

GEOLOGICAL SURVEY OF NAMIBIA
MINISTRY OF MINES AND ENERGY

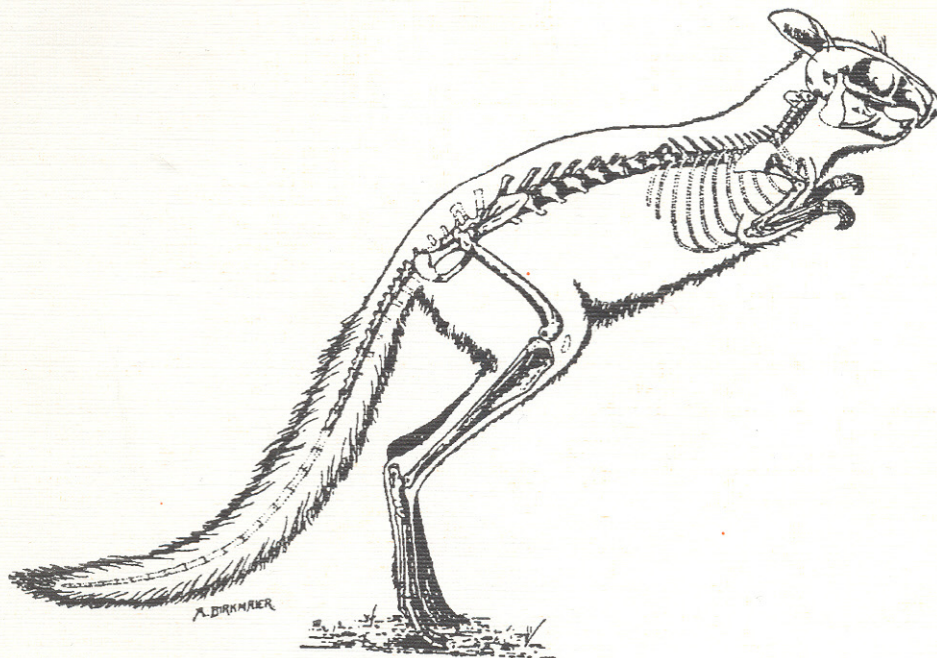


GEOLOGY AND PALAEOBIOLOGY OF THE NAMIB DESERT
SOUTHWESTERN AFRICA

GEOLOGIE ET PALAEOBIOLOGIE DU DESERT DU NAMIB
AFRIQUE DU SUD - OUEST

by

Martin Pickford and Brigitte Senut



Parapedetes namaquensis

MEMOIR 18
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**MINISTRY OF MINES AND ENERGY
GEOLOGICAL SURVEY OF NAMIBIA**

Director : Dr G I C Schneider

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**GEOLOGY AND PALAEOBIOLOGY OF THE CENTRAL AND
SOUTHERN NAMIB DESERT, SOUTHWESTERN AFRICA**

**VOLUME 1 :
GEOLOGY AND HISTORY OF STUDY**

by

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NB : All GPS readings of latitude and longitude were taken on WGS 84 datum.

PRÉFACE

Yves Coppens

Après leurs travaux remarquables et remarqués, en Ouganda, clos, au moins pour une première phase, par deux généreux volumes, Martin Pickford et Brigitte Senut ferment, de la même élégante manière, leurs recherches dans le désert du Namib (Namibie et Afrique du Sud) par un rapport de synthèse d'une rare densité, rapport d'au moins deux volumes dont celui-ci est le premier.

Particulièrement complète, ce qui n'étonnera personne, par son approche géologique et géomorphologique, tectonique et eustatique, paléoclimatique et paléoécologique, paléontologique et taphonomique, biostratigraphique et paléogéographique, etc., leur étude commence véritablement par le commencement, l'ouverture de l'Atlantique sud, il y a 135 millions d'années, pour ne s'achever qu'avec les conditions actuelles. Cet impressionnant bilan leur a demandé sept années de prospection active, de révision sur le terrain de l'ensemble des conclusions ou des propositions de conclusions de la littérature existant sur ces divers sujets, de collecte d'échantillons de roches et de sédiments, de faunes continentale et marine, de macroflore et de pollens et l'analyse de ces documents en laboratoire. Il en ressort une remise en ordre nécessaire de la succession des événements affectant localement la terre, la mer et l'atmosphère et sa mise en correspondance avec l'histoire générale du globe grâce, en grande partie, aux données chronologiques précieuses fournies par la paléontologie - dont celles originales de l'évolution des coquilles d'oeuf de grands oiseaux du groupe des Autruches découvertes dans au moins 7 niveaux différents.

Endémique pour un certain nombre d'espèces animales et végétales, ce grand sud-ouest de l'Afrique, aride depuis au moins les quinze derniers millions d'années, ne s'en intègre pas moins désormais, grâce à Martin Pickford et à Brigitte Senut, par un grand nombre d'autres espèces dans l'ensemble du continent auquel il appartient.

Comme il se trouve que ces régions ont été également très remarquées par les miniers car particulièrement riches en diamants, il se trouve aussi que les auteurs, dans leur étude fondamentale, ont su apporter, à ces exploitations, tant dans l'explication de la minéralisation de ces pierres que dans celles de leur remaniement par des agents fluviaux, éoliens ou marins, de très utiles informations. Bien que la paléontologie n'ait nullement besoin de justifier de son utilité, il est amusant parfois de montrer, comme dans ce cas précis, l'application à court terme de cette science dont d'aucuns se demandent, sans voir plus loin que le bout de leur nez, à quoi elle sert dans la vie quotidienne.

Que cette préface soit donc un chaleureux hommage au courage, au travail et à la compétence de l'équipe Pickford-Senut, désormais fameuse dans le monde entier. Et qu'elle soit aussi un hommage personnel à leur fidélité.

PREFACE

Yves Coppens

After their remarkable works in Uganda which were concluded by two generous volumes, Martin Pickford and Brigitte Senut close their researches in the Namib Desert (Namibia and South Africa) in the same elegant manner with a synthesis of rare density, a report in at least two volumes of which this is the first.

Particularly complete, which will astonish no-one, by its geological, geomorphological, tectonic and eustatic approach, together with palaeoclimatology, palaeoecology, palaeontology, taphonomy, biostratigraphy and palaeobiogeography etc., their study truly starts with the opening of the South Atlantic 135 million years ago and ends with the present day. This impressive account took them seven years of active prospecting and field revision of all the conclusions or propositions that exist in the literature on these diverse subjects, from the collection of rocks and sediments, marine and continental faunas, macro flora and pollen, followed by laboratory analysis of these documents. There emerges a reordering of the succession of events which locally affected the earth, the sea and the atmosphere and their correspondence with the overall history of the globe, in great measure thanks to the precious chronological data furnished by palaeontology - including original information afforded by the eggs of giant struthious birds that occur in at least seven different levels.

Marked by endemism in a number of animal and vegetal species, the southwest corner of Africa - arid since at least the past 15 million years - does not remain divorced from the rest of the continent, thanks to Martin Pickford and Brigitte Senut who have collected a large number of widespread species.

These areas have been equally noted by miners for their fabulous diamond wealth, and in this fundamentally important work the authors have been able to supply precious information concerning the *g n sis* of the ore deposits and their reworking by fluvial, aeolian and marine agencies. Even though palaeontology does not in the least need to justify itself, it is sometimes amusing to show, as in this particular case, the application in the short term of this science which some people who can see no further than the ends of their noses, ask to what end it serves in daily life.

This preface is a warm acknowledgement of the courage, the work and the competence of the world famous Pickford-Senut team. It is equally a personal homage to their fidelity.

ABRIDGED FRENCH VERSION

MOTIVATION POUR L'ÉTUDE DU DÉSERT DE NAMIB

1. INTRODUCTION À LA PALÉONTOLOGIE DU NAMIB

Bien que les sédiments cénozoïques de la Namibie et du Namaqualand (Afrique du sud) aient livré des fossiles depuis la première décennie de ce siècle, très peu de projets de terrain à long terme ont été lancés par des paléontologues ou des géologues dans ces régions. Les découvertes de fossiles réalisées en Namibie ont été faites un peu au hasard et ces derniers furent exportés pour étude par des paléontologues qui n'avaient jamais vu les localités d'où provenaient le matériel. Ainsi, pour de nombreux échantillons récoltés avant 1978, peu de données sur leur contexte de récolte étaient connues, et souvent, ces dernières se sont avérées inexactes, ou bien les faunes de différents sites étaient mélangées. Pour toutes ces raisons, il était inévitable que des incertitudes ou des erreurs aient été faites dans la littérature et qu'elles aient persisté car il n'y a pas eu de contrôle des données de base. Par contre, dans le Namaqualand, les études de quelques couches littorales ont été bien coordonnées et les faunes étudiées dans un contexte clair; toutefois, on trouve dans la littérature plusieurs traitements un peu rapides des fossiles et de leur contexte, ce qui complique l'étude des strates et de leur contenu faunique.

2. GÉOLOGIE ÉCONOMIQUE

Dans la Sperrgebiet (région interdite) riche en diamants (Namibie) et sur la côte du Namaqualand (République sud-africaine), les recherches paléontologiques ont été un peu gênées par les problèmes de sécurité, car pendant plusieurs dizaines d'années, très peu de gens ont été autorisés à prospecter cette région. L'accès était limité au personnel des mines et à quelques géologues dont le travail était d'assurer la vie des champs diamantifères, en partie grâce à une cartographie des dépôts sédimentaires. Des cartes extrêmement détaillées des sédiments superficiels de la Sperrgebiet et du Namaqualand ont été établies, mais n'ont jamais été publiées. Il en résulte donc, à quelques exceptions près, que les âges relatif ou absolu des différents affleurements sédimentaires étaient souvent basés sur des données imprécises.

Un premier stade fut atteint à la fin des années 70 et au début des années 80 quand il devint clair que les décisions concernant l'exploitation des dépôts superficiels de la ceinture côtière étaient biaisées par un manque de données sur l'âge de ces derniers. En effet, jusqu'à 1978, il n'y avait que 4 ou 5 localités dans la Sperrgebiet et encore moins dans le Namaqualand pour lesquelles un âge pouvait être déduit soit des associations fauniques, soit des

mesures radioisotopiques. Pour les autres, les âges étaient estimés sur des arguments géomorphologiques ou sur des associations détritiques. Dans quelques cas, on pouvait observer une superposition de couches; quelquefois des corrélations étaient supposées sur des cycles glaciaires/interglaciaires de haute latitude ou bien encore sur les variations du niveau de la mer, eux-mêmes sujets à débat. Bien que ces approches puissent être utiles, elles sont souvent biaisées par des arguments circulaires. Cependant, les déterminations de l'âge basées exclusivement sur des données géomorphologiques présentaient des marges d'erreur assez grandes.

Au fur et à mesure que les réserves minérales superficielles s'épuisaient, il devenait impératif pour la compagnie diamantifère (à l'époque la CDM (Pty) Ltd, aujourd'hui la NAMDEB) de trouver des sédiments de sub-surface et de connaître les limites exactes d'autres dépôts mal connus pour étendre la vie des mines. Il était également essentiel de reconnaître ceux à ne pas prospecter ou à ne pas miner. Un premier pas était fait pour obtenir des informations plus précises sur la genèse des minéraux et en particulier sur les processus et la chronologie de formation de ces derniers. Les géologues de la CDM ont donc commencé à concentrer des efforts sur la localisation de fossiles qui pouvaient potentiellement fournir un âge.

3. LES CONSIDÉRATIONS GÉOGRAPHIQUES

Les membres de la Namibia Palaeontology Expedition avaient d'autres raisons de travailler dans la Sperrgebiet et le Namaqualand. Bien que l'intérêt de travailler dans les champs de diamants mondialement célèbres n'ait pas été négligeable, la raison principale de lancer cette recherche était de compléter nos connaissances sur la paléontologie africaine. En effet, on connaît en Afrique 4 grandes régions où des faunes continentales miocènes sont présentes (fig 1-1) : 1) le Maghreb et l'Afrique du nord littorale, 2) le Tchad, 3) le grand rift est-africain, et 4) les plaines côtières de l'Afrique du sud-ouest. De ces 4 régions, la Sperrgebiet et le Namaqualand étaient de loin les moins connus.

Le point intéressant concernant ces régions est qu'elles couvrent le continent à ses deux extrémités latitudinales et en son milieu -l'équateur. Pour ceux qui s'intéressent aux événements paléoclimatiques et paléogéographiques en Afrique, il est avantageux d'obtenir des informations de différentes latitudes, car la diversité des organismes et la répartition des ceintures éco-climatiques varient en fonction, justement, des latitudes.

4. POTENTIEL PALÉONTOLOGIQUE DU DÉSERT DE NAMIB

Le fait que les géologues et les mineurs aient extrait des fossiles de vertébrés et d'invertébrés de la Sperrgebiet et du Namaqualand pendant une période supérieure à 70 ans, indique que les sédiments des plaines côtières pourraient bien constituer un bon matériel pour des études paléontologiques détaillées à long terme. Plusieurs milliers de fossiles appartenant à près de 200 taxons ont été signalés dans la plaine côtière du Namib. Leur âge s'échelonne du Crétacé à l'Actuel et ils représentent des biomes à la fois marins et terrestres.

5. QUESTIONS TAXONOMIQUES

Au début du siècle, les fossiles récoltés dans des niveaux fluvio-palustres de la Sperrgebiet et du Namaqualand, et envoyés pour étude dans les laboratoires européens et nord-américains ont focalisé l'intérêt sur ces régions. Dans les années 30, plus de 25 articles scientifiques leur avait été consacrés. Malheureusement, de nombreux spécimens récoltés avant la première guerre mondiale et décrits en 1926 ont été perdus ou détériorés en Allemagne au cours de la deuxième guerre mondiale. C'est pour cette raison que dans leurs synthèses sur les faunes de l'Afrique du nord et de l'est les chercheurs ont été gênés dans leurs interprétations. Le principal problème résidait dans les études taxonomiques ou systématiques, pour lesquelles il était essentiel, mais difficile, de comparer les fossiles nouvellement trouvés avec les taxons publiés antérieurement. Certains auteurs, pensant que les données namibiennes étaient mal établies, ont accordé une importance particulière aux fossiles est-africains et ont minimisé ou ignoré le matériel namibien. De nombreuses espèces est-africaines ont été mises en synonymie avec des espèces ou des genres érigés sur des fossiles namibiens, sur la base exclusive des figures et des mesures publiées. Ainsi, dans quelques cas, comme celui des rongeurs ou des macroscelididés, les fossiles est-africains sont devenus les bases des comparaisons, plutôt que les fossiles originaux namibiens. Certaines conclusions s'avèrent aujourd'hui sans fondement. Plusieurs holotypes d'espèces érigées sur du matériel namibien sont fragmentaires et les hypodigmes limités. Pour résoudre certains problèmes de taxonomie, il était essentiel de trouver du matériel plus complet des localités-types et des échantillons assez grands pour pouvoir apprécier la variation.

La découverte de la riche faune de vertébrés d'Arrisdrift en 1976 a ressuscité l'intérêt de la paléontologie namibienne, avec plus de 35 articles publiés sur ce site. Toutefois, de nombreux groupes n'ont pas été analysés dans le détail, malgré la présence de plusieurs nouveaux genres et espèces dans l'échantillon.

Le grand intérêt du nouveau travail de terrain en Namibie est que toutes les espèces érigées par Stromer (1923, 1926) ont été ré-échantillonnées, permettant ainsi

des comparaisons détaillées des espèces est-africaines et de meilleures bases taxonomiques. De nombreux taxons, jusqu'à alors mal connus sont aujourd'hui représentés par des centaines de spécimens, ce qui signifie que la variabilité de certaines espèces peut être clairement démontrée.

6. BIOGÉOGRAPHIE ET PALÉOÉCOLOGIE

Le désert de Namib est aujourd'hui une des régions les plus sèches du continent africain. Il renferme une faune et une flore abondante. De nombreuses espèces sont endémiques à la région alors que d'autres appartiennent à des lignées largement répandues dans d'autres parties arides du continent. Plusieurs espèces animales et végétales sont en effet communes au Namib et à l'Afrique orientale (Roberts, 1937; Moreau, 1952; Meester, 1965; Verdcourt, 1969).

De plus, au Miocène inférieur, plusieurs espèces de mammifères trouvées dans le Namib sont proches ou identiques à celles présentes au Kenya, suggérant une parenté biogéographique entre les deux zones plus étroite à l'époque qu'elle ne l'est aujourd'hui. Enfin, les mammifères du Miocène inférieur montrent que le paléoenvironnement du Namib était très différent il y a 20 millions d'années (sub-tropical avec pluies d'été) de ce qu'il est aujourd'hui (tempéré à pluies d'hiver). A l'époque, le Namib a dû probablement avoir des affinités de type savane, comme le suggère la faune (Stromer, 1926; Hopwood, 1929; Braestrup, 1935).

La faune du Miocène moyen d'Arrisdrift présente des signes d'endémisme chez les ruminants, mais de nombreuses lignées mammaliennes sont largement répandues, certaines existant même en Europe. L'abondance des crocodiles à Arrisdrift indique qu'au cours du Miocène moyen, la région était située sous des latitudes tropicales à sub-tropicales.

Il apparaissait clairement, à la vue des données disponibles à la fin des années 80 (Hendey, 1978), qu'il était indispensable de reconstituer en plus grand détail l'histoire biogéographique et paléoécologique du Namib. Il était également intéressant de déterminer si les limites biogéographiques avaient varié au cours du Cénozoïque, comme cela a été démontré par Pickford et Morales (1994) pour l'Europe.

7. BIOSTRATIGRAPHIE

Jusque dans les années 70, il était généralement admis que les diamants de la Sperrgebiet et du Namaqualand provenaient de placers côtiers formés au cours du Quaternaire, avec de nombreuses plages surélevées porteuses ou des dépôts de terrasses corrélés à des événements dans les successions glaciaire/interglaciaire de haute latitude ou des variations de niveaux de mer. On estimait aussi que les dépôts de terrasse du fleuve Orange dataient du Pléistocène.

tocène (Fowler, 1976). Encore récemment, Pether (1994) corrélait les sédiments du Namaqualand avec ces variations quaternaires du niveau de la mer, liées par certains à la croissance et à la décroissance des calottes de glace.

Dans le nord de la Sperrgebiet, la situation était plus complexe car, dans ce secteur, les diamants avaient été trouvés en association avec des dépôts supposés Éocène ou même Crétacé. Dans le Namaqualand, des diamants ont été trouvés dans des sédiments plus vieux que le Miocène inférieur.

En 1978, des mammifères fossiles ont été récoltés lors des prospections diamantifères à Arrisdrift, localité située dans la vallée du fleuve Orange, à 35 km en amont d'Oranjemund. Avant cette découverte, on pensait que les terrasses du fleuve étaient pléistocènes sur la présence d'assemblages lithiques de surface et parce que d'un point de vue géomorphologique, les terrasses semblaient assez jeunes.

La faune d'Arrisdrift prouvait qu'il y avait des dépôts du Miocène moyen dans la vallée. Puisque les sédiments fossilifères - assignés à la terrasse de la Proto-Orange - étaient diamantifères, il devint évident que le fleuve Orange avait charié des diamants de l'intérieur vers la côte sur une période de temps considérablement plus longue qu'on ne le pensait. Cette découverte avait des implications économiques immenses.

Dans le Namaqualand, les géologues étaient gênés par le fait qu'ils avaient peu de dépôts datés avec fiabilité. Ils ont donc utilisés d'autres moyens de calibrage comme l'altitude des terrasses marines et d'autres données géomorphologiques et stratigraphiques, mais dont les résultats étaient discutables. Des essais de biostratigraphie se sont avérés extrêmement utiles pour déterminer la séquence des événements, mais le tempo correct de ces derniers est resté flou jusqu'à ce que des mammifères fossiles soient récoltés dans les différents dépôts de terrasse par la Palaeontology Expedition to South Africa.

En 1990, 7 localités fossilifères étaient connues dans le Cénozoïque de la Sperrgebiet et dans le parc du Namib-Naukluft au nord. Il y avait aussi quelques sites signalés dans des niveaux pré-miocènes de la région, dont l'âge était connu. Même cette avance modeste conduisit à repenser les modes de genèse des dépôts diamantifères. En conséquence, la CDM (Pty) Ltd (aujourd'hui la NAM-DEB) décida de s'associer les services de paléontologues qui avaient l'expérience des terrains continentaux néogènes de l'Afrique, pour essayer d'obtenir des données complémentaires.

Au sud du fleuve Orange, seuls 3 niveaux stratigraphiques avaient permis d'estimer un âge de magnitude correcte. Il y avait une tendance à sous-estimer les âges des 3 plages surélevées et de surestimer les âges des couches non marines qui leur étaient sous-jacentes. Les

géologues des Namaqualand Mines à Klein Zee ont invité les auteurs à examiner la région qu'ils exploient pour préciser l'âge des dépôts, et l'accès aux mines de la région d'Hondeklip Bay fut accordé par les Buffles Bank Mines et la Redaurum Ltd.

Les âges des successions de faunes mammaliennes du Cénozoïque d'Afrique ont été déterminés avec une certaine fiabilité (Pickford, 1981). En particulier, en Afrique orientale où de très nombreux niveaux fossilifères ont pu être calibrés grâce à des méthodes radioisotopiques. Ces derniers présentent un grand intérêt car ils servent de référence pour la période considérée, et on peut estimer la position chronologique relative des faunes d'autres régions du continent souvent avec une précision surprenante de l'ordre de 0,5 Ma. Des études détaillées des faunes de Namibie et du Namaqualand devraient conduire à une meilleure datation des dépôts d'où elles proviennent. Aussi extraordinaire que cela puisse paraître, des corrélations avec les séquences mammaliennes européennes peuvent être aussi proposées, car quelquesunes des lignées trouvées dans la Sperrgebiet et le Namaqualand appartiennent à des groupes très dispersés, comme les fissipèdes ou les créodontes.

La NPE voulait également localiser des sédiments continentaux dans lesquels il pouvait y avoir des intercalations marines dans l'espoir de compléter et affiner les séquences biostratigraphiques respectives.

8. VITESSES D'ÉVOLUTION

En ce qui concerne les vitesses d'évolution dans le désert de Namib, deux idées principales ont été évoquées. Certains auteurs pensent que l'évolution de plantes bizarres telles que *Welwitschia* ainsi que celle des coléoptères très diversifiés du Namib a dû se passer sur des laps de temps très longs. Ils supportent donc l'idée que le Namib est devenu un désert au Crétacé et qu'il est resté aride de puis cette époque. D'autres chercheurs pensent, au contraire, que les flores et les faunes du Namib ont évolué très rapidement, résultant d'une forte pression sélective. Ceux-ci suggèrent donc que le Namib a une histoire beaucoup plus courte, de quelques millions d'années seulement. Le débat a été très bien exposé et résumé par Ward et Corbett en 1990.

Un but important de la NPE était de déterminer l'âge des plus anciennes éolianites de la région pour essayer de résoudre la question d'une origine ancienne ou récente de ce désert et tenter d'apporter des éléments pour comprendre les vitesses d'évolution dans les environnements désertiques.

9. ÉVOLUTION DES FAUNES AFRICAINES MIO-PLÉISTOCÈNES

Une meilleure connaissance des assemblages fossiles namibiens conduira à une meilleure compréhension de

l'évolution des faunes africaines au cours du Cénozoïque. Quelques chercheurs ont eu tendance à focaliser leurs travaux exclusivement sur des régions limitées du continent. L'étude des origines de l'homme souffre souvent d'une telle approche aveugle, qui propose que les humains sont nés dans les rifts est-africains. Il est plus probable que les préhumains ont eu une large répartition sur le continent et que, si les recherches étaient effectuées dans d'autres régions, on récolterait d'autres données. A l'occasion, des études restreintes similaires ont été appliquées à d'autres éléments fauniques, mais en général les paléomammalogistes africanistes ont tendance à aborder le sujet dans une perspective plus holistique que les paléanthropologues.

10. TAPHONOMIE

Bien que des auteurs anciens, comme Stromer (1926), aient fait des remarques générales sur la taphonomie des fossiles du Namib, il n'y a aucune étude taphonomique détaillée de la région. Un des buts de la NPE était d'évoquer cet aspect sur les sites fossilifères pour tenter de déterminer, quand cela est possible, les agents conduisant à la formation des localités fossilifères. Par exemple, les microfaunes récoltées à Elizabethfeld ontelles été rassemblées par des chouettes ou des rapaces diurnes qui régurgitaient des pelotes sous des arbres comme le suggérait Stromer, ou bien d'autres agents comme des petits carnivores ont-ils été responsables de ces accumulations?

11. PALÉOHYDROLOGIE

Les fossiles du Miocène inférieur de la Sperrgebiet auraient été récoltés dans des dépôts dulçaquicoles de remplissages de vallées entaillées dans le socle. Ces vallées faisaient-elles partie d'un réseau de drainage pré-miocène? Si c'est le cas, elles devraient éclairer l'histoire paléohydrologique d'une région qui est aujourd'hui hyperaride.

12. LES NIVEAUX DE MER ANCIENS

Le long de la côte sud-ouest de l'Afrique, il y a de nombreux témoins de plages sur-élevées et de chenaux sous-marins d'origine fluviale, qui prouvent que le niveau de la mer a beaucoup fluctué pendant le Cénozoïque. Un des buts de la NPE et de la PESA était de prospecter les sédiments afin de déterminer les époques auxquelles les fluctuations ont eu lieu ainsi que l'amplitude des variations.

Un aspect important de ce travail fut la démonstration que les élévations dans le niveau de la mer produisaient un remblayage des drainages qui s'écoulaient vers l'Atlantique, si bien que les sédiments passagers des vallées s'y déposaient plutôt que de se lessiver vers l'océan. C'est ainsi que les dépôts fossilifères et diamantifères se sont formés là où ils n'auraient pas dû le faire. A l'inverse, des niveaux marins plus bas que l'actuel ont contribué à

une érosion de la région côtière et au lessivage de ces sédiments.

13. PALÉOCLIMATOLOGIE

Un autre apport des NPE et PESA concerne l'histoire climatologique du Namib et sa place au sein du continent africain: les rapports entre ce désert austral et les autres déserts africains doivent être pris en considération. Quelles sont donc les relations, si elles existent, entre le Namib et le Sahara; ou entre le Namib et le désert zaïrois miocène (Veach, 1935)? Le courant de Benguela contribué-t-il à maintenir les conditions hyper-arides qui existent le long de la côte sud-ouest de l'Afrique comme on le dit très souvent dans la littérature (Brain, 1984)? Ou bien peut-on mettre en évidence un décalage important dans le déroulement des événements : entre l'origine du désert de Namib et les remontées d'eau marine liées au courant de Benguela (comme l'ont suggéré Ward et Corbett en 1990)? La croissance de la calotte de glace de l'Antarctique est-elle directement liée à l'établissement des conditions désertiques dans le Namib (comme cela a été proposé par Brain en 1984)? Toutes les ceintures arides de moyenne latitude dans les continents austraux ont-elles une origine commune?

14. LES INTERACTIONS BENGUELA-NAMIB

Pour comprendre la géologie et la paléontologie du Namib, il faut connaître le détail des interactions entre le courant du Benguela et la bande côtière du Namib. On trouve deux écoles de pensée concernant les relations entre les deux; certains auteurs soulignent l'évolution isolée mais étonnement parallèles des deux systèmes; d'autres font ressortir leur lien profond. La divergence d'opinion disparaît si on considère les échelles de temps auxquelles les différents auteurs raisonnent. Ceux qui examinent le phénomène à une échelle hémisphérique et à l'échelle du temps géologique considèrent très souvent l'interaction comme permanente et intime; tandis que ceux qui ont un point de vue plus parochial, ou qui examinent le problème à l'échelle d'une vie humaine admettent une intermittence des rapports entre les deux qui doivent être des systèmes complètement séparés.

Tous les chercheurs ont, cependant, reconnu un lien fort entre l'établissement du courant de Benguela - avec ses remontées d'eaux froides - et le début de l'aridité dans le Namib, l'atmosphère fournissant l'intermédiaire par lequel s'effectuent les échanges d'énergie et de matière entre les deux systèmes.

15. CHANGEMENTS CLIMATIQUES GLOBAUX

Pendant tout le Cénozoïque, des changements climatiques se sont produits à l'échelle du globe. Certains d'entre eux furent de nature cyclique ou quasi-cyclique, mais d'autres séculaires. Ainsi, les cycles de type Milankovich semblent

avoir été prédominants à l'échelle mondiale pour un laps de temps très long, peut-être depuis le Protérozoïque. Au cours du Tertiaire, la température des eaux des océans ont montré ce que l'on pourrait appeler une variation «séculaire», comme il y avait une tendance générale au refroidissement des eaux depuis la fin de l'Éocène (Miller & Fairbanks, 1985). Toute étude des tendances climatiques dans le Namib doit prendre en compte les changements, à la fois au niveau local et global.

16. CHANGEMENTS CLIMATIQUES RÉGIONAL ET LOCAL

Les changements de configuration géographique des marges continentales dus à la tectonique des plaques et les modifications des lignes de rivage liées aux variations du niveau de mer ont, sans aucun doute, joué un rôle sur l'évolution des climats à une échelle locale et régionale. Les variations des modes de circulation des eaux peuvent aussi induire des changements climatiques régionaux, tout comme le feraient des fluctuations de température des eaux marines. Ainsi, le déversement des eaux froides de l'Antarctique dans l'Océan atlantique a inévitablement induit des variations significatives du climat du sud-ouest de l'Afrique; directement par la remontée d'eaux froides le long de la côte namibienne, ou moins directement en contraignant la position de l'anticyclone sud-atlantique.

Toute étude sur le désert de Namib et ses origines doit prendre en compte le rôle des changements climatiques à des échelles variées, de l'échelle globale à la locale en passant par la régionale.

17. LES ORIGINES DU DÉSERT DE NAMIB

Nous voulions également déterminer l'époque à laquelle le Namib avait connu une aridité ou une hyperaridité et trouver quels en étaient les facteurs responsables et si ces conditions avaient varié au cours des temps géologiques. Là encore, il faut considérer des échelles différentes : globale, régionale et locale.

18. LES ZONES CLIMATIQUES

Les zones écoclimatiques du globe (arctique, boréale, tempérée et tropicale) sont en gros parallèles aux lignes de latitude. Il y a deux grandes familles d'hypothèses concernant les variations de ces zones. Celle qui est la plus souvent citée dans la littérature est celle de l'«accordéon», dans laquelle les largeurs latitudinales des ceintures fluctuent en accord avec les cycles de Milankovich. Dans ce modèle, la position de l'équateur est supposée généralement constante. Dans le second modèle, celui des «graticules», la position des ceintures écoclimatiques varie à la surface du globe en rapport avec la variation de position des pôles de rotation du globe et donc de l'équateur (Koppen et Wegener, 1924; Pickford, 1992, 1996; Marchal, 1996). Les NPE et PESA se sont intéressés à trouver des éléments permettant de déter-

miner le modèle qui explique les changements à grande échelle, tels qu'ils sont observés au Cénozoïque.

19. TECTONIQUE

Dans la théorie de la tectonique des plaques, les marges continentales de l'Atlantique sud sont considérées classiquement comme des marges passives. Toutefois, nous savons qu'au cours du Mésozoïque et du Cénozoïque, une activité tectonique a eu lieu dans le secteur sud-ouest de l'Afrique. La plupart de cette activité est due au soulèvement épirogénique du continent depuis le Mésozoïque, mais on trouve aussi localement des témoins de formations de cassures et de bombements. Ainsi, il a pu y avoir des soulèvements localisés de la croûte quand les volcans du Klinghardt furent actifs à l'Oligocène. Une question saute alors à l'esprit : l'altitude actuelle des plages surélevées du Namib est-elle exclusivement due à l'eustatisme ou bien les mouvements épirogéniques ont-ils contribué à cette élévation par rapport au niveau de la mer? Il faut ré-examiner sérieusement les rapports selon lesquels les terrasses marines ont été déformées depuis leur formation, car si cette hypothèse est correcte, il faut alors réviser tout le cadre tectonique régional du sud-ouest de l'Afrique. Il est clair que l'Afrique australe s'est soulevée à la suite du morcellement du Gondwana et il serait intéressant de préciser l'âge auquel ce soulèvement s'est produit, si ce soulèvement fut de nature sporadique ou continue, uniforme ou non (des parties du continent se seraient-elles soulevées plus vite que d'autres?). Il a été dit que la plate-forme continentale a subi des affaissements thermiques entre le Crétacé terminal et l'Actuel. S'il en est ainsi, quelles ont été les relations entre la plate-forme subsidente et le continent en surrection?

20. GÉOMORPHOLOGIE

Les apports de la géomorphologie peuvent souvent donner une idée de la succession d'événements dans une région donnée, mais une précision fiable du tempo de ces derniers n'est en général pas possible. Le Namib ne fait pas exception à la règle, en raison notamment des vues largement divergentes sur les vitesses des processus géomorphologiques que la région a subi. Ainsi, pour certains chercheurs, la plaine côtière était formée à la fin du Crétacé alors que pour d'autres elle n'aurait atteint son développement actuel qu'au cours du Miocène.

L'érosion de la bande côtière du sud-ouest de l'Afrique entre l'Océan Atlantique et le Grand Escarpement était nécessaire à la formation du Namib. Comment cette érosion s'est-elle effectuée et à quelle vitesse les processus érosifs se sont-ils produits? Le Grand Escarpement s'est-il formé par érosion régressive, ou résulte-t-il d'une érosion régionale verticale? Les deux processus ont-ils été actifs? Quels ont été les effets des changements du niveau de base de l'Atlantique sur les processus géomorphologiques en cours dans la région?

Aujourd'hui, l'activité éolienne est le principal facteur de modelage du Namib. Non seulement, le vent charié d'énormes quantités de sables, de silts et de particules d'argiles, causant ainsi une érosion et un transport de sédiments importants, mais il dépose également ces matériaux sous le vent lorsque la force de ce dernier faiblit. Les éolianites qui recouvrent le socle les protègent des processus érosifs ultérieurs. Mais le point important les concernant, c'est qu'elles ne se déposent pas nécessairement dans les bassins. En fait, la grande majorité des éolianites a été replaquée sur le continent après avoir résidé un certain temps dans l'Océan Atlantique, à la suite du transport de l'intérieur du continent par le fleuve Orange et d'autres cours d'eau qui se déversaient dans l'océan.

Les NPE et PESA voulaient déterminer l'époque à laquelle l'activité éolienne a commencé à jouer dans l'évolution géomorphologique du Namib et juger l'importance relative de ce type d'érosion dans l'histoire de la bande côtière.

21. SÉDIMENTATION DANS LE NAMIB

Une grande diversité de sédiments a été signalée dans le Namib. On trouve des conglomérats et des régolithes grossiers, des phosphorites, sables, silts, argiles et évaporites. La majorité des sédiments cénozoïques est composée d'éolianites, mais des quantités importantes de dépôts fluviaux et littoraux marins sont connus. Déterminer le rôle des différentes composantes sédimentaires dans la formation des sédiments cénozoïques du Namib devrait éclairer l'histoire géologique de la région et celle de la genèse des dépôts fossilifères.

22. LES PALÉOSOLS DU NAMIB

Le type principal de paléosol cartographié dans le Namib du sud consiste en un socle et des sédiments kaolinisés. Ces derniers sont particulièrement bien développés dans le Namaqualand, mais on les connaît aussi au nord

du fleuve Orange. Les autres types de paléosols présents dans le Namib sont constitués de paléosols marneux, de croûtes calcaires, gypseuses et silicifiées, et de cuirasses de fer. Leur étude devrait apporter des éléments intéressants sur les conditions de sédimentation qui ont prévalu dans le passé dans le Namib. Ainsi, la formation des croûtes gypseuses dans la bande côtière semble être fortement liée à la présence d'un embrun enrichi en hydrogène sulfureux (H_2S), dérivé des boues côtières riches en matière organiques en voie de décomposition.

23. SÉDIMENTS MARINS

Bien que les membres de laNPE et de laPESAn'aient pas été en mesure d'échantillonner les sédiments marins au large des côtes de la Namibie et du Namaqualand, une étude des travaux publiés s'avérait d'un grand intérêt et ce, pour plusieurs raisons. La première, c'est qu'il y a probablement un lien très étroit entre ce qui s'est passé dans la mer et sur la plaine côtière et comprendre ce qui s'est passé dans l'Atlantique du sud-est pouvait être pertinent dans l'explication des phénomènes terrestres. La seconde est qu'en comparant les séquences terrestre et marine, on pouvait proposer des corrélations plus précises entre les successions biostratigraphiques marine et terrestre qui jusque-là se sont avérées impossibles.

24. RÉSUMÉ

En étudiant les aspects différents de la géologie et de la paléontologie du Namib mentionnés ci-dessus, les expéditions des NPE et PESA espéraient faire des avancées substantielles dans la compréhension de l'évolution de la paléobiosphère africaine. Bien qu'il soit possible de tirer de nombreuses informations de travaux réductionnistes, mais très détaillés déjà publiés nous considérons qu'une approche holistique est beaucoup plus satisfaisante car les fossiles sont pris comme faisant partie d'écosystèmes en évolution plutôt que comme des objets isolés de leur contexte géologique et environnemental.

A NOTE ON THE GEOLOGICAL TIME SCALE USED IN THIS MONOGRAPH

In East Africa, there was a major change in continental faunas between Rusinga (17.8 Ma) and Buluk (17.2 Ma) - about 80% of the mammal fauna changed - and as a result it has become usual to locate the Early Miocene - Middle Miocene boundary between these two sites. This corresponds to the boundary between Faunal Sets II and III of Pickford (1981), Rusinga being the type locality for Faunal Set II while Buluk is the type locality for Faunal Set IIIa. Arrisdrift in Namibia has been correlated to the Middle Miocene by all authors who have studied its faunas, it being equivalent to Faunal Set IIIa of East Africa and MN 4a of Europe, while the sites in the northern Sperrgebiet (Elisabethfeld, Langental) have been consistently assigned to the Early Miocene, being equivalent to Faunal Sets I and II in East Africa and MN 2 and MN3 of Europe.

The positions of Cenozoic epoch boundaries in recently published geological time scales vary appreciably from author to author. A problem now arises if we apply the generally accepted position of the boundary between the Early and Middle Miocene as it is expressed in papers that deal predominantly with the marine realm calibrated by magnetic reversal data - where it is located at about 16.4 Ma (Berggren *et al.*, 1995) - in that Arrisdrift would then correlate to the Early Miocene, albeit its terminal part. This would have the effect of locating in the Early Miocene, a site with a typical Middle Miocene fauna, making a mockery of the biostratigraphic information yielded by the fauna.

Palaeomagneticians working on continental sedimentary successions appear to have extreme difficulties in making correlations to the Geomagnetic Polarity Time Scale, with differences of opinions about certain correlations running to 1.5 - 2 million years. This is undoubtedly due to the fact that all palaeomagnetic correlations in continental sediments require prior information for correlations to be possible. This is because the palaeomagnetic signature contains no evidence of its age, which must therefore be estimated from other data, usually radio-isotopic or biochronologic. Since European faunal successions have very few chronological control points (Odin *et al.*, 1997), there are widely varying opinions about the ages of the MN Zones (fig. 1). For example, Krijgsman *et al.* (1994) show an uncertainty in the position of the MN 3-MN 4 boundary of about 0.8 million years (17.8 to 18.6 Ma). These same authors situate the MN 4 - MN 5 boundary at 14.1 Ma while Schlunegger *et al.* (1996) place it at 17 Ma. Given the uncertainties of correlation between the continental and marine realms, and the added error margins implicit in geomagnetic polarity time scales 'upon which the marine time scale is heavily dependent, we prefer to retain the traditional continental biostratigraphic correlations for the Namib faunas, rather than to complicate the issue by strict adherence to the marine time scale calibrated by palaeomagnetic data.

For the purposes of this monograph, we thus place the Early Miocene - Middle Miocene boundary at about 17.5 Ma (fig. 2) just over a million years older than it is located by Berggren and colleagues (1995). Readers who prefer to emphasise the latter time scale may place Arrisdrift in the Early Miocene if they so wish, but they need to keep in mind that its fauna is of Middle Miocene aspect and is appreciably more evolved than the faunas from the northern Sperrgebiet sites of Elisabethfeld, Langental, Grillental and Fiskus which have a characteristic Early Miocene aspect. A correspondence chart between the MN Zones of Europe (Mein, 1990) and the Faunal Sets of East Africa is attached for ease of reference (fig. 2), as is a correlation chart of fossiliferous localities in Southern, Eastern and Northern Africa (fig. 3).

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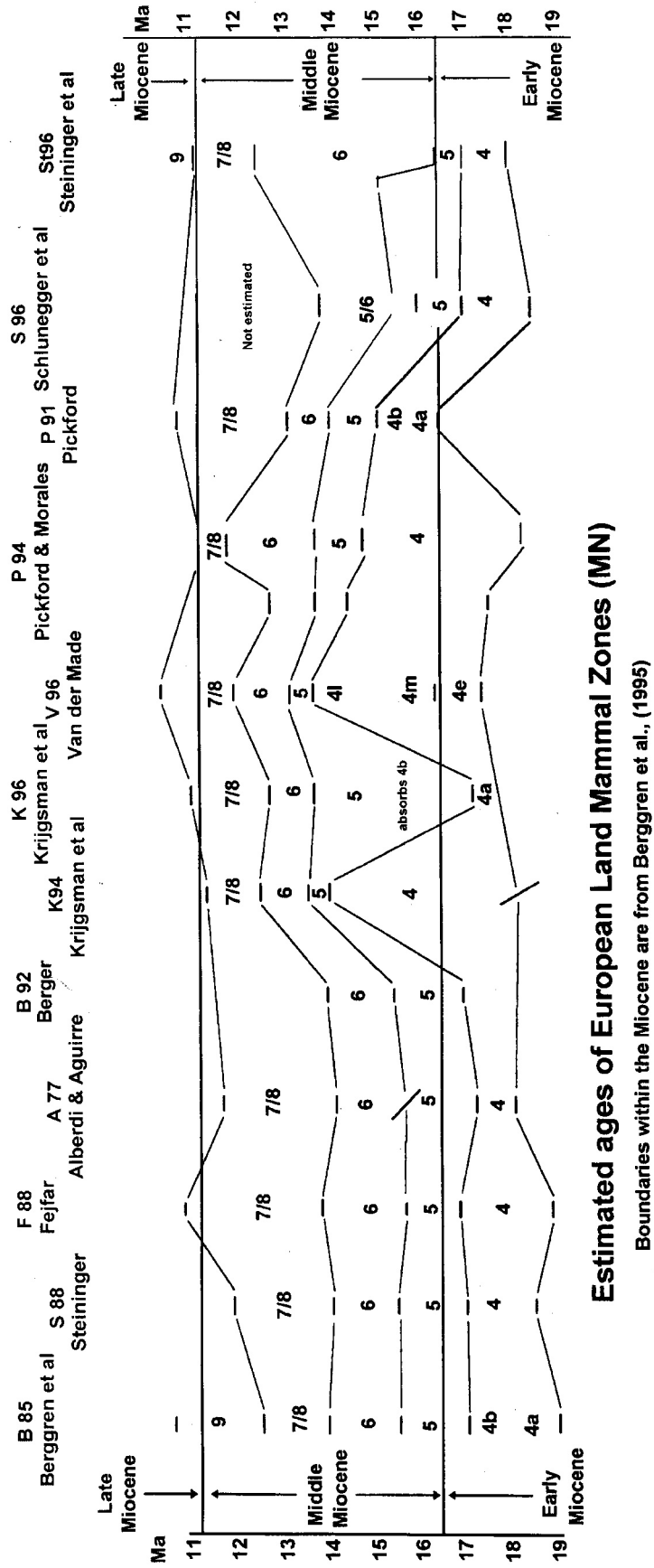


Figure 1.- Various opinions about the ages of boundaries between European Land Mammal Zones.

AGE	EPOCH	EUROPEAN MAMMAL ZONES	EAST AFRICAN FAUNAL SETS
Ma			
1	Pleistocene	Q 1 - Q 6	C 1
			C 2
2	Pliocene	MN 17	C 3
3		MN 16	C 4
4		MN 15	C 5
5		MN 14	C 6
6		MN 13	P VIII = C 7
7		MN 12	P VII = C 8
8	Late Miocene	MN 11	P VI
9			
10			
11			
12	Middle Miocene	MN 7/8	P V
13		MN 6	P IV
14		MN 5	P IIIb
15			
16		MN 4b	P IIIa
17	MN 4a		
18	Early Miocene	MN 3	P II
19		MN 2	P I
20			
21		MN 1	P 0
22			
Ma			

----- Early/Middle Miocene Boundary according to Berggren et al., 1995
 C1-C8 = Coppens (1974) faunal zones : P0-PVIII Pickford (1981) Faunal Sets

Figure 2.- Correspondence between East African Faunal Sets and European Land Mammal Zones.

AGE Ma	NORTHERN AFRICA	ARABIA	TROPICAL AFRICA	CHAD	SOUTHERN AFRICA	AGE Ma
0	Djebel Ressas 4 Djebel Ressas 7				Etaneno Berg Aukas MM7	0
1	Djebel Ressas 2, 3 Oued Kremia Djebel Ressas 5, 6, 8 Djebel Ressas 1	An Nafud	Ngaloba Olpira		Asis Ost, Namib IV Berg Aukas MM6 Aigamas Nosib	1
2	Ain Boucherit Jebel Orousse, A. Brimba		Naidabad Ndolanya Kaiso Village	O M R	Jägersquelle Berg Aukas MM5 Kaukausib, Hondeklip (30 mP)	2
3	Lac Ichkeul, Jebel Mellah Saiz, Amama 3		U.Laetoli L.Laetoli Kyeoro	G O U	Makapansgat, Ngami Sterkfontein (inferieur)	3
4	Ain Guetarra, Argoub Kemelal Hamada Damous Oued Athmenia		Kanapoi Warwire	P	Chiwondo Rooilepel (daberas) Karingarab (daberas)	4
5				Atoumanga Bochianga Kolinga, Moualla	Areb Berg Aukas MM4	5
6	Khendek el Ouaich Wadi Natrun Sahabi, Menacer	Dubai	Kazinga, Ishasha Nkondo, Lukeino, U.Oluka Sinda, Kanam	Kollé Agranga	Langebaanweg Klein Zee, Hondeklip (50 mP)	6
7	Amama 2		Mpesida Lothagam			7
8	Mascara Rabat, St Donat, Sidi Salem Gafsa, Segui		Nyamavi, Karugamania L.Oluka		Rooilepel (laini) Karingarab (laini)	8
9	Djebel Krechem, Kechabta Amama I, Oued Zra Mdilla, Douaria		Luanida Nakali, Samburu Hills Ngeringerowa		Harasib 3a Berg Aukas MM3	9
10	Beni Amir, Khenchella Jebel Semmene, Bou Hanifia Assif Assermo, Conde Smendou		Kakara Chorora, Ngorora "E" top		Rooilepel (wardi), Prospect Hill Karingarab (wardi)	10
11	Cherichera, Sbeitla Bled Douarah Supérieur, Hakima		Ngorora 'E' base		Berg Aukas MM2	11
12	Bled Douarah Inferieur, Tozeur Nementcha, Farafra Oum Douil, Sehib Beni Mellal	Al Jadidah	Ngorora 'C-D' Kisegi Ngorora 'A-B'		Hondeklip Bay (basal gravels) Rooilepel (corbetti) Berg Aukas MM1	12
13	Pataniak 6, Testour		Tambach Kapsibor, F.Teman, Serek		Rooilepel (oshanai)	13
14		Ajfar			Karingarab (oshanai)	14
15	Foum el Guelta		Kirimun Majiwa, Maboko Kaloma, Nyakach			15
16		Ad Dabtiyah As Sarrar Rotem Yerovem	Nachola Muruyur Moruorot, Moroto		Bosluis Pan	16
17	Gebel Zelten Kabylie, Kouif	Jabal Midra	Kalodirr Buluk, Kajong		Arrisdrift, Baken	17
18	Wadi Faregh Wadi Moghara Siwa	Wadi Sabya Ghaba	Rusinga, Karungu, Chianda Bukwa, Adi Ugri		Auchas (AMSE), Ryskop Auchas (AM02) Zebra Hill (aepyornithoid)	18
19			Loncherangan Napak, Koru, Songhor Chamtwarra		Langental E-Bay, Fiskus, Bohrloch Grillental, Elisabethfeld	19
20						20
21						21
22			Meswa Bridge			22

Figure 3.- Geochronology of fossiliferous localities in northern, tropical and southern Africa.

1. MOTIVATION FOR STUDY OF THE NAMIB DESERT

1.1 INTRODUCTION TO NAMIB PALAEOLOGY

Even though Cenozoic sediments in the coastal plains of Namibia and Namaqualand, South Africa, have yielded fossils since the first decade of this century there have until recently been only a few well planned, long term, palaeontological field projects carried out by palaeontologists and geologists. In the Namib, fossil discoveries tended to be made in an uncoordinated, almost random, way, with fossils usually being sent abroad for study by palaeontologists who never saw the localities from which the fossils came. Indeed, many of the fossil samples collected prior to 1978 had little or no precise field data, and were often mixed together from widely scattered sites. For these reasons, it was inevitable that uncertainties and errors would enter the literature which have persisted because of a lack of controlled follow-up studies. In Namaqualand, studies of some of the littoral strata have been well co-ordinated and the faunas comprehensively worked out, but there are several examples of somewhat cavalier treatment of fossils and their context to be found in the literature, which complicates the study of the strata and their faunal contents.

1.2 ECONOMIC GEOLOGY

In the diamond-rich Sperrgebiet (Forbidden Territory) of Namibia and coastal Namaqualand, palaeontology was hampered for several decades because of security considerations - very few people were allowed to visit the area. Access was limited to mining personnel and a few field geologists whose job was to extend the life of the diamond fields by mapping the sedimentary deposits of the region. Extremely detailed maps of the superficial sediments in the Sperrgebiet and Namaqualand were prepared but not published. As a result, with few exceptions, what was known about the relative or absolute ages of the scattered sedimentary outcrops was often insecurely based.

A stage was reached in the late 1970s and 1980s when it became clear that decisions regarding future exploitation of the superficial deposits of the coastal belt were marred by a paucity of knowledge concerning their ages. In effect, until 1978, there were only four or five localities in the Sperrgebiet for which the ages could be estimated on the basis of fossils or radioisotopic dates and there were even fewer in Namaqualand. For the rest, the main line of argument appears to have been based on geomorphological settings, on clast assemblages or on rare instances where superposition of strata could be observed, or on supposed correlations to high latitude glacial/interglacial cycles or sealevel curves which were themselves the subject of debate. Whilst these methods can be useful, they suffer from a strong element of circular argument that often crops up in such studies. In any case, age determinations based solely on geomorphological evidence tend to have wide error margins.

As the known ore reserves of the Sperrgebiet began to dwindle, it became imperative for the mining company (at that time CDM (Pty) Ltd, now NAMDEB) to delineate subsurface and other unknown or poorly known deposits in order to extend the life of the mines. It would also be useful to know which sedimentary deposits not to prospect or mine. A first step was to obtain more precise information regarding ore genesis, in particular the processes of ore emplacement and the timing of these processes. Accordingly, CDM geologists began making efforts to locate fossils from which age information could be obtained. Thus, even though enormous quantities of diamonds have been recovered without in depth knowledge of the ages of the strata, it was felt that such knowledge could extend the life of the mines.

1.3 GEOGRAPHIC CONSIDERATIONS

The members of the Namibia Palaeontology Expedition (NPE) and the Palaeontology Expedition to South Africa (PESA) had other motives in agreeing to work in the Sperrgebiet and Namaqualand. Whilst the glamour of being associated with the study of two of the world's great diamond fields was a point to be considered, the main incentive for undertaking the research was to further the aims of African Palaeontology. In effect, there are four main areas in Africa (fig. 1-1) where Miocene continental faunas occur: 1) the Maghreb and North African littoral zone, 2) Chad, 3) the Great Rift Valley of Eastern Africa, and 4) the coastal plain of southwestern Africa. Of these, by far the most poorly understood were the Sperrgebiet and Namaqualand.

The interesting point about these areas is that they straddle the continent at its two latitudinal extremities and its middle - the equator. For those interested in reconstructing palaeoclimatic and palaeobiogeographic events in Africa, it is advantageous to have information from a variety of latitudes, because many of nature's bold signatures, such as organismal diversity and the distribution of eco-climatic belts vary with latitude.

1.4 PALAEOLOGICAL POTENTIAL OF THE NAMIB DESERT

The fact that geologists and mining personnel have recovered fossil vertebrates and invertebrates from the Sperrgebiet and Namaqualand over a period in excess of 70 years, indicates that the coastal plain sediments would well repay detailed, long term, study by palaeontologists. Many thousands of fossils belonging to nearly 200 taxa have been recorded from the Namib coastal plain, ranging in age from Late Cretaceous to Recent, and representing both marine and terrestrial biomes.

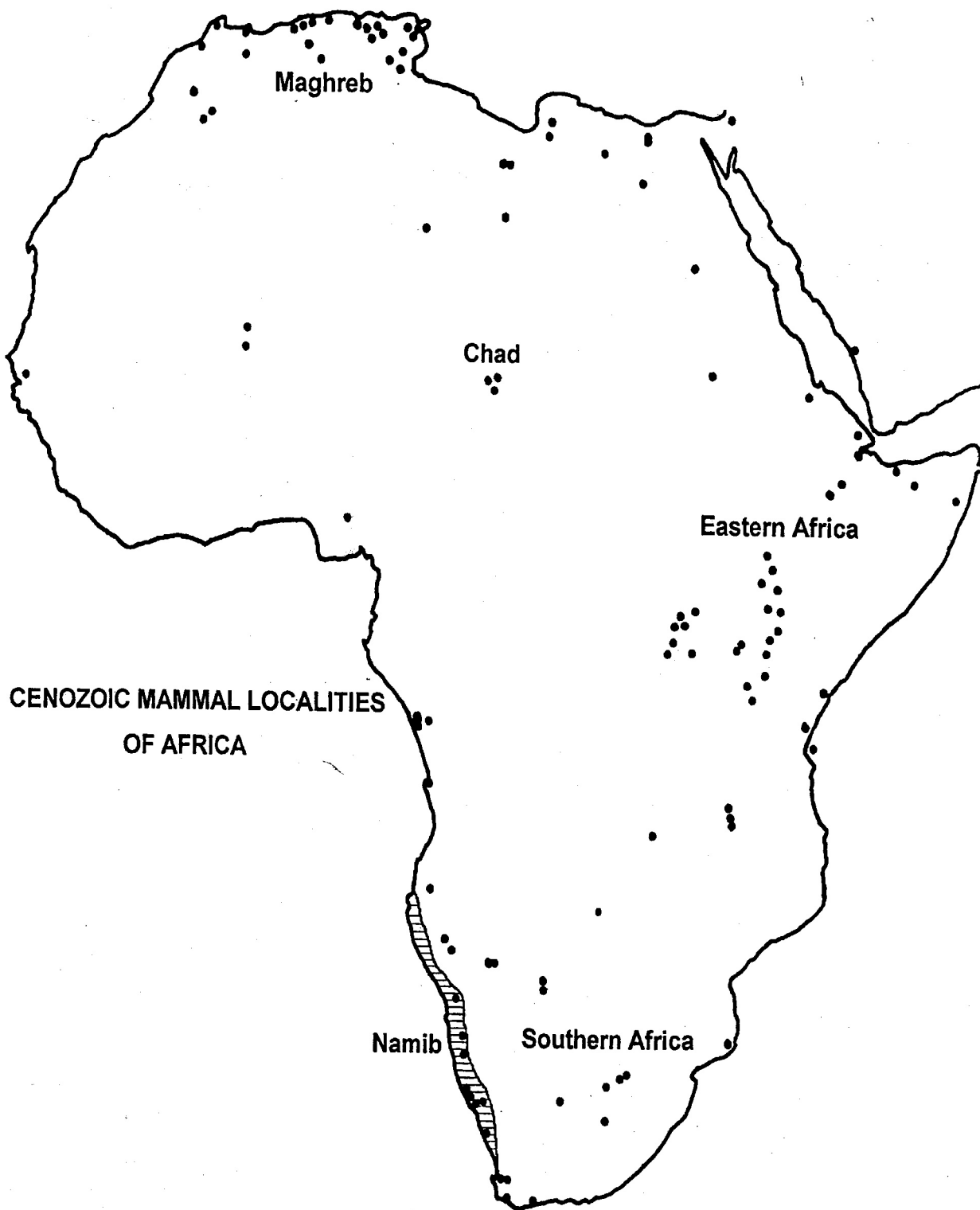


Figure 1.1 Location of fossiliferous localities in Africa.

1.5 TAXONOMIC QUESTIONS

Fossils collected from the fluvio-paludal strata in the Sperrgebiet and Namaqualand and sent for study to Europe and North America fanned interest in the region's palaeontology, and by 1930 over 25 scientific papers had been consecrated to them. Unfortunately, the bulk of fossils collected prior to the First World War, and described in 1926, was lost or destroyed in Germany during the Second World War. For this reason, scientists subsequently working up the results of palaeontological field work in eastern and northern Africa were hampered in their comparisons. The main problem area was that of taxonomy and systematics, in which comparison of newly found fossils with established taxa is essential. Some authors, in the erroneous belief that the Namibian localities were worked out (Hamilton & Van Couvering, 1977), tended to highlight East African fossils in their studies, and to ignore or diminish the importance of the Namibian material. Many of the East African species were declared to be synonyms of species or genera erected on Namibian fossils, the decisions being based almost exclusively on published figures and measurements. Subsequently, in a few cases such as rodents and macrotelodonts, the East African fossils became the yardsticks for comparison, rather than the original specimens from Namibia. Some of these revisions now appear to be unsound. Several of the holotypes of species erected on Namibian material are fragmentary and the hypodigms restricted. In order to solve some of the taxonomic problems it is essential to obtain more complete material from the type localities and to have available large enough samples so that variation can be documented and appreciated.

Discovery of the rich vertebrate fauna at Arrisdrift (Anon, 1976) led to a renewal of interest in Namibian palaeontology, with over 35 papers being published. However, many of the species were not analysed in detail despite the presence of several new species and genera in the sample.

The value of the new field work in Namibia is that all the species erected by Stromer (1922, 1923, 1924, 1926) have been resampled, thus allowing the East African species to be compared in detail with those from Namibia, thereby providing a real basis upon which taxonomic decisions can be made. Many of the taxa hitherto poorly sampled are now known from hundreds of specimens, which means that the range of variability in the species can be soundly demonstrated.

1.6 BIOGEOGRAPHY AND PALAEOECOLOGY

Today, the Namib Desert is one of the driest parts of the African continent. It contains an abundant fauna and flora, many species of which are endemic to the region. Others belong to lineages that occur widely in the arid parts of the continent, there being several animals and plants common to the Namib and East Africa (Roberts, 1937; Moreau, 1952; Meester, 1965; Verdcourt, 1969).

Being so long and narrow, the Namib comprises several distinct regions. It is usefully subdivided into northern, central and southern sectors. The northern sector, which does not concern us greatly in this monograph extends from the Carunjamba River in the north to Swakopmund in the south. It has a summer rainfall regime and only limited sand cover. The Central Namib runs from Swakopmund to Lüderitz and comprises the Sossus Sand Sea and has a predominantly summer rainfall pattern. The Southern Namib extends from Lüderitz to the Olifants River and experiences winter rainfall.

In the Early Miocene several of the mammal species found in the Southern Namib were close to, or identical with, material from Kenya, suggesting a closer biogeographical relationship between the two areas than exists today. Furthermore, these Early Miocene mammals indicate that the palaeoenvironment of the Southern Namib was quite different 20 million years ago (sub-tropical with summer rainfall) from what it is today (temperate with winter rainfall). At that time the Namib was likely to have had savanna or woodland affinities, judging from the fauna (Stromer, 1926; Hopwood, 1929; Braestrup, 1935).

The Middle Miocene fauna from Arrisdrift shows signs of endemism among the ruminants, but many of the mammalian lineages represented there are widespread, some of them even occurring in European deposits. The presence of abundant crocodiles at Arrisdrift indicates that during the early part of the Middle Miocene the early Orange valley lay within the sub-tropics, whereas today it is temperate with winter rainfall.

Clearly, it would be of interest to determine in greater detail the past biogeographic and palaeoecological history of the Namib, given the clarity of the signals available up to the end of the 1970s (Hendey, 1978). It would also be of interest to examine whether biogeographic boundaries have shifted latitudinally during the Cenozoic, as was demonstrated for the northern hemisphere by Pickford & Morales (1994).

1.7 BIOSTRATIGRAPHY

In the northern Sperrgebiet, diamonds had been found in association with deposits dated by German scientists as Eocene (Kaiser, 1926). Up to the late 70s, the prevailing notion regarding ore genesis in Namaqualand and immediately north of the Orange River mouth was that most littoral terraces along the coast had formed during the Plio-Quaternary, with various diamond-bearing raised beaches or terrace deposits being correlated to events in the high latitude glacial/interglacial succession or to sea-level curves (Hallam, 1964). Prior to the discovery of fossils at Arrisdrift, even the terrace deposits of the Orange River were thought to be Pleistocene in age (Fowler, 1976). As recently as 1996 correlations of Namaqualand marine sediments were being made to Plio-Quaternary sea-level curves thought to be related to the waxing and waning of ice caps (Pether, 1994; Corbett, 1996). It was known, however, that richly diamondiferous deposits underlay the

marine sediments of Namaqualand, and these were generally thought to be pre-Miocene in age.

In 1976, Middle Miocene fossil mammals were found during diamond prospecting activities at Arrisdrift, a site in the Orange River Valley some 35 km upstream from Oranjemund (Anon, 1976). Prior to this discovery, the Orange River terraces were thought to be of Pleistocene age, partly on account of the stone tool assemblages found on their surfaces and partly because, from a geomorphological point of view, the terraces appeared to be rather young.

In Namaqualand, geologists were hampered by having very few reliable chronological fixed points in their strata. Consequently, the altitude of marine terraces and other geomorphological and stratigraphic data were employed with equivocal results. Biostratigraphy based on molluscs was also attempted and proved eventually to be extremely useful for determining the sequence of events, but the correct timing of events remained elusive until fossil mammals were found in the various terrace deposits by the Palaeontology Expedition to South Africa.

By 1990, seven fossil localities were known in the Cenozoic sediments of the Sperrgebiet and the Namib-Naukluft Park to the north. There were also a few age-controlled points in the pre-Miocene strata of the region. Even this modest advance led to a re-thinking of the processes of ore genesis, but many questions remained to be answered.

South of the Orange River, there were only three stratigraphic levels for which the age determinations were of the correct order of magnitude. There was a tendency to underestimate the ages of the three main raised marine packages, and to overestimate the ages of the non-marine strata below them. Geologists at Namaqualand Mines, Klein Zee, TransHex at Buffels Bank and Baken, and Redaurum Ltd (Avontuur Mine at Ryskop) invited the authors to examine their mining areas with a view to determining the ages of the strata more precisely.

The successions and ages of Cenozoic mammal faunas of East Africa have been determined with reasonable accuracy (Pickford, 1981). Those in East Africa are of particular interest because many of the fossiliferous levels have been dated by radioisotopic methods. Using the East African sequence as a yardstick, the relative chronological position of faunas from other parts of the continent can be determined with a surprising degree of accuracy (± 0.5 Ma for example). Detailed study of faunas from Namibia and Namaqualand should lead to a better understanding of the ages of the deposits from which they came. Extraordinary as though it may seem, correlations to European faunal sequences can also be proposed because some of the mammal lineages found in the Sperrgebiet and Namaqualand belong to extremely widespread groups, such as fissioned and creodonts.

The NPE also wanted to examine the possibility of locating strata in which both marine and continental fossils occur, in the hope of finding ties between their respective biostratigraphic sequences.

1.8 RATES OF EVOLUTION

There have been two basic ideas concerning rates of evolution in the Namib Desert. For some people, the evolution of such bizarre plants as *Welwitschia* and of the highly diverse beetle fauna of the Namib were thought to require immense time spans (Koch, 1962). These scientists tended to support the idea that the Namib became a desert in the Cretaceous period and that it had remained arid ever since. For others however, the evolution of the Namib flora and fauna could have happened more rapidly as the result of intense selection pressure (Endrödy-Younga, 1982). Such researchers tended to think that the Namib had a much shorter history - only a few million years. The debate was well summarised by Ward & Corbett (1990).

An important aim of the NPE was to determine the age of the earliest aeolianites in the region with a view to resolving this debate and thereby to throw light on the question of rates of evolution in desert environments.

1.9 EVOLUTION OF AFRICAN MIOCENE- PLEISTOCENE FAUNAS

Improved knowledge of Namibian fossil assemblages will lead to a better understanding of the evolution of African faunas during the Cenozoic. Some researchers have tended to focus their attention exclusively on restricted sectors of the continent. The study of human origins often suffers from such a blinkered approach, with many scientists proposing that humans originated in the East African Rifts. It is much more likely that early humans and pre-human ancestors ranged far and wide over the continent, and that should searches be carried out in appropriate places, evidence for this view will be found. Similar parochial studies have on occasion been applied to other faunal elements, but in general researchers of African fossil mammals have tended to approach the subject with a more holistic perspective than have palaeoanthropologists.

1.10 TAPHONOMY

Whilst previous researchers, such as Stromer (1926) made general remarks of a taphonomic nature when dealing with Namib fossils, there has been no detailed study of taphonomy in the region. One of the aims of the NPE was to look into this aspect of the fossil sites and to determine if possible, the agents leading to the formation of fossiliferous localities. For example, were the Elisabethfeld microfossils collected by owls or diurnal birds of prey which regurgitated pellets below trees in which they perched, as suggested by Stromer? Or were other agents such as small carnivores responsible?

