Because of this, it seems reasonable to suppose that the hydrogens reported in Frondel and Ito's analysis are, in fact, absent from the structure, and that in the recorded analysis the loss on ignition was due rather to a loss of some of the other constituents, especially B and alkali. The density computed for the ideal formula, $CsB_{12}Be_4Al_4O_{28}$ (except that the alkali mixture found by Frondel and Ito was used instead of pure Cs), in an isometric cell of edge $a = 7.319$ Å, is 3.478 g/cm^3. This is essentially the same as that of Frondel and Ito's preferred formula which requires 3.47, as compared with a measured density of 3.44. The small excess in calculated density could readily be attributed to a small error in the proportions of the several alkalies making up the alkali site.

The ideal formula $CsB_{12}Be_4Al_4O_{28}$ appears to be unbalanced in the amount of one excess positive charge. In other words, the alkali appears to behave formally as a neutral atom. It also appears to be held, clathrate fashion, within the large hole at the origin. For the Manjaka rhodizite, the composition of the alkali in the hole is $Cs_{.47}Rb_{.17}K_{.33}Na_{.03}$. It is evident that these various atoms, whose radii vary from about 1.7 Å down to 1 Å for ionic radii, or about 2.4 Å to 1.6 Å for metallic radii, cannot all fit the same-sized void. The occurrence of neutral Na in the clathrate structure Na_8Si_{46} and Na_xSi_{136} has just been discovered and discussed by Kasper *et al.* (*6*). Rhodizite appears to offer another example of a neutral alkali in a cage.

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Shaping of the Continental Rise by Deep Geostrophic Contour Currents

Abstract. *Geostrophic contour-following bottom currents involved in the deep thermohaline circulation of the world ocean appear to be the principal agents which control the shape of the continental rise and other sediment bodies.*

The continental rise is a broad, uniform, gently sloping and smooth-surfaced wedge of sediments, 100 to 1000 km wide and 1 to 10 km thick which, wherever trenches are absent, lies at the base of the continental slope. It is normally covered with, and probably is largely composed of, monotonously homogeneous fine gray lutites. These "hemipelagic" or "terrigenous" sediments were deposited at comparatively high rates. Postglacial rates ranged from 5 to 50 cm per 1000 years, and even higher rates predominated during the Pleistocene (*1*). In most instances seismic refraction investigations reveal that the wedges of sediment are thickest beneath the upper continental rise and gradually thin seaward (*2*). It has been suggested that these modern geosynclines lie in ancient deep-sea trenches and that they were filled in large measure by turbidity currents. However, recognizable turbidites constitute a small proportion of the glacial and postglacial sediments of the continental rise (*1*). Since hemipelagic lutites are derived almost entirely from denudation of land, a seaward diffusion of lutite is generally assumed, but the transporting mechanisms and directions of transport are difficult to infer because of the lack of sediment variability.

The continental rise off eastern United States merges south of Cape Hatteras with the broad, southeasterly plunging Blake-Bahama Outer Ridge. Seismic investigations (*3*) indicate that this southerly extension of the continental rise is an undeformed sediment wedge similar in seismic velocity and geological structure to the normal continental rise sediment wedge found further north.

The outer ridge is separated from the continent by the Blake-Bahama Basin and by the broad Blake Plateau (Fig. 1). Terrigenous sediments derived from southeastern United States are barred from the eastern Blake Plateau, the Blake Escarpment, and the western Blake-Bahama Basin by the vigorous northerly transport of the Gulf Stream which flows at velocities of 100 to 300 cm/sec along the western margin of the Blake Plateau. Thus the existence of the accumulation of a continental-rise-type sediment 1000 km seaward of Florida suggests a north-to-south abyssal transport of terrigenous sediments.

Agassiz concluded that the Blake Plateau is "swept clean of slime and ooze." He did not specify the destination of the detritus, but Stetson concluded that much of the finest material is transported with the Gulf Stream far into the northern North Atlantic (*4*).

The growing Gulf Stream draws over 12 million m^3/sec of the Antilles Current (*5*) across the Blake Plateau. Transportation by this westerly flow may account for the relatively thin veneer of Recent sediments and the frequent exposure of Tertiary and Mesozoic marls on the Blake Plateau and Blake Escarpment. Numerous unconformities were encountered in the reduced Tertiary carbonate section penetrated by JOIDES (Joint Oceanographic Institutions' Deep Earth Sampling Program) (*6*) drill holes, which suggests that a vigorous but fluctuating westerly transport had persisted throughout the Tertiary. Some of this detritus, including all of the bedload, must be deposited somewhere near Cape Hatteras where the Gulf Stream flows into the deep Atlantic, but there is no obvious topographic feature directly east of Cape Hatteras which might represent a pile of detritus. Although the Gulf Stream apparently has locally eroded the Blake Plateau, its main effect has been to prevent terrigenous deposition seaward of the stream and to inhibit deposition of the normally thin pelagic carbonate oozes.

