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ABYSSAL SEDIMENT WAVES IN THE
AMIRANTE PASSAGE, WESTERN INDIAN OCEAN

by

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ABSTRACT

The deep western boundary current (DWBC) of the Indian Ocean flows northward along the western margin of the Mascarene Basin, and is funneled through a narrow passage (near 09°S , 52°E) prior to entering the Somali Basin to the north. Recently completed geological and geophysical operations within this passage reveal the presence of fields of well-developed abyssal sediment waves, with amplitudes of 10 to 50 meters and wavelengths of hundreds of meters to ~ 1 km. The two principal fields of sediment waves are confined to the flanks of the passages, and are restricted to a narrow depth interval (~ 3950 to 4150 meters). Individual waves appear to be elongated parallel to the passage axis and the presumed flow direction of the DWBC. The waves are relatively transparent to low-frequency echo sounding (3.5 kHz) and seismic profiling (17-70 Hz), although weak internal reflectors are present within individual waves. These reflectors are conformable with the overlying sea floor, thereby suggesting neither upslope nor downslope migration of the waves.

The sediment comprising the waves is a well-sorted calcareous ooze dominated by fine silt components (principally coccoliths), in marked contrast to the heterogeneous biogenic ooze on the adjacent channel floor. The lithology and local distribution pattern of the waves suggest that they are constructional bedforms associated with the flow of the DWBC, and not slump structures. A deep hydrocast at the sill of the channel indicates a near-bottom layer of Antarctic Bottom Water ($\theta < 0.9^{\circ}\text{C}$) approximately 200 meters thick, whose depth range corresponds with that of the sediment waves.

Interpretations of the origin of the sediment waves in terms of the local flow regime will require (1) a more precise description of the physiography and structure of individual sediment waves; and (2) closely-spaced measurements of the near-bottom velocity structure of the DWBC within regions of the passage where sediment waves are apparently forming.

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INTRODUCTION

In this report we present recent bathymetric, physiographic, structural, and hydrographic data from the northernmost Mascarene Basin in the western Indian Ocean. Previous interpretations of the abyssal flow characteristics in the region (Wyrтки, 1971; Warren, 1974; Kolla et al., 1976b) have documented the presence of a well-defined deep western boundary current (DWBC) which flows northward along the western margin of the Mascarene Basin (Figure 1). The volume transport of the DWBC in the Mascarene Basin at 12°S has been estimated to be approximately 4 to 5 x 10⁶ m³/sec (Warren, 1974), making this current comparable in total transport to the DWBC of the southwestern Pacific (Warren, 1973) and the southwestern Atlantic (Johnson et al., 1975; Stuiver, 1976). There is evidently very little return flow to the south along the eastern margin of the Mascarene Basin (Warren, 1974); rather, the hydrographic data suggest that a significant portion of the flow passes into the Somali Basin to the north via a sill located near 09°S, 52°E.

The sill region connecting the Mascarene and Somali Basins, herein designated as the Amirante Passage due to its close proximity to the Amirante Trench (Figure 1), was selected for an investigation of sediment/current interactions during the late Cenozoic. Comparable studies have been completed in other similar regions including the Samoan Passage (Hollister et al., 1974a; Johnson, 1974) and Vema Channel (Johnson et al., 1976a; 1976b). With the undertaking of a comparable investigation in the western Indian Ocean, it may soon be possible to make ocean-to-ocean comparisons of the geological evidence bearing upon the history of bottom water flow in the major ocean basins during the latest Cenozoic.

The Amirante Passage was the focus of work during portions of two legs of cruise AII-93 in 1976. Five days were spent during Leg 7 (April-May 1976; E. T.

Bunce, chief scientist), and one day during Leg 10 (July 1976; B. Warren, chief scientist). Leg 7 operations centered around underway geophysical surveying and piston coring; during Leg 10 a deep hydrographic station was occupied at the sill of the western Amirante Passage, and supplementary bathymetric coverage was obtained. This report includes underway geophysical data (3.5 kHz profiles and seismic profiles) illustrating the physiography and structure of abyssal sediment waves within the Amirante Passage, together with deep hydrographic data from the sill of the passage and preliminary descriptive information on sediments cored within the passage. A detailed treatment of these sediments and paleo-oceanographic interpretations will be presented in subsequent publications.