1.11 PALAEOHYDROLOGY

The Early Miocene mammals from the Sperrgebiet were reported to have been found in freshwater deposits filling valleys cut into the basement rocks. Were these valleys parts of ancient pre-Miocene drainage lines as thought by Beetz (1926)? If so, then they might throw a great deal of light on the palaeohydrology of a region which today is hyperarid.

1.12 ANCIENT SEA LEVELS

There are abundant occurrences along the south west African coast of raised beaches and submarine channels of fluvial origin which, taken together, provide ample evidence that sea levels have fluctuated greatly during the Cenozoic. One of the aims of the NPE and PESA was to examine the sedimentary evidence in order to determine when sea level changed and by how much.

An important aspect of this work was the demonstration that rises in sea level tended to lead to backfilling of drainages that flowed into the Atlantic, so that the transient sediment in the valleys settled therein rather than being flushed out into the ocean. By this means fossiliferous - and diamondiferous - deposits formed where they would normally not have done so. Conversely, sea levels lower than present day msl, tended to promote erosion of the coastal region and to remove or rework these transient sediments.

1.13 PALAEOCLIMATOLOGY

One of the aims of the NPE and PESA was to look into the climatological history of the Namib in order to determine its place with respect to that of the rest of the continent. The relationship of the Namib to other desert regions of Africa needs to be examined. For example, what relation, if any, exists between the Namib and the Sahara, or the Namib and the Miocene Zaire Desert? (Veatch, 1935). Does the Benguela Current contribute to the maintenance of hyperarid conditions that exist along the south west African coast as is often postulated in the literature? (Brain, 1984). Or was there an important offset in timing of the origins of the Namib desert and upwelling associated with the Benguela current as postulated by Ward & Corbett (1990). Was there a connection between the growth of the Antarctic Ice Sheet and the onset of desert conditions in the Namib as suggested by Brain (1984)? Was there a common origin for all the mid-latitude arid belts of the southern continents?

1.14 BENGUELA-NAMIB INTERACTIONS

An understanding of the geology and palaeontology of the Namib requires detailed knowledge of the interactions between the Benguela Current and the Namib coastal strip.

There are two schools of thought about the efficiency of the interactions between the two systems, some authors accenting their separate, yet 'coincidentally' parallel, nature, while others stress the 'intimate' relation between them (Shannon *et al.*, 1989a, b). The dichotomy of opinion is resolved if one examines the scale at which each author is thinking. Those who view the phenomena at a regional to hemispheric scale and at the scale of geological time, often see the interaction as a permanent and intimate one, whereas those who take a more parochial viewpoint, or who examine it on the scale of the human lifetime, stress the intermittent connection between the systems, which must, they conclude, thus be separate ones.

There can be no doubt, however, that virtually all researchers have made the rather obvious link between the establishment of the Benguela Current - with its cold upwelling water masses - and the onset of hyperaridity in the Namib, the atmosphere providing the medium by which energy and matter are transferred from one system to the other.

1.15 GLOBAL CLIMATIC CHANGES

There were global scale climatic changes throughout the Cenozoic Era. Some of these were of a cyclic or quasi-cyclic nature, but some were secular. For example, Milankovich type cycles appear to have been a feature of the world's climate for an extremely long time, perhaps since the Proterozoic. During the Tertiary, the temperature of the world's oceans show what may be termed 'secular' variation, there being an overall trend towards ocean water cooling since the end of the early Eocene (Miller & Fairbanks, 1985). Any examination of climatic trends in the Namib needs to take into account both categories of global climatic change.

1.16 REGIONAL AND LOCAL CLIMATIC CHANGE

Changing geographic configurations of continental margins due to plate tectonic activity and modifications of coastlines due to changing sea levels undoubtedly played a role in modifying climates on a local to regional scale. The modification of ocean water circulation patterns may also produce regional climatic changes, as would fluctuations in the temperature of ocean waters. For example, the pumping of cold Antarctic waters meridionally into the Atlantic Ocean has undoubtedly led to significant changes in the climate of south western Africa, partly directly such as, for example, by the upwelling of cold waters along the Namib coast, or less directly by constraining the position of the South Atlantic Anticyclone.

Any study of the Namib Desert and its origins needs to examine the role of climatic change at various scales, from global to regional and local.

1.17 ORIGINS OF THE NAMIB DESERT

The NPE aimed to determine when the Namib began to experience aridity and hyperaridity, and to find out what physical conditions were responsible for inducing such conditions and whether these have changed over geological time. Much has been written about the origins of the Namib regarding both the timing of the onset of arid conditions in the region and the processes responsible for aridification. The matter needs to be examined at various scales ranging from global to local.

1.18 CLIMATIC ZONES

The world's ecoclimatic zones (arctic, boreal, temperate, tropical) are arranged approximately parallel to lines of latitude. There are two broad families of hypotheses regarding changes in the latitudinal width of ecoclimatic belts. The most commonly encountered in the literature is the «concertina» or accordion model, in which the latitudinal widths of the belts fluctuate, usually according to the Milankovich model. In this model, the position of the equator is considered to be invariable. In the second set of hypotheses - the graticule shift model - the position of the ecoclimatic belts is considered to have shifted over the surface of the globe due to changes in the position of the poles of rotation (and hence of the equator) (Koppen & Wegener, 1924; Pickford, 1992, 1996; Marchal, 1996). The NPE and PESA were interested in finding evidence that might throw light on which model is more likely to have caused the large scale changes known to have taken place during the Cenozoic.

1.19 TECTONICS

Within the Plate Tectonic paradigm, the continental margins of the South Atlantic are classic passive margins. There is evidence however, that tectonic activity has occurred in the south west African sector during the Mesozoic and Cenozoic. Most of this has been related to epeirogenic uplift of the continent since the Mesozoic resulting in the African Swell (Partridge *et al.*, 1995a, b) but there is, in addition, evidence of localised faulting and upwarping. For example, there might well have been some localised uplift of the crust when the Klinghardt volcanoes were active during the Oligocene. A question which immediately springs to mind is whether the raised beaches of the Namib owe their present altitudes solely to eustatic variation of sea level, or whether epeirogenic uplift of the continent contributed to their uplift relative to sea-level (Partridge *et al.*, 1995a, b). Reports that Namib marine terraces have been warped since their formation (Stocken, 1978) need to be examined carefully, because if they turn out to be correct, then the regional tectonic framework of southwestern Africa needs to be re-examined. It is evident that southern Africa has been uplifted since the break-up of Gondwana and it would be interesting to determine when uplift occurred, whether it was sporadic or continuous and whether uplift was uniformly

expressed or whether some parts of the continent rose faster than others (Partridge *et al.*, 1995a, b). It has been proposed that the continental shelf underwent thermal sag during the Late Cretaceous to Recent (Light *et al.*, 1992, 1993). If so, what were the relations between the subsiding shelf and the rising continent?

1.20 GEOMORPHOLOGY

Geomorphological evidence can often yield an idea of the sequence of events that have occurred in a region, but determination of the timing of events is usually not possible with any degree of accuracy. The Namib is no exception, with widely divergent views being expressed about the rates of geomorphological processes that the zone has undergone. For example, for some researchers, the coastal plain was formed by the end of the Cretaceous (Ward & Corbett, 1990) whereas for others it reached its present extent and form only during the Miocene (Ollier, 1978).

Erosion of the coastal strip of south western Africa between the Atlantic Ocean and the Great Escarpment was a necessary prelude to the formation of the Namib. How was this erosion achieved and how fast did erosive processes operate? Was the Great Escarpment formed by backwearing, or was erosion of the coastal strip mainly by downwasting? Or were both processes active? What effect, if any, did changes in the Atlantic base level have on the geomorphological processes operating in the region?

Aeolian activity is the dominant factor currently shaping the Namib. Not only does the wind shift large quantities of sand, silt and clay particles, thereby causing significant amounts of erosion and sediment transportation, but also it deposits these materials downwind as the strength of the wind peters out. The accumulation of aeolianite which blankets the basement rocks protects them from further attack by surface processes. The point about aeolianites is that they do not necessarily accumulate in basins. Indeed, the bulk of the sands in the Namib have been blown back onto land after residing in the Atlantic Ocean for some time (Corbett, 1989) having been delivered there from the interior of Africa by the Orange River and other streams that debouch into the ocean.

The NPE and PESA wanted to know when aeolian activity started to dominate Namib geomorphology, and thus to gauge its relative importance in the history of the coastal strip.

1.21 SEDIMENTATION IN THE NAMIB

A great variety of sediments has been reported in the Central and Southern Namib. These range from conglomerates and coarse grained regoliths, through sands, silts, clays and evaporites to phosphorites, silcretes, travertines, ferricretes, gypcretes and calcretites. The great bulk of Cenozoic sediments is composed of aeolianite, but important amounts of fluvial and littoral marine strata are known. Determining the role that the various sedimentary

agencies played in producing the Cenozoic sediments of the Namib would throw much light on the geological history of the region and on the genesis of fossiliferous deposits.

1.22 PALAEOOLS OF THE NAMIB

The bulk of palaeosols mapped in the southern Namib consists of kaolinised bedrock and sediments. Kaolinised horizons are especially well developed in Namaqualand, but are known north of the Orange River as well. Other palaeosol types recognised in the Namib consist of marly palaeosols, calcretes, silcretes, gypcretes and ferricretes. A study of these might well throw light on past conditions in the Namib. For example, the formation of gypcretes in the coastal strip appears to occur where there is a high incidence of aerosols derived from sea spray which contains traces of hydrogen sulphide (H₂S). The latter appears to be derived from coastal muds rich in decaying organic matter and from organic matter in the ocean which reaches land as an aerosol or sea water spray.

1.23 MARINE SEDIMENTS

Whilst the NPE and PESA were not in a position to sample the marine sediments offshore Namibia and Namaqua-

land, a study of published works would undoubtedly be of interest for several reasons. The first is that there were surely close connections between what was happening in the sea and events in the coastal plain, so that an understanding of what was going on in the southeastern Atlantic would be pertinent to explaining what occurred on land. The second is that by comparing the marine and terrestrial sequences one might be able to propose more precise correlations between continental and marine biostratigraphic successions than have hitherto been possible.

1.24 SUMMARY

By studying each of the above aspects of Namib Geology and Palaeontology, the NPE and PESA hoped to make substantial advances in our understanding of the evolution of the African palaeobiosphere. Whilst a great deal can be said in support of reductionist but highly detailed studies by many scientists - the so-called multidisciplinary approach - it is considered that a holistic perspective is inherently more satisfying because fossils are viewed as having been parts of evolving ecosystems rather than as objects to be studied in isolation from their geological or environmental context.

2. THE STUDY AREA

2.1 LOCATION OF THE NAMIB DESERT

The Namib, south western Africa, is that «narrow tract of land, some 2000 km long and mostly less than 200 km wide, lying west of the Great Escarpment between the Olifants River (Cape Province, South Africa) and the Carunjamba River (Moçamedes District, Angola)» (Ward *et al.*, 1983) (figs 2-1, 2-2). As such, the Namib is one of the five «west coast» deserts of the world, the others in the southern hemisphere being the Atacama Desert in South America and the Western Desert in Australia. These deserts are considered by some scientists to owe their origins to the development of the Antarctic Ice Cap during the Middle Miocene as well

as to their positions on the west coast of large continental masses. The northern hemisphere «west coast» deserts are the Western Sahara in north Africa and the Baja California Desert in North America.

The focus of this study will be the Central and Southern Namib (Geiss, 1971), in particular the portion between the Kuiseb and Olifants Rivers, but where geological and palaeontological evidence from neighbouring areas is available and pertinent to understanding the history of the Namib, it will be included.

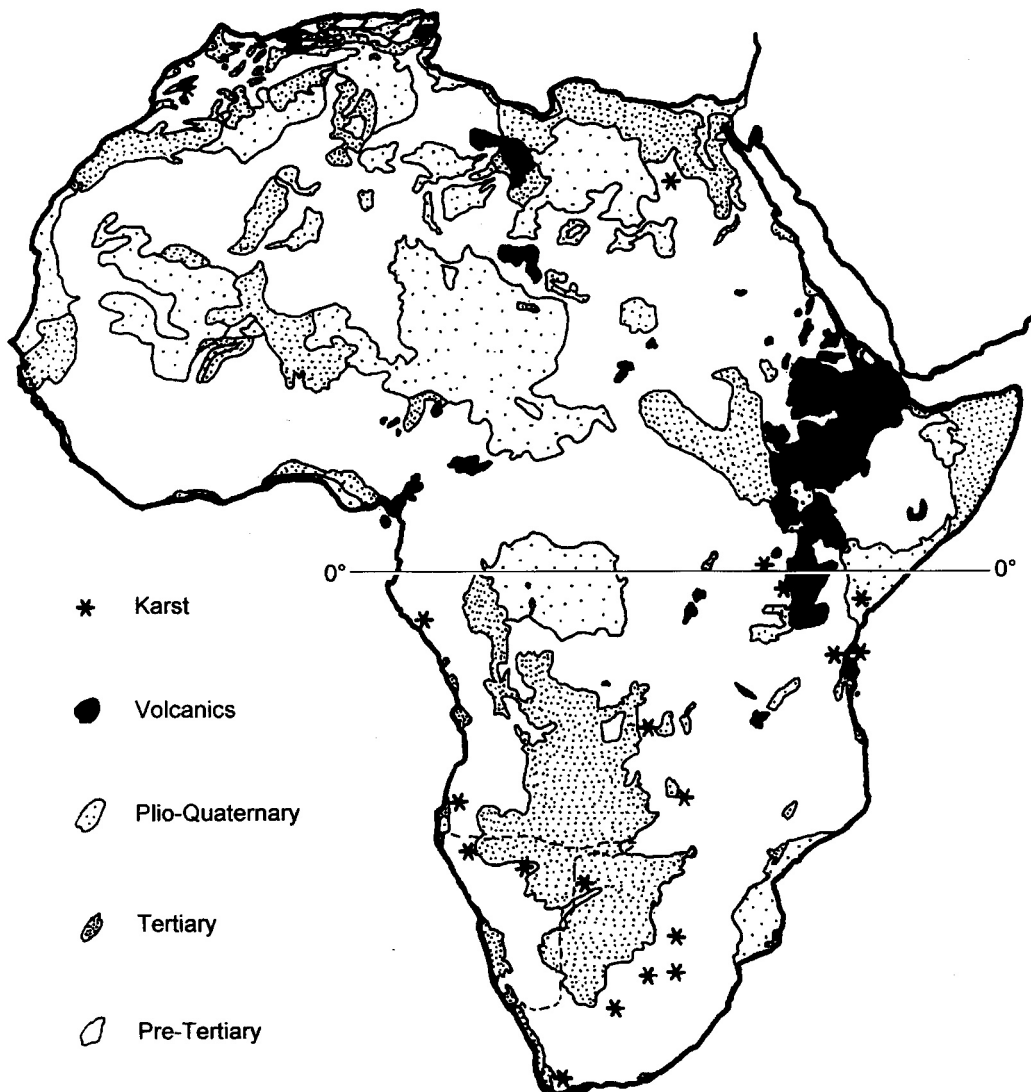


Figure 2-1.- Cenozoic Sedimentary and Volcanic strata of Africa. This figure locates the continental and marine deposits of the Central and Southern Namib dealt with in this monograph. Despite their relatively small extent, these deposits have yielded a rich assortment of fossils ranging in age from Early Miocene to Recent and there are Cretaceous and Eocene marine deposits in the same region.

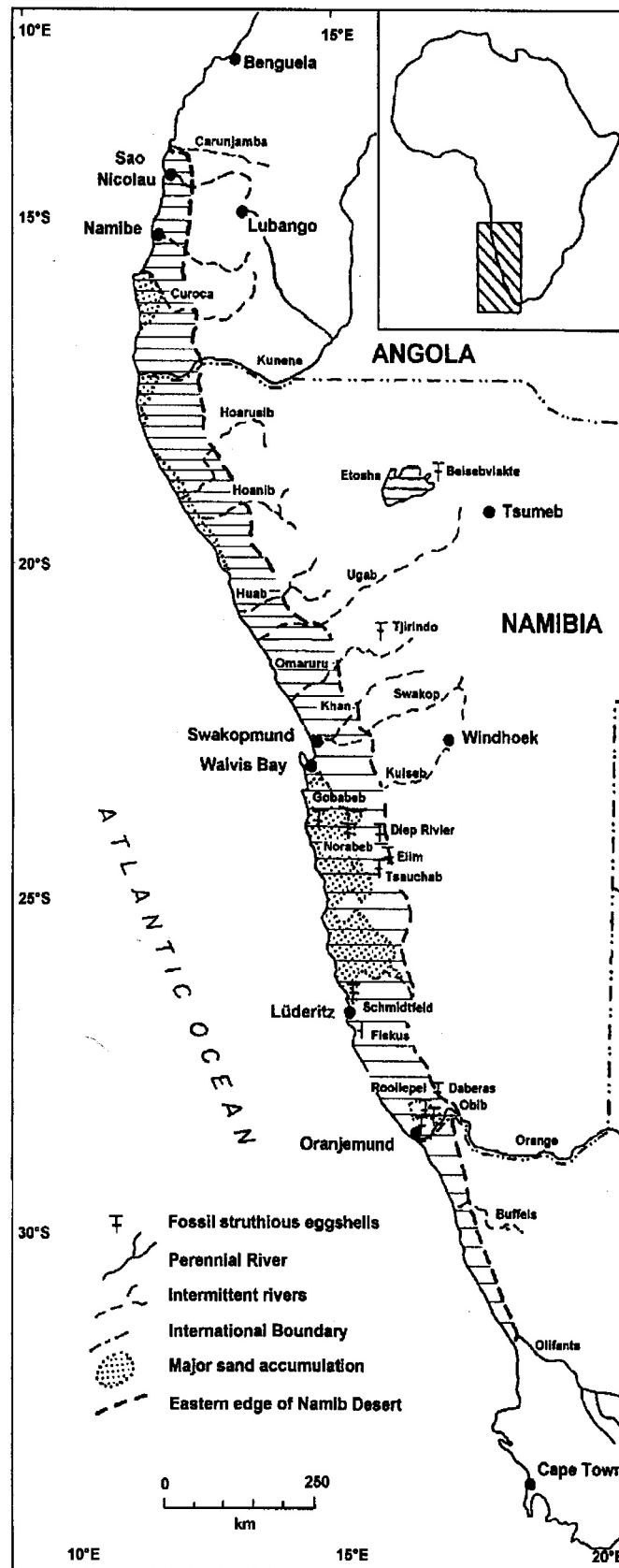


Figure 2-2.- Extent of the Namib Desert. The Namib, *sensu stricto*, extends from the Olifants River in the south to the Carunjabma River in the north, a distance of some 2,000 km. It is about 150 km wide at its greatest extent, being limited inland by the Great Escarpment. It should not be confused with the much larger Kalahari Desert which occupies the high interior of Namibia and Botswana. Fossil evidence indicates that desertic conditions have prevailed in the Southern Namib since the end of the Early Miocene, whereas the Kalahari system appears to be considerably younger (based on data in Ward, 1987).

2.2 CLIMATE OF THE NAMIB DESERT

Namibia is located in the southern warm-temperate zone (fig. 2-3). If it weren't for the activity of the Benguela Current and the South Atlantic Anticyclone, it might well be sub-tropical, because on the east side of the continent, sub-tropical conditions extend further south than they do on the west side. The Namib is more affected by the Benguela Current than is the interior of Namibia, and it is in the coastal strip that the effects of cold upwelling waters are most evident.

The mean annual temperature of the Namib is relatively low (14°-18°C) and its southern half, south of the Lüderitz-Aus road, experiences winter rainfall. Most of the rest of the Namib is subject to summer rainfall, while the southeast corner is subject to rare but intense rain showers throughout the year (fig. 2-4). In the Namib rainfall is intermittent and usually less than 125 mm per year (fig. 2-5). Walter (1971) distinguished between the coastal, or external, Na-

mib which is subjected to frequent fogs, and the inland, or internal, Namib which is usually devoid of fog.

The bank of fog that develops above the cold upwelling cells of the Benguela Current is often carried inland during the night by southwesterly winds. It disperses during the day as the desert is warmed up by the sun. Precipitation from the fog is of the order of 0.1 mm per event, but can be higher than this, though figures above 0.7mm have never been recorded (White, 1986). The total annual precipitation from fog may thus reach as high as 40 to 50 mm. Aerosols derived from the spray zone and drifting inland from the coast contain sodium chloride and other impurities such as hydrogen sulphide, and as a result, much of the coastal Namib has saline or gypsiferous soils, whereas the inland Namib soils are not salty (White, 1986).

Selby (1977b) divided the Namib in the vicinity of Swakopmund into three zones that are approximately parallel to the coastline. These are the «cool fog desert» extending about 40 km inland, the «alternate fog desert» from 40 to 60 km inland and beyond this the «desert steppe» as far as the great escarpment. It is these three zones that are swept

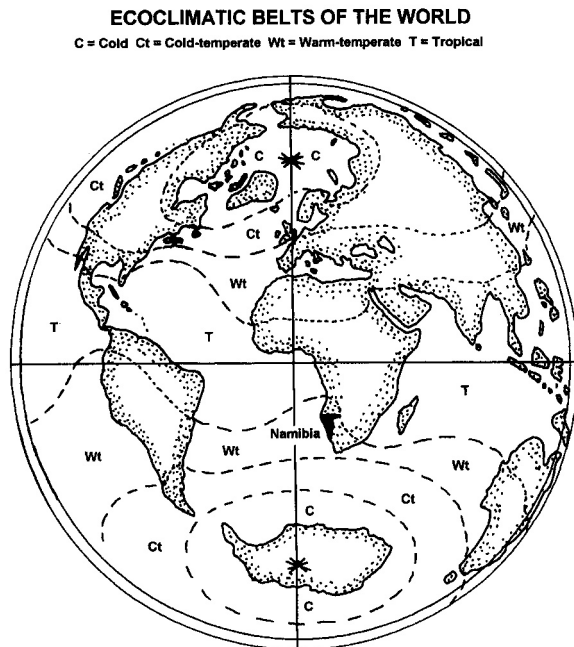


Figure 2-3.- Ecoclimatic belts of the world. These belts tend to be oriented parallel or sub-parallel to the Equator, but important anomalies occur where cold upwelling waters impinge on mid-latitude coastlines. In these areas the temperate zone can extend further meridionally than would normally be the case. Namibia and Chile provide two examples where temperate conditions occur in areas that would otherwise be tropical. The fossil and sedimentary record of the Namib Desert indicates that it has been temperate since at least the Middle Miocene, but that prior to this the region lay within the tropics. Evidence from the Atacama Desert indicates that it too became a desert during the Middle Miocene. It has been proposed that intensification of aridity in these regions was due to the growth of the Antarctic Ice Caps to continental size during the Middle Miocene.

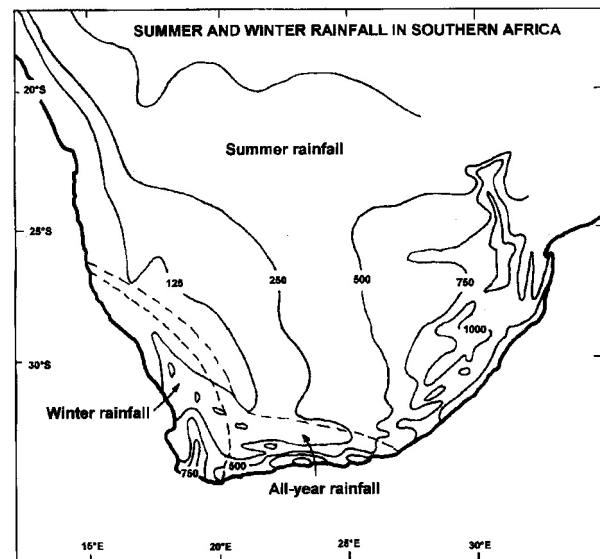


Figure 2-5.- Rainfall in southern Africa (in mm). The Namib falls entirely within the 125mm isohyet, much of the desert receiving considerably less than this figure. In the south, rainfall occurs during the winter months, while in the north it occurs during the summer. A narrow band of the Namib receives rainfall in any month of the year, often in short but intense rainstorms. The vegetation communities that inhabit the Namib vary strongly according to the rainfall regime. In the south they are dominated by fynbos types related to those of the Cape Flora, whereas in the north, the vegetation has affinities closer to tropical types. Winter rainfall has probably occurred in the southern Namib ever since the Middle Miocene, but prior to this the region was sub-tropical in its climatic affinities.

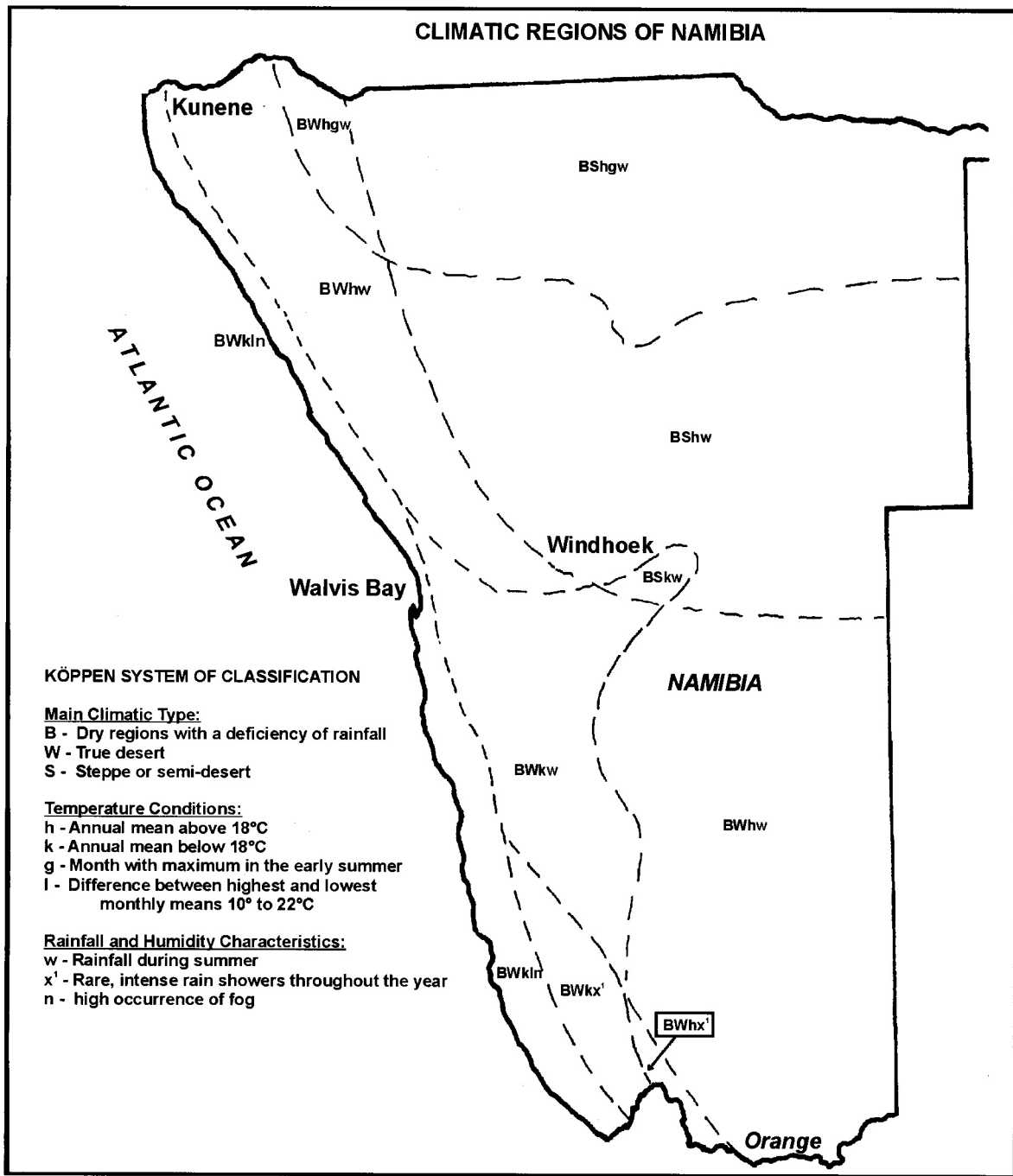


Figure 2-4.- Climatic regions of Namibia based on the Köppen System of Classification. The entire country is dry with a deficiency of rainfall, but only the coastal strip and the southeast are classified as true desert. Most of the country, with the exception of the southern Namib, falls within the summer rainfall belt, but the coastal strip has a high occurrence of fog. The fossil and sedimentary record of Namibia indicates that the coastal strip has been arid since the end of the Early Miocene or the onset of the Middle Miocene, yet the northern parts of the interior, such as the Otavi Mountainland, have at times been more humid than they are now during the same period.

violently by the berg winds which result in the sculpting and faceting of bedrock and boulders of the central Namib (Whitaker, 1984).

The prevailing winds in the Namib blow from south to north almost parallel to the coastline (Corbett, 1990), but strong berg winds blowing from the highlands towards the southwest occur on average 8 times per year (range 5-12) (Whitaker, 1984). The berg winds have had a major impact on exposed rock surfaces in the region between the Swakop and Kuiseb Rivers (Heine, 1986).

2.3 BENGUELA-NAMIB INTERACTIONS

There can be little doubt that there is a feedback relationship between the Benguela current and the Namib desert. Upwelling of cold waters along the Namib coastline has intensified the already arid conditions that prevailed in the area, whilst the strong southerly winds that typify the region play a role in blowing warm surface waters away from the Namib, thereby promoting the upwelling of cold (dense), nutrient-rich water masses along the coast. In addition to this rather obvious relationship, there are other, more subtle, interplays between the two systems. For example, the high prevalence of fog along the Namib coast is largely due to the presence of upwelling cells of cold water, whilst the deposition of gypsum in exposed coastal sediments is probably due to the inland drift and precipitation of aerosols which contain dissolved hydrogen sulphide, itself derived from shallow marine sediments.

2.4 ECOLOGY OF THE NAMIB

Ecologically, the Namib lies within the Karoo Namaqual-

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Ecologically, the Namib lies within the Karoo

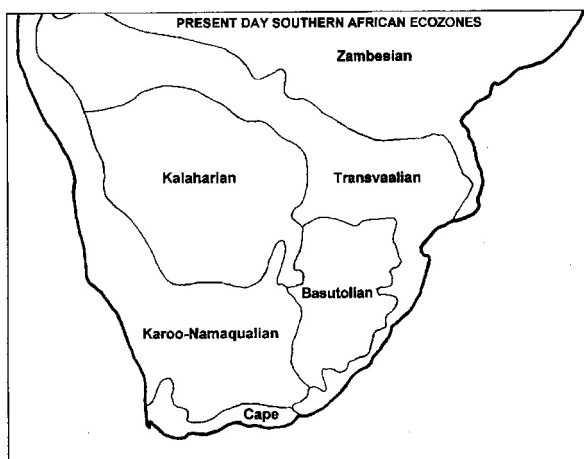


Figure 2-6.- Southern African ecozones (after Klein, 1980 and Deacon & Lancaster, 1988). Many ecological subdivisions of Southern Africa have been proposed. This one highlights vegetation types and climate as well as altitude and shows clearly the tendency for the eastern parts of the sub-continent to be more humid and more tropical (Zambeesian and Transvaalian Ecozones) than the equivalent latitudes in the western parts which are more temperate and drier (Cape and Karoo Namaqualian Ecozones).

ian ecozone (Deacon & Lancaster, 1988) (fig. 2-6). The entire area of the Namib is arid to hyper-arid. The Karoo Namaqualian ecozone has a growing season of less than four months per year; in the Namib the growing season is less than three months per year, and over much of its extent it is less than one month long (fig. 2-7). In the immediate vicinity of the coast, however, fog often drifts inland and provides an important source of moisture to the flora and fauna.

There are only two permanently flowing rivers which cross the Namib, the Orange in the south and the Kunene in the north (fig. 2-2), but several large ephemeral rivers traverse it (Jacobson *et al.*, 1995). Tongues of sub-tropical riparian vegetation extend down these valleys into the desert.

2.5 VEGETATION OF THE SOUTHERN NAMIB

The vegetation of the southern Namib comprises part of the Karoo-Namib regional centre of endemism (Giess, 1971; White, 1986), in particular the part that is subjected to winter rainfall (figs 2-8, 2-9). The entire centre of endemism contains some 3,500 plant species of which half are endemic. The Southern Namib, however, is endowed

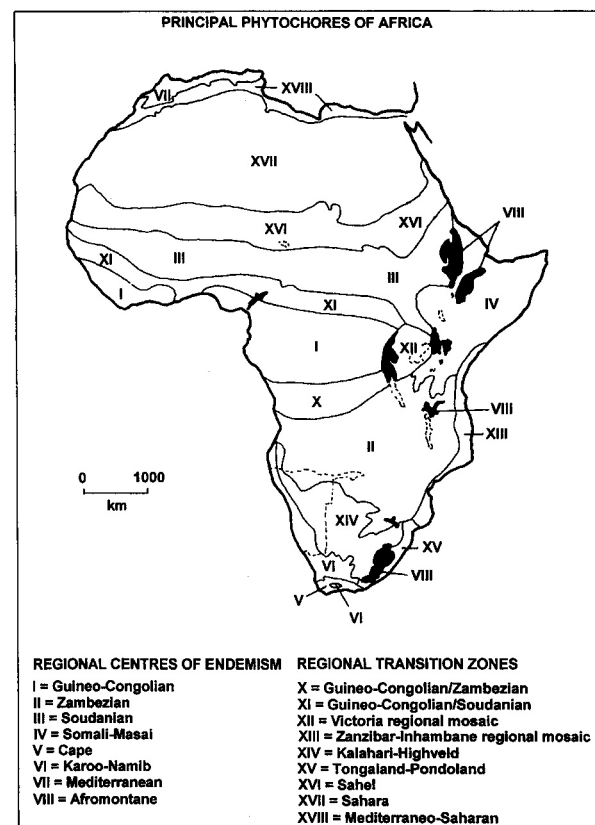


Figure 2-8.- Principal phytochores of Africa (after White, 1986). During the Oligocene and Early Miocene coastal Namibia was probably clothed in Zambeesian type vegetation (II), in strong contrast to the Karoo-Namib vegetation (VI) which it presently supports and which has probably been in place since the base of the Middle Miocene.

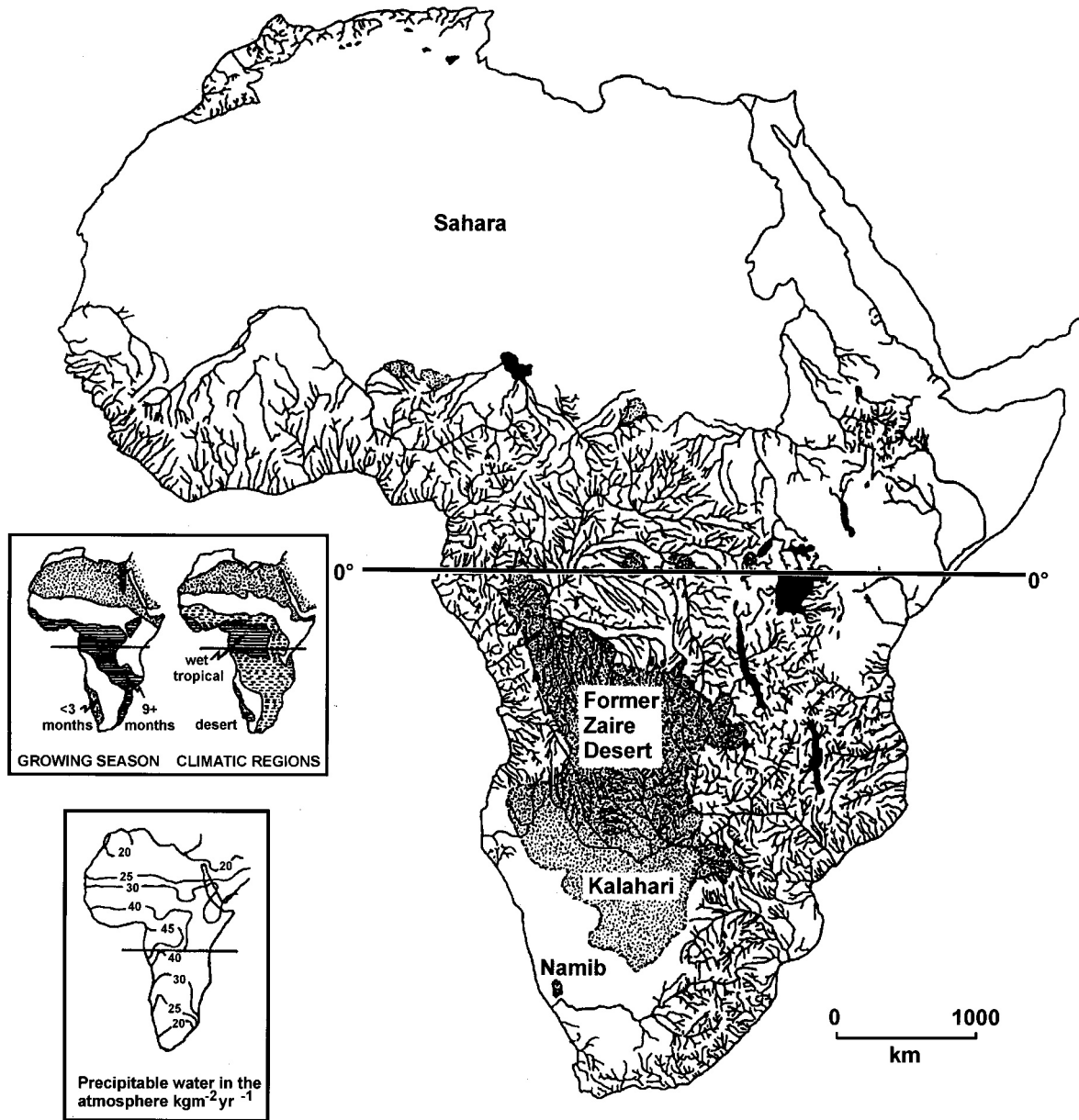


Figure 2-7.- African climatic regions, growing seasons and precipitable water in the atmosphere, together with a map showing the permanently flowing hydrographic network of the continent. Superposed on the latter map are aeolianites of Miocene and Pleistocene age south of the Sahara, to show the extent of climatic change that has occurred in Africa during the Neogene. For instance, during the Middle Miocene dune desert occupied the greater part of the Congo Basin as far north as 1°N, an area which is today the most humid in Africa, with 45 $\text{kgm}^{-2}\text{yr}^{-1}$ of precipitable water in the atmosphere. For such dune deserts to form, the atmosphere needs to be much more arid than this - less than 25 $\text{kgm}^{-2}\text{yr}^{-1}$.

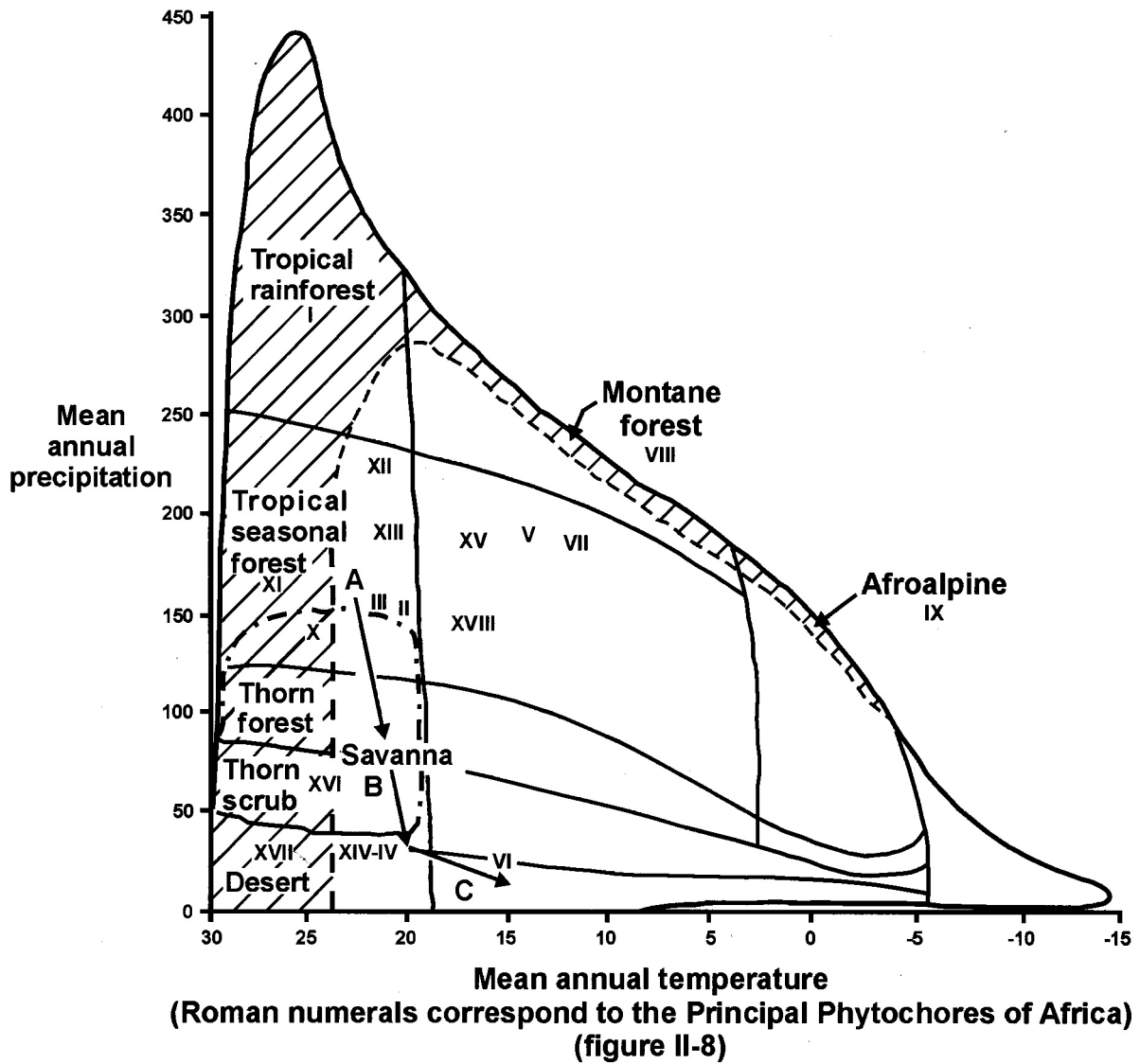


Figure 2-9.- African vegetation types plotted onto an ecological chart of precipitation and temperature (after Putnam, 1984). The Namib fossil sites are depicted in order to show that the region has varied between tropical and temperate climates, but has always been rather arid. A-B-C represent the ecotrajectory that was experienced by the Namib coastal strip. Starting out humid in the Oligocene, the Namib became drier with the passage of geological time. There were fluctuations within this overall tendency, with, for example, changes from arid desert to semi-arid steppe and back during the Pleistocene during which extensive calcretes were formed in the Namib.

with fewer than 2,000 species, many of which are rare. The Sperrgebiet, for instance, is known to contain at least 680 plant species and some 90 species of lichens (Williamson & Jacobson, 1995). Forty five of these plants are endemic to Namibia, whilst many more occur only in the Sperrgebiet and the neighbouring Richtersveld, South Africa.

2.6 CONTINENTAL BIOGEOGRAPHY OF THE NAMIB DESERT

The Namib, unlike the Sahara, is a relatively cool desert, its proximity to the cold upwelling waters of the Benguela Current undoubtedly being largely responsible for the cool temperatures that prevail in the coastal strip. The Namib's climate is peculiar in that its northern half is subjected to summer rainfall while its southern half experiences winter rainfall, whereas along its southeastern edge, near the Great Escarpment, rainfall can occur in both winter and summer.

Because of its rainfall regime, the Namib shows various affinities with neighbouring biogeographic regions. In the south, its flora and fauna are close to those of the Cape floristic and faunistic zone sharing with it many characteristic species of succulent plants, snails and small mammals. The northern Namib in contrast has stronger biogeographic affinities with sub-tropical Africa, with many species of animals and plants being shared with the 'semi-arid belt' or 'drought corridor' (fig. 2-10 & 2-11) of sub-equatorial Af-

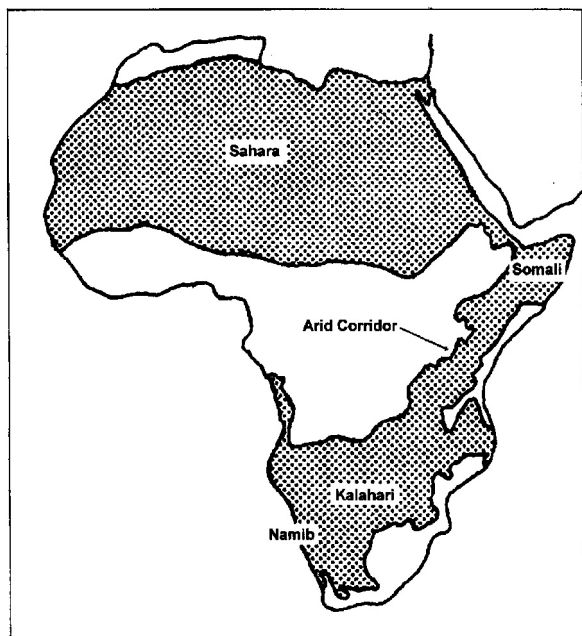


Figure 2-10.- Map of Africa showing the 'drought corridor' between Namibia and East Africa. The stipples indicate areas in which rainfall is less than 10mm per month in at least three consecutive months (modified from Bigalke, 1968). This corridor explains, to a great extent, why East African and Namib vegetation and faunas have much in common.

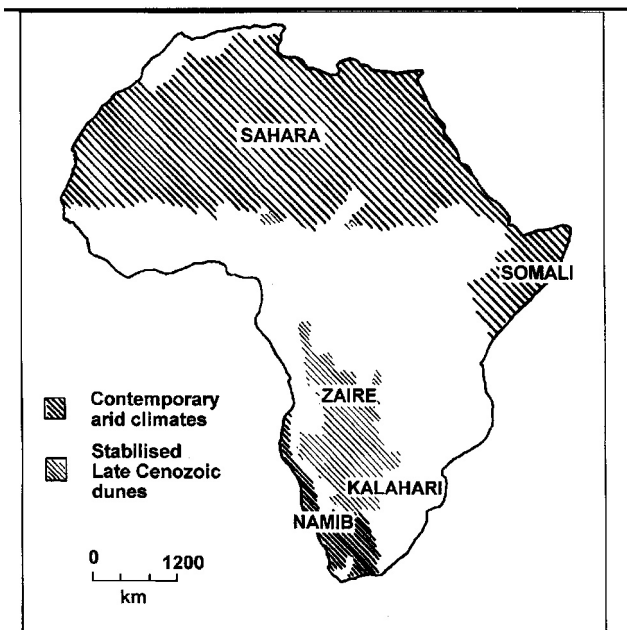


Figure 2-11.- The distribution of stabilised dunes and contemporary arid climates in Africa. With the exception of coastal dunes at Buntfeldschuh, the oldest dunes in the Namib are of terminal Early Miocene and basal Middle Miocene age. The stabilised dunes that extend from Botswana northwards into Angola, Zaire, Congo and Gabon consist of both Quaternary and Miocene dunes. Dunes of the Sahara in contrast appear to be relatively young (Quaternary), although Late Miocene aeolianites have been reported from Morocco.

rica (Bigalke, 1968). Verdcourt (1969) lists numerous plant species common to the Namib and Somalia, from which he deduced the former presence of an arid corridor between north-east and south-west Africa. Fluctuations in the position of the boundary between the two sub-divisions of the Namib and between the Namib and neighbouring zones have undoubtedly occurred in the past.

2.7 MARINE BIOGEOGRAPHY OF THE NAMIB COAST

At present, the marine coastal zone of the Namib is dominated by cold water faunas related to those that occur further south near the Cape of Good Hope. In the past however, molluscan faunas of coastal Namibia and Namaqualand have included warm water lineages, some with affinities to west African faunas, others being closer to Indian Ocean forms (Haughton, 1932; Pether, 1994). The fossil record demonstrates clearly that marine biogeographic affinities of the Namibian coast, like those on land, have changed drastically in the past.

2.8 SEDIMENTARY RECORD OF THE NAMIB

The Namib has been the site of intermittent marine and continental sedimentation since the early Cretaceous break-

up of Gondwana. The bulk of sediments in this region is composed of aeolianites- and mobile sands disposed on an eroded surface of Proterozoic rocks - the Namib Unconformity Surface (Ollier, 1978; Ward, 1987a, b). Lesser volumes of marine, fluvio-lacustrine, fluvial, playa (or pan) and pedogenic sediments occur in many places in the Namib and provide useful information concerning its history, in particular its palaeoenvironments and geochronology (Ward, 1982).

2.9 BIOSTRATIGRAPHY OF THE NAMIB

Patches of sediment in the Central and Southern Namib have yielded fossils of various ages, ranging from Cretaceous to Recent. Fossils have provided basic data for biostratigraphic correlations to be made not only within the Namib but also between the Namib and other areas in Africa and even Europe. Fossil mammals, for example, have long been used to estimate the relative ages of Namib deposits (Stromer, 1926). The calibration of fossil faunas in East Africa by radio-isotopic techniques during the past three decades means that ages can now be proposed for comparable Namibian faunas. Onland exposures of marine strata have yielded correlations to the marine biostratigraphic scale, while cores offshore Namibia have yielded relatively complete successions as far back as the Oligocene.

South of the Orange River, the biostratigraphy of the littoral marine deposits has been researched for over 60 years. The sequence of faunas has been well worked out, but the timing of events has generally been poorly controlled due to a lack of knowledge concerning the rates of evolution of marine molluscs. The discovery of terrestrial mammal fossils in these strata has yielded precious information regarding their chronology and this has led to a revision of previous ideas.

2.10 SUMMARY

The Namib, although representing only a tiny fraction of the area of Africa, is of great interest due to its proximity to the southern termination of the continent and because of its hyperarid climate. Its xeric environment contrasts strongly with those prevalent at other African Cenozoic fossil localities such as those in the Gregory Rift (semi-arid savanna to woodlands and forest) and the Albertine Rift (tropical rain forest and forest savanna mosaic). Previous researches in the region have highlighted its palaeontological potential and have underscored the lack of geochronological control of events in the region. The fact that the fossiliferous deposits of the Namib are often diamondiferous is of economic interest, because fossils can provide information concerning the timing of ore genesis, which is critical for a more rational exploration and exploitation of the deposits.

3. PREVIOUS RESEARCH GEOLOGY, CLIMATOLOGY AND PALAEOLOGY OF THE NAMIB

3.1 BACKGROUND

The geological development of the Namib has been multifaceted. Following the break-up of Gondwana in the mid-Cretaceous, many forces have been active in shaping it and it is necessary to apply an integrated approach to its study in order to understand its development. These include modifications in erosional regimes due to shifts in base level and changes in climate. Base-level changes have been caused by sea level fluctuations (Haq *et al.*, 1987; Dingle *et al.*, 1983) and epeirogenic uplift of the continent (Korn & Martin, 1957; Partridge & Maud, 1987). The region's Neogene and present day climate has been forged by its mid-latitude position on the western coast of Africa (Ward & Corbett, 1990) and by regional and global climatic changes. The role of the Atlantic - especially the Benguela, Agulhas and Angola Currents - has been ever present, not only in controlling base level but also in determining the coastal climate. The establishment of cold upwelling water masses associated with the Benguela Current has undoubtedly played a significant part in the Namib's history. The few rivers draining westwards from the interior of Africa across the Great Escarpment and thence through the Namib into the Atlantic have been important in supplying sediments to the region, including much of its alluvial wealth. Berg winds (blowing from the interior of the continent out to the Atlantic in a south-westerly direction) have been important in transporting dust and sand out to sea (Whitaker, 1984). Since at least Late Miocene times, southerly winds have dominated the climate of the nearshore parts of the southern Namib (Seely, 1984; Lancaster, 1985). Currently these winds are among the most persistent on Earth. As soon as extensive deposits of wind-blown sand had begun to accumulate in the coastal belt, the erosional regime of the Namib was greatly modified, because even positive relief bedrock features which, under more normal circumstances, would continue to be exposed to erosive agents, were often buried under great thicknesses of sand and protected from further attack. The nature of the Proterozoic bedrock has determined local rates of erosion. Calcrete pedogenesis greatly modified the landscape during the later stages of the Namib's development and deposition of travertines led to local modifications of topography and sedimentation.

Given the multiplicity of geomorphological agents which have moulded the Namib Desert, it is perhaps understandable that published reconstructions of its history have been varied, especially regarding the timing of events (Hallam, 1964; Stocken, 1978; Ward & Corbett, 1990; Corbett, 1996; Besler *et al.*, 1994).

3.2 PRECURSORS OF THE NAMIB DESERT

There are aeolianites of Mesozoic age both onshore (Damara region, Etjo, Gamsberg) and offshore Namibia (Kudu) (Light *et al.*, 1992, 1993). Offshore, aeolianites of Triassic, Jurassic and Early Cretaceous age have been encountered in boreholes and inferred from seismic profiles, while on land Triassic and Cretaceous deposits are known. Even though these aeolianites indicate the former presence of arid to hyper-arid conditions in coastal and interior Namibia during the Mesozoic, they are not strictly speaking precursors of the present day Namib Desert. This is because the geomorphological and climatic conditions at the time of their deposition were not comparable to those that are responsible for today's Namib. The Atlantic Ocean had barely started to open in the early Cretaceous. Furthermore, the presence of aeolianites at Kudu, some 130 km west of the present day coastline of Namibia, reveal that the Cretaceous coastline was far to the west of its modern position (fig. 3-1). Post-Gondwana uplift of the African continent and down faulting of the continental shelf would not have been as great in the Cretaceous as it is now. Under these circumstances, the climatic circulation patterns over Africa and the nascent Atlantic Ocean would probably have been rather different during the Cretaceous than they are today. Bigarella (1970) discussed the palaeoclimatic situation in the nascent South Atlantic and concluded that a high pressure cell could have existed as early as the Late Cretaceous. This would be about the time that the Wanderfeld IV beds were laid down. Palaeowind directions in Namibia at this time would have been from the southwest towards the interior of the continent (fig. 4-37) and not parallel to the coast as the predominant winds are today. It was only during the Cenozoic that the South Atlantic became so wide that the winds associated with the south Atlantic anticyclone would have swept more or less parallel to the Namibian coastline.

Aeolianites of Palaeogene age have not been recorded from Namibia, either onshore or offshore (Light *et al.*, 1993), suggesting that arid conditions were absent or were not marked in this part of the world for some 100 million years. Indeed, fossils from Late Cretaceous and Eocene marine sediments in the Sperrgebiet indicate that coastal Namibia was likely to have been tropical during this period (Böhm & Wiessermel, 1913; Böhm, 1926). Aeolianites at Buntfeldschuh must be later than Middle Eocene because they are underlain by marine sediments which contain teeth of the sand shark, *Isurus*, which is not known from sediments older than this, but their age is unknown. It was only during the Miocene that regional scale fully desertic conditions were established in the Central and Southern Namib.

Late Mesozoic-Cainozoic (LM-C) and Miocene Models for the development of the Namib
 Time Scale variable. E = Early; M = Middle; L = Late

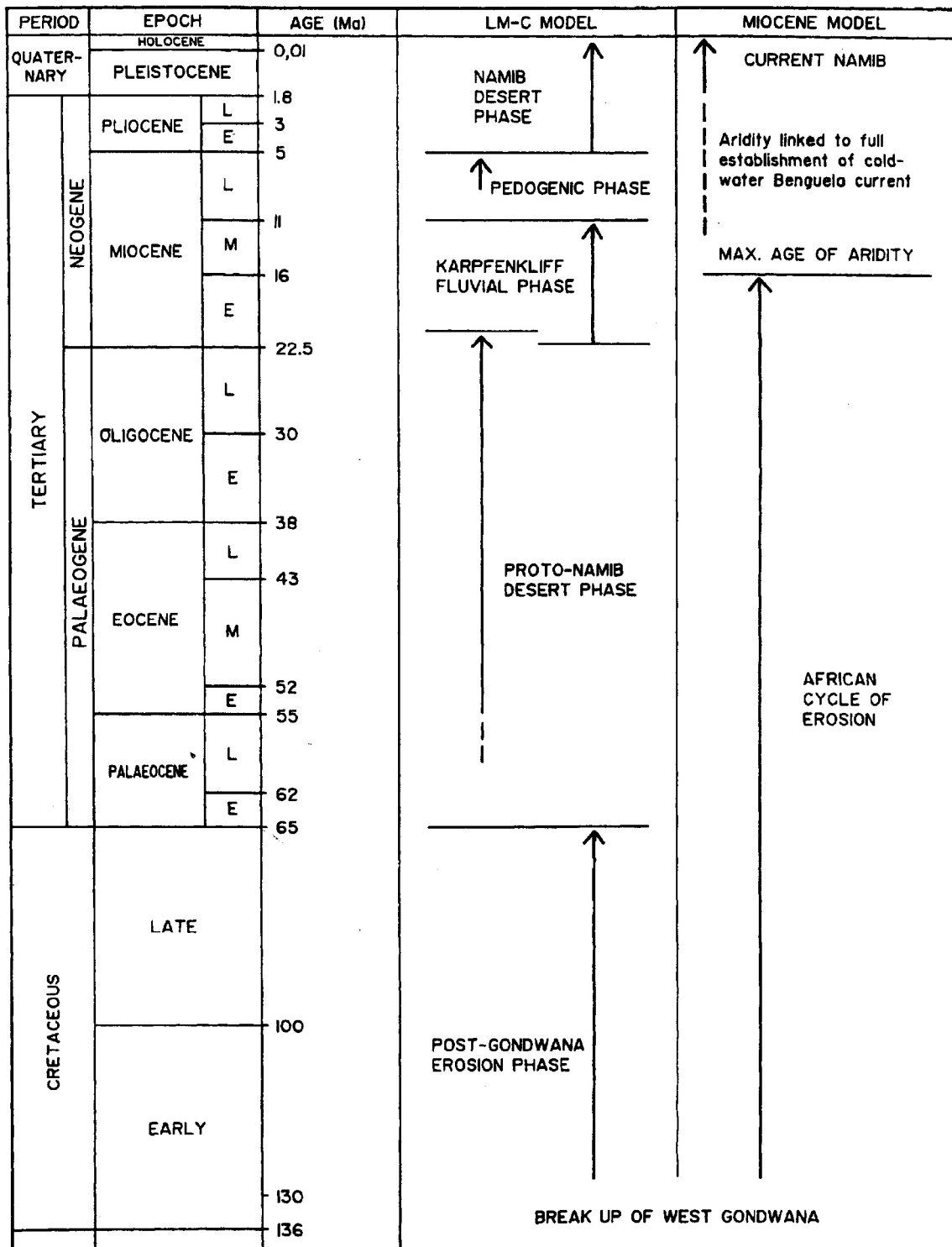


Figure 3-1.- Comparison of two schools of thought regarding the age of the Namib Desert - the Late Mesozoic-Cenozoic (LM-C) and Miocene models (from Ward & Corbett, 1990). The main difference between the two models, apart from the vastly different times that aridity is perceived to have begun, concerns the role of the Benguela Current. In the LM-C model, the décalage between the onset of aridity and installation of the Benguela Current is some 40 million years, whereas in the Miocene model, these two events are much closer in time.

3.3 HISTORY OF DEVELOPMENT OF IDEAS CONCERNING THE NAMIB SAND SEA

Ward & Corbett (1990) summarised previous ideas concerning the genesis of the Central Namib Desert. Two main families of hypotheses have been published, one in which the history of aridity is thought to have been very long (Cretaceous to Recent), the other in which it is considered to have been short (Miocene to Recent) (fig. 3-1). Cox (1992) for example wrote that the Namib Desert dates from 80 million years.

Ward and Corbett (1990) took an intermediate view, considering that aridity began during the Eocene based on the Buntfeldschuh aeolianites (fig. 3-2). They divided the history of development of the region into five broad phases.

1. Post-Gondwana erosion phase - Cretaceous
2. Proto-Namib Desert phase - Palaeogene
3. Pluvial phase - Early to Middle Miocene
4. Pedogenic phase - Late Middle Miocene
5. Namib Desert phase - Late Miocene to today.

Besler *et al.* (1994) built upon the work of Corbett (1989) and Ward & Corbett (1990) in the Southern Namib and interpreted the geological history of the Central Namib in the light of the latter publications. They added appreciable detail to the Plio-Pleistocene and Holocene sections but accepted the pre-Pliocene history of the region reconstructed by Corbett (1989).

While there has been some consensus reached about the sequence of events outlined by Ward & Corbett (1990) based as it is on a study of the sediments which crop out in the Namib, there has been little agreement about the timing of events and many of the details of events within each of the broad phases summarised above (fig. 3-3) (Pether, 1994). The sequence of events requires modification in places, especially regarding the positions of the fluvial deposits at Grillental, Elisabethfeld, Langental and the proto-Orange deposits in the Sperrgebiet relative to the Tsondab aeolianites. With the exception of Palaeogene dunes at Buntfeldschuh, all the indurated aeolian sandstones in the Namib are younger than the above mentioned fluvial deposits. The Karpfenkliff Conglomerates which are considerably younger than the Early and Middle Miocene fluvial deposits of the Sperrgebiet are also younger than most

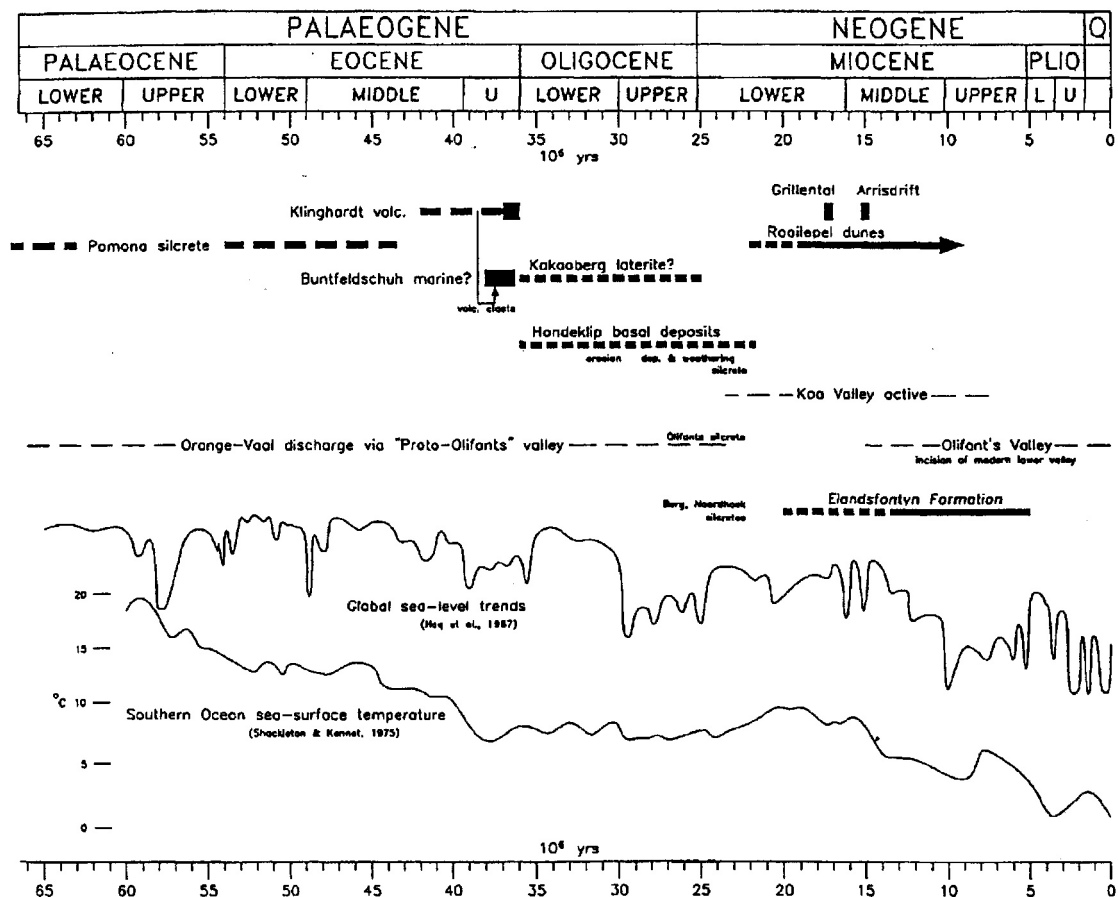


Figure 3-3.- Graphic summary of the geological history of the Namib Coastal Plain according to Pether (1994) together with correlations to global sea-level trends and sea-surface temperature. This is the most recent and most comprehensive summary of the Cenozoic geology of the Namaqualand coastal strip.

