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Ages of Horizon A and the Oldest Atlantic Sediments

Coring at an outcrop of horizon A establishes it as a buried abyssal plain of Upper Cretaceous age.

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Although strongly reflective interfaces within the unconsolidated sediments of the North American basin have been evident since the early seismic studies, the continuity of these reflectors was not understood before the development of deep-ocean continuous seismic-profiling techniques (*1*). Seismic profiles have shown that one of these reflecting horizons, horizon A, is continuous over most of the North American basin (*2, 3, 4*). The horizon marks an abrupt oceanwide change in sedimentation and has been proposed as an important target of deep-ocean sedimentary drilling (*5*). The presence of a similar reflector in South Atlantic basins has been reported (*6, 7*), and horizons in the Pacific Ocean and Caribbean Sea have been identified as possibly synchronous with the Atlantic horizon A (*8, 9*).

Recent surveys have defined an outcrop of horizon A in the North American basin, and sediment cores taken from the outcrop area have identified the reflective interface as the top of a turbidite sequence of Upper Cretaceous age. This finding supports earlier speculation that the horizon is a fossil abyssal plain; the moderate amount of distortion of the horizon indicates that the major Atlantic basins have been relatively stable at least through most of Cenozoic time. We now present the seismic data associated with horizon A and the outcrop area, and discuss their pertinence to the questions of stability of the basins, the possible age of the deepest sediments below horizon A, and the geologic history of the oceans.

Horizon A

Horizon A, sometimes referred to as reflector A, is commonly the strongest and most continuous coherent subbottom reflective horizon in the Atlantic Ocean basins. The horizon often defines the top of a stratified zone in the sediments, which is identified on the seismic records as a group of closely spaced and mutually conformable reflectors. This stratification varies both locally and regionally, but one cannot always be sure to what extent its appearance on the profile records may be influenced by the thickness and nature of the overlying sediments, or by the type of seismic technique involved. In general the thickness of the zone of stratified sediments immediately below the horizon rarely exceeds 500 meters (0.5-second reflection time).

The sediment both above and below the stratified zone is usually acoustically transparent and may contain several weak reflectors. The transparent zones are thought to represent quiescent deposition of pelagic sediment, or deposits composed only of very fine particles transported by density currents (*10*).

Horizon A extends from beneath the continental rise, eastward across the Bermuda rise; in some places it apparently continues to the base of the mid-Atlantic ridge. It has been mapped southward from the Kelvin seamount group to the edge of the north wall of the Puerto Rico trench. In some areas, such as the abyssal-hills province and parts of the Sohm abyssal plain, the horizon is rendered difficult to identify by structural deformation, shallow burial, or masking by more recent coarse turbidites.

Its presence in the area east of longitude 60°W in the Nares basin is also uncertain; here the Nares abyssal plain consists only of fingers extending eastward from the main plain to the base of the mid-Atlantic ridge, and in these fingers of the plain there is a prominent reflector that closely resembles horizon A. This reflector has not been connected with certainty to the horizon in the main part of the North American basin because of the insufficiency of survey lines, but the connection probably could be made. A core in the abyssal-hills province nearby penetrated Upper Cretaceous sediments (*11*), but the relation of this core to the horizon is unclear.

Generally relatively smooth and level, horizon A is covered by an average of 300 to 500 meters of sediment. In the central area of the North American basin the horizon has a gentle westerly dip, which may reflect postdepositional deformation by the combined effects of uplift in the Bermuda rise area and subsidence along the continental margin—possibly because of the great thickness of sediment on the continental rise. The greatest observed thickness of sediment overlying the horizon is of the order of 3.0 to 3.5 kilometers and is represented by the southern New England continental rise and the Blake-Bahama outer ridges. These ridges

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are wholly sedimentary units deposited atop the horizon and have no direct structural relation with the underlying layers.

The overall relief of the horizon probably does not exceed 1.5 kilometers; its steepest regional slopes rarely exceed 1:200, and these are found only in structurally deformed areas. In the southern- and eastern-basin areas and near the outcrop area, the horizon has somewhat variable regional dips that reflect complex tectonic events—including probably differential subsidence caused by the Blake-Bahama outer ridges, and possible uplift in the outcrop area.

The great areal extent of horizon A, its smooth and relatively level character, and the dense and conformable stratification of reflectors immediately beneath it indicate that it is a synchronous interface representing an abrupt change in depositional conditions. The conditions preceding this change are speculative, but the stratified beds rest on a nearly level surface formed by deposition of older sediments that have filled in the major relief of the basement surface. Both the stratification and horizontality of the horizon are characteristic of deposits attributed to turbidity and flow mechanisms, for which reason it has been suggested that it represents an immense fossil abyssal plain (*3*). Certainly its great extent in the ocean basins must be regarded as indicating an oceanwide and perhaps a worldwide event in geologic history. Figure 1 shows several examples of the horizon in profiler sections from various parts of the North American basin; the sections are located in Fig. 2.

