Discovery measurements during August 1964 (*1*) but not to that determined from *Chain* measurements during August 1970 (*3*), which showed the current turning offshore at 5°N to 6°N and a separate large gyre to the northeast of this location.

6) Small-scale meanders occur with relatively large changes in direction of the isotherms over 20 to 40 km, which suggest a degree of instability of the current alongshore before it turns offshore to the east.

7) The pronounced upwelling of cold water off Ras Mabber is also similar to that observed in 1964 (*4*).

8) Figure 2 shows the bathymetry along the Somali coast with two small seamounts at 6°25'N and 6°45'N. Although the top of each is between 1500 and 2000 m in depth, which is considerably deeper than the relatively shallow Somali Current, there is an apparent change in the flow pattern between 6°N and 7°N. A somewhat similar pattern of meandering can be observed commencing near 5°N from the 1964 temperature maps (*3*). It is quite possible, of course, that the meandering is caused by other factors, and it might be only a coincidence that it is observed in this location during these surveys.

As part of the study of the Somali Current we are now setting XBT probes from tankers paralleling the coast and hope soon to be able to monitor changes occurring throughout the entire monsoon period.

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Estimates of Cenozoic Oceanic Sedimentation Rates

Abstract. *Estimation of average Cenozoic sedimentation rates for the Atlantic, Indian, and Pacific oceans indicates global synchronous fluctuations. Paleocene–early Eocene and late Eocene–early Miocene rates are only a fraction of middle Eocene and middle Miocene–Recent rates. These changes must reflect significantly different modes of continental weathering, which may be due to alternate states of atmospheric circulation marked by reduction of global precipitation.*

Estimates of the average rates of sedimentation in the Atlantic, Pacific, and Indian oceans have been prepared from data on cores recovered by the Deep Sea Drilling Project (DSDP). To prepare the estimates, the average sedimentation rate and average carbonate content for each of the 13 unequal Cenozoic time increments were calculated for each site where such values could be determined.

The data analyzed were provided by DSDP from their lithologic data bank at Scripps Institution of Oceanography. The information in the data bank has been compiled from original records and from published DSDP reports (*1*). The data we used came from 334 sites (Atlantic, 110 sites; Pacific, 170; Indian, 54). The 13 Cenozoic time increments are those chosen by Premoli-Silva *et al.* (*2*) for the preliminary atlas of the results of the DSDP. The age boundaries assigned to them for this calculation are as follows (in million years before present): Pleistocene, 0 to 2; late Pliocene, 2 to 4; early Pliocene, 4 to 6; late Miocene, 6 to 11; middle Miocene, 11 to 14; early Miocene, 14 to 22; late Oligocene, 22 to 32; early Oligocene, 32 to 38; late Eocene, 38 to 45; middle Eocene, 45 to 49; early Eocene, 49 to 54; late Paleocene, 54 to 59; and early Paleocene, 59 to 64.

Rates are expressed in meters per million years since analysis (*3*) shows that, for the purposes of gross comparison, the effects of compaction can be ignored. Precise comparison would demand rates expressed as mass per unit area per unit time.

The sedimentation rate for each of the increments at each site was determined according to the following rules.

1) If sediment representing a time increment is bounded by the adjacent increment both above and below, and if coring and biostratigraphy permitted both boundaries to be known exactly, the thickness is the interval between the upper and lower boundaries of the increment.

2) If, because of a coring gap or uncertain biostratigraphy, the exact position of one or both of the boundaries is not known, but sediment of the adjacent time increments is present, the position of each boundary is estimated as the midpoint of the interval of uncertainty; the thickness of the unit is then the interval between the midpoint of an interval of uncertainty and an exactly known point or another midpoint of an interval of uncertainty.

3) If sediment older than Pleistocene is exposed on the sea floor at a particular drill site, all the thickness of sediment representing all time increments younger than that exposed on the sea floor is reckoned to be zero.

4) If sediment of one time increment rests directly by hiatus or unconformity on sediment of a time increment older than that immediately preceding it, the thickness of sediment of all missing increments is reckoned to be zero.