3. PREVIOUS RESEARCH

Summarized stratigraphy and revised model for the post-Gondwana history of the Namib Desert
 CGL = Conglomerate; GRV = Gravel; FM = Formation

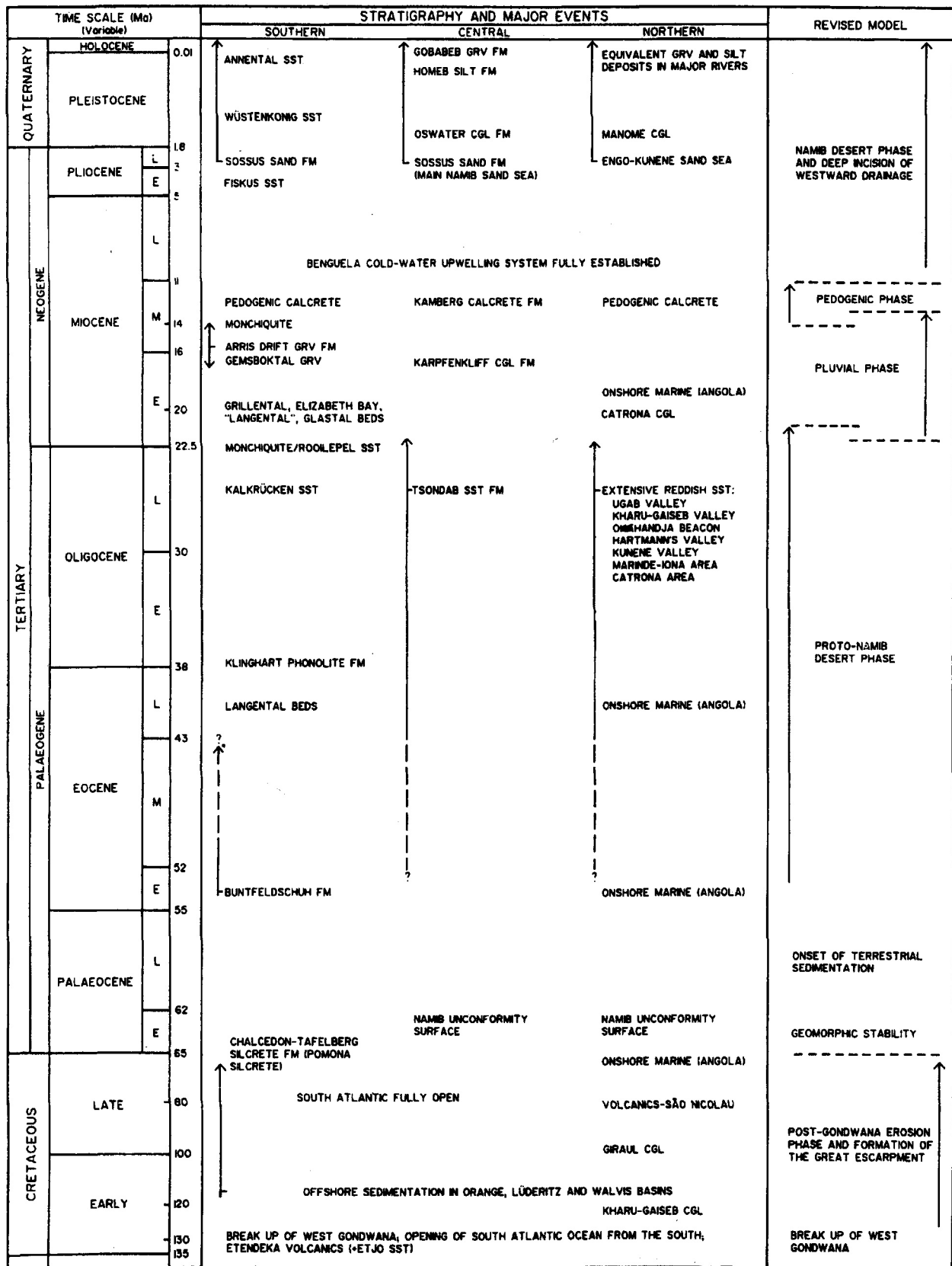


Figure 3-2.- Summarised stratigraphy and revised model for the post-Gondwana history of the Namib Desert according to Ward & Corbett (1990). In this model, arid conditions are thought to have prevailed in the Namib since the Palaeogene. New data indicate that the onset of desertification occurred at the end of the Early Miocene or the beginning of the Middle Miocene.

of the aeolianites assigned to the Tsondab Formation but are older than the Sossus Sand Sea.

3.3.1 GEOMORPHOLOGY

The Namib Desert occupies a low-lying coastal plain located between the Atlantic Ocean and the Great Escarpment of southern Africa (fig. 2-2).

Studies of the bedrock geomorphology of the Namib are hampered by the sand cover, but some research has been done on the inselbergs and other areas where basement rocks are exposed (Gevers, 1936; Goudie, 1972; Hüser, 1977; Kaiser, 1920a, b; Logan, 1960; Mabbut, 1955; Marker, 1977, 1982; Maud & Partridge, 1987; Oilier, 1977, 1978; Oilier & Seely, 1977; Partridge & Maud, 1987; Rust & Wieneke, 1976; Range, 1910; Scholtz, 1972; Selby, 1976; Sprietzer, 1966; Sweeting & Lancaster, 1982; Watson, 1985, 1988; Wienecke & Rust, 1973a, b, 1975; Besler *et al.*, 1994).

There can be little doubt that the predominant geomorphological process resulting in the formation of the Namib coastal plain erosional surface on which the aeolianites reside, has been backwearing of the Great Escarpment (Partridge & Maud, 1987). Changes in sea-level have undoubtedly played a role by shifting the altitude of the marine base level, while changes in climate have affected rates of erosion. Differences in basement rock types have had a determining effect upon rates of erosion, with the result that inselbergs of resistant rock are common throughout the Namib.

It should be emphasised that the Namib Unconformity Surface (NUS) (Oilier, 1978; Ward, 1987a, b) was not the result of a single erosional event of short duration. Parts of this surface near the coast are of Cretaceous age while sectors near the Great Escarpment only formed during the Early Miocene. Backwearing of the Great Escarpment is still in progress, but in the Namib Sand Sea it has been slowed down because of the widespread sand cover on the NUS which has had the effect not only of burying much of the surface, but also of infilling valleys crossing it, thus raising the local base level over much of the region. Where deeply incised valleys cross the Namib Coastal Strip the NUS has been destroyed, especially in areas affected by gramadulla formation (Ward, 1987).

Estimates of the rates of backwearing vary greatly depending upon which evolutionary model is espoused. In the LM-C version, post-Gondwana erosion would have been exceptionally rapid until the Palaeogene, and would then virtually have ceased once the erosion surface was covered by the Tsondab Sandstones of the proto-Namib phase. In the Miocene model, more leisurely erosion rates would have acted for considerably longer, being active from break-up of Gondwana until the base of the Middle Miocene.

Studies of the volumes of siliciclastic sediment deposited in the oceans around South Africa suggest that there

were two major periods of exceptionally voluminous deposition presumably related to rapid erosion of the continent, one during the Eocene, the second during the Miocene and more recent times (Dingle & Hendey, 1984). Partridge & Maud (1987) related these massive inputs of sediment to periods of epeirogenic uplift of the entire subcontinent of southern Africa, a process which they viewed as being episodic. However, it is likely that climatic regimes were as important, if not more important than uplift, with arid climates corresponding to greater rates of erosion than humid climates (Ward, 1987).

3.3.2 TECTONICS

At present, the west coast of Africa comprises a passive continental margin. However, this does not imply that it has been tectonically quiet since break-up of Gondwana. It simply means that, within the plate tectonics paradigm, the continental margin has not experienced subductive or transcurrent fault activity of any significance since the Jurassic. In the Namibian sector, there has been little tectonic activity since the mid-Cretaceous (Light *et al.*, 1992), marine sediments younger than this being relatively free of faults, although often showing evidence of gravity induced slumping.

Light *et al.* (1992), basing their studies largely on seismic surveys supported by data from drill cores in the Kudu hydrocarbon field, divided the tectonic/stratigraphic history of the continental shelf of Namibia into two broad categories. The earlier of these was dominated by rifting related to break-up of Gondwana, and comprised three main stages known as the Prerift, Synrift I and Synrift II periods spanning respectively the Permo-Trias, the Jurassic to Early Cretaceous and the Middle Cretaceous periods. According to these authors, after a Transitional phase dated to Late Middle Cretaceous (lower Aptian), the tectonostratigraphy of the shelf has been dominated by thermal sag (Mid-Aptian to Recent). The presence of several widespread unconformities in the sediments attests to intermittent exposure of the shelf, during which erosion took place. The main unconformities occurred during the Turonian, at the base of the Tertiary, and during the Oligocene.

There is little doubt that there has been tectonic activity of various sorts in the Namib and its vicinity during the Tertiary. Calcretes of Plio-Pleistocene age have been faulted in the Central Namib and the Sperrgebiet (Korn & Martin, 1957; personal observations, M.P.) The Waterberg Thrust fault of central Namibia, which was probably active during the Tertiary, led to regional uplift of the country north of the fault. It would appear from available evidence from the continental shelf (Light *et al.*, 1992, 1993) that during the Tertiary the coastal region was not directly affected by faulting, although some of the slumping activity that is known to have occurred could have been triggered off by Tertiary seismic activity.

A report of Eocene marine fossils at Usakos, at an altitude of 900 metres (Zöller & Böhm, 1929), which, if correct, would imply tremendous post-Eocene uplift of the continental margin, appears to be erroneous. The only fossils found in the area during subsequent surveys consist of freshwater species of Late Pleistocene to Holocene age (Gevers, 1934; personal observations, M.P.).

There is other evidence to support the notion that epeirogenic uplift has been important in modifying the development of the Namib, if only because the Namib has been affected by regional uplift associated with the African Superswell (fig. 3-4) (Partridge *et al.*, 1995a). For example, the down-cutting that occurred at the end of the proto-Namib Desert phase has been attributed to changes in base level brought about either by vertical land movements or to changes in sea-level, but it is more likely, as was pointed out by Ward & Corbett (1990) and Martin (1950) that the down-cutting was a response to a change in climate from extremely arid before to more mesic (semi-arid) afterwards (Stocken, 1978; Ward, 1987b). Other relevant papers have been published by Du Toit (1934), Martin (1950, 1973a, b) and Ziegler (1969).

There may well have been localised uplift or upwarping in the region of the Klinghardt Volcanic field in the Sperrgebiet when phonolitic intrusions were emplaced, and this may have affected regions near the coast. For example, the Buntfeldschuh marine deposits are 120-140 metres above sea-level. Does this mean that sea-level was 140 metres higher during the Eocene, as some geologists have suggested (Stocken, 1962; Dingle *et al.*, 1983) or does it mean that the deposits have been uplifted since their deposition? The Buntfeldschuh deposits have been affected by thrust faulting (Ward, personal communication, 1997) which would suggest that some change in altitude has occurred since deposition.

Raised beaches in the southern Sperrgebiet said to be of Plio-Pleistocene age appear to diminish in altitude from south to north (Stocken, 1978; Dingle *et al.*, 1983), implying tilting of the land in Recent times. However, some of the deposits are of Miocene age and the appearance of tilting could be an artefact caused by erosion. The terrace floors and the deposits which accumulated upon them slope seawards. Thus, if their upper sections are eroded away and the lower parts survived, then this would give the erroneous impression of tilting of the terraces (fig. 3-5).

Low fault scarps cutting calcretes in the desert south of the Aus-Lüderitz road and near the Great Escarpment close to Naukluft, and thus of relatively recent age, have been noted in the Namib (pers. obs. M.P.). These more localised tectonic features have nevertheless helped to shape the geomorphology of the Namib, and they complicate interpretation of its history.

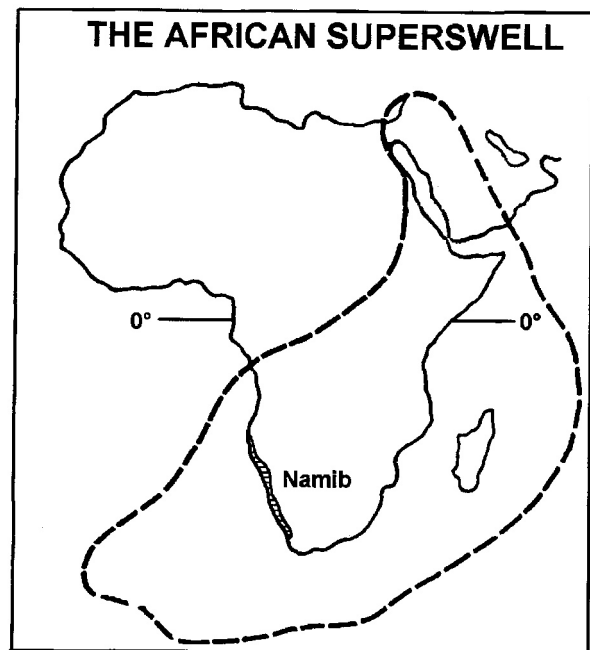


Figure 3-4.- The Namib Coastal Plain in relation to the African Superswell (after Partridge *et al.*, 1995). There can be little doubt that epeirogenic activity has affected the Namib, but to some extent uplift related to the superswell has been cancelled out by thermal sag offshore Namibia. The interior of the continent has been uplifted more than 1 kilometre since the Mesozoic. Dashes outline the approximate limits of the African Swell.

3.3.3 SEA LEVEL FLUCTUATIONS

Sea levels fluctuated on a worldwide scale during the Tertiary (Haq *et al.*, 1987; Vail & Hardenbol, 1979). There is good evidence from seismic surveys and DSDP cores taken from the continental shelf off South Africa that this region was greatly affected by such changes (Siesser & Dingle, 1981; Dingle *et al.*, 1983; Gresse, 1988; Light *et al.*, 1992, 1993; SACS, 1980).

According to Siesser & Dingle (1981) the Eocene appears to have been a period of relatively high sea levels, during which the marine Langental Formation was deposited (Dingle *et al.*, 1983). In contrast, the Late Oligocene was a period of extremely low sea level, during which extensive canyons were cut into the continental shelf (Light *et al.*, 1992). The present day Orange River flows over sediments deposited in a deep bed-rock channel which extends well out to sea (Hoyt *et al.*, 1969). A comparable channel exists south of Elisabeth Bay, being a former extension of the Kaukausb drainage (Murray *et al.*, 1970; O'Shea, 1971). Offshore deposits assigned to a "Lüderitz River" by Dingle & Robson (1990) resulted from a river that flowed from the region of the Central Namib into the ocean some 2° north of Lüderitz, an area which is today deeply covered by the Namib Sand sea. These channels were probably cut during the Oligocene. During Early Miocene times the sea began to rise, a process

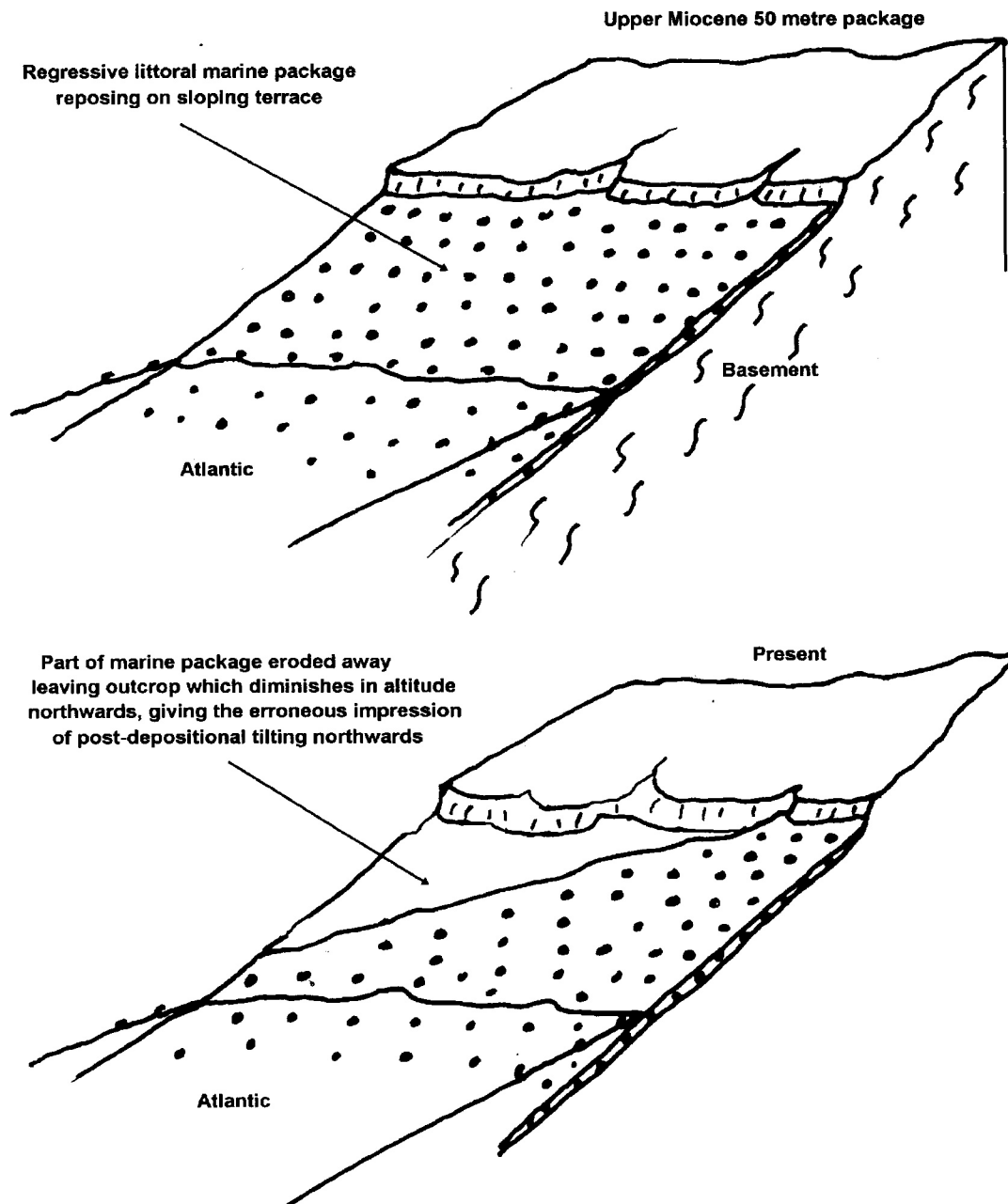


Figure 3-5.- A possible non-tectonic explanation for the diminution in altitude of the CDM beaches north of Oranjemund. Differential erosion of a uniform blanket of terrace sediment could result in the upper edge of the deposit diminishing in altitude northwards, giving an erroneous impression of northwards tilt of the strata.

which culminated in sea-levels at least 50 metres above Modern levels by the onset of the Middle Miocene about 17.5 Ma. Evidence of brackish-water serpulids at Arrisdrift provides the main evidence in support of this event, but marine and terrestrial fossils at Ryskop and Hondek-lip Bay in Namaqualand provide additional evidence of a marine high stand at least 50 metres asl at the end of the Early Miocene. In Namaqualand there is an extensively developed wave cut terrace 95-75 metres above sea-level which indicates that sea-level could have risen well above the 50 metre mark, leaving behind the so-called 90 metre package during the subsequent regression. Alternatively,

there may have been differential uplift of the Namaqualand terraces and their superposed sediments. Evidence for this comes from the observation that these terraces and their sediments decline in altitude north of Oranjemund and south towards the Cape.

The raised beach deposits north and south of the Orange River yield evidence of fluctuating sea levels during the Late Miocene, Pliocene and Pleistocene. These fluctuations have been related by most researchers to the build up and subsequent decay of high-latitude ice caps during the Quaternary (Hallam, 1964; Gresse, 1988; Corbett,

1996). However, there has been active debate concerning these raised beach deposits (De Villiers & Sönghe, 1959; Stocken, 1962; Hallam, 1964; Keyser, 1972, 1976; Pether, 1986; Davies, 1973; Corbett, 1996) which indicates that their characterisation and interpretation is not a simple matter. Some authors (Stocken, 1978) have estimated a Middle Miocene age for the highest beaches while others (Pether, 1986; Corbett, 1996) have concluded that the same beaches are Latest Miocene, Pliocene or Pleistocene in age. Rogers *et al.*, (1990) reported 5 terrace units in the region north of Kleinsee. The highest (95-75 m asl Kleinsee Upper Terrace) was thought to be Early Pliocene, the second (65-45 m asl Kleinsee Upper Middle Terrace) and the third (45-30 m asl Kleinsee Lower Middle Terrace) were thought to be Late Pliocene, the fourth (30-10 m asl Kleinsee Lower Terrace) was considered to be Early Pleistocene while the fifth represents the sub 10 metre beaches or Quaternary Terraces. In the Alexander Bay region these authors recognised only 4 terraces at 95-75 metres (Alex Grobler Terrace), at 60-30 metres (Alex Upper Terrace), 30-15 metres (Alex Middle Terrace) and at 15-0 metres (Late Quaternary Alex Lower Terrace).

H. Leser, in Besler *et al.* (1994) presented an overview of marine terraces over a stretch of coastline more than 1000 kilometres long running from Grootmis in the south to Kreuzkap (Cape Cross) in the north, but like previous workers, he considered that all the subaerial littoral marine terraces were of Pleistocene age, including one at Grootmis at an altitude of 120 metres asl. Even though Leser recognised three widespread terraces in most of the areas he studied (10m, 6m and 2m terraces), he recognised several more localised terraces at intermediate altitudes in some sections (8m, 4m, 3m and 1.5m terraces). Terraces higher than 10 metres were only recognised by Leser in four places (Grootmis, Port Nolloth, Swakopmund and Wlotzkasbak) and none of these occurred over long distances.

Recently, work in Namaqualand by the Palaeontology Expedition to South Africa indicates that some of the beach deposits are considerably older than previously thought. On the basis of terrestrial mammal fossils, there can be no doubt that there were high sea levels at the end of the Early Miocene (18 - 17 Ma), the end of the Middle Miocene (11-10 Ma), and at the end of the Miocene (7 - 5 Ma), as well as during the Plio-Pleistocene and Recent.

3.3.4 GEOCHRONOLOGY

There has been active debate regarding the age of the Namib Desert (Seely, 1987; Vogel *et al.*, 1981) with some researchers considering it to be extremely ancient dating as far back as the Cretaceous (Cox, 1992; Koch, 1961, 1962; Ward *et al.*, 1983; Ward & Corbett, 1990) while others have thought that it was relatively young, being no older than the Middle Miocene (Endrödy-Younga, 1982; Siesser, 1978, 1980; Van Zinderen Bakker, 1975; Tankard & Rogers, 1978; Tankard *et al.* 1982; Dingle *et al.*, 1983;

Partridge, 1985a, b; 1986; Maud & Partridge, 1987; Partridge & Maud, 1987).

Ward & Corbett (1990) summarised the debate and showed that, despite the diversity of views expressed, there were essentially two schools of thought - 1) that arid conditions could have developed during the Cretaceous and Palaeogene (the LM-C (Late Mesozoic-Cenozoic) model) and 2) that arid conditions developed during the Miocene (the Miocene model). Ward & Corbett (1990) supported a compromise between the LM-C and Miocene models, considering that there had been a proto-Namib phase that spanned most of the Palaeogene, during which the Tsondab Sandstone Formation accumulated, a process that was interrupted by a pluvial interval of Early Miocene age during which the fluvio-lacustrine strata of the northern Sperrgebiet were deposited, followed by a pedogenic interval during the Middle Miocene which resulted in formation of the Kamberg Calcrete, after which came the Namib Desert phase of Late Miocene to Recent age, comprising essentially the Sossus Sand Formation (fig. 3-2).

The debate was fuelled to a great extent by the paucity of evidence concerning the age of the strata in the desert. Koch (1961, 1962) based his view on the diversity of extant endemic beetles in the Namib, which he believed must have taken many millions of years to evolve. In contrast, Endrödy-Younga (1982) thought that the beetles did not necessarily denote a great age for the desert - they might have evolved rapidly due to extreme selection pressures. Siesser (1978) and Van Zinderen Bakker (1975) both derived their age estimates for desertification from a study of marine strata in which they considered they could observe evidence for the onset of cold upwelling along the coast which they linked to the intensification of arid conditions along the coast of southwestern Africa.

Corbett (1989) was the first to report on fossils from aeolianite deposits of the Namib. He estimated a Late Miocene age for aeolianites of the northern Sperrgebiet based on fossil struthious eggs found at Kolmanskop. He also reported on the presence of struthious eggs and rodents of Early Miocene age at Rooilepel in the southern Sperrgebiet. Ward & Corbett (1990) extended the data base by including age estimates of fluvio-lacustrine strata in the northern Sperrgebiet. However, the amount of chronological data was very limited - seven sites for which age estimates could be obtained, only two of which were from aeolianites deposited under undoubtedly desert conditions.

3.3.5 THE BENGUELA CURRENT

There can be little doubt that the upwelling of cold oceanic water along the coast of Namibia is responsible for the intensification of the arid conditions that prevail in the adjacent coastal region, transforming it from semi-arid to hyper-arid (Brain, 1984; Lutjeharms & Meeuwis, 1987; Nelson & Hutchings, 1983; Siesser, 1978; Van Zinderen Bakker, 1975). Important questions are when was the Ben-

guela Current installed and when did it begin affecting the climate of the Namib coastal strip? Van Zinderen Bakker (1975) considered that it began in the Palaeogene whilst Siesser (1978) timed its onset as Late Miocene.

During the Eocene, corals grew near Bogenfels (Böhm, 1926), suggesting a warm, tropical to sub-tropical marine environment. Siesser (1978) and Van Zinderen Bakker (1975) estimated an Oligocene age for the onset of the Benguela Current on the basis of evidence from sediments sampled by drilling off the southwest African coast. According to these authors, the initial effects of the current along the Namibian coast were limited and sporadic, but by the Late Miocene a marked change occurred, resulting in the permanent installation of a cold current with upwelling cells along the coast. However, some of the marine molluscs from the 90 mP (metre package), 50 mP and 30 mP of Namaqualand belong to warm water lineages (Haughton, 1928; Pether, 1994) suggesting that littoral waters of the southeast Atlantic were warmer than they are today. The existence of the Benguela Current has been linked to ocean cooling during the Tertiary and the formation of permanent ice caps in the Antarctic (Brain, 1984).

Off the coast of southwestern Africa there is a persistent high pressure anticyclone. Near the coast the winds moving round this anticyclone are responsible for producing the Benguela Current by blowing warm surface waters from the littoral strip northwestwards into the Atlantic promoting the upwelling of Antarctic Intermediate Water along the coastline. According to Boyd (1983) the upwelling of cold water is due to the action of the wind close to the coast moving surface waters westwards towards the centre of the persistent high pressure cell. This displacement of relatively warm surface water leads to upwelling of deeper, colder water (8.3°-11°C) to the surface (Dingle *et al.*, 1996).

The six main upwelling cells off southern Namibia and South Africa vary in their temperature, salinity, dissolved oxygen and total organic matter. Dingle *et al.*, (1996) provide a detailed breakdown of the various parameters of the Namib, Walvis, Lüderitz, Namaqua, Columbine and Peninsula Cells. Temperatures range from 8.3°C for the Columbine Cell to as much as 11°C for the Walvis Cell, while salinities range between 34.63‰ to 35.00‰. The various upwelling cells are home to different assemblages of ostracods which means that ancient sediments which contain ostracods can be analysed and their palaeoecology reconstructed.

The movement patterns of marine water masses are extremely complex, there being several upwelling centres along the coast of South Africa and Namibia (figs 3-6 and 3-7). Not only do the positions of upwelling centres fluctuate, but upwelling itself occurs in pulses, the frequency of which varies throughout the year. At present the Benguela Current terminates northwards near the mouth of the Kunene River where it meets and intermixes with the

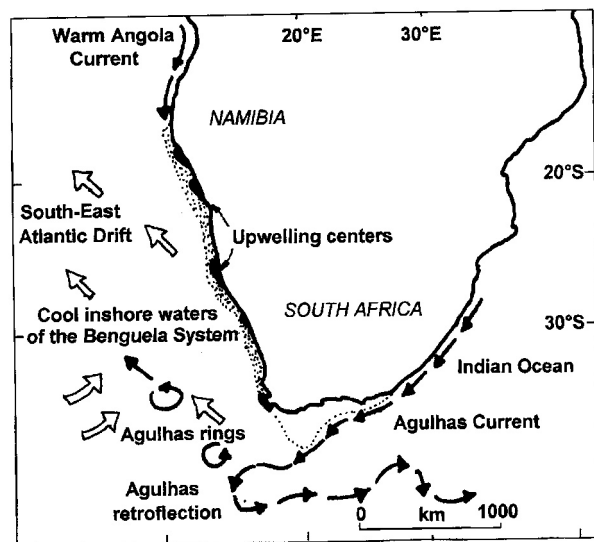


Figure 3-6.- Present day interplay between the Agulhas, Benguela and Angola Currents in the southeast Atlantic (after Cohen *et al.*, 1992). The Agulhas Current carves off rings of warm water which drift northwestwards and supply considerable quantities of energy to the Benguela Current which brings in cool waters from the Antarctic Intermediate Water. Upwelling masses of cold water from the Benguela Current impinge along the Namib coast, thereby greatly altering climatic conditions in the coastal strip. The south flowing Angola Current mixes with the north flowing Benguela Current at the latitude of southern Angola and thereby limits the northern extension of the Namib Desert, which today is the Carunjabamba River. In the past, however, this limit extended appreciably further north or south, depending on the position of the upwelling cells of cold water.

warm Angola Current. To the south the Benguela Current interacts with the Agulhas Current which carves off warm water eddies which move generally northwestwards with the flow of the South-East Atlantic drift (Cohen *et al.*, 1992) thereby contributing considerable quantities of heat to the Benguela system.

In the past, the latitudinal limits of the Benguela Current have varied so that at times it extended further north than it generally does today. According to Coetzee (1980) the Benguela Current may have reached as far north as Gabon. From time to time during the Plio-Pleistocene, northwards shift of its southern limits occurred which allowed warm water molluscs of Indian Ocean affinities to colonise the coastal waters of southwestern Africa as far north as Chameis Bay, if not further. In the north, its limits shifted southwards from time to time, so that the Atlantic warm water bivalve *Arca senilis* could establish itself as far south as Sechomib in the southern parts of the Skeleton Coast well south of its modern distribution limits in Angola.

It is likely that the northern and southern limits of the Benguela Current have been «mobile» ever since it was established in the Oligocene or Miocene. If this is so, then the effects of the current could at times have reached

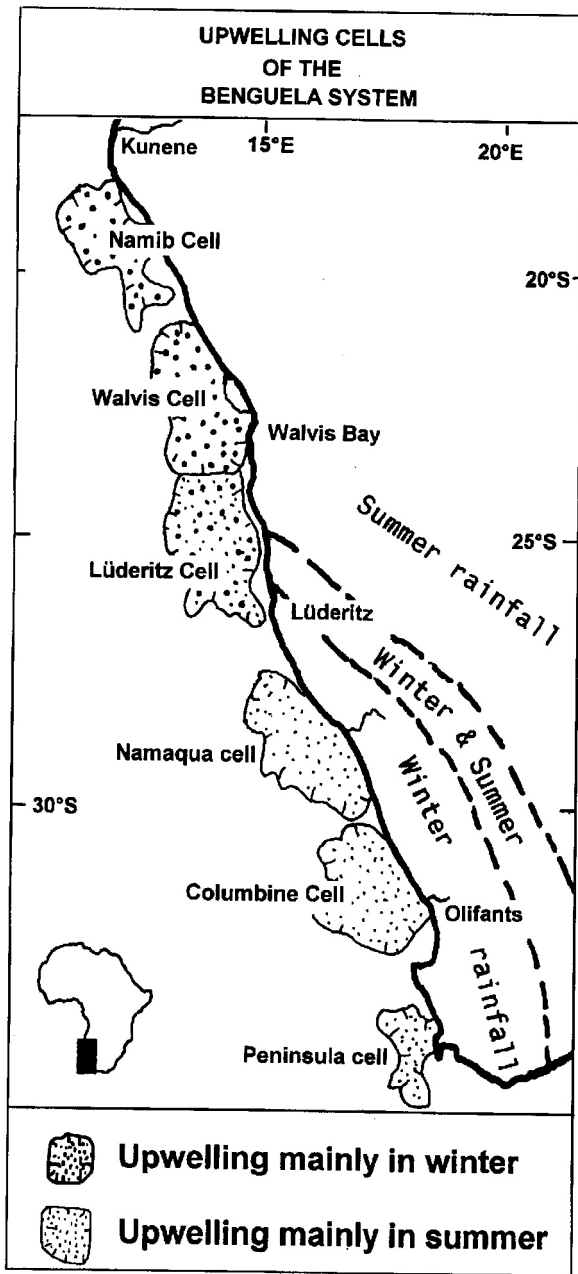


Figure 3-7.- Upwelling cells of the Benguela System according to Dingle (1994). At least six upwelling cells occur along the southwestern coast of Africa between latitudes 18°S and 35°S. Those north of Lüderitz tend to upwell mainly in winter, while those south of Lüderitz upwell predominantly in summer. At present, these cells are fairly stable in position, but during the geological past it has been suggested that they were displaced northwards as far as the Equator. This would allow warm waters from the Agulhas Current to circulate from the Indian Ocean northwards along the Namaqualand and Namibian coasts, which would in turn lead to the establishment of conditions suitable for warm water Indian Ocean molluscs to inhabit the coast of Namibia as far north as Chameis. Conversely, when the upwelling system is displaced southwards from its present position, warm waters of the Angola current can sweep the Namibian coast as far south as Sechomib, favouring the spread of tropical Atlantic molluscs far to the south of their present day distribution limits.

northwards well into Angola and at others have been withdrawn southwards to the central parts of Namibia.

One of the effects of the cold upwelling water masses is to produce an atmospheric temperature inversion in the air above the Namibian coast (Taljaard & Schumann, 1940). In the air column above Walvis Bay, for example, the temperature between 610 and 1830 metres increases before decreasing again above 1830 metres. This phenomenon not only traps the fog produced by the sea and keeps it close to sea-level, but also prevents the formation of rain clouds over coastal Namibia.

Widespread dune sand deposits (aeolianites) began to accumulate in the Namib towards the end of the Early Miocene. Prior to this aeolianites, such as those at Buntfeldschuh, were of localised distribution and are not precisely dated but must be post-Middle Eocene. Several researchers (summarised by Ward & Corbett, 1990) suggested that desert conditions characterised the Namib long before upwelling of cold waters associated with the Benguela Current was definitively established in the Miocene, but this seems not to be the case. New estimates of the ages of the Tsondeb Sandstones based on fossil discoveries place the onset of aeolian deposition at the end of the Early Miocene or the beginning of the Middle Miocene, meaning that the temporal offset between the establishment of desert conditions and the Benguela upwelling system was more apparent than real. There can be little doubt that the two phenomena are closely related.

3.3.6 CLIMATE

The climate of the Namib has been a source of interest ever since humans first came across it (Besler, 1972). Much has been written during the past century following its exploration, exploitation and colonisation by Europeans. A useful summary of the climate of southern Africa is given by Deacon & Lancaster (1988) in which the Namib is placed within its regional setting. A few pertinent points need to be made.

The climate of the region is to a great extent controlled by the position of the South Atlantic anticyclone to the west of the continent and the Indian Ocean anticyclone to the east, both of which are centred on latitude 30°S. The circum-polar westerlies lie to the south of the continent (Hay, 1993).

Because of southern Africa's mid-latitude position, its southwardly tapering shape and the presence of anticyclones off its shores, its climate is generally arid. Only the eastern fringe of the continent enjoys a growing season longer than 9 months of the year (fig. 3-8). In contrast, in the Namib the growing season is less than 3 months per year. North of 20°S latitude the climate is influenced by the seasonal movement of the Inter-Tropical Convergence Zone (ITCZ) with the result that more humid and

more tropical conditions prevail in the interior. However, the northern Namib remains extremely arid because of the influence of the Benguela Current and because of its position on the rain shadow side of the continent.

3.3.7 BENGUELA-NAMIB INTERACTIONS

It is often assumed that the Namib Desert and the Benguela Current are mutually inter-related systems, the upwelling of cold waters leading to intensification of aridity in the region, whilst the presence of the desert promotes strong winds which blow relatively warm surface waters away from the coast, thereby leading to increased upwelling of relatively cold, dense water. The intermediary in many of the Benguela-Namib interactions is the atmosphere, but there are others which have played a role in the geological past, including sea-level changes, regional climatic changes and biological factors among others (Shannon *et al.*, 1989a, b).

As Shannon *et al.* (1989b) point out «Wind transports water and inorganic and organic matter both ways between the land and the sea, affecting energy flows and nutrient cycling in both systems». These authors also stress that it is possible to view «the Benguela and the Namib

as two largely separate conveyor belts, moving parallel to each other in a northerly direction with some lateral connections between them as they shed air, water, nutrients and sand at their interface.» As a result, one sees in the literature many papers either stressing or playing down the interactions between the Benguela and the Namib.

Given that the cold waters of the Benguela Current are derived ultimately from the Antarctic Intermediate Water (Moroshkin, *et al.*, 1970; Currie, 1953; Darbyshire, 1963), and the powerful winds that prevail along the Namib coastline are related to the South Atlantic Anticyclone (Coetzee, 1980), one could indeed conclude that there are two separate 'engines' working in the region, which 'coincidentally' happen to cover parts of the same or juxtaposed territory. The fact that the Namib Desert and the Benguela Current have persisted as parallel entities since the Middle Miocene, suggests, however, that there is probably an overall link between the two at some level, perhaps on the scale of the South Atlantic Ocean. At more local levels or scales, it is possible to infer the presence of more subtle interactions, some of which might operate intermittently, thereby suggesting juxtaposed but separate systems.

3.3.8 WINTER RAINFALL

South of the Aus-Lüderitz road, the Namib is subjected to winter rainfall, which is why the main growing season occurs during the coldest part of the year. Because the area is also extremely windy and the soils generally of poor quality, plants have adapted in various ways to this triple peculiarity, producing the fynbos of the Cape Floristic Zone. The fynbos is dominated by succulents and low plants with small leaves. Palaeobotanical evidence (leaves, stems, seeds) from Swartlinterjies (Namaqualand) indicate that fynbos had already become established in the southern Namib by the end of the Miocene, and it may have its origins in the Middle Miocene.

The acavid snail *Trigonephrus* is today restricted to areas of winter rainfall in southern Africa (fig. 4-43). Its presence in aeolianites of the Sperrgebiet which range in age from Middle Miocene to Recent, indicates that the southern Namib has been subjected to winter rainfall for the past 15 Ma. Faunal and floral evidence from sediments older than this indicate that prior to 15-16 Ma the southern Namib used to be sub-tropical with summer rainfall. Another acavid snail *Dorcasia*, whose present day southern distribution limit is the Orange River (fig. 4-43) has been found abundantly as far south as Saldanha Bay, South Africa, in Middle Miocene and later sediments. Furthermore, the land snail *Xerocerastus* (fig. 4-44) which is a steppe to savannah group, has been found in aeolianites of Early Pleistocene age at Daberas, southern Sperrgebiet. All this suggests that the various climatic zones of southwestern Africa have fluctuated in position during the Miocene and Plio-Pleistocene.

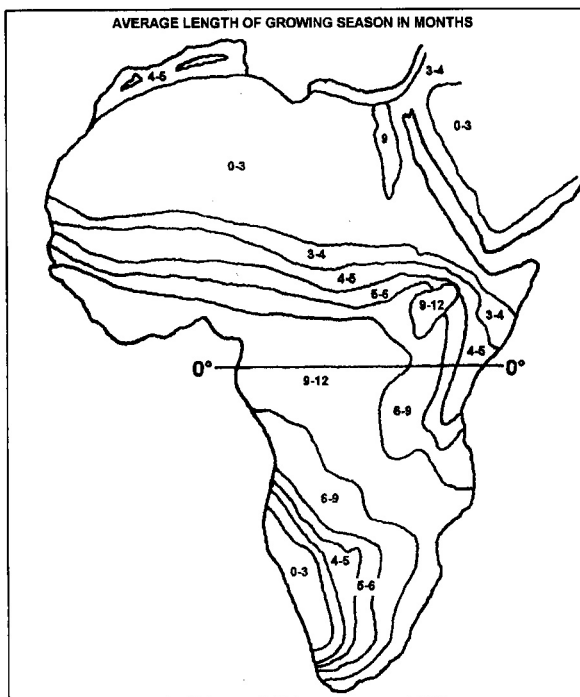


Figure 3-8.- Average length of growing season in months in Africa. In much of Namibia the growing season is less than 4 months per year, while along the coastal strip it is usually between 0 and 3 months. In the Namib south of Lüderitz, the growing season occurs in winter, whereas to the north it occurs during the summer. In the Namib Desert close to the coast, humidity derived from fog is an important source of water, which effectively lengthens the growing season of some plant species adapted to tapping this source.

3.3.9 PALAEOCLIMATOLOGY

Studies carried out by numerous authors have led to varying interpretations of the climatic history of the region (Brain, 1984; Coetzee, 1978; Cooper, 1974; Dingle, 1973, 1976; Dingle & Hendey, 1984; Dingle & Scrutton, 1973; Dingle & Siesser, 1977; Heine, 1983; Heine & Geyh, 1984; Johnson & Shackleton, 1988; Korn & Martin, 1937; McMillan, 1987; Rogers, 1977; Shackleton, 1988; Siesser, 1978, 1980; Tankard & Rogers, 1978; Van Zinderen Bakker, 1975, 1984; Vogel, 1987). It has been proposed that upwelling along the southwest African coast associated with the Benguela Current became established during the Late Miocene (Siesser, 1980) although the current may have been in existence since the Oligocene (Van Zinderen Bakker, 1975). There is little doubt that cold upwelling centres accentuate the aridity of coastal Namibia and southern Angola (Andrews & Hutchings, 1980; Shannon, 1985).

Ward *et al.* (1983) and Brain (1984) discussed the origin of the Namib in its regional climatic context, concluding that its arid nature is related to a combination of three factors - a) the mid-latitude position of the region dominated by anticyclonic weather systems which renders mid-latitude Africa semi-arid to arid, b) the area lies on the rain-shadow side of the continent, and c) the Benguela current which affects the climate of the coast of southwestern Africa (Andrews & Hutchings, 1980; Cohen *et al.*, 1992), intensifies the already arid nature of the region to make it extremely arid (Brain, 1984; Siesser, 1980; Van Zinderen Bakker, 1975, 1984).

Between the two desert phases in the Namib, Ward & Corbett (1990) recorded a pluvial phase followed by a pedogenic phase which they believed occurred during the Middle Miocene. Pedogenesis resulted in the widespread formation of calcretes in the Namib along its inland and coastal edges. Recent researches have revealed, however, that some of the sediments which were taken by Ward & Corbett (1990) as evidence for pluvial conditions were deposited during the Early Miocene prior to the accumulation of the aeolianites of the Namib Sand Sea (i.e. before the deposition of the Rooilepel Sandstones and the Tsondab Sandstones), while others such as the Karpfenkliff Conglomerates post-date the Tsondab Sandstones. The Kamberg calcretes which are younger than the Karpfenkliff Conglomerates were originally considered to provide evidence of Late Miocene pedogenesis but are now known to be younger than the Pliocene on the basis of their stratigraphic position. 15 metre thick calcretes at Areb, northern Namaqualand, South Africa, overlie clays which yielded the Pliocene equid *Hipparion namaquensis*, which indicates that they are thus younger than ca 4 Ma. Interfluvial calcretes in the Namib, which may or may not be equivalent in age to the Kamberg Calcrete (detailed study remains to be done on these deposits) contain Late Pleistocene mammalian remains in several outcrops. Calcretes in the Kuiseb area yielded Late Pleistocene C 14 ages of 16 Ka and 26 Ka (Heine, 1985a, b, 1992) but the deposits may well be older (Ward, personal communica-

tion, 1998) on the grounds that the Oswater Conglomerate contains pedogenic calcrete clasts. All this means that the sequence and timing of events in Namib history need adjustment.

According to Heine (1992), there were two periods during the Late Pleistocene during which the highlands of Namibia were more humid than they are today: ca27-29 Ka and 13-17 Ka. Nearer the coast, Heine found evidence of greater humidity than modern levels at about 2 Ka and 5-8 Ka. The youthfulness of the calcretes analysed has been confirmed by Blümel (1976, 1979, 1981, 1982) and Blümel & Vogt (1979).

3.3.10 PALAEOWIND DIRECTIONS

Ward & Corbett (1990) reported that the Tsondab Sandstone and equivalent aeolianites of their proto-Namib Desert phase accumulated under a prevailing southerly palaeo-wind regime and they concluded that the younger dunes assigned to the Sossus Sandstones also accumulated under a southerly wind regime. They pointed out that all the outcrops of sandstone assigned to their Namib Desert Phase have cross bedding invariably oriented northwards. Outcrops observed by them include those at Kolmanskop and Annental in the southern Namib, sandstones associated with the Oswater Conglomerate and the Khommabes Carbonate in the central Namib, aeolianites in the Tumas valley, in the Omaruru fan delta, and in the Uniab and Engo-Kunene areas.

Cross-bedding in the Tsondab aeolianites tends to support this thesis, yet there are important exceptions. For example, the strata which contain eggshells of *Namornis oshanaï* at Elim and Diep Rivier (i.e. basal Middle Miocene in age) have south west oriented cross-bedding. To the south west of Haiber Hill, the aeolianite exposures which contain eggs of *Diamantornis laini* (i.e. Late Miocene in age) have cross-bedding indicating that wind was blowing from the north to the south at the time of deposition, while the underlying strata that yield eggs of *D. wardi* (Middle Miocene) have northerly oriented cross-bedding. It is not yet known whether these exceptions represent localised wind patterns or whether they represent regional scale changes in wind regimes during the past.

In the area north of the Kuiseb River, the predominant orientation of wind sculpted features on boulders and bedrock is from the northeast towards the southwest (Harmse, 1980, 1982; Heine, 1987; Selby, 1977b; Sweeting & Lancaster, 1982; Besler, 1980) (fig. 3-9). This direction coincides precisely with the orientation of the berg winds of western Namibia (Whitaker, 1984) (figs. 3-10 and 3-11) and it is likely that these powerful winds have caused the sculpting and faceting of the bedrock and loose clasts. The south winds, even though they occur more times per year, are not as powerful as the berg winds, and thus leave less noticeable traces of their passage in this region.

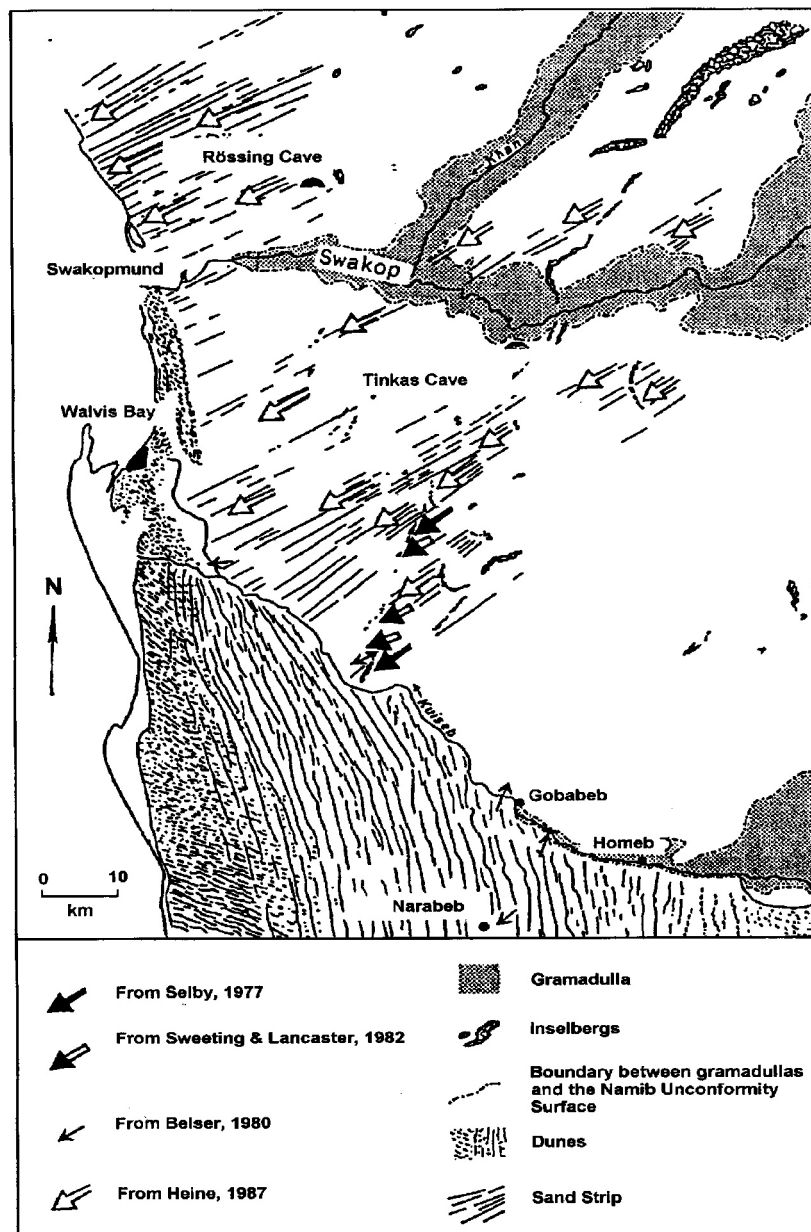


Figure 3-9.- Palaeowind indicators in the Central Namib (from Heine, 1986). In the area between the Swakop and Kuiseb Rivers, Berg Winds blow strongly from northeast to southwest, accomplishing a great deal of superficial erosion of exposed bedrock and boulders, whereas to the south of the Kuiseb, in the Namib Sand Sea, the traces left by the passage of these winds are soon eradicated by the prevailing southerly winds that blow parallel to the coastline.

3.3.11 PALAEOENVIRONMENTS

The general view concerning the Namib is that it has been almost continuously arid throughout the Neogene, with only a few relatively short episodes of more humid conditions during the Miocene and Quaternary (Ward & Corbett, 1990), the latter being deduced principally from sedimentological and pedological data (former lakes in the Namib, calcretes). Fossil evidence which might throw light on palaeoenvironments of the Namib has until recently been extremely limited. What little that has become available is restricted to short parts of the geological column, with most of it being from Late Pleistocene to Holocene deposits.

The lack of palaeontological data is due mainly to the nature of the sediments in the Namib which means that classic methods of palaeoenvironmental reconstruction, such as palynology, can be applied only infrequently. In view of the dearth of information, there have been few attempts to view the evolution of the Namib in a wider context, such as its interactions over geological time with neighbouring biogeographic districts.

There are better data from a fuller geological succession from the Western Cape Province, South Africa, which has enabled Coetzee (1977) to reconstruct the long term pal-

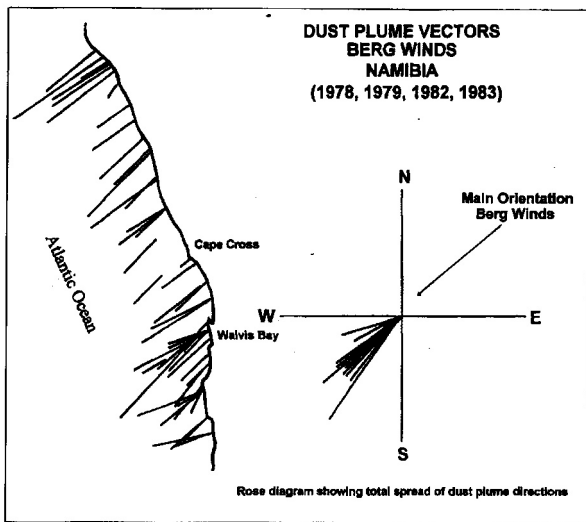


Figure 3-10.- Dust plume vectors of Berg Winds in coastal Namibia. Dust plumes observed on Meteosat imagery dating from 1978, 1979, 1982, 1983 (data from Whitaker, 1984) reveal that they have a regular southwesterly orientation quite different from that of the prevailing southerly winds which flow parallel to the coastline.

aeoenvironmental and biogeographic changes that took place from Late Oligocene times onwards. Coetzee reported that at the Cape palm-dominated sub-tropical to tropical vegetation alternated with conifer forests during the Tertiary. From Pliocene times onwards, the Cape became more arid and a winter rainfall regime was established.

Coetzee (1977) recognised eight pollen zones in cores from the southern Cape (Table 3-1).

Even though the stratigraphy of Coetzee's (1977) reconstruction is rather coarse, and the subdivisions relatively long lasting, it seems likely that the climate at the Cape has fluctuated between tropical and temperate types since the Oligocene. Despite the limitations of the data base and its relatively poor time resolution, this reconstruction is interesting, because it is becoming clear from the Namib fossil record that comparable changes also occurred in southern Namibia. For example, in the Early Miocene and at the base of the Middle Miocene, the Namib was evidently sub-tropical to tropical because crocodiles and large tortoises could survive there. By the middle of the mid-Miocene, these reptiles had disappeared and a temperate fauna (including the acavid snail *Trigonephrus*) inhabited the region.

Southern European climates also fluctuated during this time period (Pickford & Morales, 1994). At present southern Europe is temperate, but during the Miocene it was often sub-tropical to tropical. Coetzee (1977) discussed the Cape palynological evidence in relation to events in the Antarctic, and cited warm periods in the Antarctic at 19 Ma, 14 Ma and 8 Ma. These warm periods coincide in

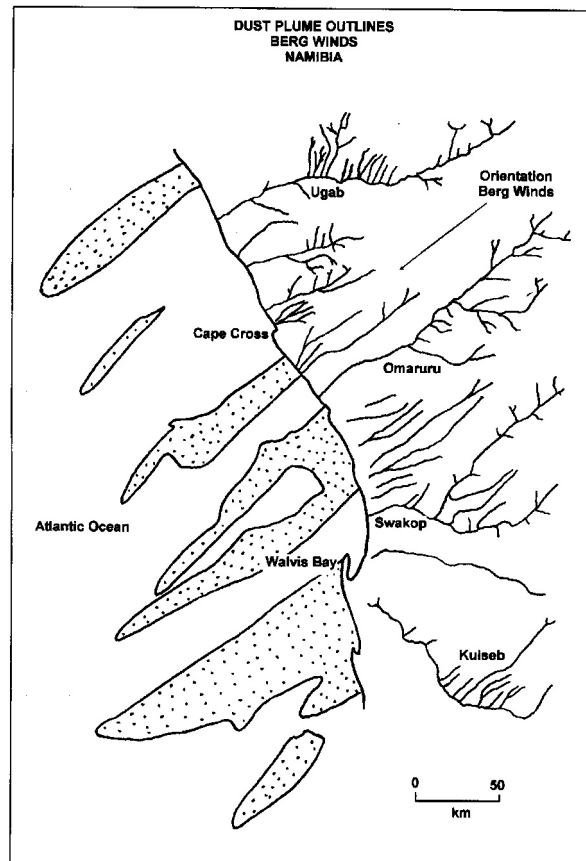


Figure 3-11.- Outlines of Dust Plumes produced by Berg Winds in coastal Namibia between 1978 and 1983. These plumes are parallel to the major drainage lines in the Central Namib (redrawn from Whitaker, 1984). These plumes are a major source of terrigenous sediment in the southeast Atlantic, locally being more important than the various rivers which drain towards the Atlantic but which often do not debouch into the ocean, depositing their sediment load near the coast but onland.

time with cold periods in southern Europe (Pickford & Morales, 1994). The opposite polarity of these climatic changes in the two hemispheres suggests that they were asymmetric with respect to the Modern Equator which supports the graticule shift model of climatic change rather than the concertina or accordion model (Pickford, 1992) (fig. 4-46).

A fuller understanding of the timing of events and the history of climatic change in the northern and southern hemispheres would be of interest as it might allow resolution of the debate concerning how global climates change - the graticule shift and accordion models of ecoclimatic belts (Pickford, 1992). Although the concertina model has been prevalent in the literature over the past half a century, it would appear that recently the graticule shift model is obtaining more and more support of the kind that refutes or weakens the concertina model.

TABLE 3 - 1

POLLEN ZONES OF THE SOUTHERN CAPE PROVINCE (after Coetzee, 1977)			
POLLEN ZONE	INFERRED VEGETATION	INFERRED CLIMATE	SUGGESTED STRATIGRAPHY
M	Present Macchia	Present day type	Quaternary
Lvii	First strong development of Macchia	Colder drier	Pliocene
Lvi	Forest : Coniferae, Casuarinaceae, Cupaniedites	Cool wet	Late Miocene
Lv	Palmae	Sub-Tropical to Tropical	
Liv	Restionaceous swamp	Temperate, locally wet	
Liii	Forest : Coniferae, First Compositae	Cool wet	
Lii	Palmae	Sub-tropical to Tropical	Late Oligocene
Li	Forest : Coniferae	Cool wet	Late Oligocene

3.4 POST BREAK-UP SEDIMENTS OF THE NAMIB

3.4.1 ONSHORE GEOLOGY

3.4.1.1 Marine strata

3.4.1.1.1 Wanderfeld IV Outcrop

Small outcrops of marine strata at Wanderfeld IV consist of a silty limestone bed rich in molluscan shells, principally *Rhynchostreon suborbiculatum*, overlying a yellowish-brownish silty sand with lamellibranchs.

The thickness of the strata is about 20 cm. Klinger (1977) and Cooper (1974) estimated a Cenomanian age for these beds (Table 3-2, p. 43).

3.4.1.1.2 Buntfeldschuh

The extensive cliff exposures at Buntfeldschuh have yielded very few fossils. It has become almost traditional to consider the scattered outcrops of sediment at Buntfeldschuh, Langental, Eisenkieselklippenbake and Advokat Bake to be part of a single depositional episode of Palaeocene-Eocene age. However, the argument is based on altitudinal and geomorphological considerations and not on direct evidence of contemporaneity. The only well dated strata among these localities are those at Langental.

The marine strata at Buntfeldschuh lie on a wavecut platform carved into kaolinised Late Proterozoic rocks some 120-140 metres above sea level. The most comprehensive description of the Buntfeldschuh sediments was given by

Corbett (1989) who recognised a lower marine formation (subdivided into two units) some 45-50 metres thick and an overlying sandstone member 50-60 metres thick, part of which has been extensively ferruginised subsequent to its accumulation (Kaokoberg). Corbett (1989) reported that at the northern end of the escarpment, the base of the marine unit overlies Pomona silcrete.

Shark teeth (*Isurus* sp.), brachiopods (*Lingula* sp.) and burrows (probably made by *Lingula* sp.) are the only fossils so far found at Buntfeldschuh. *Isurus* has a long stratigraphic range (Lutetian to Present) meaning that the Buntfeldschuh sediments cannot be as old as Palaeocene. They must be younger than Early Eocene. Haughton (1930a, b, 1963) considered that the Buntfeldschuh sequence post-dated the terrestrial Pomona Beds on the grounds that the basal gravels at Buntfeldschuh contain reworked pebbles of Pomona lithologies. The presence of clasts of phonolite in gravel layers at Buntfeldschuh suggested to Pether (1994) that the sediments post-date the Klinghardt volcanics (37 ± 1 Ma (Kröner, 1973)) and would therefore date from the Oligocene. However, Ward and McMillan (pers. comm. 1997) consider that the marine succession is Bartonian in age on the basis of tectonostratigraphic resemblances to offshore successions in the southeast Atlantic, and if they are correct, then the Buntfeldschuh sediments would be older than those at Langental Eocene site, in accordance with suggestions made by Siesser & Salmon (1979) on geomorphological evidence. If the correlation is valid, then the Buntfeldschuh deposits would date between 41.2 and 36.9 Ma (Berggren *et al.*, 1995). It should be noted however, that Stocken (1978) considered the marine strata at Buntfeldschuh to be equivalent to those at Langental Eocene site on the basis of clast assemblages (SACS, 1980). The marine strata at Buntfeld-

schuh are overlain by aeolianites, possibly of Eocene or Oligocene age, and by calcrete and unconsolidated sands of Quaternary age.

The southern end of the cliffs at Buntfeldschuh have been heavily ferruginised (Corbett, 1990) and the name Kaokoberg (Chocolate Mountain) has been applied to it.

3.4.1.1.3 Langental Eocene Deposits

The Langental Eocene strata are 7-8 m thick. The sediments consist of 4 m of pebbly sandstone overlain by thin concretionary calcareous sandstones, marls and silts overlying about 3-4 m of unfossiliferous sandstones. The outcrops are richly fossiliferous, containing a varied and abundant microflora (Siesser & Salmon, 1979) and macrofauna (Böhm & Wiessermel, 1913; Böhm, 1926; Oppenheim, 1912, 1914, 1919) of marine affinities (Tables 3-3, 3-4, p. 43-44). The age of the strata has been estimated as Late Eocene (NP19-20 = Priabonian) (Siesser, 1977; Siesser & Salmon, 1979). According to Berggren *et al.*, 1995, this would mean that the deposits are between 35.5 and 34 Ma.

3.4.1.1.4 Phosphates

Huge reserves of phosphorite occur in the coastal waters of Namibia and South Africa (Watkins *et al.* 1995). In places phosphorites crop out on land, for example at Walvis Bay, in Namaqualand and at Langebaanweg, Cape Province, South Africa (fig. 3-12). These phosphate rocks are usually thought to have accumulated in Miocene to Recent times, with the main period of formation taking place in the Early Pliocene (McArthur *et al.* 1990; Rogers, 1977; Birch, 1975). They probably owe their origin to upwelling of nutrient-rich cold waters of the Benguela Current followed by the precipitation of phosphate as the waters warmed up on their approach to the coast which is known to have contained a warm water fauna during the Late Miocene and Pliocene.

3.4.1.1.5 Rooikop Gravels

East and southeast of Walvis Bay occur coarse grained shallow marine deposits containing reworked phosphatised sediments and fossils (Miller & Seely, 1976). These deposits, called the Rooikop Gravels by Ward (1987) are rich in fossils, principally shark teeth, internal moulds of gastropods and oyster shells. Pether (1986) recorded the species *Donax rogersi* and *Fissurella glarea* in these gravels, and proposed a correlation to the 30 metre package of Namaqualand. On the basis of the faunal content Ward (1987) suggested that these gravels accumulated in warm waters. He tentatively correlated them with the older beaches in the Oranjemund area. However, as was pointed out by Ward, the Rooikop Gravels appear to represent a composite sedimentary unit possibly deposited at widely different times, ranging in age from Late Miocene to Pleistocene.

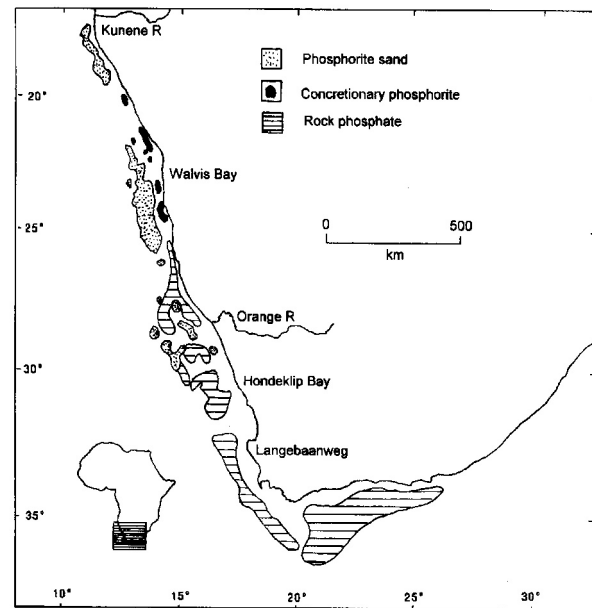


Figure 3-12.- The distribution of phosphorites in the coastal waters of Namibia and South Africa, based on Bremner & Rogers (1989) and Watkins *et al.*, (1995). There is a close spatial relationship between the phosphorites and the upwelling centres of the Benguela Current, suggesting a cause and effect phenomenon, upwelling waters being rich in nutrients. Phosphogenesis is at present extremely slow to absent due to the absence of warm waters along the shoreline. During the Miocene and Pliocene, coastal waters were warm - supporting a tropical malacofauna - with the result that nutrient-rich cold waters warmed up as they approached the coast, whereupon they precipitated much of their phosphate content.

Similar marine sediments containing abundant molluscs and some vertebrates were found by the NPE at Tsondabmund (Conception Bay Pump Station) in dumps excavated from subcrops below sand dunes. These overlie basement rocks, and like those at Rooikop 100 km to the north, are ferruginous and possibly phosphatic.

3.4.1.1.6 Mio-Plio-Pleistocene Beach deposits

Stretching along the coast both north and south of the Orange River mouth, is a series of raised beach deposits. They are seldom more than 3 km wide, but are hundreds of kilometres long, hugging the present day coastline (Gresse, 1988) as far north as Chameis Bay. There are other discontinuous occurrences even further north along the Namibian and Angolan coasts (Besler *et al.*, 1994). The earliest of these beach deposits is generally considered to have formed during the Early Pleistocene, although some researchers have correlated the earliest beaches to the Middle Miocene. There have been various interpretations of these sediments (Stocken, 1962, 1978; Hallam, 1964; Gresse, 1988), in particular regarding the number of beaches present, their geomorphological conformation and their ages (Davies, 1973; Fowler, 1976; Hendey, 1981; Pether, 1986; Stocken, 1978; Stocken &

Campbell 1982).

The highest (and oldest?) beach deposits contain warm water fossil faunas (Haughton, 1931) while the lower (youngest) beach deposits yield cold water faunal elements (Kensley & Pether, 1986). Stocken & Campbell (1982) correlated the older beach deposits with the mid-Miocene Arrisdraft deposits on account of their altitude and the presence in the latter of brackish water serpulids, but this correlation was questioned by Pether (1986) who preferred a Pleistocene age for all the raised beach deposits of the southern Namib because of the presence in them of *Donax rogersi*.

Recent studies in the Hondeklip Bay area, Namaqualand (Pickford & Senut, 1997) reveal that marine deposits between 40 and 45 metres above mean sea level (msl) contain terrestrial and marine fossils of Early Miocene (18-17.5 Ma), Middle Miocene (12-10 Ma) and Late Miocene (7-5 Ma) age, indicating that this particular altitudinal interval was occupied by the sea at least three times during the Neogene. In many places Early Miocene beach deposits at such altitudes have been destroyed or reworked during later episodes of high sea level, and are effectively now unrecognisable. Nevertheless, durable clasts, including diamonds, could have been reworked and then redeposited at much the same altitude that they had during earlier depositional episodes. During redeposition such durable clasts would have been joined by newly input materials, making for richer deposits than would otherwise have been the case.

