TERTIARY SEA-LEVEL MOVEMENTS AROUND SOUTHERN AFRICA

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ABSTRACT

Sedimentological, micropaleontological and seismic-profiling data elucidate the history of Tertiary sea-level movements around southern Africa. These new data show that landward movement of the sea began in early Paleocene time and continued into the early Eocene. The sea probably reached its maximum Paleocene height during the early Eocene, and is today represented by outcrops up to at least 204 m, and probably as high as 360 m, above modern sea level. A brief regressive pulse occurred during the middle Eocene, with renewed transgression in the late Eocene. A major regression followed, probably spanning all of Oligocene and early Miocene times. This regression exposed much of the continental shelf and is clearly represented on seismic-reflection profiles by a widespread unconformity. The major Neogene transgression began in the middle Miocene and probably reached its greatest extent in the late Miocene or early Pliocene. The overall middle Miocene to early Pliocene transgression was interrupted by a brief regressive pulse near the Miocene-Pliocene boundary. Seas withdrew again in the late Pliocene. Rocks deposited during the Miocene-Pliocene transgression are today found up to 330 m above sea level. This scheme should be viewed as showing only the gross movements of the seas around southern Africa during the Tertiary. Nevertheless, the timing of these southern African transgressions/regressions is closely parallel to the timing recently established for sea-level movements in other parts of the world.

INTRODUCTION

Changes in sea level around southern Africa during various epochs of the Tertiary have been discussed by numerous authors (e.g., King 1967; Haughton 1969; Truswell 1970; Tankard 1976). Opinions as to timing are diverse. Dingle (1971, 1973) and Dingle and Scrutton (1974) were perhaps the first to present substantial evidence as to the timing of sea-level movements for the entire Tertiary Period. They postulated a late Maastrichtian regression followed by a regional, late Paleocene-early Eocene transgression. Another regression spanning late Eocene to early Miocene time was followed by an early Miocene transgression. A late Miocene-early Pliocene regression was followed by a brief transgression, then regression again in the late Pliocene. These times were based on older published reports on the ages of onshore rocks, and on seismic evidence combined with a small number of dated rocks from the continental shelf.

Almost 200 new dates based on calcareous nannofossils and planktic foraminifers are now available for Tertiary strata on the continental margin (Siesser 1977a, 1978a and unpublished data) and for certain onshore coastal rocks (Siesser 1977b, Siesser and Miles 1979). The actual presence onshore, or close inshore, of rocks deposited during different time intervals is our strongest evidence for transgression at those times. Data based on lithologic facies and seismic-profile records add further information to the history of sea-level movements around southern Africa (fig. 1).

Based on these new data, we present here a revised interpretation of relative sea-level movements around southern Africa. Our sea-level curve (fig. 2) should be viewed as a "generalized" curve, showing the gross direction of sea-level movements during epochs and sub-epochs of the Tertiary. Local uplift or subsidence may have caused one area of the coast to emerge or submerge slightly earlier than another area.

STRATIGRAPHY

The sedimentation history of southern Africa was dominated by erosion rather than deposition during the Tertiary, and there are relatively few onshore Tertiary outcrops.
Fig. 1. – Map showing the localities mentioned in the text.
TERTIARY SEA-LEVEL MOVEMENTS

Offshore, however, the surface of the continental margin is made up mostly of Tertiary rocks, overlain by thin, unconsolidated Quaternary sediments.

Paleogene. — Lowermost Paleocene rocks have not been found either onshore or on the surface of the continental shelf around southern Africa, but “middle” Paleocene has been identified in Mozambique (Flores 1973; Förster 1975), at Richards Bay (middle Danian – Maud and Orr 1975; Stapleton 1975) and on the continental shelf off Cape St. Lucia (Siesser 1977a) (fig. 1).

This pattern suggests that a regression initiated in late Cretaceous time continued into the Paleocene. Lowermost Paleocene marine sediments were not deposited in the inshore zone, although a complete sequence was deposited farther offshore, as indicated by DSDP drilling on the outer continental margin (Bolli et al. 1975).

