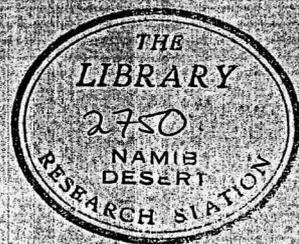


ANTARCTIC GLACIAL HISTORY AND WORLD
PALAEOENVIRONMENTS

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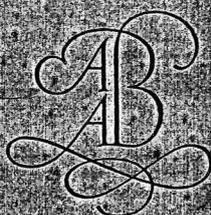
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Benguela Current

Sediments

D. Namib - palaeoecology/climatology



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Aridification of the Namib Desert: Evidence from oceanic cores

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1978

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ABSTRACT

Extreme aridity in the Namib Desert is the result of several interacting atmospheric and oceanic phenomena. The presence immediately offshore of the Benguela Current is one of the major controlling factors. These cold, upwelled waters cool moisture-laden sea breezes, and combined with the atmospheric factors, prevent rain from falling in the Namib. If we can establish the time of the initiation of major cooling and upwelling in the Benguela Current System, we can approximate the time when aridification of the Namib was initiated, or at least greatly intensified.

Recent deep drilling on the Walvis Ridge Abutment has recovered a complete sequence of sediments ranging from Middle Eocene to Late Pleistocene. These open-ocean biogenic sediments provide a wealth of information on the history of the overlying waters in which they were formed: the Benguela Current.

Studies of sediment accumulation rates, diatom frustule abundance, planktonic Foraminifera and cal-

careous nannoplankton temperature preferences, primary productivity (expressed in C_{org}) and phosphorus incorporation in calcareous skeletons all suggest changes in the characteristics of the Benguela Current. These sedimentological, palaeontological and geochemical data suggest weak, spasmodic introduction of cool, upwelled waters along this coast from Middle or Late Oligocene until Middle Miocene times. In the early Late Miocene conditions changed markedly, strongly suggesting intensification of upwelling which brought cold, nutrient-rich waters to the surface along this coast.

Onshore faunal remains indicate that the Namib was mostly wooded-grasslands until Middle Miocene times, suggesting that the early spasmodic conditions of the Benguela did not cause significant aridification. It is suggested that the major cooling-upwelling of the Benguela in early Late Miocene times initiated aridification of the Namib Desert.

INTRODUCTION

Most of South West Africa has an arid or semi-arid climate. An extremely arid belt, the Namib Desert, extends along the entire coast from the Kunene River to the Orange River, eastwards at least to the Great Escarpment (Fig. 1). The reasons for the generally arid climate are two-fold: 1) the drying influence of the high-pressure (anticyclonic) cell located in the South Atlantic and 2) the effect of the cold Benguela Current and its intimately associated upwelling (van Zinderen Bakker, 1975a). The intensely arid Namib Desert adjacent to the coast is caused by several interacting atmospheric and oceanic phenomena, of which the Benguela Current is a major controlling factor. These cold waters cool moisture-laden sea breezes and, in combination with the atmospheric factors, prevent rain from falling in the Namib.

The 'Oldest Desert in the World'. This is a statement often heard when the Namib is described. But is it the oldest? What unequivocal evidence do we have which indicates the age of this desert? And in any case, how *do* we date a desert? The purpose of this paper is to present new evidence on the timing of aridification in South West Africa, with particular reference to the extreme aridification causing the Namib Desert.

TIMING OF THE INITIATION OF ARIDIFICATION

It is clear that if we can establish the time of the initiation of major cooling and upwelling in the Benguela Current System it will approximate the time of the initiation or, at least, intensification of aridification. Van Zinderen Bakker (1975b) made the first attempt to date the related Benguela Current-Namib Desert system. He presented a variety of evidence, part of which comes from Deep Sea Drilling Project (DSDP) cores raised from the sea floor off Antarctica. Oxygen and carbon isotope analyses of those cores showed that the temperature of high-southern-latitude bottom waters dropped markedly to the present low levels during Early Oligocene times (Shackleton & Kennett, 1975). On the basis of this and other evidence van Zinderen Bakker (1975b) concludes that '... in Early Oligocene times, when the cold Antarctic Intermediate Water could move northward, the stage was set for the origin of the Namib Desert'. But the initial availability of cold bottom waters in the high latitudes does not imply immediate development of cold, upwelled water off South West Africa. Certainly some sluggish, spasmodic upwelling may have been generated fairly soon (and there is evidence for this, as will be discussed in later sections), but major, intensive cooling/upwelling of waters began only in Late Miocene times, some 25 million years after the Early Oligocene origin of South Atlantic cold bottom waters.