Figure 1. Regional bathymetry of the western Indian Ocean, modified from Simpson (1974). Contours are in km, with a contour interval of 0.5 km. Arrows designate the flow of the DWBC through the principal deep basins. The box outlines the sill region of the Amirante Passage (see Figure 3).

Figure 2. Sources of echo-sounding data used in preparing revised bathymetric chart of Amiran Passage region. Solid lines designate cruises for which the original soundings were used, and for which satellite navigational control was available. Dashed lines designate tracks for which compilation sheets of spot soundings were made available (courtesy of R. L. Fisher).

Figure 3. Revised bathymetry of Amirante Passage region in northernmost Mascarene Basin. Sources of data are shown in Figure 2. Contours are in corrected meters (x100). The box outlines the region of detailed study of abyssal sediment waves (see Figure 5). Line WW' is the location of the seismic profile shown in Figure 4.

REGIONAL BATHYMETRY AND PHYSIOGRAPHY

The three principal deep basins (> 4500 m) of the western Indian Ocean are the Madagascar, Mascarene, and Somali Basins (Figure 1). The basins are interconnected below 4000 meters, thereby allowing northward transport of Antarctic Bottom Water to equatorial latitudes (Wyrtki, 1971). There is virtually unrestricted flow from the Madagascar into the Mascarene Basin, but the northern Mascarene Basin narrows abruptly near the southern end of the Amirante Trench, restricting the DWBC to a passage no greater than 100 km in width near 09°S . This narrow region, herein referred to as the Amirante Passage, is bounded on the west by a linear ridge of reefs and atolls extending northeastward from Malagasy, and on the east by the arc-shaped Amirante Ridge and Trench.

The extensive track coverage of R/V Atlantis II, Cruise 93 in the Amirante Passage region (Figure 2) has enabled us to combine these recent bathymetric data with those obtained previously (Fisher et al., 1967) to produce a revised bathymetric contour chart (Figure 3). The principal difference between this chart and the earlier one of Fisher et al. (1967) is the identification of pronounced topographic lineations in the sill region between the Mascarene Basin and the Amirante Trench (Figure 3). These lineations are oriented in a NNE-SSW direction, and form several identifiable sills south of the Amirante Trench near 09°S (Figure 3). The sill depth is relatively shallow (~ 4000 m) on the west, and apparently becomes progressively deeper in troughs to the east (Figure 3). The relatively poor bathymetric coverage at the southern end of the Amirante Trench between 53°E and 54°E (Figures 2 and 3), however, does not allow reliable determination of sill widths and depths in this eastern part of the passage.

A continuous seismic reflection profile (Figure 4), oriented approximately normal to the topographic lineations, reveals the first-order physiographic features of the region. The elongated topographic ridges appear as elevations of acoustic basement, covered by thicknesses of sediment ranging from negligible (right side of profile WW') to a few hundred meters. Sediment thickness is generally greater in the troughs separating the ridges, suggesting preferential accumulation; however, 3.5 kHz echo-sounding profiles within some troughs show truncated near-bottom reflectors indicating a complex erosional and depositional history within the troughs.

The troughs on the western side of the Amirante Passage are generally wider and have shallower sill depths than those to the east. The westernmost channel within the Passage (Figure 4) is relatively wide (20 to 50 kilometers), is flat-floored except at the margins, and has a sill depth of approximately 4050 meters. This channel is flanked by fields of relatively transparent abyssal sediment waves, which are illustrated at the left side of profile WW' (Figure 4). These waves are morphologically similar to features identified in other abyssal regions (e.g. Embley, 1975). Some of these features are apparently associated with the flow of thermohaline bottom currents; others may be related to terrigenous depositional pathways or may be deformational structures associated with gravitational slumping. In this report we describe the morphology, lithology, and regional distribution of the sediment waves in the Amirante Passage, and consider how these factors may place constraints on possible origins for these bedforms in this region.

