths on either side of the transform (Murray, this volume) indicate the continental and oceanic crust have remained coupled while subsiding to their present depths since middle Eocene and probably late Paleocene time. Interpretation of the seismic data also shows that the present relief of 5.5 km was created by Paleocene time (Roberts et al., this volume). Since the transform was created in the Late Cretaceous and remained active until 52 m.y., it is inferred that vertical as well as horizontal decoupling took place during the active phase. Consideration of the regional seismic data suggests that the relief between the transform offset and the adjacent rifted continental crust is greatest at the rifted continent/ocean boundary but decreases towards the interior of the continent. Much of the initial relief of the transform may therefore be created by down-faulting of the rifting continental crust against the adjacent transform. The juxtaposition of transform and rifted margins poses several questions concerning deformation in the lower part of the crust during rifting and transform faulting that cannot be assessed from the data presently available. Nonetheless, the Leg 48 results suggest that continental and oceanic crust may remain coupled across transform margins jointly subsiding to their present depths after the separation of the trailing edges of the continents.

MARGIN PALEOENVIRONMENTS

The lithology and volume of sediments that comprise the post-rift sequence of both starved and mature margins are clearly dependent on the oceanic paleoenvironment climate, sea level, and indeed the size and geology of the continental hinterland. In a general sense, the ocean basin margins can be said to distort the largely wind-driven latitudinal surface

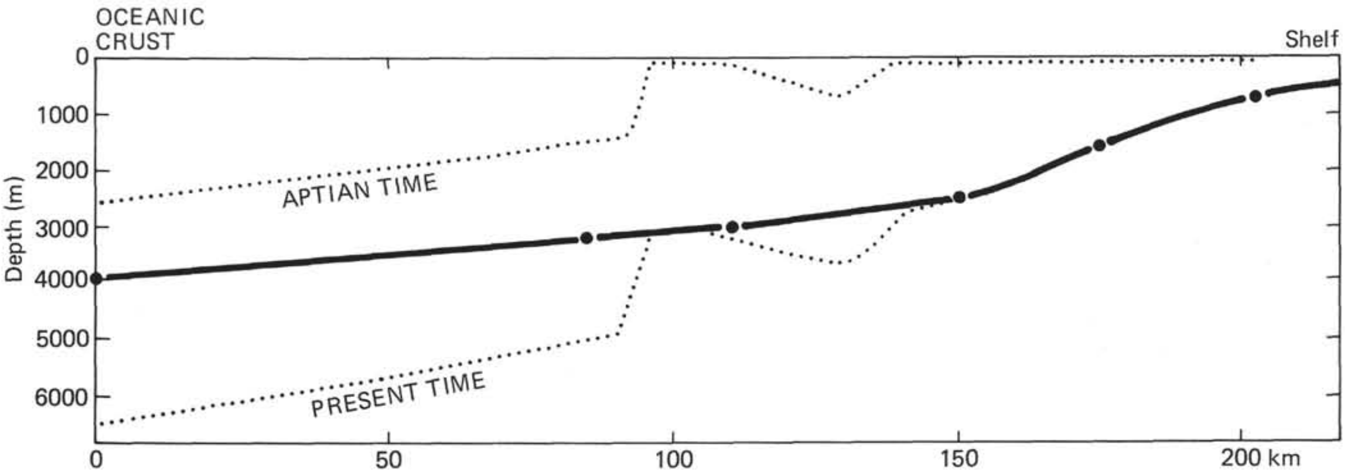

Figure 6. *Absolute amount of post-rifting subsidence of the North Biscay margin from the shelf to the oceanic crust. Upper dotted line: simplified topography of the rift at Aptian time. Lower dotted line: present depth of Aptian corrected for loading. Full line: amount of subsidence.*