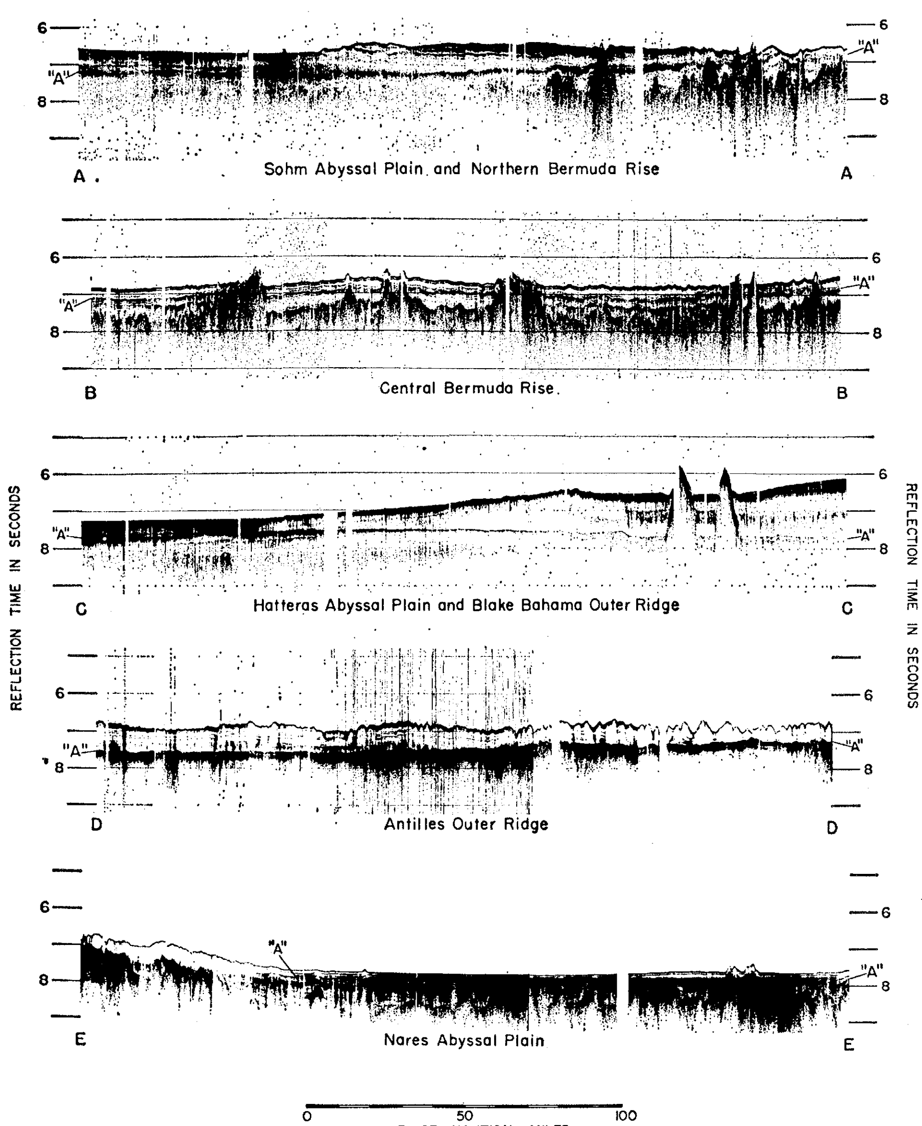

Fig. 1. Typical reflection profiles (located in Fig. 2) from the North American basin; horizon A is indicated in each. Vertical exaggeration, about 25:1.

Physiography of the Horizon A Outcrop Area

An outcrop of horizon A was first identified during R.V. *Vema*'s cruise 18 in 1961. The desirability of dating the time of deposition of this horizon gradually increased as subsequent work showed its importance as a major event in the history of the ocean basins. The resultant effort in profiling and coring has expanded the initial survey to include some 3500 nautical miles (6485 km) of track in the study area (Figs. 2 and 3). The known outcrop area is centered 55 miles northeast of San Salvador and covers about 8000 square miles of sea floor.

The exposure area (Fig. 3) appears to be associated with two broad valleys that open onto the southwestern corner of the Hatteras abyssal plain. The valleys in turn are closely related physiographically to a group of recent and fossil erosional channels near the south end of the inner Blake-Bahama ridge. The youngest of these channels, called Cat Gap by Heezen and Menard (*12*), appears to extend along the base of the Bahama escarpment; it turns northeastward at about the longitude of San Salvador and then enters the outcrop area (southern valley) around the north end of a ridge extending northeastward from San Salvador. An older channel, probably a breach in this ridge, is evident approximately 20 miles south of the present channel. The northern valley has a more complex relation with what appear to be older erosional courses. The break in the 2400-fathom (4400-m) curve and the series of small ridges in the northwestern study area suggest that a broad channel existed approximately 60 miles north of Cat Gap. The isopachs also show a thinning of the sediments overlying horizon A in this area, which thinning further suggests the effects of such a channel. The broad 2400-fathom hill NNE of San Salvador appears then to be a remnant of the end of the inner Blake-Bahama ridge, created by eroding turbidity currents flowing first through the northern channel and later through the southern (Cat Gap) channel. This erosion has also produced the broad valleys in the outcrop area.

It is clear that these channels have been directly related to the exposure of horizon A. The outcrop is evident on the seismic profile shown in Fig. 4 and is thought to be partly the result of erosion and nondeposition probably associated with structural uplift. However, the relative importance of these mechanisms cannot be determined without further profiling and coring. The effects of bottom currents are evident in bottom photographs taken in the eastern outcrop area that clearly show large linear ripples on the sea floor.

Two crossings to the south of the study area show that the outcrop continues southeastward near the base of the Bahama escarpment. However, limited seismic coverage in the southern study area does not permit accurate delineation of the boundary of the outcrop.