Figure 4. Seismic reflection profile across portion of Amirante Passage. Bracket on lower profile denotes hill shown in more detail on upper profile. Note that the channels become generally narrower and deeper toward the east.

Figure 5. Distribution of abyssal sediment waves along the flanks of the western Amirante Passage. Dotted lines designate 3.5 kHz echo-sounding tracks used in inferring distribution pattern. 3.5 kHz and seismic profiles across sediment waves are shown in Appendices I and II, respectively.

ABYSSAL SEDIMENT WAVES: MORPHOLOGY, STRUCTURE, AND GEOGRAPHIC DISTRIBUTION

In this section we describe the morphology and acoustic structure of the two principal fields of sediment waves which are distributed along the flanks of the western Amirante Passage (Figure 5). Representative echo-sounding profiles (3.5 kHz) and seismic reflection profiles which cross the waves are illustrated in Appendices I and II. Index charts for these profiles are presented in Figures I-1 and II-1, preceding the profiles.

The western Amirante Passage is bounded on the west by the volcanic basement of the Farquhar Island lineament, and on the east by a sediment-covered basement ridge (Figure 4). Both the eastern and western flanks of the passage are characterized by fields of well-developed abyssal sediment waves. In seismic profiles these waves are most evident on the western flank (Figure 4), but 3.5 kHz profiles show well-formed waves on both the western and eastern flanks (Figures I-2 through I-5).

The transition zone between the floor of the passage and the waves is generally abrupt (Figures I-2 and I-3). The passage floor has low relief, is a relatively strong reflector on 3.5 kHz and seismic profiles, and is underlain by > 0.5 sec of acoustically stratified sediment (Figure 4). The sediment waves, by contrast, have irregular small-scale relief, and are relatively non-reflective to both 3.5 kHz and seismic frequencies by comparison with the adjacent channel floor. In some instances the channel slopes away from the waves (profiles A and F); at other locations there is a depression in the transition region (profiles B and E).

Individual wave forms are characteristically several tens of meters up to ~ 100 meters in height, with wavelengths from several hundred meters up to 2 km (Figures I-2 through I-5). The waves appear to be preferentially oriented sub-parallel to

the axis of the passage, since profiles along this orientation within the field of sediment waves (Figure I-4, Profile I; Figure II-4) show relatively low relief of the near-surface sediment. The close correspondence between wave morphologies in two adjacent profiles on the east flank of the channel (Figure I-3, Profiles F and G) indicates that crests of individual waves may be relatively continuous over distances of several hundred meters or more. However, the difficulty in matching waves on more widely-spaced profiles (e.g., Figure I-2) indicates that individual waves are probably not continuous over distances greater than a few km along their axes.

The wide-beam echosounding and seismic profiling techniques used in this survey were not sufficient for resolving the details of individual wave forms, the nature of their slopes, and the geometry of the narrow regions between individual waves. Some of the 3.5 kHz profiles (e.g., Profiles C, E, G, H) show a strong sub-horizontal reflector beneath overlapping hyperbolic echoes in the transition region between waves, suggesting that some of the "waves" may actually have relatively steep slopes with flat-floored troughs between them, analogous to the abyssal furrows on the Bahama Outer Ridge (Hollister et al., 1974b; Flood and Hollister, 1974). In other profiles (e.g., Profile L) the hyperbolic returns overlap to such an extent that interpretation of the true sea floor morphology is impossible.