Slope water off northeastern North America is bluish or grayish green, while the Gulf Stream and Sargasso Sea are a clear deep ultramarine. Slope water, which north of Hatteras lies at the surface between the Gulf Stream and the continental slope and laps up on the continental shelf, not only supports a much richer biota than the Sargasso Sea, but also contains at least an order of magnitude more suspended matter and is, therefore, a potentially

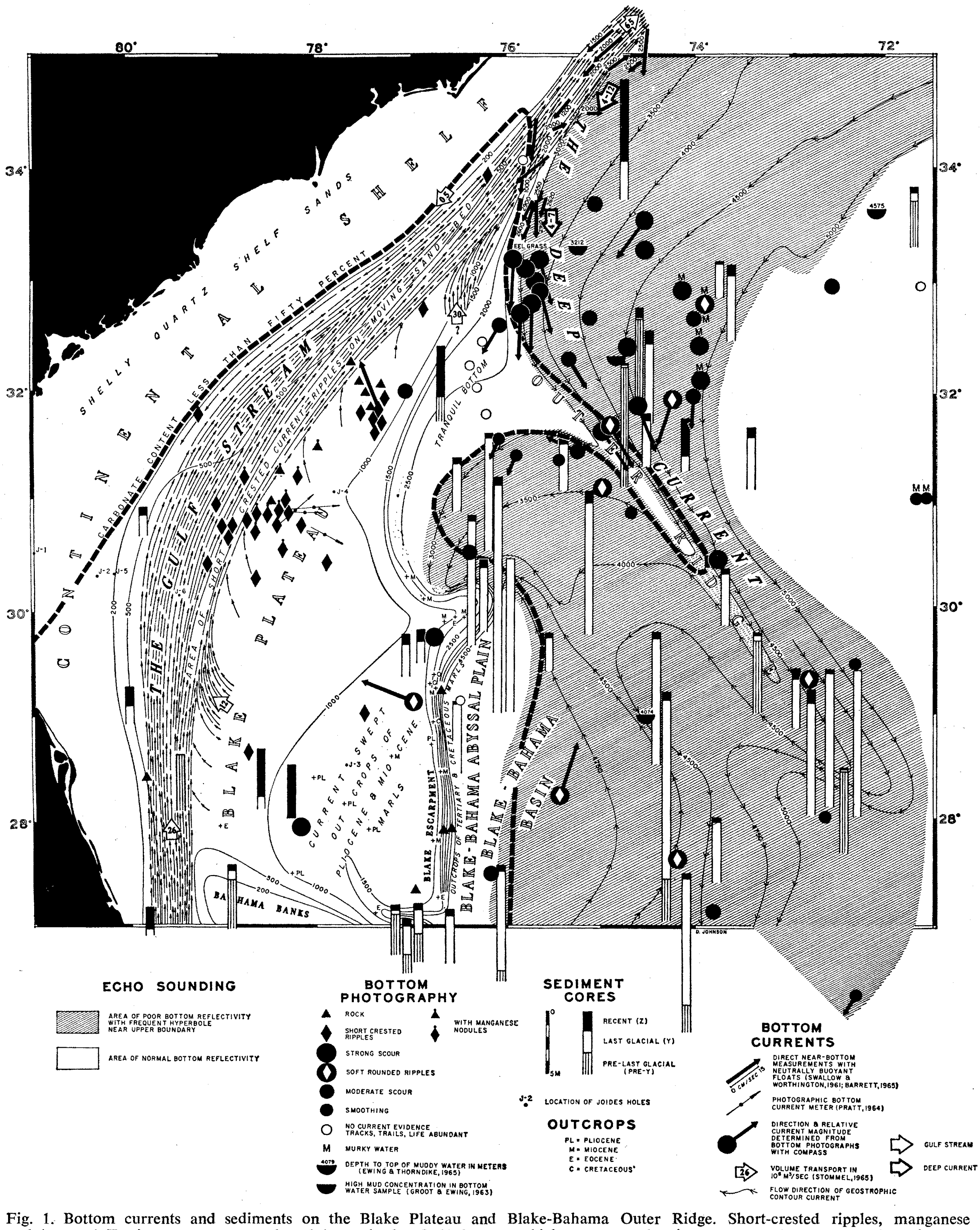

Fig. 1. Bottom currents and sediments on the Blake Plateau and Blake-Bahama Outer Ridge. Short-crested ripples, manganese nodules, and Tertiary outcrops are found beneath the Gulf Stream which acts as a barrier to seaward transport of terrigenous sediment. The outer ridge is formed by rapid deposition of lutite from the southerly flowing sediment-laden Western Boundary Undercurrent which flows parallel to the contours. Thirty-three additional photograph stations obtained from R.V. *Eastward* in March 1966 (not shown) further support the current pattern indicated.