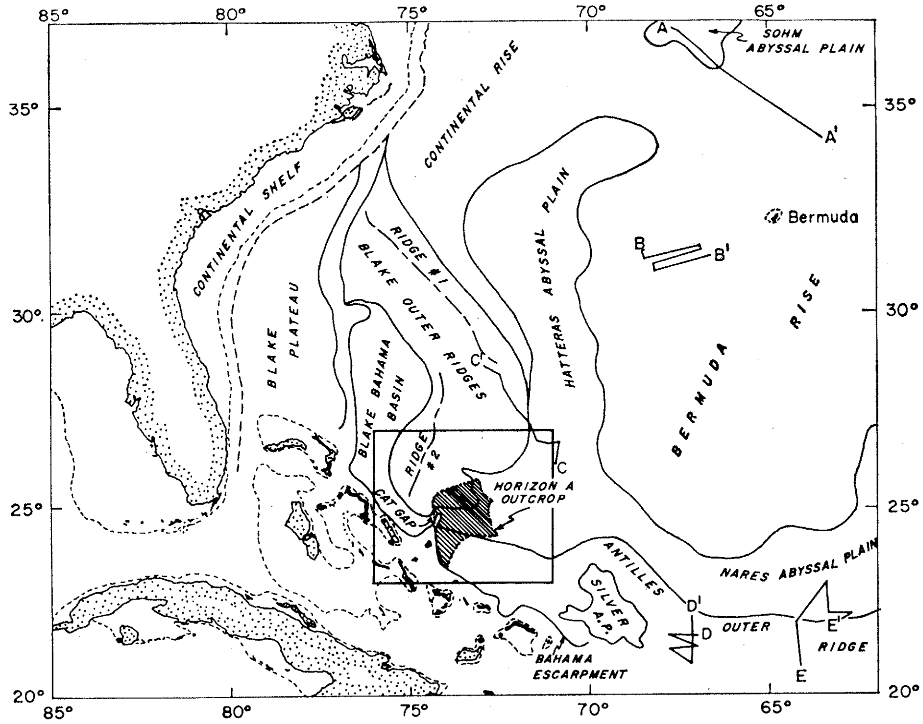

Fig. 2. Sources of seismic-reflection profiles (Fig. 1) and the area of the horizon A outcrop (study area; rectangle).

Sediments of the Outcrop Area

Of 30 cores taken in the general study area and described (*13*), 25 are from the apparent surface of the outcrop. Eight of the 25 have been identified as Upper Cretaceous in age from their fossil assemblages of coccoliths and Foraminifera, and four have been identified as Lower to Middle Miocene; the remainder are Pleistocene in age. Seven of the Cretaceous cores were taken at the stratigraphic level of horizon A, or slightly below it, and are of Maestrichtian age; the eighth was taken from a deeper stratigraphic level and is Cenomanian. These Cretaceous sediments are turbidites deposited at a depth not greatly different from their present depth in the outcrop.

For the following reasons it cannot be argued that the Cretaceous sediments in the outcrop area have been reworked from a Cretaceous source: (i) Cretaceous forms are present in the pelagic clays interbedded with the turbidites, (ii) there is no contamination in the Cretaceous sediment by more recent fossils, and (iii) the Cretaceous sediments sampled were in the normal stratification sequence.

Care was required in the selection of coring sites (Fig. 3, bottom) because of a cover of young sediments too thin to be resolved by the profiler but usually too thick to be penetrated by the corer; cores were taken only where both the seismic profiler and the depth recorder indicated a probable exposure. It is evident from the number of older cores that these methods are often effective.

Saito and Burckle also have presented paleontological and lithological evidence that the outcrop surface is represented by slightly uplifted Upper Cretaceous turbidites (*13*). This finding supports an earlier conclusion based on similarity of reflections from horizon A to reflections from modern abyssal plains.

The four Lower to Middle Miocene cores in the southern outcrop area are thought to represent a thin cover of turbidites containing very coarse material probably transported from a southerly source; the absence of Miocene cover to the north may result from its removal by bottom currents, facilitated by the probably finer size of the materials at a greater distance from the source. This thin Miocene cover cannot be distinguished on the profiler records because of insufficient resolution by the seismic techniques employed. There is little doubt that horizon A marks the end of a period in Late Cretaceous time when extensive turbidity deposition occurred in the North American basin.

Seismic Profiles in the Outcrop Area

Profiler records along track *A–D* (Fig. 3, bottom) appear in Fig. 4, together with orientation points along the track. Horizon A is indicated at a depth of 0.3 second below the water-sediment interface at the beginning of the profile and at 0.2 second at the end; it appears to outcrop between miles 69 and 228.

The variation in thickness of the stratified zone (Cretaceous turbidites) below the horizon in these profiles is considerably greater than that observed in most of the North American basin. This fact reflects the somewhat greater-than-normal thickness of the turbidites in the areas between miles 35 and 93 and 270 and 303; the thick turbidites lie in a broad depression that extends into the northern valley of the survey area (Fig. 3, top). The shape of this depression in this valley is approximately outlined by the 2800-fathom contour. The density and intensity of reflectors in the Cretaceous turbidites diminish eastward of mile 303 (point *D*), suggesting that their reflectivity is closely related to facies changes caused by increasing distance from the source of sediment. From core V22-16, taken at mile 133 and containing Cretaceous (Maestrichtian) turbidites typical of these cores from the more-stratified zone in the vicinity of the peak at mile 77, it is concluded that the surface of the horizon is essentially continuous with the sea floor in most of the outcrop area. The usually transparent sediments that lie immediately above the horizon and below the zone of stratification are clearly evident throughout the profiles.