Lower, middle and upper Eocene rocks are known onshore in Mozambique (Flores 1973; Förster 1975), and lower Eocene at Birbury in South Africa (Siesser and Miles 1979). In Namibia, possibly Paleocene/lower Eocene rocks are exposed near Buntfeldschuh (Siesser and Salmon 1979), and upper Eocene rocks are found at Bogenfels (Siesser 1979b). Upper Eocene foraminifers re-worked into Miocene rocks show the former presence of upper Eocene deposits in Zulu-

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Fig. 2. — Curve showing gross direction of Tertiary sea-level movements around southern Africa. Curve maxima above coastline are elevations in metres at which rocks deposited during the relevant transgressions now lie; below coastline indicates levels at which erosion surfaces cut during the relevant regressions now lie. Dashed lines indicate uncertainty. Letters refer to chief outcrop localities on which interpretations are made: AB – Agulhas Bank, B – Birbury, E – east coast, N – Namibia, NC – Needs Camp, S – south coast, W – west coast, Z – Zululand. Time scale is from Vail et al. (1977).

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land (Frankel 1968, 1972). Offshore, lower and upper Eocene rocks are common on the continental shelf (Siesser 1977a). Middle Eocene rocks are definitely known on the shelf only from deep oil-exploration boreholes (Du Toit and Leith 1974; Dingle et al. in press). Nevertheless, a recognizable stratigraphic break occurs within the middle Eocene sequence in the boreholes (Dingle et al. in press).

The deposits suggest that the Paleocene transgression continued at least into the early Eocene. The absence onshore and scarcity offshore of middle Eocene rocks around most of southern Africa probably represents a regressive pulse, with seas moving shoreward again in late Eocene times.

Another regression followed, spanning all of Oligocene time. From seismic records, Dingle (1971) recognized this as a widespread Oligocene unconformity on the continental shelf. Locally, some marine Oligocene rocks are reported in Mozambique (Flores 1973), but none onshore in South Africa or Namibia. Oligocene rocks are similarly rare on the continental shelf, being found only in the J(c)-1 borehole and on the continental shelf south of Plettenberg Bay (a single upper Oligocene sample). Du Toit and Leith (1974) suggested an early Oligocene transgression, since marine limestones overlie deltaic deposits in the J(c)-1 borehole. However, data from all other areas militate against an Oligocene transgression. A possible alternate explanation for limestone over deltaic deposits is simple cessation of delta growth and the inevitable local "transgressive" covering by the sea, owing to wave erosion and delta destruction (e.g., see Rainwater 1964).

Neogene. — Miocene sea-level movements are a subject of some debate in southern Africa. Most of the outcropping Miocene rocks in Mozambique are middle and upper Miocene (Frankel 1972; Flores 1973). Frankel (1972) and Flores (1973) accordingly suggested a middle or late Miocene transgression followed by a late Miocene-Pliocene regression. Conversely, Förster (1975) believed transgression occurred in early Miocene times, followed by regression with short, local transgressions occurring in middle Miocene-Pliocene times. The outcrop evidence supporting Förster's interpretation is not entirely clear.

A similar controversy exists in Zululand, where King (1953 et seq.) favored an early Miocene transgression, followed by erosion, then a Pliocene transgression. Frankel (1968, 1972) implied a middle or late Miocene to early Pliocene transgression for the same rocks. A late Miocene-early Pliocene age has recently been firmly established for these rocks, based on onshore micro- and nannofossil dating (Maud and Orr 1975; Stapleton 1977; Siesser and Miles 1979). It may be that the sea only reached Zululand in late Miocene time, at the earliest.

Neogene limestones are also exposed intermittently along the Cape Province coastline between Bathurst and Saldanha Bay. These limestones are Miocene and/or Pliocene, but their precise age is difficult to establish (see Siesser 1971, 1972a for a review of the ages assigned to these limestones).