significant intermediate source of terrigenous lutite. Bottom water velocities on the continental shelf almost always exceed those required for the erosion and transportation of silt and clay. Thus, lutite eroded from the continents largely bypasses the continental shelf where sand and gravel are the predominant sediment. Upon reaching the slope water, much of this fine material remains in suspension and drifts to greater depths.

The pronounced seaward dip of near-bottom isotherms frequently observed on the continental slope and continental rise constituted the first evidence of relatively strong deep contour-following geostrophic currents (*5*). Pressure gradients indicated by the inclined isopycnals must be opposed by an opposite and equal force which would seem to be provided by a current on which the Coriolis forces are acting normal to the direction of motion (to the right in the northern hemisphere). These currents flow along isopycnals which are approximately parallel to the bathymetric contours. We refer to these currents as contour currents.

Wüst (*5*) demonstrated that a relatively strong Antarctic Bottom Current flows north in depths of 3000 to 5000 m along the western side of the South Atlantic, and he predicted the existence of a similar intensification in the southerly flowing deep current along the western side of the North Atlantic. Relatively strong inclinations of the deep isotherms below 3000 m have frequently been observed along continental margins in the western North Atlantic (*5, 7*). Near-bottom velocities up to 18 cm/sec have been observed in the southerly flowing Western Boundary Undercurrent east and southeast of Cape Hatteras, east of Cape Cod, and off Greenland and Labrador (*8*). These measured velocities are competent to transport all the sizes of sediment generally found on the continental rise (*9*). However, most measured or calculated current velocities in the deep sea are closer to the minimum values required for transportation of rise sediments. Under a delicate balance between transportation and deposition, faster portions of the current will produce thicker deposits because of their greater total volume transport.