3.4.1.2 Continental deposits

3.4.1.2.1 Silcretes and other silicified sediments

Much has been written about silcretes in southern African contexts (Partridge & Maud, 1987). Most opinion appears to favour a Cretaceous age for the South African silcretes and in Namibia this has been taken as evidence of age of siliceous surface rocks in the Namib (Ward, 1987, Stocken, 1978).

Some of the silcretes in the Namib may indeed be of Cretaceous age, including siliceous rocks at the summit of Skilpadberg and other hills in the vicinity of the Orange River. In any case they are positioned far above river level and presumably predate the downcutting of the Orange River Valley. The silcretes of the northern Sperrgebiet were thought to be pre-Eocene on the grounds that clasts of silcrete occur in the Eocene marine sediments at Langental (Beetz, 1926). However, in the fossiliferous parts of the Langental basin there are no silcrete clasts, while the unfossiliferous beach deposits cropping out nearby and assumed to be of Eocene age, contain siliceous boulders and pebbles which are not of pedogenic origin, but which are more likely to have formed as veins and vug fillings in the basement during near-surface hydrothermal

activity. The age of these siliceous boulders is unknown as is the age of the beach deposits in which they occur.

The Pomona Beds were reported by Du Toit (1954) to consist of a basal pebble conglomerate which is overlain by clayey and calcareous sandstones with pebble stringers. The beds were said to be up to 35m thick and are capped by dolomitic silcrete and calcrete. Du Toit (1954) reported the discovery of the acavid land snail *Dorcasia antiqua* in the Pomona beds, probably on the basis of a specimen found by Beetz (1926). However, Beetz's specimen was found in calcrete overlying the 'silcrete' and the fossil is consequently of Pleistocene age. Calcrete overlying quartzites collected near Pomona (Corbett, pers. comm.) contains sandstone nodules with eggshell fragments of *Struthio daberasensis*, a post-Miocene species.

The sedimentary facies of the Pomona Quartzite suggests that these strata are continental in origin and not marine. Martin (1973a, b) recorded that the silcrete and calcrete were overlain and baked by alkaline lavas from the Klinghardt Mountains. If this were so, then these beds would probably be older than 37 ± 1 Ma (Kröner, 1973). However, the Swartkop quartzite occurrence, which was the basis for Martin's observations, is a silicified fluvial conglomerate overlain by a phonolite lava flow. This outcrop therefore has no direct bearing upon the determination of the age of the "Pomona Quartzites" in the vicinity of Pomona. The regolithic nature of the quartzites of the tafelberge near Pomona is confirmed by Pether (1994) who showed that their geochemical composition was typical of silicified sediments rather than of pedogenic silcretes (fig. 4-27).

Stocken (1978) discussed the history of ideas concerning the Pomona siliceous deposits and the sediments that underlie them. The word Pomona has been used rather indiscriminately in the literature to the point where it has become virtually synonymous with silicified rocks of any sort and age that occur in southwestern Africa (Kaiser, 1926; Reuning, 1931; Stocken, 1978; Partridge & Maud, 1987; Pether, 1994). Stocken (1978) attempted to clarify the situation by recognising two deposits in the tafelberge around Pomona, a lower clastic unit which he called the Pomona beds, and an upper silicified unit which he called the Tafelberg Quartzites. He considered both units to be Late Cretaceous in age. He rightly recognised that the deposits at Chalcedon Tafelberg had nothing to do with the Tafelberg Quartzites, and he mentions that they overlie a monchiquite intrusion of Middle Miocene age. Nevertheless at some stage the siliceous deposits at Chalcedon Tafelberg became erroneously incorporated into the "Pomona Quartzites" (SACS, 1980) and the name Chalcedon Tafelberg Silcrete has subsequently featured in arguments about the geomorphological history of the region (Partridge & Maud, 1987).

Corbett (1989) considered the Pomona beds and the Tafelberg Quartzites of Stocken (1978) to be lateral facies

variations within a single unit which he collectively termed the Pomona Silcrete. Incidentally, Corbett appears to have credited Stocken (1978) with naming the Chalcidon Tafelberg Silcrete, but this appears to be an error. The name appears to date from SACS (1980). The Chalcidon Tafelberg deposits accumulated in a depression as carbonate-rich sediments intercalated with cherts. These siliceous rocks eroded more slowly than the superjacent country rocks, leaving the resistant infilling of the depression elevated above the surrounding countryside - a fine example of inverted relief. The important point about this outcrop is that it reveals something about the rate of erosion by downwasting in the area - dozens of metres in some 15 Ma.

In fact the Pomona Tafelberg field consists of silicified grits and regoliths which infilled valleys in an irregular topography, similar to the alluvial-filled valleys that occur in the same region today. Once these surficial deposits had been silicified, they were more resistant to erosion than the surrounding bedrock, with the consequence that, today, they form mesa-like erosional remnants oriented in two subparallel lines of outcrops (fig. 3-13). The Pomona quartzites are not, strictly speaking, silcretes, even though they have often been called such (Pether, 1994). They are silicified alluvial sediments, with virtually no pedogenic characteristics apart from some development of colloform structures (Ward, personal communication, 1998). In a few places, the Pomona Quartzites overlie kaolinites, «laterites» and other palaeosols which affected rocks of the Gariiep Complex. In contrast, at Chalcidon Tafelberg, the Miocene cherts overlie a deep soil profile which formed on the monchiquite intrusion prior to the infilling of the crater by sediments. This soil is not like the nearby kaolinites developed on basement rocks, being a grey-green soil developed on a volcanic substratum.

In Namaqualand there are silicified strata of various ages. The «Pomona Quartzites» (or 'hard banke') of Namaqualand, which crop out near the Oliphants River, Namaqualand (Reuning, 1931) are of Neogene age, being intercalated within Miocene littoral marine sediments. Similar deposits occur further north at Hondeklip Bay, Somnaas, Swartlintjies and elsewhere. The correlation by Reuning of the Namaqualand 'hard banke,' with the silicified deposits near Pomona, Namibia, is debatable, since their lithologies are completely different from each other (Pether, 1994).

3.4.1.2.2 Early Miocene fluvio-lacustrine deposits of the northern Sperrgebiet

Fluvio-lacustrine deposits were recorded in the northern part of the Sperrgebiet as early as the first decade of this century (Merensky, 1909). These deposits (fig. 3-14) subsequently yielded abundant terrestrial fossils (Stromer, 1926; Hopwood, 1929; Hamilton & Van Couvering, 1977) and it became clearly established that they were of Early Miocene age. Sedimentological studies on the Elisabeth Bay Formation were carried out by Greenman (1966,

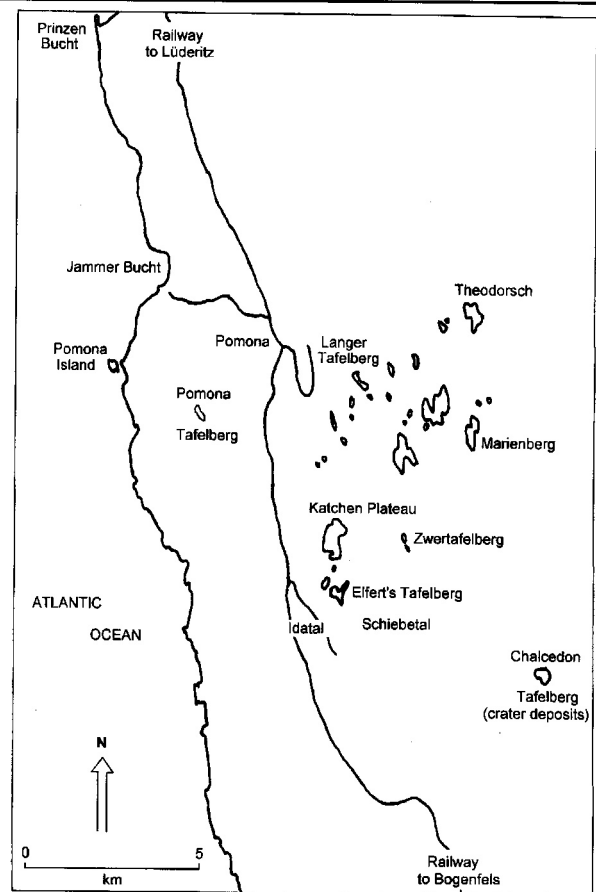


Figure 3-13.- Outcrops of the Pomona Silcretes in the northern Sperrgebiet. Two sub-parallel lines of quartzite mesas trend northwest to southeast with a gentle inclination towards the coast. The silicified deposits accumulated in valleys but now stand proud of the surrounding countryside due to the more rapid erosion of the superjacent basement rocks. It is doubtful that there was a regional silcrete sheet in the Sperrgebiet of which these few remnants are all that remain. It is more likely that these deposits were always localised in their distribution and that they are not of pedogenic origin. The siliceous deposits at Chalcidon Tafelberg to the southeast of the Pomona mesas represent a different depositional environment - they are silicified sediments that accumulated in a crater.

1970) (fig. 3-15) and subsequently by Corbett (1989). It is clear from the form of the outcrops in the northern Sperrgebiet that these Early Miocene sediments occupy ancient valleys incised into the coastal plain (fig. 4-2). The upper reaches of these ancient valleys are filled with Late Tertiary to Quaternary deposits, but near the coast these have been removed by erosion so that the underlying Early Miocene sediments are exposed. At Elisabethfeld, the outcrops occur in the base of a deflation basin. The depth of the pre-Miocene valley that they fill is unknown. Off-shore, a submarine valley that is possibly the downstream extension of the Kaukausibital (Grillental- Elisabethfeld complex) has been mapped (O'Shea, 1971).

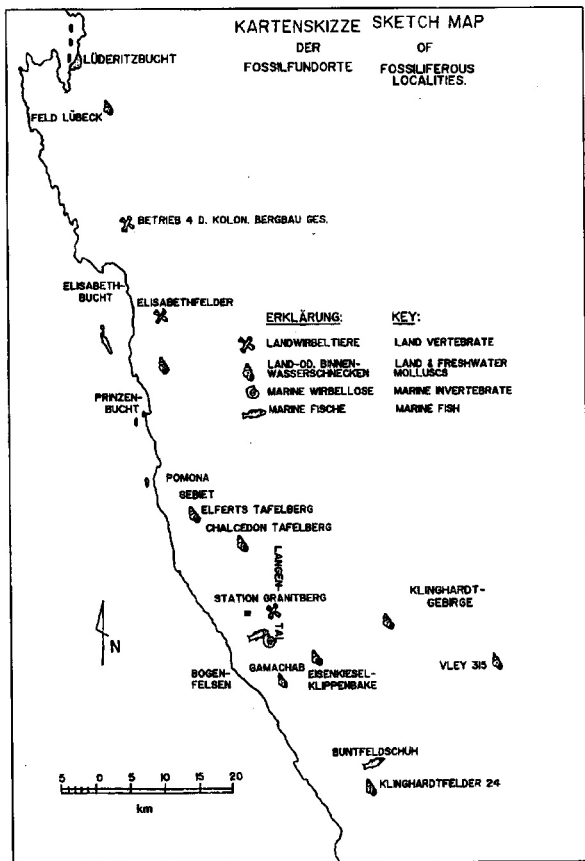


Figure 3-14.- Fossiliferous localities of the northern Sperrgebiet known to Stromer (1926).

Ward and Corbett (1990) considered that the Early Miocene fluvio-lacustrine deposits in the northern Sperrgebiet (Grillental, Elisabeth Bay, Langental and Glastal) resulted from an onset of pluvial conditions which terminated the proto-Namib Desert phase during which the Tsondab Sandstone had been deposited. They thought that this pluvial phase continued through the Early and Middle Miocene, during which the proto-Orange deposits accumulated (Arrisdriфт notably) and only terminated when the Kamberg Calcrete formed, as they thought, at the end of the Middle Miocene.

However, it is now known that the fluvio-lacustrine deposits in the northern Sperrgebiet accumulated prior to the Tsondab Sandstone and its equivalents. The timing and sequence of events reconstructed by Ward & Corbett (1990) thus need amending, principally by shifting their Proto-Namib and Kamberg Calcrete events upwards in time.

3.4.1.2.3 Palaeo-Orange deposits (Arries Drift Gravel Formation)

The Orange River has drained a large sector of the interior of South Africa since at least the Oligocene if not the Cretaceous (fig. 3-16). In places, remnants of its bedload

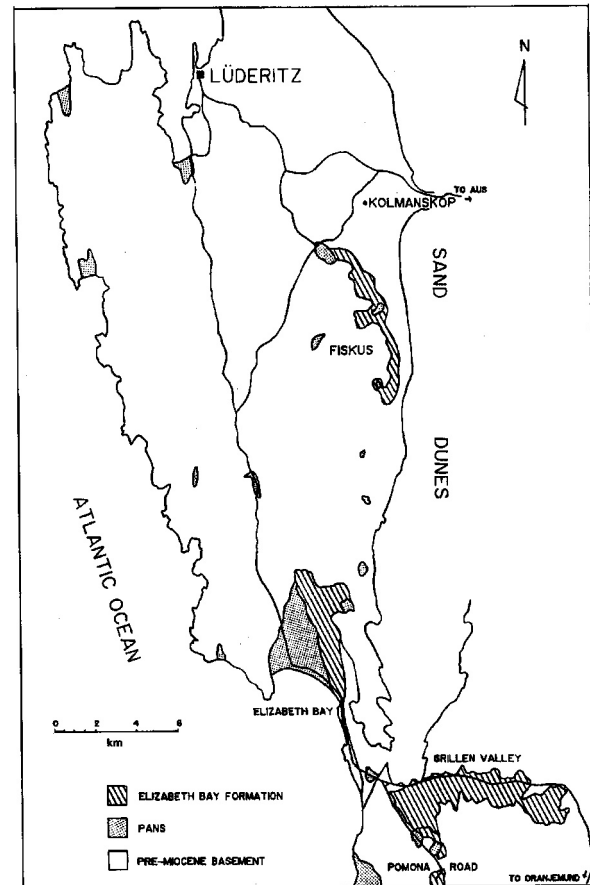


Figure 3-15.- Distribution of the Elisabeth Bay Formation in the northern Sperrgebiet, Namibia (based on Greenman, 1970). This formation occupies former drainage lines incised into Late Proterozoic rocks. Recent study has revealed that the Elisabeth Bay Formation of Greenman is a composite unit, the basal clays and marls being of Early Miocene age and fluvio-paludal origin, whilst the overlying strata are of Latest Miocene and younger age and consist of aeolianites and travertines.

(the Arries Drift Gravel Formation (SACS, 1980)) have survived since the Miocene and these provide precious evidence concerning its history, the most extensive deposits occurring in its lower reaches between the Richtersveld and the Atlantic. At Bosluis Pan in the Koa Valley, a tributary of the Orange (fig. 4-1), there are Middle Miocene sediments (Senut *et al.*, 1996).

Sediment-filled loop-shaped and lateral valleys in the Orange River Valley have been intensively studied and exploited on account of their diamond content. Fossils were first recorded from these sediments in 1976 (Anon, 1976; Corvinus, 1978b; Corvinus & Hendey, 1978). Fossil vertebrates have since been found at Auchas (Pickford *et al.*, 1995) and Baken and these all date from the Early Miocene and basal Middle Miocene.

There are several sedimentary terraces in the Orange

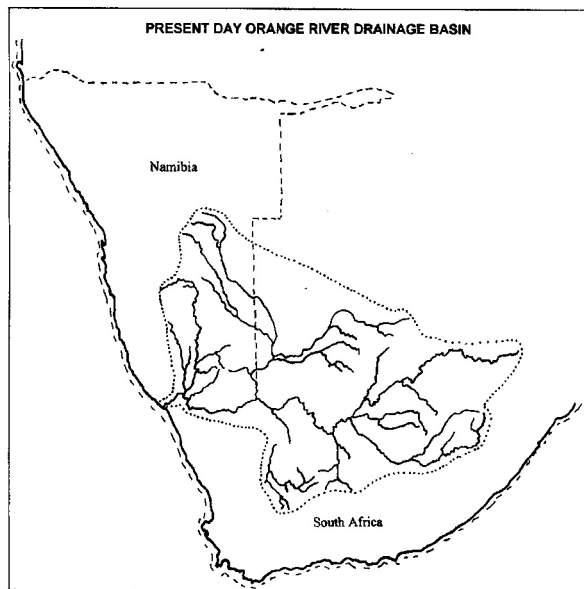


Figure 3-16.- The present day Orange River Drainage Basin.

River valley (Fowler, 1976) dating from different periods of aggradation and down-cutting, but apart from the proto-Orange (Early to Middle Miocene) terraces, no fossils have been found in them.

3.4.1.2.4 Aeolianites

Several studies of the aeolianites of the Namib Desert have been published (Martin, 1950; Barnard, 1973; Besler, 1977, 1980; Besler & Marker, 1979; Ward, 1984a, 1988; Ward & Corbett, 1990; Ward *et al.*, 1983), but the main thrust of research has been focussed on the mobile sands of the desert - the Sossus Sand Formation, or, as it is colloquially known, the Namib Sand Sea (Barnard, 1973; Besler, 1977, 1980; Corbett, 1989, 1993; Korn & Martin, 1957; Lancaster, 1980, 1983a, b, 1984a, b, 1985, 1989; Lancaster & Oilier, 1983; Lancaster & Teller, 1988; Lancaster *et al.*, 1984; McKee, 1982; Rogers, 1979; Selby, 1977b; Ward, 1983, 1984b, 1987a, b; Ward & Seely, 1990) and dunes near the Orange River (Le Roux, 1992). Preliminary results of the NPE have been published (Pickford *et al.*, 1995; Senut & Pickford, 1995; Senut *et al.*, 1994, 1995).

The Namib Unconformity Surface (NUS) (Oilier, 1978; Ward, 1987) was being actively eroded until it became the depository for immense volumes of wind-blown sand which eventually covered much of the exposure of basement rocks in the coastal lowlands (fig. 3-17). At the base of these aeolianites Ward (1987) has described regolithic deposits, often dominated by quartz and other resistant rocks, lying on the surface of the NUS in the Kuiseb Valley and elsewhere. There are many exposures of bedrock in the Namib, however, where aeolianites rest directly on bare basement rock. At Rooilepel wind-faceted dolomites underlie the aeolianites, indicating a period of wind-driven erosion prior to the onset of aeolianite accumulation in the area. At Elim and other places in the northern part of the Namib-Naukluft Park, aeolianites rest upon fresh

granite outcrops with no sign of regolith or of palaeosols. These exposures do not however, show obvious signs of wind sculpting probably due to differences in wind regimes in the various parts of the desert.

3.4.1.2.5 The Karpfenkliff Conglomerate

The north-eastern edges of the Central Namib, in the Kuiseb, Tsondab, Tsauchab and other valleys, contains extensive conglomeratic deposits assigned by Ward (1987), to the Karpfenkliff Conglomerate Formation. In the Kuiseb and neighbouring regions, these conglomerates contain clasts of Tsondab Sandstone and they clearly post-date at least part of this formation. Ward (1987) and Ward & Corbett (1990) cited the Karpfenkliff Conglomerates as evidence for a middle Miocene Pluvial Phase which separated the older Proto-Namib Desert Phase (during which the Tsondab Sandstone was deposited) from the younger Namib Desert Phase, represented by the Sossus Sand Sea. The Karpfenkliff Conglomerates have been extensively cemented by carbonates and are overlain by the Kamberg Calcrete (Ward, 1987). Reappraisal of the timing of events in the Namib indicate that this a really widespread unit is appreciably younger than previously thought.

3.4.1.2.6 Pan carbonates and pan silts of the Namib

Ward (1983, 1987a, b, 1988) provided detailed descriptions of localised indurated masses of carbonate in the northern margins of the Central Namib which he assigned to the Zebra Pan Member of the Tsondab Sandstone Formation. The carbonate bodies tend to be limited in areal extent (± 100 metres diameter) and are thin (up to 1 metre thick). They are usually composed of dolomite and most are intercalated in aeolianites. Ward (1987) concluded that these carbonates accumulated in ancient playas or pans (fig. 3-18).

In the Rooilepel depression, there is a horizon comprised of two levels with well bedded silts and carbonate nodules. These silts appear to have been deposited in a former pan that existed in the area during the Middle Miocene. It lies between aeolianites that yield eggshells of

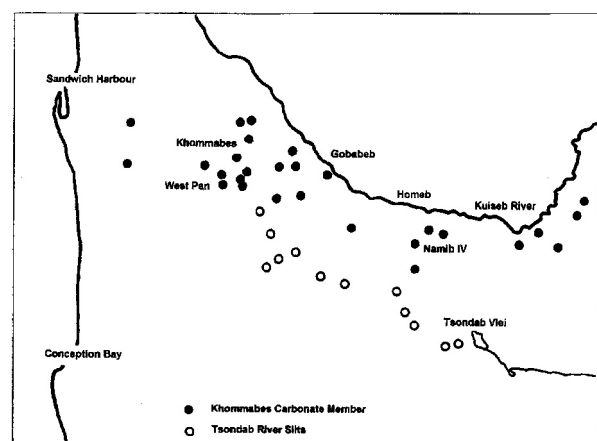


Figure 3-18.- Distribution of pan carbonates and fluviatile silts in the region of the Kuiseb River, Namibia (based on Ward, 1987b).

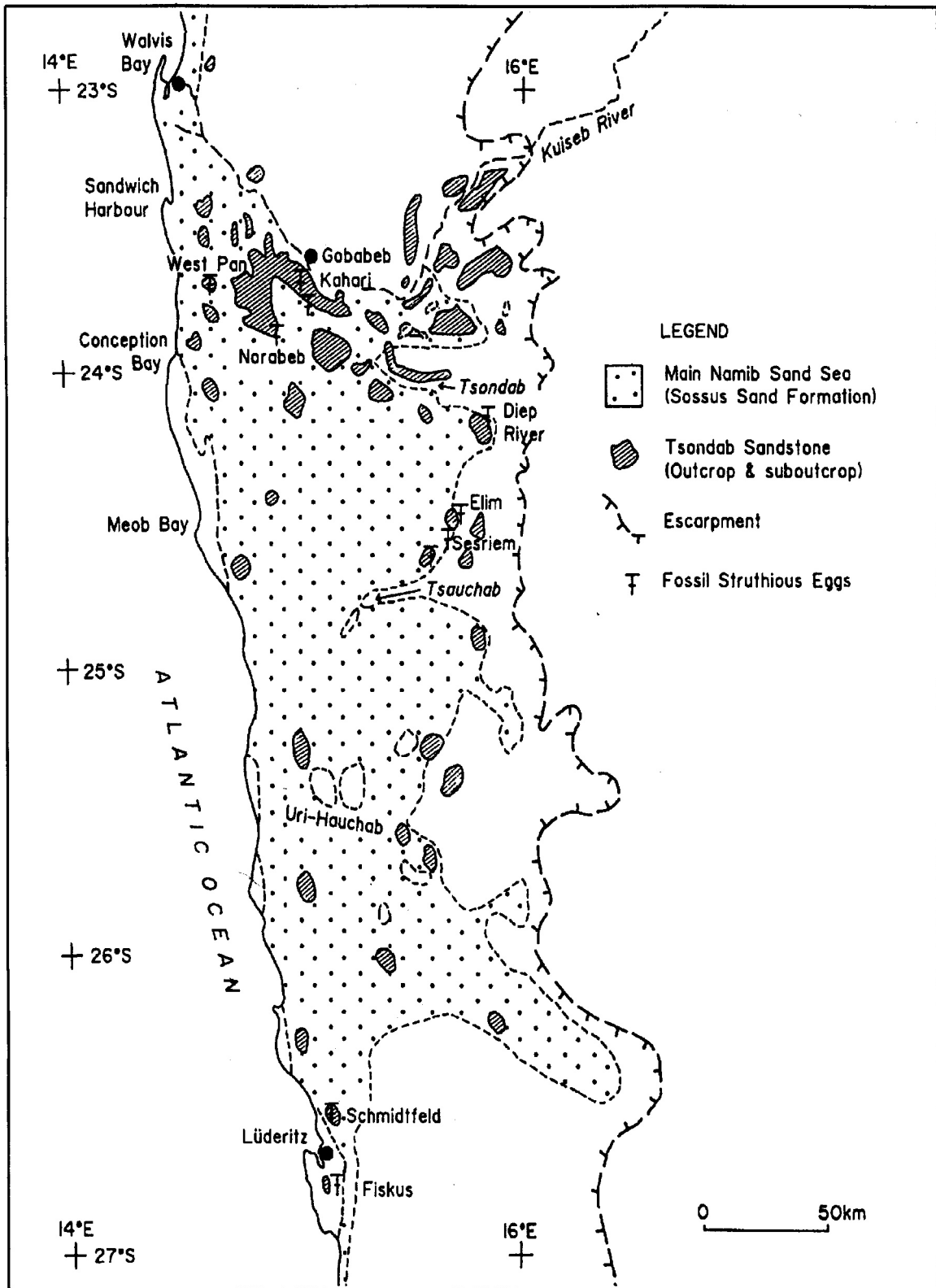


Figure 3-17.- The distribution of the main Namib Sand Sea (Sossus Sand Formation) and the Tsondab Sandstone Formation, together with fossil avian eggshell sites. The Tsondab Sandstone ranges in age from terminal Early Miocene to Pleistocene, and consists of numerous sand bodies separated by super-bounding surfaces.

Diamantornis corbetti below and those of *Diamantornis wardi* above.

In much of the Namib Desert, pan sediments are usually rare, although in the strip immediately south of the Kuiseb River, numerous Pleistocene to Holocene carbonate bodies assigned to the Khommabes Carbonates are known (Ward, 1984a) (fig. 3-18). North of Bushman Hill, similar carbonates bearing plant remains are well preserved.

Silt deposits intercalated in the Sossus Sands are known in many exposures in the north of the Namib-Naukluft Park (Ward, 1984a, b) principally in the sectors downstream of the Tsondab and Tsauchab Vleis.

3.4.1.2.7 Calcretes of the Namib

A severe difficulty encountered with Namib stratigraphy has been the determination of the age of calcrete pedogenesis. Ward & Corbett (1990) concluded that the Kamberg Calcrete and correlative units elsewhere in the Namib formed during the Middle Miocene. Ward (1987) considered that the Kamberg Calcrete formed during the Late Miocene as did Stocken (1978). In its type area and surrounding region, the Kamberg Calcrete overlies Tsondab Sandstone and Karpfenkliff Conglomerate and is either overlain by loose sands of the Sossus Sandstone or is exposed at the surface. Calcrete pedogenesis predated canyon incision by the Kuiseb drainage. Thus the Kamberg Calcrete Formation predates deposition of the Oswater Conglomerate and other formations confined to the Kuiseb Valley including the Hudaob Tufa, the Homeb Silts, the Awa-Gamteb Muds, the Gobabeb Gravels and Kuiseb alluvium.

In all areas where fossils or stone tools have been found in calcrete by the Namibia Palaeontology Expedition, the indications are that calcrete pedogenesis occurred during the Late Pleistocene and Recent periods. Calcrete localities which have yielded Late Pleistocene to Recent fossils and stone tools include outcrops not far from Kamberg, Tsondab, Elim, Tsauchab, Awasib, Sandkop, Rosh Pinah, Skorpion, Rooilepel, Skilpadberg borrow pits, and other inland sites. Calcretes in the Kuiseb area yielded Late Pleistocene Carbon isotope ages (Heine, 1985; Hüser, 1976). Calcretes developed on aeolianites near the coast north of Oranjemund and in the Pomona area contain fossil struthious eggshells. At Trigieville, some 40 km north of Oranjemund, the eggs are probably of *Diamantornis wardi* or *D. laini*, meaning that the calcrete is younger than Middle Miocene. At Pomona the calcrete contains shells of *Struthio daberasensis* indicating that the calcrete is post-Pliocene in age. There thus appears to have been at least two phases of calcrete pedogenesis in southwestern Africa, an earlier one comprising the Kamberg Calcrete (*sensu stricto*) which is most likely of Plio-Pleistocene age (pre-dating the Oswater Conglomerate) and a series of later deposits containing stone tools and Late Pleistocene mammal fossils (*Equus*, *Oryx*, *Lepus*, *Pedetes*).

In Namaqualand, south of the Orange River, calcretes

also yield Pleistocene to Recent fossils at several sites, including a rich locality at Swart Duinen, south southeast of Klein Zee. At Areb, northern Namaqualand, 15 metre thick calcrete deposits overlie a clay horizon which yielded equid fossils aged between 6 and 4 Ma.

3.4.1.2.8 Post-Kamberg Calcrete incision in the Kuiseb drainage and related deposits

The most comprehensive study of the geology of the Kuiseb drainage was carried out by Ward (1987) and Vogel (1982, 1989) and there have been other studies by Heine (1985). Subsequent to the formation of the Kamberg Calcrete, the Kuiseb River incised itself deeply culminating in the formation of the Kuiseb Canyon and the immense gramadullas on either side of the river. Remnants of transient sediment being carried down the valley at various stages in its history have been preserved as small patches of outcrop clinging to the sides of the valley. The few fossils found in these sediments reveal little about their ages, except the Homeb Silt Formation which has yielded a Modern rodent species, and is thus probably Latest Pleistocene to Holocene in age. Radioisotopic evidence supports the conclusion that the Kuiseb sediments are all very young (Heine, 1985, 1987; Rust *et al.* 1984; Vogel, 1982, 1989). The Kuiseb Valley sediments have been assigned to various units by Ward (1987). From oldest to youngest they comprise the Oswater Conglomerate (27,900 to 46,800 yr B.P. according to Vogel, 1989, but likely to be about 2.5-3 Ma on the basis of their likely correlation to the 30 metre littoral marine package), Hudaob Tufa (30,000 to 34,000 yr B.P. with some younger activity ca 10,000 yr B.P.), Homeb Silt (ca 20,000 yr B.P., Vogel, 1989), Awa-gamteb muds, Gobabeb Gravels and the Kuiseb River Alluvium. Immediately to the south of the Kuiseb River is the Namib Sand Sea (Sossus Sand Formation). In the Gobabeb region Ward recognised two lithological units which accumulated in post-Kamberg times. These are the Khommabes Carbonates and the Sossus Sand Formation. The Khommabes unit yielded *Oryx gazella* (Ward, 1987) and *Elephas recki* in archaeological context with stone tools of Acheulean typology (Shackley, 1980, 1982, 1985) and is thus of Middle Pleistocene age. The Sossus Sands have only yielded eggshell fragments of the extant ostrich *Struthio camelus*.

3.4.1.2.9 The Oswater Conglomerates

Younger than the Karpfenkliff Conglomerates, which predate the Kamberg Calcrete and the deep incision of the Kuiseb Canyon, occur the Oswater Conglomerates which were deposited during the incision process (Ward, 1987). Being appreciably more confined within the canyon than the Karpfenkliff unit which was more widespread, these conglomerates extend further downstream and probably contributed significantly to the boulder deposits in the Rooibank area near Walvis Bay which lie about 30 metres asl.

3.4.1.2.10 Naukluft travertines

In the Naukluft Mountains there are huge carapaces of travertine clinging to steep cliffs in dry river courses. In a few places travertines are still forming, but many of the occurrences, such as those in the Tsondab Valley, are dead. These travertines are rich in plant remains, and the crab *Potamonautes perlatus* is often found preserved in tufa, but no age diagnostic fossils have been reported from them. Although the period during which they formed has not been established, it is likely that they formed during the Pleistocene, at the same time as the Hudaob Tufa Formation in the Kuiseb Valley (Ward, 1987).

3.4.1.2.11 Gypcretes of the Namib

Superficial deposits of silt and other sediments in the Orange River Valley and in the Rooikop area east of Walvis Bay contain substantial amounts of post-depositional gypsum, forming a hard pan or 'gypcrete' (Miller & Seely, 1976; Schreiber, 1996; Martin, 1973; Carlisle, 1978). The distribution of the gypsiferous sediments near the coast, especially in areas prone to exposure to aerosols derived from the sea by spray activity, suggests that the sulphide ions are ultimately derived from decaying organic matter in soft sediments in the seabed (as H₂S) and are carried onto land (as H₂SO₄). A possible explanation of the genesis of these deposits is that when this aerosol settles onto the surface of the land, the sulphuric acid reacts with calcium carbonate in the sediments to form gypsum, water and carbon dioxide being the other products of the reaction.

3.1.4.2.12 Other Pleistocene to Holocene deposits of the Namib

Pleistocene sediments in the Namib have been studied quite extensively, partly because of their archaeological and fossil contents (Selby *et al.*, 1979; Shackley, 1980, 1982, 1985; Lancaster & Teller, 1988; Teller & Lancaster, 1985, 1985, 1986, 1987; Teller *et al.*, 1988; Thackeray, 1979; Yaalon & Ward, 1982; Ward, 1987b; Wilkinson, 1988, 1990; Seely, 1984; Miller & Seely, 1976; Heine, 1985a, b, 1987; Schreiber, 1996). These studies reveal that local climatic conditions varied appreciably throughout the Quaternary between extremes ranging from semi-arid to hyper-arid.

The youngest sediments in the Orange River Valley, apart from still mobile material, are brown silts which look similar to the Homeb Silts of the Kuiseb and other valleys north of the Namib Sand Sea. The widespread geographic distribution of these silts suggest that they resulted from backponding of rivers draining into the Atlantic, possibly caused by a rise in sea level during the Late Pleistocene, although it has been suggested that the backponding could have been due to dunes blocking off river mouths, thereby damming the river waters behind them. However, Zawada (1997) has suggested that the Orange River silts resulted from megafloods in the drainage, of which he recognised 13 palaeo floods during the past 5,500 years.

At Tsondabmund and Fischer's Brunn, in the coastal area opposite the Tsondab River, there are immense areas of travertine and associated sediments. These contain abundant plant remains, principally sedges and other paludal species. The geomorphological setting of these deposits indicate that they are geologically very young, possibly Late Pleistocene or even Holocene. Vogel (1989) dated similar 'calcified reed beds' at Koichab Pan, Hoanib Oasis, Khowaribschlucht and Möwe Bay as ranging between 22,800 and 29,000 yr B.P.

3.4.1.3 Offshore Geology

In order to obtain a complete picture of the evolution of the coastal belt of Namibia and adjacent countries, it is necessary to study offshore sediments as well as those on land. This is partly because the position of the shoreline has fluctuated due to changes in mean sea level, but also because there has been epeirogenic and more localised vertical land movement (Dingle & Hendey, 1984). A great deal of research has been done on marine sediments off the coasts of Namibia and South Africa.

Useful overviews of offshore stratigraphy have been published by Light *et al.* (1992, 1993). Almost continuous Cretaceous to Recent sedimentary successions occur in various basins along the Namibian continental shelf. There are however, several unconformities within the sequence, and in places the sediment pile has experienced slumping and other post-depositional disturbances. The strata record the complex interplay of sedimentation and erosion controlled to a great extent by rising and falling sea levels and by varying output of clastic material from rivers draining the African hinterland. Periods of low sea level occurred during the Valanginian, Hauterivian, mid-Aptian, Turonian, Basal Tertiary, Oligocene and mid-Miocene, and these are recognised in the seismic profiles as disconformable surfaces. As a result, onlap and offlap sequences are common.

Studies of DSDP cores have been made on samples obtained from the vicinity of the Walvis Ridge (Diester-Haass, 1985, 1988; Diester-Haass & Rothe, 1987; Diester-Haass & Schroeder, 1979; Diester-Haass *et al.*, 1986; Hay & Brock, 1992; Siesser, 1980; Repeta *et al.*, 1992). Much of this work is extremely detailed and concerns palaeontological, sedimentological, diagenetic, geochemical and organic geochemical aspects of the cores. Nevertheless, the authors usually interpret their data within models of the Benguela Current and upwelling systems along the Namibian shelf. Conclusions concerning the time of onset of upwelling vary according to author, some (Van Zinderen Bakker, 1975) suggesting that upwelling began during the Oligocene, while others, such as Siesser (1980) appear to be confident that strong upwelling only began in the Late Miocene (some 10 Ma). Since the number of cores is limited, and the sites are all near the Walvis Ridge, caution needs to be exercised in interpreting the results of these DSDP studies.

3.4.2 PALAEOLOGY

The start of palaeontological research in the Namib followed closely on the heels of the discovery of diamonds in 1908. Merensky (1909) realised that fossils would provide the key to understanding the timing of sedimentary events in the region, including diamond mineralisation. Since then, much research has been concentrated in the Sperrgebiet, as well as south of the Orange River in Namaqualand, South Africa. Palaeontological studies have been much less complete in the northern half of Namibia, but pick up again in southern Angola, where predominantly marine strata crop out south of the Carun-jamba River. The interest in Angolan deposits is mainly of an economic nature, the shallow marine basins of Angola being world class petroleum sources.

3.4.2.1 The Sperrgebiet

Merensky (1909) was the first to report on the presence of fossils from the Sperrgebiet. His identification of Cretaceous marine invertebrates near Elisabeth Bay and his interpretation that the diamond concentrations found on the present day land surface were derived by deflation of diamond-bearing Cretaceous marine beds, sparked a long and complex debate concerning the origins of the diamonds (Corbett, 1989, 1996; Krause, 1910; Marloth, 1909; Lotz, 1909).

Following Merensky's (1909) initiative, there was a flurry of palaeontological activity in the northern Sperrgebiet during the first and second decades of this century, mainly because fossils were considered to be important for determining the ages of the strata from which the diamonds were thought by some geologists to originate. This set in motion the first of two main periods of palaeontological research in the Sperrgebiet, the earlier (1910-1930 : over 25 scientific papers) dealing with the northern Sperrgebiet, and the later focussed on the southern Sperrgebiet (1970-1990: over 30 scientific papers). The latter activity followed the discovery, during diamond prospecting operations, of the Arrisdrift fossil locality of basal Middle Miocene age.

Up to the mid 1970s 812 mammalian fossils were known from the Namib Desert north of the Orange River, and only a handful from Namaqualand. Stromer (1926) had available a sample of 273 vertebrate fossils from three localities in the northern half of the Sperrgebiet. Hopwood (1929) described 23 fossils from «South of Lüderitz». Schroeder collected a ruminant mandible from 'Bogenfels' which he presented to the South African Museum (Cooke, 1955). Greenman (1970) gathered 23 fossils from Grillental while Hamilton & Van Couvering (1977) collected 456 specimens from four localities. In 1983 Schneider collected a single fossil from Glastal and sent it to the South African Museum and in 1978 Corvinus collected 35 fossils in the northern Sperrgebiet. The diversity of vertebrates in these samples was reasonably high, with at least 28 species being described of which 20 are based on holotypes from the region.

The richest vertebrate site in the Namib is undoubtedly

Arrisdrift, discovered in 1976, which by 1980 had yielded over 4,000 specimens belonging to 22 species.

The few sites in the Sperrgebiet of Early and Middle Miocene age were clearly of fluvio-paludal facies. Up to 1990, the immense outcrops of Namib aeolianites had yielded few fossils apart from ubiquitous ichnofossils and some gastropods (Stocken, 1978). Consequently, there was a great deal of debate in the literature concerning the age of the Namib Desert and its history (Ward & Corbett, 1990). By the end of the 80s however, fossil rodents were found (Corbett, 1989) which indicated an Early Miocene age for the Rooilepel aeolianites. Many gastropods and bird eggshells were found at Rooilepel and other sites which indicated that extended surveys in the aeolianites would be likely to produce important data concerning the biostratigraphy and palaeoecology of the Namib.

The palaeontological importance of the Sperrgebiet can be gauged from the fact that at least 80 new species have been erected on the basis of specimens found in the region (Böhm, 1919, 1926; Böhm & Weissemel, 1913; Corvinus & Hendey, 1978; Dauphin *et al.*, 1996; Flynn *et al.*, 1983; Harris, 1977; Heissig, 1971; Hendey, 1978; Hopwood, 1929; Lavocat, 1973; Morales *et al.*, 1995; Mourer-Chauviné *et al.*, 1996a, b; Patterson, 1965; Pickford, 1984, 1986a, b, 1994, 1995a; Pickford & Dauphin, 1993; Pickford & Fischer, 1987; Pickford *et al.*, 1995; Rauff, 1926; Senut, 1997; Savage, 1965; Siebenrock, 1910; Stromer, 1926; Van Couvering & Hamilton, 1983; Van Couvering & Van Couvering, 1976; Weissemel, 1926; Wenz, 1926; Wood, 1958). The total number of species of macrofossils recorded from the Sperrgebiet is well over 200 ranging from Cretaceous to Eocene and Late Cenozoic.

In order to resolve certain stratigraphic uncertainties, geologists and prospectors were encouraged to collect fossils whenever they came across them, but before and immediately after the First World War there was no systematic field survey carried out by trained palaeontologists. Beetz (1926) found many of the fossils published by German authors in the Kaiser (1926) monograph and elsewhere, but the geological context of these collections was often not clearcut and has sometimes given rise to erroneous interpretations. For example, land snails from Elfert's Tafelberg, said to be associated with quartzite, turn out to be from calcrete overlying the quartzite, and thus of considerably younger age.

Most of the sediment thought by Merensky to be Cretaceous has since been dated to the Eocene (at Bogenfels) and to the Early Miocene (at Elisabeth Bay) and Pliocene (at Kolmanskop). Most of it is not marine in origin, but is continental. Nevertheless, restricted outcrops of Cretaceous marine strata occur at Wanderfeld IV in the Bogenfels area (Haughton, 1926, 1930a, 1930b; Klinger, 1977) (Table 3-2). Onland Cretaceous fossils and sedimentary rocks are extremely rare in Namibia, the Wanderfeld IV occurrence being one of a few known outcrops on the Atlantic coast south of Angola. A second locality was recorded at Kharugaiseb by Ward & Martin (1987) while a third occurrence is at Albin (Swart, 1993). The

only other known occurrence of Cretaceous sediments in Namibia is in the interior at Gross Brukkaros (Kelber *et al.*, 1993) which are associated with a volcanic structure. According to Klinger (1977) the Wanderfeld IV site is so small that it cannot even be considered a mappable unit. However, because of its geographic position its scientific importance is great.

Eocene marine fossils are quite abundant in the Bogenfels area (mainly in the Langental) (Böhm & Weissermel, 1913; Böhm, 1926; Siesser, 1977; Siesser & Salmon, 1979), even if the area of outcrop is restricted and the sediments not very thick. In contrast, the sediments exposed in impressive cliffs some 5.5 km long at Buntfeldschuh, have yielded only a few fossil shark teeth (*Isurus* sp.), some brachiopods (*Lingula* sp.) (Corbett, 1989) and bioturbation traces, but none of these fossils is diagnostic of age although *Isurus* indicates a Lutetian (Middle Eocene) or later age. Nevertheless, geomorphological evidence

has been taken to support an Eocene age for the lower part of the Buntfeldschuh strata (Stocken, 1962) (Tables 3-3, 3-4).

Neogene continental fossils were found as early as 1913 in the green silts of the Elisabeth Bay Formation north of Elisabeth Bay, and at Fiskus, Grillental and elsewhere (Stromer, 1914, 1921, 1922, 1923, 1924, 1926; Wenz, 1926). These Neogene continental strata are much more extensive than the marine Palaeogene and Cretaceous beds, and it is with the continental strata such as occur north and east of Elisabeth Bay that many of the diamonds are spatially (but not stratigraphically) associated. This association was a consequence of the geomorphology of the region - valleys sculpted during pre-Miocene times became sediment traps during the Early Miocene, and later acted as diamond traps during the post-Miocene period. However, some of the diamonds may well have become associated with the Late Neogene and Quaternary

TABLE 3-2

CRETACEOUS FAUNA FROM THE SPERRGEBIET (Compiled from Klinger, 1977) * = Type specimen from the Sperrgebiet
<i>Protocardia hillana</i>
<i>Turritella bonei</i>
<i>Turritella (Haustator) meadi</i>
<i>Exogyra</i> cf <i>columba</i> (= <i>Rhynchostreon</i> cf <i>suborbiculatum</i>)
<i>Placenticerias merenskyi</i> * (= <i>Proplacenticerias merenskyi</i>)

TABLE 3-3

EOCENE MARINE MICROFOSSILS FROM THE SPERRGEBIET (compiled from Siesser and Salmon, 1979)	
Calcareous nannofossils	Benthic Foraminifera
<i>Braarudosphaera bigelowi</i>	<i>Lenticulina simplex</i>
<i>Braarudosphaera discula</i>	<i>Lenticulina</i> cf <i>pseudomammiligerus</i>
<i>Chiasmolithus</i> sp.	<i>Lenticulina</i> cf <i>oblonga</i>
<i>Coccolithus eopelagicus</i>	<i>Lenticulina subalata</i>
<i>Coccolithus formosus</i>	<i>Lenticulina</i> spp.
<i>Discoaster saipanensis</i>	<i>Textularia</i> sp.
<i>Discoaster tani</i>	<i>Astacolus</i> sp.
<i>Isthmolithus recurvus</i>	<i>Siphoglobulina</i> ? sp.
<i>Reticulofenestra bisecta</i>	<i>Glandulina</i> sp.
<i>Reticulofenestra coenura</i>	<i>Elphidium</i> cf <i>crispum</i>
<i>Reticulofenestra umbilica</i>	<i>Elphidium</i> spp.
<i>Zygrhablithus bijugatus</i>	<i>Nonion costiferum</i>
	<i>Nonion sloanii</i>
	<i>Valvulineria aegyptina</i>
	<i>Ammonia</i> cf <i>beccarii</i>
	<i>Ammonia</i> sp.
	<i>Pararotalia inermis</i>
	<i>Cibicides pseudoungerianus</i>
	<i>Cibicides</i> spp.

TABLE 3-4

EOCENE MARINE MACROFAUNA FROM THE NORTHERN SPERRGEBIET (compiled from Böhm (1926) and Wiessermel (1926)) * = Type specimens from the Sperrgebiet.	
Bryozoa	Malacostraca
<i>Gramella crassimarginata</i>	<i>Calianassa erecta*</i>
<i>Conopeum lamellosum</i>	<i>Calianassa cf fraasi</i>
<i>Schizoporella latisinuata</i>	Brachyura
Lamellibranchiata	<i>Brachyuridarum</i> sp.
<i>Perna</i> sp.	Tabulata
<i>Ostrea subradiosa*</i>	<i>Diplochaetetes longitubus*</i> <i>typica</i>
<i>Crassostrea afra*</i>	<i>Diplochaetetes longitubus vermicularis*</i>
<i>Crassostrea rutriformis*</i>	Hexacoralla
<i>Crassostrea cymbaeformis*</i>	<i>Litharaea</i> ? sp.
<i>Crassostrea roncana tenuis*</i>	Hydrozoa
<i>Exogyra scheibei*</i>	<i>Thaumatostroma* verrucosum*</i>
<i>Lithodomus beetsi*</i>	<i>T. v. var. elliptica*</i>
<i>Arca (Noetia) reuningi*</i>	Milleporidae
<i>Arca (Noetia) koerti*</i>	<i>Diamantopora* lotzi*</i>
<i>Leda rangei*</i>	<i>Milleporidium ? kaiseri</i>
<i>Tellina (Peronaea) oppenheimeri*</i>	Pisces
<i>Spisula dernburgi*</i>	<i>Notidamus serratissimus</i>
<i>Mactra tumida*</i>	<i>Cestracion vincenti</i>
<i>Mya schweinfurthi (= M. klinghardti*)</i>	<i>Odontaspis macrota</i>
<i>Rocellaria clausa*</i>	<i>Odontaspis winkleri</i>
<i>Rocellaria sacculus*</i>	<i>Oxyrhina desori</i> var. <i>praecursor</i>
<i>Rocellaria</i> sp.	<i>Oxyrhina</i> sp.
Gastropoda	<i>Lamna vincenti</i>
<i>Turritella kaiseri*</i>	<i>Lamna barnitzkei*</i>
<i>Turritella merenskyi*</i>	<i>Alopecias smithwoodwardi*</i>
<i>Turritella atlantica disjuncta*</i>	<i>Galeocerdo latidens</i>
<i>Turritella (Haustator) bijugata* diminuta*</i>	<i>Galeocerdo</i> sp.
<i>Archimediella schettleri*</i>	<i>Galeus</i> sp.
<i>Tenagodes</i> sp.	<i>Galeus porrectus*</i>
<i>Natica exilis*</i>	<i>Galeus robustus*</i>
<i>Pseudoliva thielei*</i>	<i>Carcharias (Aprionodon) frequens</i>
<i>Pseudoliva leutweini*</i>	<i>Carcharias (Physodon) quartus*</i>
<i>Ocenebra dietrichi*</i>	<i>Rhaibodus* rapax*</i>
<i>Melongena</i> sp cf <i>cornuta patuloidea</i>	<i>Squatina prima</i>
<i>Streptosiphon piriformis*</i>	<i>Oxypristis ferinus*</i>
<i>Streptosiphon lotzi*</i>	<i>Myliobatis cf dixonii</i>
<i>Streptosiphon klinghardti*</i>	<i>Rhinoptera rasilis*</i>
<i>Heligmotoma clavaeforme*</i>	? <i>Pimelodus cf gaudryi</i>
<i>Vexillum lindequisti*</i>	<i>Labrodon stromeri*</i>
<i>Voluta</i> sp.	<i>Chrysophrys blanckenhorni*</i>
<i>Turricula excelsa*</i>	<i>Cylindracanthus cf rectus</i>
<i>Sconsia</i> sp.	<i>Paranarrhichas* damesi*</i>
<i>Bullinella aff. convoluta</i>	<i>Odontorhynchus* pappenheimeri*</i>
Cephalopoda	<i>Sphyraenodus hastatus*</i>
<i>Aturia lotzi*</i>	
Crustacea	
<i>Balanus asteroides*</i>	
<i>Balanus</i> sp.	

deposits by way of a sojourn in marine strata as originally proposed by Merensky (1909), because diamonds occur in the gravels at the base of the Buntfeldschuh cliffs, which are marine or estuarine deposits thought to be of mid-Palaeogene age. There is also evidence that some, if not most, of the diamonds reached the Atlantic coast from the interior of Africa via the Orange River during the Oligocene, Miocene and Plio-Pleistocene periods and were subsequently transported northwards by ocean currents (Hallam, 1964; Stocken, 1962, 1978; Rogers *et al.*, 1990). Thus Merensky's insights as to the origin of the Lüderitz diamonds need to be modified somewhat concerning the period and processes of initial mineralisation and the subsequent formation of economically important placers (Corbett, 1989, 1996).

The role that palaeontology has played in understanding the sequence of events which led to the formation of economic deposits in the Sperrgebiet has been crucial, even if sometimes misunderstood or undervalued. In view of a number of unresolved stratigraphic problems, fossils will continue to be of great importance to Sperrgebiet geology and, now that ore reserves are diminishing, to the Namibian and Namaqualand diamond mining industries.

Most of the Sperrgebiet fossils collected prior to and immediately following the First World War found their way to the Staatssammlung Munich and other research institutes in Germany (Table 3-5), where they formed the basis for a series of scientific papers, culminating in monographs by Böhm & Weissermel (1913), Böhm (1926), Rauff (1926), Stromer (1926), and Wenz (1926). A collection of fossil mammals made by H. Lang was donated to the American Museum of Natural History, New York, where it was described by Hopwood (1929).

A major drawback to these mammal collections was that they had virtually no stratigraphic context, and in many cases, the geographic co-ordinates of the fossil sites were imprecise or very wide. Hopwood, for example, could only report that the Lang collection was from «South of Lüderitz». Even sites such as Bohrloch Betrieb 4 of Stromer (1926) are not located where the literature says they are. The latter site, which is the location of an artesian well, said to be 2 km west of Betrieb 4, is actually about 10 km south of it.

Because of the methods of collecting employed, there has always been some doubt concerning the context of the Sperrgebiet «Lower Miocene» mammals. Faunal lists drawn from Stromer (1926) and from Hopwood (1929) look rather different, and it has consequently been suggested that there may be at least two time successive Miocene mammalian faunas in the northern Sperrgebiet (Hendey, 1978; Dingle *et al.*, 1983). Further survey needs to be done, but there is no doubt that the bulk of the faunal remains described by Stromer (1926) comprise a unit fauna, because most of the species known to him have recently been resampled at Elisabethfeld in a single deposit 5 cm thick and less than 0.5 metres in diameter, in which numerous skeletons of diverse species were intermingled.

New collections from Langental, from which it is believed that most of the material described by Hopwood (1929) came, have been made, and the faunas from this region appear to be slightly different from the more northerly positioned sites at Elisabethfeld and Grillental. It is likely that Langental is slightly younger than Elisabethfeld, but both localities are of Early Miocene age.

It is by no means evident that the proposed synonymy of some of Hopwood's species with those erected by Stromer can be upheld. Furthermore, the supposed synonymy of Sperrgebiet species with material from Kenya (Whitworth, 1954) needs to be reassessed in view of the biostratigraphic implications that such synonymy would indicate. Most of the proposed synonymies were the result of studies carried out during the 1950's and 1960's, after the Munich collections had been partly destroyed, meaning that direct comparisons between Kenyan and Namibian fossils were not always possible. The basis for a revision now exists, because abundant new fossil material from Namibia has recently become available.

With the publication of palaeontological reports in the late 1920's and early 1930's, it became clear that there were at least three important periods of sedimentation in the northern part of the Sperrgebiet, the earliest being of Cretaceous age (Cenomanian: 91-95 m.y.) which was followed by a period of erosion.

The next period of marine deposition occurred during the Eocene. Ward (pers. comm.) reports that the Buntfeldschuh marine unit dates from the Bartonian (ca 43 Ma) on the basis of correlations to tectonically disturbed strata of this age offshore Namibia. At Buntfeldschuh remains of the shark *Isurus* indicate an age no earlier than Middle Eocene, the known stratigraphic range of this genus being from Lutetian to Recent.

According to Siesser & Salmon (1979) a second period of marine deposition occurred during the Eocene (Priabonian: 37-39 m.y. NP19-NP20 nannofossil zones of Martini) which was followed by a period of erosion. Subsequently, during the latter part of the Early Miocene and in later periods, continental sediments accumulated in valleys and depressions in the bedrock.

It soon became evident that, in the northern Sperrgebiet, the bulk of the earlier (Cretaceous and Palaeogene) sediments were marine, while the later ones (Neogene) were continental. The continental Blaubok gravels are probably Palaeogene because the Eocene deposits at Langental contain pieces of fossil wood probably derived from them and because they predate Klinghardt volcanism (Stocken, 1978).

The picture emerged that the northern coastal part of the Sperrgebiet was the site of marine transgressions during the Cenomanian, possibly the Bartonian and the

TABLE 3-5

EARLY MIOCENE CONTINENTAL FAUNA OF THE NORTHERN SPERRGEBIET * = Type specimens from the Sperrgebiet	
Ostracoda	Rodentia
Gastropoda	<i>Parapedetes* namaquensis*</i>
<i>Trigonephrus</i> sp.	<i>Bathyergoides* neotertiarius*</i>
<i>Dorcasia</i> sp.	<i>Neosciuromys* africanus*</i>
<i>Lymnaea</i> sp.	<i>Phithinilla* fracta*</i>
<i>Bulinus</i> sp.	<i>Phiomyoides* humilis*</i>
Urocyclid slug	<i>Apodecter* stromeri*</i>
Anura	cf <i>Phiomys andrewsi</i>
<i>Xenopus stromeri*</i>	<i>Diamantomys* luederitzi*</i>
Ophidea	<i>Pomonomys* dubius*</i>
Chelonia	<i>Paracryptomys* mackennae</i>
<i>Testudo namaquensis*</i>	<i>Protarsomys</i> sp.
Aves	Proboscidea
Aepyornithoid (eggshells)	" <i>Gomphotherium</i> " sp.
<i>Struthio coppensi*</i>	Hyracoidea
Macroscelidea	<i>Prohyrax* tertiarius*</i>
<i>Myohyrax oswaldi</i>	Rhinocerotidae
<i>Protypotheroides* beetzi*</i>	<i>Brachypotherium heinzellini</i>
Creodonta	Saniitheriidae
<i>Metapterodon* kaiseri*</i>	<i>Diamantohyus* africanus*</i>
<i>Metapterodon Stromeri</i>	Suidae
Lagomorpha	<i>Nguruwe namibensis*</i>
<i>Australagomys* inexpectatus*</i>	Tragulidae
<i>Australagomys simpsoni*</i>	<i>Dorcatherium</i> sp.
Tenrecoidea	Pecora
<i>Protenrec</i> sp.	<i>Propalaeoryx* austroafricanus*</i>
Erinaceidae	<i>Namibiomyx* senuti*</i>
Gen. et sp. indet.	<i>Sperrgebieto-merys* wardi*</i>
N.B. Stromer (1926) and Hopwood (1929) erected several species which have subsequently been declared synonyms of known species, but this is not evident in every case. The following are implicated : <i>Myohyrax doederleini*</i> , <i>Myohyrax osborni*</i> , cf <i>Strogulognathus sansaniensis</i> .	

Priabonian periods, during which marine sediments were deposited up to 160 metres above modern sea level (vertical tectonics related to the emplacement of the Late Palaeogene Klinghardt Phonolites may have exaggerated the altitude of these strata, but little has been studied concerning this aspect of Klinghardt geomorphology). The Late Cretaceous and early Palaeogene were periods of erosion in the Namib coastal region. During the Late Oligocene, when sea level was considerably lower than at present (Haq *et al.*, 1987) much of the marine sediment appears to have been eroded away, leaving many of its heavy minerals and resistant rock clasts behind as a lag which were then reworked locally by surface waters and by wind (Corbett, 1989). At the end of the Early Miocene, a rise in sea level occurred which led to back ponding of valleys draining into the sea at Elisabeth Bay, Grillental and Bogenfels (fig. 4-2), as well as further south (Orange,

Buffels, Hondeklip Bay). In the northern Sperrgebiet, this led to infilling of valleys with fine sediments (clays, silts and sands) and conglomerates which often contain the fossilised remains of terrestrial animals. Subsequently, wind driven erosion of the Early Miocene continental sediments has led to deflation and to exposure of fossils at the surface in places such as Fiskus Pan, Grillental, Elisabethfeld and Langental.

Younger than these Early Miocene fluvio-paludal sediments are aeolianites of various ages. At Schmidtfeld, north of Lüderitz, the aeolianites contain fossil eggshells of the giant bird *Diamantornis wardi* which is of Middle Miocene age. The aeolianites at Fiskus Pan are considerably younger, containing eggshells (Corbett, 1989) of *Struthio daberasensis*, a species of ostrich of post-Miocene age, perhaps about 5-2 Ma.

The biostratigraphic positions of several of the fossiliferous sites in the northern Sperrgebiet remain imprecisely known or are undetermined. Terrestrial gastropods from Prinzenbucht, Eifert's Tafelberg, Chalcedon Tafelberg, Gamachab, Eisenkieselklippenbake, Kalkrücken, Glastal, Vley 315, and Klinghardtfelder 24, indicate that continental sedimentation was widespread in the region, but their fossil contents do not yield precise information concerning the age of the sediments, although most of them are probably Neogene. Fossil land snails from Glastal are of Early Miocene age, but terrestrial gastropods found in calcretes at Chalcedon Tafelberg (not to be confused with the siliceous deposits near Pomona), Eifert's Tafelberg, Kalkrücken, and Eisenkieselklippenbake are very likely of Plio-Pleistocene age. Snails from Gamachab are in a subfossil condition and are not closely associated with the travertine deposits which are of Plio-Pleistocene age. Freshwater snails from the Strauchpfütz Carbonate (Corbett, 1989) yield little information about the age of the sediments.

Palaeontological work in the southern Sperrgebiet has a much shorter history, and effectively started with the discovery of the rich mammal-bearing site at Arrisdrift

in the mid 1970's (Corvinus, 1978a, 1978b, 1983; Corvinus & Hendey, 1978; Hendey, 1978, 1984; Morales *et al.*, 1998). Arrisdrift, located in a palaeo-channel of the proto-Orange River (Fowler, 1976) has yielded abundant fossils of terrestrial and aquatic fresh and brackish water animals (Table 3-6) which date from the early part of the Middle Miocene, some 17-17.5 Ma ago. The fossils occur in conglomerate and sandstone which were deposited in a lateral channel of the proto-Orange River which has subsequently cut another channel and abandoned its previous course, leaving it high and dry some 30 metres above present day river level. The fossiliferous horizon is some 40-41 metres above present sea level, but at the time of deposition the sea level must have been higher than it is today, because serpulid worm tubes are common at Arrisdrift. These essentially estuarine worms survive well in brackish water, such as occurs near the mouth of the Orange River today, and their presence at Arrisdrift indicates that the sea was perhaps not far from the site.

Prospecting and mining in other abandoned loops and channels of the Orange River during the late 1980's and early 1990's have resulted in the discovery of fossils at

TABLE 3-6

MID-MIOCENE CONTINENTAL FAUNAS ORANGE RIVER DEPOSITS : ARRISDRIFT	
Serpulidae cf <i>Mercierella</i> sp.	Lagomorpha <i>Australagomys</i> sp.
Pisces	Rodentia <i>Megapedetes</i> sp. 1 <i>Megapedetes</i> sp. 2 cf. <i>Apodecter stromeri</i> <i>Protarsomys</i> sp. <i>Vulcanisciurus</i> sp.
Amphibia	Hyracoidea <i>Prohyrax hendeyi</i> *
Reptilia Varanidae <i>Crocodylus lloydi</i> <i>Geochelone stromeri</i> Ophidea	Proboscidea "Gomphotherium" sp. <i>Prodeinotherium hobleyi</i>
Aves Struthioniformes Phasianidae Accipitridae Indeterminate	Orycteropodidae <i>Orycteropus</i> cf <i>minutus</i>
Microchiroptera <i>Rhinolophus</i> sp.	Rhinocerotidae <i>Diceros</i> sp. nov. *
Tenrecoidea <i>Parageogale</i> sp.	Suidae <i>Namachoerus</i> * <i>moruoroti</i> <i>Nguruwe kijivium</i>
Erinaceidae Gen. et sp. 1	Tragulidae <i>Dorcatherium</i> sp.
Macroscelidea <i>Myohyrax oswaldi</i> Gen. et sp. indet. 1 Gen. et sp. indet. 2	Climacoceratidae <i>Orangemerys</i> * <i>hendeyi</i> *
Creodonta <i>Hyainailourus sulzeri</i>	Bovidae Gen. nov*. sp. nov*.
Carnivora <i>Amphicyon giganteus</i> <i>Ysengrinia ginsburgi</i> * <i>Namibictis</i> * <i>senuti</i> * <i>Africanictis</i> * <i>meini</i> * <i>Diamantofelis</i> * <i>ferox</i> * <i>Diamantofelis minor</i> *	

Auchas in orange coloured silts, sands and conglomerates associated with basal gravels on the inner bank of a former loop of the proto-Orange River. Of particular interest is the common occurrence of fossil tree trunks which yield precious information concerning past vegetation formations in the Orange drainage (Pickford *et al.*, 1995b). The mammalian fossils so far collected at Auchas indicate the presence of two faunas (Table 3-7), one of Early Miocene aspect (ca 19-18 Ma) and a later one close to the Early Miocene / Middle Miocene boundary, some 17.5 Ma. No serpulid worm traces have been found at Auchas, the fauna and flora being exclusively continental in origin. A few plant and animal fossils have been found at Baken, on the South African bank of the Orange River. The identifiable mammals from Baken are similar to those from Arrisdrift.

Calcrete which caps the thick aeolianite section at Rooilepel contains abundant terrestrial gastropods –*Trigonephrus* – which are probably of Late Pleistocene to Holocene age. Calcareous sediments in the bottom of Target Pan are also fossiliferous, the main contents being terrestrial gastropods of the genus *Trigonephrus*.

Acheulean and Middle Stone Age tools are common at Obib, Daberas and other sites in the region (Corvinus, 1983) and provide an upper limit to the age of aeolianites on top of which they are found. We have not found any of this material *in situ*.

Stocken (1978) refers to fossil molluscan shells, including *Donax rogersi*, in the ancient beaches which occur north of the Orange River mouth. Details of the species collected have not been published in scientific journals, but are presented in theses and reports submitted to CDM (Pty) Ltd (now NAMDEB).

3.4.2.2 The Namib-Naukluft Park

TABLE 3-7

EARLY MIOCENE CONTINENTAL FAUNAS ORANGE RIVER DEPOSITS : AUCHAS
Crocodylia
Chelonia
Aves
Rodentia
<i>Diamantomys luederitzi</i>
Hyracoidea
<i>Prohyrax hendeyi</i>
Proboscidea
<i>Prodeinotherium hobleiy</i>
<i>Eozygodon morotoensis</i>
<i>Gomphotherium</i> sp.
Rhinocerotidae
Indet.

The Palaeontology of the Namib-Naukluft Park (formerly

The Palaeontology of the Namib-Naukluft Park (for-

merly Diamond Area N° 2) is very much more poorly understood than that of Diamond Area N° 1. However, the region is of interest because of the presence of marine strata of Miocene age. In the Walvis Bay area shark teeth, fish vertebrae and invertebrate remains and trace fossils attest to marine transgressions during the Late Miocene and Late Pliocene. Small remnants of phosphatic rock riddled with borings made by lithophagous molluscs are common in the Rooikop area where they are accompanied by shark teeth and internal moulds of gastropods. At Tsondabmund, near Conception Bay, similar ferruginous, phosphatic marine rocks also occur. These are richly fossiliferous.

Reworked phosphatic nodules also occur in Namaqualand, South Africa (Gresse, 1988) and further south towards the Cape, and they have been reported as far north as the Kunene River (Bremner, 1978). Phosphatic rocks occur *in situ* in the Saldanha Formation, South Africa, and it may well be the case that the nodules occurring in the Alexander Bay Formation of northern Namaqualand represent eroded fragments of the Saldanha Formation (Gresse, 1988).