water circulation to produce eastern and western boundary currents and major divergences. These boundary currents separate the more stable central water masses and the highly variable coastal water masses over the margin. Changes in ocean basin circulation can, therefore, profoundly influence sediment dynamics along margins by causing large hiatuses. Fluctuations in the carbonate content of sediments are apparently due to worldwide changes in the carbonate compensation depth postulated to also correlate with global transgressions and regressions (e.g., Tappan, 1968; Fischer and Arthur, 1977; Vail et al., 1977). Other types of environmental change include oxygenation and the changing geometry of the ocean basins due to the break-up of Pangaea and the subsequent reorganizations in plate motions. It has been argued that the types of environmental setting are few and arguably interdependent producing episodic but drastic changes in the pelagic realm through Mesozoic and Cenozoic time (e.g. van Andel et al., 1975; Fischer and Arthur, 1977). The relevance of margin paleoenvironments to an understanding of the evolution of sedimentary sequences in the pelagic and terrestrial realms cannot be understated because the facies of shelf, slope, and rise sediments surely result from the interaction between oceans and continents reflecting prevailing environments. A complete understanding and description of the interrelationships between these factors has yet to be developed and we here discuss individual aspects of margin paleoenvironments addressed by the Leg 48 results.

Early Margin Paleoenvironments

It has been widely considered that restricted paleoenvironments may develop in the narrow, youthful ocean basins, and the nature of the earliest post-rift sediments therefore bears relevantly on this hypothesis.

In Biscay, these sediments comprise Aptian/Albian carbonaceous limestones deposited in depths of 1500 to 2000 meters at Hole 400A and in outer shelf depths at Hole 402A (de Graciansky et al., this volume; Montadert, Roberts, et al., this volume). The Aptian sediments of Hole 400A were apparently deposited by very fine grained turbiditic flows in an abyssal environment. Low $CaCO_3$ contents and dissolution of calcareous microfossils indicate deposition took place close to the calcite compensation depth (CCD). From an analysis of the seismic reflection data, deposition is estimated to have taken place in 1500 to 2000 meters water depths during and shortly after rifting (Montadert et al., this volume). In Hole 402A, the Albian/Aptian black shales were deposited at the front of sediments prograding over a carbonate platform (de Graciansky et al., this volume). These facies models for the sites are supported by the biogenic components (Renz, this volume; Dupeuble, this volume).

Paleontological, pyrolysis, and organic geochemical shipboard and shoreside studies show that the organic matter is typically of terrestrial origin and is composed mainly of recycled or derived organic matter (Deroo et al., this volume). Organic matter of marine origin was not found in Holes 400A and 402A. If results from these sites can be regarded as being representative, reducing conditions did not then exist on the shelf or the deep waters of the youthful Bay of Biscay. These results demonstrate the importance of properly defining the nature of the organic matter and facies of the sediments before postulating global models of black shale deposition. Tissot (in press) has given a wider discussion and interpretation of the black shale phenomenon and it is clear that conditions varied from basin to basin within the same ocean from well oxygenated to anoxic although dilution of marine organic matter by terrestrial carbon is apparent. The distribution of sapropels and terrestrial carbon may be at least partly related to climate (Ryan and Cita, 1977). Areas of high production of terrestrial carbon were situated in a humid tropical zone favorable for widespread growth of vegetation in flat-lying coastal swamps where the organic matter was altered prior to transport and deposition. Areas in which preservation of organic matter took place were situated in arid zones. In this context, analogies between the present Red Sea and the barred Aptian South Atlantic may be of interest. In a wider sense the implications of the environment of the continent and pelagic realm in Cretaceous time, and the effects of the worldwide Cenomanian transgression on the accumulation of carbonaceous shales remain to be understood.

In Rockall, the earliest post-rift sediments comprise, in marked contrast, interbedded tuffs and mudstones deposited in less than 100 meters water depth. Rapid sedimentation owed much to subaerial erosion and took place in wide oxygenated shallow water marine conditions (Roberts et al., this volume; Murray, this volume).

Hiatuses

The presence of hiatuses in the deep sea geological record cannot be ascribed to emergence since they usually separate deep water pelagic sediments and have usually been attributed to erosion and/or non-deposition due to the subtle balance between the rate of sediment supply and removal by erosion or solution. Sites drilled during Leg 48 found a major hiatus between the Albian and the Campanian as well as a number of smaller hiatuses during the Cenozoic.