DSDP SITE 362/362A

Evidence in support of this timing comes from DSDP cores collected off the northern coast of South West Africa during early 1975. Descriptions of these cores and relevant palaeo-environmental information are given by Bolli et al. (1975) and Siesser (in press, a).

The drill site most important to this study is Site 362/362A (362A is an offset hole drilled immediately adjacent to 362). The site is located on the western abutment of the Walvis Ridge (Fig. 1) in a water depth of 1325 m. The total stratigraphic section

penetrated was 1081 m and a continuous sedimentary sequence from Upper Pleistocene to Middle Eocene was recovered. Sediment lithologies are remarkably consistent: they are overwhelmingly calcareous oozes, chalks and limestones dominantly composed of calcareous nannofossils with lesser amounts of planktic Foraminifera and other organisms. This has clearly been an open-ocean site from Eocene times onward. It is today under the direct influence of the Benguela Current (Moroskin et al., 1970) and has been throughout all of the late Cainozoic. Thus the sediments at this site record the changing conditions of the overlying water mass throughout most of the Cainozoic times.

Sedimentological, palaeontological, and geochemical evidence have been collected from the sediments at this site in an attempt to elucidate the history of the Benguela Current.

SEDIMENTOLOGY

Sediment accumulation rates

Figure 2 shows the sediment accumulation rates at Site 362/362A for various Cainozoic ages and sub-ages. These rates have been corrected for compaction and induration following the method of Schlanger et al. (1973). Eocene-Early Oligocene accumulation rates are low, although a definite increase occurs after Early Oligocene times. A rate between about 28 and 38 m/MY is maintained from Late Oligocene to Middle Miocene times. A dramatic increase in accumulation (72 m/MY) takes place in Late Miocene times, followed by an unexplained sharp decline in the Early Pliocene. The accumulation rate climbs again in Late Pliocene-Early Pleistocene times and by Late Pleistocene-Holocene, rates are almost back to Late Miocene levels.

The cold waters of the Benguela Current are rich in nutrients, which promote the growth of large numbers of planktic organisms in Benguela surface waters. Dead and discarded skeletons of these planktic organisms are the major components in the sediments at Site 362/362A. An onset or intensification of upwelling brings even more nutrients to the surface and should be reflected by vastly increased plankton abundance in surface waters and therefore an increased accumulation of pelagic sediment on the sea floor. It is plausible that the increase in sedimentation from Late Oligocene to Middle Miocene times may reflect the weak cooling/upwelling mentioned earlier. However, the accumulation rate in the Late Miocene almost doubles, strongly ~~indicating~~ indicating the production of more sediment-forming organisms and thus intense cooling/upwelling during that period. The brief Pliocene drop in accumulation is not supported by the other cooling/upwelling-