The aeolianites of the Namib Sand Sea have yielded fossils from time to time, but little reached the literature prior to 1993. Fossilised struthious eggshells have been collected in the vicinity of Gobabeb and at pan exposures south and west of the Kuiseb River. Eggshells were also known to occur at Elim, on the eastern edge of the Namib. Despite these discoveries, the indurated sands of the Namib were thought to be poorly endowed with fossils other than traces of bioturbation. However, the Namibia Palaeontology Expedition has located more than 100 fossil sites in aeolianites of the Namib-Naukluft Park and the Sperrgebiet, many of which have yielded rich and diverse faunas.

3.4.2.3 Coastal Namaqualand

The coastal belt of Namaqualand is richly fossiliferous. Most of the fossils are marine, but material of terrestrial origin of Late Miocene to Early Pliocene age has been recorded from time to time (Stromer, 1931; 1932; Hendey, 1984; Gresse 1988) (Tables 3-8, 3-11, 3-12). Recent work at Hondeklip Bay has resulted in the discovery of Early and basal Middle Miocene mammals, not very different in age from Arrisdrift. These mammals are associated with a rich and varied marine fish fauna.

The most comprehensive palaeontological studies in Namaqualand have been carried out on the marine faunas that occur in littoral marine deposits overlying wave cut platforms or terraces (Tables 3-9 to 3-20). From the beginning of the pioneering studies of Houghton (1928, 1931), who recognised 59 species of molluscs, it was evident that the Namaqualand fossils were useful for biostratigraphy. Even though initial efforts at establishing a precise biostratigraphic succession were hampered by the poor stratigraphic control that the collections generally had, the signals were clear enough that broad focus correlations could be made.

TABLE 3-8

EARLY MIOCENE FAUNA LITTORAL DEPOSITS RYSKOP	
Mollusca	<i>Conus</i> sp. <i>Bivalvia</i> indet
Pisces	<i>Labrodon</i> sp. <i>Lamna</i> sp. <i>Isurus</i> sp. <i>Carcharodon</i> sp.
Rodentia	? <i>Diamantomys</i> sp.
Phocidae	? <i>Mirounga</i> sp.
Hominoidea	indet.
Proboscidea	<i>Prodeinotherium</i> sp. <i>Gomphotherium</i> sp.
Rhinocerotidae	indet.
Suidae	<i>Kenyasus rusingensis</i> <i>Kenyasus namaquensis</i> <i>Nguruwe kijivium</i>
Ruminantia	indet.

TABLE 3-9

FAUNAL LISTS FOR RAISED BEACHES NORTH OF ORANJEMUND Data from Fowler, 1976	
Upper beaches (D, E, F) Middle Pleistocene according to Fowler but Plio- Pleistocene according to NPE	
<i>Donax rogersi</i> <i>Chamelea krigei</i> <i>Crassostrea margaritacea</i> (= <i>Ostrea prismatica</i>) <i>Thais praecingulata</i> <i>Fissurella</i> sp. <i>Perna tomlini</i> <i>Trigonephrus</i> sp.	
Lower beaches (A) : Recent and (B, C2, C1) Late Pleistocene according to Fowler	
<i>Donax serra</i> <i>Mytilus</i> sp. <i>Patella</i> sp. <i>Bullia</i> sp. <i>Burnupena</i> sp.	

TABLE 3-10

DISTRIBUTION OF MARINE MOLLUSCS IN RAISED BEACHES NORTH OF ORANJEMUND Data from Kleinjan, 1971 * = very common; o = common; - = rare						
Beach Species	Lower Terrace				Upper Terrace	
	A	B	C2	C1	D	
<i>Mytilus</i> sp.		*****	o	o	o	o
<i>Perna tomlini</i>					****	o
<i>Donax serra</i>		o	o	o		
<i>Donax rogersi</i>						*****
<i>Fissurella glarea</i>				-----?		o

However, for six decades confidence in biostratigraphy remained weak, so that geomorphology and the altitude of deposits tended to oust the palaeontological approach in the minds of many geologists and miners, often with unfortunate results. A major advance in knowledge was made by Carrington & Kensley (1969) who recognised that specimens hitherto identified by Haughton as *Donax rogersi* comprised two species (*D. haughtoni* and *D. rogersi*) which did not occur in the same strata. Finally, Kensley & Pether (1986) and Pether (1994) recognised 110 molluscan species in the Namaqualand 50 mP and 30 mP deposits and drew up the currently accepted biostratigraphic subdivisions. All the above authors realised that the earlier faunas contained warm water molluscs, while the sub-I 0 metre deposits contained exclusively cold water faunas.

None of the authors from Haughton (1928) onwards accurately estimated the ages of the faunas under study, even though they correctly determined the order in which they had lived. Efforts by these researchers to resolve the chronological uncertainty revolved around correlations to global eustatic and palaeoclimatic events, and researchers such as Carrington & Kensley (1969) were influenced by the youthful appearance of the shells. Thus matches were made between the glacial/interglacial sequence in vogue at the time of the studies, or with sea-level curves of the Quaternary. We now know that the geochronology was off by an order of magnitude, the 50 mP being Late Miocene to Early Pliocene on the basis of the presence in it of unrolled mammal fossils of this age. The 30 mP is probably Late Pliocene to Early Pleistocene on the basis of the reported occurrence of *Equus* fossils in it. The poorly fossiliferous 90 mP, which was also assigned to the Pleistocene by some

workers, is probably of late Early Miocene age on the basis of mammalian fossils found in it, but it must be pointed out that the fossils are rolled and polished, meaning that reworking cannot be ruled out, even though there are no signs of the fauna being mixed with younger elements. Nearby at Hondeklip Bay two late Middle Miocene mammalian fossils have been recovered, suggesting that the basal gravels preserved locally beneath the 50 mP may well be of late Middle Miocene age (ca 14-11 Ma) (Pickford & Senut, 1997; Pickford, 1997). Diamond bearing gravels assigned to the 30 mP at Kramleeg, near Ryskop, have yielded teeth of equids, possible *Equus*, indicating that they are considerably younger than sediments of the 90 mP.

Apart from the molluscs, other fossil groups have received less attention from palaeontologists, the various records being little more than lists of taxa identified at different sites. The commonest vertebrate fossils from Namaqualand are marine fishes and sharks. Short descriptions of material appear in Haughton (1928) while Pether (1994) provides a faunal list of vertebrates found in the area. The mammal fauna, even though it is limited in diversity and usually comprises fragmentary specimens, is the most useful from a geochronological point of view because the taxa identified (proboscideans, suids, carnivores, ruminants) belong to widespread lineages which occur in known geochronological contexts in East Africa. They thus form a far more secure basis for Namaqualand geochronology than correlations of marine terraces to sea-level curves or to the preservation characteristics of the molluscan shells.

TABLE 3-11

ALPHABETICAL LIST OF GASTROPODA FROM THE 50 AND 30 METRE SEDIMENT PACKAGES NAMAQUALAND	
<i>Afrocominella capensis</i>	<i>Marginella</i> sp.
<i>Amblychilepas scutellum</i>	<i>Melanella</i> sp.
<i>Argobuccinum casus</i>	<i>Melapium hawthornei</i>
<i>Bolma anoropha</i>	<i>Namamurex odontostoma</i>
<i>Bullia annulata</i>	<i>Nassarius kochianus</i>
<i>Bullia digitalis</i>	<i>Nassarius litorafontis</i>
<i>Bullia laevisissima</i>	<i>Natica</i> cf <i>adansoni</i>
<i>Burnupena aestus</i>	<i>Nucella dubia</i>
<i>Burnupena papyracea</i>	<i>Nucella praecingulata</i>
<i>Burnupena rogersi</i>	<i>Ocenebra bonaccorsii</i>
<i>Calliostoma depressa</i>	<i>Ocenebra purpuroides</i>
<i>Cantharidus striatus</i>	<i>Ocenebra petrocyon</i>
<i>Calyptraea helicoidea</i>	<i>Oxystele sinensis</i>
<i>Calyptraea kilburni</i>	<i>Patella argenvillei</i>
<i>Calyptraea viridarena</i>	<i>Patella barbara</i>
<i>Clanculus lutosus</i>	<i>Patella granatina</i>
<i>Clanculus murrayi</i>	<i>Patella hendeyi</i>
<i>Conus mozambicus</i>	<i>Patella hoffmani</i>
<i>Crepidula porcellana</i>	<i>Patella miniata</i>
<i>Crepidula deprima</i>	<i>Patella</i> sp.
<i>Cylichna tubulosa</i>	<i>Pseudoliva lutulenta</i>
<i>Diodora elevata</i>	<i>Ringicula turtoni</i>
<i>Drillia tempestae</i>	<i>Sinum concavum</i>
<i>Epitonium lycocephalum</i>	<i>Terebra canisaxi</i>
<i>Fasciolaria dinglei</i>	<i>Thais arenae</i>
<i>Fissurella glarea</i>	<i>Tricolia capensis</i>
<i>Fissurella robusta</i>	<i>Triumphis dilemma</i>
<i>Fissurellidae aperta</i>	<i>Trophon carringtoni</i>
<i>Fusus faurei</i>	<i>Tugali barnardi</i>
<i>Gibbula zonata patula</i>	<i>Turbo cidaris</i>
<i>Haliotis saldanhae</i>	<i>Turritella carinifera</i>
<i>Helcion</i> sp.	<i>Turritella declivis</i>
<i>Hesperorato oppenheimeri</i>	<i>Turris nigrovitta</i>
<i>Littorina</i> sp.	<i>Vermetus</i> sp.

TABLE 3-12

ALPHABETICAL LIST OF BIVALVIA FROM THE 50 AND 30 METRE SEDIMENT PACKAGES NAMAQUALAND	
<i>Arca avellana</i>	<i>Hinnites</i> sp.
<i>Arca halmyrus</i>	<i>Isognomon gariesensis</i>
<i>Arca noae</i>	<i>Leporimetic hanleyi</i>
<i>Aulacomya ater</i>	<i>Lutraria</i> sp.
<i>Barnea truncata</i>	<i>Macra</i> cf <i>dernbergi</i>
<i>Cardita unica</i>	<i>Melliteryx capensis</i>
<i>Carditella calipsamma</i>	<i>Notocallista schwartzi</i>
<i>Cardium</i> sp.	<i>Nuculana bicuspidata</i>
<i>Chamelea krigei</i>	<i>Ostrea</i> cf <i>subradiosa</i>
<i>Chlamys</i> sp.	<i>Perna perna</i>
<i>Choromytilus meridionalis</i>	<i>Petricola prava</i>
<i>Corbula palaegialus</i>	<i>Phaxas decipiens</i>
<i>Cuna aquadulcensis</i>	<i>Scissodesma spengleri</i>
<i>Donax haughtoni</i>	<i>Standella namaquensis</i>
<i>Donax rogersi</i>	<i>Striostrea margaritacea</i>
<i>Dosinia sicarisinus</i>	<i>Tellina ponsonbyi</i>
<i>Gastrana fibrosa</i>	<i>Tellina trilatera</i>
<i>Gastrana rostrata</i>	<i>Theora</i> sp.
<i>Gastrana</i> sp.	<i>Tivela</i> cf <i>compressa</i>
<i>Glycymeris fulleri</i>	<i>Venus verrucosa</i>
? <i>Hiatella</i> sp.	

TABLE 3-13

SYNONYMS AND HOMONYMS AMONG THE GASTROPODS OF THE NAMAQUALAND LITTORAL ZONE MASTER LIST FROM KENSLEY & PETHER (1986)	
Abbreviations.- CK'69 = Carrington & Kensley, 1969; H'31 = Houghton, 1931; K'72 = Kensley, 1972; KT'75 = Kilburn & Tankard, 1975; P'94 = Pether, 1994	
Extinct taxa are in bold letters	
<i>Afrocominella capensis</i>	<i>Marginella</i> sp.
<i>Amblychilepas scutellum</i>	<i>Melanella</i> sp.
<i>Argobuccinum casus</i> <i>Cabestana casus</i> P'94	<i>Melapium hawthornei</i>
<i>Bolma anoropha</i>	<i>Namamurex odontostoma</i> <i>N. odontostoma</i> CK'69: 198
<i>Bullia annulata</i> <i>Bullia magna</i> H'31: 46	<i>Nassarius kochianus</i>
<i>Bullia digitalis</i>	<i>Nassarius litorafontis</i> <i>Nassa litorafontis</i> CK'69: 195
<i>Bullia laevis</i>	<i>Natica</i> cf. <i>adansoni</i> <i>Natica imperforata</i> H'31: 45
<i>Burnupena aestus</i>	<i>Nucella dubia</i>
<i>Burnupena papyracea</i>	<i>Nucella praecingulata</i> <i>Thais praecingulata</i> H'31: 48
<i>Burnupena rogersi</i>	(<i>Spinucella</i> in P'94)
<i>Calliostoma depressa</i> <i>Calliostoma depressa</i> CK'69: 205	<i>Ocenebra bonaccorsii</i> <i>Tritonalia bonaccorsii</i> CK'69: 196
<i>Cantharidus striatus</i>	<i>Ocenebra purpuroides</i>
<i>Calyptraea helicoidea</i>	<i>Ocenebra petrocyon</i>
<i>Calyptraea kilburni</i> <i>Calyptraea aurita striata</i> CK'69: 201	<i>Oxystele sinensis</i>
<i>Calyptraea viridarena</i> <i>Calyptraea viridarena</i> CK'69: 202	<i>Patella argenvillei</i> <i>Patella argenvillei</i> H'31: 43
<i>Clanculus lutosus</i>	<i>Patella barbara</i>
<i>Clanculus murrayi</i> <i>Clanculus murrayi</i> CK'69: 203	<i>Patella granatina</i> <i>Patella granatina</i> H'31: 44
<i>Conus mozambicus</i> <i>Conus elongatus</i> H'31: 49	<i>Patella hendeyi</i> <i>Patella</i> sp. H'31: 30
<i>Crepidula porcellana</i>	<i>Patella hoffmani</i>
<i>Crepidula deprima</i>	<i>Patella miniata</i>
<i>Cylichna tubulosa</i>	<i>Patella</i> sp.
<i>Diodora elevata</i>	<i>Pseudoliva lutulenta</i>
<i>Drillia tempestae</i>	<i>Ringicula turtoni</i>
<i>Epitonium lycocephalum</i> <i>Epitonium</i> sp. H'31: 45	<i>Sinum concavum</i>
<i>Fasciolaria dinglei</i> <i>Fasciolaria</i> sp. CK'69: 193	<i>Terebra canisaxi</i>
<i>Fissurella glareae</i> <i>Fissurella glareae</i> CK'69: 206	<i>Thais arenae</i>
<i>Fissurella robusta</i> <i>Fissurella robusta</i> H'31: 42	<i>Tricolia capensis</i>
<i>Fissurellidea aperta</i>	<i>Triumphis dilemma</i> <i>Triumphis dilemma</i> KT'75: 200
<i>Fusus faurei</i>	<i>Trophon carringtoni</i> <i>Latiaxis</i> sp. CK'69: 195
<i>Gibbula zonata patula</i>	<i>Tugali barnardi</i>
<i>Haliotis saldanhae</i> <i>Haliotis saldanhae</i> K'72: 176	<i>Turbo cidaris</i> <i>Turbo cidaris</i> H'31: 43
<i>Helcion</i> sp.	<i>Turritella carinifera</i> <i>Turritella carinifera</i> H'31: 45
<i>Hespererato oppenheimeri</i> <i>H. oppenheimeri</i> CK'69: 199	<i>Turritella declivis</i>
<i>Littorina</i> sp. <i>Littorina punctata</i> H'31: 44	<i>Turris nigrovitta</i> <i>'Turris' nigrovitta</i> CK'69: 193
	<i>Vermetus</i>

TABLE 3-14

SYNONYMS AND HOMONYMS AMONG BIVALVES OF THE NAMAQUALAND LITTORAL ZONE MASTER LIST FROM KENSLEY & PETHER, 1986 Abbreviations : CK'69 = Carrington & Kensley, 1969; H'31 = Haughton, 1931 Taxa in bold letters are extinct	
<i>Arca avellana</i>	<i>Arca avellana</i> CK'69: 206
<i>Arca halmyrus</i>	<i>Arca halmyrus</i> CK'69: 206
<i>Arca noae</i>	
<i>Aulacomya ater</i>	
<i>Barnea truncata</i>	
<i>Cardita unica</i>	
<i>Carditella calipsamma</i>	<i>Carditella calipsamma</i> CK'69: 209
<i>Cardium</i> sp.	
<i>Chamelea krigei</i>	<i>Chamelea krigei</i> H'31: 35
<i>Chlamys</i> sp.	
<i>Choromytilus meridionalis</i>	
<i>Corbula palaegialus</i>	<i>Aloidis palaegialus</i> CK'69: 221
<i>Cuna aquaedulcensis</i>	
<i>Donax haughtoni</i>	<i>Donax haughtoni</i> CK'69: 213
<i>Donax rogersi</i>	<i>Donax rogersi</i> H'31: 36
<i>Dosinia sicarisinus</i>	
<i>Gastrana fibrosa</i>	
<i>Gastrana rostrata</i>	<i>Gastrana rostrata</i> CK'69: 218
<i>Gastrana</i> sp.	
<i>Glycymeris fulleri</i>	
? <i>Hiatella</i> sp.	
<i>Hinnites</i> sp.	
<i>Isognomon gariesensis</i>	
<i>Leporimētis hanleyi</i>	
<i>Lutraria</i> sp.	
<i>Mactra cf dernbergi</i>	
<i>Melliteryx capensis</i>	
<i>Notocallista schwarzi</i>	
<i>Nuculana bicuspidata</i>	
<i>Ostrea cf subradiosa</i>	
<i>Perna perna</i>	
<i>Petricola prava</i>	
<i>Phaxas decipiens</i>	
<i>Scissodesma spengleri</i>	
<i>Standella namaquensis</i>	<i>Standella namaquensis</i> CK'69: 210
<i>Striostrea margaritacea</i>	<i>Ostrea prismatica</i> H'31: 39
<i>Tellina ponsonbyi</i>	
<i>Tellina trilatera</i>	
<i>Theora</i> sp.	
<i>Tivela cf compressa</i>	
<i>Venus verrucosa</i>	<i>Antigona verrucosa</i> H'31: 35

TABLE 3-15

HAUGHTON'S 1931 BIOSTRATIGRAPHY OF THE LITTORAL DEPOSITS OF SOUTHWESTERN AFRICA					
Taxa in bold letters are extinct					
(A-E are Haughton's Biostratigraphic Zones)					
(E - oldest to A - youngest)					
Zone	E	D	C	B	A
Taxon					
<i>Chlamys pusio</i>	-----				
<i>Epitonium</i> sp.	-----				
<i>Patella natalensis</i>	-----				
<i>Kraussina lata</i>	-----				
<i>Ostrea prismatica</i>		-----			
<i>Mytilus tomlini</i>		-----			
<i>Chamelea krigei</i>		-----			
<i>Fissurella robusta</i>		-----			
<i>Patella umbella</i>		-----			
<i>Tylos</i> cf <i>granulatus</i>		-----			
<i>Thais praecingulata</i>		-----			
<i>Bullia magna</i>		-----			
<i>Turbo cidaris</i>		-----			
<i>Donax rogersi</i>				-----	
<i>Burnupena limbosa</i>		-cf--		-----	
<i>Burnupena lagenaria</i>		-----		-----	
<i>Patella argenvillei</i>		-----		-----	
<i>Patella granularis</i>		-cf--		-----	
<i>Patella granatina</i>		-----		-----	
<i>Patella oculus</i>		-cf--		-----	
<i>Tellina rosea</i>			-----		
<i>Venus verrucosa</i>			-----		
<i>Macrocallista</i> cf <i>lilacina</i>			-----		
<i>Mactra glabrata</i>			-----		
<i>Turitella carinifera</i>			-----		
<i>Turitella kryснаensis</i>			-----		
<i>Marginella capensis</i>			-----		
<i>Nassarius plicatellus</i>			-----		
<i>Fasciolaria lugubris</i>			-----		
<i>Ostrea atherstoni</i>			-----		
<i>Paphia corrugata</i>			-----		
<i>Gastrana abildgaariana</i>			-----		
<i>Burnupena porcata</i>			-----		
<i>Megatabennus scutellum</i>			-----		
<i>Turitella capensis</i>			-----	-----	
<i>Murex purpuroides</i>			-----		-----
<i>Mytilus</i> sp.				-----	
<i>Paphia deshayesi</i>				-----	
<i>Paphia currugata</i>				-----	
<i>Solen capensis</i>				-----	
<i>Lutraria capensis</i>				-----	
<i>Crepidula hepatica</i>				-----	
<i>Argobuccinum argus</i>				-----	
<i>Burnupena anglicana</i>				-----	
<i>Nassarius</i> cf <i>babylobicus</i>				-----	
<i>Philine aperta</i>				-----	
<i>Donax serra</i>				-----	
<i>Mytilus crenatus</i>				-----	
<i>Patella barbara</i>				-----	
<i>Patella compressa</i>				-----	
<i>Patella cochlear</i>				-----	
<i>Helcion pectunculatus</i>				-----	
<i>Diodora elevata</i>				-----	
<i>Bullia laevisissima</i>				-----	
<i>Bullia digitalis</i>				-----	
<i>Thais cingulata</i>				-----	
<i>Thais squamosa</i>				-----	
<i>Kraussina rubra</i>				-----	
<i>Nassa plicosa</i>				-----	

TABLE 3-16

STRATIGRAPHIC DISTRIBUTION OF GASTROPODA NAMAQUALAND			
Data from Kensley & Pether, 1986			
(Taxa in bold letters are extinct)			
Taxon	50 Mp	30Mp	Recent
<i>Cabestana casus</i>	-----		
<i>Burnupena aestus</i>	-----		
<i>Caliostoma depressa</i>	-----		
<i>Calyptrea viridarena</i>	-----		
<i>Clanculus lutosus</i>	-----		
<i>Crepidula deprima</i>	-----		
<i>Drillia tempestae</i>	-----		
<i>Fasciolaria dinglei</i>	-----		
<i>Haliotis saldanhae</i>	-----		
<i>Patella hoffmani</i>	-----		
<i>Pseudoliva lutulenta</i>	-----		
<i>Terebra canisaxi</i>	-----		
<i>Trophon carringtoni</i>	-----		
<i>Calyptrea kilburni</i>	-----		
<i>Clanculus murrayi</i>	-----		
<i>Epitonium lycocephalum</i>	-----		
<i>Fissurella robusta</i>	-----		
<i>Melapium hawthorni</i>	-----		
<i>Namamurex odontostoma</i>	-----		
<i>Nucella praecingulata</i>	-----		
<i>Ocenebra bonaccorsi</i>	-----		
<i>Patella hendeyi</i>	-----		
<i>Afrocominella capensis</i>	-----		----
<i>Bullia annulata</i>	-----		----
<i>Bullia laevis</i>	-----		----
<i>Burnupena papyracea</i>	-----		----
<i>Cantharidus striatus</i>	-----		----
<i>Crepidula porcellana</i>	-----		----
<i>Cylichna tubulosa</i>	-----		----
<i>Fissurellidea aperta</i>	-----		----
<i>Fusus faurei</i>	????		----
<i>Gibbula zonata</i>	-----		----
<i>Helcion</i> sp.	-----		----
<i>Melanella</i> sp.	-----		----
<i>Ringicula turtoni</i>	-----		----
<i>Tricolia capensis</i>	-----		----
<i>Tugali barnardi</i>	-----		----
<i>Turritella declivis</i>	-----		----
<i>Amblychilepas scutellum</i>	-----		----
<i>Bullia digitalis</i>	-----		----
<i>Conus mozambicus</i>	-----		----
<i>Diodora elevata</i>	-----		----
<i>Marginella</i> sp.	-----		----
<i>Nucella dubia</i>	-----		----
<i>Ocenebra purpuroides</i>	-----		----
<i>Oxysteles sinensis</i>	-----		----
<i>Patella argenvillei</i>	-----		----
<i>Patella barbara</i>	-----		----
<i>Turbo cidaris</i>	-----		----
<i>Turritella carinifera</i>	-----		----
<i>Vermetus</i> sp.	-----		----
<i>Burnupena rogersi</i>	-----		
<i>Fissurella glare</i>	-----		
<i>Ocenebra petrocyon</i>	-----		
<i>Thais arenea</i>	-----		
<i>Calyptrea helicoidia</i>	-----		
<i>Littorina</i> sp.	-----		
<i>Nassarius kochianus</i>	-----		
<i>Natica</i> cf <i>adansoni</i>	-----		
<i>Patella granatina</i>	-----		
<i>Patella miniata</i>	-----		
<i>Patella</i> sp.	-----		
<i>Simum concavum</i>	-----		

TABLE 3-17

STRATIGRAPHIC DISTRIBUTION OF BRACHIOPODA : NAMAQUALAND			
Data from Kensley & Pether, 1986			
Taxon	50mP	30 mP	Recent
<i>Kraussina lata</i>	-----		
<i>Kraussina laevicostata</i>	-----		
<i>Kraussina cuneata</i>		-----	
<i>Kraussina rotundata</i>	-----	-----	
<i>Cancelothris platys platys</i>		-----	

TABLE 3-18

STRATIGRAPHIC DISTRIBUTION OF BIVALVES LITTORAL DEPOSITS OF SOUTHWESTERN AFRICA			
Data from Kensley & Pether, 1986			
(Taxa in bold letters are extinct)			
Taxon	50 Mp	30 Mp	Recent
<i>Chamelea krigei</i>	-----		
<i>Donax haughtoni</i>	-----		
<i>Glycymeris fulleri</i>	-----		
<i>Notocallista schwartzi</i>	-----		
<i>Carditella calypsamma</i>	-----		
<i>Dosinia sicarisinus</i>	-----		
<i>Isognomon gariesensis</i>	-----		
<i>Petricola prava</i>	-----		
<i>Standella namaquensis</i>	-----		
<i>Arca avellana</i>	-----		-----
<i>Cardium</i> sp.	-----		-----
<i>Chlamys</i> sp.	-----		-----
? <i>Hiatella</i> sp.	-----		-----
<i>Hinnites</i>	-----		-----
<i>Melliteryx capensis</i>	-----		-----
<i>Theora</i> sp.	-----		-----
<i>Scissodesma spengleri</i>	-----		-----
<i>Striostrea margaritacea</i>	-----		-----
<i>Nuculana bicuspidata</i>	-----		-----
<i>Leporimetis hanleyi</i>	-----		-----
<i>Gastrana</i> sp.	-----		-----
<i>Aulacomya ater</i>	-----		-----
<i>Barnea truncata</i>	-----		-----
<i>Lutraria</i> sp.	-----		-----
<i>Perna perna</i>	-----		-----
<i>Phaxas decipiens</i>	-----		-----
<i>Tellina ponsonbyi</i>	-----		-----
<i>Tellina trilatera</i>	-----		-----
<i>Tivella cf compressa</i>	-----		-----
<i>Venus verrucosa</i>	-----		-----
<i>Cuna aquaedulcensis</i>		-----	
<i>Cardita unica</i>		-----	
<i>Donax rogersi</i>		-----	
<i>Choromytilus meridionalis</i>		-----	
<i>Arca noae</i>		-----	
<i>Donax serra</i>			-----

TABLE 3-19

MOLLUSCA OF THE CDM BEACHES ORANJEMUND			
Taxa in bold letters are extinct			
(from Fowler, 1976)			
CDM Beaches	F-E-D	B-C-A	
Taxon			
Chamelea krigei	-----		
<i>Crassostrea margaritacea</i>	-----		
Donax rogersi	-----		
<i>Fissurella</i> sp.	-----		
Perna tomlini	-----		
<i>Thais praecingulata</i>	-----		
<i>Donax serra</i>		-----	
<i>Mytilus</i> sp.		-----	
<i>Patella</i> sp.		-----	
<i>Bullia</i> sp.		-----	
<i>Burnupena</i> sp.		-----	
(From Kleinjan, 1971)			
CDM Beaches	D-C	B-A	
Taxon			
Donax rogersi	-----		
Fissurella glareata	-----		
Perna tomlini	-----		
<i>Mytilus</i> sp.	-----		
<i>Donax serra</i>		-----	
(From Houghton, 1931)			
Uub Vlei Main Terrace	(10-12 metres asl)		
Taxon			
<i>Mytilus tomlini</i>	-----		
Donax rogersi	-----		
Chamelea krigei	-----		
Fissurella robusta	-----		
<i>Patella</i> sp.	-----		
<i>Bullia</i> sp. cf. <i>magna</i>	-----		

TABLE 3-20

MOLLUSCS FROM THE ALEXANDER BAY TERRACES			
(Taxa in bold letters are extinct)			
(From Houghton, 1928)			
Terraces (Altitude)	Upper 33-38m	Middle 10-25m	Lower 0-8m
Taxon			
<i>Ostrea prismatica</i>	-----		
Thais praecingulata	-----		
Chamelea krigei		-----	
<i>Cominella</i> sp.		-----	
<i>Comus elongatus</i>		-----	
Donax rogersi		-----	
Fissurella robusta		-----	
<i>Patella</i> sp.		-----	
<i>Tellina</i> cf. <i>triangularis</i>		-----	
<i>Turbo</i> sp.		-----	
<i>Tylos granulatus</i>		-----	
<i>Patella argenvillei</i>		-----	
<i>Patella</i> cf. <i>barbara</i>		-----	
<i>Burnupena lagenaria</i>			-----
<i>Burnupena limbosa</i>			-----
<i>Helcion pectunculus</i>			-----
<i>Patella cochlea</i>			-----
<i>Patella granatina</i>			-----
(From de Villiers & Sönghe, 1959)			
Terrace (Altitude)	Upper 44m	Middle	Lower
Taxon			
Fissurella robusta	-----		
<i>Patella robusta</i>	-----		
<i>Patella barbara</i>		-----	
<i>Patella oculus</i>		-----	
<i>Bullia</i> sp.			-----
<i>Cominella</i> sp.			-----
<i>Crepidula rugosa</i>			-----
<i>Patella granularis</i>			-----
(From Houghton, 1931)			
Oyster Line (ca 35 metres asl)			
Taxon			
Chamelea krigei	-----		
Donax rogersi	-----		
<i>Ostrea prismatica</i>	-----		
<i>Ostrea</i> sp.	-----		
Thais praecingulata	-----		
Fissurella robusta	-----		
<i>Patella argenvillei</i>	-----		
<i>Patella</i> cf. <i>granularis</i>	-----		
<i>Patella granatina</i>	-----		
<i>Patella</i> cf. <i>oculus</i>	-----		
<i>Patella umbella</i>	-----		
<i>Tylos</i> cf. <i>granulatus</i>	-----		

4. RESULTS OF THE NAMIBIA PALAEOLOGY EXPEDITION (NPE) AND THE PALAEOLOGY EXPEDITION TO SOUTH AFRICA (PESA)

4.1 INTRODUCTION

Since 1991, the Namibia Palaeontology Expedition and the Palaeontology Expedition to South Africa have been examining Cenozoic fossiliferous strata of Namibia and Namaqualand, South Africa (fig. 4-1) and have discovered well over 200 fossil localities both in the coastal strip and in the high interior east of the Great Escarpment (Partridge & Maud, 1987; Ward & Corbett, 1990).

In Namaqualand, fossils discovered in diamond mines in the Hondeklip Bay region have been crucial to determining the ages of the littoral marine strata that crop out in a narrow belt oriented parallel to the coastline, both north and south of the Orange River. Some of these fossils were collected many years ago and presented to the South African Museum, while others were collected by the Palaeontology Expedition to South Africa. Many of these sites have yielded fossils which can be used to estimate the ages of the enclosing strata. The main result of these findings has been a comprehensive revision of the geological history of the Namib.

The fossil sites of relevance to developing an understanding of the evolution of the Namib fall into several categories. Firstly, there are assemblages from marine strata of Cretaceous to Miocene age which crop out near the present day coast. Secondly, in the northern Sperrgebiet occurs a series of fossil sites (E-Bay, Fiskus, Grillental, Elisabethfeld, Langental) in which sediments accumulated in pre-Miocene valleys that used to drain into the Atlantic. These sites are predominantly of Early Miocene age (Faunal Sets PI and PII of Pickford, 1981) some 20-18 Ma. Thirdly, abandoned sediment-filled loops and channels of the Orange River at Auchas, Arrisdrift and Baken have yielded important fossil faunas and flora aged about 18-17 Ma (Faunal Sets PII and PIII). Fourthly, aeolianites of the Namib Desert have yielded abundant fossils at over 100 sites spanning most of the Miocene, Pliocene and Quaternary. Grits intercalated in travertines at Kaukausib have yielded Pliocene fossils while at Chalcedon Tafelberg there are fossiliferous sediments that accumulated in a crater lake. Finally, at several localities in calcretes developed along the coast north of Oranjemund and in the interior not far from the base of the Great Escarpment, fossil mammals and invertebrates of post-Pliocene age have been found. South of the Orange River, the calcretes are younger than the early Pleistocene on the basis of the discovery of teeth of *Equus capensis* and Acheulean tools in sediments below the calcrete which developed on the 50 metre terrace. Gresse (1988) estimated that these sub-calcrete beds were about 1.6 Ma old. A fossil locality in calcreted aeolianites at Swart Duinen, south-southeast of Klein Zee, has yielded a rich assemblage of fossils, all of which appear to belong to extant species.

The most comprehensive palaeontological studies by the NPE have been done in Diamond Area N° 1 (the Sperrgebiet in the southwest corner of Namibia) and in the Namib-Naukluft Park (formerly Diamond Area N° 2) especially in the area between Kamberg and Awasib. There are several fossiliferous localities within the central part of the coastal plain, principally near Gobabeb and in the Namib Sand Sea to the south. The Walvis Bay area (Rooikop, Rooibank) has yielded interesting marine fossils of Miocene age, including molluscs, shark teeth and borings made by lithophagous molluscs. Similar sediments occur at Tsondabmund, some 150 km south of Walvis Bay. In the north, the coastal stretch from Swakopmund to the Skeleton Coast has yielded few fossils, probably because it has not yet been examined closely by palaeontologists.

Surveys in the Sperrgebiet by the NPE have resulted in the collection of abundant fossils. Significant advances have been made in understanding of the biostratigraphy and palaeoecology of the region. For example, it is now known that the aeolianites of the Namib do not comprise a simple stratigraphic unit, hitherto called the Tsondab Sandstone, but that it consists of numerous major sand bodies deposited at different times overlain by a younger sand body, the modern dune fields of the Sossus Sand Formation. Preliminary observations of bedding within the palaeo-dunes reveal that wind directions varied over geological time. For example, aeolianites at Elim and Diep Rivier, which yield eggshells of *Namornis oshanai* (Middle Miocene ca 15-16 Ma), have cross-bedding that dips consistently towards the east, indicating a regime dominated by winds blowing from the west, i.e. inland from the Atlantic Ocean. Other sand bodies have bedding which indicate winds blowing mainly from the south, while yet others, such as those at Haiber that yield eggshells of *Diamantornis laini* (Late Miocene ca 10-8 Ma) have cross-bedding indicative of northerly wind regimes.

In the northern Sperrgebiet, there are numerous small bodies of fluvio-paludal sediment geographically separated from one another, which has made mapping and stratigraphy difficult and correlations uncertain (Beetz, 1926; Stocken, 1962, 1978). The so-called Fiskus Aeolianite, originally thought by Merensky (1909) to be Cretaceous, is now known to consist of sands deposited during two different time periods, those at Schmidtfeld being Middle Miocene and those at Fiskus being post-Miocene in age. The available fossil evidence corroborates the geological and geomorphological results of Corbett (1989). Strata at a number of localities have not yet yielded direct evidence of their chronostratigraphic position and they are currently positioned on the basis of geomorphological arguments.

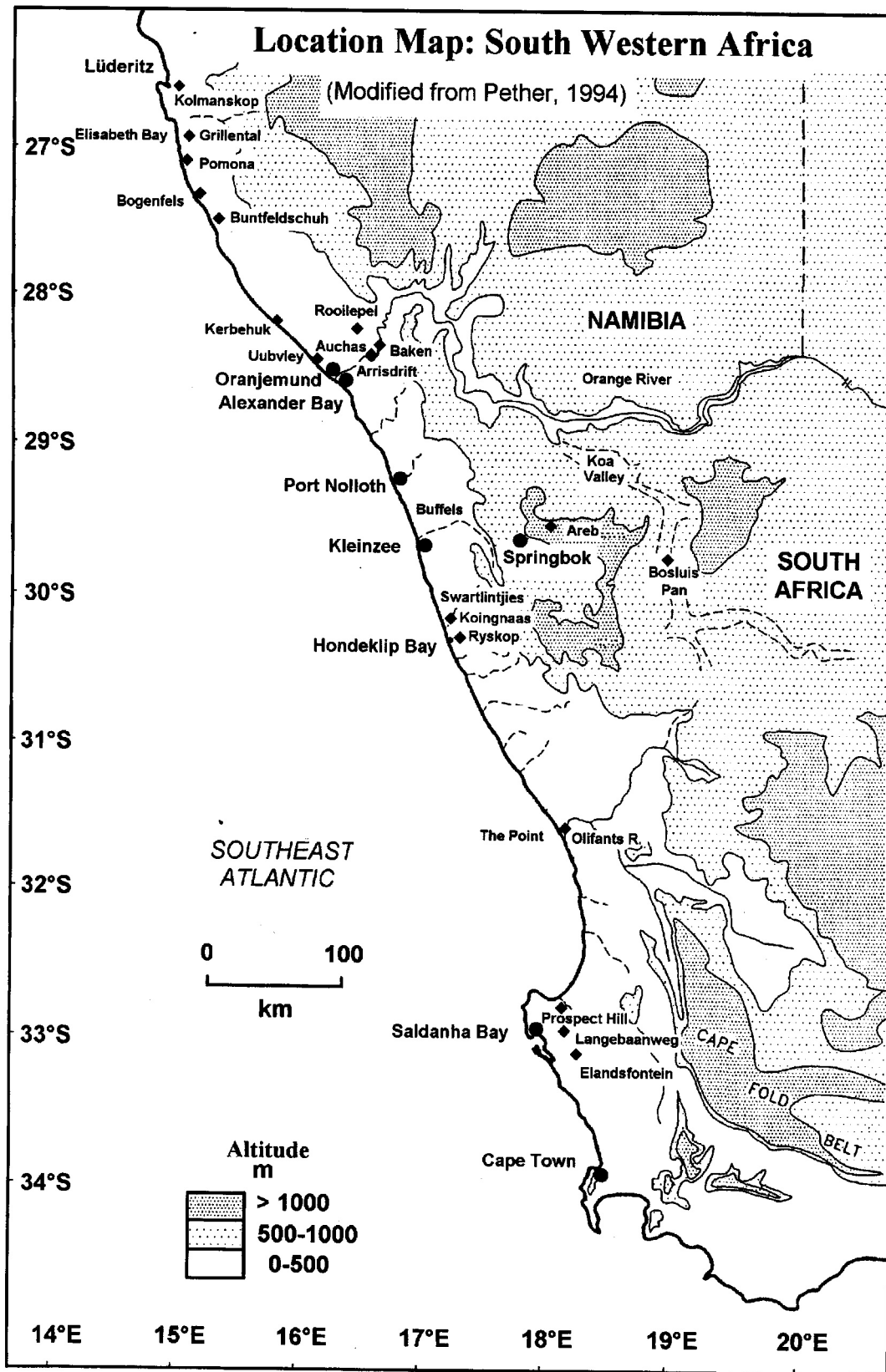


Figure 4-1.- Location map of southwestern Africa showing the principal fossiliferous localities (diamond symbol), main towns and topography.

The outcrops of the Elisabeth Bay Formation in the northern Sperrgebiet are of great palaeontological interest. Visits to the sites of Elisabethfeld, Grillental and Fiskus by members of the Namibia Palaeontology Expedition resulted in the collection of abundant vertebrate fossils *in situ* and eroding out of these strata. Even though the age of the formation has been reasonably well worked out as late in the Early Miocene (ca 20-18 Ma) there remain several gaps in our knowledge of the species represented. It is now clear that the Elisabeth Bay Formation of Greenman (1966, 1970) is a composite unit, comprising Early Miocene fluvio-paludal strata and post-Miocene aeolianites separated by an unconformity representing some 15 Ma.

Miocene terrace deposits of the Proto-Orange River have continued to yield fossils in abundance, especially at Arrisdrift. New localities at Auchas contain fewer fossils but they are nevertheless of interest because they are older than the classic Proto-Orange site at Arrisdrift in Namibia and Baken in South Africa.

4.2 GEOMORPHOLOGY OF THE NAMIB COASTAL PLAIN

4.2.1 ORIGIN AND SHAPING FORCES

The Namib Coastal Plain is an elongate low-lying zone between the Great Escarpment in the east and the Atlantic Ocean in the west. The geomorphology of the Namib coastal plain has resulted from the interplay of many forces and processes. It began to form as soon as the break-up of Gondwana ruptured the southern part of Africa from South America some 135 Ma. Since that time the interior of the African continent in the vicinity of Namibia has risen by some 1.2 km as revealed by the observation that undeformed Permian marine strata at Schlip, near Rehoboth, lie at this altitude (Martin *et al.*, 1970). The Great Escarpment formed predominantly by a process of backwearing, but there is ample evidence that vertical downwasting has also been important in shaping the Namib Coastal Plain, especially in the northern Sperrgebiet where erosion of this type has resulted in the production of mesas and other landforms. Offshore there has also been thermal sag of the continental margin (Light *et al.*, 1992, 1993). There is thus a hinge line running more or less parallel to the coastline but its position has not been determined precisely because the degree of tilting is very low. However it is probably onshore (Partridge *et al.*, 1995b). Inland from this hinge line, the land has risen whereas offshore the sea-bed has subsided.

Erosion has been carried out by a variety of processes. In the early history of the coastal plain flowing water was the main agent for erosion, but since the Middle Miocene the wind has played a predominant role in shaping the Namib, not only by eroding exposed rocks, but also by transporting and dumping huge volumes of sand onto its surface. The Namib as we see it today is thus the result of 135 million years of weathering, erosion, transportation, and deposition by water and wind, tempered by epeirogenic uplift, eustatic sea-level changes and volcanic activity.

4.2.2 THE NAMIB UNCONFORMITY SURFACE

Below an incomplete cover of Miocene to Recent rocks, the Namib Unconformity Surface (NUS) separates the Late Proterozoic bedrock from younger rocks. This surface has appreciable relief with immense inselbergs and deep valleys, but over much of the Namib it is not possible to discern the relief due to the thick sand cover. Where the sand cover is thin or absent, various landforms can be made out including river valleys and marine terraces among others. Originally defined by Ollier (1977, 1978) as the inselberg-studded surface upon which the initial accumulation of surficial deposits of the central Namib occurred, it was considered to have predated incision of the Kuiseb River (Ward, 1987).

Ward (1987) and Ward & Corbett (1990) concluded that the NUS dated from the end Cretaceous, but it is considerably younger than this in its type area near the great Escarpment in the Kuiseb Valley where it is overlain by Miocene sediments. In the northern Sperrgebiet it is overlain by considerably older strata at Buntfeldschuh and by the Eocene Langental Formation (Ward & Corbett, 1990). In the northern part of the Sperrgebiet, there are several valleys containing sediments rich in Early Miocene faunal assemblages (fig. 4-2). These strata were considered by Ward & Corbett (1990) to have accumulated during a postulated "pluvial phase" which they thought ended the Proto-Namib Desert phase, well after the formation of the Namib Unconformity Surface. These valleys were eroded in pre-miocene time prior to the onset of desertification and they are thus older than the NUS in its type area which is overlain by Middle Miocene strata. Maud & Partridge (1987) argued that in the northern Sperrgebiet the NUS was cut below kaolinised and silcrete capped remnants of the African surface and was thus incised during the Post-African I cycle, in which case it could not be older than the mid-Miocene. Thus Ward (1987) and Maud & Partridge (1987) included erosional surfaces of diverse ages in the NUS. In effect, the concept of the NUS has expanded to include erosion surfaces of several ages, and by default it has become little more than any bedrock surface in the Namib Coastal Plain upon which post-Mesozoic rocks repose and which was formed prior to the incision of the Kuiseb. The latter event is geologically recent, post-dating the Kamberg Calcrete which is Pliocene in age (Rust & Wieneke, 1974, 1980; Vogel, 1989; Ward, 1982).

4.2.3 THE KLINGHARDT MOUNTAINS

In the central parts of the Sperrgebiet there are the volcanic Klinghardt Mountains (Lock & Marsh, 1974). Lavas from various vents have been dated by radioisotopic methods and give age estimates near the Eocene-Oligocene Boundary (ca 37 Ma) (Stocken, 1978). At Swartkop, phonolite lava overlies sediment which reposes upon kaolinised bedrock. This sediment is heavily silicified and has previously been taken as evidence for estimating a pre-Oligocene age for the Pomona Quartzites, but these rocks have nothing in common with each

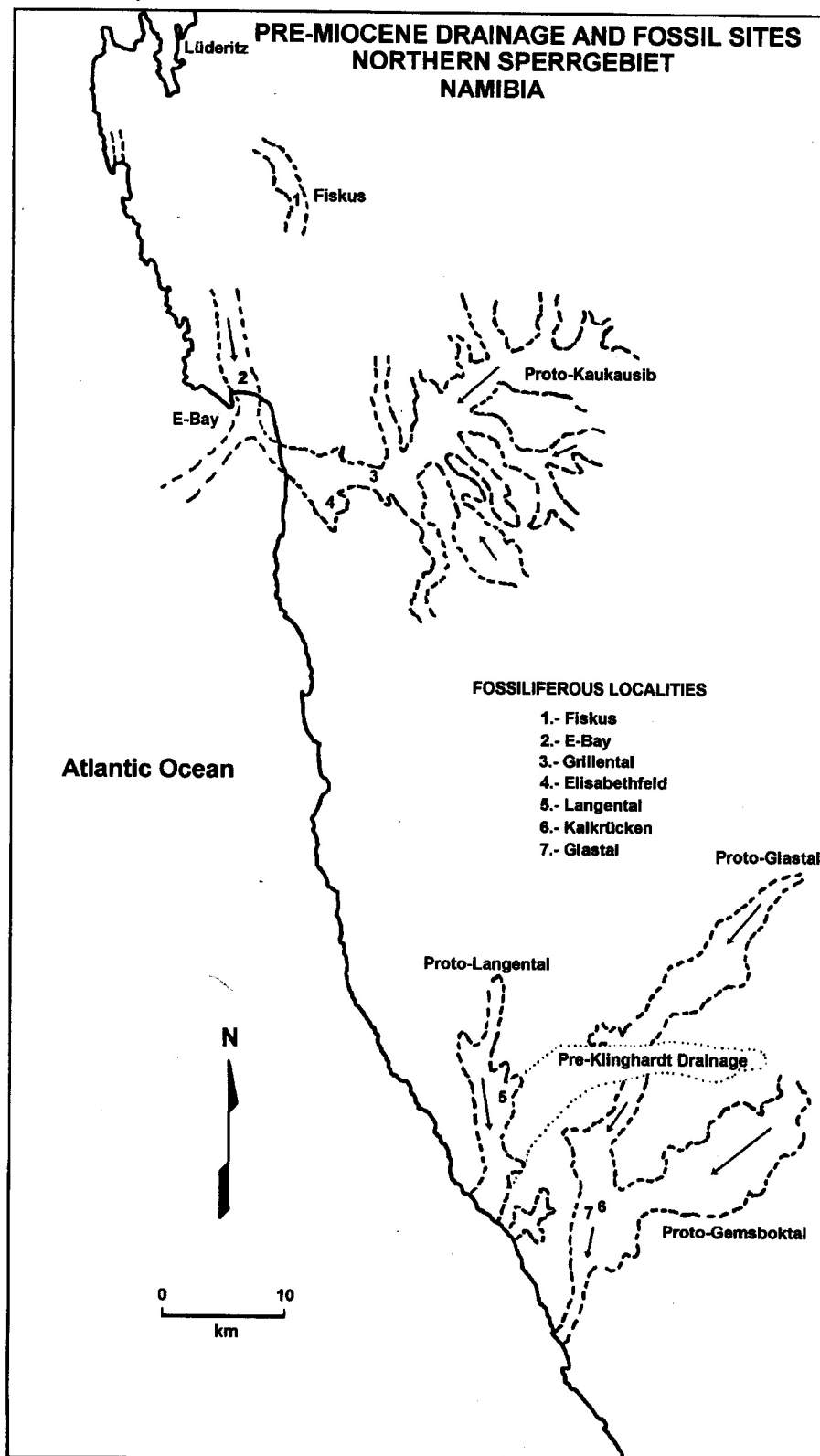


Figure 4-2.- Pre-Miocene drainage of the Northern Sperrgebiet, Namibia. Fossiliferous sedimentary infillings which accumulated in valleys incised into bedrock south of Lüderitz contain abundant Early Miocene faunas. The valleys were incised either during the Late Oligocene or the basal Early Miocene when sea level was appreciably lower than it is today. A rise in sea level at the end of the Early Miocene appears to have arrested the movement of transient sediments in these valleys. The resulting strata are still preserved in parts of the ancient drainage system and are visible where younger (post-Miocene) strata have been removed by erosion. In the Klinghardt area, there is the possibility of an even more ancient drainage line which was active prior to the Klinghardt volcanics.

other except for the fact that both are rich in silica. The Klinghardt Mountains have been positive relief features since they formed, and have supplied phonolite clasts to many of the drainages flowing away from them (Stocken, 1978).

4.3 PALAEOHYDROLOGY

4.3.1 PRE-MIOCENE VALLEYS

In the northern Sperrgebiet it is possible to reconstruct part of the palaeohydrographic network. Two main networks have been recognised (fig. 4-2) one of which is readily observed in satellite images. This, the Proto-Kaukausb, is filled with Early Miocene sediments in the Grilental and Elisabethfeld. Other fossiliferous sediments occur at Elisabeth Bay, Bohrloch site (near Betrieb IV) and Fiskus, all of which probably accumulated in parts of the same drainage network, which came together at E-Bay and then flowed into the Atlantic when sea-level was lower than it is today, probably during the Late Oligocene low stand.

In the Pomona area, ancient drainage lines can be reconstructed by mapping out the sediments. Early Miocene strata occur in the Proto-Langental and the Proto-Glantal valleys, and there is possibly a pre-Oligocene valley in the same general area in which the Blaubbok Gravels occur.

Further south there is evidence for a fossil drainage line at Kerbehuk and Dub Vlei, while the Orange, Buffels and Olifants Rivers are all known to possess offshore valleys incised into bedrock, probably during the Oligocene. In Namaqualand there are also several channels containing sediments which are hidden under the extensive sand cover. The main examples are at Koingnaas and Ryskop where lignitic sediments and sandstones have been encountered during mining activities. Similar lignitic valley infillings have been recorded further south in the coastal plain south of 31°S latitude (Cole & Roberts, 1996) where they are assigned to the Elandsfontyn Formation which is considered to be of Middle Miocene age.

Thus, from the Cape Peninsula northwards to Lüderitz there are remnants of pre-Miocene drainage lines preserved in the coastal plain at Ryskop, Koingnaas and Langklip. South of the Orange River, sediments which accumulated in these valleys are characterised by their lignitic content and lack of vertebrates, whereas north of it, the sediments are rich in vertebrates and there are no lignites known. The differences between these two kinds of deposit are probably due to climatic differences, the southern deposits having accumulated in relatively humid, perhaps even waterlogged, environments, while the northern sites accumulated under semi-arid conditions.

In the vicinity of Pomona there is a pre-Miocene valley containing sediments in which there are no volcanic clasts. Since this valley passes through part of the Klinghardt country, it must predate the eruption of the volcanoes and is thus probably of Eocene or pre-Eocene age.

In the northern Sperrgebiet other pre-Miocene valleys, including the Kaukausb, containing sediments with phonolitic clasts have been cut into fresh or kaolinised bedrock, sometimes to below sea-level, attesting to a pre-Miocene low stand of the ocean. Similarly, in Namaqualand and further south towards Cape Town, ancient valleys have been recorded under the cover of younger rocks. Sediments which infilled the valleys are richly fossiliferous, having yielded abundant Early Miocene faunal remains in the north and lignitic successions in the south.

The Orange River today flows in a valley which it has occupied since at least the Late Oligocene (fig. 4-3). The oldest sediments found in it so far are of Early Miocene age (ca 19 Ma) but it seems clear from offshore data that there is a submarine channel down which the river used to flow in pre-Miocene times (Birch, 1975). This valley was very probably incised during the Late Oligocene, which worldwide was a period of exceptionally low sea-levels. When sea-level rose towards the end of the Oligocene and during the early Miocene, transient sediments in the various drainage lines that flowed into the Atlantic stopped moving, blocked the valleys and promoted the formation of fluvial terrace deposits of various sorts. In the Orange River Valley, these are the Proto-Orange Terrace I deposits. Subsequently, sea-level dropped again, and the rivers that were still flowing cut new channels for themselves, sometimes through their own terrace deposits, sometimes to one side or other of them.

During the Late Miocene a further episode of sea-level higher than the present day one repeated the story, with the result that a second set of fluvial terraces was produced, the so-called Meso-Orange Terrace II. The same thing happened again at the end of the Pliocene to produce the Meso-Orange Terrace III. More recently, fine silts were deposited up to several metres above the present level of the Orange River suggesting that the river was dammed or that the level of its outlet rose for a while.

The Buffels River in northern Namaqualand has well developed fluvial terraces at Kommaggas, Nuttabooi and elsewhere, but their ages are unknown because no fossils have been recovered from them. It seems probable that they would correspond in some way with the Orange River Terraces, since in both river systems the terraces probably resulted from a change in base level brought about by rising sea-levels.

4.3.2 MARINE TERRACES

In the southern Sperrgebiet and Namaqualand, there are ancient marine terraces at various altitudes above and below sea-level (fig. 4-4). The highest marine strata in the region are at Eisenkieselklippenbake (ca 160 metres above sea-level (asl)) and Buntfeldschuh (ca 140 metres asl). These are often assigned to the Eocene or Oligocene, but direct evidence of their ages have not been forthcoming, although it is unlikely that Buntfeldschuh is older than Lutetian (Middle Eocene).

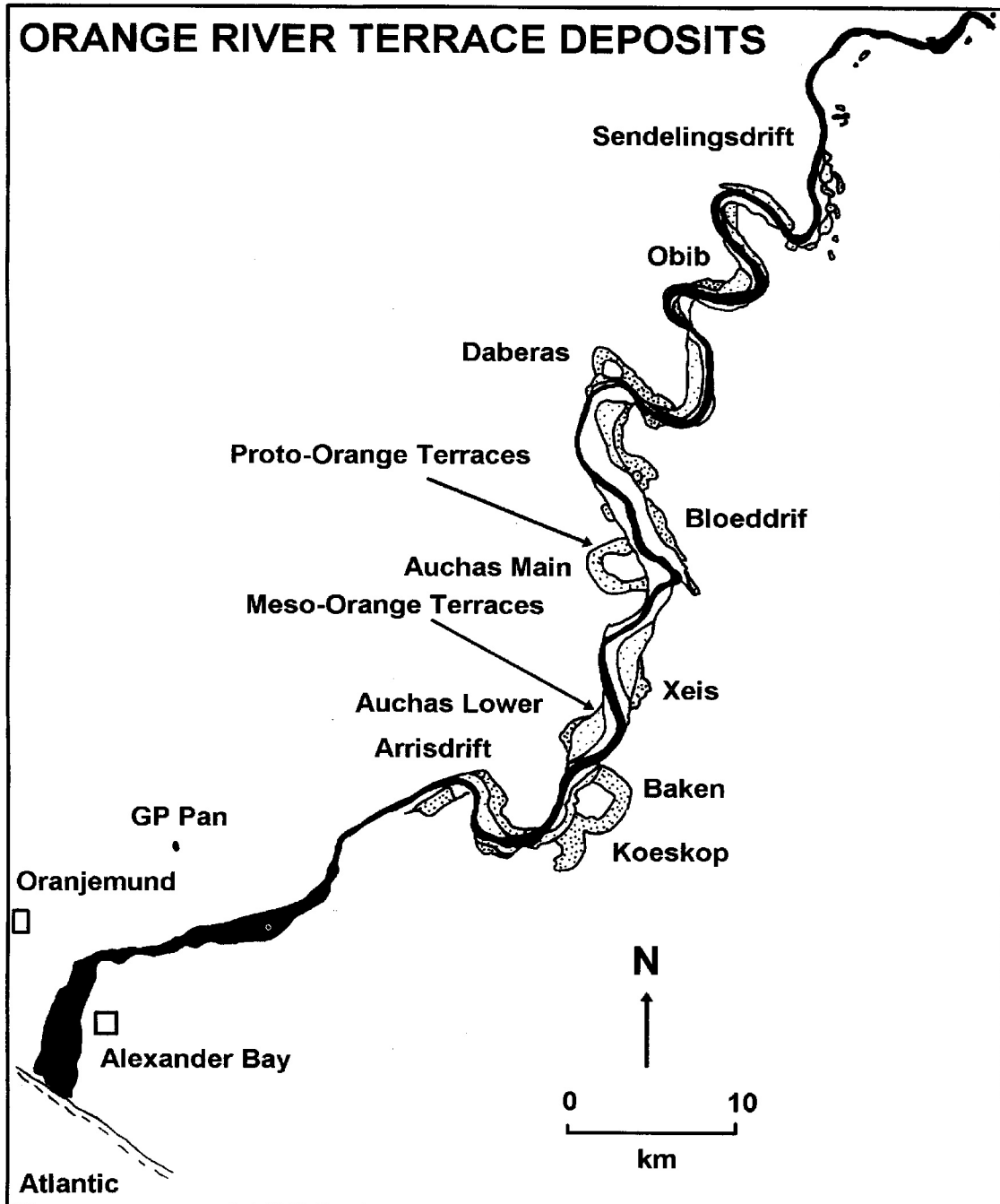


Figure 4-3.- The lower reaches of the Orange River and its terrace deposits. The distribution of the Proto-Orange terraces (dense dots) reveal that the river followed a slightly different course within the valley during the Early and Middle Miocene and indicate that the river has probably been encased in its valley since the Late Oligocene. Later terraces (dispersed dots and clear patches) of Plio-Pleistocene and Recent age are more closely associated with the modern Orange River (courtesy U. Burger).

Lower than this there are several other terraces, the number and altitude varying from author to author. In the north of Namaqualand, the highest recognised terrace is the so-called Grobler or 90 metre Terrace which in places backs onto a cliff suggesting that it is a wave-cut feature. Other commonly recognised terraces in Namaqualand occur at about 50 metres and 30 metres above sea-level and these have been traced into the Sperrgebiet north of the Orange River. The outcome is that there is a long narrow deposit of littoral marine sediments paralleling the coastline from Chameis Bay in the north to the Olifants River in the south.

Fossils found in marine sediments that accumulated upon these terraces indicate that they are all Neogene in age, the 90 metre terrace being Early Miocene, the 50 metre terrace Late Miocene and the 30 metre terrace Late Pliocene in age (Pickford & Senut, 1997).

Younger than these terraces are the so-called sub-10 metre raised beaches (Pether, 1994), which occur widely up and down the Namib coastal plain as well as further afield in southern Africa and Angola.

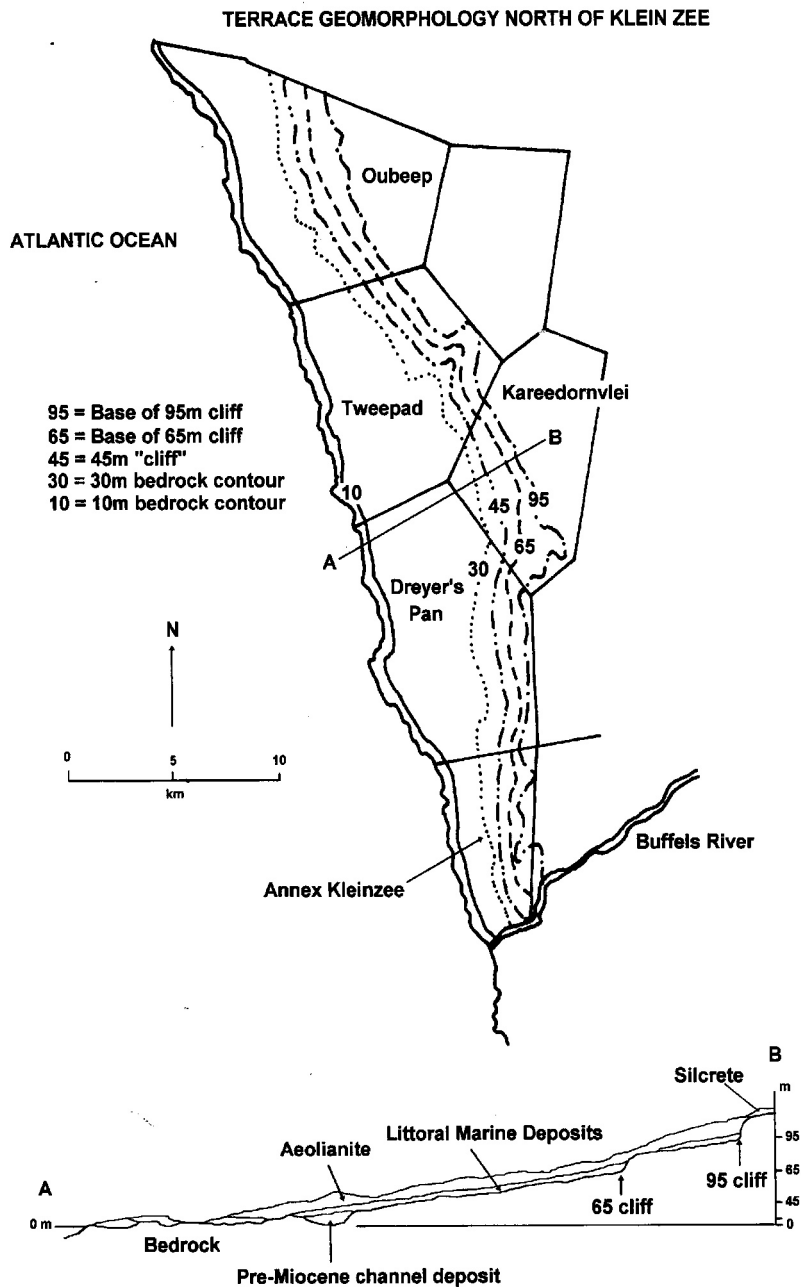


Figure 4-4.- Terrace geomorphology north of Klein Zee, Namaqualand. Prominent cliff features occur at 95 and 65 metres above sea-level and a less well-developed one occurs at about 45 metres above sea-level. Deposited on the surface of these terraces, which have floors that slope seawards, are littoral marine gravels and an important cover of aeolian sand (modified from Rogers *et al.*, 1990).

4.3.3 THE ORANGE RIVER-ATLANTIC-NAMIB SAND SEA CONVEYOR BELT SYSTEM

Since the beginning of the Middle Miocene the ocean has also played another major role in shaping the Namib coastal plain (fig. 4-5). Currents sweeping northwards up the coast have fed immense quantities of sand onto the beaches which has then been moved inland by the southerly winds which are among the most persistent in the world. The sands that move inland from the coast are de-

rived ultimately from the hinterland of Africa from where they are transported by the Orange, Buffels, Olifants and other rivers to be dumped into the Atlantic. A proportion of the Namib sands is derived directly from the banks of the Orange River once it leaves the shelter of the Richtersveld Mountains. There is thus an immense conveyor belt comprising the Orange River, the Atlantic Ocean and the southerly winds which has moved billions of tons of sand from the interior of Africa to the Namib where it has been accumulating for some 16-15 million years.

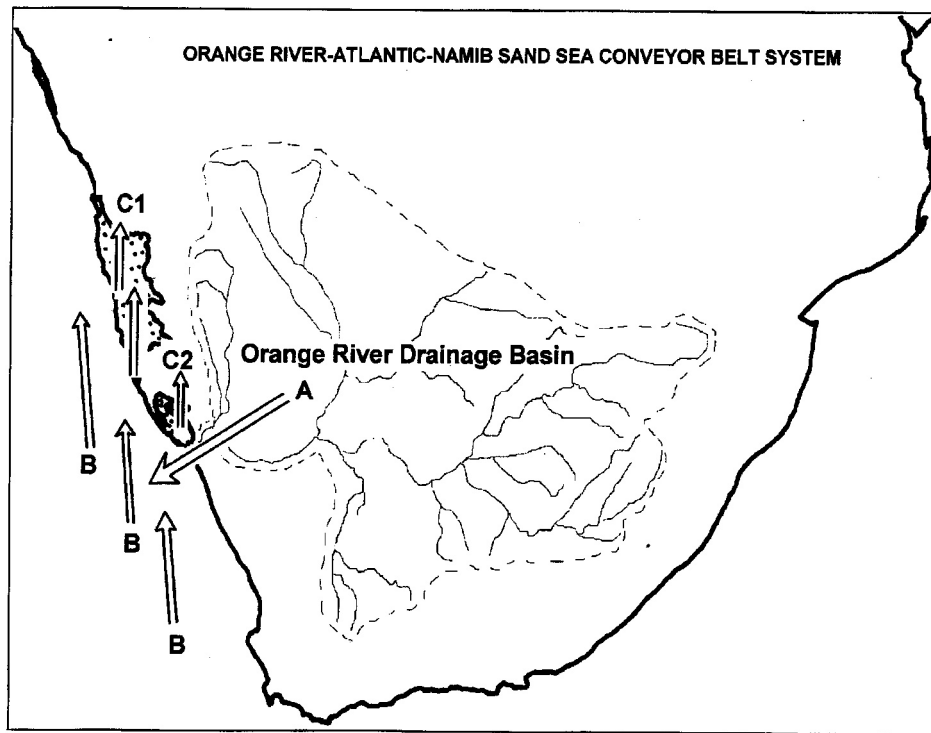


Figure 4-5.- The sands of the Namib Desert are derived from the interior of Africa via rivers, such as the Orange, which transport the sediment towards the Atlantic Ocean. Some of this sand is blown northwards before reaching the ocean (C2 in the figure) but the bulk is transported northwards by ocean currents upon reaching the sea (B), and is then blown onshore by strong, persistent southerly winds (C1 in figure).