The Albian/Campanian or Cenomanian hiatus was found at all three sites in the Bay of Biscay and lies, respectively, between deep water Albian and Campanian chalks (Hole 400A), shallow water Albian carbonaceous limestones and deep water Campanian chalks (Site 401), and shallow water Albian carbonaceous limestones and Eocene deep water limestones (Hole 402A). The hiatus is at least partly erosional in origin and is of wide interest because it is found in deep as well as shallow water sediments and is contemporaneous with the well-known transgression. An abnormally shallow CCD in Aptian time is indicated by dissolution at Hole 400A. The duration of the hiatus observed in Biscay is much greater than elsewhere in the Atlantic (Ryan, Sibuet, et al., in press). Statistical studies show that the peak of the hiatus occurs in late Turonian time in close coincidence with independent estimates of the highest sea level stance (van Andel et al., 1977; Pitman, in press; Vail et al., 1977). The hiatus appears to be associated with a decrease in water temperatures (Savin, 1977; Fischer and Arthur, 1977). It is tempting to suppose that the sea level rise resulted in changes in water temperatures and a possibly rapid turnover in circulation. However, O^{18} analyses across the key stratigraphic intervals are presently insufficient to confirm or deny such changes. It is conceivable that the change in sea level may have led to a rise in the CCD and perhaps also to changes in the wind pattern. Communication with the South Atlantic may also have been a contributing factor. In the absence of quantitative paleoceanographic data, the precise cause must remain largely speculative although it is here tentatively attributed to stronger bottom current activity coupled with a rise in the CCD.

Several prominent hiatuses (Figure 7) during the Cenozoic, notably during Paleocene/Eocene, Eocene/Oligocene, and Oligocene/middle Miocene time that were recognized at the Leg 48 sites have been previously noted at other North Atlantic DSDP sites (van Andel, 1975). A comparison of the distribution of these hiatuses with paleotemperature and sedimentological results from Leg 48 has several implications (Létolle et al., this volume; Vergnaud-Grazzini et al., this volume; Hailwood et al., this volume; Auffret and Pastouret, this volume). The data suggest that the most complete parts of the geological record coincide with intervals characterized by warmer surface and bottom water temperatures (Roberts and Montadert, this volume). The hiatuses in contrast seem to coincide with the change from warmer to colder conditions, suggesting that greater temperature gradients resulted in an intensified circulation and thus erosion and/or non-deposition as well as faunal changes (Müller, this volume; Schnitker, this volume). In the Bay of Biscay, for example, the early Eocene/middle Eocene change is marked by a change in sediment color, decrease in carbonate and NRM, together with evidence of an erosional unconformity (Hole 400A; Montadert, Roberts et al., this volume). A comparable change occurs after the early Oligocene in Biscay and the hiatuses observed at Sites 403 to 406 may be related to the same events. The drastic ocean circulation change that caused the hiatuses can be most plausibly related to the well documented paleoceanographic events of the Southern ocean, e.g., the Eocene/Oligocene cooling (Kennett, 1977). However, they may also have been "overprinted" by effects arising from changes in the morphology of the North Atlantic basins. For example, the earlier Eocene cooling in the North Atlantic may be related to the opening of the Norwegian and Greenland seas (Talwani and Eldholm, 1977). During midddle Miocene, the fall in bottom water temperatures may be due to not only a greater poleward temperature gradient, but also to the initiation of a fuller exchange of water across the Iceland-Faeroes Ridge (Thiede, in press). The bottom circulation pattern developed in post-middle Miocene time has remained similar in pattern though not necessarily in intensity to that observed today, significantly influencing the distribution and deposition of post-middle Miocene sediments (Roberts, 1975).

One of the main objectives of the passive margin drilling program was to examine the stratigraphic record of passive margins for a relationship between deep-sea hiatuses, sea-level changes, and the spreading history of the North Atlantic (Figures 8 and 9). Allowing for the imprecision in defining hiatuses, there does not appear to be unexpected correlation between sedimentation rate changes and spreading rate changes, for example, during Paleocene/Eocene time. This correlation is most plausibly related to ocean circulation changes arising from plate reorganizations (Roberts and Montadert, this volume). The pre-Ypresian and pre-Lutetian movements recorded on the shelf appear to correlate with the opening of the North Atlantic between Greenland and Rockall Plateau. However, these warping movements are limited oceanward for there is only sparse evidence for renewed faulting on the margin during the Cenozoic (Montadert et al., this volume; Roberts et al., this volume). The warping phases also seem to correlate with some of the global eustatic changes in sea level documented by Vail et al. (1977). Although evidence is weak for a correlation between Cenozoic deep-sea hiatus events on the shelf and spreading rate changes, it has sufficient strength to warrant further investigation by drilling on more thickly sedimented margins.

