3. SITE 531: WALVIS RIDGE[1]

Shipboard Scientific Party[2]

HOLE 531

Date occupied: 19 August 1980

Date departed: 19 August 1980

Time on hole: 9 hr., 15 min.

Position: 19°38.44′S; 09°35.31′E

Water depth (sea level; corrected m, echo-sounding): 1267

Water depth (rig floor; corrected m, echo-sounding): 1277

Bottom felt (m, drill pipe): 1284

Penetration (m): 1

Number of cores: 1

Total length of cored section (m): 1

Total core recovered (m): 0.02

Core recovery (%): 2

Oldest sediment cored:
Depth sub-bottom (m): 128.5
Nature: Nannofossil-foraminiferal ooze
Age: Holocene

HOLE 531A

Date occupied: 19 August 1980

Date departed: 19 August 1980

Time on hole: 5 hr., 12 min.

Position: 19°38.40′S; 9°35.47′E

Water depth (sea level; corrected m, echo-sounding): 1267

Water depth (rig floor; corrected m, echo-sounding): 1277

Bottom felt (m, drill pipe): 1279

Penetration (m): 1

Number of cores: 1

Total length of cored section (m): 1

Total core recovered (m): 0.27

Core recovery (%): 27

Oldest sediment cored:
Depth sub-bottom (m): 1280
Nature: Calcarenite, with calcareous algae
Age: Uncertain

PRINCIPAL CONCLUSIONS

1. It was established on Leg 75 that the flat top of the guyot-like feature at Site 531 has a reef-like cap, with rounded coralline algal and possibly coral fragments.

2. A consideration of subsidence history leads to the conclusion that the reef-like cap must be Cretaceous, making this the southernmost Cretaceous reef-like deposit known.

3. The thickness of the reef-like sediments is what would be expected if reef growth was terminated by a 200 m fall in sea level about 97 m.y. ago (based on the oceanic-crust subsidence curve calibrated at Site 530 and Vail's sea-level curve, isostatically adjusted for oceanic observations).

4. The crustal subsidence curve and isostatically adjusted sea-level curve provide reasonable results when tested for other features on the Walvis Ridge and Rio Grande Rise and may be generally applicable.

BACKGROUND AND OBJECTIVES

One important objective of Legs 73, 74, and 75 was to study the paleoceanographic effects of the subsidence of an aseismic ridge and to determine the extent to which the Walvis Ridge has served as a barrier to paleocirculation, thereby affecting calcium carbonate compensation and current transport of sediments. Knowledge of the subsidence history of the ridge is critical to interpretation of the paleoceanography of the southwest Atlantic. The best calibration points for subsidence of the ridge are those moments when particular topographic features subsided below sea level. The information existing prior to operations at Site 531 has been plotted on Figures 1 and 2.

Seismic data indicated that proposed Site SAI-4C (Site 531) was located near the boundary between the oceanic and continental crustal domains on the Walvis Ridge; the original intent of drilling at this site was to determine whether or not continental crust is present. Some faint oblique reflectors, which might prove to be older sediments, appear within the basement. To avoid the possibility of trapped hydrocarbons, Site SAI-4C was located at the edge of the plateau, where the oblique reflectors have been exposed. They outcrop on the flanks of the plateau or are buried under a relatively thin sedi-

[1] Hay, W. W., Sibuet, J.-C., et al., *Init. Repts. DSDP*, 75: Washington (U.S. Govt. Printing Office).

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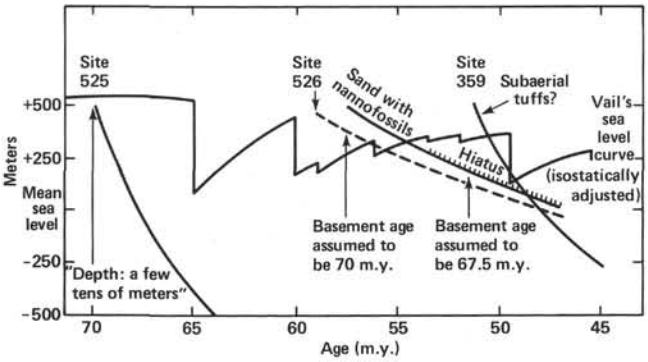