4.4 RATES OF EROSION

There have been two schools of thought about the rates of erosion in the Namib Coastal Plain. For some authors (Ward & Corbett, 1990) the coastal plain had largely achieved its present form by about the end of the Cretaceous. For them the Namib Unconformity Surface (NUS) is of end Cretaceous to early Palaeocene age, which would mean that the coastal plain eroded rapidly from continental break-up some 136 Ma to about 62 Ma after which very little erosion has taken place. For other authors, such as Maud & Partridge (1987) the NUS didn't start forming until the mid-Miocene, and thus took 120 million years to erode rather than only 74 million years.

For both sets of authors evidence concerning rates of evolution came from geomorphology and stratigraphy, and there was a limited quantity of geochronological controls consisting of radioisotopic dates on the Klinghardt Phonolites, some intrusive rocks (a monchiquite plug) and some biostratigraphy (Langental Eocene and Miocene sites, Arrisdrift and Tsondab Sandstone). Given the paucity of dated horizons it was perhaps inevitable that divergent views would be put forward.

Maud & Partridge (1987) concluded that the NUS must be no older than mid-Miocene on the grounds that it is cut below kaolinised and silcrete capped remnants of the African Surface. However, the Chalcedon Tafelberg Silcrete

Formation that they cite as evidence of age is not a pedogenic deposit as they thought, but is a silicified and dolomitised crater fill of Miocene age (post 15 Ma). Thus it is not possible for the marine Eocene Langental Formation to overlie the Chalcedon Tafelberg siliceous strata. In fact, the two outcrops are separated by a wide swath of bedrock and their relative stratigraphic positions must be inferred from other data.

Ward & Corbett (1990) following SACS (1980), positioned the Pomona Quartzites and the Chalcedon Tafelberg Silcrete at the Cretaceous/Tertiary boundary slightly earlier than the Namib Unconformity Surface which they considered was Early Palaeocene. The Pomona Quartzite is not the same as the Chalcedon Tafelberg deposits, the quartzites being silicified pediment deposits (silicified regolith) now cropping out as mesa-like massifs. As such, labelling these rocks as silcrettes is erroneous and misleading (Pether, 1994). A search in the Eocene marine strata at Langental by the NPE failed to reveal the presence of reworked Pomona Quartzite clasts as claimed in the literature (Beetz, 1926) all the siliceous pebbles found being agates, chalcedony, jasper and vein silica. Thus the relative ages of the Pomona Quartzite and the Langental Eocene marine strata cannot be determined on the basis of clast assemblages.

The point made by Maud & Partridge (1987) that the local equivalent of the NUS is incised below the Chalcedon Tafelberg deposits is correct, the crater fill now standing

proud above an incised surface of kaolinised bedrock. The lacustrine deposits at Chalcedon Tafelberg are underlain by a thick palaeosol which is partly silicified at its top, (MP pers. observation) which formed on hexagonally jointed monchiquite. The latter crops out in several places on all sides of the hill, suggesting that the sediments accumulated in a crater floored by monchiquite and soil. Differential erosion has left the resistant sedimentary cherts and dolomites high above the surrounding country rock, a fine example of inverted relief. The monchiquite has been dated radio-isotopically as Middle Miocene (ca 15 Ma) (Stocken, 1978), and thus the present relief in the vicinity was achieved in less than 15 million years. Stocken (1978) reported that monchiquite had intruded into green feldspathic sandstones, but the authors failed to observe any cross-cutting relationships between sediments and the monchiquite.

The Pomona silicified mesas repose on kaolinised bedrock and regolith. They crop out in the region between of Chalcedon Tafelberg and Pomona. It is possible, though there is no direct evidence for it, that the silicification of the Pomona Quartzite and Chalcedon Tafelberg sediments took place at the same time as part of a regional silicification event. Silcretes in other parts of southern Africa such as the Little Karoo (Hagedorn, 1988) and the silicified marine strata at Somnaas and The Point (Reuning, 1931), suggest that the Late Miocene was a period of silicification of surface deposits. Whatever the case may be, the Pomona mesas should not be confused with genuine silcretes such as those that occur at the summit of Skilpadberg and elsewhere in southern Africa.

It should be borne in mind that at Chalcedon Tafelberg some 70 or more metres of erosion of the surrounding country rock was required to produce the inverted relief that characterises this crater deposit, and that this erosion took place in less than about 14 million years. This means that vertical downwasting in the local area was accomplished at about 5 metres per million years or 5 mm per thousand years. In fact the rate of erosion could have been more rapid than this, depending upon when erosion started and acknowledging the fact that the present land form around the outcrop had been achieved by the Pleistocene as shown by the disposition of the calcrete of this age which caps the hill and drapes down into the neighbouring valleys.

All this suggests that rates of erosion in the Namib can be very great. That this is so is highlighted by the fact that flat-lying Plio-Pleistocene travertines between Elisabethfeld and Grillental, which accumulated in low lying ground some 30 metres above sea level, now form a prominent plateau at least 12 metres above the surrounding depressions. Travertine masses of similar age at Kaukausib and Gamachab also form impressive positive relief features, although it must be admitted that in these two cases the travertine formed their own domes above the surrounding countryside. If

Corbett (1989) is correct that the Elisabethfeld travertines formed at the same time as the 30 metre package then the relief in Elisabethfeld has been produced in less

than 3-2.5 million years. Erosion of about 12 metres in 2 million years would be a reasonable figure judging from the geomorphological setting and the age of the strata.

These figures for the Namib compare favourably with rates of 15 metres of regional downwasting per million years calculated for the Otavi Mountains, northern Namibia, and the Kwihaba Hills in western Botswana despite the different processes involved (karst dissolution in the case of Otavi and Kwihaba, versus water and wind erosion at the surface in the Namib) (Pickford, in prep.).

At Langental and Grillental there are numerous small trommel screen heaps comprising coarse clasts left behind by German miners who were active between the two world wars. These heaps were left on relatively flat ground but they now cap low hillocks of sediment due to differential erosion by the wind. In effect, the unprotected sediments exposed between the trommel dumps have been deflated while the dumps protected the sediments upon which they were left. The relief present in these two areas is between knee height and waist height, meaning that about 1 to 1.5 metres of sediment has been removed from between the dumps in a period of about 70 years. These erosion rates are extremely high, and it is evident that virtually all of it was accomplished by aeolian activity, and that rainfall has had a negligible effect.

Elsewhere in the Namib, rates of erosion are also deduced to have been very high. The onset of incision of the Kuiseb coincided with, and indeed may have led to the deposition of the coarse conglomerates associated with the 30 metre package at Rooikop, from which it follows that the deep incision of these valleys took place in the last 2-2.5 million years rather than over a longer time period comprising the past 11 million years (Ward & Corbett, 1990).

Nevertheless, in parts of the Namib, erosion ceased during the Early to Middle Miocene as a result of the accumulation of aeolianites of the Proto-Namib Desert, which effectively protected the NUS from further attack.

4.5 STRATIGRAPHY OF THE NAMIB COASTAL PLAIN

Outcrops of post break-up strata in the Namib Coastal Plain (fig. 4-6) are either scattered and separated from each other or are covered by extensive deposits of aeolianite, making it difficult in many cases to observe their superpositional relationships. Furthermore, many different geological processes have been involved in shaping the coastal plain and its sedimentary cover. Sediments of many different types are known to occur, including fully marine strata at Wanderfeld IV and shallow marine deposits at Langental Eocene site, littoral marine regressive packages along the coast, fluvial deposits in pre-Miocene and later valleys incised into the plain, aeolian deposits throughout the region, plus various travertine deposits and palaeosols. These sediments have been exposed to a variety of diagenetic processes, including calcrete pedogenesis, phosphatation, leaching, kaolini-

sation, silicification, dolomitisation, gypcrete formation, ferruginisation and salification. This makes the practice of stratigraphy difficult (Corbett *et al.*, 1995) which is why so many different views about the sequence and timing of geological events in the region have been published.

With the discovery of fossil mammals and bird eggshells in many outcrops, it has been possible to determine more precisely the timing of events in the Namib, and in some cases to propose a more accurate succession of events (Pickford *et al.*, 1996; Senut & Pickford, 1995; Senut *et al.*, 1995). These are summarised in tables 5-1 and 5-2 in part 5 - Conclusions. There do remain, however, some intractable problems, including the age of the Buntfeldschuh strata and the ferruginised deposits at Kaokoeburg among others.

4.6 DEPOSITIONAL ENVIRONMENTS

Sediments which repose on the Namib Unconformity Surface (NUS) accumulated in various depositional settings. Waterlain deposits tend to occupy basins, either in marine settings or in valleys and other depressions incised into the coastal plain. However, littoral marine regressive packages occupy terraces cut into the NUS by wave action and these are not strictly speaking basins or depressions since they are open sided depositories, the sediments being pushed shorewards by wave and current action. Aeolianite deposition is also not confined to depressions or

basins, most of the sand in the Namib having travelled uphill from the coast to arrive where it is today.

Travertine deposits are also not confined to basins even though this is where the most extensive deposits tended to accumulate, such as for example at Elisabethfeld. At Kaukausib and Gamachab, travertine accumulated in positive relief settings close to where lime-charged water was seeping to the surface. The outcome of all this activity and variety of depositional environments, is that there is an array of many different sediment types, the facies of which vary rapidly both laterally and vertically.

In broad terms, not counting the subaerial volcanics associated with the Klinghardt Mountains, there are three main categories of depositional environment in the Namib (table 4-1). Each of these categories has several sub-categories of deposits.

4.7 SEDIMENTS OF THE NAMIB COASTAL PLAIN

4.7.1 FULLY MARINE DEPOSITS OF THE NAMIB

4.7.1.1 Wanderfeld IV

Late Cretaceous outcrops of marine limestone and silts occur in a small patch in the Langental. The outcrop was mapped and described by Klinger (1977). The limestones

TABLE 4 - 1

DEPOSITIONAL ENVIRONMENTS IN THE NAMIB COASTAL STRIP		
1. Marine deposition	Fully marine	Wanderfeld IV, Langental Eocene
	Littoral marine	90 metre, 50 metre, 30 metre packages and sub 10 metre raised beaches, phosphorites, Rooikop Gravels, Tsondabmund Gravels
2. Freshwater deposition	Fluviatile	Auchas, Arrisdriift, Baken, Grillental, Elisabethfeld, Fiskus, Glastal, Nuttabooi, Kommaggas, Orange River Silts etc.
	Paludal/Lacustrine	Koingnaas lignites, Ryskop lignites, E-Bay clays
	Pans	Zebra Pan dolomites, Strauchpfütz carbonate, Target Pan etc.
	Crater	Chalcedon Tafelberg
	Pediments	Pomona mesas
	Travertines	Kaukausib, Elisabethfeld, Gamachab, Naukluft
	Pedogenetic deposits	Kamberg calcrete, Namib calcrete, Swartduinen calcrete, gypcrete, Swartlintjies murrum, Namaqualand calcrete
3. Aeolian deposition		Rooilepel, Tsondab, Sossus, Obib, Kolmanskop, Baker's Bay, Namaqualand etc.

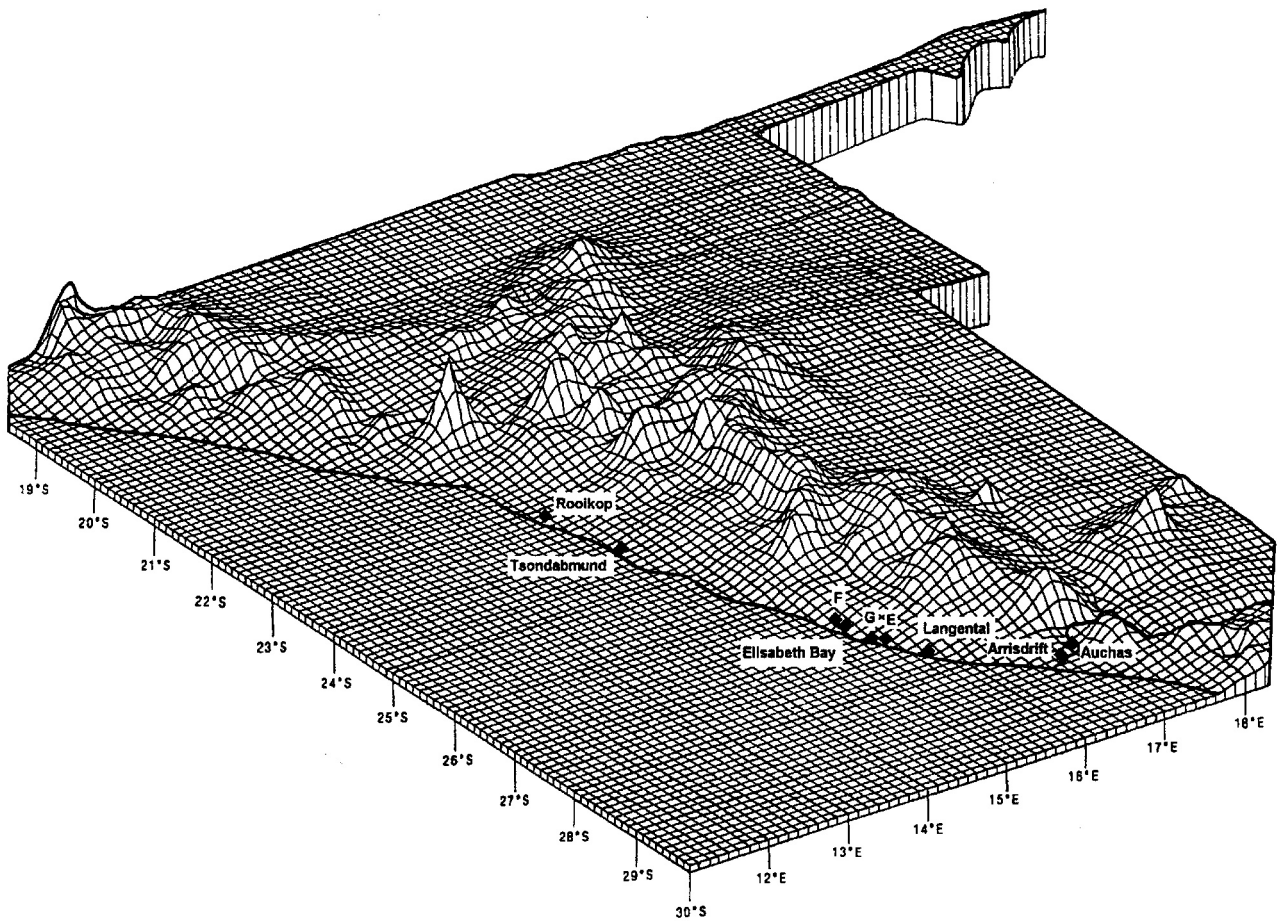


Figure 4-6.- Relief map of Namibia showing location of important fossil localities in the coastal strip. The southern localities are mostly Early to Middle Miocene in age, while the Rookop suite are probably Late Miocene. (F = Fiskus, G = Grillental, E = Elisabethfeld).

are rich in the remains of oysters and the fauna as a whole, whilst limited in diversity (table 3-2), indicates a Late Cretaceous (Turonian) age. The scientific value of the occurrence lies in the fact that it is the only known Cretaceous marine deposit in the coastal strip of southwestern Africa south of Angola. Apart from indicating that marine sedimentation occurred in the Namib Coastal Plain above Modern sea-level, the available data indicates that the waters of the Atlantic in the latitude of Namibia were relatively warm.

4.7.1.2 Buntfeldschuh

The Buntfeldschuh cliffs are an impressive accumulation of marine and terrigenous rocks, the base of the succession lying at ca 120-140 metres above sea-level (Siesser & Salmon, 1979; Corbett, 1989). They have yielded a few fossils such as the brachiopod *Lingula* and teeth of the sand shark *Isurus*, neither of which yield precise information concerning the age of the deposits. *Isurus*, for example, is known from Lutetian (Middle Eocene) to the present day (Capetta pers. comm.). However, the presence of this shark at Buntfeldschuh indicates that the deposits there are not older than the Middle Eocene. Brown lithified sands are traversed by more or less vertical burrows (Siesser & Salmon, 1979) possibly made by the brachiopod *Lingula* which occurs sporadically in the same strata. Siesser & Salmon raised the possibility that the Buntfeldschuh beds were of Palaeocene age, but their arguments were based on an absence of direct geochronological evidence, and *Isurus* refutes this suggestion. Instead they highlighted the differences between the Buntfeldschuh beds and the Langental Eocene outcrops, which they believed could not belong to the same stratigraphic succession. Following this observation they then considered that Buntfeldschuh must be older than Langental because it crops out at an appreciably higher altitude. Pether (1994) correlated the sediments to the Late Eocene. According to Corbett (1989) and Pether (1994) the presence of phonolite cobbles in the Buntfeldschuh sediments which are considered to have been derived from the Klinghardt Mountains would suggest a post-Eocene age on the grounds that the Klinghardt Volcanics date from the Early Oligocene, but the evidence is not conclusive.

4.7.1.3 Langental Eocene

In the Langental there are several outcrops of Eocene marine sediments (Martin, 1973a, b) which are locally exceptionally rich in fossils (tables 3-3 and 3-4) (Siesser & Salmon, 1979). The diversity of molluscs and other marine organisms is high which suggests that the area was tropical to sub-tropical during the period of deposition, an indication supported by the common presence of corals in the deposits (Böhm, 1926; Wiessermel, 1926) although Siesser & Salmon (1979) suggested that the overlying watermass was cool temperate on the basis of the benthic microfauna. These outcrops, which are some 70 metres above Modern sea-level, attest to a marine high stand during the Late Eocene (Siesser & Dingle, 1981). The sediments are only just over 4 metres thick. Their faunal content points to a Late Eocene age:

NP19-20 (37.2-39.5 Ma) or the *Isthmolithus recurvus* subzone (38-41 Ma). Ward (pers. comm.) reports that these strata are more properly correlated to the Bartonian (Middle Eocene).

4.7.2 KLINGHARDT PHONOLITES AND ASSOCIATED STRATA

The Klinghardt Mountains consist of several volcanic massifs which were emplaced during the Early Oligocene (ca 37 Ma) on the basis of radioisotopic dates. According to Ward (pers. comm.) the dates may need revising. There are both intrusive and extrusive volcanics in the region, and the area has been an important source of easily recognisable phonolite clasts which occur abundantly in sediments which accumulated in basins fed by surface waters draining away from the Klinghardts. Phonolite cobbles have been found in fluvial sediments as far north as Grillental and south as far as Buntfeldschuh.

At Swartkop, phonolite overlies silicified sediments. Examination of these sediments failed to result in any fossil discoveries. This outcrop was taken by Du Toit (1934) and by Martin (1973a, b) as evidence for a pre-Klinghardt age for the Pomona Quartzites, but the two occurrences have nothing in common other than that they are both rich in silica.

4.7.3 PRE-MIOCENE FLUVIATILE STRATA OF THE NAMIB COASTAL PLAIN

4.7.3.1 Koingnaas and Ryskop

In the Klein Zee-Hondeklip Bay sector of the Namaqualand coast, there are several channels with fluvial infillings that underlie Tertiary Marine strata. One of these channels at Kareedornvlei (fig. 4-4) is reported to be of Early Cretaceous (Neocomian) age (Rogers *et al.*, 1990), based on pollen and spore analyses, but its unkaolinised nature and its geomorphological setting suggest that it may be considerably younger. Other channels are incised into kaolinised bedrock and in some cases conglomerates in the base of the channels have also been kaolinised. These weathered conglomerates are highly diamondiferous and are stratigraphically the earliest deposits in Namaqualand to yield diamonds. Channel infillings overlying kaolinised conglomerates and gneiss consist of peaty to lignitic clays, for example at Koingnaas and Ryskop, and an overlying cross-bedded sandstone with ferruginised lenses and layers. This sandstone is probably of fluvial origin but has been reworked in patches to form aeolianite. The age of channel incision and its subsequent infilling is not precisely known. Estimates in the literature range from Cretaceous (Turonian) to Oligocene or even Early Miocene. The fossils found in the channel deposits (palaeobotanical and foraminiferal) do not give clear cut evidence. At present, all we can say with a certain degree of confidence is that the infillings are older than 18 Ma. This is based on the discovery of Early Miocene mammals in the basal diamondiferous marine gravels at Ryskop and Hondeklip Bay. These gravels unconformably overlie the channels

with peaty clays and ferruginised sandstones. Indeed, the Early Miocene marine transgression planed off the upper parts of the channel infilling and the kaolinised basement forming the two banks of the channel leaving behind a planar surface upon which reside the diamond-bearing gravels. In the gravels there are reworked blocks of ferruginised sandstone, evidently derived from the channel fill and redeposited in the neighbourhood as part of the marine bedload.

In broad descriptive terms and in their stratigraphic position below the raised marine deposits and phosphorites of southwestern Africa, these peaty clays and sands recall strata assigned to the Elandsfontyn Formation in the Saldanha Bay area (Rogers, 1980), which in their turn repose on kaolinised bedrock. Cole & Roberts (1996) report the presence of lignitic sediments in channels in the western coastal plain of South Africa at Koekenap, Bergrivier and Kraaifontein. The geomorphological setting of these channel deposits resembles the Koingnaas and Ryskop occurrences in Namaqualand to the north, a fact which invites correlation between them. Cole & Roberts estimated the age of incision of these channels as Late Oligocene and their infillings as Early and basal Middle Miocene. We agree that the period of incision was probably Late Oligocene and that the valley infillings began to accumulate during the Early Miocene ca 20 Ma. This is because the deposits are most likely to be due to retrogradation of sediments in the valleys consequent to a rise in base level. There is now ample evidence from Namibia and Namaqualand to indicate that sea-level was rising from about 22-17.5 Ma. Fossiliferous fluvial deposits which accumulated in pre-Miocene valleys in the Sperrgebiet suggest this as do the littoral marine packages that occur along the Atlantic coast of southwestern Africa. For example the 90 mP at Ryskop, which unconformably overlies lignitic channel deposits, contains a mammalian fauna that indicates that it is ca 18 Ma. Valley fillings at Elisabeth Bay, Elisabethfeld, Grillental and Langental in the northern Sperrgebiet all date from ca 20-19 Ma, while the proto-Orange terraces have yielded faunas suggesting ages of 19 Ma and 17.5 Ma for the backfilling of this valley.

Scott (1995) reported that lignitic sediments had been encountered in a borehole at Noup in northern Namaqualand. Although the Noup occurrence is undated, Scott estimated a Miocene age for it on the basis of similarities of pollen spectra to those from sites near the Cape. The vegetation indicated by the sample was of tropical to subtropical type very different from the present day flora of the region.

4.7.4 LITTORAL MARINE SEDIMENTS OF THE NAMIB COASTAL PLAIN

4.7.4.1 Mio-Plio-Pleistocene Beach Deposits

An extensive literature on the littoral marine deposits of the Namib Coastal Plain exists on account of the economic resources that occur therein. There are vast archives in the various mining enterprises that are located

between Lüderitz in the north and the Olifants River in the south, but these are generally unavailable for study. Serious geological interest in the region began after the discovery of diamonds in 1908. There are some publications of geological observations older than this, but most are of an anecdotal nature made by scientists and amateurs who were passing through the region (Pether, 1994). The major exception was the work of Krige (1927) who studied sea-level changes in South Africa.

Many of the earlier works focussed closely on the marine or wave-cut terraces in the region (Wright, 1964) because it was upon these that the richest concentrations of diamonds were encountered. However, some stratigraphic and palaeontological studies were carried out from the start, but these tended to be done during rapid surveys with rather flexible concepts of the measurements of altitude being adopted (Haughton, 1931). The outcome of this focus on the benches, in particular their altitude above sea level, has been the development of a confusing notion of the timing and sequence of geological events that characterise the Namaqualand coastal plain. People didn't appear to realise that the terraces possessed little or no evidence as to when they were cut. It was assumed that the higher terraces were older than the lower ones, but in only one or two cases has this been demonstrated by geomorphological evidence. The deposits that accumulated on top of the terraces were evidently younger than the period during which the terraces were cut, but there was no way of determining how long a time gap separated the cutting of the terrace and its subsequent burial. This is essentially because the erosion of terraces occurs during transgressive phases whereas deposition accompanies regression. Furthermore, subsequent transgressions can re-occupy previously cut terraces, generally, but not always reworking the deposits that lie upon them. Many of the terraces are not horizontal, most of them sloping gently seawards, and thus there is not a unique altitude figure which can characterise such sloping surfaces or the deposits which accumulated upon them. Finally, some authors, on the basis of altitudinal evidence, have concluded that there has been warping of the Earth's crust in Namaqualand, tilting the terraces generally towards the south. If this is so, then altitude on its own cannot be used to determine whether two terraces separated by intervening ground are the same or not.

Nevertheless, most of the authors have based their sequence and timing of events on geomorphological evidence, or have tied in their findings to the 'terrace' sequences in vogue at the time of their work. The commonest such sequence is the tripartite one of 'upper', 'middle' and 'lower' terraces, with the occasional addition of subdivisions in cases where two terraces blended laterally into a single level, or when a hitherto unidentified terrace, such as the high level Grobler Terrace was discovered near Alexander Bay. The result has been the development of a series of local terrace sequences utilising similar nomenclature, which are not always equivalent to each other. Thus the 'upper' terrace at Alexander Bay corresponds to the 'middle' terrace at Klein Zee and Hondeklip Bay. The Grobler Terrace at Alexander Bay,

the highest one recognised in Namaqualand, corresponds to the 90 metre terrace at Port Nolloth and Hondeklip Bay.

Other geologists have opted to base their results on the sediments that overlie the terraces. Carrington & Kensley (1969) considered that all the littoral strata in Namaqualand were transgressive complexes. Whilst it is true that the deposits would not be there today if there had not been marine transgressions, it is reasonably clear that in fact the deposits accumulated during regressive episodes upon terraces that were eroded during transgressive events. By 1986, Kensley & Pether had realised that these sediments were essentially regressive in origin. Gresse (1988) classed all the raised marine strata in the Alexander Bay region into a single formation, the Alexander Bay Formation. Whilst this simplified the geologist's task of mapping the strata, it failed to take into account the fact that these sediments accumulated intermittently during the Neogene, and that through most of this time there was either no deposition, or there was erosion of marine sediments both during low sea stands and during subsequent transgressions.

The most comprehensive study of the Namaqualand marine deposits has been the work of Pether (1994) who recognised various sediment 'packages' - the 90 mP, the 50 mP, the 30 mP and the sub-10 metre beaches. The identification tabs attached to each sediment package were based on the observation that each unit accumulated as a regressive deposit which began to accumulate when sealevel was at the stated altitude above Modern mean sea level. As each regressive episode occurred the various near-shore facies - lower shoreface, upper shoreface, foreshore and terrestrial - migrated downslope leaving a stack of inclined deposits behind it as sea-level declined (fig. 4-7). Thus deposits assigned to the 50 mP occur at various altitudes both above and below 50 metres. Deposits assigned to the 30 mP are likewise spread over a range of altitudes and there is frequent altitude overlap between the deposits assigned to various packages. For this reason, altitude on its own does not serve to distinguish to which package a sedimentary unit belongs, just as altitude of marine terraces did not provide useful evidence regarding the ages of the sediments that accumulated on them.

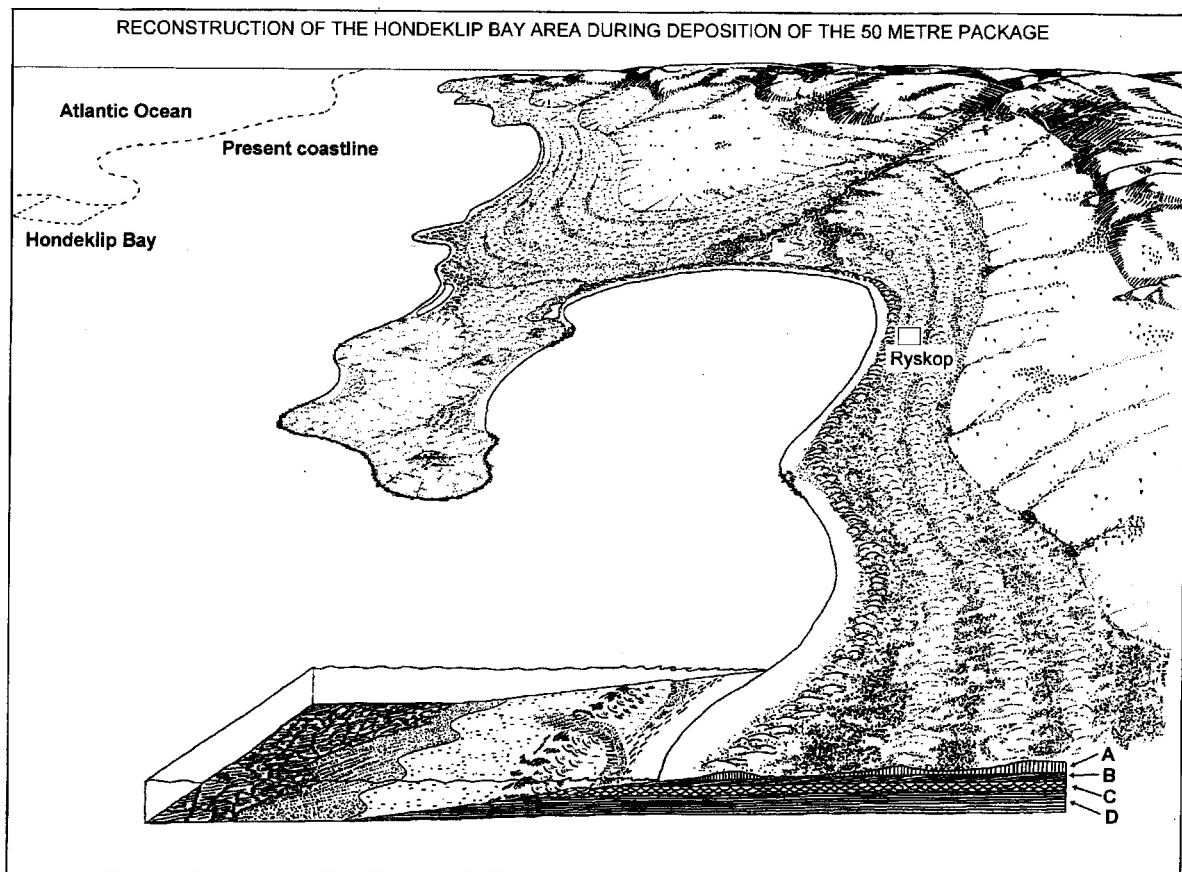


Figure 4-7.- Reconstruction of a regressive sediment package in the Hondeklip Bay area. Four main facies accumulated as the sea-level decreased from its peak level, in this case 50 metres asl. The position of Ryskop is shown where remnants of a pre-existing 90 metre sediment package underlie the 50 metre package (modified from Pether, 1994). (A = Terrigenous deposits, B = Foreshore deposits, C = Upper shoreface deposits, D = Lower shoreface deposits).

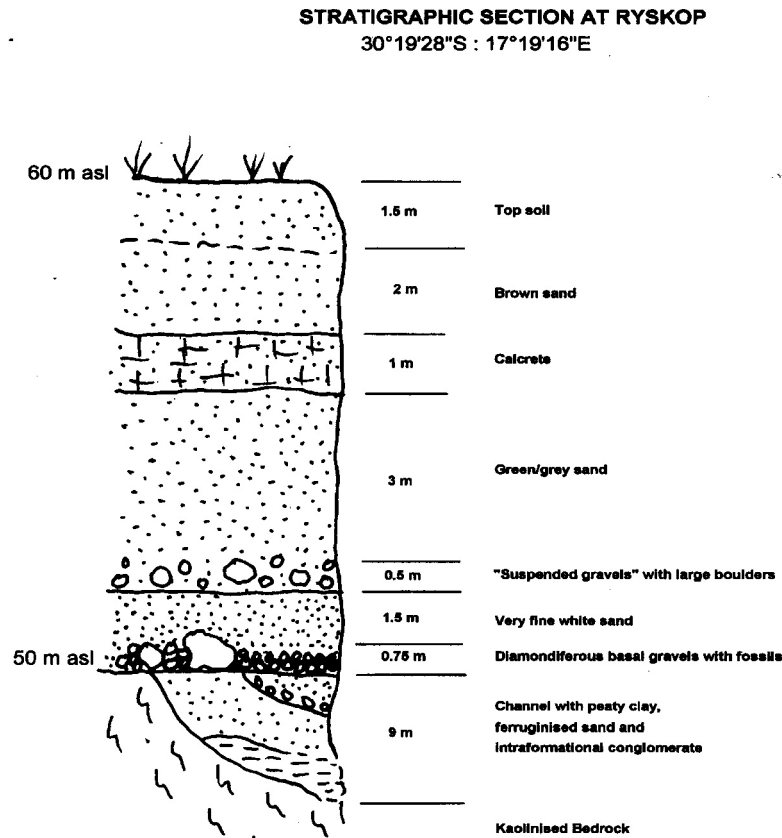


Figure 4-8.- Stratigraphic section at Ryskop, Namaqualand. The section between 50 and 52.25 metres asl is assigned to the 90 metre package (ca 18 Ma) while the rest belongs either to the 50 metre package (ca 7-5Ma) or to younger strata (calcrete, brown sand and top soil) (from Senut *et al.*, 1997).

If pre-existing sediment packages were not eroded away during subsequent transgressions, then superposition of parts of two regressive packages could be produced, with some counter-intuitive results. For example, sediments at Ryskop (fig. 4-8) which crop out at an altitude of 50-52 metres asl are assigned to the 90 mP. They are altitudinally lower than sediments in the same section assigned to the 50 mP the base of which crops out at 52 metres asl and the top of which is at an altitude of 55.5 metres. At Hondeklip Bay, sediments of the 30 mP are higher than deposits assigned to the 50 mP. Because the various facies which make up each regressive package tend to be similar, it is difficult, if not impossible, to assign a sedimentary unit to its correct package without having obtained additional information concerning its relative position. It is clear from the literature that, in Namaqualand, it has been the fossil record which has best served as this base (Pether, 1994).

Palaeontological studies began to throw some light on the sequence of events from the beginning of the 1930s (Haughton, 1928, 1931), but the studies done were not comprehensive nor detailed enough to result in a convincing view of the biostratigraphy of the deposits. Poorly controlled follow-up studies were carried out by geologists who were not familiar with molluscan taxonomy with the result that published faunal lists are much in need of revision. Unfortunately, most of the old collections appear to be lost.

Furthermore, there were cases where little heed was taken of the discovery context of the fossils. The latter practice naturally put the results of the palaeontological studies out of focus at the data gathering stage.

Real headway was made during the 1970s and 1980s with detailed studies of the faunas being made by committed students working for periods of several months to years in the field (Carrington & Kensley, 1969; Kensley & Pether, 1986; Pether, 1986, 1994). The long term result has been the recognition of three major faunal assemblages which have been satisfactorily shown to be molluscan chronofaunas of use for biostratigraphy. However, even though the sequence of faunas has been established, the timing of the existence of each of the faunal assemblages has not been achieved with the same degree of success. Most authors have placed all three molluscan associations into the Pleistocene or Plio-Pleistocene (Kensley & Pether, 1986; Pether, 1994) and various correlations to local and global geological and palaeoclimatic events have been proposed (Pether, 1994; Hendey 1981; Gresse, 1988). It is now evident on the basis of mammalian biostratigraphy that, discounting the 'E stage' molluscs which are preserved only as internal moulds, the earliest of the three Namaqualand molluscan associations is of Late Miocene age (the 50 mP), the second one is probably Late Pliocene (the 30 mP) and the third is Late Pleistocene to Holocene (the sub-10 metre beaches).

It is clear from Pether's (1994) work, that the only reli-

able way of determining to which package a particular sediment body belongs is by examining the fossils in it. Altitude on its own has often been the basis for identifying sediment units, but is no longer used on account of the overlap between various units. In addition the littoral facies which comprise each package (lower shoreface, upper shoreface, foreshore and terrestrial) are repetitive, each package looking very similar to its precursors. Since the precise altitudes at which the various sediment packages formed are not known, the labels 90 metre package, 50 metre package and 30 metre package are not only imprecise, but can be misleading. In our opinion it would be far less confusing to label each package according to its faunal content, and thus to base the stratigraphic nomenclature of the region on unique aspects of each sedimentary unit, rather than to rely on inferred altitudes of deposition or other secondary evidence such as the heights of terraces upon which the strata occur. This would also shift the focus of research from geomorphology, especially altitude, with all its inherent weaknesses, to faunal content with all its geochronological advantages.

The following schema is proposed -

The *Kenyasus*/*Nguruwe* sediment package. This is of Early Miocene age (ca 18 Ma). Its type area is Ryskop, where a partial succession is preserved overlying kaolinised bedrock and a channel infilled with peaty clay and ferruginised sandstone. At Ryskop, the remnant of this package is only 2 metres thick (its top has been truncated by the overlying sediment package) and it crops out between 50 and 52 metres above sea level. It may be equivalent in age to the so-called 90 metre package of Pether (1994) and the Grobler Terrace deposits of other authors. There are no signs of phosphorite within this package, but there are a few internal moulds of gastropods and bivalves which are chocolate-coloured. The only readily identifiable mollusc is *Conus*.

The *Agnotherium*/*Tetralophodon* sediment package. This package consists predominantly of gravels below the so-called 50 mP at Hondeklip Bay. These gravels were thought to represent the 90 mP by Pether (1990) but they are considerably younger, being late Middle Miocene to early Late Miocene in age, some 12-10 Ma. The sediments attest to a high sea stand of this age, evidence of which has been largely destroyed by subsequent marine reworking at the end of the Late Miocene - the so-called 50 mP. Aeolianites of similar age at Prospect Hill, near Saldanha have yielded eggshell fragments of *Diamantornis wardi* as well as terrestrial tortoise carapaces and mammal bones.

The *Donax haughtoni* sediment package. This package is of Latest Miocene to basal Pliocene age (ca 7-5 Ma). Its type area is at Hondeklip Bay Mine (Pether, 1994) where it has yielded abundant marine fossils as well as fossil mammals similar to those that abound at the well known site of Langebaanweg, Western Cape. The fossil suids and proboscideans in particular indicate close chronological ties to this site. Previously, Pether (1994) considered that

this package - his 50 mP - dated from the Late Pliocene (ca 2.6 Ma) but this estimate is too young, because the suid species to which he refers (*Nyanzachoerus* sp.) is a Late Miocene to basal Pliocene species (*Nyanzachoerus kansasensis australis*) also found at Langebaanweg. Gravels at the base of this package, and rock surfaces underlying these sediments contain abundant phosphorite layers and nodules. Phosphorite boulders occur in this package at Ryskop.

The *Donax rogersi* sediment package. This package - called the 30 mP by Pether (1994) - is younger than the *Donax haughtoni* one, but its precise age is not yet known. It is probably Early Pleistocene, or perhaps even Late Pliocene in age (ca. 3-2 Ma). Records of the extinct equid *Equus capensis* from various sites in the region could be from the terrestrial facies of this package, which would indicate an age younger than 2.6 Ma, but the definitive association of this species with the 30 metre package remains to be demonstrated.

The *Donax serra* or sub-10 metre raised beach deposits. These are of Late Pleistocene to Recent age. Commonly known as the sub-10 metre beaches, there are three deposits at 8 metres, 5 metres and 2 metres asl (Kensley & Pether, 1986) which are widely preserved along the coasts of South Africa and Namibia. All three raised beach deposits contain extant cold water molluscan faunal elements, in contrast to the warm water faunas that occur in the *Donax haughtoni* and *Donax rogersi* packages. These packages truncate calcreted sandstones and underlying sands which contain remains of *Equus capensis* and Acheulean artefacts and are thus younger than Middle Pleistocene (Gresse, 1988). Terrestrial facies younger than and contemporary with these packages have yielded abundant faunas and archaeological remains (Middle Stone Age) suggesting that they are younger than 200,000 years but probably older than 10,000 years.

4.7.4.2 Phosphorites of the Namib Coastal region

Phosphatic sediments have been recorded in southern African littoral deposits for more than a century (Watkins *et al.*, 1995). In 1975, Tankard assigned phosphorites in the Saldanha Bay area to the Saldanha Formation and included in the unit all the phosphorites on the southwestern coastline of South Africa from Ysterplaat near Cape Town in the south to Hondeklip Bay in the north, including phosphatic sandstones and phosphorites of the South African continental shelf. The type section of this formation is at Hoedjiespunt, Saldanha. Tankard considered that all occurrences of this unit belonged to the Middle Miocene transgressive complex. He included in this formation the 'lower E stage' of Haughton (1931) in the Hondeklip Bay area. Pether (1986) considered that the *in situ* phosphatic deposits assigned to this stage at Hondeklip Bay (18-20 metres asl) were relicts of the seaward extension of the 90 metre package, for which he estimated a Middle Pliocene

age, thereby disagreeing with Tankard's correlation of the 'lower E stage' with the 'controversial Mid-Miocene Saldanha Formation'.

If Pether is right about these deposits being part of the 90 mP, then phosphogenesis began early in the Middle Miocene. However, at Hondeklip Bay the most extensive deposits of phosphorite occur in association with the 50 metre and 30 metre packages (Pether, 1986). The remnant of the 90 metre package at Ryskop, which is ca 18 million years old on the basis of the fossil mammals that occur in it, yields rare internal moulds of molluscs which are chocolate-coloured and are therefore possibly phosphatised. In any case, phosphatisation of these molluscs probably took place after they had been fossilised. It would seem unlikely that the richly phosphatic sediments at Hondeklip Bay nearby were formed during deposition of the 90 metre package as suggested by Pether (1986), unless there were strongly expressed facies variation within the unit. The bulk of the mammal fossils found at Hondeklip Bay belong to Late Miocene and early Pliocene species. Two teeth, a carnassial of the amphicyonid *Agnotherium*, and a molar of *Tetraiodon*, from basal gravels rich in phosphorite boulders at Hondeklip Bay belong to late Middle Miocene mammal species. This suggests that the main phosphorite deposits at Hondeklip Bay were probably formed during the late Middle Miocene to Early Pliocene.

Dingle *et al.*, (1983) concluded that phosphatisation commenced in the Middle Miocene based on the studies of foraminiferans by Siesser (1978) and that it continued until Pliocene times and ceased before the Pleistocene. Watkins *et al.*, (1995) state that the offshore phosphorites of southern Africa are Miocene to Holocene in age. The main phosphogenic event off Namibia was reported by these authors to have taken place during the early Pliocene. There does remain a small degree of doubt about the age of the onset of phosphorite genesis in the southeast Atlantic because of the poorly controlled context of the mammal fossils that have been collected in the region, but the main depositional event now seems to be reliably dated to Late Miocene and Early Pliocene times.

In summary, it is likely that phosphogenesis commenced after the *Kenyasus/Nguruwe* (? 90 mP) package had accumulated about 18 Ma. It peaked during the Late Miocene and Early Pliocene (ca 7-5 Ma) while the *Donax haughtoni* package (50 mP) was accumulating, and began to decline before the deposition of the *Donax rogersi* package (30 mP), to cease or become exceedingly slow by the time of the establishment of cold water molluscan faunas in the region. Thus the main phosphorite deposits of the southeast Atlantic formed while the coastal waters of southwestern Africa were inhabited by molluscs which suggest that the waters were relatively warm. As soon as these coastal waters became cool, as shown by their molluscan assemblages, then phosphogenesis ceased, or at least slowed down considerably.

4.7.4.3 Rooikop Gravels

In the Rooikop area north of the Kuiseb and east of Walvis Bay at altitudes between 20 and 40 metres above sea-level, there are gravels with phosphatised shark teeth and molluscs. Interbedded in the gravels are fine grained phosphate-rich sediments which frequently contain the burrows of lithophagous molluscs, showing that the sediments were already indurated at the time that they were subjected to this kind of attack. The sediments are poorly exposed (Ward, 1987) and the only biostratigraphically significant fossils found have been *Donax rogersi* which indicates a Late Pliocene age for some of the sediments, equivalent to the Namaqualand 30 metre package of Pether (1994). The commonest mollusc remains are unidentifiable internal moulds, but shells of *Striostrea margaritacea* occur in some abundance. On the basis of the phosphate-rich nature of the deposits and their occurrence up to 50 metres above sea-level, it is tempting to correlate part of the succession with the 50 metre package of Pether (1994) in Namaqualand, in which case deposits of Late Miocene age also occur in the region. Ward reached much the same conclusion when he indicated that the Rooikop sediments resemble the fossil beach deposits D, E and F north of Oranjemund, and suggested that the Rooikop Gravels are a composite unit comprising deposits of more than one marine incursion.

The oysters and the phosphate both suggest that the coastal waters of the area were warm at the time of deposition as was already noted by Ward (1987).

4.7.4.4 Tsondabmund

Near Conception Bay opposite where the Tsondab River would probably debouch into the Atlantic if the Namib Sand Sea were not there, pits have been excavated in search of fresh water. In the rubble heaps beside the holes, fine grained phosphate-rich rocks are found alongside rounded boulders and coarse sandstones cemented with phosphate. The silty rocks are rounded and rolled suggesting that they have been reworked. They are rich in internal moulds of fossil molluscs, but none are readily identifiable. Nevertheless, the style of preservation recalls the phosphatic silts at Rooikop, and they probably denote a Late Miocene age for the deposits.

4.7.5 FLUVIATILE DEPOSITS OF THE NAMIB

4.7.5.1 Elisabeth Bay

Elisabeth Bay is the seaward end of a large, wide valley oriented north-south (fig. 4-2). The floor of the valley extends out to sea and was probably incised during the Oligocene marine low stand. It now contains various sediments of Early Miocene and more recent age, assigned to the Elisabeth Bay Formation by Greenman (1966). Remapping of these and neighbouring deposits reveals that Greenman included rocks of very diverse ages and origins within this formation, including Early Miocene fluvial silt, sands, grits and conglomerates, Plio-Pleistocene aeol-

lianites and Plio-Pleistocene travertines. It is here proposed to restrict this name Elisabeth Bay Formation to the fluvial facies of Early Miocene age, and to place the aeolianites into the Fiskus Formation.

The oldest sediments known in this valley occur at E-Bay Mine (Block 105EN) where green clays rich in fossil ostracods, molluscs, frogs and a few mammals have been exposed by mining activity. These clays have suffered local microtectonics, and in places wedges of clay have been overthrust onto sands. Among the mammals from this site are *Myohyrax* species and *Apodecter stromeri* which indicate an Early Miocene age (ca 20-19 Ma). Up the valley at the Bohrloch site near Betrieb IV (26°52'53.0"S : 15°14'01.2"E) fossil mammals were found in 1923 or 1924 by F. Beetz in the debris drilled while making an artesian well. The depth at which the fossils were found is not known, but the borehole bottoms out at a depth of 30 metres. The faunal assemblage from this deposit is typical of the Early Miocene (Stromer, 1926).

Above the Early Miocene clays and silts of the E-Bay Valley, there are various younger sediments, in particular coarse, light brown, aeolian sands. These crop out widely round the Bohrloch site and are assigned to the Fiskus Sandstone. Although these aeolianites have not yielded fossils at E-Bay, similar rocks at Kolmanskop and Fiskus have yielded eggshells of *Struthio daberassensis* suggesting that they are Pliocene or Pleistocene in age. A feature of these sands is the local abundance of trace fossils, in particular some which recall those made by the golden mole *Eremitalpa granti*. A fine occurrence of such traces occurs near the old railway station between Kolmanskop and E-Bay (26°44'15.0"S : 15°14'07.0"E).

At the summit of a small hill composed of grey aeolianite, locally known as Russel's Perch on account of the fine view overlooking the E-Bay Mine, various fossils were found *in situ* in grey aeolian sands. Eggshells of *Struthio camelus* and the valves of *Patella* indicate that this aeolianite is younger than the light brown Fiskus Sandstone, and that it is probably Latest Pleistocene or even Holocene.

4.7.5.2 Fiskus

North of the abandoned treatment plant at Fiskus Pan, green clays and silts crop out in the floor and sides of the depression (Greenman, 1966). At the eastern edge of the pan (26°45'04.9"S : 15°14'41.4"E) the silts and clays are fossiliferous, and have yielded a varied chelonian and mammal fauna comprising rodents, macroscelidids, ruminants, suids, carnivores and rhinocerotids, the assemblage as a whole indicating an Early Miocene age (ca 19-20 Ma). The clays also contain several calcified hives of the termite *Hodotermes*, but the precise age when termites built these structures is not known. Unconformably overlying the green sediments there is a porous travertine horizon containing abundant moulds of plant stems, and this is in

turn overlain by coarse light brown sands of the Fiskus Sandstone. At this site eggshells of *Struthio daberassensis* were found which indicate that the sands accumulated during the Pliocene to Pleistocene.

About a kilometre north of the Fiskus mammal site (26°44'36.3"S : 15°14'34.3"E) is another outcrop of green silts with manganese nodules and plates. This site yielded several chelonian scutes.

4.7.5.3 Elisabethfeld

Elisabethfeld is undoubtedly the most important fossil occurrence in the northern Sperrgebiet. It has yielded many thousands of fossil specimens representing a highly diverse fauna of Early Miocene age (Stromer, 1926). It occurs as a deflation basin some 6 metres below the surrounding countryside (figs. 4-9 to 4-11) (26°58'58.5"S : 15°15'53.9"E). The fossiliferous strata occupy the base of the depression in a wide area around the spring which is still active, though extremely feeble. There is a thickness of just over 5 metres of Early Miocene sediment exposed west of the spring. The basal strata are richly fossiliferous, pink to red silts with gypsum plates and limey concretions up to 85 cm thick. The upper 4.6 metres of sediment are green and yellow, in stark contrast to the underlying red beds. Filling a channel cut into the red silts is a pale green sand with brown plates rich in chelonian scutes and mammals. Above this bed there are 4.1 metres of fluvial sand and conglomerate which are poorly fossiliferous, but which yielded a partial skeleton of a ruminant (26°58'52.5"S : 15°15'57.1"E). These fluvial sediments and the overlying aeolianites and travertine were assigned to the Elisabeth Bay Formation by Greenman (1966), but the aeolianites and travertine are considerably younger than the fluvial strata, being of Plio-Pleistocene age. Even though the fluvial sediments at Elisabethfeld are the same age as those in the Grillental, and they belong to the same ancient river network, they differ from classic Elisabeth Bay Formation by being red rather than green. The reason appears to be that pedogenetic processes were more active at Elisabethfeld than at Grillental so that ferrous oxides in the sediments were oxidised to the ferric state. It is also possible that the silts at Elisabethfeld were oxidised during transport and deposition, whereas those in Grillental and Elisabeth Bay accumulated in reducing environments.

North of the main outcrops of Early Miocene strata at Elisabethfeld, there is a plateau capped by indurated greenish and grey sands and onyx-like travertine (fig. 4-9) which separates Elisabethfeld from the Grillental. The sands are some 9 metres thick and are considerably younger than the underlying Early Miocene beds. Most of the sand is aeolianite, but there are interbeds of sheetwash conglomerates. There are travertine dykes cutting through the sands as well as forming sheets interbedded with aeolianite. It is clear from sand lenses included in travertine horizons that aeolian sands were accumulating at the same time that the travertine was forming. The upper levels of aeolianite contain reworked blocks of travertine. Thus

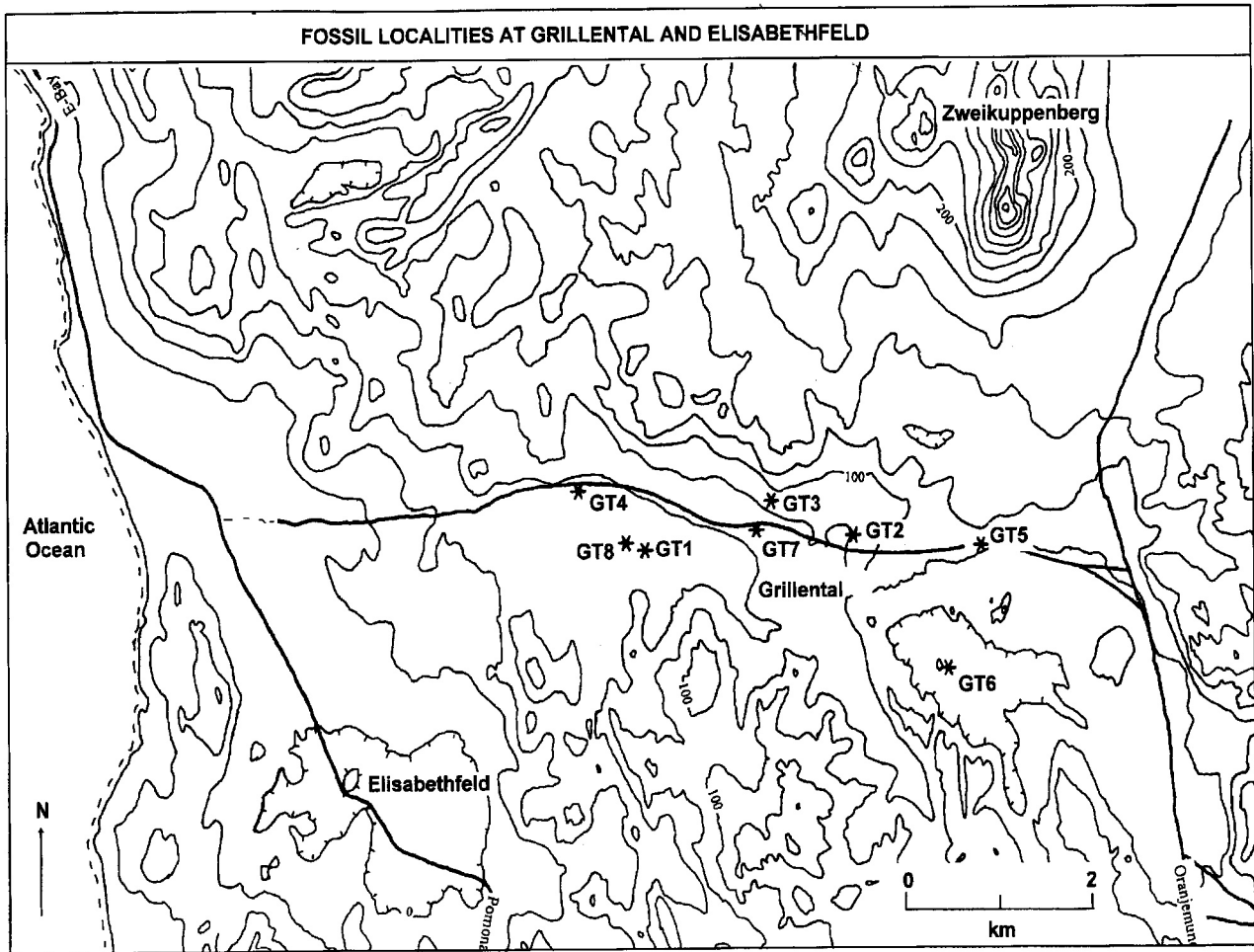


Figure 4-9.- Fossiliferous localities at Elisabethfeld and Grillental, Northern Sperrgebiet, Namibia. All these sites are of Early Miocene age (ca 20-19 Ma), but the travertine-capped ridge with aeolianites that separates Elisabethfeld from Grillental is of Pliocene age.

aeolian deposition preceded, was coeval with, and continued after travertine accumulation. Locally no fossils have been recovered from these sediments, but elsewhere, such as Kaukausib, fossil mammals indicate a Late Pliocene or Early Pleistocene age for travertine activity. This estimate accords with the evidence yielded by eggshell fragments found in the Fiskus Sandstone, which belong to a Plio-Pleistocene species of ostrich, *Struthio daberasensis*.

4.7.5.4 Grillental

The Kaukausib Valley is one of the most obvious features to be observed in satellite images of the northern Sperrgebiet. The downstream reaches of the valley are known as Grillental (figs 4-9, 4-12 to 4-13). This valley leads out into the Atlantic where it probably joined the southward flowing Elisabeth Bay Valley (fig. 4-2) and like the latter, the Grillental was probably incised during the Late Oligocene.

GT 1 is a fossil rich locality located where an old aqueduct crosses a gully in the bed of the Grillental. At this site green clays rich in rodents crop out as cliffs capped by coarse, white cross-bedded grits. The grits contain cheilonian scutes and the remains of large mammals (Plate 3, fig. 2). The entire sequence is Early Miocene in age. At GT6 and GT7 there are hives of the termite *Hodotermes* but these may have been constructed some time after the deposition of the sediments.

There are several fossiliferous localities in the Grillental (GT1 to GT8 in fig. 4-9) all of which have yielded Early Miocene mammals. The most informative site is GT6 (fig. 4-13) where a thickness of about 9 metres of sediment is exposed. The section consists of interbedded sands and silts bedded on a scale of 10 cm to 1 metre, and the entire succession is probably fluvial in origin. Rodents have been recovered from two of the beds and these belong to species typical of the Early Miocene faunas of the region, including

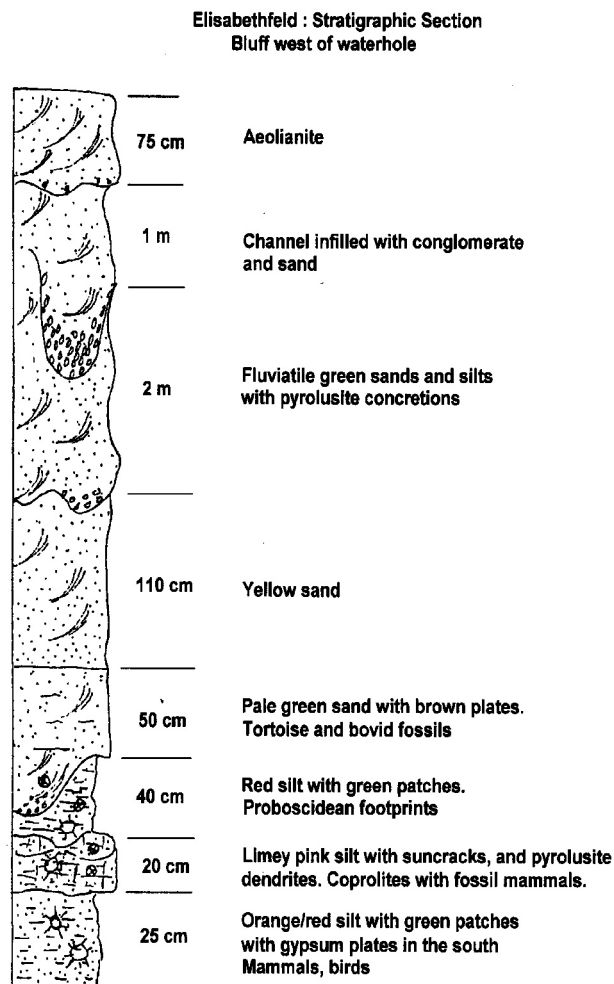


Figure 4-10.- Stratigraphic section at Elisabethfeld at a low bluff west of the waterhole. The red silts and limey pink silt are exceptionally rich in fossils, having yielded an abundance of carnivore scats containing micromammals. The depositional environment of these silts was subaerially exposed fluvial floodplain. They are overlain by yellow to green fluvial channel deposits which also yield fossil vertebrates.

Diamantomys luederitzi and *Bathyergoides neotertiarius*. Two beds have also yielded abundant ostracods, charophytes, and freshwater and land gastropods. Among the freshwater snails there are forms similar to extant *Lymnaea natalensis*, but there are also some enigmatic forms, including some that recall estuarine and even marine species. The land snails consist of *Trigonephrus* and *Dorcasia*.

4.7.5.5 Langental Miocene

At Langental (27°24'27.9"S : 15°24'27.9"E) there are exposures of Early Miocene sediment occupying a valley that leads southwards towards the Atlantic (figs 4-2, 4-14). A thickness of only 1.5 metres of sediment is exposed, but the areal extent of the site is several hectares, much of which is pocked with small heaps of mine tailings. The

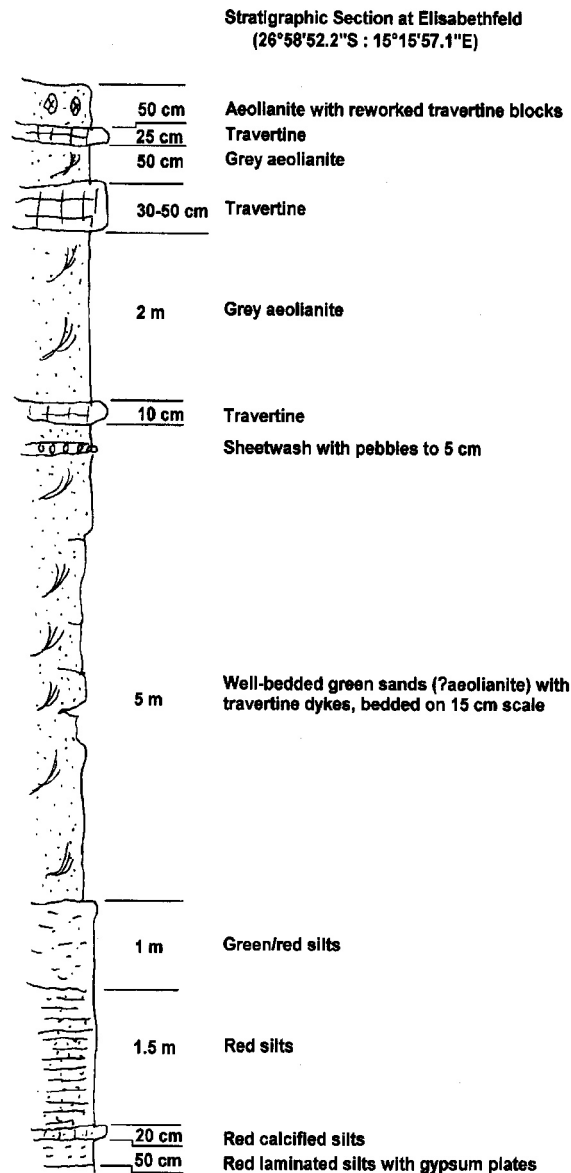


Figure 4-11.- Stratigraphic section at Elisabethfeld measured northeastwards towards the travertine plateau. The lower 3 metres are of Early Miocene age, while the travertines and aeolianites at the top of the section are Plio-Pleistocene in age.

sediments are variegated brown/green marly silts with occasional gypsum crystals and calcareous nodules. There is a grit layer near the top of the succession which unconformably caps a low ridge at the main site (1 in fig. 4-14). The sediments are most likely fluvial in origin, but they have been subjected to pedogenic processes.

The rich fauna from this site is typical of the Early Miocene of Africa.

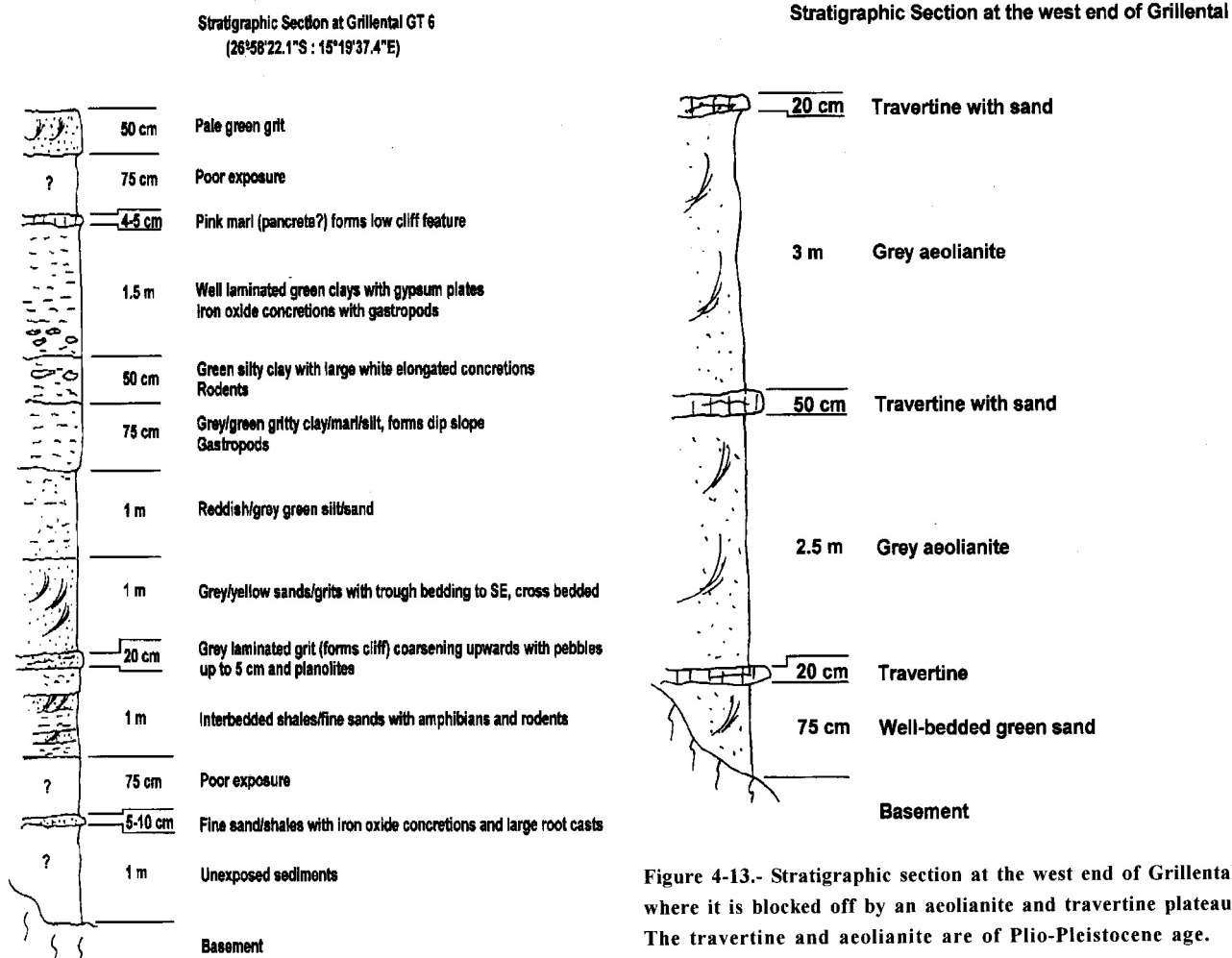


Figure 4-12.- Stratigraphic section at locality GT 6, Grillental. Although this section is only about 8 metres thick and the extent of the outcrop is limited, it has yielded abundant fossil vertebrates, invertebrates and plants from several levels.