OCEAN SURFACE WATER CIRCULATION AND THE OCEANIC WATER COLUMN

The establishment and history of the hydrographic regime at continental margins as a function of changes in surface water circulation, the water column, and subsidence history remain a prime objective of passive margin drilling. Variations in the supply of biogenic silica, carbonate, and

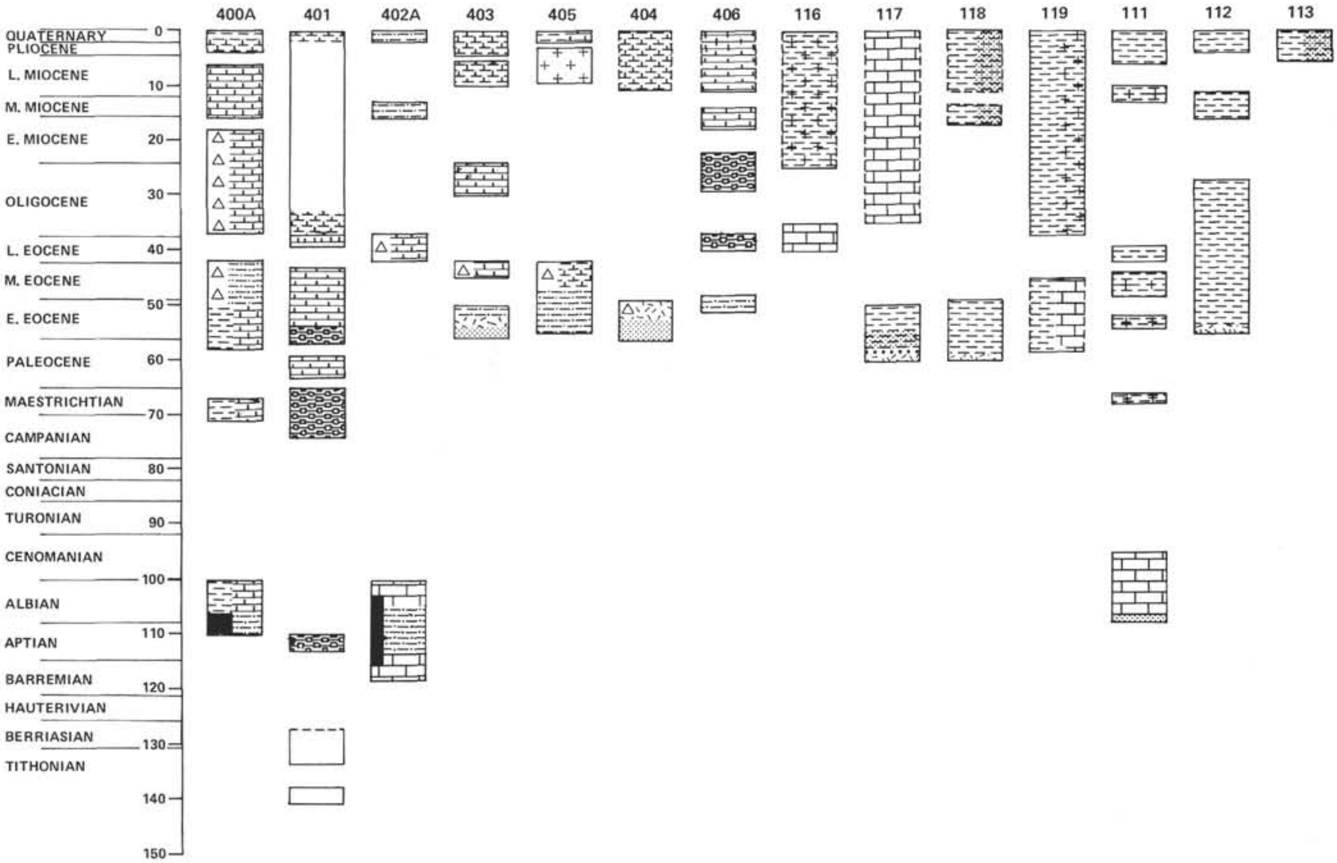

Figure 7. *North Atlantic DSDP sites, principal hiatuses, the O^{18} paleotemperature record and the global sea level curve of Vail et al. (1977).*