5) If sediment of a time increment rests directly on igneous or metamorphic rock considered to be basement, the thickness of sediment is reckoned to be the interval from the contact with the superjacent unit to the basement rock.

6) The thickness of sediment representing a time increment is reckoned to be indeterminate if the contacts with adjacent units cannot be determined exactly or estimated by the midpoint method; indeterminate thicknesses were not used in calculating the average rates.

The carbonate sedimentation rates were estimated by multiplying the average sedimentation rate for each increment by the average carbonate value for each increment.

As shown in Fig. 1, data from the Atlantic, Pacific, and Indian oceans produce very similar curves. The correspondence between Atlantic and Pacific curves is almost perfect. The Indian Ocean curve deviates slightly, but has the same inflection points and trends. Despite the admittedly large scatter in the original data, the general trends and the similarities between the oceans are unmistakable.

It might be suggested that the curves in Fig. 1 are an artifact of either a bias of the core recovery process or the age scale used. However, we have checked this rather thoroughly, and if there is a core recovery bias, it would tend to even out differences in sedimentation rates. Similarly, the age scale would not have a significant effect on the curves unless the generally accepted radiometric ages for Cenozoic epochs are wrong by a factor of 2 to 3 for either the entire pre- or post-middle Miocene.

Because the DSDP sites are overwhelmingly biased in favor of oceanic pelagic sediments, and because a simple averaging technique was used, the total sediment curves represent predominantly pelagic sedimentation. The carbonate fraction curves are a more strict measure of pelagic sedimentation. The high average sedimentation rates for the Pacific compared to the Atlantic may be a reflection of bias due to the concentration of sites in the equatorial region.

Four distinct sedimentation episodes are evident for the Cenozoic. The Paleocene–early Eocene has very low rates, with a very high proportion of carbonate sediment. The middle Eocene has high rates, with a much larger noncarbonate component. The late Eocene–early Miocene is again characterized by very low rates and a high carbonate content. The middle Miocene–Recent has high sedimentation rates and a relatively low proportion of carbonate. It should be noted that, although the relative proportions of carbonate and noncarbonate change, both components of the sediment show the same general trends. This implies gross fluctuation of river input on a global scale.

These curves are inexplicable in terms of present ideas concerning chemical and mechanical denudation. Garrels and Mackenzie (*4*) and Hay and Southam (*5*) have shown that the chemical (dissolved) load of rivers varies as a simple linear function of continental area exposed or of continental area draining to the ocean. The mechanical (detrital) load is supposed to vary as a linear function of continental area exposed and an exponential function of the average elevation of the continent. According to the data of Livingstone (*6*) and Yevetyev (*7*), all continents except ice-covered Antarctica and desert Australia closely obey these rules. The average sedimentation rates for the middle Miocene–Recent and for the middle Eocene, determined from DSDP results, closely correspond to the pelagic sedimentation rates predicted by the Garrels-Mackenzie and Hay-Southam models. However, the very low global rates of the early Paleocene–early Eocene and the late Eocene–early Miocene are only one-fourth to one-tenth of what would be expected if the load of rivers then was similar to what it is today. It can be easily demonstrated that the volumes of continental shelf sediments deposited during these intervals cannot accommodate the missing material, and the suggestion is that the supply by rivers must have been much lower than it is at present. The generally high proportion of carbonate also suggests that the dissolved load of rivers must have been unlike that observed today.