Reflectors mapped in wide areas of the Pacific and in the Caribbean Sea appear to be synchronous with horizon A but are not necessarily attributed to similar despositional processes; those believed to correspond approximately to the Mesozoic-Cenozoic boundary in the Pacific and Caribbean separate an upper layer of acoustically transparent sediment from a deeper layer that is noticeably more opaque (*8*, *9*). Unlike the Atlantic horizon A, the Mesozoic-Cenozoic boundary in the Pacific appears to be associated only with change in the kind of sediment deposited or in the rate of sedimentation, and does not appear to be related directly to turbidite deposition.

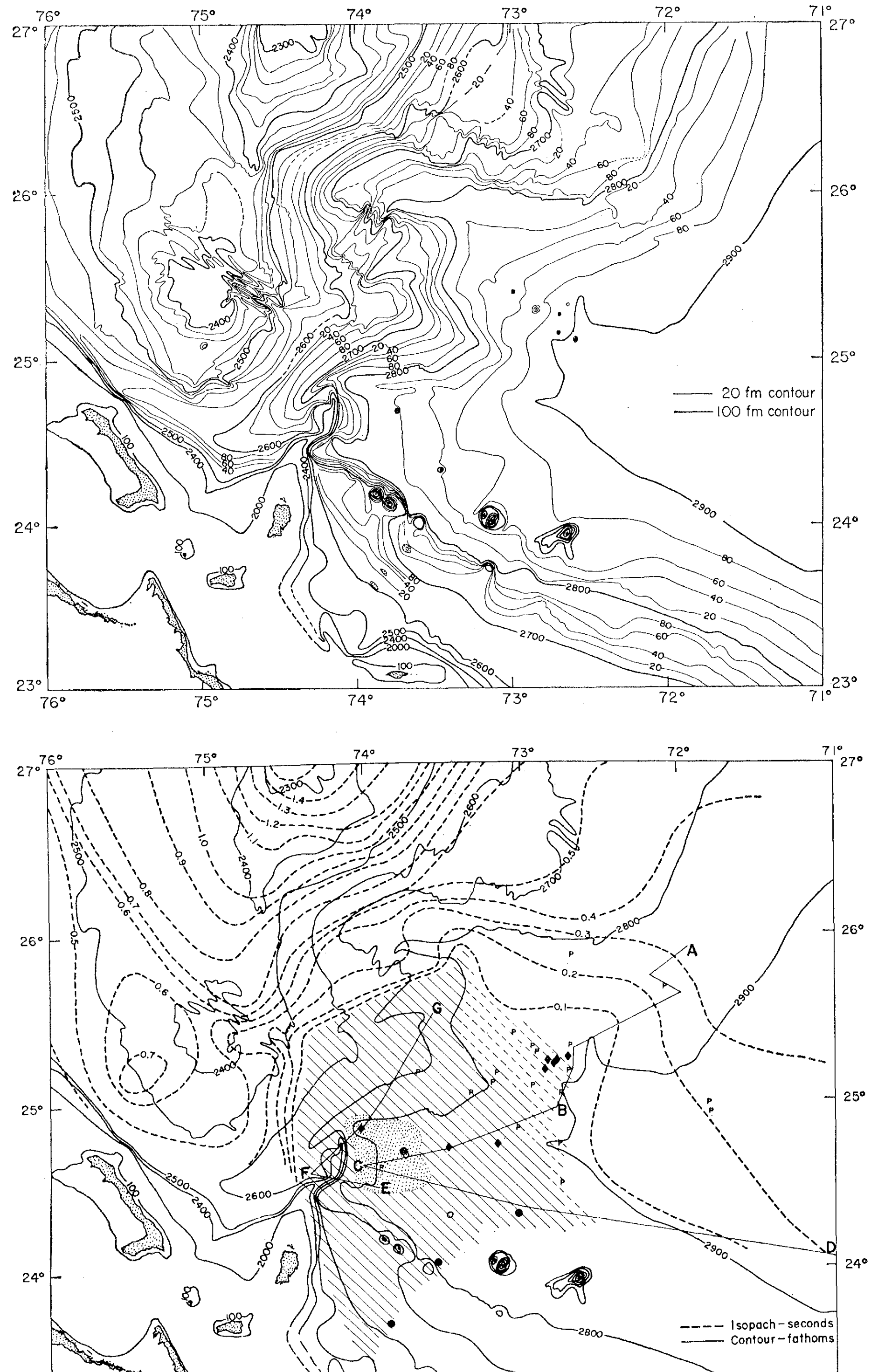

Fig. 3. (Top) Contour map of the area of the horizon A outcrop. (Bottom) Isopach map of the sediment overlying horizon A. Isopachs (dashed) represent sediment thickness in seconds of reflection time. Continuous hachures, horizon A outcrop surface; broken hachures, the portion of the outcrop that is locally exposed through a thin cover of recent sediment; stippled area, an apparent outcrop of horizon β (a reflector beneath horizon A); solid diamonds, sources of Cretaceous cores; solid circles, sources of Miocene cores; *P*'s, sources cf Pleistocene cores; *A–D* and *E–G*, ship's tracks for Figs. 4 and 5, respectively.

Sediments below Horizon A

The stippled zone in the central exposure area in Fig. 3 (bottom) represents a possible outcrop of a strong reflector that is stratigraphically below horizon A and that is evident on the profiles in Fig. 4 at miles 110 and 190; to simplify discussion, we shall refer to this zone of reflectors as horizon β (*8*). This prominent horizon is the top of a stratified zone similar to but not as strongly reflective as horizon A. The average thickness of the stratification is of the order of 200 to 300 meters. Horizon β appears less extensive than horizon A, but the thicker cover of sediment makes its identification difficult in many areas; and in some regions it so closely overlies the basement surface as to be nearly indistinguishable from it.