Figure 1. Evidence used to calibrate subsidence of the Walvis Ridge sites: 359, 525, and 526. The sites have been backtracked using the formula $h_t' = -2.3644t^{0.1773} + (h_R - h_R')$ where h_t' is the depth of unloaded basement at age t, h_R is the predicted depth of unloaded basement at present, and h_r' is the present depth of basement after removing sediment and making isostatic adjustment. The sea-level curve is that of Vail et al. (1977), calibrated by Sleep's (1976) estimate of the Cretaceous high stand of sea level relative to the continental craton and multiplied by 1.435 to correct for isostatic loading of the seafloor by water, so that the curve is that observed on an oceanic island. Sediment thicknesses for the sites near their time of origin are small and have not been indicated. Two curves are shown for Site 526, one assuming a basement age of 67.5 m.y., the other a basement age of 70 m.y. It is evident that a feature which subsides below sea level a longer time after its origin will provide a better calibration of the subsidence curve.

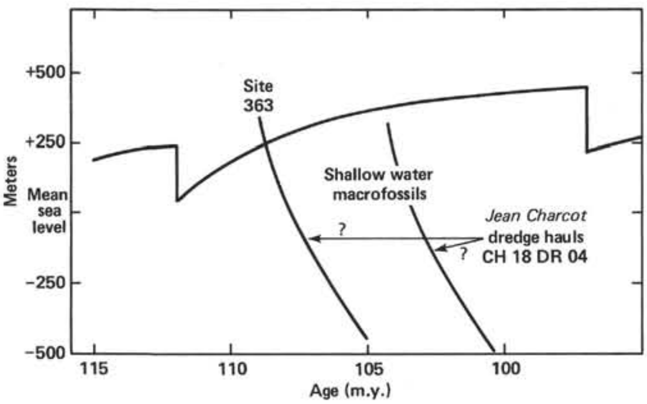

Figure 2. Evidence used to calibrate subsidence of the Walvis Ridge from DSDP Site 363 and R/V *Jean Charcot* dredge hauls CH 18 DR 04. All available evidence fits the subsidence formula given above and the isostatically adjusted sea-level curve after Vail et al., 1977.

ment cover. Whatever the nature of the basement, the BGR-36 processed seismic profile (Fig. 3) shows a flat-topped platform which could correspond to a wave-cut surface.

Another major objective at this site was to date the age of the subsidence of this "guyot"-like feature below sea level. Because it lies at a water depth of only 1300 m it is thought that this feature subsided below sea level more recently than did other, deeper parts of the ridge. Preliminary estimates suggested that it subsided below sea level about 20 m.y. after the formation of adjacent ocean crust and thus would provide precise calibration for the ridge subsidence curve. Site 363 (2247 m water depth; Pastouret and Goslin, 1974), about 30 miles west of Site 531, is thought to have been near sea level in the mid-Cretaceous. If Site 531 were on oceanic crust or on continental crust near the ocean/continent boundary and the time of its subsidence below sea level could be ascertained, it would be possible to determine the subsidence curve of aseismic ridges and to learn whether their subsidence follows that of adjacent oceanic crust or is slower. In any case, information gained at Site 531 would complement that from Site 530 and provide information on the connection between the Angola and Cape Basins.

On the basis of the BGR-36 seismic profile, the interpretation of the sedimentary sequence was speculative, although it was felt that part of it would be reef and/or carbonate platform. Site 531 is isolated from any turbidite input, and it was expected that the upper part of the section would be a pelagic section on top of the carbonate bank or reef. This would provide information on the nature of Miocene to Recent accumulation of organic matter because Site 531 is located at the fringe of the area of high productivity associated with the Benguelan upwelling system.

OPERATIONS

Glomar Challenger approached proposed Site SAI-4C (Site 531) on a course of 105° at 6.0 knots mean speed. Maximum size chambers (100 and 60 c.i.) for the air guns had been used at Site 530 departure in order to follow the basement in the deep Angola Basin. The *Glomar Challenger* approach duplicated BGR-36 line in order to drop the beacon on a bathymetric feature. At 2336 hours on 18 August 1980, the beacon was dropped. The vessel continued on this course and speed for 20 minutes. At 0000 hours on 19 August 1980 we reversed course and commenced pulling in the towed gear. Figure 4 shows the ship's track for the approach to Site 531. Figure 5 is the seismic record.