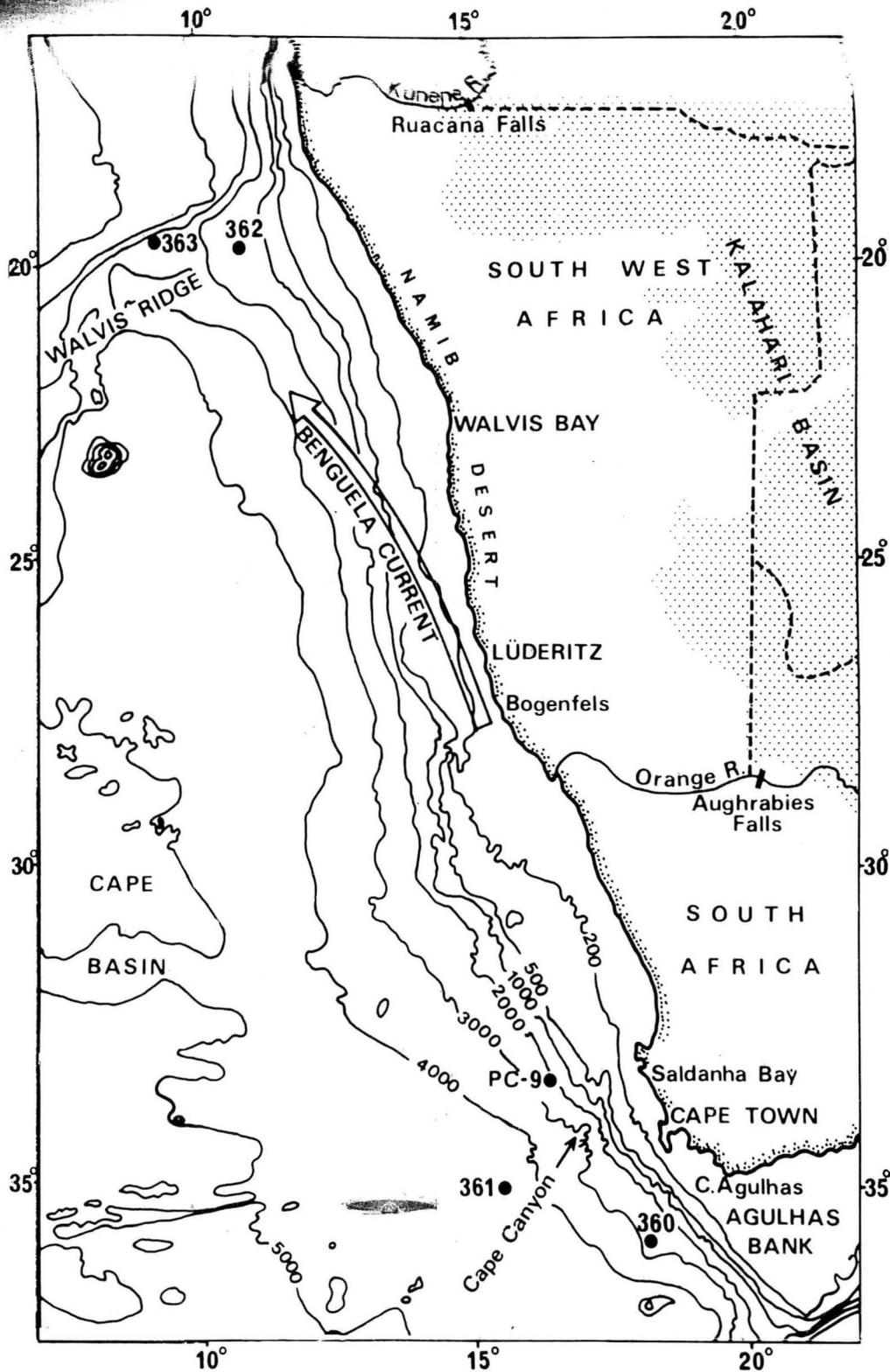


Fig. 1. Location map, showing Namib Desert and Deep Sea Drilling Project (DSDP) Sites. Isobaths are in metres