On the west coast, Corvinus and Hendey (1978) and Hendey (1978a) reported serpulid polychaete worm tubes (cf. Mercierella) in middle Miocene river-terrace deposits at Arrisdrift, on the Orange River about 30 km from the river mouth. This is a typical estuarine worm, implying that the middle Miocene coastline was much closer to Arrisdrift than it is today. However, estuaries can extend a considerable distance inland, and it is difficult to estimate the actual height of sea level based on these worm tubes. Nevertheless, the presence of the estuary, together with the height of the river terraces (some 50 m above present sea level), strongly suggest a middle Miocene sea level higher than today. Further strong support for a middle-late Miocene transgression is found on the continental shelf. Middle and upper Miocene rocks are common on the shelf, but only one definitely lower Miocene sample has been found (Siesser 1977a).

We believe the seas began to move landward in middle Miocene time, perhaps reaching the present coastline during middle
Miocene, but certainly by late Miocene. This overall transgression continued into early Pliocene; it is represented in Mozambique by Pliocene rocks (Flores 1973), and some of the coastal limestones from the South African south coast are Pliocene as well (Siesser 1971; King 1973). Only lower Pliocene has been definitely recognized among the Pliocene rocks on the continental shelf (Siesser 1977a).

The Miocene-Pliocene transgression was probably broken by a regressive pulse close to the Miocene-Pliocene boundary. Vertebrate remains in the Varswater Formation at Saldanha Bay (fig. 1) have a maximum age range of 3.5 to 7 m.y. B.P. (Hendey 1978b), although Hendey (1978c; pers. commun., 1979) believes 4 to 5 m.y. may be a closer estimate. These vertebrate remains occur in regressive fluvial and estuarine sands. The underlying marine Varswater deposits thus can be no younger than early Pliocene and could well be late Miocene in age. In any case, they were almost certainly deposited during the middle Miocene-early Pliocene transgression. Siesser and Rogers (1976) found evidence for a brief westward shift in the offshore Benguela Upwelling System at this time, which they suggested was caused by a brief late Miocene-early Pliocene regression. Siesser (1978b) also suggested sea-floor erosion sometime during the middle Miocene-Pliocene interval, based on the incorporation of Miocene phosphatic clasts in Pliocene phosphorites.

Further regression, with strong erosion, is inferred to have occurred in late Pliocene time, as shown by the widespread regressive deposits onshore in both Mozambique (Frankel 1972) and South Africa (Siesser 1971, 1972a) and the destruction and extensive reworking of offshore phosphorite beds (Dingle 1974; Siesser 1978b).

**MAGNITUDE OF SEA-LEVEL MOVEMENTS**

*Transgressions.* — The available evidence is somewhat scanty to prove which of the Paleogene transgressions was most extensive. The Paleocene-early Eocene transgression deposited rocks now found at 204 m at Birbury. The Eocene outcrops at Needs Camp (about 360 m) and at Buntfeldschuh (163 m) are also probably early Eocene, although this cannot be conclusively proved (Siesser and Miles 1979; Siesser and Salmon 1979). The upper Eocene, on the other hand, is only known from low-lying elevations, about 70 m at Bogenfels and about 28 m in Zululand (Eocene reworked into Miocene).

Transgression beginning in the middle Miocene deposited rocks now resting at 90 m in Zululand (Frankel 1972, and our own observations). Along the southern coast of South Africa the marine Miocene-Pliocene limestones reach a height of about 300 m near Bathurst (Siesser 1972); Pliocene limestones in the same region (at Paterson) arefound at about 330 m (King 1973).

The possibility of differential uplift along the southern African coast (Siesser 1978a) makes it difficult to assess the true height sea level reached during the various Tertiary transgressions, but the present elevations quoted here give some idea of the relative magnitudes (fig. 2).

The approximate water depth during each transgression can be inferred based on the lithology, paleontology, and sedimentary structures of the rocks deposited. The Tertiary marine rocks exposed onshore, and most of those exposed on the continental shelf, are limestones, phosphorites, and calcareous sandstones deposited under shallow neritic conditions (Frankel 1968; Siesser 1971; Siesser 1972a; Du Toit and Leith 1974; Förster 1975; Siesser and Salmon 1979). Parker and Siesser (1972) and Siesser (1972b) have suggested that some of the limestones and phosphorites exposed on the continental shelf were deposited under deeper, but still neritic, conditions (probably in a middle or outer shelf environment).