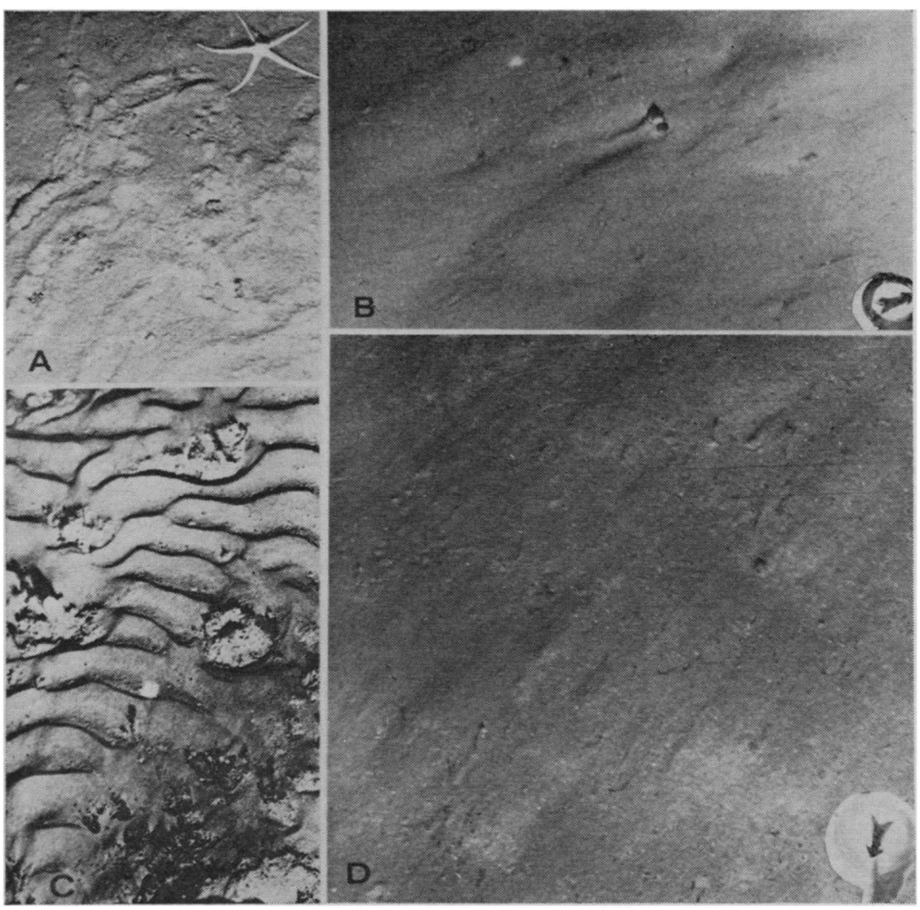

Fig. 2. Bottom photographs of the Blake Plateau and Blake-Bahama Outer Ridge. (*A*) Tranquil bottom on crest of outer ridge near base of continental slope. In this area four stations reveal abundant life and no current evidence. E41-58-1; 2164 m; 32°24'N, 76°18'W. (*B*) Current lineation east of crest of the outer ridge. At 14 stations from both the eastern side of the outer ridge between 3000 and 5000 m and from the base of the continental slope off North Carolina, abundant lineations indicate a southerly current flowing precisely parallel to the contours. The compass is 10 cm in diameter. E41-49-8; 3975 m; 31°42'N, 74°49'W. (*C*) Short-crested current ripples beneath the Gulf Stream on the Blake Plateau. Surface of the Blake Plateau is characterized by rippled sand, manganese nodules, or manganese-encrusted tabular outcrops of Tertiary sediment. E19-D; 872 m; 30°52'N, 78°41'W. (*D*) Current lineations made by the southerly flowing Western Boundary Undercurrent east of the crest of the outer ridge near the base of the continental slope. Direct current measurements nearby indicate a southerly flowing near-bottom current of up to 18 cm/sec (*8*). E41-61-17; 3183 m; 32°51'N, 75°45'W.

Unoriented photographs have revealed the presence of ripple and scour marks on the Blake-Bahama Outer Ridge (*9*). An expedition to the continental rise and Blake-Bahama Outer Ridge was conducted as a student training cruise aboard Duke University R.V. *Eastward* during August 1965 to investigate the nature and orientation of the effects of geostrophic contour currents on bottom sediments. Deep-sea cameras equipped with punch core and compass and a precision echo sounder were the principal tools used on this expedition. A further investigation was completed in October 1965 from C.S. *Long Lines* in connection with a cable route survey.

Along the base of the continental slope off Beaufort, North Carolina, and along the eastern flank of the outer ridge, current lineations consisting of streamers of sediment deposited in the lee of burrow mounds and other objects on the bottom were observed at 29 localities (Fig. 2, *B* and *D*). At 24 stations a compass was placed within the field of view; at 14 stations from both the eastern side of the outer ridge between 3000 and 5000 m and from the base of the continental slope off North Carolina, abundant lineations indicated a southerly current flowing parallel to the local contours (Figs. 1 and 2). Where current lineations were abundant the bottom was smooth and remarkably free of benthic life, and the water appeared muddy. Neither current lineations, ripples, nor turbid water was observed on the outer ridge in four out of the five stations obtained in depths less than 3000 m. In such