SEDIMENT ACCUMULATION RATES

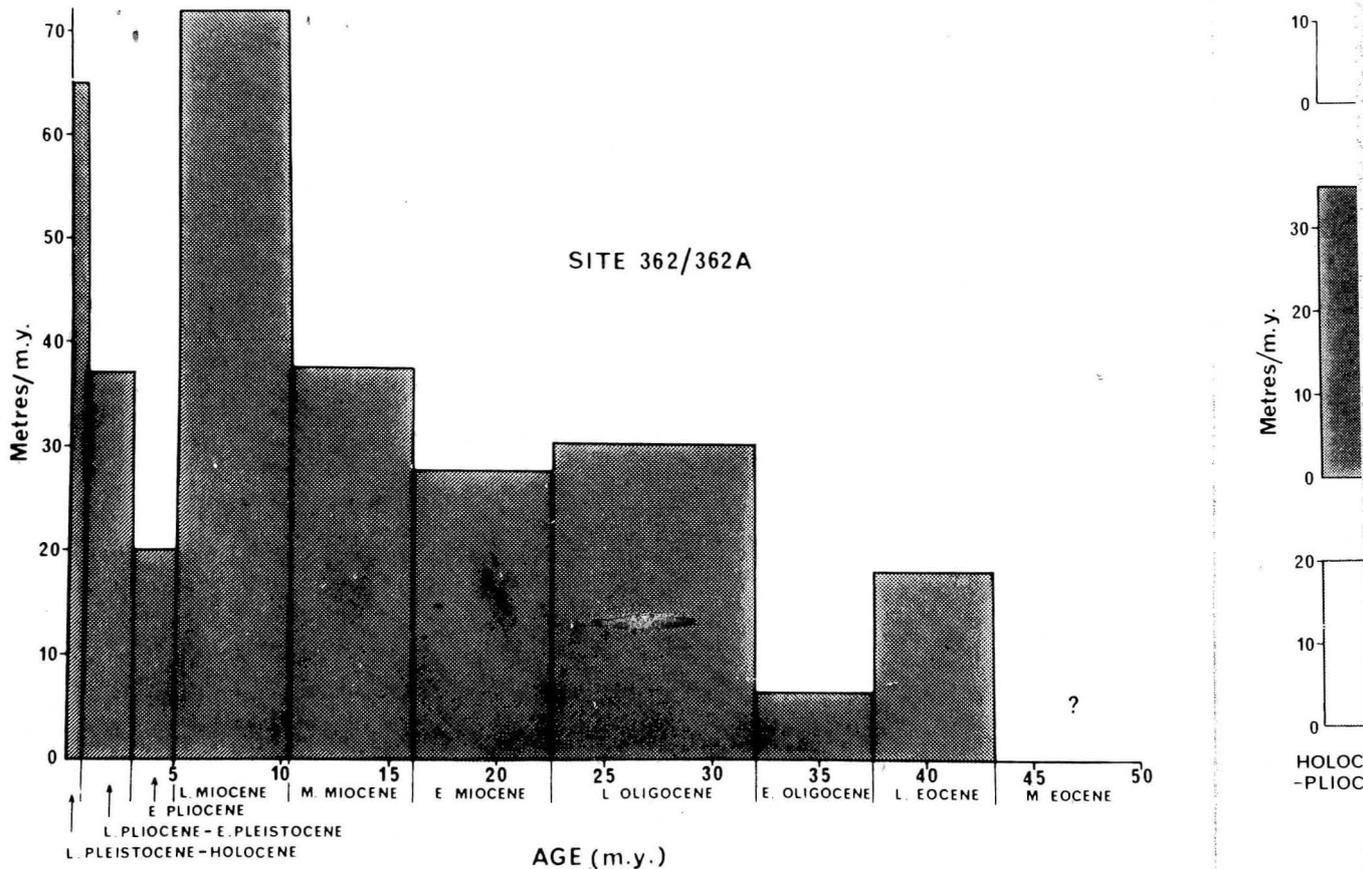


Fig. 2. Sediment accumulation rates in metres/million years at DSDP Site 362/362A. Rates are corrected for compaction and induration

indicative parameters, discussed in the following paragraphs. High Late Pleistocene-Holocene levels suggest near-modern accumulation rates similar to those in the Late Miocene.

The influence of the Benguela Current in pelagic-sediment production is clearly portrayed by a comparison of this Benguela-influenced site with sites (360/361 and 363 (Fig. 1)) that have never been directly influenced by the Benguela. Figure 3 shows sediment accumulation rates for these sites to the north and south of Site 362/362A. These data are calculated for each epoch as a whole, and are uncorrected, but still serve satisfactorily for comparison among the sites.

The differences are only a few m/MY at all sites during Palaeocene and Eocene times. Sites 360/361 and 363 still have similar rates during the Oligocene, but Site 362 shows the first slightly increased rate. This increase becomes dramatic in Miocene-Holocene times, almost doubling the rate at Site 360/361 (post-Miocene sediments were not recovered at Site

363), reflecting the influence of the Benguela Current over Site 362/362A.

PALAEONTOLOGY

Diatom frustules

Abundant diatom production is almost synonymous with cold, upwelled marine waters; diatom abundance is generally low in normal oceanic waters. These minute one-celled plants (Fig. 4), which build a skeleton out of opaline silica, extract nutrients (phosphates, nitrates, silicates) from sea water and form the lowest link in the food chain that makes the present-day waters off South and South West Africa one of the world's richest fishing grounds. Thus the relative abundance of these organisms, which are so dependent on upwelled nutrients for their growth, should record the history of the Benguela Current and its associated upwelling.