Three cores were taken in the horizon β outcrop area but only one of these recovered older sediment. Core V22-8 was taken where Cat Gap channel enters the outcrop area and where a group of reflectors similar to those of horizon β appear to outcrop; the cored sediment has been identified as a Cenomanian turbidite (*13*). Section *E–G* of the ship's track along which the core was taken is shown in Fig. 3 (bottom); the seismic-profiler records along this section appear in Fig. 5.

If the sediment sampled in fact represents horizon β, the Late Cretaceous section must be very thick in this part of the North American basin. However, the seismic records indicate that the outcrop could also represent a younger sediment similar to but about 300 meters above the true β surface. We must point out that the apparent basement surface is covered by about 700 meters of sediment in the vicinity of core V22-8. This sediment accounts for a considerable period of deposition before Cenomanian time, but it is apparent that rates of sedimentation here have been high and variable.

The Basement

The basement surface in the outcrop area is best identified by the various peaks and ridges, whose strong and reverberant reflections suggest that they represent a locally rough material whose acoustical impedance is high relative to that of the overlying sediments. However, in much of the outcrop area the deepest reflector is too smooth and its reflections are too coherent to be those of the usually rough basement surface; this type of surface is particularly noteworthy in Fig. 4 between miles 100 and 140.

As our studies of the oceanic areas by seismic profiler have expanded to significant coverage, it has become apparent that "smooth basement" areas are not uncommon in regions substantially removed from ridges, rises, and other major physiographic units affected by tectonic or volcanic activity. It is important to establish the nature of the material below this deep, smooth reflector designated horizon B in the Atlantic (*7*), B′ in the Pacific (*8*), and B″ in the Caribbean (*9*). If it is simply smooth basement (layer 2) and if the basement is igneous, then we can accept the thickness of sediment measured by the seismic profiler as the total amount desposited. Alternatively, the smooth basement may represent an old, high-impedance layer of sediment whose thickness is sufficient to mask a rough igneous basement. Certainly the acoustic inhomogeneities imposed by a variable cover of high-velocity sediment would be helpful in explaining the broad range of basement-velocity identifications (4.5 to 5.5 km/sec). Hamilton (*14*) has suggested that a portion of or all the basement (layer 2) is sedimentary in origin.

Tectonic Trends

A basement ridge associated with the southwestern boundary of the thick zone of turbidites in the northern outcrop area is represented by the buried peak at mile 94 in Fig. 4. The ridge is at least 60 miles long and its NW—SE strike is identical with that of a linear group of exposed and buried seamounts located approximately 20 miles to the northeast; the peak at mile 74 (Fig. 4) is one of this group. It is interesting that the trend of these features is strikingly similar to those of other crustal features in

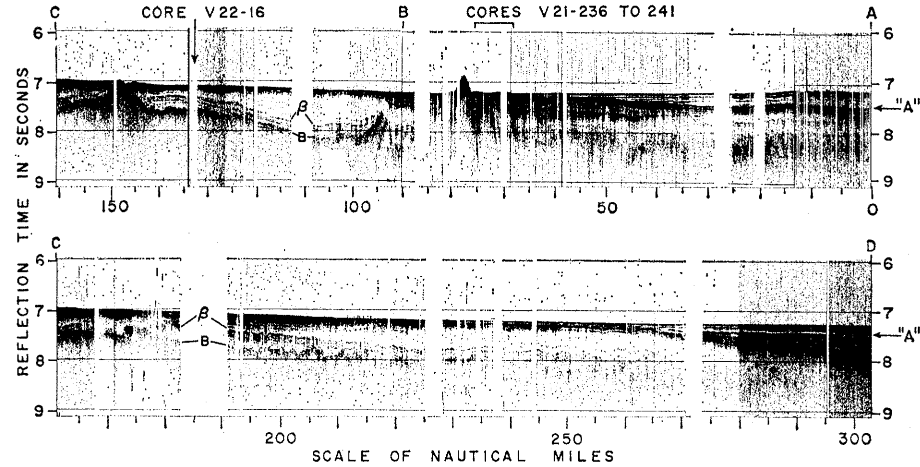

Fig. 4. Seismic-reflection profiles along *A–D* (Fig. 3, bottom).

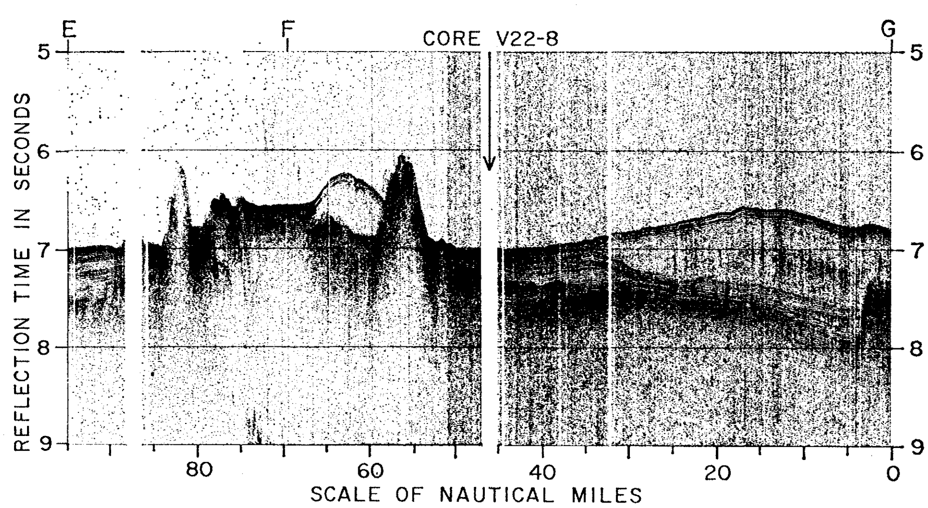

Fig. 5. Seismic-reflection profile along *E–G* (Fig. 3, bottom); core V22-8 is Cenomanian.

the North American basin. The New England seamount group is noteworthy among these, and recently published magnetic studies southeast of the outcrop area (*15*) show a similar lineation of anomalies. The magnetic data in the outcrop area are still subject to review. It is speculated that a roughly NW—SE trend in basement structures may represent an important crustal-fracture pattern in the North American basin. In the outcrop area these lineations appear to have developed before the deposition of horizon A.