The *Challenger* arrived at Site 531 at 0100 on 19 August 1980. The bottom-hole assembly was made up with an F 93CK bit, 646 KR, which had previously been used for 29.8 hours. The drill string was run in and the heave compensator picked up. Hole 531 was spudded in at 0842, with a mudline core attempted at 1284–1285 m below the rig floor. The bottom was firm and could not be penetrated. The core barrel was on deck at 0910. The core catcher contained a few cubic centimeters of foraminiferal ooze. Hole 531 was terminated at 0915.

The bit was pulled up to 1182.0 m by 1014 and the *Challenger* moved about 300 m on a bearing of 105° for another attempt to spud in.

Hole 531A was spudded in at 1231. Again the bottom was firm and could not be penetrated. The core barrel arrived on deck at 1304, with a very short core of foraminifer ooze and a small pebble. The hole was terminated, and the bit was at the derrick floor at 1618. The *Challenger* was underway to Site 532 (DSDP Leg 40, Site 362) at 1637 on 19 July 1980.

Coring results are listed in Table 1.

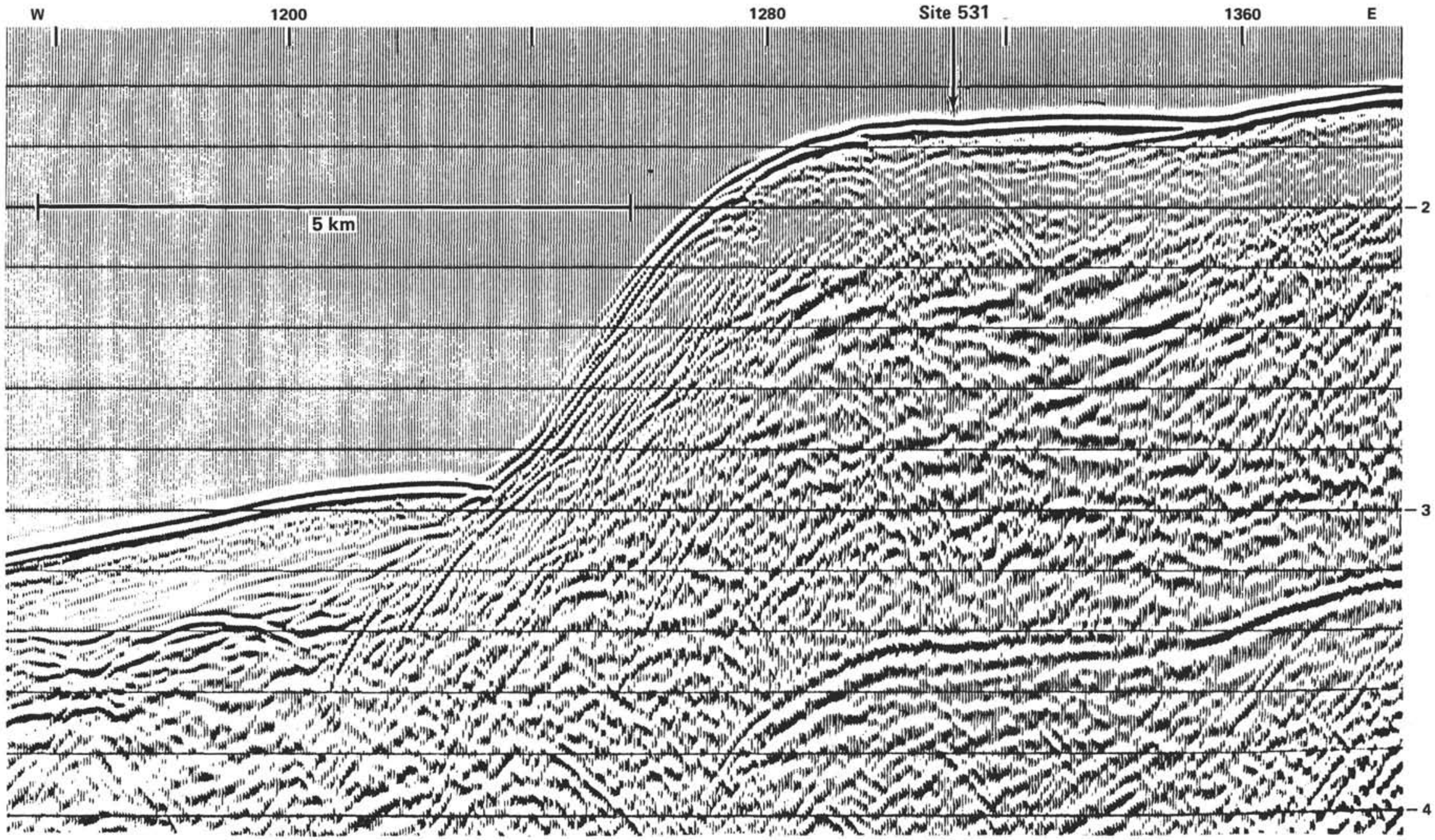

Figure 3. BGR-36 processed seismic line showing the projection of Site 531.

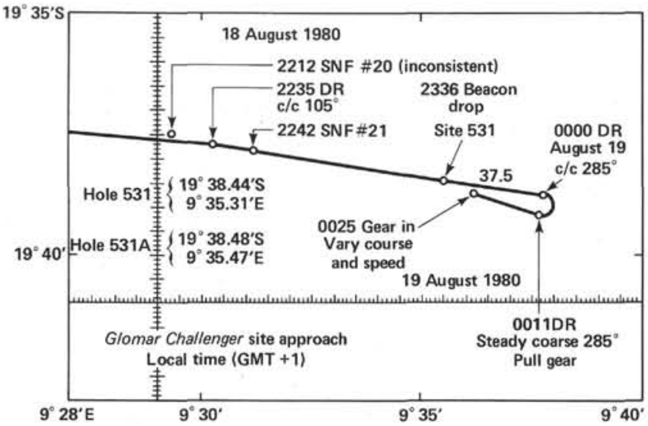

Figure 4. Track chart of the D/V *Glomar Challenger's* approach to Site 531 (SNF = satellite navigation fix; DR = dead reckoning; C/C = change course).

SEDIMENT LITHOLOGY AND AGE

About 20 cm^3 of nannofossil-foraminiferal ooze were recovered at Site 531. A 27-cm section of gray-yellow nannofossil foraminiferal ooze and a single small rock fragment about 1 cm across were recovered in Hole 531A.