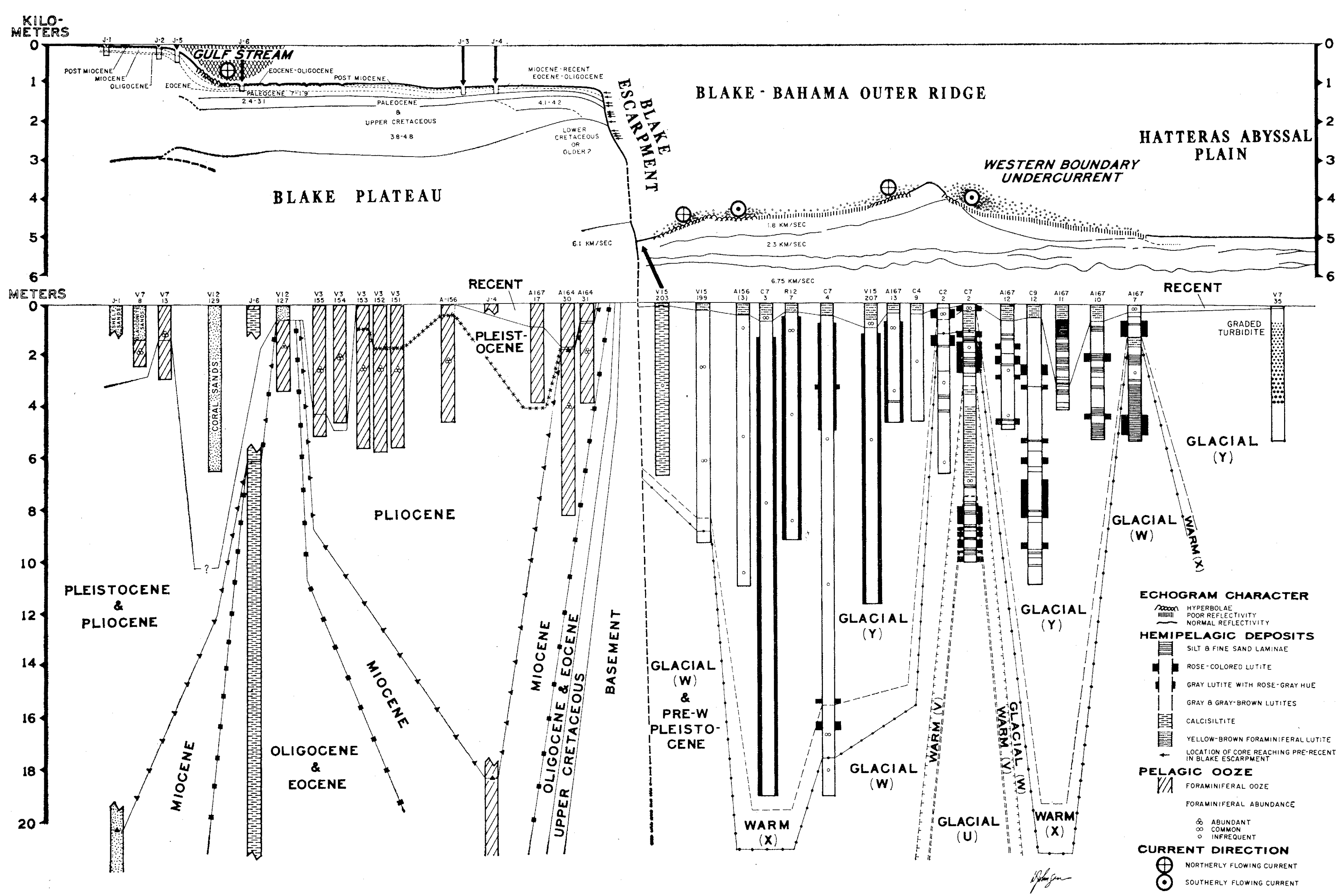

Fig. 3. Profile across Blake Plateau and Blake-Bahama Outer Ridge. Thick Pleistocene and Recent wedges of lutite on the Blake-Bahama Outer Ridge thin eastward toward the Hatteras Abyssal Plain and westward toward the Blake-Bahama Abyssal Plain in response to decreased volume transport of the Western Boundary Undercurrent (*3*, *6*). The greatest water depth west of the outer ridge occurs at the base of the Blake Escarpment, precluding any significant seaward sediment dispersal. Climatic zones are based on foraminiferal assemblages (*1*).

depths the bottom was marked by tracks and trails and by a relatively normal abundance of benthic life (Fig. 2*A*). Rounded ripples occurred in seven stations at a depth of 3500 to 5000 m.

On the Blake Plateau the Recent is variable in thickness and consists of reworked shelly green-sand and phosphorite on the landward side of the Gulf Stream, reworked coral sand and manganese nodules beneath the Gulf Stream, and globigerina ooze on the outer Blake Plateau (*10*). Near the seaward edge of the Blake Plateau the Pleistocene is absent and Pliocene or Miocene marl is either exposed at the surface, covered by a few centimeters of ooze, or coated with a manganese crust (*1*). The outer ridge, on the other hand, is covered by a thick sequence of Quaternary sediments.

The thickness of the Recent (Fig. 3) (*1*) increases from the Hatteras Abyssal Plain toward a maximum of over 1 m on the eastern flank of the outer ridge, then decreases markedly, and reaches a minimum east of the crest. West of the crest the thickness of the Recent ranges from 30 to 80 cm, again decreasing to 20 cm on the Blake-Bahama Abyssal Plain. The late glacial (*Y*) zone generally exceeds the 10- to 20-m penetration of the cores. In three cores near the apparent axis of the undercurrent, Recent and late glacial sediments are thin or absent, which suggests either slow deposition or considerable erosion along narrow linear belts (Fig. 3).

In only three other cores on the outer ridge was the late glacial (*Y*) zone penetrated. The underlying warm zone (*X*) was reached at 16 and 12 m on the outer ridge at 30° and 28°N, respectively. In one core at 31°N over 19 m of late glacial (*Y*) was penetrated without reaching the underlying warm (*X*) zone. Thus the thickness of the late glacial (*Y*) zone decreases from over 19 m at 31°N to less than 12 m at 28°N as the total thickness of the outer ridge accumulation decreases from 5 to 3 km (*3*).