paleotemperature were considered as monitors of changing ocean chemistry and circulation (van Andel et al., 1975: van Andel, 1975). At the Leg 48 sites, there is a broad correlation between changes in carbon isotope ratio, paleotemperature, silica accumulation, and the CCD that may have a frequency of about 30 m.y. (Roberts and Montadert, this volume; Fischer and Arthur, 1977). These changes in the chemistry and circulation have profoundly influenced the deposition and facies of margin sediments. Slower circulation rates reflected by decreased temperature gradients would have led to increased residence time and slower turnover of nutrients in deep waters, thus allowing them to increase in nutrients, opal, and carbon dioxide. Consequences include higher production of carbonate and silica due to upwelling of fertile deep water. Enhanced silica accumulation at margin sites may reflect basinwide rises of the CCD, perhaps further elevated along the margin. These changes are clearly coincident with changes in paleotemperatures and turnover rates resulting in hiatuses. The Leg 48 data have also been examined for a correlation between changes in the CCD and the sea-level changes postulated by Vail et al. (1977). The most obvious correlation is in the early Miocene, although the late Oligocene transgression was undoubtedly associated with warmer water temperatures; the Eocene transgression and contemporaneous fall in the CCD may also be related phenomena. The correlation between sea-level rise and CCD elevation may reflect increased carbonate production in shelf waters that may lead ultimately to a rise in the CCD.

RETROSPECTIVE

The results of the first systematic drilling on passive margins thus have resolved many of the original questions but have not answered others, and new problems, tractable by drilling and geophysical study, have been raised. Only a few of these can be highlighted here. In terms of the nature of rifting and the transition from rifting to spreading, new questions are raised as to the nature of the continent/ocean boundary formed under subaerial and deep water conditions. The presence of deep-seated Hercynian granites overlain by a thin Mesozoic sedimentary cover has important implications for mechanisms of crustal attenuation. One approach may be to drill holes on either side of the continent/ boundary, penetrate pre-, syn- and post-rift sediments to establish both the duration of rifting and changes in continental elevation at sites near and far from the continent/ ocean boundary. Differences in the nature of the first oceanic crust may be relevant to the formation of quiet magnetic zones.

Although one of the prime objectives of passive margin drilling was to examine unconformities within the post-rift sediments, relative to environmental and tectonic factors, a