The amount of uplift in the outcrop area is difficult to establish. Horizons A, β, and B attain regional topographic highs in the vicinity of the outcrop, and the dip of the deeper reflectors is considerably greater than that of typical abyssal plains. If one assumes that horizons β and B represent abyssal-plain desposits, the total uplift in the outcrop may be as much as 700 meters. If one also assumes that this uplift occurred subsequent to the deposition of horizon A, a considerable thickness of sediment must have been eroded from this area. A single determination of sediment velocity of 2.7 kilometers per second was made in the outcrop area from measurements of wide-angle reflection; this value is high for typical unconsolidated deep-ocean sediments and may partially result from consolidation of the present surface sediments by a fairly thick overburden that has been eroded. In any case the variations in thickness of sediments between the various reflectors is not a reliable indication of structural events. The outcrop of horizon β in the central outcrop area appears to result rather from local tectonism, as evidenced by its apparent outcropping at the flank of a buried seamount at mile 150 in Fig. 4.

This work has shown that horizon A is the top of a turbidite sequence of Upper Cretaceous (Maestrichtian) age; the shape, extent, and acoustic

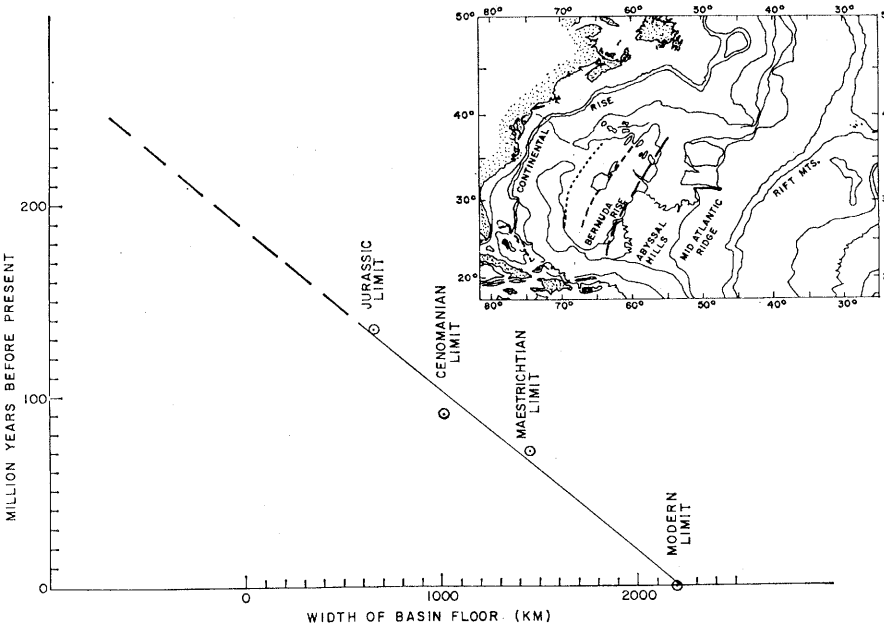

Fig. 6. Minimum values of width of North American basin as a function of time. Inset: approximate eastward limits of horizons A (long dashes), β (short dashes), and B (dots). Widths are measured from the base of the continental slope east of Cape Hatteras. [Physiography after Heezen and Menard (*12*)]

properties of the horizon had previously indicated that it was a fossil abyssal plain and the cores have confirmed this fact. The Maestrichtian age of the turbidites and interbedded pelagic lutites is firmly established by both coccoliths and Foraminifera (*13*). Measurements of shear strength and analysis of particle size indicate good contrast in impedance between the turbidites and the overlying younger lutite, which indication is consistent with the observation that horizon A is a good acoustic reflector (*16*). Although the horizon has been sampled only in the area described in this paper, it has been mapped by seismic profiling over most of the deeps of the North American basin, and its presence in other Atlantic basins is strongly suggested by reflectors that are similar acoustically and physiographically.

Although we can only infer from this evidence that the other basins had a similar history, we can definitely conclude that the North American basin received a great flood of turbidites near the end of the Mesozoic era; these produced an abyssal plain of enormous areal extent, reaching out well to the east of the longitude of Bermuda and perhaps to the flank of the mid-Atlantic ridge. This conclusion is consistent with the fact that a major marine regression occurred in Late Cretaceous time. The present continental rise and Blake-Bahama and Antilles outer ridges are depositional features that were built on this ancient plain. There is doubt about the presence of horizon A in the middle and lower Sohm abyssal plain (that is, the southeastern part). If present, it is probably not far beneath the present surface and is difficult to distinguish from the modern turbidites that form the plain.

In the rough abyssal-hill area between the Sohm and Nares abyssal plains, the only recorded events that may relate to horizon A are prominent reflectors in some of the larger pockets of sediment. Unless these are uplifted remnants of the old abyssal plain, we deduce that this area has always been sufficiently isolated to be out of reach of all but locally derived turbidites. Similar pockets of sediment have been observed well up on the flank of the mid-Atlantic ridge.