Regressions. — Offshore, the main regressions are represented by unconformities on seismic records and breaks in the succession in boreholes. In table 1 and figures 2, 3 and 4 we have plotted a summary of data from each continental shelf, including
<table>
<thead>
<tr>
<th>Erosion Surface</th>
<th>Shelf width</th>
<th>East Coast</th>
<th>Agulhas Bank</th>
<th>Stable Block (Agulhas Arch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Pliocene-lower Pleistocene</td>
<td>2 20 km</td>
<td>80 m 1:444</td>
<td>150 m 1:566(E)</td>
<td>150 m 1:833(W)</td>
</tr>
<tr>
<td>Upper Miocene-lower Pliocene</td>
<td>532 m 1:488</td>
<td>150 m 1:784</td>
<td>150 m 1:74</td>
<td></td>
</tr>
<tr>
<td>Upper Cretaceous-lower Paleocene</td>
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<td>no data</td>
<td>440 m 1:78</td>
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<tr>
<td>No data</td>
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<td>375 m 1:1818</td>
<td>340 m 1:187</td>
<td></td>
</tr>
<tr>
<td>No data</td>
<td>352 m 1:74</td>
<td>1350 m 1:78</td>
<td>540 m 1:1068</td>
<td></td>
</tr>
<tr>
<td>130 km (min. value)</td>
<td>75 km</td>
<td>50 km</td>
<td>52 km</td>
<td>130 km</td>
</tr>
</tbody>
</table>
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Late Cret./early Pal.  | Olig./early Mio.  | late Mio./early Plio.  | late Plio./early Pleist.

Fig. 3. — Plot of Tertiary erosion surfaces on the continental shelves around southern Africa: erosion-surface gradient (filled circles) and maximum depth of erosion (crosses) versus age of surface. Note the anomalously high value for the Oligocene-early Miocene gradient on the flanks of the Agulhas Arch, which is a stable basement block. Data from table 1.

The maximum seaward depths to which individual erosion surfaces can be identified, and the seaward gradients of the surfaces. Although the paucity of data does not allow a very comprehensive statement, a few points do emerge clearly. As might be expected, there is an approximately inverse relationship between erosion-surface gradients and maximum depth of erosion when plotted against age (fig. 3). In general, the deepest levels of erosion and steepest gradients are oldest, and the shallowest levels of erosion and lowest gradients are youngest. The depth of the oldest Tertiary erosion surface (Maastrichtian-lower Paleocene) varies considerably from 1350 m off the east coast and more than 610 m on the west coast, to only 540 m on the flanks of a buoyant basement block (the Agulhas Arch). Elsewhere the erosion surface is too deeply buried to be picked up clearly on seismic records in shallow-water areas.

The mid-Tertiary (Oligocene-lower Miocene) erosion surface is the most widespread and easily recognized. Its maximum depth occurs at a remarkably constant level (532 m to 425 m) in the sediment basins: on the side of the positive Agulhas Arch it is only slightly shallower (375 m).

Regional information on the upper Miocene-lower Pliocene erosion surface is not complete. No evidence has been found for it off the east coast, nor on the flanks of the Agulhas Arch, but off the south and west coasts its outer edge lies at 350 and 285 m, respectively. The last major period of erosion to affect the southern African continental margin cannot be dated accurately, but we consider it to be late Pliocene-early Pleistocene in age, with the resultant erosion surface obviously being further modified by later Pleistocene low sea-level stands. The late Pliocene-early Pleistocene erosion affected the continental shelves...
around the whole coastline and trimmed the older rocks down to levels of between 80 m (east coast) and 210 m (west coast).

Table 1 shows that those shelves with the deepest levels of erosion are the widest and have the lowest gradients (west coast), whereas the narrowest shelf (east coast) has the steepest gradient and shallowest erosion level. This relationship seems to hold only for those areas overlain by thick sediment (i.e., not a basement high such as the Agulhas Arch). Further investigation shows an approximately linear relationship between shelf width and maximum erosion level (fig. 4). This suggests that since the late Pliocene-Pleistocene erosion surface was cut, the shelves around southern Africa have all subsided through the same angle about a hinge that runs around southern Africa at a common distance (somewhere between 80 and 120 km) inland from the present coastline. This may approximate the Great Escarpment axis recognized by King (1967).