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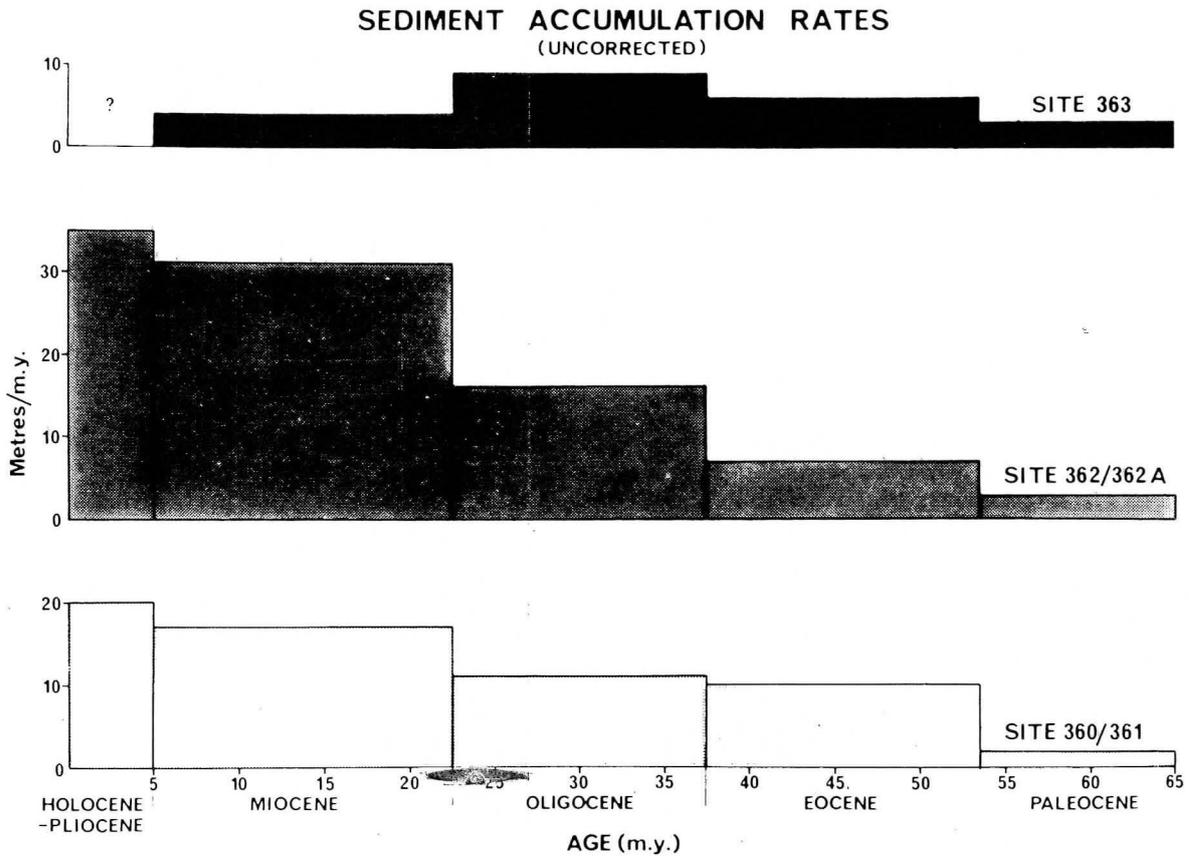


Fig. 3. Sediment accumulation rates in metres/million years at DSDP Site 360/361, 362/362A and 363. Rates are uncorrected

Figure 5 plots the average abundance of diatoms in each core against time. Negligible numbers of diatoms were found in sediments from Middle Eocene to earliest Late Miocene times. In the early Late Miocene the first recordable numbers of diatoms start to appear. Their abundances remain low until about the Late Miocene–Early Pliocene boundary, when a marked increase begins, which, although fluctuating, appears to continue increasing into the Pleistocene.

This is considered to be a real increase, and not, as might be suggested, resulting from progressive dissolution of buried diatom frustules. The only diatom frustules which normally reach the sea floor are those of robust species. Most of the weakly silicified, delicate diatoms are dissolved during their descent through the first few hundred metres of the water column. The robust species that accumulate at depths tend to be very stable, much more so than the calcareous skeletons of other planktic organisms. Thus, it is not uncommon to find pelagic red clays at depths greater than 4 000 m still containing diatom frustules, whereas all the skeletons of calcareous

nannoplankton and Foraminifera have been dissolved.

The presence of solution-prone calcareous nannoplankton species with delicate skeletons in both cores where robust diatoms were and were not found indicates that solution has not removed robust diatoms from the older samples: they simply were not present in any abundance in the overlying waters.

Calcareous Nannoplankton and Foraminifera

Unlike diatoms, planktic Foraminifera and calcareous nannoplankton are found in great abundance in most oceanic water masses and not just in upwelling areas. Nevertheless, one would expect an increase in their abundance because of greater upwelling-induced nutrient production. However, this increase would be directly reflected by the sediment accumulation rates shown on Figure 2 and therefore has not been plotted separately.

But other valuable information can be obtained by an examination of the temperature preferences of

species belonging to these groups, since certain species in both groups are closely restricted to water masses of given temperature ranges. The assemblages found at Site 362/362A indicate a very definite change in temperature of the overlying water with time. Middle Eocene to Lower/Middle Miocene sediments contain tropical-subtropical Foraminifera and 'warm-water' calcareous nannofossils. From Middle or Late Miocene times onward a marked cooling occurs, which is demonstrated by the dominance of cool-temperate-water planktic Foraminifera and calcareous nannofossils. By Pliocene times the assemblages are decidedly cold-water ones.