A downslope thinning of beds has been observed on the continental rise from the upper few tens of meters to the basement surface (*11*). This wedging might be attributed solely to sedimentation resulting from a gradual mixing and diffusion of finely divided terrigenous material with increasing distance from the continental sources, were it not for the presence of a similar wedging on both flanks of the outer ridge. This latter fact suggests that transport parallel to the isobaths by deep-sea currents plays a significant role in the transportational history of continental rise deposits.

The boundary between the area of tranquil bottom and smoothed current-lineated sediment corresponds to an abrupt deterioration in bottom reflectivity (Fig. 1). Near the upper or shallower edge of the area of current lineations, hyperbolas approximately tangent to the average sea floor profile are frequently recorded on the echo sounder (*1*). In slightly deeper water echoes are irregular and indistinct, which suggests the presence of lineations of smaller size. Still further from the crest, bottom reflectivity gradually improves toward the abyssal plains.

Areas of poor reflectivity correlate with high rates of late glacial sedimentation. Cores from such areas have a higher water content than normal sediments do, and the resulting poor contrast in acoustic impedance probably contributes to poor bottom reflectivity.

There is a sharp contrast in color and lithology between the late glacial (*Y*) deposits to either side of the outer ridge (Fig. 3). To the east numerous thin laminae of silt and fine sand are intercalated in gray-brown and rose-colored lutites, whereas to the west silts are absent and the rose-gray hue becomes increasingly diluted and is not observed in the westernmost cores.

Ericson (*1*) first discovered rose and rose-gray lutites in glacial age sediments on the continental slope and continental rise off eastern North America. Subsequently, red and brick-red marine tills were described from the Cabot Strait and adjacent continental slope (*12*). Deposition of these red detrital sediments ceased before the end of the last glaciation (*Y*). Thus, the rose, rose-gray, and light rose-gray lutites found on the outer ridge may have been derived from Triassic and Paleozoic red sediments of the Gulf of St. Lawrence and transported 3000 km to the south by the southerly flowing Western Boundary Undercurrent (*13*). The rose-gray sediment is also found in earlier glacial (*W* and *U*) sediments but not in interglacial sediments.

In a water sample collected 200 m above the east flank of the outer ridge (*14*) suspended sediment was found in a concentration of about 1×10^{-6} g/cm^3. Ewing and Thorndike (*14*) devised an instrument to estimate the relative concentration of suspended matter. Their first profile extending east from the continent to the abyssal plain revealed a near-bottom layer of muddy water a few hundred meters thick. They concluded that the "suspension of lutite" was "apparently in sufficient quantity to induce downslope flow," and that "The flow down the continental slope and rise that would result from the sediment loading . . . would acquire deflection toward the south from the Coriolis force, providing a mechanism for transmitting the sediment toward the Blake-Bahamas outer ridge" (*14*). We maintain that the muddy water is simply being transported parallel to the contours by the Western Boundary Undercurrent (*5*).

The Gulf Stream transports approximately 26 million m^3/sec of water through the Straits of Florida (*5*), but east of Cape Hatteras its flow has increased to over 65×10^6 m^3/ sec. Since the Antilles Current apparently contributes only about 12×10^6 m^3/sec to the Gulf Stream on the Blake Plateau, some 30×10^6 m^3/sec must join the Gulf Stream near Cape Hatteras from the adjacent Sargasso Sea and North Atlantic deep water. Such flow must come in at nearly all levels from near the surface to a depth of over 4000 m and from both south and north of the outer ridge.

Transport of the Western Boundary Undercurrent has been calculated at 4 to 12×10^6 m^3/sec east and 3 to 7×10^6 m^3/sec southeast of Cape Hatteras (*8*). This transport appears to remain essentially constant as the deep current passes from north to south beneath the Gulf Stream. If the Western Boundary Undercurrent contains 1×10^{-6} g/cm^3 of sediment, and if over the past 10,000 years an average of 5×10^6 m^3/sec of Western Boundary Undercurrent water passed to the south of Cape Hatteras, then the order of 1.6×10^{18} cm^3 of clay has flowed in the direction of the outer ridge since the last glacial. Total thickness of the nonpelagic sediment component is approximately 30 cm over an area of 5×10^5 km^2. Thus the total sediment volume is 150 km^3 or 1.5×10^{17} cm^3. This rough calculation suggests that approximately an order of magnitude additional material has passed beyond the outer ridge in post-glacial times.