Low-frequency echo sounding (3.5 kHz) shows that the surface of the sediment waves is relatively non-reflective in comparison with the sediments of the adjacent channel floor. In one region near the center of the channel where a small field of sediment waves is present (Figure 5), the waves are sufficiently transparent to allow identification of horizontal reflectors in the channel sediment beneath (Figure I-6, Profile N). Internal reflectors within the waves are identifiable in some instances (e.g., Profiles B, G, J, K, N), and these reflectors appear conformable with

the overlying sea floor. There is no evidence in our profiles for migration of the waves either upslope or downslope, although we cannot rule out such a possibility because of the absence of good internal reflectors within the waves, and the limited resolution of the wide-beamed 3.5 kHz echosounder.

On seismic profiles the acoustic transparency of the entire field of sediment waves is even more striking (Figures II-2 through II-8). The field is commonly lens-shaped in cross-section, with highly reflective horizontal strata extending beneath the field of waves from the adjacent channel floor (e.g., Profiles P, R). The thickness of relatively transparent sediment comprising the sediment waves is generally around 0.2 sec (two-way travel time), although in some regions the thickness may be up to twice that amount (e.g., Profiles U and V). The total thickness of relatively stratified sediment beneath the waves and in the adjacent plain is not known, since acoustic/volcanic basement is rarely identifiable (Figure 4).

The two principal fields of waves flank the western Amirante Passage (Figure 5), and are generally confined to a depth interval of 3950 to 4150 meters (Figures I-2 to I-5). In some instances (e.g., Figure I-6) the sediment waves may be forming within the floor of the passage, but as a rule the waves become well developed only adjacent to the relatively steep borders of the passage.

LITHOLOGY OF SEDIMENT WAVES

Figure 5 shows the location of piston cores taken during Leg 7 of cruise AII-93. One core (#9) was within the field of sediment waves, one (#10) was in the transition region, one (#11) was within the flat-floored channel in the western Amiran Passage, and six (#6-8; 12-14) were on a sediment-covered ridge to the east. Although the cores have not yet been split and studied in detail, initial analysis of core samples taken at 150-cm intervals reveals a striking difference between the sediment comprising the waves (core #9) and that of the adjacent channel floor (core #11). The sediment of the channel floor is a heterogeneous calcareous-siliceous ooze of clay to fine-sand size, with common well preserved calcareous and siliceous microfossils, rare detrital mineral grains, and rare reworked Tertiary discoasters. Sand-sized ($> 62\mu$) microfossils (radiolaria, foraminifera) are common. In contrast, the sediment waves are composed of a relatively well-sorted gray hemipelagic lutite of fine silt and clay size. The silt size fraction is biogenic pelagic carbonate fragments, including abundant nannofossils and rare foraminiferal debris. In both the sediment waves and the channel floor there is no evidence of reworked shallow water material from the nearby island-atoll chain to the west, and there are only trace amounts of reworked discoasters of Tertiary age.

This initial examination of the sediment waves and adjacent channel flow documents that the waves are comprised of hemipelagic lutite, and suggests that the lithologic constituents of the waves may represent the fine fraction winnowed from the sediments of the adjacent channel floor. The absence of shallow-water debris in the sediment waves, and the distribution of the waves within the channel axis (Figure I-6) as well as on both the eastern and western margins (Figure 5), suggests that the waves are not slump structures, but are probably constructional bedforms related to the flow of the DWBC through the channel.

HYDROGRAPHY

The deep western boundary current of the Indian Ocean flows northward along the western margin of the Mascarene Basin (Figure 1). Hydrographic stations in a section across the basin at 12°S indicate that the DWBC is clearly defined at this latitude, with a width of 300-400 km (Warren, 1974, Figure 14) and characteristic values of $T < 1.2^{\circ}\text{C}$ ($\theta < 0.9^{\circ}\text{C}$) and $\text{O}_2 > 4.5 \text{ ml/l}$ (Warren, 1974, Figures 7 and 9). The level of no motion above the DWBC of the Mascarene Basin is not easily selected from hydrographic data alone, since both lower North Atlantic Deep Water and Antarctic Bottom Water may contribute to the DWBC in this region (Reid and Lynn, 1971). Warren (1974) has used 3600 meters as a reference level in computing geostrophic transport at 12°S , but there are no direct current measurements available to confirm this choice.