It is interesting to note that at Site 363, less than 150 km to the north, but over the crest of the Walvis Ridge, tropical faunas and floras were being deposited throughout the early and middle Tertiary, even into Miocene times when waters to the south were markedly cooler. This bears out other evidence (Bolli et al., 1975) that the Walvis Ridge, submerged though it may be, has acted as a substantial barrier to oceanic currents throughout the Tertiary. The Miocene cooling of the surface waters at Site 362/362A was caused by upwelling of Cold Atlantic Central Water. Large-scale upwelling did not occur at Site 363, owing to the Walvis Ridge barrier, and surface waters over that site remained warm.

GEOCHEMISTRY

Organic carbon

The high primary productivity of the cold Benguela Current and its associated upwelling has already been mentioned. Productivity is usually measured in terms of organic carbon (C_{org}). Foresman (in press) has measured the amounts of total C_{org} in these cores, and Figure 6 has been prepared from data presented by him.

C_{org} remains at very low levels from Middle Eocene to early Early Miocene times. A moderate increase occurs from late Early Miocene to middle Middle Miocene times, but again drops to negligible amounts near the Middle-Late Miocene boundary. However, in early Late Miocene times a marked increase in C_{org} begins, which persists into Late Pleistocene times. Extremely high values of C_{org} (3.6 and 4.2%) are recorded in the undifferentiated Late Pliocene/Early Pleistocene interval.

The curve shown on Figure 6 suggests increased Benguela upwelling from Late Miocene times onward, corroborating the timing interpreted from data already presented. But, unlike the sediment accumulation rates, diatoms, and planktic assemblages – for all of which evidence can be presented showing that their fluctuations represent real trends

– the C_{org} plot cannot be proven to be real. Organic matter progressively oxidizes with time, and what we see may simply be the amount of C_{org} that has not yet been destroyed (and therefore is more abundant in the younger cores) and not the amount that was originally deposited. On the other hand, oxidation of C_{org} is greatly retarded in environments of rapid sediment accumulation, and most of it tends to be preserved. Moreover, Foresman (pers. communic.) cites isotopic evidence which indicates that these C_{org} values do represent the original C_{org} content.

Phosphorus

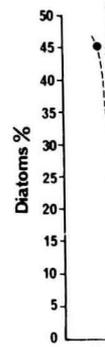
A less equivocal chemical parameter that can be measured is phosphorus uptake in phytoplankton. It is well known that marine organisms extract minor and trace elements from the ambient sea water, incorporating these elements firmly within the crystal lattice in their skeletons. It has been stressed that Benguela Current waters are greatly enriched in nutrients such as phosphates, nitrates and silicates. Calcite skeletons of calcareous nannofossils were analysed using an electron microprobe to see what minor and trace elements might have been incorporated. The only element found, other than the expected components of calcium carbonate, was phosphorus. Siesser (in prep.) has described the techniques and results of this study.

Coccolithus pelagicus, a long-ranging Tertiary species was used throughout as a control species to avoid interspecific variation. The plot presented by Siesser (in prep.) shows that, after a Middle Eocene high, these organisms incorporated a low, fluctuating phosphorus content from Early Oligocene until Middle Miocene times. From Late Miocene times onward there is a slight, but steady increase in phosphorus uptake.

There are, of course, two possible explanations for this increase: 1) a physiological response on the part of the plants, reflecting progressively increasing need for, or ability to extract, phosphorus from the surrounding waters. Many marine organisms, for example, extract and incorporate Mg in direct proportion to ambient water temperatures. Is this, then, a reflection of warmer sea-surface waters? Information previously presented suggests this was in fact a time of cooling surface waters, and thus a warm-water environment factor seems unlikely.

The other explanation, 2) is simply increased availability of phosphorus in the water. This would obviously be the case if upwelling brought phosphate-rich waters into the zone where the plants lived, and this explanation seems best suited to explain the available facts.