The rock fragment consists dominantly of rounded to subrounded, coarse, sand-size fragments of volcanic rocks, red coralline algae, rocks, mollusks, and coral cemented by calcite (Fig. 6). Red coralline algal fragments form approximately 70% of the total. Much of the biogenic material has been replaced by cryptocrystalline calcite, although the cellular structure of the red algae is well preserved. The sediment is well sorted, with a mean grain size of 0.15 mm and a range in diameter of 1.8 mm

Table 1. Coring summary, Site 531.

Core	Date (August 1980)	Time	Depth from drill floor (m)	Depth below seafloor (m)	Length cored (m)	Length recovered (m)	Percent recovery (%)
Hole 531							
1	19	0910	1284.0–1285.0	0.0–1.0	1.0	0.02	2
Hole 531A							
1	19	1304	1279.0–1280.0	0.0–1.0	1.0	0.27	27

to 0.08 mm. The rock is grain supported, with sparry calcite cement in the intergrain spaces.

The red coralline algae are identified as *Archaeolithothamnium* (John L. Wray, pers. comm.) on the basis of distinctive rows of loose sporangia (spore cases) which are illustrated in Figure 6A. It is likely that this single genus dominates, although many of the fragments of cellular material are not identifiable. Diagnostic features for identification at species level are not preserved.

Archaeolithothamnium is a primitive genus of the family Corallinaceae and ranges from early Late Jurassic to Recent. Corallinaceae are cosmopolitan, although exclusively marine. As a group, they live in diverse environmental conditions, from the tropics to polar regions and from the intertidal zone to 250 m in depth (Wray, 1977). Genera and species are more restricted in terms of temperature, salinity, depth, substrate, and energy of the environment. Recent *Archaeolithothamnium* is restricted to the tropics and subtropics but occurs in a range of depths; it occurs as crusts or with branched thalli and is important as a reef builder, as are the other Corallinaceae.