Since the geophysical evidence obtained on Leg 7 of cruise AII-93 showed strong evidence for the effects of the DWBC in the form of sediment waves, a deep hydrographic station was occupied at the sill of the western channel of the Amirante Passage during Leg 10 of AII-93 (Figure 5). The data from this station reveal water properties clearly indicative of the DWBC below $\sim 3800 \text{ m}$ (Table 1; Figure 6). A near-adiabatic layer adjacent to the bottom ($\theta \sim 0.8^{\circ}\text{C}$) is approximately 200 m thick, and is capped by a benthic thermocline extending upward several hundred meters with an average temperature gradient of $\sim 0.1^{\circ}\text{C}/100 \text{ m}$ (Figure 6). This thermocline is comparable with the one overlying the DWBC of the Samoan Passage (Macdonald and Hollister, 1973), but is not as steep as the abyssal thermocline of the Vema Channel (Johnson et al., 1976a). The benthic thermocline may delineate the depth range over which turbulent mixing is occurring between the DWBC and the overlying water.

In the absence of near-bottom current measurements within the western Amirante Passage, we cannot speculate on the nature of the flow regime in the vicinity of the sediment waves which flank the passage. The close correspondence between the depth range of the sediment waves and the vertical extent of the near-bottom adiabatic layer suggests that the flow regime within, but not above, this layer may be responsible for creating the wave forms.

Since the DWBC within the northern Mascarene Basin at 12°S is centered near the western margin of the basin in a depth interval between 3800 and 4400 meters (Warren, 1974, Figures 7, 9, 14), we anticipated encountering the most well-defined geological evidence of bottom current effects within the westernmost sill region of the Amirante Passage. The evidence presented in this report suggests that significant DWBC flow is indeed present within this westernmost channel (Figure 4). However, we do not exclude the possibility that comparable DWBC flow and associated geologic effects may be present within the deeper sill areas to the east (Figures 3 and 4). Deep western boundary currents are characteristically hundreds of km in width (Warren, 1976), and consequently the DWBC may not be restricted to only the western channel of the Amirante Passage. More extensive hydrographic data and/or direct current measurements in these eastern troughs will be required in order to clarify this question.

Table 1. Atlantis II, Cruise 93, Station 2265, 5 July 1976

09° 06'.5S, 52° 16'E

Depth = 4018 m

$\frac{\text{Depth}}{(\text{m})}$	$\frac{T}{(^{\circ}\text{C})}$	$\frac{\theta}{(^{\circ}\text{C})}$	$\frac{S}{(\text{‰})}$	$\frac{\sigma_t}{\text{}} \text{ }_4$	$\frac{\text{O}_2}{(\text{ml/l})}$	$\frac{\text{PO}_4}{(\mu\text{g.at./l})}$
2518	2.00	1.81	34.747	45.84	3.54	2.53
2805	1.81	1.59	34.741	45.87	3.69	2.62
3090	1.73	1.49	34.740	45.89	3.82	2.74
3376	1.61	1.34	34.748	45.92	4.18	2.61
3569	1.49	1.21	34.733	45.94	4.13	2.47
3666	1.395	1.105	34.729	45.96	4.24	2.71
3762	1.290	0.991	34.721	45.97	4.43	2.56
3810	1.195	0.892	34.723	45.99	4.23(?)	2.49
3858	1.120	0.813	34.723	46.005	4.56	2.47
3905	1.112	0.802	-	-	4.68	2.58
3953	1.098	0.782	34.716	46.005	4.58	2.52

Figure 6. Profiles of near-bottom temperature and oxygen in western Amirante Passage.