Both on the ridge flank and in the deep, rough area, there are thin and apparently pelagic sediments that often appear to be divided into an acoustically transparent upper part and a more opaque lower part. Evidence from the Pacific Ocean (*8*) indicates that an interface defined by a similar change in sedimentary properties corresponds approximately to the Mesozoic-Cenozoic boundary. Thus pelagic sediments, periodically carried into pockets by local turbidity currents, may appear acoustically as distinct upper and lower units and be separated by a distinct reflector. Although admittedly speculative, this line of thought merits consideration in view of the fact that sediment pockets with one predominant internal reflecting interface are found within 100 miles of the crest of the mid-Atlantic ridge. The possibility, however remote, that this reflector may be synchronous with horizon A must be considered; only deep drilling may provide the answer.

Horizon A has been traced continuously from the outcrop area to a point near the middle of the Nares plain. Recent survey by R.V. *Conrad* indicates that the outermost fringes of the Nares plain partially fill long, linear depressions similar to those associated with the *Vema* fracture zone and others that apparently offset the axis of the ridge. Although there are no traverses that permit continuous tracing of horizon A into these depressions, at least one depression contains a reflector very similar in appearance to horizon A and lying at the appropriate depth to be a continuation of it. The presence of the reflector in the depression and the relatively small amount of distortion observed suggest that the structure was formed before late Upper Cretaceous time and that little motion has since occurred along it.

Dating the horizon A sediments as Upper Cretaceous permits us to make useful estimates of the age of the deepest part of the section that is unquestionably composed of sediments —the part just above horizon B. Core V22-8 appears to have sampled sediment from a level just above reflector β (Fig. 5), and its age is Cenomanian. If this evidence is taken at face value, it indicates a very high rate of sedimentation during Upper Cretaceous time, from which we may deduce that none of the sediment above reflector B is older than Cretaceous. Simple extrapolation could date reflector B as the top of the Jurassic, but unfortunately core V22-8 comes from an area obviously characterized by nonuniform deposition and erosion; thus the thickness of any layer may not be a meaningful measure of the duration of accumulation.

On the western part of the Bermuda rise, where there is no evidence of anomalously fast or irregular deposition or of erosion, the ratio of the thicknesses of sediments below and above horizon A is about 2:1 (in terms of reflection time). If allowance is made for a reasonable amount of consolidation of the deeper beds, we must deduce that there is more than twice as much Cretaceous and older sedimentary material as there is younger than Cretaceous. If the sedimentation rate remained the same before and after the deposition of horizon A, the sediments just above horizon B must be well over 200 million years old—corresponding to early Mesozoic or late Paleozoic age.

As we have mentioned, horizon B is so smooth and produces such a coherent echo pattern that it is difficult to imagine it as other than the top of a sedimentary bed. The possibility that horizon B may well be as old as Paleozoic raises the question of the relation of rough-basement to smooth-basement areas (the latter, horizon B areas, are those in which the deepest reflector recorded by the seismic profiler is smooth). If the difference results simply from one area having been roughened by intrusive or tectonic activity while the other has remained undisturbed, Paleozoic sedimentary rocks may be the main constituents of layer 2 and may be present in essentially all oceanic areas (*14*). Alternatively, one may judge that old sediments are present only in the horizon B areas, that they are thick enough to smooth the relief in an underlying igneous basement, and that the acoustic impedance and seismic velocities in the old sediments and in the basement are not significantly different. A recent survey in the North American basin (*17*) has shown that the smooth basement (horizon B) occurs west of a line roughly midway between Bermuda and the continental margin; the possibility that this line corresponds to the eastern limit of old sediments is difficult to ignore, but quite reasonably one may also consider it as the western limit of active tectonism or intrusion, perhaps associated with formation of the Bermuda rise.

In view of current active interest in the spreading-floor model of continental drift advanced by Hess (*18*) and Dietz (*19*), the following observations or opinions seem appropriate.

1) If we accept a late-Jurassic age for horizon B, Cenomanian for horizon β, and Maestrichtian for horizon A, and if we accept the apparent eastern limits of each as representing the position of the base of the mid-Atlantic ridge at the time of deposition, we can plot the rate of expansion of the North American basin (Fig. 6). The plot indicates a spreading rate of about 1 centimeter per annum, and extrapolation back to zero basin width gives an age of about 190 million years for the earliest deep basin. The initial break-up of the continents would have occurred about 60 million years before this date, if a constant rate of spreading is assumed. The basin widths plotted in Fig. 6 are believed to correspond to deep basin floors on which gravity-transported sediments were deposited. At every stage, including the earliest, the total basin width would have included the width of the continental slope and of the flank of the mid-Atlantic ridge. The shape of the ridge flank probably would have been governed primarily by the speed of the convecting flow, and if the convection has been continuous and steady the ridge flank would probably have had a shape and size comparable to its present shape and size throughout most of its history. Thus the extrapolated time of zero basin width in Fig. 6 would in fact correspond to the time when the basin had approximately its present depth but was still V-shaped. Further extrapolation along the curve to account for the width of the flank of the ridge would give a time about 250 million years before present, when the continental blocks would have been in contact.

Such reasoning clearly can be used to support the spreading-floor concept if the assumptions on which it is based are correct. Neither the eastward limits of reflectors B and β, nor their ages, are exactly established. Horizon β may well be older than Cenomanian, and the eastern limits of both B and β may extend farther than indicated; thus the line in Fig. 6 probably can be considered to represent the maximum possible rate of expansion, as movement of the Jurassic or Cenomanian points either upward or to the right would steepen the slope. Even if we ignore the Jurassic point, which is certainly the more questionable, the line could still be valid for continuous spreading since Cenomanian.