4.7.5.6 Glastal

Glastal (27°27'22.9"S : 15°28'28.8"E) is another pre-miocene valley that leads southwards into the Atlantic (fig. 4-14). Like the others, it was probably incised during a period of low sea-level of Late Oligocene age. There are limited exposures of silts and marls in the floor of the valley, but these are poorly fossiliferous. Some chelonian and rhinocerotid bones have been found in pinkish silts with carbonate concretions, possibly of pedogenic origin. The same nodules sometimes contain shells of the land snail *Dorcasia*. In the eastern flank of the Glastal at Kalkrücken, the Early Miocene strata are overlain by aeolianites above which are coarse conglomerates of much more recent age. In places the aeolianites have been heavily affected by calcrete pedogenesis, sometimes to the extent of forming almost pure calcrete caps up to 50 cm thick. In the surface of the Kalkrücken aeolianites there are concentrations of the land snail *Trigonephrus*, but few other fossils have been

recovered from them. These aeolianites are probably Late Miocene or even younger in age because they unconformably overlie the Early Miocene Glastal marls. A single fossil eggshell found in the aeolianites at Kalkrücken was not identifiable with certainty but it is clear that it didn't belong to *Namornis* or any of the early forms of *Diamantornis*. It was closest to *D. laini* but it could belong to a younger species such as *Struthio karingarabensis*.

4.7.5.7 Proto-Orange and Meso-Orange Terraces (Arries Drift Gravel Formation)

From the Richtersfeld to Oranjemund, the Orange River Valley contains several flights of fluvial terraces ranged up to 50 or 60 metres above the Modern river level (fig. 4-15). Originally thought to be of Pleistocene age, and thus related to changing sea-levels caused by the waxing and waning of polar ice caps (Fowler, 1976), the discovery of Early and Middle Miocene fossils in the so-called Proto-Orange Terrace (Corvinus & Hendey, 1978; Hendey, 1978; Pickford *et al.*, 1995) showed that the history of the river deposits was appreciably longer than hitherto thought possible and this has had considerable implications for the diamond mining industry (Stocken, 1978).

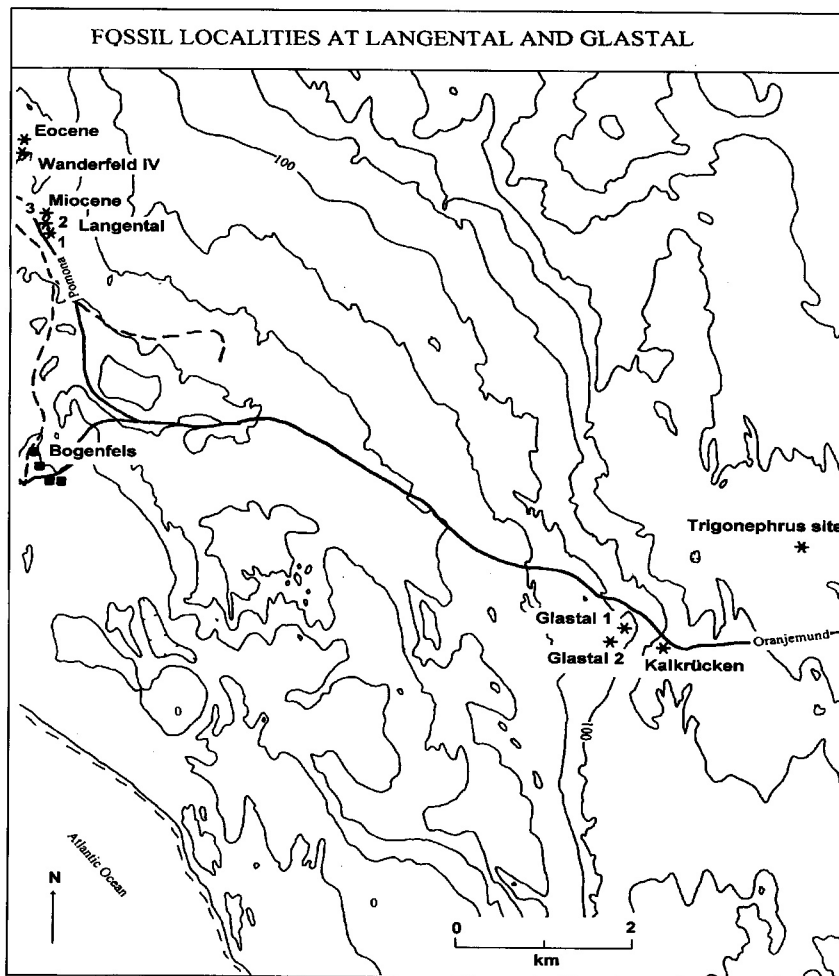


Figure 4-14.- Fossiliferous localities at Langental and Glastal, central Sperrgebiet, Namibia. North of the abandoned village of Bogenfels there are marine Cretaceous and Eocene sediments as well as Early Miocene terrestrial deposits. At Glastal there are Early Miocene fluvial deposits overlain by considerably younger aeolianites at Kalkrücken which have been subjected to calcrete formation such as at the *Trigonophrus* site. (1, 2, 3 = fossil localities).

Figure 4-3 shows the layout of the main terraces between Sendelingsdrift and the mouth of the Orange River. Proto-Orange terrace deposits (dense dots) occupy several loops and channels lateral to the present day river, while Meso-Orange terrace deposits (less dense dots) tend to occupy lower ground nearer the Modern river. The clast assemblages differ from terrace to terrace, the boulders in the Proto-Orange terrace deposits generally being smaller than those of the Meso-Orange terraces. Fossils found in Proto-Orange deposits at Auchas are of Early Miocene age (ca 19 Ma) while faunas from Arrisdrift and Baken are of early Middle Miocene age (ca 17.5 Ma). The Meso-Orange deposits have not yet yielded fossils, but the terraces are younger than the Proto-Orange ones and are likely to date from the end of the Miocene and the Pliocene.

The Auchas Main loop lies west of the Orange River. It is an abandoned meander loop containing up to 60 metres of fluvial deposits. Fossils from the main fossilifer-

ous interval (39-42 metres asl) are of Early Miocene age (Pickford *et al.*, 1995). The floor of the loop is 27 metres above sea-level (fig. 4-16) which is some 13 metres above the present river level. There is appreciable relief in the bottom of the loop (bedrock profiles 2, 11 and 12 in fig. 4-16) with extinct waterfalls, gigantic potholes and huge boulders (megaclasts), which indicate that prior to being infilled with sediment the loop contained a raging torrent of water. The river then backed up towards the end of the Early Miocene due to a rise in the base level of its mouth and the transient sediment in the river settled out to form the terrace deposits. The change in base level was probably a rise in sea-level that occurred during the Early Miocene as attested by the fact that the 90 metre package of littoral marine sediments date from this period.

Fossils have been found at AM 02, AM 11 and AMSE (near AM 11). The richest deposits are bright orange silts and sands, often intercalated in conglomerates. AM 02, in

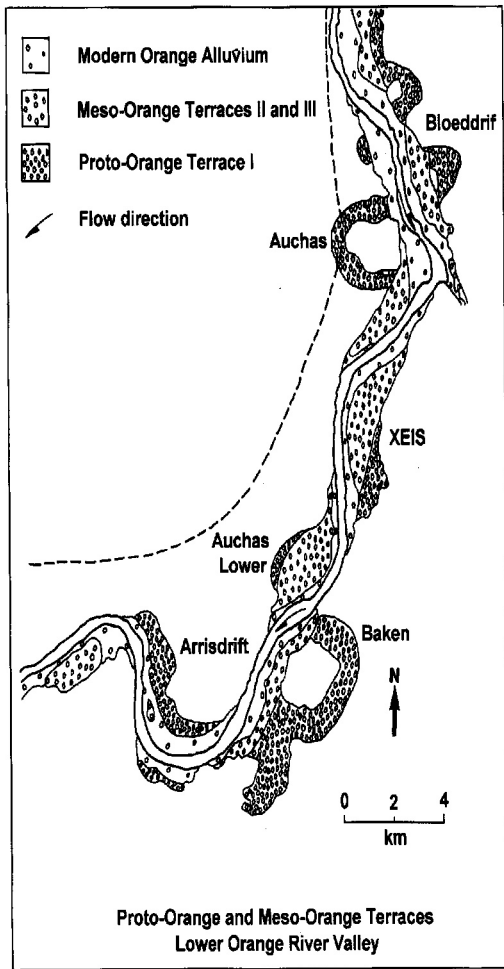


Figure 4-15.- Details of the terrace deposits in abandoned channels of the Proto- and Meso-Orange in the Auchas to Arrisdriif sector of the valley (after Rogers *et al.*, 1990).

particular, yielded abundant petrified tree trunks and large mammal and reptile remains. Prominent among the vertebrates are proboscidean skulls and teeth and large chelonian carapaces, but small mammals have also been found including the rodents *Diamantomys luederitzi* and *Megapedetes*.

The Proto-Orange terrace at Arrisdriif (I in fig. 4-17) lies lateral to the Modern river bed. The main fossil occurrence is 41-42 metres above sea-level and it occupies a shallow channel within the overall valley (profile 8 in figs 4-17 and 4-18). At the time of deposition the base of the valley was 20 metres above sea-level, some 13 metres above the Modern river level. The abundant fossils from Arrisdriif (AD 8 Pit 2 in fig. 4-17) are younger than those from Auchas (ca 17.5 Ma versus ca 19 Ma for Auchas), but the fossiliferous facies closely resemble the Auchas deposits, being bright red sands and silts intercalated with conglomerate horizons (fig. 4-19 and 4-20). The abundance of serpulid worm tubes at Arrisdriif affords good evidence that sea-level at the beginning of the Middle Miocene was at least 40 metres above is present level. Today these worms live typically in brackish estuarine situations.

Combined, the deposits at Auchas and Arrisdriif suggest that sea-level was high from at least 19 to 17.5 Ma and perhaps that it began rising from its Oligocene low stand about 21-22 Ma. Some time after 17.5 Ma, sea-level then decreased again, upon which the Proto-Orange incised itself a new channel through its alluvial plain leaving terrace deposits high and dry in abandoned loops and channels lateral to the new one.

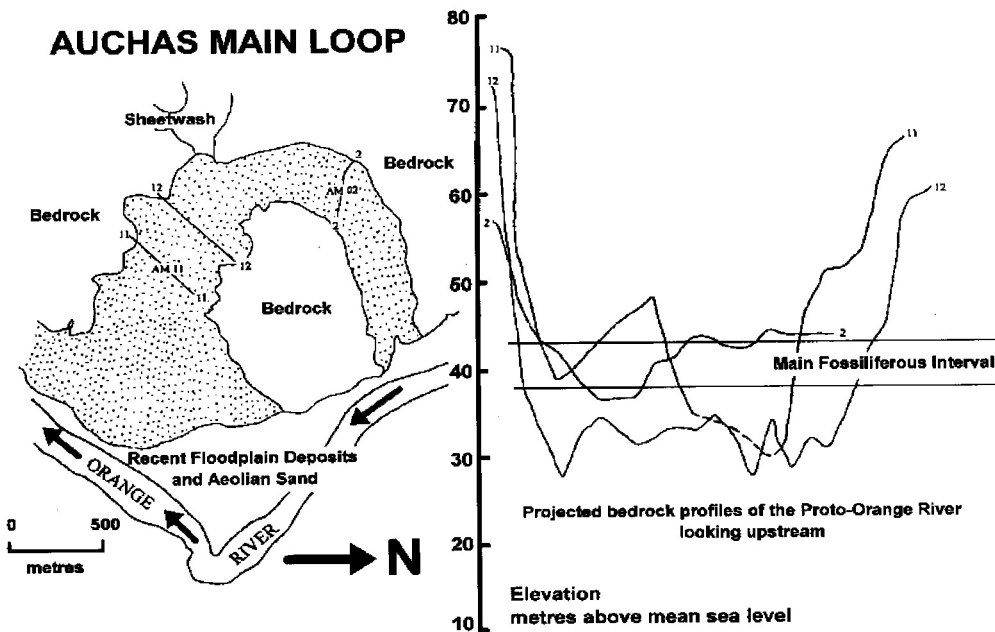


Figure 4-16.-The Auchas loop of the Proto-Orange River in plan and bedrock profiles in three sections of the loop. The main fossiliferous interval is been 39 and 43 metres asl (based on data from Fowler, 1976).

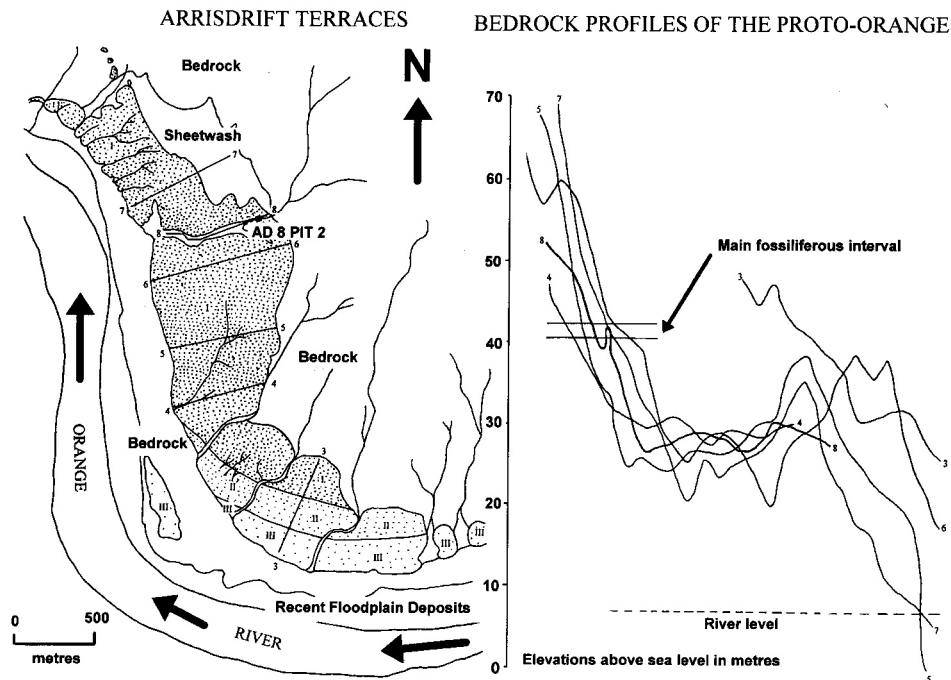


Figure 4-17.- The Arrisdrift lateral channel in plan and five bedrock profiles. The main fossiliferous interval occurs between 40 and 41 metres asl in a small subsidiary channel in profile 8 (based on data in Fowler, 1976).

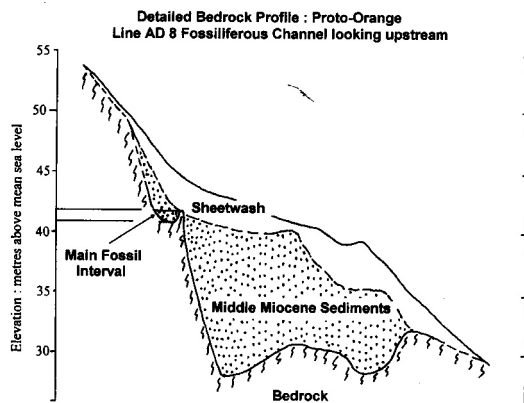


Figure 4-18.- The broad stratigraphic relations of the Middle Miocene sedimentary infilling of the Proto-Orange channel on Line AD 8 showing the position of the fossiliferous site in its subsidiary channel (based on data in Fowler, 1976).

Figure 4-18.- The broad stratigraphic relations of the Middle Miocene sedimentary infilling of the Proto-Orange channel on Line AD 8 showing the position of the fossiliferous site in its subsidiary channel (based on data in Fowler, 1976).

The Meso-Orange Terraces remain undated on account of the lack of fossils in them. However, these terraces (II and III in fig. 4-15) must be younger than the Proto-Orange terrace since in places, the edges of the Meso-Orange deposits overlie Proto-Orange sediments. It is likely that the two Meso-Orange terraces correlate with the 50 metre and 30 metre packages that occur widely along the Namaqualand

and Namibian Coasts (Pether, 1994). These littoral marine packages are regressive units that formed when sea-level dropped following transgressions at the end of the Miocene and end of the Pliocene respectively. The overall number of terraces in the Orange River is the same as the number of littoral terraces (three in each case) and they occur in the same altitudinal order in both settings (90 mP, 50 mP and 30 mP along the coast, and I, II, III (highest to lowest) in the Orange River Valley). The earliest terraces in the two settings (I in the river valley and 90 mP along the coast) are known to have the same age (Early to basal Middle Miocene, ca 19-17.5 Ma) and it would be surprising if the others did not also have similar ages to each other. Thus Meso-Orange Terrace II would correspond to the 50 metre package along the coast (ca 7-5 Ma) and Meso-Orange Terrace III would correspond to the 30 metre package (ca 3-2.5 Ma). All three units would then have the same overall cause: transgressions of the sea followed by regressions.

As before, when sea-level dropped following the transgressions, the river cut itself new channels through its Meso-Orange alluvium, leaving some of its deposits lateral to the new channel. By this time however, the lower Orange River was more deeply incised within its valley with the result that the Meso-Orange deposits are always closer to the Modern river than are those of the Proto-Orange.

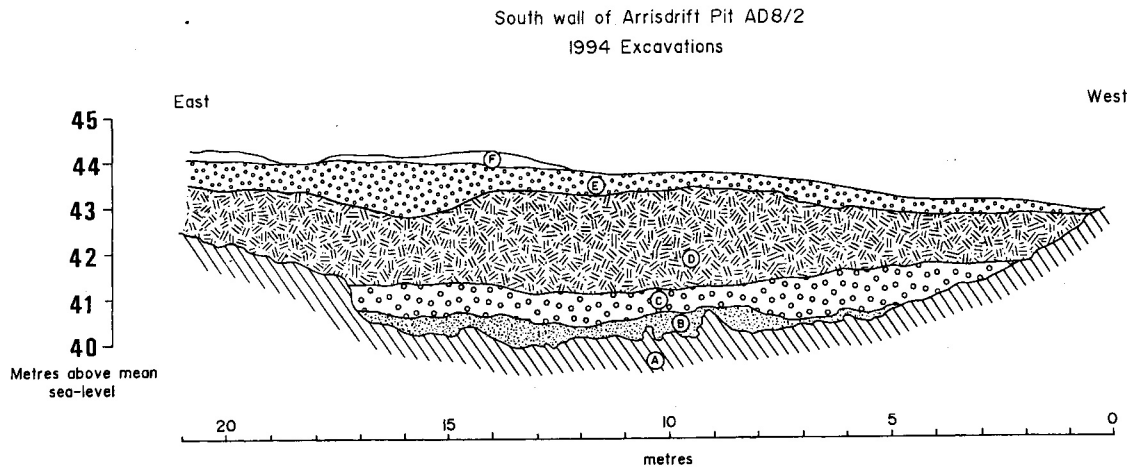


Figure 4-19.- Detailed section of the south wall of the Arrisdrift fossil site during the 1994 excavations. A = Bedrock, B = basal silts, clays and gypsum lenses, C = conglomerate, D = massive gypsiferous sands, E = unconsolidated sheetwash, F = grey aeolian sand. Fossils are abundant in beds B and C.

4.7.5.8 The Karpfenkliff Conglomerate

The NPE did not have the opportunity of studying the Karpfenkliff Conglomerates in any detail, but it is likely that they are considerably younger than previously thought. In the vicinity of the Kuiseb and Tsauchab drainages the Tsondab Sandstones contain fossil eggs of various *Namornis* and *Diamantornis* species as well as eggs of *Struthio daberasensis*, a late Miocene to middle Pliocene species, and the conglomerates are thus probably younger than Early Pliocene. There can be little doubt that some conglomerates would have been deposited by ephemeral flow from the edges of the Great Escarpment from time to time throughout the Miocene and Pliocene, but the are ally extensive and thick deposits assigned to the Karpfenkliff Conglomerates are of Plio-Pleistocene age. As described by Ward (1987) the Karpfenkliff Conglomerates wedge out westwards towards the Atlantic seaboard and clast size decreases in the same sense. The a really extensive nature of the deposits suggests that they were deposited as fans by braided streams issuing from the Great Escarpment prior to incision of the Kuiseb Canyon (Ward, 1987).

The Orange River differed from the Proto-Kuiseb and other Namibian rivers flowing into the Atlantic in that its drainage area was sub-continental in scale, whereas all the others are considerably more localised in extent. For this reason, it is probable that the Orange was a permanently flowing river throughout the Neogene, whereas the Kuiseb, Tsondab, Tsauchab and other drainages were inactive for most of the Neogene. Even during the Plio-Pleistocene humid phase when these rivers may have been permanently flowing, they were probably prone to flash flooding during summer storms, and these floods would have carried large clasts rapidly downstream.

If the Plio-Pleistocene age of the Karpfenkliff Conglomerate is correct, then it would predate the 30 metre littoral sediment package that occurs along the coast of south-western Africa. The conglomerates may well be coeval with the Kaukausib, Grillental, Gamachab and other travertines in the coastal strip, which are of late Pliocene to basal Pleistocene age.

The Karpfenkliff Conglomerates do appear to indicate the presence of a more vigorous fluvial regime during their deposition than existed before or afterwards, but it is not clear whether these conditions can be called pluvial in the strict sense. Perhaps a more appropriate term would be a relatively humid phase. During this humid phase which most likely spanned the late Pliocene and early Pleistocene, conditions were generally wetter than they are today or were during the Miocene and most of the Pliocene, but we consider that the climate of the Namib did not ameliorate enough for savannah or woodland conditions to be installed throughout the region. Instead, it probably became a steppe with linear oases following river valleys such as the Kuiseb, Tsondab, Tsauchab, Orange and other valleys that flowed towards the Atlantic Ocean. An important element of this humid phase would have been an increase in the volume of ground water in the region, with much surface evaporation contributing to the formation of the Kamberg Calcrete and allied deposits, and contributing to resurgences near the coast which formed the travertine deposits. It is perhaps no coincidence that at present, close to all the major travertine occurrences there are resurgences in the form of weak saline springs, but, at present, none of them are depositing travertine.

In upland Namibia and Botswana, the late Pliocene was a period of cavern formation in dolomite country rock, as was shown by Pickford, 1990. This period of karstic activ-

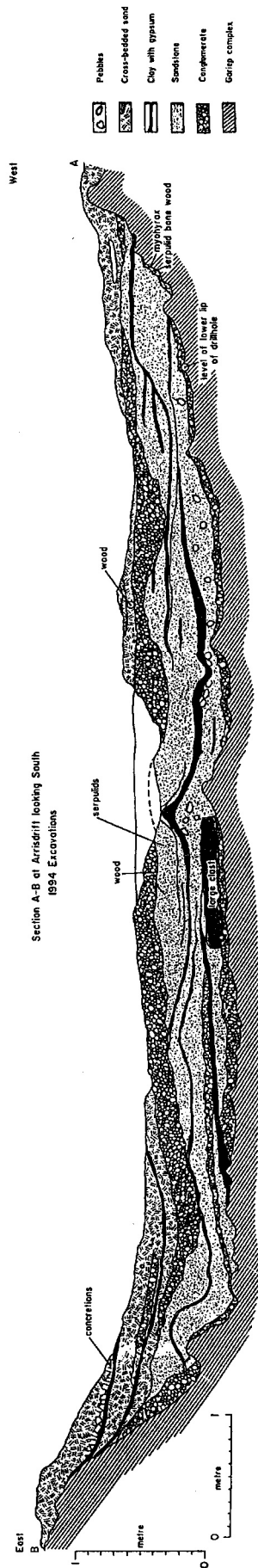


Figure 4-20.- Section across the Arrisdrift lateral channel to show the disposition of the fossiliferous fluvial sediments. Note the clay drapes (in black) which are intercalated with conglomerates and sands.

ity may well be due to the same regional increase in humidity

suggested by the Karpfenkliff Conglomerate, the coastal travertines and other lines of evidence.

Thus, it is concluded that the Karpfenkliff Conglomerates record part of a general process of humidification in the Namib and the inland regions of south-western Africa during the late Pliocene and early Pleistocene.

4.7.5.9 Nuttabooi and Kommaggas

Like the Orange River, the Buffels in northern Namaqualand has terrace deposits that date from an ancient period of the river's history. At Nuttabooi (fig. 4-21), parts of the fluvial sequence have been heavily silicified, as have some of the Orange River deposits. However, no fossils have been found either at Nuttabooi or Kommaggas terraces, so there is no direct evidence as to their age. Hendey (1984) reported the presence of shark teeth at Kommaggas, but it is now known that the material upon which this record was based was actually collected at Hondeklip Bay. The error arose because the mine at Hondeklip Bay is named Buffelsbank Mine, the name having followed the organisation when it transferred from the original mine at Kommaggas on the Buffels River (Pether, pers. comm.).

Having examined the deposits at Nuttabooi, we consider that the terrace deposits can be no earlier than Early Miocene. If they were older than this, then they would probably have been kaolinised during the Oligocene, and they are clearly not affected by this kind of weathering. Instead, parts of the deposits have been silicified as have Neogene strata at Somnaas, The Point and elsewhere in Namaqualand and in parts of the Orange River succession. With presently available evidence we are unable to go beyond this.

4.7.5.10 The Oswater Conglomerates

As was noted by Ward (1987), the Oswater Conglomerates tend to be thicker in their downstream exposures than they are nearer the head of the Kuiseb Canyon, indicating that they represent an aggradational deposit. It is probable that the aggradation was caused by a rise in the marine base level, and it appears most likely that their accumulation occurred at the same time as the deposition of the 30 metre littoral marine package (Pether, 1986) to which they contributed abundant clasts. If this correlation is good, then the Oswater Conglomerates would represent the Kuiseb Valley equivalent of the Meso-Orange deposits (specifically the Meso-Orange III Terrace)

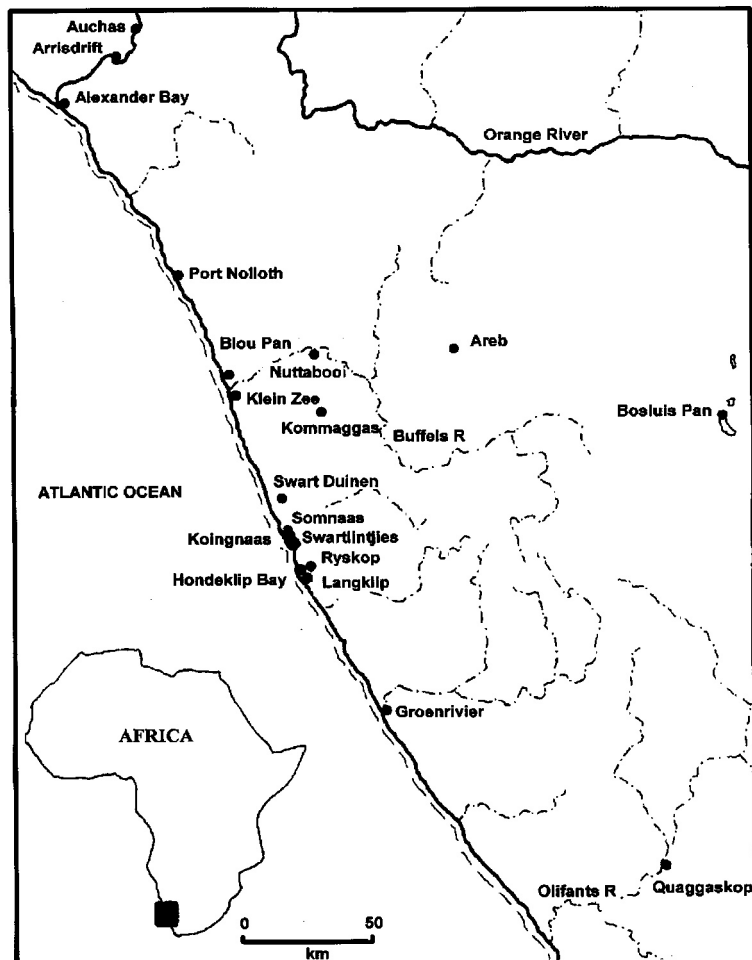


Figure 4-21.- Location map of important fossil sites in Namaqualand.

4.7.5.11 Young silts in the Orange and Kuiseb Rivers

In the lower reaches of the Orange River Valley below the Richtersveld there are fairly extensive deposits of finely stratified, soft brown silts. The geomorphological setting and unindurated nature of these deposits indicate that they are Recent in origin. Similar silts occur in other rivers draining into the Atlantic, including the Kuiseb (Marker, 1979, 1979/ 81; Marker & Müller, 1978; Ward, 1987). Vogel (1982) concluded that the Homeb silts in the Kuiseb Valley accumulated between 23 and 19 Ka on the basis of stable isotope analyses. It is tempting to invoke a regional event to account for these widely scattered occurrences on the grounds that they seem to be extremely similar in sediment type and to have similar ages of deposition. If the silts in the various valleys did indeed accumulate in response to a regional geological event, then it would appear that the only explanation would be a rise in sea-level, in which case the silts would probably correlate with one of the sub-10 metre raised beaches of the littoral zone, possibly the 8 metre beach. The major problem with this hypothesis is that the silts occur well upstream in the Orange River Valley as far as the Richtersveld, and it would be unlikely that any of the Pleistocene marine high stands would have been sufficiently elevated to account for the silts. Alternatively, these silts could be due to megaflood episodes. Zawada (1997) considered on the basis of these silts that there have been 13 palaeofloods in the Orange River drainage during the past 5,500 years. If Zawada is correct, then one would have to invoke separate flooding events for each of the drainages in the Namib, thereby removing the need to find a single explanation to account for the silts.

4.7.5.12 Kaukausib Gravels

In the Kaukausib drainage upstream from Grillental, there are extensive deposits of brown gravel and grit, unconformably overlying green grit and clay of Early Miocene age. These deposits are clearly related to the present day Kaukausib Valley and can readily be distinguished in satellite images of the northern Sperrgebiet as a pale outcrop whose edges conform closely to the shape of the valley. Fossils found at two places in the grits indicate that they are of Late Pliocene to Early Pleistocene age. At a site whose exact location is unknown, but which is not far from Grillental, Corvinus recovered an upper molar of a white rhinoceros *Ceratotherium simum* which was reported to be in association with Middle Stone Age implements. At Kaukausib Fountain, there is a complex dome of interlayered travertine and coarse brown sand and grit. Fossils have been located in several of the grit layers, and all of them appear to be of Late Pliocene or Early Pleistocene species, including a giant suid which might represent *Notochoerus capensis*. If this identification is correct then the travertine spring was actively building its dome in the Late Pliocene, since this species is considered to be about 2.7 to 2.8 Ma (White, 1995).

4.7.6 CRATER FACIES AT CHALCEDON TAFELBERG

At Chalcedon Tafelberg (27°16'02.9"S : 15°22'58.6"E), there is a roughly circular outcrop of lacustrine sediments forming the cap of the hill some hundreds of metres in diameter and 10-15 metres thick. The sediments consist of interbedded, well bedded dolomites and cherts with numerous plant and algal remains and molluscs (*Hydrobia* and *Lymnaea*). These sediments are underlain by a 2 metre thick palaeosol (partly silicified) developed on hexagonally jointed monchiquite which has been dated by radioisotopic methods to be Middle Miocene (14.7 Ma) (Stocken, 1978). They are unconformably overlain by brownish calcrete which drapes down into the nearby valleys where it can be seen overlying kaolinised bedrock. This calcrete, like many of the other calcretes in the Namib, is of Pleistocene age.

Judging from the form of the outcrop, the inward dips of the strata, the fine nature of the sediments, their thin bedding (10 cm scale) and their occurrence overlying hexagonally jointed monchiquite, we conclude that these deposits most probably accumulated within a crater. The period of accumulation was probably soon after the formation of the crater towards the end of the Middle Miocene. The restricted diversity of fauna and flora indicate that the water within the crater was probably alkaline, a suggestion borne out by the presence of syngenetic chert with elephant skin surface patterning. The principal diagenetic agents were dolomitisation and silicification which have made the strata more resistant to erosion than the surrounding rocks of the Gariiep Group. As a consequence the sediments now stand proud as a positive relief feature some 50-60 metres above the surroundings, a classic example of inverted relief.

4.7.7 AEOLIANITES OF THE NAMIB DESERT

Aeolianites, or indurated wind blown sands, occur widely in the Namib area, although most of them are buried under a cover of mobile sands assigned to the Sossus Sandstone Formation. Outcrops of aeolianite are known in many places in the Namib coastal plains from the Atlantic seaboard to the foot of the Great Escarpment some 100 km inland (fig. 4-22) and these have generally been assigned to the Tsondeb Sandstone Formation (Ward, 1987). In several places along the foot of the Great Escarpment aeolianites are seen to overlies Proterozoic rocks of various kinds. There are several distinct sandstone units within the Tsondeb Formation which range in age from Middle Miocene to Late Pliocene. In many outcrops, the Tsondeb Sandstone consists of distinct units separated by super-bounding surfaces. These surfaces are not depositional in nature, but are erosional. The strata between the super bounding surfaces usually consist of dune sands with characteristic high-angle, large scale cross-bedding. In the Awasisib area, the aeolianites are about 120 metres thick and consist of at least 12 units separated by super-bounding surfaces (Senut *et al.*, 1995).

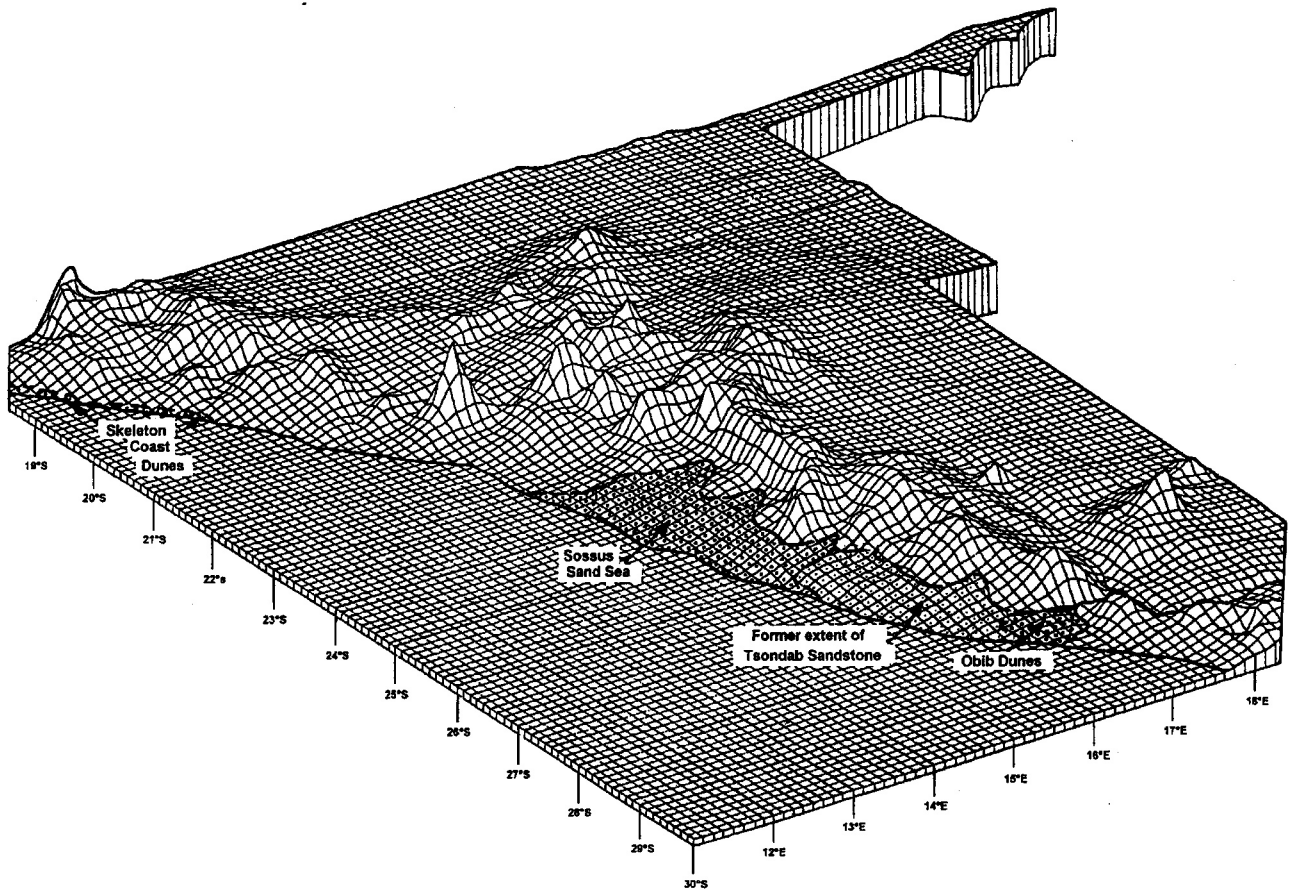


Figure 4-22.- Geomorphology of the Namib Coastal Plain and its cover of Miocene and Recent sands. The low relief coastal strip has been the site of hyperarid sedimentation since at least the Middle Miocene.

Many of the Miocene aeolianites have undergone pedogenesis.

Occasionally, finer-grained, silt to clay grade sediments are intercalated in the sandstones, and these represent ancient pan deposits. These are rare in the Awasib area, but are more prominent in the north near the Kuiseb drainage (Ward, 1987) where dolomitised silts are well preserved. In the north these strata have been called the Zebra Pan Carbonates (Ward, 1987). Lag deposits (microregs) also occur in patches where wind action has winnowed the finer clasts away, leaving coarse sand to fine gravel layers intercalated in the dune sands.

4.7.7.1 The northern fringe of the Central Namib Sand Sea

Eggshell fragments collected from Gobabeb (Lancaster pers. comm.) represent the Daberas Ostrich species (*Struthio daberasensis*) which indicates a post-Miocene age for some of the aeolianites to the south of the middle reaches of the Kuiseb. Other eggshell fragments have been collected from time to time in the Sand Sea south and west of Gobabeb. The earliest of these specimens was found reworked in Pleistocene gravels at West Pan. It consists of an

eggshell of *Diamantornis corbetti*, suggesting that Middle Miocene aeolianites crop out nearby. The other eggshells belong either to *Struthio daberasensis* or to the modern species of ostrich, *Struthio camelus*.

4.7.7.2 The Kamberg-Diep Rivier-Tsachab-Sesriem- Vreemdelingspoort Area

Many years ago Mr H. Zur Strassen discovered a rodent skull and skeleton in the Tsondab Sandstone Formation north of Tsachab Vlei and northwest of Sesriem Camp. In 1985, Dr John Ward found fossilised struthious eggshell fragments at Elim, some 5 km north of the eastern nose of Elim Dune. The NPE has visited the area several times and has found a number of fossiliferous localities of Miocene and Pleistocene age.

In the Kamberg-Vreemdelingspoort sector, the Tsondab Sandstones have yielded abundant fossils at many outcrops.

1.- Gamsberg Pass Road. Sandstones underlying a calcrete cap on the Gamsberg Pass road in the region of Paradys Valley contain rhizoliths. A single fragment of thin eggshell was found at this locality. It could represent an

aepyomithoid eggshell similar to material found at Zebra Hill.

2. At Zebra Hill in the Kamberg area aepyomithoid eggshell fragments are extremely common. A few fossil mammals (Pedetidae) from the super-bounding surface which traverses the hill (Ward, 1987, Plate 12b) indicate that these dunes formed during the Early or Middle Miocene. Overlying the indurated sands is the Kamberg Calcrete which has yielded fragments of mammalian bone. Nearby, lateral equivalents of the Kamberg Calcrete have yielded fossil mammals of Pleistocene age. Loose sands overlying the aeolianites contain eggshell fragments of *Struthio daberasensis* of post-Miocene age.

3. In aeolianite cliffs immediately south of the Tsondab Valley near Estcourt, eggshell fragments of *Diamantornis wardi* were found *in situ*, implying a Middle Miocene age. On Estcourt and in the Tsondab Valley near its junction with Diep Rivier, the calcrete overlies indurated Tsondab Sandstone. At several localities fossilised teeth of Gemsbok have been located in this calcrete, and there are numerous Acheulean tools, many of which are coated in calcrete. Thus the calcrete in this area is mid-Pleistocene in age.

4. Immediately south of the junction of Diep Rivier and the Tsondab River, there are cliffs of aeolianite which are rich in traces of bioturbation. A fossil eggshell found *in situ* at this site belongs to the Modern ostrich *Struthio camelus*, suggesting that the sands are Pleistocene in age.

5. In the Tsondab drainage, as in Sesriem Canyon, very much thicker calcretised fluvial conglomerates occur. No fossils have yet been found in these deposits, so no direct evidence of their age is available. However, they seem to overlie or to have been deposited in valleys cut into Tsondab Sandstone and may well also be Pleistocene in age.

6. Eggshell fragments of *Namornis oshanaï* occur sparsely at Diep Rivier. The impressive aeolianite cliffs at Diep Rivier are thus of Middle Miocene age. Bioturbation is common in these exposures, but vertebrate remains are rare.

7. The Elim exposures of the Tsondab Sandstone (24°25'00"S : 15°45'25"E) yielded numerous eggshell fragments of a large Ostrich, *Namornis oshanaï* (Sauer) in three main concentrations, indicating a basal Middle Miocene age for these outcrops. The Elim aeolianites are riddled with plant root ichnosystems and termite burrowing tubes and nests, and the environment of deposition was evidently one of interdune flats and low relief dunes.

Study of the Elim Gullies reveals that there are at least three generations of bioturbation in the area. Contemporary with Middle Miocene dune formation there are burrows, usually of small diameter, and hives of the sand termite, *Psanmotermes*. There may also be tubes made by the White Lady Spider (*Leucorhynchus arenicola*) (J. Henschel, pers. comm.). These traces generally terminate upwards at specific horizons (bounding surfaces of dunes).

A much later generation of bioturbation affects the upper two to three metres of the entire aeolianite field irrespective of stratigraphic position. Many of the cylindrical features are 4-5 cm in diameter and up to several metres long. These may well be root traces, representing plants which grew over the entire dune field once it had stabilised. At this time the termite *Hodotermes* established itself, and many of its hives and white-lined foraging tubes were formed. Both these episodes of bioturbation are preserved in sandstone with no extraneous material. The second episode of bioturbation is post-Miocene. Finally, contemporary with calcrete formation during the late Pleistocene to Holocene, a third bioturbation event occurred, identifiable as being related to the calcrete period because the infillings of the tubes and hives contain fragments of foreign rock and calcrete, generally of a yellowish colour. Among the identifiable agents is the termite *Hodotermes*.

Of interest is the observation that the «*Namornis oshanaï*» dunes at Elim appear to have accumulated under a northwesterly wind regime, the dunes moving southwards. This is quite a different direction from the wind directions of the aeolianites in the Tsauchab area and the Modern dunes.

8. The lower parts of the aeolianite outcrops near the waterhole north of Sesriem airstrip have yielded fossil eggshells belonging to *Diamantornis wardi*, a late Middle Miocene species. At the top of the sequence, above a Modern dune which separates the lower from the upper outcrops of aeolianite, there is a large area of indurated sands with abundant eggshell fragments of *Struthio daberasensis* suggesting a Pliocene age for these aeolianites. Overlying this aeolianite is a deflation Jag containing calcrete nodules, Middle Stone Age tools and bone fragments, as well as modern ostrich eggshell fragments.

9. The Tsauchab exposures of the Tsondab Sandstone (24°30'14.4"S : 15°43'01.4"E) have yielded numerous vertebrate and invertebrate fossils. Several mandibles and maxillae of tiny rodents and isolated spring hare teeth were found. Abundant eggshell fragments of *Diamantornis laini* occur at this locality, which is of basal Late Miocene age. In addition, several thin small sheet-like structures in calcite were recovered from this locality and several *in situ* specimens were left in the field. The morphology of these structures is similar to the trap door webs of the "buck spoor" spider *Seothyra* (Peters, 1992; Henschel, 1989; Lubin & Henschel, 1990; Dippenaar-Schoeman, 1990).

The deflation surface at the Tsauchab site yielded several snake vertebrae, a lizard jaw and some small bird and bovid remains of Pleistocene age. Apart from the vertebrates there are numerous signs of termite activity, and plant root systems are common. The depositional environment was one of hummocky dunes and inter-dune flats.

10. A site northwest of a Windmill sited about 1 km south of the nose of Elim Dune yielded a complete skeleton of a small bathyergid rodent (H. Zur Strassen pers. comm.). Apart from this fossil, the aeolianites at this out-

crop have yielded no other vertebrates. However, there are numerous Middle Stone Age artefacts lying on the deflation surface at this site, as well as a few Holocene or Late Pleistocene fossils (*Lepus*, *Struthio camelus* (eggshell fragments), chamaeleon, bovid, *Equus*) but no Miocene vertebrates were seen.

11. About 1 km southwest of the bathyergid site and still in the same narrow valley, there were a few eggshell fragments of *Diamantornis laini* suggesting a Late Miocene age for the Tsondab outcrops there.

12. A low cliff 1.5 km southwest of the latter site, near a small depression in the Tsondab Sandstone, the depression filling with water during the rains. At the time of the survey, this waterhole was visited by immense quantities of sand grouse. Immediately west of this waterhole there are abundant eggshell fragments of *Diamantornis laini* of Late Miocene age.

13. The calcrete which overlies the Tsondab Sandstone at Elim has yielded several bones and teeth and numerous stone tools. The bones are generally in poor condition, but *Equus* (zebra) and *Oryx* (gemsbok) are identifiable and suggest a Late Pleistocene to Holocene age. Most of the stone tools are of Middle Stone Age typology, although some that could represent the Oldowan industry are also present.

14. The deflation surface underlying the Recent sands of the Namib Sand Sea in the shoulders of the Tsauchab drainage yield abundant Middle Stone Age artefacts and a few poorly preserved fossils of extant taxa (*Lepus*, *Equus*, *Oryx*, *Struthio camelus*, lizard).

15. At the base of the Vreemdelingspoort aeolianite cliffs, eggshells of *Diamantornis wardi* were found *in situ* suggesting a Middle Miocene age for these fossilised dunes. At the top of the cliffs is a deflation surface covered in Acheulean and Middle Stone Age stone tools and a few Pleistocene to Recent bovid bones and tooth fragments.

16. In a low indurated dune north of the Vreemdelingspoort cliffs abundant eggshell fragments of *Diamantornis corbetti* and *Diamantornis wardi* occur in Tsondab Sandstones, implying that deposition occurred during the Middle Miocene. In the deflation lag are Acheulean tools and a few bones and teeth of *Pedetes* (Spring Hare) and *Antidorcas* (Springbok).

4.7.7.3 The Bushman Hill-Awasib-Haiber-Tree Pan sector.

In the Awasib area, there are up to 120 metres of Tsondab aeolianites. In places these are overlain by calcrete deposits of Late Pleistocene age, but the general cover consists of mobile sands of the Namib Sand Sea. Near outcrops of Proterozoic rocks, aeolianites are occasionally covered with sheetwash consisting of angular debris derived from the inselbergs, and this sheetwash is

in places indurated with calcrete. Throughout the area, even deep in the sand sea, there are large quantities of manuports and artefacts, some of surprising dimensions. These range from Acheulean, through Middle Stone Age to grind-stone technologies, indicating that humans have lived in the area intermittently since at least the Middle Pleistocene. Finally, in patches throughout the area, the aeolianites are being deflated, and outcrops are often covered in a lag comprised of nodules of sandstone, usually root casts and ichnofossils. This lag is usually less than 5cm thick, but in places where the action of water has swept the debris into depressions and hollows it can be half a metre thick.

Aeolianites of the Awasib region have yielded abundant fossils ranging in age from Middle Miocene to Pleistocene. The calcretes are less fossiliferous, but the few specimens collected are important in showing that calcrete pedogenesis occurred during the Late Pleistocene and Recent.

1. North of Bushman Hill (25°02.1'S : 15°48.4'E) : In the sand dunes north of the ancient lake north of Bushman Hill, outcrops of aeolianite occur behind a fringing dune. These aeolianites yielded eggshell fragments of *Struthio daberasensis* and are thus post-Miocene in age. A few bone and tooth fragments of gemsbok were found on the deflation surface at the top of the aeolianites, as were abundant Middle Stone Age and a few Acheulean stone tools.

2. West of Bushman Hill (25°08'00.4"S : 15°44'28.9"E): West of the western most promontory of Bushman Hill occurs a series of south facing cliffs of aeolianite surrounded by recent dunes. Teeth of *Pedetes* and abundant eggshell fragments of *Struthio daberasensis* which indicate a post-Miocene age occur on the lag surface under the mobile dunes. The deflation surface at the top of the aeolianites is rich in Middle Stone Age tools and there are scattered bone fragments of gemsbok, some of which show signs of having been burnt.

3. Depression north of Awasib Cliffs (25°13'21.0"S : 15°38'14.0"E) : In a blowout depression northwest of the track descending towards Awasib Cliffs there are extensive outcrops of aeolianite beyond a long ladder dune that extends northwards from the main dune field. The sandstones are rich in bioturbation traces, but are poor in vertebrate remains. Nevertheless a bovid femur in poor condition was found as well as eggshell fragments of *Struthio daberasensis*. A post-Miocene age for these aeolianites is probable.

4. 8-9 km north of Awasib Water Hole are extensive aeolianite cliffs (Awasib Cliffs) (Hoal, 1990). A complete succession of fossil struthious eggshells has been found in this area (Senut *et al.*, 1995). In the low slopes leading up towards the base of the cliffs (25°18'28.7"S : 15°38'43.6"E) occur eggshells of *Namornis oshanai* of basal Middle Miocene age. A little closer to the base of the cliffs (25°18'23.0"S : 15°38'55.2"E) occur eggshells of *Diamantornis corbetti*. In the basal part of the cliffs eggs

of *Diamantornis wardi* are common. In the middle sector of the Awasib Cliffs abundant eggs of *Diamantornis laini* are exposed in several super-bounding surfaces. In the upper parts of the cliffs eggshell fragments of *Struthio daberasensis* are common, while in loose sands occur eggs of *Struthio camelus*.

5. 10.5 km north northeast of Awasib Water Hole (Aeolianite Gullies) eggs of *Diamantornis wardi* are common. In calcretes that cap the aeolianites in this sector, bones and teeth of *Oryx gazella* have been found.

6. 9 km northwest of Awasib Water Hole (elbow in aeolianite outcrop) (25°18'31.4"S : 15°36'12.8"E) eggs of *Struthio daberasensis* are common in aeolianites near the top of the cliffs.

7. Aeolianites west of Awasib Water Hole have yielded a variety of egg types. 5.37 km from Awasib at a bearing of 294° (25°22'01.6"S : 15°36'41.3"E) there are abundant eggs of *S. karingarabensis*. 6.5 km west of the waterhole (25°22'48.4"S : 15°34'42.1"E) eggs of *N. oshanai* and at 25°22'47.7"S : 15°34'28.8"E those of *Diamantornis wardi* occur, implying a Middle Miocene age, while at the top of the succession (25°22'35.3"S : 15°34'16.3"E) there is a nest of *S. daberasensis* with thousands of eggshell fragments in a good state of preservation.

8. In a series of low cliffs west of Awasib Mountain and south of Numabis (25°33.3'S : 15°37.2'E) there are outcrops of aeolianite, sometimes capped by calcrete. These aeolianites are poorly fossiliferous but eggshell fragments of *Struthio daberasensis* were found indicating a post-Miocene age.

9. Northeast of Haiber Rodent Locality (25°37'14.5"S : 15°39'34.9"E): In the flattish area north of the Haiber Rodent Locality and the large depression east of it there are extensive exposures of aeolianite. These are poorly fossiliferous, but immediately north of the depression they yielded eggshell fragments of *Diamantornis wardi* indicating a Middle Miocene age for these sediments.

10. Haiber Rodent Locality (25°37'52.2"S : 15°39'25.8"E): This site, which was found in 1994, yielded several rodent skulls and mandibles in sandstone nodules. Other finds include a bovid tooth, a bovid maxilla with four teeth, several cerambycid cocoons and eggshells of *Diamantornis laini*. The rodents belong to the genus *Ternania* but are more evolved than those from Fort Ternan, Kenya, which suggests that the strata at the locality are uppermost Middle Miocene or basal Late Miocene in age.

11. In aeolianites 6 km southwest of Haiber Hill (Haiber Gullies), eggs of *Diamantornis wardi* have been found.

12. Exposures of aeolianite 8 km southwest of Haiber Hill (25°40'07.9"S : 15°40'11.3"E) yielded cocoons of Cerambycidae, eggs of *Diamantornis laini* and rodents

(*Ternania* sp.). In the upper part of the succession eggs of *Struthio daberasensis* occur.

13. At exposures 8.5 km south southwest of Haiber Hill eggshells of *Diamantornis laini* are common. Rodentia occur in the same site.

14. 13.5 km south southwest of Haiber Hill, a calcified fungus garden of *Hodotermes* was found. Eggshells of *Struthio camelus* occur in a crest of loose sands nearby.

15. Tree Pan (Southern Locality - Hoal, 1990) is bordered on its northern side by impressive outcrops of aeolianite. Ichnofossils are extremely common and very well preserved.

16. In aeolianite cliffs 3 km northwest of Tree Pan occur abundant ichnofossils including *Gyrolithus*, *Daimonhelix* and *Termitichnus*.

17. In small outcrops of aeolianite 0.5 km east of Tree Pan *Diamantornis laini* eggs have been located.

18. Small exposures of fossilised sand dunes 0.5 km south of Tree Pan yielded eggshells of *Diamantornis laini*.

19. 3 km south of Tree Pan there are aeolianites which yield Carnivora and Rodentia (*Ternania* sp.).

20. At Elbow Dune (9.5 km southeast of Tree Pan) there is an interesting blow-out depression cut into Miocene aeolianites and bordered on all sides by mobile sands. The consolidated sands have yielded eggs of *Diamantornis wardi* while recent deposits in the bottom of the depression contain *Struthio camelus*, *Oryx gazella* and Viveridae associated with grind stones.

4.7.7.4 Aeolianites of the Northern Sperrgebiet

The oldest aeolianites in the Lüderitz area occur at Schmidtfeld, where a small outcrop of sandstone with eggshells of *Diamantornis wardi* has been recorded (Bill Shaw field notes). These sands would be of Middle Miocene age. The next oldest aeolianites are assigned to the Fiskus Sandstone which is generally a bright orange colour and can contain extremely coarse sand and even granules. Eggshells found in this unit at Kolmanskop and Fiskus belong to *Struthio daberasensis* indicating a Late Pliocene or Pleistocene age for these deposits. Overlying the Fiskus Sandstone is a variety of aeolian deposits including indurated sands at Russel's Perch near E-Bay, which contains Recent fossils (*Struthio camelus*, *Patella*). Unconsolidated sands occur over much of the area.

4.7.7.5 Aeolianites of the Southern Sperrgebiet

Fossils were first found in the aeolianites north of the Orange River by CDM geologists. Stocken (1978) reported the presence of the terrestrial gastropod *Trigonephrus*

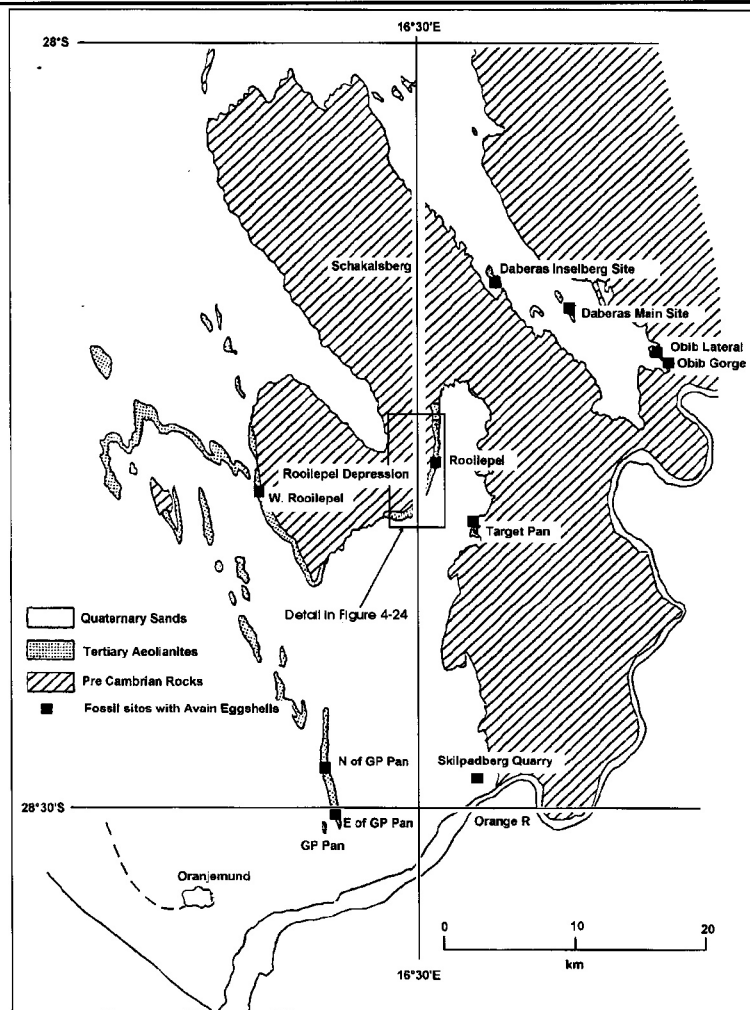


Figure 4-23.- Aeolianites in the Southern Sperrgebiet, overlying bedrock and covered by unconsolidated sands. Fossil avian eggshells have been found at all the named localities.

and bioturbation in the indurated sands at Rooilepel. Corbett (1989) described and figured the first known avian eggshells from Rooilepel, and illustrated examples of the snail *Trigonephrus*, one of which was found in a burrow-shaped cylinder of sand. Corbett (1989) and Ward & Corbett (1990) reported rodents and eggshell fragments in the same area as well as at other sites nearby. As a result of these discoveries, which indicated an Early Middle Miocene age for the aeolianites, palaeontological work was carried out by the Namibia Palaeontology Expedition. Abundant and varied fossils have been recovered from aeolianites of diverse ages at Rooilepel, Rooilepel West, Target Pan, Gypsum Plate Pan, Obib and Daberas, north of Schakalsberg, Karingarab and Tsaus (fig. 4-23 and 4-24). Preliminary assessment of the fossils indicates that aeolianites began accumulating during the Middle Miocene (Rooilepel basal horizon), a process that continued throughout the Middle Miocene (Rooilepel middle levels, Rooilepel West, GP Pan), the Late Miocene (Rooilepel upper levels, Target Pan), and Plio-Pleistocene (Daberas, Obib) (Senut & Pickford, 1995). Aeolianites exposed in a quarry at the foot of Skilpadberg contain: Fig.

4-24 eggshells of *Diamantornis wardi*. Calcretes and gypcretes in the same exposures contain abundant internal moulds of *Trigonephrus*. Many of these snails have been incorporated in road beds of the area, including the track leading up to the summit of Skilpadberg.

At Hoher Rücken (27°46'07"S : 16°03'01"E) (Map sheet 2716CC) R. Spaggiari found eggshells of *D. wardi*, chelonian scutes and internal moulds of *Trigonephrus*. Close by (27°47'20"S : 16°05'35"E) eggshells of *D. corbettii* occur.

Aeolianites at Wolverkop (28°07'51"S : 16°12'17"E) (Map sheet 2816AA) have yielded chelonian remains. Nearby (28°09'26"S : 16°13'31"S) eggshells of *D. corbettii* and *D. wardi* were collected while at 28°11'27"S : 16°14'21"E eggs of *D. corbettii* are found. At 28°08'27"S : 16°12'34"E eggs of *D. corbettii* and *D. wardi* have been collected. None of these aeolianites yielded mammals.

On map sheet 2816AB, eggshells of *D. wardi* were found at 28°12'23"S : 16°21'27"E.

4. RESULTS OF THE NPE AND THE PESA

On Map sheet 2716CC, aeolianites yielded chelonian scutes and eggshells of *D. wardi* at 27°45'57"S : 26°01'54"E, while nearby (27°46'05"S : 16°03'50"E) eggshells of *D. wardi* were collected. At 27°46'11"S : 16°03'45"E, eggs of *D. wardi* occur. At 27°50'05"S : 16°05'30"E eggs of *D. wardi* have been found.

On map sheet 2715DB at 27°43'42"S : 15°56'36"E eggs of *D. wardi* were collected.

At Tsaus, abundant fossil eggs occur at various places along the low west-facing cliffs. Most of these belong to *D. laini* but older egg types occur, including *N. oshanaï*, *D. corbetti* and *D. wardi*. Site 1 is at 27°14'30.5S : 16°08'43.7E. Site 2 is 27°13'59.0S : 16°09'09.5E, while the third site is at 27°13'34.9"S : 16°08'44.1"E

North of Schakalsberg, fossils have been found in five different exposures of aeolianites. At 28°00'04"S : 16°26'46"E there are eggshells of *D. wardi* and internal moulds of *Trigonephrus*. At 27°59'04"S : 16°28'20"E eggs of *D. corbetti* occur. At the third site (27°59'04"S : 16°31'24"E) a succession of aeolianites occurs which have yielded eggs of *D. corbetti* at the base and eggs of *D. wardi*, a pedetid, chelonians, *Trigonephrus* and a hive of *Hodotermes*. The fourth locality, at 27°59'43"S : 16°27'14"E, eggs of *D. wardi* and internal moulds of *Trigonephrus* have been found. Finally, at 27°58'48"S 16°26'35"E there are poor exposures which yielded eggshells of *D. wardi* overlain by calcrete with *Trigonephrus*. Thus north of Schakalsberg, the aeolianites are predominantly of Middle Miocene age and are overlain by calcrete of Pleistocene to Recent age.

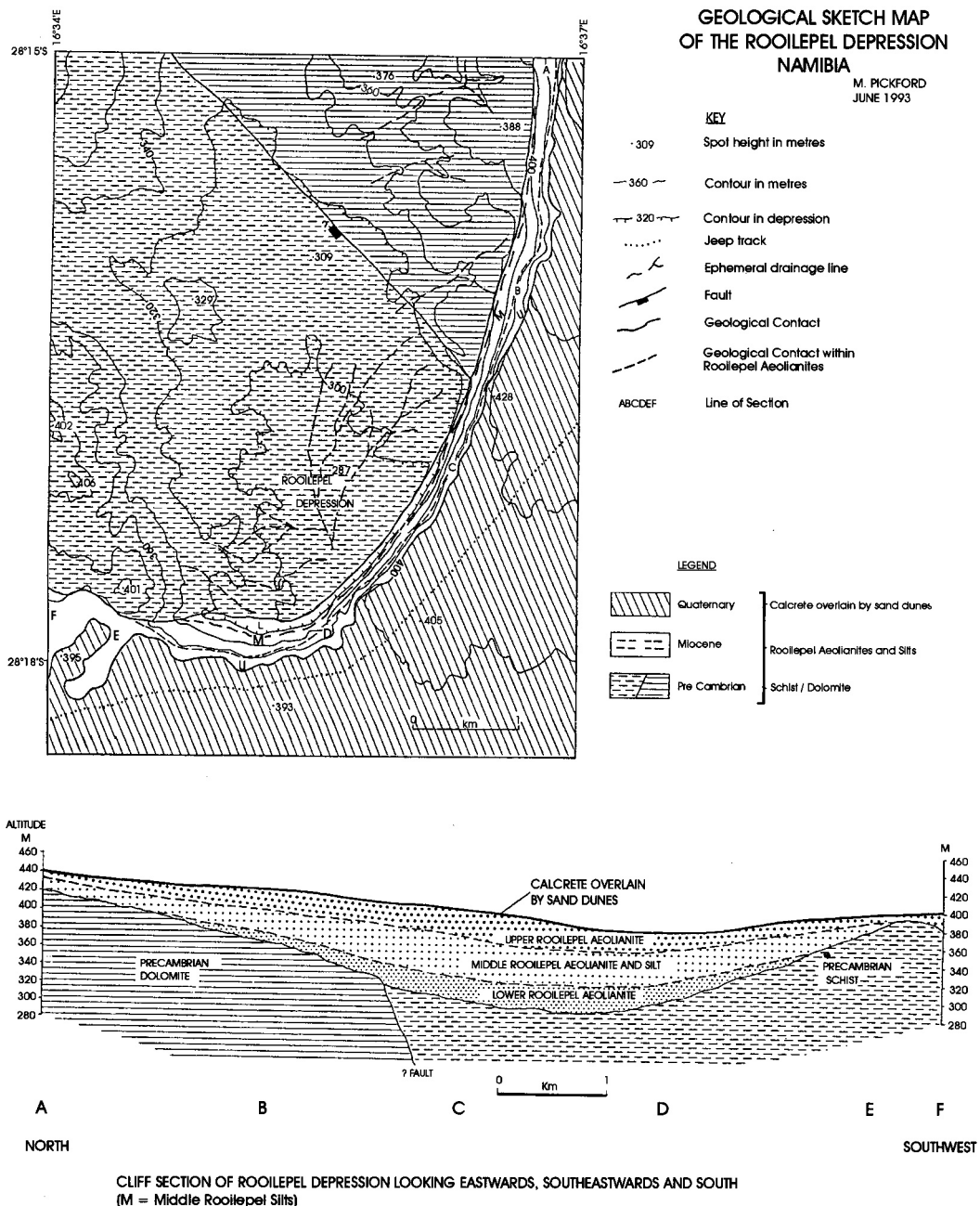


Figure 4-24.- Geological map and section of the Rooilepel area.