TABLE 2. CHARACTERISTICS OF ABYSSAL SEDIMENT WAVES (modified after Embley, 1975)

Geographic Location	Depth Range (m)	Wave length (km)	Amplitude (m)	Azimuth of sediment wave strike	Azimuth of Regional Contours	Migration Direction	Current Direction	Current Velocity (cm/sec)	Lithology of Sediments	References
1. Lower continental rise, NE N. America	4500-5300 4700-5300	5-11 3-12	60-100 10-100	E-W 120°	NE-SW NE-SW	N-upslope ?	SW SW	10-20 (approx.)	Gray and brown hemipelagic clays and silts	Fox et al., 1968; Rona, 1969
2. Blake-Bahama Outer Ridge	4700-4800	2-3	30-50	010°	335°	E-upslope	325°-335°	9-10	Gray and brown hemipelagic clays	Bryan and Markl, 1966; Hollister et al., 1974b
3. Argentine Rise	4700-5600	5-8	20-50?	variable	-	variable	-	-	Gray hemipelagic clays	Ewing et al., 1971
4. Madagascar basin	4800-4900	4	20-80	55°W	?	NE	North	-	Gray hemipelagic clays	Ewing et al., 1968
5. Continental rise NE South America	4300-4900	2-7	10-20	350°	270°-320°	W-upslope	-	10	Gray hemipelagic clays with interbedded thin silt layers	Embley, 1975
6. Continental rise of NW Africa	4200-4600	0.5-5	5-20	NE	NE	SE-upslope	-	10	Interbedded brown marls and gray clays with occasional silt-sand layers	Jacobi et al., 1975
7. Turbidite channel, Gulf of Alaska	3400-3550	2	5-10	30°W	NW	W-upslope	-	-	Gray hemipelagic clays with interbedded silt and sand layers	Embley, 1975
8. Amirante Passage, W. Indian Ocean	3950-4150	0.5-2	20-100	NNE	NNE	?	NNE	?	Gray hemipelagic clay and biogenic ooze	This report
9. Colombian continental rise	2400-2600 3800-3900	0.5-7	3-65	?	E-W	?	?	?	?	Bouma and Treadwell, 1975
10. Western Bay of Bengal	2600-3700	1-3	5-10	?	N-S	W-upslope	S	?	Thinly laminated sands and silts	Kolla et al., 1976a

DISCUSSION

Sediment waves comparable with those discussed in this report have been described in other abyssal regions (Table 2). These features appear to exhibit some common characteristics, yet other characteristics appear to vary significantly from region to region:

<u>Common Characteristics</u>	<u>Variable Characteristics</u>
1. Wave geometry (amplitude, length, rhythmic character, preferential orientation)	1. Orientation of individual waves relative to regional contours
2. Migratory nature of waves: generally upslope	2. Orientation of individual waves relative to local bottom current flow
3. Orientation of sediment wave zone parallel to regional contours	3. Association with regions of steady thermohaline flow
4. Wave lithology: absence of coarser (sand-sized) constituents	4. Proximity to turbidite pathways
	5. Wave lithology: proportion of biogenic vs. terrigenous constituents

The sediment waves described in this report have each of the four characteristics common to those of other regions (listed above), with the possible exception of their migratory nature. Our profiles (Appendices I and II) show no evidence for migration of the waves in the Amirante Passage; however, the absence of strong internal reflectors beneath the waves and the wide-beam profiling techniques used preclude a definitive answer to this question at this time.

Many characteristics of abyssal sediment waves vary considerably from region to region (Table 2), and consequently the waves may represent more than one type of origin. All of the fields of waves which have been surveyed in any detail exhibit a preferential orientation, but this orientation is not in any systematic relation to that of the regional bathymetry or the regional thermohaline flow (where flow direction has been measured or can be inferred from indirect evidence). In the Amir-

ante Passage the waves are apparently elongated toward the NNE, a direction which parallels the regional contours and DWBC. In most other regions of abyssal sediment waves (Table 2) the local flow characteristics have rarely been measured directly, although in some cases the flow direction and relative flow intensity may be inferred through indirect techniques (e.g., oriented bottom photographs). The lower continental rise hills off eastern North America trend in an eastward direction which is approximately 45° to that of the regional contours and DWBC flow (Fox et al., 1968). The high-amplitude waves on the Blake-Bahama Outer Ridge are oriented approximately 45° to measured bottom currents (Flood and Hollister, 1974).