As we have mentioned, horizon A cannot yet be identified in the central and southern areas of the Sohm abyssal plain, but its presence there is not ruled out; there is rather good evidence that it does extend entirely out to the base of the ridge in the Nares basin and in the northern part of the Guiana basin. If this suspicion is confirmed by further survey, we must face the fact that in these areas Upper Cretaceous turbidites were carried out essentially as far as modern turbidites; therefore, the third point in the graph (Fig. 6) might be shifted to the right by some 600 to 700 kilometers. Such a change would restrict post-Cretaceous spreading to the ridge province.

So far we have assumed that the sediments at each stage of the deposition flowed out from the North American continent and covered essentially the entire basin floor that existed at the time. We should point out that the observed pattern of eastern limits versus age of sediment might be expected if the width of the basin had not changed at all.

2) The relatively small amount of distortion of horizon A is remarkable if spreading of the sea floor has indeed transported the basin some 1000 kilometers westward during the 70 million years since its deposition. Except on the Bermuda rise, horizon A still resembles reasonably well an abyssal plain—that is, it is relatively flat and smooth and in most places composed of several closely spaced reflecting interfaces having acoustic properties similar to those of the modern abyssal plains.

3) The fact that the seismic profiler has recorded no sediments in a strip 100 to 150 miles wide in the crestal area, during many crossings of the mid-Atlantic ridge, may be evidence of recent spreading, although it is possible that the sediments have been buried by lava rather than been carried away by a spreading crust. The remainder of the flank area shows little indication that one part of it has been receiving sediments longer than another part. Therefore, if the sediment thickness is a proper measure of the elapsed time since a segment of ridge flank was generated at the crest, the process—such as convective spreading —does not appear to persist at a steady rate; rather, there seems to have been a long period of quiescence during accumulation of the flank sediments, before a recent period of activity. The observation that the thermal gradient is high only in a narrow strip along the crest of the mid-Atlantic ridge also poses serious objections to a long-sustained convective flow (*20*); the objections would be less serious if the convection had been stopped for a long time and only recently resumed.

It seems possible, therefore, that a recent resumption of convection, after a period of quiescence extending back possibly to the end of Cretaceous time, can explain the sediment distribution, the pattern of heat flow, and the pattern of magnetic anomalies (*21*), but there is serious conflict between recent convective spreading and the recovery of Miocene fossils from the rift valley unless we allow the possibility that "patches of older sediment were left behind in the crestal area rather than being completely swept away from the axis" (*11*).

4) Some of the larger pockets of sediment on the flank of the mid-Atlantic ridge contain a very prominent internal reflector, raising the possibility that these are uplifted horizon-A areas. Alternatively, if these pockets contain only pelagic sediments that have been ponded by local turbidity flows, there is still the possibility that the prominent reflector is synchronous with horizon A and that there is a distinct change in the acoustic properties of the sediments at about the Mesozoic-Cenozoic boundary as was reported for the Pacific sediments (*8*).

Although we have no direct information about the composition or age of this reflector, it is mentioned because, if it should prove to be uplifted horizon A or a deposit synchronous with this horizon, its presence as close to the crest as 100 miles would impose serious restrictions on the amount of permissible spreading of the sea floor during the Cenozoic.

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Diversity

More diversity in our science, our patterns of living, and our education would enrich us all.

John R. Platt

I celebrate diversity. Our research, our lives, our goals, our pursuit of excellence are all too homogeneous. La Rochefoucauld writes: "God has put as differing talents in man as trees in Nature: and each talent, like each tree, has its own special character and aspect. . . . The finest pear tree in the world cannot produce the most ordinary apple, and the most splendid talent cannot duplicate the effect of the homeliest skill."

I think he means that other men are not like him in being able to produce maxims of this kind. But what he says is true. How many of us have gotten D's and F's in apple-tree courses simply because the teacher was too narrow to see that we had to be nurtured as pear trees? Progress would be faster and life would be more interesting if we pursued more diverse goals, goals of excellence to be sure, but goals of our own, different from what everybody else is pursuing—and if we tolerated and encouraged the same sort of individuality in others. I want life to be various. I want to see around me not only apple trees but pear trees, not only fruit trees but slow-growing oaks and evergreen pines and rosebushes and bitter but salubrious herbs and casual dandelions and good old spread-out grass. Let us be different, and enjoy the differences!

The Scientific Bandwagon

Nowhere are we as diverse as we might be. Science and technology today encompass thousands of specializations, yet it is easy to see that the specialists are probably overconcentrating on certain subjects while other subjects, of equal interest and importance and ripeness for development, are almost entirely neglected. A short time ago it was announced that there were over 400 government and industrial contracts and projects for studying the new device known as the optical laser, which is able to produce a peculiarly coherent and brilliant beam of light. Now this is an interesting field, but—400 projects! This represents several thousand scientists and engineers who have jumped, or been pushed, onto this bandwagon in the 5 years since the laser was invented. The motorcar was developed with less than 40 manufacturing and development teams, and the whole field of atomic spectroscopy was developed in perhaps no more than 40 research laboratories. One cannot help wondering whether everything important to discover in the field of lasers might not have been discovered just as fast with only 40 projects, with the other 360 groups doing something less repetitious. One suspects that many of the 400 projects might not have been started if their leaders had known in advance—before they got their grant money and could not back out—that they would be competing with 399 others.

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