The observation that present day elevations of the outer edges of the mid-Tertiary erosion surfaces lie at roughly the same level (532-425 m) after the subsidence that has followed the cutting of the Pliocene-Pleistocene surface produces the following corollary: the Miocene-Pliocene subsidence (deformation) of the mid-Tertiary surface was greatest on the narrowest continental shelves. (The rule does not, however, seem to apply to a buoyant area such as the flanks of the Agulhas Arch.) Although we do not have sufficient data for a comparison (only one reliable value in a sedimentary basin), a similar situation may have existed between early and mid-Tertiary times. Whether the basic difference between Eocene-to-Pliocene and post-Pliocene/Pleistocene subsidence was a change in location of hinge axis or merely a difference of angular rotation from place to place during the earlier period is not clear and will require further investigation.

**CAUSES OF SEA-LEVEL MOVEMENTS**

We stressed earlier that our sea-level curve (fig. 2) is a generalized curve, showing the gross movements of sea level around southern Africa during the Tertiary. But are these gross movements in themselves only regional events or are they part of global eustatic changes occurring during the Tertiary?
It is worth emphasizing that the timing of such global events would not be expected to coincide exactly. The same local subsidence and uplift that might cause a slight variance in timing around the coast of one area (southern Africa for example), would be multiplied when other continental masses are considered. Nevertheless, the pattern of "gross" movements should remain.

Vail et al. (1977) provided the most comprehensive and up-to-date synthesis of global Tertiary sea-level changes, with a curve (fig. 5) based on the modal averages from many areas around the world. Most of their data come from oil wells and seismic sections in the Northern Hemisphere; the only Southern Hemisphere localities are around Australia and New Zealand. Vail and his colleagues also pointed out the expected distortion from continent to continent caused by regional subsidence, sedimentary loading, deformation, etc., as well as the differences in timing artificially created by local differences in techniques of age dating.

With these constraints in mind, it is intriguing to note the similarities between our southern African sea-level cycles and the modal global cycles described by Vail et al. (1977, p. 93). They proposed sea-level highstands in the late Paleocene-early Eocene, the late middle Eocene to early Oligocene (with fluctuations), the middle Miocene and the early to "middle" Pliocene. Lowstands are mid Paleocene, early middle Eocene, mid late Oligocene to early Miocene (with fluctuations), late Miocene and late Pliocene-early Pleistocene.

Their curves (Vail et al. 1977, fig. 3) show gradually rising sea levels followed by abrupt falls. This has probably also been the nature of southern African sea-level changes. However, we have no direct evidence to prove this and have accordingly shown smooth, rather than asymmetric, curves depicting the rises and falls in our area.

Major global transgressions in Eocene and late Miocene times have also been documented by other workers, as has a global
Oligocene regression (Rona 1973; Flemming and Roberts 1973).

In the Southern Hemisphere it is interesting to compare our sea-level curve with that proposed by Quilty (1977) for Western Australia (fig. 5). He found that the first Tertiary transgression began in early Paleocene time (middle Danian) and continued into early Eocene. Seas reached their maximum extent in the late Paleocene. Sedimentation ceased in late early and early middle Eocene. Late Eocene was a time of major transgression in Western Australia and was followed by major regression during the early Oligocene. Seas transgressed again from late Oligocene to early Miocene time. Then, after a brief regression in the late early Miocene, seas transgressed again in the middle Miocene. This was the second great Tertiary transgression in Australia. A hiatus spanning late middle and early late Miocene time was followed by further transgression in latest Miocene, which more or less continued into the Quaternary (the Pliocene is apparently not as well documented as earlier epochs in Western Australia). In southeastern Australia, however, Carter (1979) has clearly demonstrated the late Miocene transgression was followed by a regression extending from latest Miocene to earliest Pliocene. Renewed transgression began in the early Pliocene, followed by another regression in the late Pliocene.