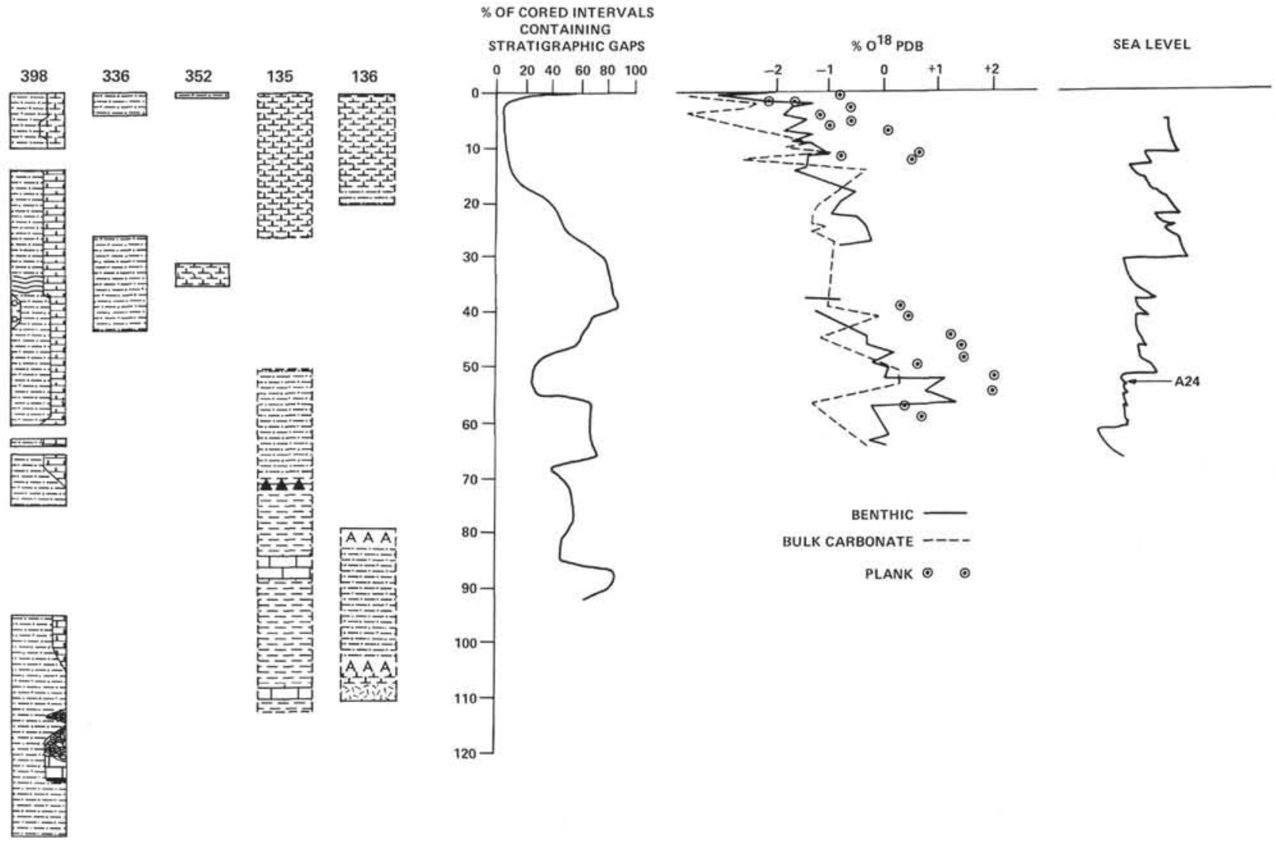

Figure 7. *(Continued).*

relationship has yet to be proven and understood. Transects which drill thicker and more complete sedimentary sequences on slope, rise, and abyssal plain may provide the requisite stratigraphic resolution to contribute toward this problem.

The paleoenvironmental studies made of the Leg 48 cores have emphasized the importance of a thorough understanding of the changes in horizontal and vertical oceanographic gradients through time, to which a knowledge of the subsidence history will be indispensable. These gradients can be best determined by drilling, along transects, thick sequences, or at least thick key stratigraphic intervals in carefully selected areas. The importance of passive continental margins as a link between land, shelf, and deep ocean paleoenvironments cannot be understated here. In a wider sense, the drilling should provide a deeper understanding of the unity of the stratigraphic record that will contribute perhaps decisively in deciphering the blurred and often fragmentary record exposed on land.