It is not known whether a steady thermohaline current is in fact present in all regions of abyssal sediment waves. The large migrating waves in the Argentine Basin (Ewing et al., 1971) are found well away from the western margin of the basin where the thermohaline flow is presumably most intense. The waves in the Gulf of Alaska, described by Embley (1975, pp. 156-158), occur on the levees of deep-sea channels in a region where steady thermohaline flow has not been documented. Similarly there is no known steady bottom current near the dune-like features on the Magdalena Fan in the Colombian Basin (Bouma and Treadwell, 1975). Consequently, it would be premature at this stage to use abyssal sediment waves as definitive indicators of present or past thermohaline flow until such a relationship has been documented for more of the regions in which these features have been identified (Table 2).

The regions of abyssal sediment waves (Table 2) do not bear any consistent physiographic relationship to turbidity current pathways. Although the sediment comprising the waves is characteristically fine-grained and may have a substantial terrigenous component (Table 2), not all fields of sediment waves are in close proximity to routes of terrigenous sediment supply. The large-amplitude waves on the Blake-Bahama Outer Ridge (Bryan and Markl, 1966) are separated from the continental

margin by the Blake-Bahama Basin to the west, and by the Blake Outer Ridge to the north. The waves in the Argentine Basin (Ewing et al., 1971) are separated from the lower continental rise off South America by several hundred km. The waves in the western Amiran Passage provide additional evidence that turbidite pathways are not necessarily required, since the nearest canyon/channel systems for supplying terrigenous material are several hundred km to the south. The small field of sediment waves near the axis of the channel (Figure I-6) cannot be easily explained in terms of nearby turbidite pathways or gravitational slumping.

It is equally uncertain whether or not hemipelagic lutite of terrigenous origin is a necessary constituent of abyssal sediment waves. Embley (1975) has suggested that this may be the case, yet the data presented in this report demonstrate that comparable fields of sediment waves may form in regions dominated by biogenic pelagic deposition with relatively little direct terrigenous input nearby.

From the foregoing discussion, it would appear that more than one process may be required to explain the numerous features classified as "abyssal sediment waves" (Table 2). Long-term measurement of near-bottom flow characteristics remains the most critical type of observation required in interpreting their origin.

The data included in this report do allow the following tentative interpretations concerning the origin of the sediment waves in the western Amirante Passage:

<u>Interpretation</u>	<u>Evidence</u>
1. Waves are constructional bedforms, not slumping or deformational structures.	1. Lithology and geographic distribution of waves; presence of waves in channel axis as well as on channel flanks.
2. Waves are related to flow of DWBC through Amirante Passage.	2. Limited depth range of waves; correspondence with near-bottom adiabatic layer; comparability with bedforms beneath DWBC elsewhere.
3. Flow over flat topography may not be sufficient to form waves; some kind of sloping boundary perhaps required.	3. Waves most well developed along flanks of channel, only rarely within channel floor.
4. Waves are a relatively recent geological feature in Amirante Passage.	4. Highly reflective layers of channel floor are traceable beneath waves.

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APPENDIX I: 3.5 KHZ PROFILES

Figure I-1. Index chart for illustrated 3.5 kHz profiles in region of abyssal sediment waves within Amirante Passage.

Figure I-2.

Figure I-3.

Figure I-4.

Figure I-5.

Figure I-6.

APPENDIX II: SEISMIC PROFILES

Figure II-1. Index chart for illustrated seismic profiles in region of abyssal sediment waves within Amirante Passage. In each case the track line shown designates the extent of the lowermost profile (Precision Graphic Recorder, 10-sec sweep). Brackets denote the extent of sediment waves where indicated in simultaneously obtained 3.5 kHz profiles.

Figure II-2.

WEST

EAST

Figure II-3.

Figure II-4.

Figure II-5.

Figure II-6.

Figure II-7.

Figure II-8.