The similarities between southern Africa and Australia with respect to Tertiary sea-level movements are striking. In both regions the first major Tertiary transgression began in middle Danian time and continued into the early Eocene. Little middle Eocene sedimentation occurred in either region, but both experienced a major transgression during the late Eocene. Again, both regions experienced a major regression during the Oligocene. Here the only significant difference between the two areas arises: we believe this regression continued into the early Miocene around southern Africa whereas Quilty reported renewed transgression in the late Oligocene. Both regions experienced a second major transgression in middle Miocene time. The Western Australian sequence is broken by nondeposition in late middle and late Miocene, whereas in southeastern Australia the regressive pulse spans the Miocene-Pliocene boundary—exactly as we have suggested for southern Africa. Moreover, an early Pliocene transgression is followed by the late Pliocene regression in both regions.

If Tertiary sea levels changed in a grossly uniform manner, the cause almost certainly was related to some form of tectono-eustacy, glacio-eustacy, or both (see Donovan and Jones 1979 for a discussion of these and some possible second-order causes of eustacy).

Tectono-eustacy. — Tectono-eustacy refers to the change in ocean capacity owing to diastrophism. This broad concept was originally suggested by Suess (1906), and has since taken various forms. Tectono-eustatism related to sea-floor spreading is a mechanism which has probably received the most attention in recent years. In essence, the volume of the ocean basins changes because of elevation or subsidence and/or accelerating or decelerating spreading rates of the Mid-Oceanic Ridge system. The basic idea is that uplift of the Ridge system (a volume increase of the Ridge) causes a volume decrease in ocean-basin capacity. The displaced water spills onto the continents and causes a transgression. Subsidence (volume decrease) of the Ridge has the opposite effect. A refinement of this basic hypothesis links it to sea-floor spreading.

Hallam (1963) was one of the first workers to suggest that rapid spreading of the Mid-Oceanic Ridge caused a global transgression. Hays and Pitman (1973) corroborated Hallam's ideas. Hays and Pitman (1973) assumed that the volume of a ridge at any time is a function of the spreading rate, since cooling and subsidence of the ridge as it moves away from the axis is time dependent. They calculated the volume of the Ridge at various times during the Mesozoic and Cenozoic and compared known spreading rates for various ridge segments at those times.

Flemming and Roberts (1973) also suggested that eustatic changes are connected with global spreading-rate changes. They
estimated the spreading rate during Tertiary epochs and plotted this beside a generalized global eustatic curve.

We have attempted to investigate the relationship between southern African sea-level movements and regional ridge-spreading rates. Average Tertiary spreading rates have been calculated for the southeast Atlantic (on a traverse north of Gough Island) using the data given by Emery et al. (1975), and are shown in figure 6, together with local sea-level movements. Because of recent controversy over recognition of Cretaceous magnetic anomalies (e.g., Larsen and Ladd 1973, Emery et al. 1975, Rabinowitz 1976, Du Plessis pers. commun.) in the southeast Atlantic, and in particular the older limit of the quiet zone and the position of M.O., it is not possible to calculate a Late Cretaceous spreading rate.

Spreading rates progressively increased during the Tertiary, from 13.5 km/m.y. in the Paleocene-early Eocene to 25.9 km/m.y. during the late Miocene-Quaternary interval. No correlation between spreading rates and sea-level movements is apparent. Regional fast spreading related to regional transgression, or vice versa, is certainly not indicated. For example, the main Paleogene transgression occurred during the time of slowest spreading, whereas the major Tertiary regression occurred during a time of fast spreading (fig. 6).