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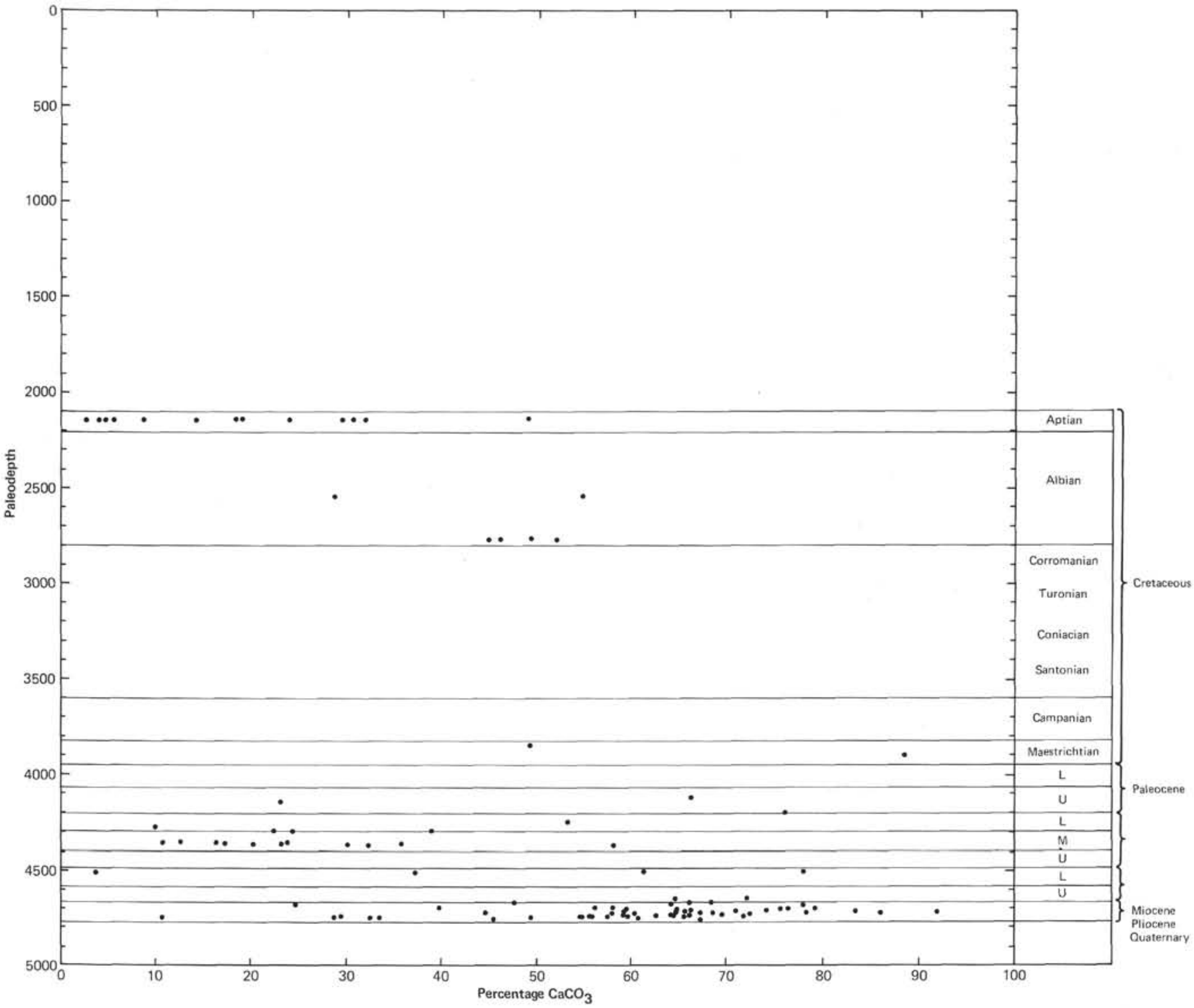

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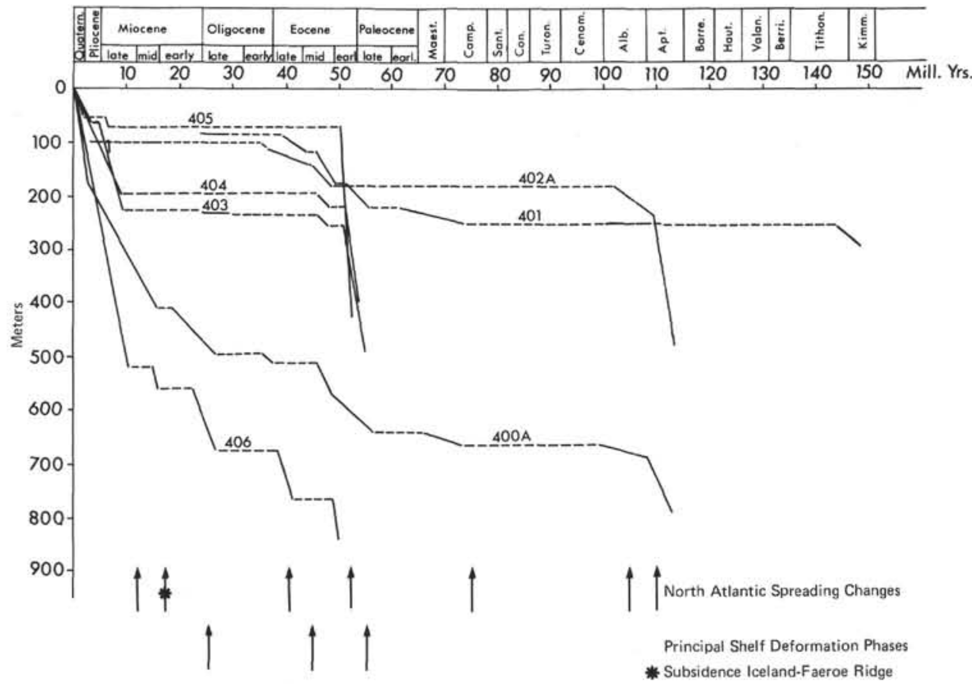

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