If the same assumed volume transport and sediment concentration is applied to the 15 m of nonpelagic last glacial (*Y*) sediments, a similar amount of bypassing is again indicated. However, the concentration of suspended matter in glacial times might have been an order of magnitude (or more) greater than at present. These rough calculations show that transport of lutite in the Western Boundary Undercurrent is adequate to build the Recent and last glacial (*Y*) thicknesses observed on the outer ridge.

Since the axis of the highest velocity and greatest volume transport is deflected to the right side of the current, sediment transport is greatest high on the continental rise and decreases with increasing depth and distance from the current axis (Fig. 4). Since current velocities are sufficiently high for lutite transport but not high enough for erosion of lutite, this flow pattern produces an accumulation of sediment that is relatively uniform in thickness at any bathymetric level but decreases in thickness with increasing water depth and decreasing current velocities as a consequence of decreasing volume transport. As long as current velocities lie below those required for erosion, the quantity of sediment that is deposited will be roughly proportional to volume transport of the current (*15*).

The easterly deflected northerly flow along the western flank of the outer ridge explains the convergence of sediment horizons from the outer ridge toward the Blake-Bahama Abyssal Plain and accounts for the sharp contrast in acoustic properties between the smooth Blake-Bahama Abyssal Plain and the gently rising western flank of the outer ridge (*16*).

Normally it would not be possible to evaluate the role of currents flowing parallel to the continental margin in the transport and deposition of the very fine continental rise sediments. The relative uniformity of clay mineral contributions plus the lack of larger identifiable mineral species which might have regional peculiarities make it nearly impossible to determine the source and transportational history of a specific sample. However, the Gulf Stream, in providing an effective barrier to the seaward transport of terrigenous sediments off Florida, Georgia, and the Carolinas, allows us to look at a portion of the continental margin in which direct seaward dispersal of sediments has been prevented for a very long period.

The steep (slope, 1 : 3) Blake Escarpment, unburied by post-Cretaceous sediments, may represent the abrupt form of the normal structural edge of the continent. It is widely held that the continental rise was constructed at the foot of an original faulted continental slope by a series of coalescing deep-sea fans or cones built by downslope transport at the mouths of submarine canyons (*17*) and by the seaward diffusion of very fine terrigenous lutite through the water column. This simple picture, although essentially correct, is not complete, for it fails to explain the nearly identical form of successive profiles across the continental rise and the characteristic lack of irregularities seen on profiles run along the continental rise in most parts of the world, and it completely fails to explain the Blake-Bahama Outer Ridge.

The principal characteristics of the continental rise which have not previously been explained are: the persistent uniformity in morphology, sediment type, stratification, and structure; the abrupt morphologic boundaries with both the abyssal plain and the continental slope; and the seaward convergence of all bedding planes in the Quaternary, Tertiary, and late Mesozoic sediments (Fig. 4).

Deep geostrophic currents are deflected by the Coriolis force against the side of the oceanic basin; the highest velocity axis, being deflected the most, lies high on one side and the lowest level at which such a current can effectively flow lies at the margin of the nearly level abyssal plains (*18*). This flow pattern may provide an explanation for the abrupt boundaries of the continental rise.

In marked contrast to the steady, low-velocity (2 to 20 cm/sec) contour-following geostrophic currents which never flow downslope, turbidity currents are intermittent, high-velocity (up to 2500 cm/sec) downslope movements which can possess much greater com-