The nannofossil-foraminiferal ooze consists of a mixed Pleistocene assemblage. A precise biostratigraphic age could not be determined for the rock fragment be-

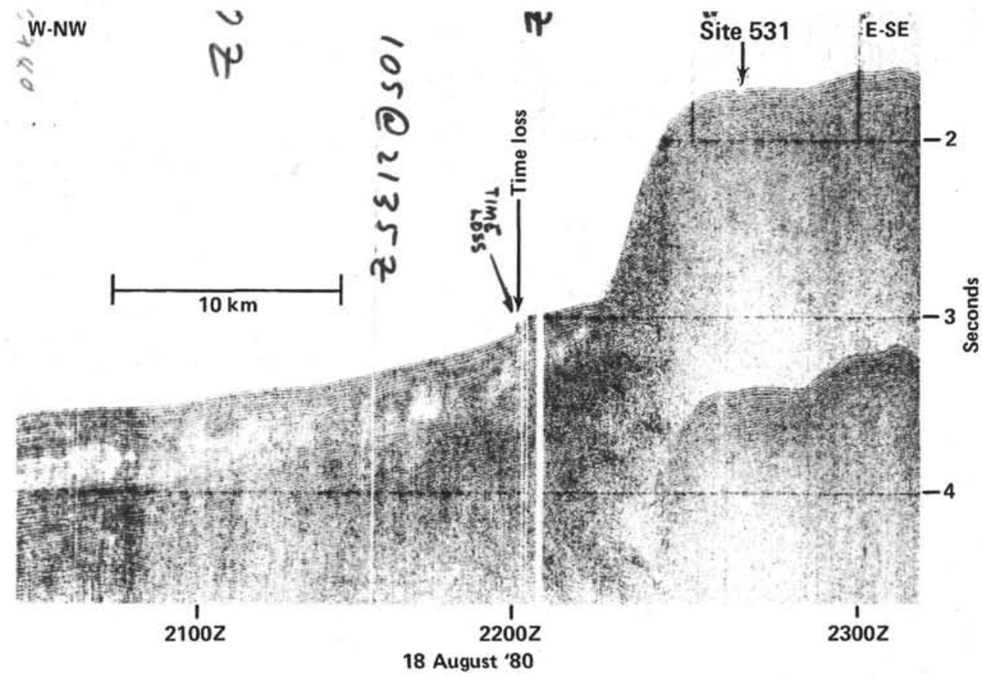

Figure 5. *Glomar Challenger* seismic line showing the location of Site 531.