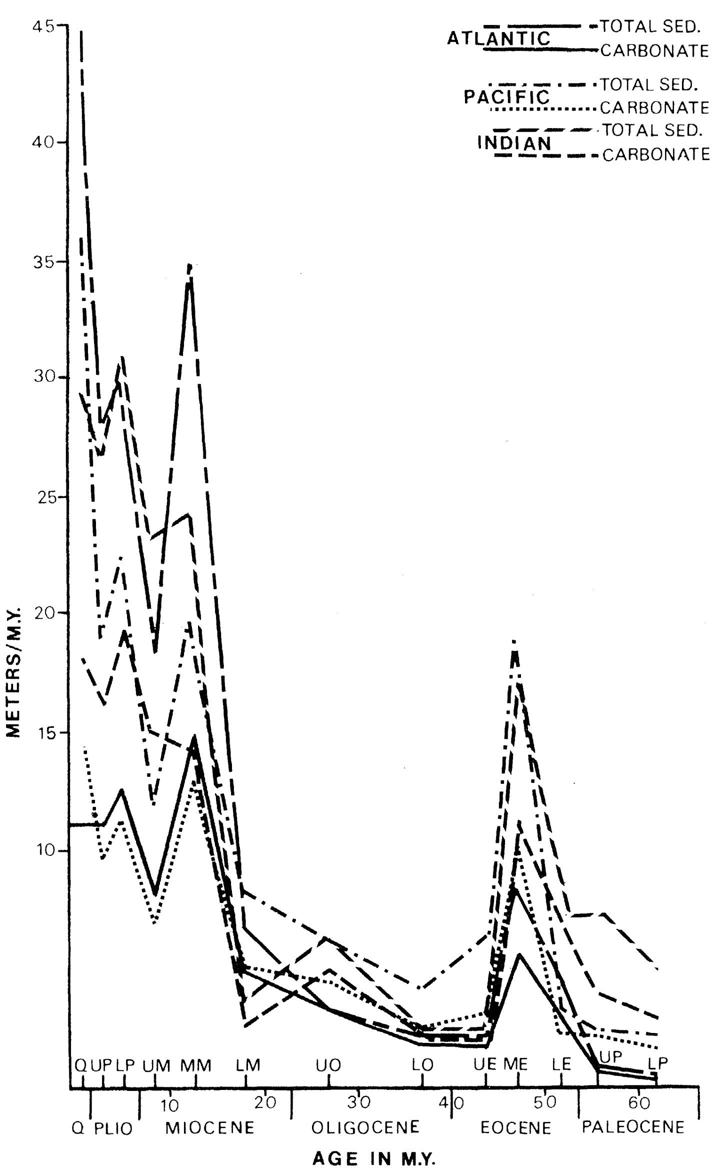

Fig. 1. Rates of sediment accumulation (total sediment and carbonate).

Before this analysis was carried out, following the argument of Garrels and Mackenzie, we expected that the total sedimentation in the world ocean would be stable and almost constant with time, reflecting only transgressions and regressions and agreeing closely with the predicted models presented above. This was expected to be the case particularly for the major biogenic component of the rate, $CaCO_3$, which over the long term depends strictly on dissolved load and thus should be virtually independent of the effects of mountain building. It had been assumed by us, and by many others, that regional differences in sedimentation would be a function of partitioning of the almost constant supply between the ocean basins. This first analysis of the DSDP data produced an unexpected pattern, suggesting virtually no intrabasin partitioning, but very large synchronous fluctuations in rate in all basins. Further, the very low sedimentation rates of the Oligocene and Paleocene correspond to about 70 percent of all continents being denuded in the manner of present-day Australia.

These data suggest that there may have been significantly different modes of weathering of continental materials during the Paleocene–early Eocene and late Eocene–early Miocene. This implies that continenal climates over wide areas were unlike those prevailing today and may reflect a different state of atmospheric circulation. Continental deposits of these ages should be assessed to determine whether they lend support to a hypothesis of altered climate and weathering.

If the analogy with Australian weathering is correct, it implies that precipitation on most continents must have been much less than at present. This in turn implies that evaporation-precipitation may have been supplanted by ocean currents as the dominant process of heat transport across latitudes. This might imply oceans with overall cooler temperatures, but temperature contrasts within the oceans might have been less than those observed today. Newell (*8*) has suggested a similar possible state to explain the effects of glacial-interglacial intervals.