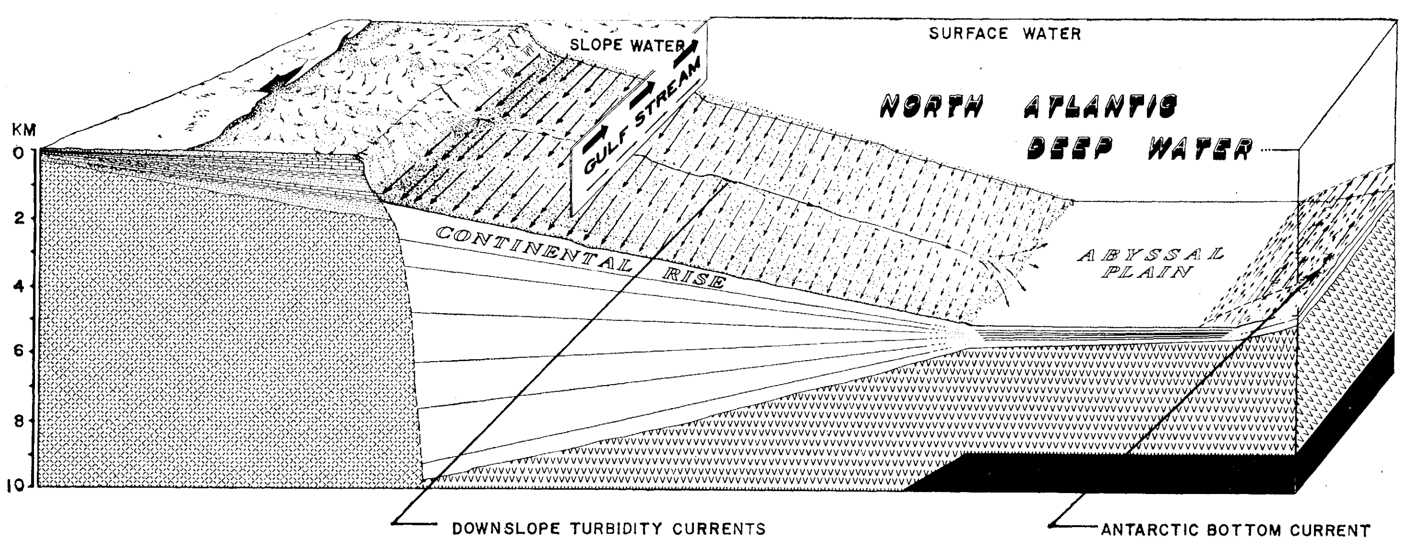

Fig. 4. Shaping of the continental rise by geostrophic contour currents. Arrows indicate prevailing bottom currents. Continental and oceanic crust is shown by patterns; mantle is solid black. Sedimentary rock is shown by conventional symbols; turbidites by horizontal ruling and rise deposits by open wedges. In addition to the measurements reported here, the transport directions are supported by further oriented photographs of current lineations obtained in November 1965 on the continental rise off Nova Scotia (*13*) and on the western Bermuda Rise (*18*). With the exception of the shifting position of the Gulf Stream this schematic diagram, drawn on the basis of an average section off eastern North America, is intended to illustrate the principal processes shaping a "normal continental rise" in any part of the world.

petence. Turbidity currents account for the sands and gravels which underlie the perfectly flat, strongly reflecting abyssal plains, for gravel and sand in submarine canyons, and for finer sediments in natural levees and abyssal cones, but they fail to account for the uniform shape and stratification of the enormous accumulation of continental rise lutite. Massive transport of continental rise sediment parallel to the contours for at least 1500 km is demonstrated by the construction of the Blake-Bahama Outer Ridge. This illustrates the powerful smoothing potential of deep geostrophic contour currents in the shaping of the continental rise.

The thickest sediments in the ocean are found beneath or very near the axes of deep geostrophic contour currents, and these deposits become thinner with increasing distance from the current axes. That this pattern holds for all beds from the latest postglacial to the underlying basement is demonstrated by cores, echograms, deeper-penetrating reflection profiles, and deep refraction studies. Thus the characteristic downslope thinning wedges of sediment which, stacked one upon another, comprise the continental rise appear to gain their shape through controlled deposition by deep geostrophic contour currents.

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Piezoelectricity in Secondary Explosives

Abstract. *A theory for the formation of "hot spots" necessary for the initiation of an explosion is discussed in light of experimental evidence that most solid explosives are highly piezoelectric.*

It is generally accepted that the initiation of explosion in all explosives, both primary and secondary, is connected with the formation of "hot spots" (*1*) within those materials. However, up to now there has been no really acceptable explanation regarding the formation of hot spots, and hence the question of explosive sensitivity is still unresolved. Because of this situation we have initiated a program aimed at elucidating some of the electrical properties of secondary explosives in the belief that these properties may be important in explosion initiation.

The fundamental, relatively unknown, properties of the secondary explosive cyclotetramethylene tetranitramine (HMX) are now reported. Large single crystals of β-HMX were used in our experiments. HMX powder free of trinitrotriazacyclohexane (RDX) was obtained by extracting 98-percent-pure HMX (*2*) with 1,2-dichloroethane for 24 hours. The product was then dried in a vacuum and dissolved in boiling acetone; the acetone solution was cooled at the rate of 3°C per day, a rate that usually produced about ten large single crystals of β-HMX. After filtration the crystals were dried in air.

The single crystals of HMX exhibited piezoelectricity since a d-c voltage is generated when a load is applied to the crystal. This phenomenon was studied as a function of the applied load. A typical example for δ-HMX is shown