The fluctuating values from Early Oligocene to Middle Miocene could represent the spasmodic introduction of phosphorus by irregular and discon-



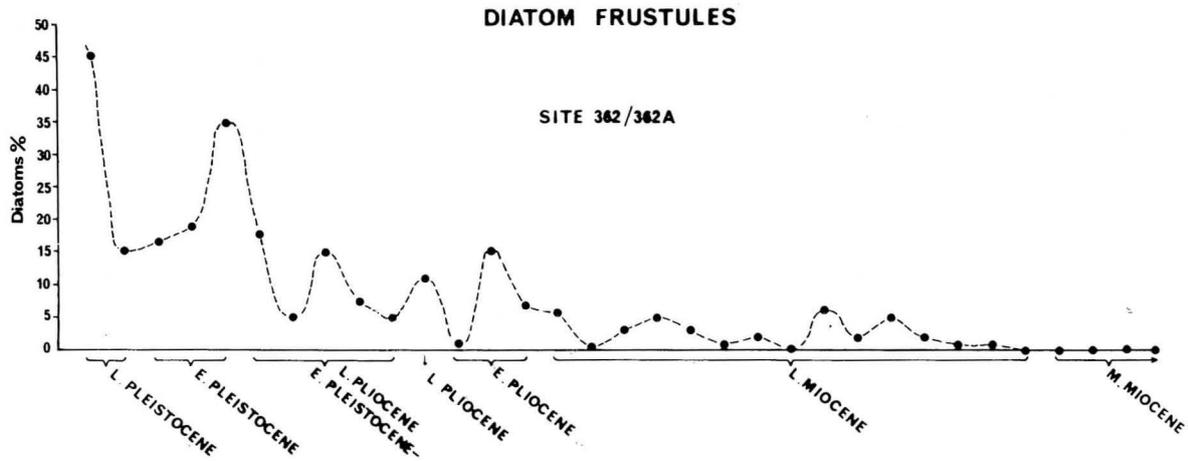


Fig. 5. Diatom frustule abundance at DSDP Site 362/362A. Diatom percentages are based on shipboard smear-slide estimates

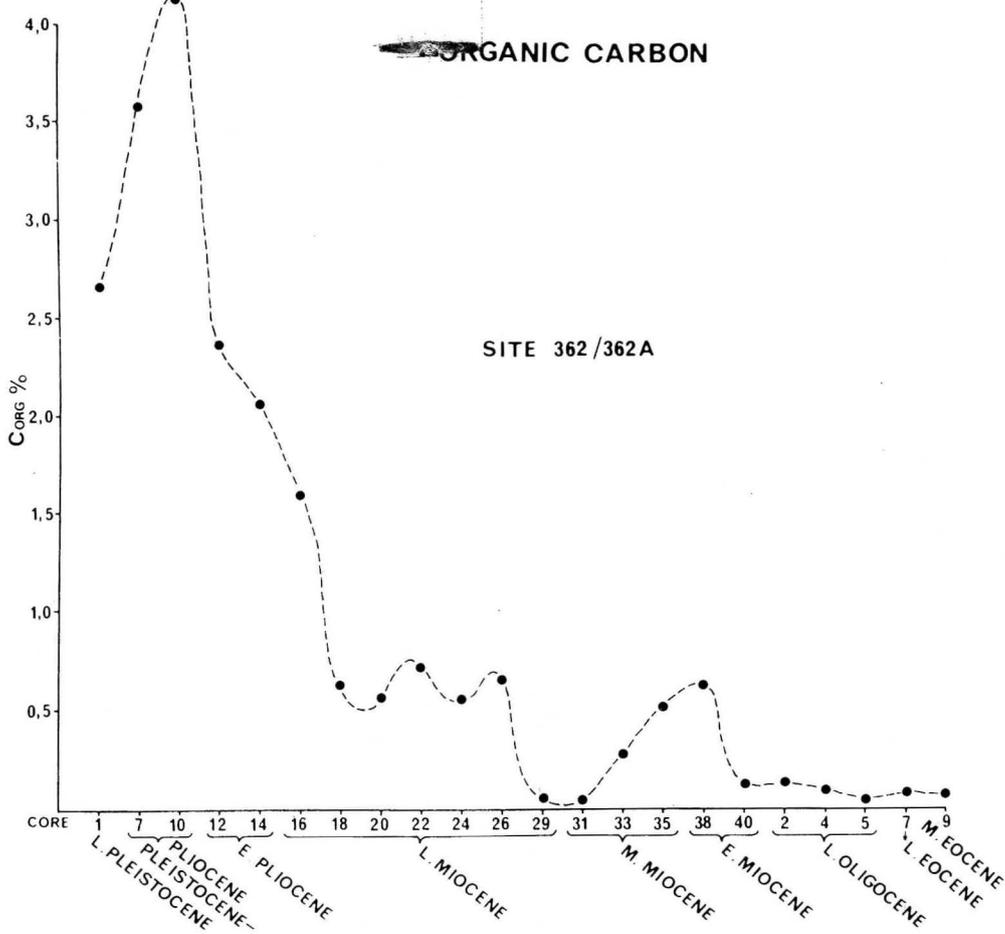


Fig. 6. Total organic carbon content at DSDP Site 362/362A. C_{org} percentages measured by combustion-gas chromatography