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7. Author(s) David A. Johnson and Elizabeth T. Bunce		8. Performing Organization Rept. No. WHOI-77-7	
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15. Supplementary Notes			
16. Abstracts <p>The deep western boundary current (DWBC) of the Indian Ocean flows northward along the western margin of the Mascarene Basin, and is funneled through a narrow passage (near 09°S, 52°E) prior to entering the Somali Basin to the north. Recently completed geological and geophysical operations within this passage reveal the presence of fields of well-developed abyssal sediment waves, with amplitudes of 10 to 50 meters and wavelengths of hundreds of meters to ~1 km. The two principal fields of sediment waves are confined to the flanks of the passages, and are restricted to a narrow depth interval (~3950 to 4150 meters). Individual waves appear to be elongated parallel to the passage axis and the presumed flow direction of the DWBC. The waves are relatively transparent to low-frequency echo sounding (3.5 kHz) and seismic profiling (17-70 Hz), although weak internal reflectors are present within individual waves. These reflectors are conformable with the overlying sea floor, thereby suggesting neither upslope nor downslope migration of the waves. **</p>			
17. Key Words and Document Analysis. 17a. Descriptors			
17b. Identifiers/Open-Ended Terms <p>** The sediment comprising the waves is a well-sorted calcareous ooze dominated by fine silt components (principally coccoliths), in marked contrast to the heterogeneous biogenic ooze on the adjacent channel floor. The lithology and local distribution pattern of the waves suggest that they are constructional bedforms associated with the flow of the DWBC, and not slump structures. A deep hydrocast at the sill of the channel indicates a near-bottom layer of Antarctic Bottom Water ($\theta < 0.9^{\circ}\text{C}$) approximately 200 meters thick, whose depth range corresponds with that***</p>			
17c. COSATI Field/Group			
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of the sediment waves.

Interpretations of the origin of the sediment waves in terms of the local flow regime will require (1) a more precise description of the physiography and structure of individual sediment waves; and (2) closely-spaced measurements of the near-bottom velocity structure of the DWBC within regions of the passage where sediment waves are apparently forming.

<p>Woods Hole Oceanographic Institution WHOI-77-7</p> <p>ABYSSAL SEDIMENT WAVES IN THE ANIMATE PASSAGE, WESTERN INDIAN OCEAN by David A. Johnson and Elizabeth T. Bunce. 46 pages. February 1977. Prepared for the National Science Foundation under Grant OCE 76-21522.</p> <p>The deep western boundary current (DWBC) of the Indian Ocean flows northward along the western margin of the Mascarene Basin, and is funneled through a narrow passage (near 09°S, 52°E) prior to entering the Somali Basin to the north. Recently completed geological and geophysical operations within this passage reveal the presence of fields of well-developed abyssal sediment waves, with amplitudes of 10 to 50 meters and wavelengths of hundreds of meters to ~1 km. The two principal fields of sediment waves are confined to the flanks of the passages, and are restricted to a narrow depth interval (~3950 to 4150 meters). Individual waves appear to be elongated parallel to the passage axis and the presumed flow direction of the DWBC. The waves are relatively transparent to low-frequency echo sounding (1.5 kHz) and seismic profiling (17-70 Hz), although weak internal reflectors are present within individual waves. These reflectors are comfortable with the overlying sea floor, thereby suggesting neither upslope nor downslope migration of the waves.</p> <p>The sediment comprising the waves is a well-sorted calcareous ooze dominated by fine silt components (principally coccoliths), in marked contrast to the heterogeneous biogenic ooze on the adjacent channel floor. The lithology and local distribution pattern of the waves suggest that they are constructional bedforms associated with (Cont. on back)</p>	<p>1. Sediment Waves</p> <p>2. Deep Western Boundary Current</p> <p>3. Azurite Passage</p> <p>I. Johnson, David A.</p> <p>II. Bunce, Elizabeth T.</p> <p>III. OCE 76-21522</p> <p>This card is UNCLASSIFIED</p>
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