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Antarctic Soft-Bottom Benthos in Oligotrophic and Eutrophic Environments

Abstract. *The benthos of the east and west sides of McMurdo Sound, Antarctica, is characterized by dramatically different infaunal assemblages. The eutrophic East Sound has higher infaunal densities than almost any other benthic assemblage in the world. In contrast, the oligotrophic West Sound, bathed by currents from beneath the Ross Ice Shelf, has patterns of mobile epifauna and low infauna density similar to bathyl deep-sea communities.*

The benthos of the Antarctic continental shelf has been isolated from other continental shelf faunas by cold temperatures and by the circumpolar current systems for approximately 40 million years (*1*). With the exception of the embayments of the Weddell and Ross seas, the continental shelves are relatively narrow, and most of the obligatory shallow-water benthic species apparently became extinct during the massive Pliocene and Pleistocene glaciations (*2, 3*). Subsequent to these extinctions the temperature and current barriers prevented reintroduction of temperate shallow-water species. It was probably the extremely constant physical regime of the Antarctic Sea, closely approximating deep-sea conditions (*3, 4, 5*), that made possible a colonization of the shallow water by largely endemic benthic species with deep-sea affinities or large vertical depth ranges (*2, 6*), which escaped extinction from ice-age glaciation. There have been alternating expansions and retreats of large continental ice shelves. Denton *et al.* (*1*) estimate that there were at least four major advances of the Ross Ice Shelf in the last 1.2 million years, the last major expansion occurring over 47,000 years ago. The Ross Ice Shelf floated free of the ground at least 5,000 years ago, and there is little geological evidence of important changes since then (*7*). The Ross Ice Shelf thus has been in existence for a considerable period; knowledge of the organization of the benthic communities in its vicinity can give valuable insights into important natural geological and biological processes.

This is a preliminary report of our benthic research in the vicinity of the northwestern edge of the Ross Ice Shelf in McMurdo Sound. Specifically we contrast the extremely dense infaunal populations of the East Sound at Cape Armitage, Ross Island, in an area of seasonally high primary productivity, with very low-denisty infaunal patterns along a series of oligotrophic West Sound sites that seem to be bathed by a unidirectional current from under the Ross Ice Shelf (Fig. 1). We compare these data and those collected from a depth of 500 m in the Ross Sea with recorded density data from bathyl and high-productivity temperate systems.

The West Sound area is dominated by the Ross Ice Shelf, always a conspicuous feature of the McMurdo Sound region. Historically, the general location of the Ross Ice Shelf in the McMurdo Sound region has been remarkably constant since James Ross visited the area in 1841, and the early maps of the Scott and Shackleton expeditions show that only minor changes in the Ross Ice Shelf west of the Dailey Islands have occurred through 1970. Between 1970 and 1973 a large part of the shelf broke out from the Dailey Islands southwest to Garwood Valley (*8*). We examined aerial photographs taken of the McMurdo Sound region from 1956 through 1970. They show a predictable pattern of breakout of annual ice from October through January along Ross Island and the Hut Point Peninsula. This pattern is similar to that observed by the early British expeditions. The photographs documented very few West Sound breakouts by February, when aerial surveys stopped for the winter. Our diving observations from Garwood Valley northward reveal 2- to 3-year ice in floes of different ages, which suggests occasional breakups after February with different amounts of ice remaining in the area. Thus, our Garwood Valley site was under the Ross Ice Shelf at least through 1970, and the other West Sound sites, under annual ice during most of the year, have been under glacier or shelf ice during recent geologic time (*1, 7, 8*).

The very different shallow (< 100 m) current regimes also provide contrast between the East and West Sound sites. There are rather strong, sometimes oscillating, tidal currents along the Hut Point Peninsula of Ross Island, which have a marked southerly trend (*4, 9*). We corroborated the southerly trend of the shallow current on a dive at White Island, 22 km south of the northern edge of the Ross Ice Shelf. Here we observed signs of a plankton bloom impossible in the aphotic conditions existing under the shelf at White Island. In addition, the common epifaunal species seen at White Island were plankton feeders also common at Cape Armitage (*10*), such as the sponges *Polymastia invaginata* and *Latrunculia apicalis*, the alcyonarian *Alcyonium paessleri*, the actinarians *Artemidactis victrix, Isotealia antarctica*, and *Urticinopsis antarctica*, the stoloniferan *Clavularia frankliniana*, the hydroids *Lampra* spp. and *Halecium arboreum*, and the large bivalve *Laturnula elliptica*.