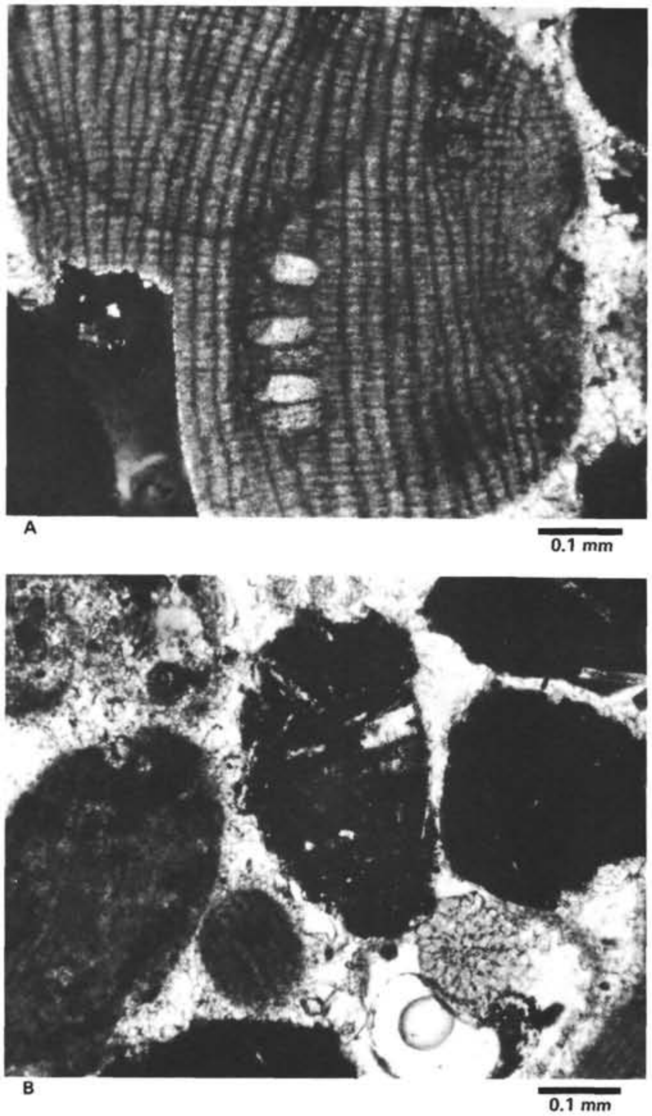

Figure 6. Thin section of the rock fragment from Hole 531A. A. Coralline red algae with three sporangia in a row (cross-nicols). B. Coralline red algae and volcanic rock fragments illustrating the degree of roundness.

cause of the long range of *Archaeolithothamnium* and because only a single, nondiagnostic, agglutinated benthic foraminifer was found in thin section.

BIOSTRATIGRAPHY

Because of operational difficulties at the commencement of drilling, only two samples of the mudline or slightly lower were collected at this site.

The core-catcher sample from Core 531-1 contains a well preserved, abundant, nannoplankton assemblage of late Pleistocene/Holocene age. The following species were found: *Gephyrocapsa oceanica, Helicosphaera carteri, Discolithina japonica, Umbilicosphaera mirabilis, Coccolithus pelagicus, Cyclococcolithus leptoporus, Pontosphaera syracusana, Syracosphaera pulchra.*

A sample from Section 531A-1-1 contains the following species in addition to those found in the 531-1 core-catcher sample: *Ceratolithus cristatus, Rhabdosphaera clavigera, Scapholithus fossilis, Emiliania huxleyi.*

The presence of *Emiliania huxleyi,* whose range covers only the past 150,000 yr., has been verified by subsequent shore-based laboratory electron microscopic investigation.

SUMMARY AND CONCLUSIONS

The shallow-water indicators found at this site are considerably better preserved than are the recrystallized rounded grains collected at Site 362. The virtual absence of younger sediments suggests that at least the edges of the plateau have been swept clean by current action.

This reef-like accumulation extends 4 to 5° poleward of the maximum extent of southern hemisphere Cretaceous carbonates plotted by Habicht (1979).

The knowledge that the sedimentary cap was constructed by shallow-water organisms (intertidal to 250 m) and that the grains are rounded by wave action provides an important clue to the subsidence history of the Walvis Ridge.

Subsidence of the Walvis Ridge

On the basis of material dredged on the northern flank of the Frio Ridge, Pastouret and Goslin (1974) have shown that the ridge has subsided from sea level to a water depth of 2500 m since it was formed during the Cretaceous. This result was confirmed by samples recovered at Site 363 (Ryan, Bolli et al., 1978). Le Pichon et al. (1978) and van Andel et al. (1977) have assumed that the subsidence of the ridge follows the subsidence curve of the oceanic crust. Detrick et al. (1977) have suggested on the basis of DSDP data that most of the sites located on aseismic ridges appear to fall slightly above this predicted subsidence curve. They proposed two possibilities to account for this discrepancy: (1) subaerial erosion, if the ridge originated above sea level, or (2) that the ridge was created off the spreading center.

There are at least two guyot-like features on the Frio Ridge which have the same water depth, about 1240 m. In first approximation these two features were created at the same time, departed from sea level at the same time, and subsided about the same amount. As shown in Figures 1 and 2, the DSDP sites and the R/V *Jean Charcot* dredge site on the Walvis Ridge have been backtracked using the empirical curve defined previously for the Angola and Brazil basins:

$$h_t' = -2.3644t^{0.1773} + (h_R - h_R'),$$

where h_t' is the depth of unloaded basement at age t, h_R' is the measured depth of basement at present, and h_R is the present depth of basement predicted by the first term on the right-hand side of the above equation (with t = basement age).