tinuous cells of upwelling. The steady increase after the Middle Miocene suggests that upwelling was established on a permanent basis after that time. The increased abundance of phosphorus in surface waters from Late Miocene times onward is strongly supported by the fact that the majority of firmly dated phosphorite rocks from the South African continental shelf are Pliocene in age (Siesser, in press, b).

CONCLUSIONS

Sedimentological, palaeontological and geochemical evidence suggests that the cold, nutrient-rich, northward-moving system we today call the Benguela Current first began to develop in Oligocene times.

Several lines of evidence suggest that from Middle or Late Oligocene until Middle Miocene times, cold, upwelled water was weakly and spasmodically introduced within this system. In the early Late Miocene times (~ 10 MY BP) a marked change may be seen in the Benguela Current: water temperature has dropped and nutrient content has increased sharply. These parameters strongly suggest intensification of upwelling, bringing more cold, nutrient-rich waters to the surface.

It is noteworthy that Savin et al. (1975) show a dramatic global cooling of bottom-water temperatures beginning in Middle Miocene, but reaching lowest values (lower, incidentally, than their calculated values for the Early Oligocene) only in Late Miocene times. This almost certainly corresponds to the development of the major Antarctic ice cap in Middle Miocene-early Late Miocene times (Kennett et al., 1975). Moreover, the circum-Antarctic current developed in Late Oligocene times, after the final separation of Australia and Antarctica, and undoubtedly had extensive influence on the spread of cold water northward.

It is difficult to assess the effect of the early, spasmodic nature of cold/upwelled water in the Benguela Current on aridification in South West Africa. Tankard & Rogers (in prep.) summarize onshore evidence for aridification along this coast. They quote Hopwood's (1929) study of Early Miocene deposits south of Lüderitz. He ascribed antelopes and jumping hares to a wooded-grassland (savanna) and tragulids to a riverine-woodland environment. Middle Miocene deposits north of the Orange River at Arrisdrift contain ruminant and rhinoceros fossils, which also suggest a wooded-grassland environment (Corvinus & Hendy, in press; quoted in Tankard & Rogers, in prep.). This suggests that the Namib was still well vegetated and watered up to at least Middle Miocene times, and that the current system offshore had not yet cooled sufficiently to promote significant aridification of the adjacent landmass.

Evidence presented here suggests that major cooling of the Benguela only became prominent in Late Miocene times, and rapid onshore desiccation probably followed. Tankard & Rogers (in prep.) reached the same general conclusions, suggesting that aridity on the subcontinent as a whole dates from the Pliocene. They further suggest that aridification was progressive, becoming fully developed during the Quaternary. Data presented here showing the overall increase in cold/upwelled offshore waters from Late Miocene to Pleistocene times also tends to support progressive aridification of South West Africa.

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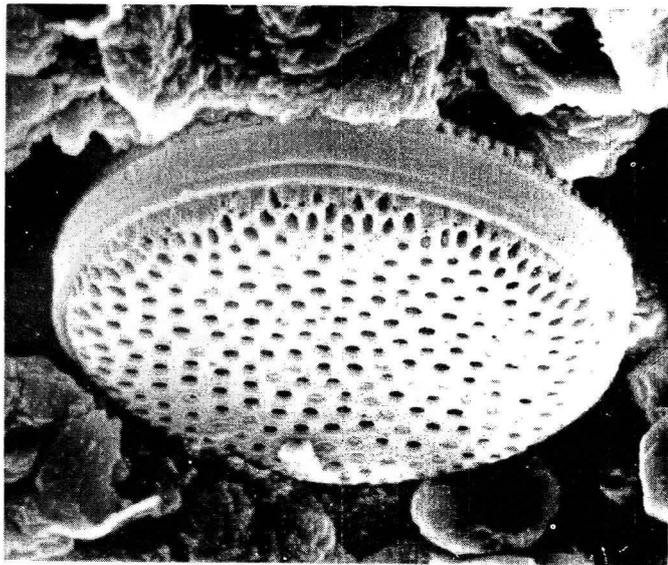


Fig. 4. Diatom frustule. Specimen is 0.13 mm in diameter