Glacio-eustacy. — Glacio-eustacy is undoubtedly the cause of Pleistocene sea-level fluctuations, but its role in Tertiary eustacy is debatable. Much new information on the timing of Antarctic glaciation has been obtained by the Deep Sea Drilling Project during the last few years. It is now known that the Antarctic ice sheet began to enlarge during the middle Miocene (about 13 m.y. B.P.). This build-up was rapid and was essentially complete by the early late Miocene (10-12 m.y. B.P.) (Kennett et al. 1975). The first ice-rafted debris was derived from this glacial accumulation. This ice sheet may have been smaller than today, but expanded between about 4.7 and 4.3 m.y. B.P. to become substantially greater (about 50%) than today (Shackleton and Kennett 1975). Shackleton and Kennett (1975) estimate a glacio-eustatic sea-level lowering of about 40 m as a result. A lesser glacial advance may have occurred about 3.5 m.y. B.P. Glaciation in the Northern Hemisphere was a later event, starting about 2.6 m.y. B.P.; more extensive glaciation in the Northern Hemisphere occurred in the early Pleistocene (Shackleton and Kennett 1975).
The glacio-eustatic lowering between 4.7 and 4.3 m.y. may correspond to the regressive pulse we postulate as occurring near the Miocene-Pliocene boundary; the growth of Northern Hemisphere glaciers from 2.6 m.y. onward probably contributed to the late Pliocene regression around southern Africa and other parts of the world.

Epéirogenesis. — Epérogenic uplift of southern Africa occurred in early Late Cretaceous times (King 1967; Truswell 1970), regenerating erosion and initiating King's (1967) "African" erosion surface – this major erosion cycle continued at least until the end of the Oligocene. At the end of that epoch, or in the early Miocene, gentle uplift of a few hundred metres occurred (King 1967, 1972; Truswell 1970). Stronger upwarping occurred again at the end of the Miocene, uplifting parts of Natal by 600 m (King 1972). This phase of epérogeny initiated the "Post-African" erosion surface which covers more area than any other in Africa (King 1967). The final, and major, Cenozoic uplift of southern Africa began at the end of the Pliocene and continued into the Quaternary. The interior of southern Africa is believed to have been uplifted by about 1200 m during this phase (Truswell 1970).

Such major epérogenesis must have had an effect on sea level. The late Neogene uplifts of the continent are easiest to relate to our sea-level curve. Uplifts at the end of the Miocene and Pliocene appear to coincide, respectively, with: 1) the regressive pulse we have proposed close to the Miocene-Pliocene boundary, and 2) the more widespread regression beginning in late Pliocene times.

Late Oligocene or early Miocene uplift also coincides, at least in the later part, with the major Oligocene-early Miocene regression we have suggested, but the Eocene and Paleocene regressions cannot be correlated with any "uplift" during the long duration of the African erosion cycle.

CONCLUSIONS

Tertiary seas first began to transgress the southern African coastline during late early Paleocene. Transgression continued into the early Eocene, followed by regression during the middle Eocene and transgression again during the late Eocene. A major regression spans all of Oligocene and early Miocene times. This was followed by renewed transgression during the middle Miocene, which continued into the early Pliocene (although broken by a regressive pulse near the Miocene-Pliocene boundary). The end of the Tertiary was marked by a late Pliocene regression.

Vail et al. (1977) have defined a "cycle" of relative change of sea level as the time interval during which a relative rise and fall of sea level takes place. They recognize first-second- and third-order eustatic cycles. Their second-order Tertiary cycles are as follows: 1) Ta supercycle: a late Paleocene to early Eocene rise and a middle Eocene fall; 2) Tb supercycle: a middle Eocene to late Oligocene rise and a late Oligocene fall; 3) Tc supercycle: late Oligocene to late Miocene rise and a late Miocene (Messinian) fall; and 4) Td supercycle: a latest Miocene to early Pliocene rise and a late Pliocene fall (about 3 m.y. B.P.).

Using a similar method of designating "cycles," we can divide our southern African regional sea-level changes as follows: 1) Ta: a late Paleocene-early Eocene rise and a middle Eocene fall; 2) Tb: a late Eocene rise and an Oligocene to early Miocene fall; 3) Tc: a middle Miocene-late Miocene rise and a latest Miocene or earliest Pliocene fall; and 4) Td: an early Pliocene rise and a late Pliocene fall. Our regional cycles correspond to the global cycles to a surprising degree.

There is a paucity of information about Tertiary sea-level changes in the Southern Hemisphere compared with the Northern (e.g., see Vail et al. 1977, p. 88); thus we hope this paper will add yet another piece to the puzzle by describing the history of Tertiary sea-level movements in a previously little-documented part of the world — southern Africa.

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