In addition, sea level changes (Vail et al., 1977) have been taken into account using Sleep's (1976) estimate of the Cretaceous high stand of sea level as it encroached on the North American craton, isostatically adjusted to yield sea level as it would be observed on an oceanic island. For an oceanic island the complementary subsidence resulting from a rise in sea level is:

$$S_{sl} = T_{sl} \frac{\varrho w}{\varrho m - \varrho w}$$

where T_{sl} is the sea level change with respect to the present-day sea level, and ϱw and ϱm are the respective densities of seawater and the mantle.

$$S_{sl} = 0.435\ T_{sl} \text{ for } \varrho w = 1.03 \text{ and } \varrho m\ 3.3 \text{ g/cm}^3$$

Figure 2 shows that both DSDP Site 362 and the R/V *Jean Charcot* CH 18 DR 04 dredge locations were created above sea level and passed through sea level during the Late Cretaceous high stands of sea level. Although the guyot-like features on the Frio Ridge are farther south than any previously known South Atlantic Cretaceous reefs, the recovery of well-rounded fragments of coralline algae and coral(?) at Site 531 confirms the hypothesis that the general flat-topped shape of these features resulted from reef construction which was halted by a rapid fall of sea level and which could not keep pace with the subsequent rise in sea level. Because the rock fragment recovered from Hole 531A cannot be precisely dated (the range of *Archaeolithothamnium* is early Late Jurassic to Recent), the timing of subaerial erosion must be based on subsidence rates calculated on the basis of the above empirical curve and on changes in eustatic sea level.

On seismic profiles, Site 531 is seen to be at the edge of a massive reef complex which may have its base at a maximum depth of 1200 m below the seafloor; on another guyot-like seamount located at 20°50′S, 08°40′E the reef construction seems to form a shoulder about 1100 m thick. According to Vail et al. (1977), two main falls in sea level occurred during the Cretaceous (at 112 and 97 m.y.) which could explain the observed features. If reef growth ended 112 m.y. ago, origin of the ridge would have to have been about 140 m.y. ago in order for the subsidence curve to take into account the present depth of the plateau and for the plateau to have been at sea level 112 m.y. ago. This is far older than the expected age of formation of this segment of the ridge and older than the initial extension (~135–125 m.y.) opening the South Atlantic.

In order to test the hypothesis of reef growth ending 97 m.y. ago, we explored subsidence history relative to changes in sea level. We assumed that there is no isostatic readjustment for the very localized loads of the reefs, but recognize that isostatic readjustment must be taken into account because of later sediment deposition in the surrounding vicinity of both locations. The thickness of sediment on the ridge is estimated to be about 630 m near Site 531 and 450 m in the area of the seamount at 20°50′S, 08°40′E. This corresponds to isostatic readjustment of 210 and 150 m, respectively, for the basement. Figures 7 and 8 show the subsidence curves for these two features created on crust 118 and 115 m.y. old, respectively.

On the flank of the seamount at 20°50′S, 08°40′E there is a flat surface about 1100 m below the top of the

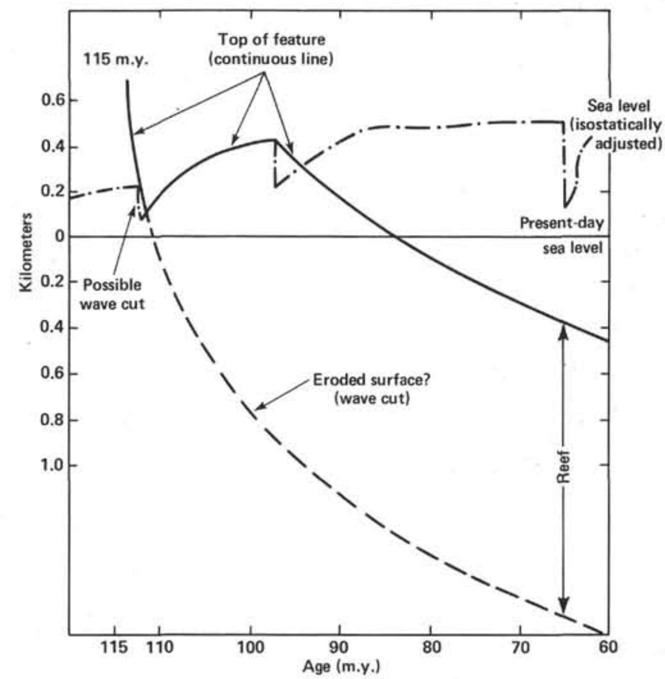

Figure 7. Subsidence of Walvis Ridge seamount, 20°50′S, 08°40′E.

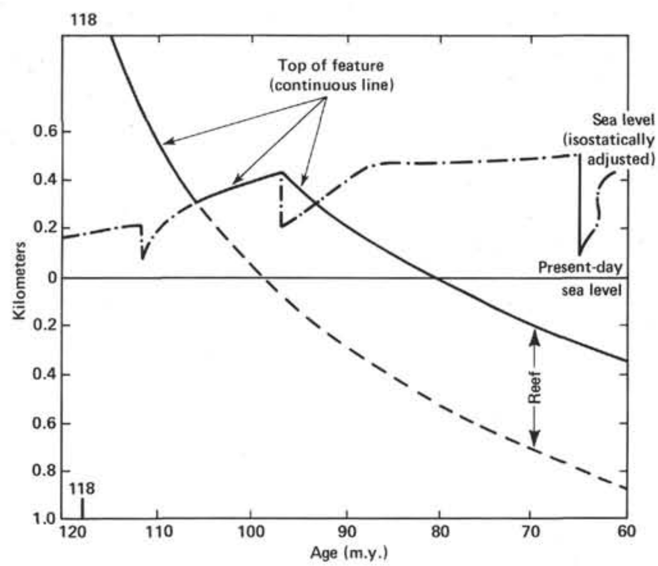

Figure 8. Subsidence of Site 531.

apparent reef. This could have been wave cut 112 m.y. ago, at the time of a fall of sea level (Fig. 7). In this scenario, with reef growth beginning on the wave cut surface and continuing until the next fall in sea level, the reef should have attained a thickness of about 1300 m, which is not far off the observed thickness of 1100 m. At Site 531, the reef could reach a maximum thickness of about 1200 m but may be less in areas where growth started later. A 500-m-thick reef, typical for the top of the feature, is shown in Figure 8.

We conclude, therefore, that the most likely explanation of the observed features is as follows: (1) the segment of the Walvis Ridge at Site 531 was formed approximately 118 m.y. ago; (2) the ridge was eroded during a sea-level drop approximately 112 m.y. ago; (3) during the subsequent sea-level rise, reef growth maintained the ridge to within 250 m of the water surface; (4) a sea-level drop 97 m.y. ago ended reef growth; wave erosion of the reef complex resulted in the rounded to subrounded, coarse, sand-sized fragments of red coralline algae recovered in Hole 531A; and (5) reef growth failed to continue with the subsequent sea-level rise and the continued subsidence of the ridge.

A precise biostratigraphic age for the reef-like deposit, which might be derived from a larger dredge sample, would test this conclusion.

By considering variations in sea level, a factor determining the development of features capped by reefs that died and subsequently subsided, it should be possible to determine when reef growth ended and to establish very precise points for the calibration of the seafloor subsidence curve and the subsidence curve of aseismic ridges or vice versa.

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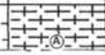
Date of Initial Receipt: July 21, 1982

SITE 531 HOLE A CORE (HPC) 1 CORED INTERVAL 0.0–.27 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	FOSSIL CHARACTER: NANNOFOSSILS	FOSSIL CHARACTER: RADIOLARIANS	FOSSIL CHARACTER: DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
mixed Pleistocene						1					*	5Y 7/4 Dusky gray yellow NANNOFOSSIL FORAMINIFER OOZE with coralline algal limestone fragment (Ⓐ).

SMEAR SLIDE SUMMARY (%):

	Nannofossil foraminifer ooze
Section, Depth (cm)	1-10
Lith. (D = Dominant; M = Minor)	
Composition:	
Quartz	<1
Clay	5
Carbonate unspec.	8
Foraminifers	70
Calc. nannofossils	17