The Obib dune field occupies a valley north of the Orange River in the eastern half of the Sperrgebiet. Fossils (*Xerocerastus*, *Trigonephrus*, *Struthio daberansensis*, *Cryptomys*, *Loxodonta*) found at several outcrops of aeolianite, both within the Obib Gorge on the eastern edge of the dunes and along its crest and western flank, are all of

Pleistocene species. In particular the rodents, macroscelidids and bird eggshells indicate that these aeolianites are considerably younger than those at Rooilepel. In the same sector there are calcrete horizons which are overlain by mobile sands.

In summary, the available biochronological evidence indicates that aeolian sands began accumulating first in the north about the latitude of the Kuiseb River towards the end of the Early Miocene and that in the south near the Orange River, deposition began somewhat later - about the onset of the Middle Miocene. The offset in timing of first aeolianite deposition is not known precisely because the northernmost outcrops have yielded only aeopyornithoid eggshell fragments. These are presumed to be earlier than *Namornis* and *Diamantornis* on the grounds that they occur in the Early Miocene sites of Grillental and Elisabethfeld, but it is not known whether they persisted into the Middle Miocene or not. What is clear is that the aeolianites near Kamberg contain only aeopyornithoid eggshells, whereas those at Elim and Diep Rivier only 30 to 40 km south yield *Namornis* eggshells identical to those found at base of the succession at Rooilepel. If there is an offset in the timing of initial sand deposition between the north and the south, then it is no more than about 4 million years, and probably less. This uncertainty will only be resolved when we obtain a better idea of the age of the aeolianites at Kamberg.

4.7.7.6 Namaqualand Aeolianites

Much of Namaqualand is underlain by aeolian sands. Underneath a surface layer of unconsolidated sand there is usually an indurated brown to red horizon of calcified sands or 'calcrete' as it is locally known. This horizon overlies the 30 metre sediment package of Late Pliocene to Early Pleistocene age and is itself overlain by deposits of the sub-10 metre beaches of Pleistocene age (Rogers *et al.*, 1990). Thus the calcreted aeolianites of Namaqualand are of Pleistocene age, considerably younger than the aeolianites north of the Orange River. They have yielded the remains of *Equus capensis* and Acheulean stone tools. At Swart Duinen, there are richly fossiliferous calcreted sands below the mobile dunes. The fauna from the calcretes consists of extant species, including meercat (*Suricata suricatta*), gemsbok (*Oryx gazella*), zebra (*Equus* sp.), rodents, macroscelidids, tortoises and ostriches (*Struthio camelus*). Thus, in strong contrast to the Namib north of the Orange River where aeolianites as old as Middle Miocene occur, there is no sign of aeolianite deposition in Namaqualand older than the Pleistocene. Further south, in the Saldanha area, eggshells of *Diamantornis wardi* have been found (Roberts 1996) indicating the presence of Middle Miocene deposition in the region. This discovery is important in that it reveals that the so-called Langebaan

Formation consists of sediments of various ages, some of them as old as Middle Miocene.

4.7.8 LACUSTRINE STRATA

North of Bushman Hill (15°48'E; 25°03.5'S) is a large pan which is surrounded by carbonate mounds which form a fringe to an ancient lake that used to fill the pan. The carbonates are rich in impressions of sedges and other aquatic vegetation, and in places filamentous algae have been preserved in travertine, producing a rock that looks like fossilised spaghetti. Although no age diagnostic fossils were found, it is evident from the geomorphological aspect of the area that the lake was of Late Pleistocene or Holocene age. Numerous Middle Stone Age tools are scattered about in the region, but none was observed *in situ*.

4.7.9 PAN DEPOSITS OF THE NAMIB COASTAL PLAIN

Small, shallow basins formed from time to time in the Namib Coastal Plain. There are several types including valleys dammed by sand dunes, deflation basins produced by wind scour, and interdune hollows. When these fill with water during infrequent desert rain showers, or by flow from rivers draining the Great Escarpment, they become pans and are the site of sediment deposition. Ward (1987) described several fossilised pans south of the Kuiseb Drainage in the north of Diamond Area W 2 (fig. 3-18). Well indurated pan sediments, usually dolomitised, have been assigned to the Zebra Hill Carbonate Formation. There are several such deposits in the Kamberg area where they occur intercalated within the Tsondab Aeolianites. There are several occurrences of silty pan infillings both in the Tsondab and Sesriem Valleys (Sossus Vlei, Dead Pan), but these have not been indurated to the extent of the Zebra Hill facies. Similar deposits have been mapped at Rooilepel, where the silts contain carbonate concretions, probably of pedogenic origin. Unfortunately, most of these pan deposits appear to be unfossiliferous, and their ages have to be inferred from their relationships to the strata in which they are intercalated.

Extensive tufa deposits characterise the flat plains southeast of Conception Bay near the ancient mouth of the Tsondab River. These tufa deposits are rich in plant remains, and the setting of their accumulation would have resembled the modern back beach environment near Walvis Bay, in which sedges, grasses and other vegetation grows. This deposit is probably Holocene or Late Pleistocene (Vogel, 1989).

4.7.10 PALAEOOLS OF THE NAMIB

4.7.10.1 Kaolinities

Kaolin is of particular interest for understanding the history of the Namib. This is because the coastal plain underwent extensive kaolinisation in pre-Miocene times and because kaolin is an important constituent of parts of the

marine sediment column offshore Namibia and Namaqualand, South Africa (Robert & Chamley, 1986, 1987; Robert & Kennett, 1992).

It is widely accepted that kaolin is a product of terrestrial weathering under humid conditions. Temperature is not such a critical parameter, whereas the leaching of ions from bedrock in order to produce kaolinite requires much water to pass through the rock. If erosion of the bedrock is rapid, then kaolin generally does not form, suggesting that a stable geomorphic setting over a significant geological time span is an important additional factor required for the generation of thick deposits of kaolinite.

In marine settings near areas of kaolinite genesis on land, kaolin will accumulate in the sediment column, thereby providing a record which can be interpreted in terms of continental palaeoclimates. Caution needs to be taken when interpreting the marine record, however, because the kaolin-rich layers in marine sediments can also form well after the period of kaolinisation on land. All that is required is

for previously existing kaolinites to be exposed and eroded for kaolin input into the marine environment to begin anew. Offshore Namibia, there were two main periods of kaolin deposition, one during the Oligocene, the other during the Middle Miocene. At Buntfeldshuh and elsewhere in the Sperrgebiet, it is clear that kaolinisation occurred in pre-Middle Eocene times. Thus the offshore kaolin-rich sediments accumulated as the result of erosion of preexisting kaolinites.

The widespread occurrence of kaolinised rocks throughout the coastal belt from Cape Town as far north as Lüderitz has provided the basis for regional correlations, but it is likely that kaolinisation persisted much longer in the south than in the north. In the Sperrgebiet, kaolinisation occurred earlier than the Lutetian (Middle Eocene) whereas south of the Orange River it appears to have persisted into the Oligocene. Kaolinisation has affected basement rocks of various types as well as sediments overlying the basement, such as at Langklip and Koingnaas. The age of these sediments is unknown but they are probably pre-Miocene.

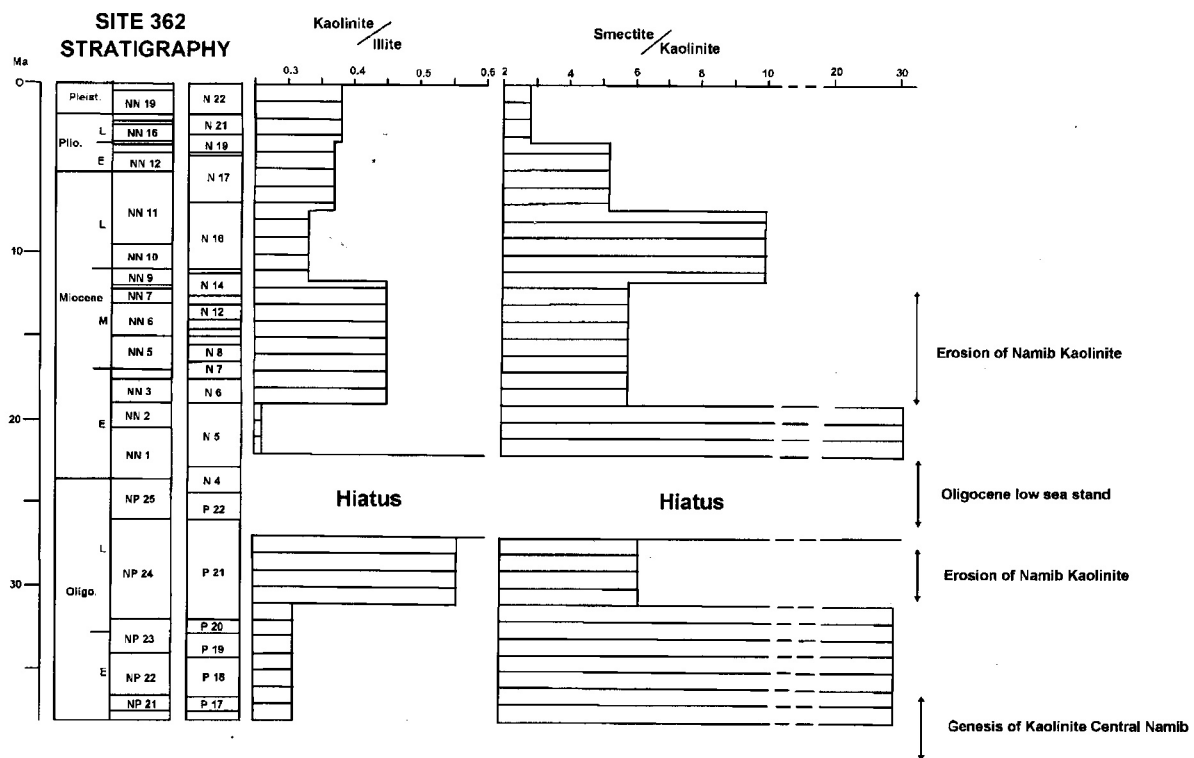


Figure 4-25.- Distribution of kaolinite in DSDP Site 362, East Walvis Ridge. Kaolin-rich sections occur in the Oligocene and Middle Miocene which have been interpreted by Robert & Chamley (1987) as indicating humid conditions onshore during these times. However, the Middle Miocene was a period of hyperarid climate in coastal Namibia. NPE correlations are shown on the right of the figure.

Judging from their stratigraphic position they could be of any age from Nama through to Oligocene. The Namaqualand kaolinised horizon underlies Early Miocene littoral marine sediments at Ryskop and Hondeklip Bay and at Noordhoek, in the Cape Peninsula, there is silcrete overlying kaolinised granite at a depth of 50 metres below sea-level (Maud & Partridge, 1978), suggesting that at the time of kaolin weathering, sea level was appreciably lower than it is today. Inland, kaolinised bedrock occurs widely, extending to the base of the great escarpment. The kaolin deposits follow the bedrock profile quite closely, rising over hills and descending into valleys, indicating that the general geomorphological lie of the land was accomplished before or during kaolin weathering. Some erosion has taken place since cessation of weathering, with the higher parts of hills showing denuded outcrops of bedrock, but in general, the kaolinised rocks are still largely preserved throughout coastal Namaqualand. It is extremely unlikely that these soft kaolinites are of Cretaceous age (Rogers *et al.*, 1990) and that they have remained uneroded for at least 65 mil-

lion years despite being exposed at the surface for much of the Tertiary. It is more likely that they formed during the Oligocene and have been exposed to erosion for a much shorter period, perhaps less than 20 million years. Judging from its position below Early Miocene sediments and its extension out to sea (Maud & Partridge, 1978), the kaolin weathering took place just prior to or during the Oligocene low sea stand (Haq *et al.*, 1987).

The results of the DSDP (Deep Sea Drilling Project) in the South Atlantic (Robert, 1980; Robert & Chamley, 1987; Robert & Kennett, 1992) (figs 4-25 to 4-26) reveal that the Chattian (Late Oligocene: NP24, P21) was a period of kaolin enrichment in marine basins offshore Namibia (DSDP Site 362 for example - East Walvis Ridge) and South Africa (DSDP well 360) which presumably means that kaolin was being eroded from pre-existing deposits during this period. The Early Miocene, in contrast, was a period of low kaolin input to the South Atlantic. A second period of kaolin deposition offshore began at the end of the Early Miocene

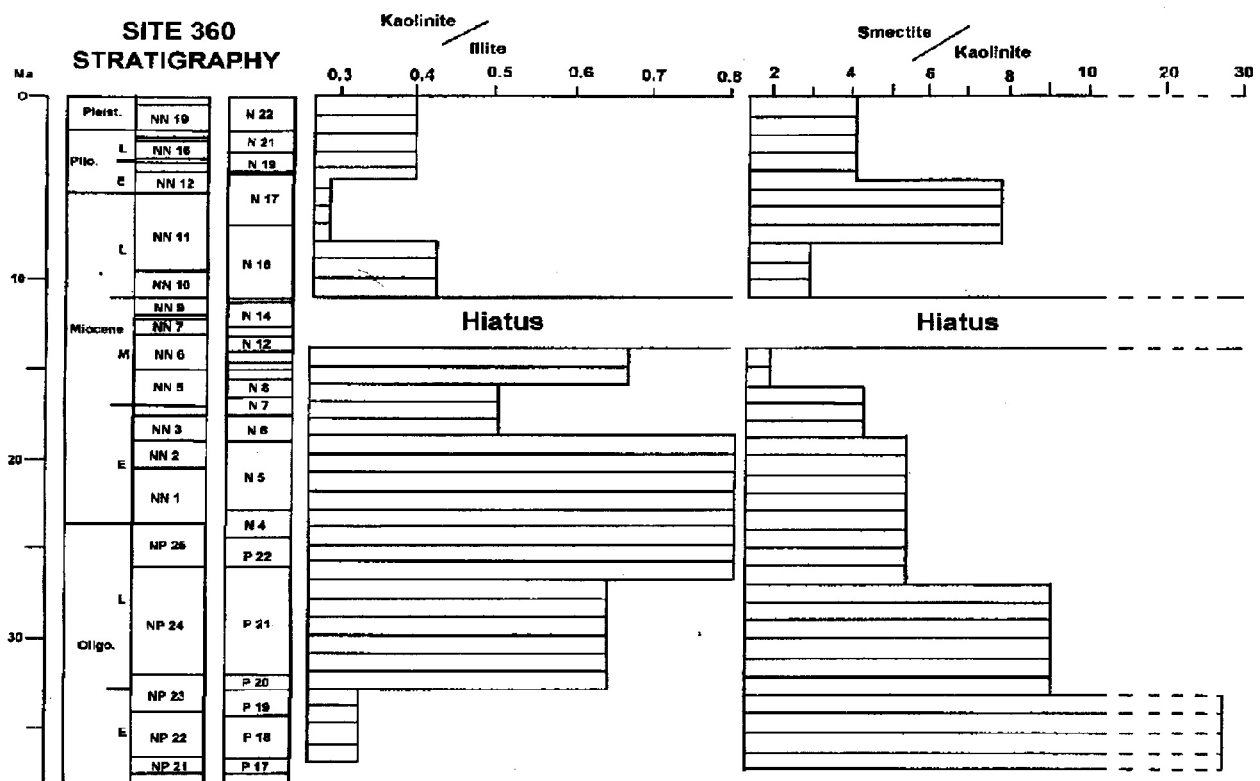


Figure 4-26.- Kaolinite distribution in DSDP Site 360, southwest of Cape Town, showing elevated levels of kaolin deposition during the Oligocene. This period probably corresponds to the formation of the pre-Miocene kaolinite weathering profiles of Namaqualand and the Sperrgebiet.

and continued into the Middle Miocene, presumably due to aeolian erosion of pre-existing kaolinities (Robert, 1980; Robert & Chamley, 1986, 1987; Robert & Kennett, 1992).

Faunal and floral evidence from the Namib reveals that the Early and basal Middle Miocene was a period of tropical to sub-tropical semi-arid climate (savanna and woodland type vegetation formations), whereas the rest of the Middle Miocene was a period of arid to hyperarid conditions during which the Rooilepel and Tsondab Aeolianites accumulated. In many outcrops, these aeolianites repose directly on unweathered to little weathered bedrock, whereas in others they overlie kaolinite-rich profiles. This means that there was a period of erosion starting about 19 Ma and prior to aeolianite deposition which removed vast quantities of kaolinite from the Namib Coastal Plain and dumped much of it in the South Atlantic (Robert & Kennett, 1992).

It is worth noting that off the coasts of southern Africa, the Oligocene was a period of low to negligible sedimentation rates except off the Limpopo River (Partridge & Maud, 1987). The deep kaolinite weathering that characterises the coastal strip could not have developed to the extent that it did had there been serious erosion at that time, such as for example, took place during the Eocene and Miocene epochs. This provides ancillary evidence that the kaolinisation of the coastal plain of Namaqualand continued into the Oligocene. If the kaolinities and so-called silcretes or 'surface quartzites' are indeed of Cretaceous age, as has been estimated by some researchers (Stocken, 1978), then they would have had to have escaped extremely high erosion rates during the Late Cretaceous and high rates during the Eocene. Given the geomorphological setting of the coastal plain and the fluctuations in sea level that occurred during the Palaeogene, then an age earlier than Oligocene for the Namaqualand kaolinities seems difficult to maintain.

Studies on the distribution of kaolinite in DSDP cores 360 (southwest of Cape Town, South Africa) and 362 (East Walvis Ridge) have yielded detailed histories of fluctuations in kaolin input into the southeast Atlantic during the Tertiary (Robert & Chamley, 1986, 1987; Robert & Kennett, 1992).

These records were interpreted by the authors in terms of continental palaeoclimatology, with the Late Oligocene and Middle Miocene being considered as periods of high humidity in southwestern Africa.

The following summary is from Robert & Chamley (1987).

(1) During the Late Oligocene increased kaolinite content at every site studied marked an increase of global humidity.

(2) During the Early Miocene increasing continental aridity is deduced from the low kaolinite contents in the Atlantic Ocean.

(3) During the Middle Miocene increased kaolinite contents at most of the sites marked a further increase of global humidity, which was especially important at low latitudes in Africa.

(4) During the Late Miocene kaolinite content and inferred continental humidity increased toward high lati-

tudes but decreased towards low latitudes, especially off tropical Africa where it marked the development of arid conditions.

(5) During the Late Pliocene kaolinite content and humidity increased again toward high latitudes while these conditions decreased again toward low latitudes, emphasizing the latitudinal climatic zonation.

The onshore evidence does not accord with this interpretation, and it is more likely that increased kaolin deposition in the marine realm records erosional periods onshore rather than increases in global humidity. For example in the Sperrgebiet, kaolinisation ceased prior to the Middle Eocene. We do not concur with the suggestion (3 above) that the Middle Miocene was a humid period (fig. 4-25). All the evidence that we have been able to gather indicates that the Namib Coastal Plain was extremely arid during the Middle Miocene.

We consider it likely that from Late Oligocene to Early Miocene times the regional climate in the Namib became increasingly arid, and agree with Robert & Kennett (1992) that the Early Miocene was relatively arid {(2) above}. During this period vegetation was probably of tropical to sub-tropical savannah type and would have provided sufficient ground cover to prevent serious erosion of the underlying Oligocene kaolinities. This suggestion is supported by the presence of petrified trunks of tropical trees at Auchas. By the onset of the Middle Miocene however, increased aridity caused diminution of the vegetation cover which in turn led to denudation of the landscape and exposure of the soft kaolinities to the elements. These soon began to erode away under the influence of desert winds, thereby yielding kaolinite to the neighbouring marine sediment column. In Namaqualand in contrast, kaolinities are still largely preserved beneath the coastal plain deposits. Thus, the high values for kaolinite in the Middle Miocene strata offshore Namibia and South Africa probably signify increased aridity rather than increased humidity.

4.7.10.2 Silcretes

Strictly speaking silcretes are of pedogenic origin and the term should not be used for silicified sediments which did not comprise part of the soil profile at the time of formation as has been done on numerous occasions in the past. Much has been written about silcrete in southern Africa. In the authors' opinion, much too much emphasis has been placed on the occurrence of siliceous rocks, examples of which are extremely uncommon and localised throughout Namaqualand and neighbouring areas. Indeed, virtually all silicified deposits in the region have, at one time or another, been called 'silcrete' or 'surface quartzites' yet few if any of the occurrences are genuine silcretes. Most are quartzites or silicified sands and gravels, some of them are silicified marine sediments (as for example at Hondeklip Bay and Somnaas), some of them fluvial (as at Nuttaboi) and some of them regoliths (as at Pomona, Namibia). Indeed, the only silcretes that the authors have seen are at the top of Skilpadberg, just north of the Orange River in Namibia. The non-silcrete nature of the bulk of the silicified rocks in

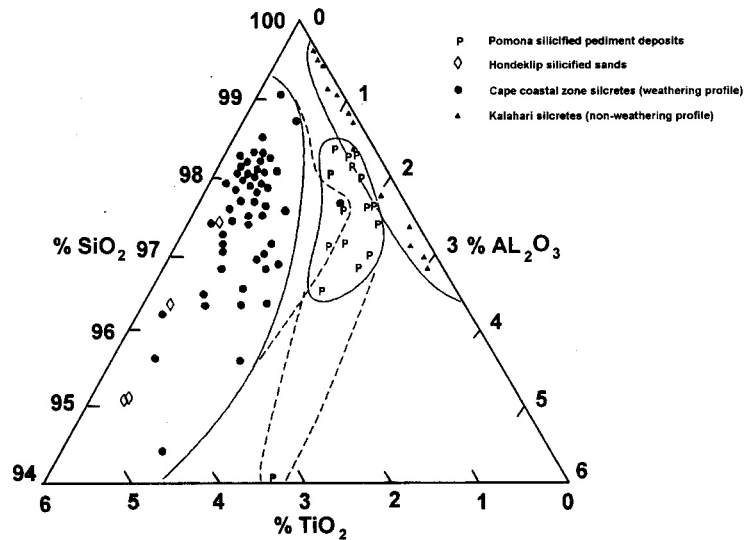


Figure 4-27.- An iron, titanium, aluminium diagram showing analyses of various silicified rocks of southern Africa. The Pomona “silcrete” differs consistently from weathering-profile silicates, and they are in fact silicified regolith or pediment sediment, and not “silcretes” in the strict sense of the term (redrawn from Pether, 1994).

Namaqualand is clear from analytical work presented by Pether (1994), who showed that the chemical composition of these rocks differed from those of genuine silcretes of pedogenic origin (fig. 4-27). For this reason, much of the debate in the literature concerning the stratigraphic position of the Namaqualand ‘silcretes’ or ‘surface quartzites’ can be discounted as being based on a melange of rock types deposited at different times and affected by different diagenetic processes during the geological past. The silcretes at Hondeklip Bay and The Point are intercalated within the Neogene sequence, as are quartzites at Somnaas. Far from forming at the surface, they formed underground, possibly as groundwater quartzites.

In Western Cape Province, Hagedorn (1988) described silcretes in the western Little Karoo between the Langeberg in the south and the Rooiberg in the north. These siliceous horizons vary between 2 and 10 metres in thickness, and contain layers of fanglomerates, while their geomorphological setting indicates that they formed as pediments which sloped gently towards the floors of the main valleys in the region. These pediments have subsequently been deeply dissected, leaving mesa-like remnants capped by resistant silcrete horizons. In overall aspect the silcrete outcrops of the Little Karoo resemble those at Pomona, northern Sperrgebiet, not only in their geomorphological setting but also in their conglomeratic content. The Little Karoo silcretes are estimated to be Late Miocene in age (ca 7-9 Ma) on the basis of ESR dates (Hagedorn, 1988).

4.7.10.3 Calcretes

There are widespread calcrete deposits in the coastal

plain of Namibia. By definition calcretes are of pedogenic origin and we here exclude from the term some rock units that have previously been called calcretes but which did not comprise part of the soil profile at the time of their formation.

Ward (1987) concluded that the Kamberg Calcrete was of Late Miocene age, in agreement with estimates of the age of calcretes developed in the Sperrgebiet at Buntfeldschuh and other localities (Stocken, 1978). This age estimate was based on stratigraphic and geomorphological arguments. Ward & Corbett (1990) positioned these calcretes a little lower in the stratigraphic column, in the Middle Miocene.

Fossils have now been found in many places in Namib calcretes from near Kamberg in the north to the Orange River in the south and from the coastal deposits north of Oranjemund, inland to the base of the Great Escarpment. Fossils also occur in calcretes south of the Orange River in Namaqualand. In every case where the fossils have yielded evidence concerning their age, they were of extant species such as *Oryx gazella*, *Equus* sp., *Lepus capensis*, and *Pedetes* sp. In several places stone tools were also found *in situ* in calcrete, or are endowed with calcrete coatings. There can be little doubt that there was an important phase of calcrete formation during the Late Pleistocene, as it is in the most widespread layers of calcrete that the Pleistocene fossils have been found. However the thickest developments of the carbonate-rich rocks at localities such as Kamberg Cliff and in the Tsondab and Sesriem drainages, where 20-30 metres of conglomerate have been cemented by carbonates, are probably of Plio-Pleistocene age.

Carbonate-rich rock units near the Great Escarpment vary

greatly in thickness in directions both orthogonal to the escarpment and parallel to it. There are both pedogenic and non-pedogenic carbonates in the region, but they were all developed near-surface. In sections close to and parallel to the Great Escarpment, where there are rivers such as the Kuiseb, Gaub, Tsondab and Sesriem flowing out of the escarpment area into the desert, carbonate-cemented units tend to be extremely thick (up to 20-30 m), but in the interfluvial areas between these major drainage lines, the carbonates are thinner (5-10 cm to 3-4 metres) and even pinch out altogether. In directions orthogonal to the escarpment the thickness of carbonates tends to decrease as the distance from the Great Escarpment increases. Thus even the very thick carbonate-cemented conglomerates of the Tsondab and Sesriem Rivers thin out downstream and laterally away from the valleys.

The distribution and thickness of calcretes near the foot of the escarpment (Blümel, 1982) indicates that most of the carbonates probably reached their depositional environment by way of the groundwater system but aeolian dust may also have played an important role in their genesis. The proximity of the lime-rich Naukluft Mountains may have been of some significance as a source of carbonate in the north east part of the Central Namib.

The same scenario of carbonate transportation does not apply to the coastal calcretes developed at Buntfeldschuh, north of Oranjemund and at Rooilepel, and these may well have resulted from aeolian transportation of fine-grained carbonate-rich clasts, as envisaged by Ward (1987).

In areas where the Kamberg Calcretes are particularly well developed, such as at Kamberg itself (Yaalon & Ward, 1982) and in the vicinity of the Ubib river, it is clear that there was not a single, unique episode of calcrete genesis, but that there were at least two, if not three or more separate periods of calcretisation. Such a conclusion is demanded in situations where there are several adjacent surfaces at different altitudes covered in calcrete, each of which backs onto an older calcreted surface. Examination of such stepped calcrete topography reveals that younger (topographically lower) levels of calcrete contain reworked calcrete nodules from earlier (topographically higher) calcretes. In these situations it seems likely that calcretisation was episodic and that between episodes of calcrete genesis some areas were subjected to erosion. In areas where no erosion took place the younger calcretes merely formed on pre-existing ones and give the erroneous impression of a single continuous process of calcretisation.

4.7.10.4 Murram

Ferruginous palaeosols are poorly developed in the Namib Coastal Plain. At Swartlintjies there is a thin horizon of sand which has been affected by pedogenesis to the stage where small murram nodules have formed. This level yields Acheulian hand axes and other tool types as well as a mammal fauna of restricted diversity (rodents, jackal, equid, proboscidean, giraffids, chelonians) (Pickford & Senut, 1997).

This occurrence would suggest that the climate was relatively humid and possibly warmer than today for the murram to form.

At Kaokoberg, capping the Buntfeldschuh Beds, there is a thick deposit of ferruginised sediment (Corbett, 1989). The shape and size of the outcrop suggest that ferruginisation was localised and was due to groundwater rather than to regional climatic conditions.

4.7.10.5 Gypcretes

In several places near the coast, sediments of the Namib have been invaded or covered by gypsum deposits. Extensive deposits have been described in the Rooikop area (Miller & Seely, 1976) east of Walvis Bay. In silts clinging to the southeast flanks of Skilpadberg, where it descends into the Orange River Valley, there are up to two metres of gypsiferous deposits. An extraordinary character of this deposit is that the gypsum has grown as pillars within the silts rather than forming a continuous, massive deposit. Elsewhere, such as at the Skilpadberg borrow pits, the gypsum forms massive deposits within the superficial sediments or is simply a cement holding the clasts together.

Such gypsiferous deposits appear to be restricted in their distribution to the coastal strip of the Namib (Martin, 1973). Indeed, they are best developed in the zone where coastal fogs and sea spray aerosols are the heaviest and most frequent, and it is probable that the gypsum owes its origin to these fogs and sea spray, which provide a possible pathway for the sulphate to travel from the ocean to the inland depositories. Hydrogen sulphide gas originating from decaying organic matter in the sea bed, for example at Walvis Bay, is dissolved in aerosol droplets thrown into the air by sea spray activity and forms sulphuric acid which then drifts inland and condenses out on contact with the ground. The H_2SO_4 solution formed in the water droplets is very weak, but it reacts with any carbonate in the sediments which the aerosols reach, thereby producing gypsum and giving off carbon dioxide gas to the atmosphere. Repeated many times each year for thousands of years, this process can yield immense quantities of gypsum such as the deposits near Rooikop. It is no coincidence that the best developed gypsum deposits along the Namib Coast are close to areas where there is maximal production of hydrogen sulphide in the sea bed.

All the near surface gypsum -deposits in the Namib coastal plain appear, on the basis of their geomorphologic and stratigraphic occurrence, to be rather young, probably Late Pleistocene to Holocene.

4.7.10.6 Salt and Saline sediments

Extensive salt deposits have formed in lagoons along the Namib Coast (Gevers & Van der Westhuysen, 1931). These are of economic value near Swakopmund and northwards along the Skeleton coast where they owe their existence to evaporation of sea water and ground water.

Many of the sediments south of Lüderitz are salty, and salt weathering is evidently taking place in many of the endorheic basins of the Sperrgebiet (Corbett, 1989). Much of this salt travels inland dissolved in droplets of sea spray and accumulates wherever the fog precipitates. Many of the springs in the Sperrgebiet such as those at the Bohrloch locality and at Elisabethfeld and Kaukausib Fontein are brackish to strongly saline.

4.7.11 TRAVERTINES OF THE NAMIB COASTAL PLAIN

4.7.11.1 Kaukausib

About 1 km upstream from Kaukausib Fontein the now dry river has incised itself through 20 metres of travertine and grits exposing a natural cross section through the sequence on both sides of the valley. In the main cliff section on the left bank of the valley, layers of white travertine are intercalated with beds of brown sand and grit. On the upstream end of the cliffs the travertine and grit layers dip upstream, whereas on the downstream side they dip downstream giving the impression of an anticlinal fold in the sediments. However, mapping out the travertine layers reveals that the strata dip outwards from a centre near the top of the hill, and that all the dips are original, and not the result of tectonic activity. The morphology of the outcrops suggests that as the travertine accumulated, it built itself a dome, with the spring emerging at the summit of the dome and the water flowing down its sides depositing travertine as it descended. Grit layers were from time to time banked against the growing dome, thereby separating discrete periods of travertine deposition from each other.

The travertine is dense and white, like onyx, and occurs in layers up to 1 metre thick intercalated between brown grit layers. The latter contain abundant fossils of Plio-Pleistocene age. In the main cliffs there are at least seven layers of travertine dipping northwards from the core of the dome, and at least four on the southern flank. In terms of volume and number of travertine layers the Kaukausib occurrence is the most important known in the Namib.

4.7.11.2 Elisabethfeld and Grillental

North of Elisabethfeld there is a low plateau which closes off the downstream end of the Grillental. The surface of this plateau is composed of intercalated white onyx-like travertine and grey aeolian sandstone, the latter assigned to the Wüstenkönig Sandstone (Corbett, 1989). In cliffs overlooking Elisabethfeld there are three main travertine layers, while in those facing Grillental there are only two (figs 4-11 and 4-12). Although no fossils have been found in these strata, they are probably the same age as those at Kaukausib Fontein. Corbett (1989, Fig. 3-19) tentatively correlated this sequence with the 30 metre package at Hondeklip Bay, a suggestion that would accord with our own that they probably correlate with the travertines and grits at Kaukausib. If this correlation is valid, then

it undermines the crustal warping theory (Stocken, 1978) for the CDM beaches north of Oranjemund, because they crop out at 30 metres altitude.

4.7.11.3 Gamachab

At Gamachabrunnen or Gamachab Spring, there are impressive sheets of onyx-like travertine draping both sides of a basement ridge. The travertine is intercalated with aeolian sandstone, the sheets being parallel or sub-parallel to the inclined slopes of the basement hill underneath. Thus on the south side of the hill, the travertine layers dip southwards, while those on the north side are inclined northwards. Calcite-rich water evidently emerged as springs along the crest and sides of the Gamachab ridge and deposited sheets of travertine along the crest and slopes of the hill. Aeolian activity took place at the same time as travertine deposition, so that layers of travertine are interlarded with layers and lenses of sandstone. Although no fossils have been found in these travertines, they are likely to have been deposited during the same period as those at Kaukausib Fontein.

4.7.11.4 Strauchpfütz Carbonate

South of Kalkrücken there is a large embayment flanked on its north side by intercalations of carbonate and conglomerates (Corbett, 1989). There are three prominent horizons of carbonate known as the Strauchpfütz Carbonate (**Strauchpfütz** means **bushy pond** in German). These limestone layers are widespread and appear to block off an ancient valley which used to drain southwards towards the Atlantic. As such they would represent exceptionally large and well developed pan deposits which accumulated in an ancient valley that may have been blocked off from the sea by dunes or some other barrier. The only fossil found in this carbonate was an indeterminate gastropod (Corbett, 1989) possibly *Lymnaea* sp. Although the deposits cannot be directly dated, it seems likely that they accumulated during the Plio-Pleistocene.

4.7.11.5 Tsondabmund Tufa deposits

Between Conception Bay and Tsondabmund, there is an extensive plain which has been incised in places to reveal an horizon of tufa overlying gypsiferous silts. The tufa contains abundant plant remains, some still retaining their organic content. This tufa deposit is Late Pleistocene to Recent (Vogel, 1989), and may have formed at a time when the Tsondab River still reached the coast, either as a surface stream or as a resurgence. Judging from the extent of the plain, there would have been an extensive wetland in the region, with abundant sedges and other plants.

4.7.11.6 Naukluft Tufa Deposits

There are impressive tufa carapaces in several valleys in the Naukluft Mountains (Arbeid Adret, Bleskrans, Lemoenputs, Tsams Ost) (Marker, 1988). Judging from their

geomorphological setting and the barely fossilised nature of crabs and plant remains found in the deposits, these tufas are probably Quaternary to Recent in age. Whilst tufa is still accumulating in selected spots in the Naukluft, most of the occurrences are extinct or relict, suggesting that optimal conditions for tufa formation occurred in the past, and that the present climate is marginal for their formation.

Tufa is a surface deposit of calcium carbonate precipitated from flowing water. It may be porous, chalky or crystalline. Those in the Naukluft are porous. Tufa deposition occurs from waters containing a high concentration of calcium ions in equilibrium with carbonate ions. When the equilibrium is displaced, causing loss of CO₂ as gas, precipitation of calcium carbonate occurs as tufa (Marker, 1988). It is generally considered that, among other factors, one of the main limiting factors to tufa genesis is the quantity of rainfall. In the Naukluft and South Africa in general this would mean that during their growth the rainfall must have been appreciably greater than it is today.

The source of the calcite for the Naukluft tufas is the dolomite of the Naukluft nappes. Whilst much of the dissolved carbonate precipitated in valleys leading out of the mountains, it is likely that the river water and groundwater flowing coastwards was relatively hard, and that there was potential for further deposition of calcite to occur. In the vicinity of the mountains, there are thick calcretes of Pleistocene to Recent age, which probably owe their origin, in part, to the precipitation of calcite from hard groundwater derived from the Naukluft. Indeed, it is likely that the main period of tufa formation in the Naukluft coincided with the main period of calcrete genesis in the Namib.

The crystalline travertine deposits near the Namib coast, such as those at Kaukausib, Elisabethfeld and Gamachab obtained their calcite from groundwater rising to the surface as springs. The source of calcite was probably the local bedrock, but, like the Naukluft tufas, the coastal travertines indicate that there must have been periods of greater rainfall at the time of travertine deposition than there is today. Fossil mammals from coarse sand intercalated with travertine at Kaukausib, suggest that the main period of activity was during the Quaternary, and it is likely that the main Naukluft tufas, the Namib calcretes and the coastal travertines are all broadly the same age.

The Hudaob Tufas in the Kuiseb Valley are also roughly coeval with the Naukluft Tufas (Ward, 1987; Vogel, 1989).

4.8 CORRELATIONS OF GEOLOGICAL EVENTS IN THE NAMIB TO EVENTS ELSEWHERE IN THE WORLD

4.8.1 $\delta^{18}\text{O}$ CURVE OF BENTHIC FORAMINIFERA

Comparison of the main climatic events in the Namib that we have been able to determine, reveal that there is

some correspondence with global trends during the Cenozoic. Figure 4-28 shows a typical global cooling curve based on oxygen isotope studies of benthic foraminifera (Miller & Fairbanks, 1985). The clearest palaeoclimatic signal recorded for the Namib Coastal Plain was the change from tropical climate with summer rainfall to temperate climate with winter rainfall that occurred during the Middle Miocene (Ward *et al.*, 1993). This coincided closely in time with the aridification of the Namib and the onset of aeolianite deposition, and correlates with a major plunge in temperature of the world's oceans (arrow in fig. 4-29).

Other correlations stand out from the same curve, including that of the sub-10 metre beaches with the rapidly fluctuating part of the temperature curve in the Quaternary.

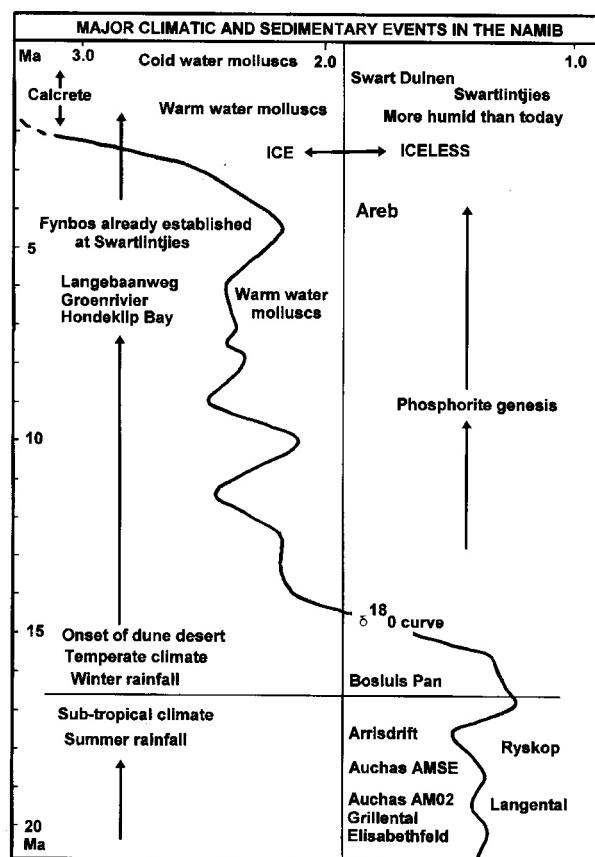


Figure 4-28.- Summary of major climatic and sedimentary events in the central Namib and correlations to the oxygen isotope curve of Miller and Fairbanks (1985). During the Early Miocene the region lay within the tropics, but during the Middle Miocene conditions changed dramatically, with the installation of a cooler, more arid climate of temperate affinities. This heralded the onset of desert conditions in the Namib. Since then the climate has fluctuated about an arid mean, sometimes being hyperarid, at others being only semi-arid. During the Quaternary, climatic amelioration occurred during which the Kamberg Calcretes were formed. Changing sea levels affected the coastline during the Miocene and the Quaternary.

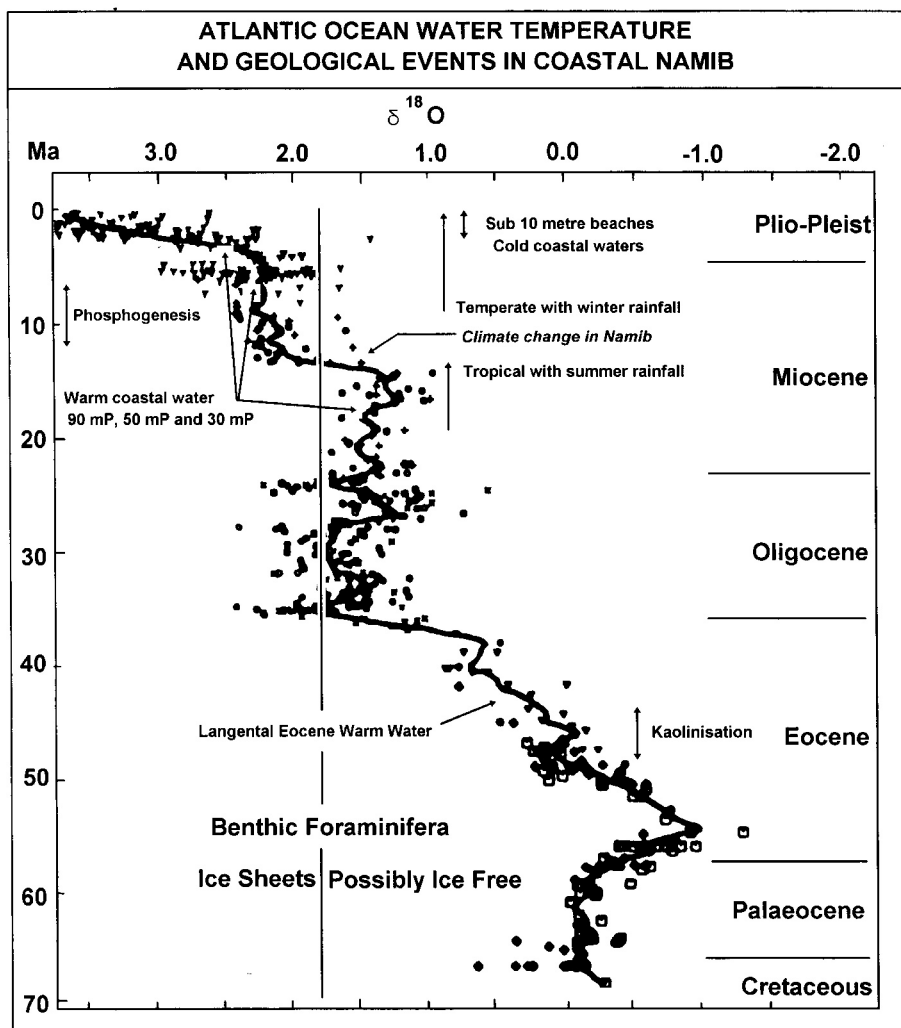


Figure 4-29.- Correlation of main geological and palaeoclimatic events in the Namib with an oxygen isotope curve of ocean palaeotemperatures from Kennett (1995). The stepwise changes in oxygen isotopes mirror quite closely the main changes in the Namib, not only in terms of temperature changes in marine littoral environments, but also in terms of kaolinisation of bedrock and phosphogenesis.

4.8.2 EUSTATIC SEA-LEVEL MOVEMENTS AROUND SOUTHERN AFRICA

Siesser & Dingle (1981) and others (King, 1967; Haughton, 1969; Truswell, 1970; Tankard, 1976; Dingle, 1973; Dingle & Scrutton, 1973) have discussed changes in sealevel in southern Africa. In very broad terms, high sea stands (transgressions) were reported to occur in the Late Palaeocene, Late Eocene, Middle Miocene and Early Pliocene, while low sea-levels (regressions) were recorded in the Early Palaeocene, Middle Eocene, Oligocene, Late Miocene and Late Pliocene. Evidence for these sea-level fluctuations come from onshore marine sediments in Namibia and the east and west coasts of South Africa, and from unconformities observed in seismic profiles of the offshore sedimentary successions.

There has always been uncertainty regarding the timing of eustatic events in southern Africa, in particular in the on-

shore marine strata which tend to be poorly fossiliferous or to yield taxa with wide-ranging or poorly understood time spans. This problem has been particularly severe for the Neogene levels, for which the biostratigraphy was poorly calibrated.

Fossil mammals collected in several of the marine littoral deposits in Namaqualand permit a more precise determination of the timing of events than was possible hitherto, with the result that previous ideas need to be modified somewhat (fig. 4-30). In particular, it is now known that high sea-levels occurred towards the end of the Early Miocene (ca 20 to 17.5 Ma), the end of the Middle Miocene, the end of the Late Miocene (ca 7-5 Ma), the Plio-Pleistocene boundary (ca 2.6 to 2.3 Ma) and the Late Pleistocene to Holocene (the three so-called sub-10 metre beaches) (Pickford, 1998).

Comparison of the results of Siesser & Dingle (1981) and others (Quilty, 1977, for Western Australia) with those of

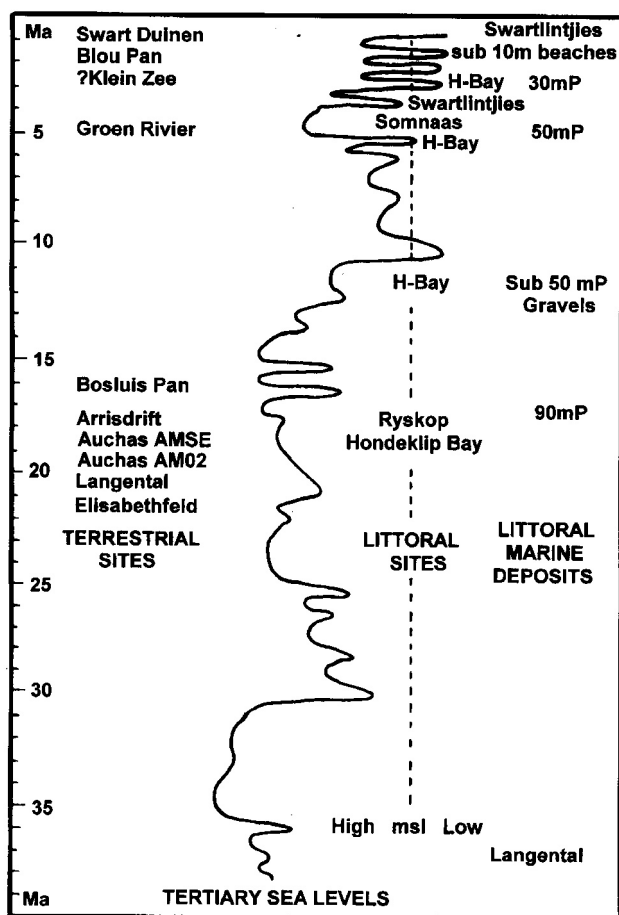


Figure 4-30.- Correlation of fossiliferous sites in the Namib to the eustatic curve of Haq *et al.*, (1987). In a general way periods of deposition in the Namib coastal plain coincide with periods of high sea-levels, but there are gaps in the sediment record where one might expect such deposits to occur.

the PESA (fig. 4-31) (Pickford, 1998) highlight the main differences between the various researches. All the curves are rather similar for the Palaeogene. For the Neogene however, there are major differences in the number of transgressive events and their timing, PESA recognising three major high stands during the Miocene compared to only one at the end of the Miocene by Siesser & Dingle (1981). This is due to the fact that the four Neogene packages of littoral marine strata along the coast of Namaqualand were all considered by previous workers to be of Plio-Pleistocene age (Carrington & Kensley, 1969; Dingle, 1973), whereas the three oldest units are in fact of Miocene age. The only Neogene sediment recognised in southern Africa by these authors were fluvial sediments with estuarine fauna at Arrisdriif, Namibia (Siesser & Dingle, 1981).

The PESA curve is closer in its overall shape to that for Western Australia, but the timing of transgressions are slightly offset in the two curves. The age offsets are most likely due to differences between marine and continental biostratigraphic scales. The concordance of Palaeogene and Neogene curves for Southern Africa and Western Australia is important in indicating that the transgressions and

regressions were global scale marine events, and were not due to the uplift or downwarping of continental margins, even if epeirogenesis did indeed occur (Carrington & Kensley, 1969). For the Quaternary the curves are not comparable because details have been suppressed by previous researchers due to the scale of observations or there is a paucity of information.

4.83 DEPOSITION OF TERRIGENOUS SEDIMENTS IN THE SOUTHEAST ATLANTIC AND SOUTHWEST INDIAN OCEANS

Maud & Partridge (1987) summarised the rates of sedimentation in various basins offshore southern Africa. These estimates, based on prior results of Dingle *et al.* (1983) reveal marked variations in rate through the geologic column. The period following break-up of Gondwana was one of rapid deposition (up to 200 metres per million years in some basins) (fig. 4-32) and this probably corresponds to a relatively rapid backwearing of the Great Escarpment. The end Cretaceous was also a period of relatively rapid but fluctuating depositional rates. During the Cenozoic, sedimentation rates were generally much lower than they were during the Cretaceous, usually less than 50 metres per million years. During the Neogene there were two periods (the Eocene and the Mio-Pliocene) during which deposition was more rapid than for the rest of the era. The only exception was rapid deposition off the Limpopo River during the Oligocene.

It is interesting to note that for most of the basins, the Oligocene was a period of low sedimentation rates, and this accords with the suggestion that this epoch was a stable, humid one, during which erosion rates must have been low in order that the thick kaolinised bedrock profiles of the Namaqualand Coastal Plain could form. Conversely, when the climate changed during the Early Miocene and the Namib became increasingly arid, then sedimentation rates offshore increased, suggesting that erosional rates on land had increased. This corresponds to the period during which the kaolinised profiles would have been deflated by aeolian activity (fig. 4-25).

4.9 GLOBAL TECTONICS

4.9.1 VERTICAL CONTINENTAL MOVEMENTS

There is little doubt that the continent of Africa has been uplifted relative to the ocean floor since the break-up of Gondwana. There are undeformed, flat-lying Mesozoic marine strata at an altitude of 1200 metres in the highlands of Namibia, implying an uplift of over a kilometre since the time of their deposition (Permo-Trias). Most of this uplift probably took place after the break-up of Gondwana. An average rate of uplift of between 5 and 10 metres per million years would seem to be in order, but it appears that the uplift was not a continuous, steady process, but occurred in pulses (Partridge & Maud, 1987; Partridge *et al.*, 1995b). Since the mid-Aptian, the tectonic activity af-

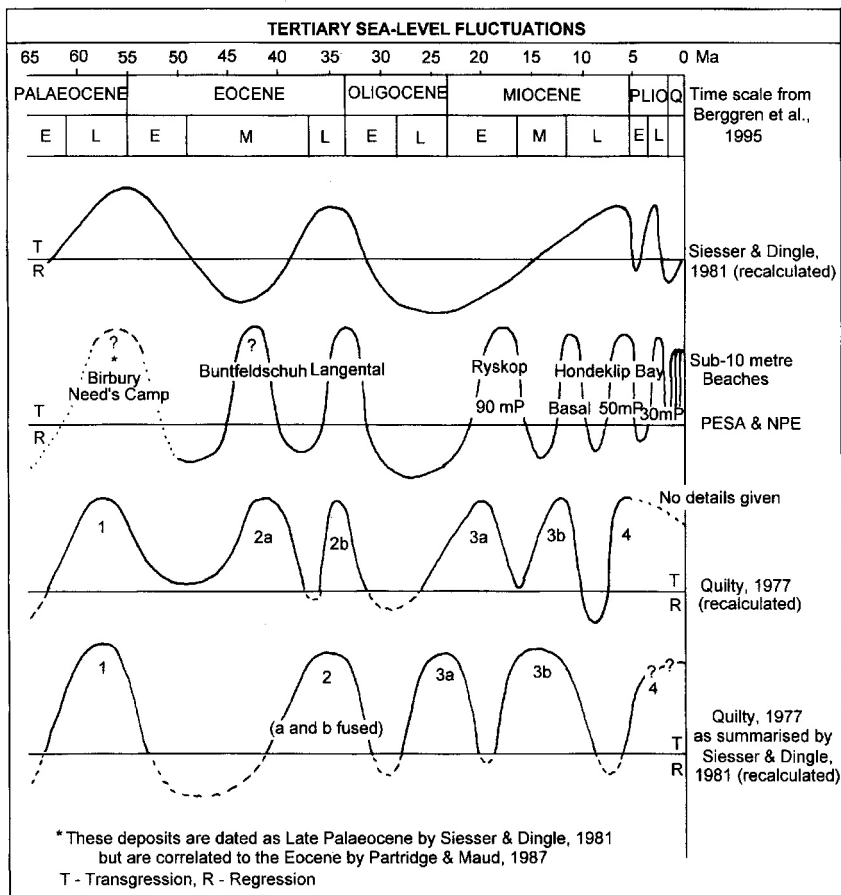


Figure 4-31.- Comparison of PESA sea-level curve for Namaqualand with previous hypotheses, global scale curves and a curve for Western Australia. Previous studies seriously underestimated the ages of the Namaqualand littoral marine packages (Siesser & Dingle, 1981). The new ages proposed for these sediment packages reveal that the South African curve is close to that from Western Australia, suggesting that the main control on transgressions and regressions was eustatic rather than epeirogenic.

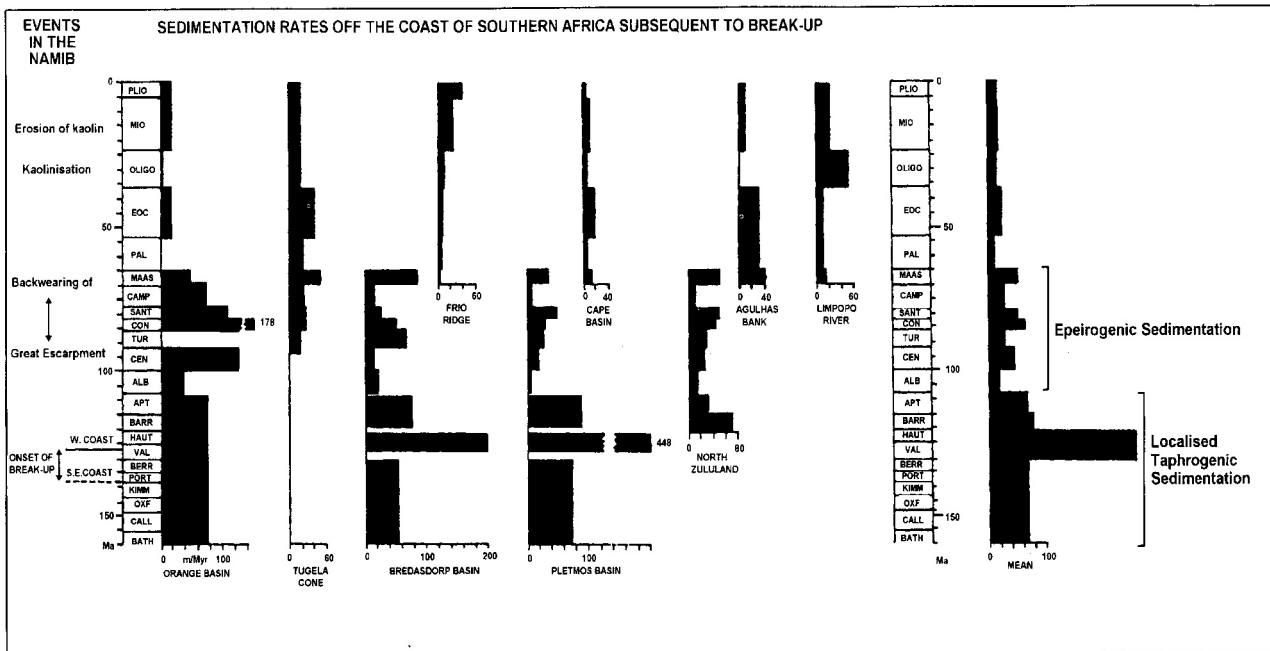


Figure 4-32.- Sediment deposition offshore South Africa (after Partridge & Maud, 1987) showing the Oligocene as a period of generally low input of terrigenous sediment except off the Limpopo. This implies low rates of erosion onland, which agrees well with the stable landscape suggested by the deep kaolinite weathering profiles of Namaqualand and the southern Sperrgebiet.

fecting the continental margin of southwestern Africa has been dominated by thermal sag (Light *et al.*, 1992, 1993). Thus, while the edges of the subcontinent were subsiding, its centre was being uplifted. The hinge line appears to have lain some distance inshore (Maud & Partridge, 1987), but in any case its position has probably not been constant, since there is some evidence to suggest that even the coastal plain has been uplifted during the Cenozoic.

Whilst it is difficult to obtain any datum from which to determine when and by how much uplift occurred, there are some pointers which give a broad image of when such movements took place. Partridge *et al.* (1995b) have examined river profiles, raised marine deposits, offshore sedimentation history and the continental geomorphology of southern Africa and have calculated an uplift of the southeastern portion of Africa by as much as 750 metres during the Late Neogene. Contours on the Post-African 1 erosion surface indicated to these authors that the eastern side of the subcontinent was uplifted by about 250 metres in the Miocene and by between 600 to 900 metres during

the Pliocene. The western side of the subcontinent also rose during the Neogene but by smaller amounts, 150 metres during the Miocene and 100 metres during the Pliocene (fig. 4-33).

In the Namib there is evidence for various raised beach terraces up to 160 metres above present sea-level. Whilst these are usually explained in terms of eustatic rise and fall of sea-level, there may well be an element of epeirogenic uplift involved in elevating these ancient beaches to altitudes greater than they had at the time of their formation. It is an intriguing fact that the oldest recognised beaches are at the highest elevations while the youngest are at the lowest elevations, with the intermediate ones occurring in the correct order in between (Table 4-2).

This could be an artefact, in the sense that if there is a transgression that reaches a higher level than a previous one, then it will tend to destroy evidence for the earlier one, and thus any series of raised marine complexes will tend to be oldest at the highest elevations and younger at successively lower altitudes. Conversely, epeirogenic uplift could

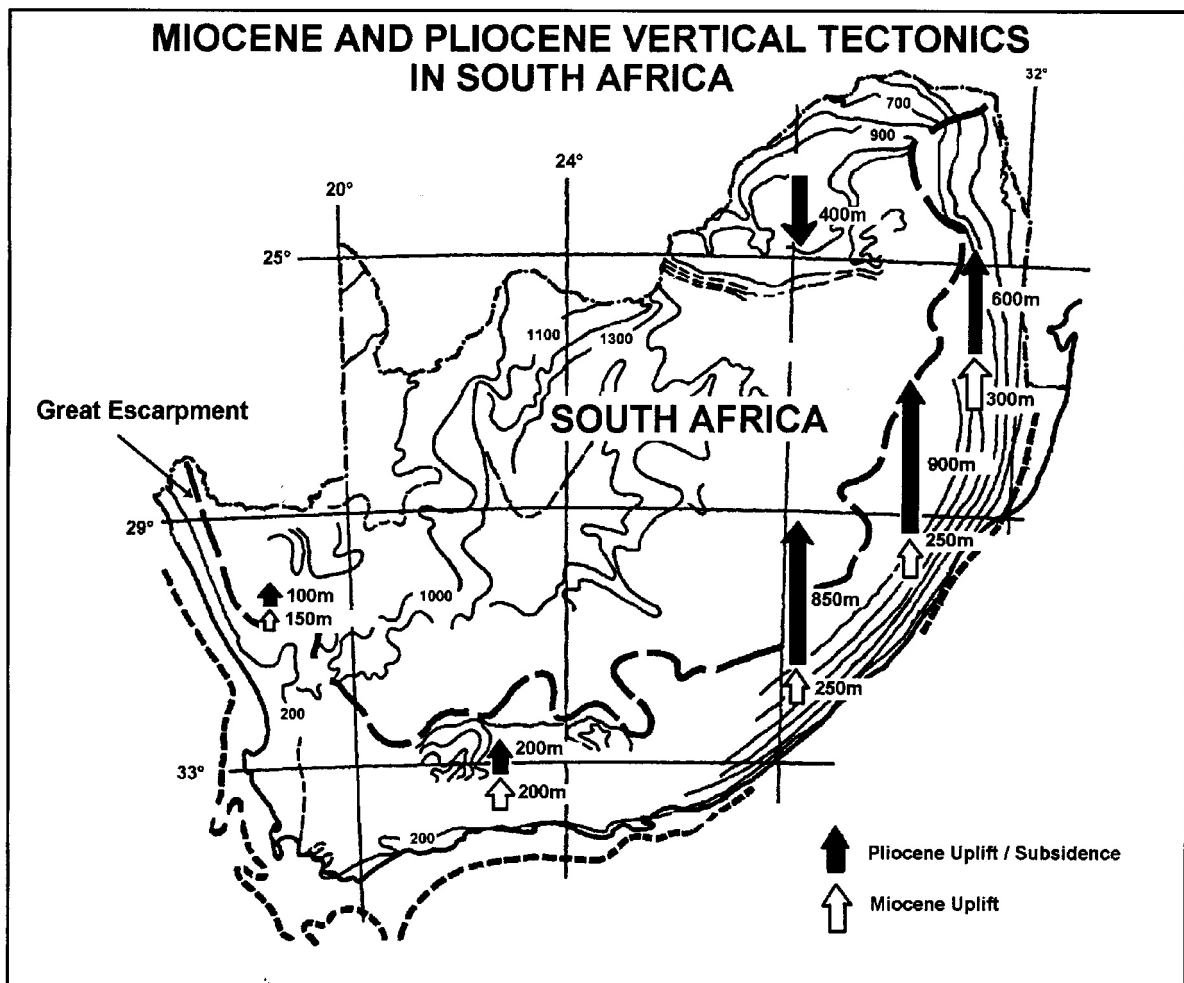


Figure 4-33.- Miocene and Pliocene vertical land movements in southern Africa.

raise a marine complex so that a later transgression to a similar altitude would not reach it, thereby leaving it out of the way of marine reworking.

For the moment, there appears to be no way of deciding the matter using evidence from the Namib coastal plain alone. The main support for epeirogenic uplift of the Namib comes from the study of continental geomorphology, global sealevel curves in relation to raised marine deposits of known age, and river profiles. Partridge *et al.*, (1995b) estimated that Late Miocene to Early Pliocene marine strata at Port Elizabeth have been uplifted by more than 300 metres since the Pliocene. This figure is calculated from an Early Pliocene base level at an elevation of 80-90 metres above Modern sealevel. In the Namib, however, the Late Miocene

place to place, producing dome-like mega-structures, which complicates calculations of the amount of uplift or downwarping that occurred at any particular spot. The result is that the interplay of eustatic and epeirogenic processes renders it difficult to sort out the contributions made by each one to the present elevation of raised marine terraces and the strata that repose upon them.

4.9.2 LATERAL CONTINENTAL MOVEMENTS

Figures 4-34 to 4-36 provide snapshots of the movements of Africa and South America from Early Cretaceous times to the present. The Atlantic continental edges of Africa and South America are both passive margins. At and immediate-

TABLE IV-2

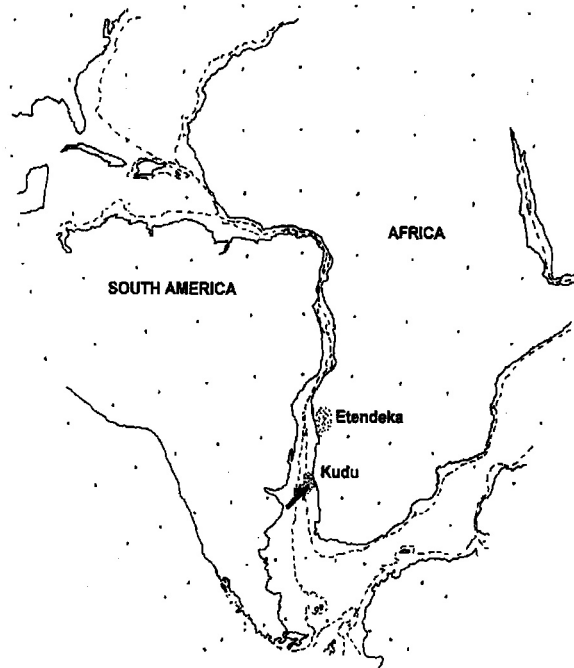
AGE-ALTITUDE RELATIONSHIP OF RAISED MARINE COMPLEXES	
Age of raised marine complex	Altitude of raised marine complex
Eocene	160-140 metres
Early Miocene	90 metres
Late Miocene	50 metres
Late Pliocene	30 metres
Pleistocene	8 metre beach
Pleistocene but younger than the 8 metre beach	5 metre beach
Latest Pleistocene to Holocene	2 metre beach

to Early Pliocene marine package (the *Donax haughtoni* package) tops out at about 50 metres asl, suggesting either that the global estimate of 80-90 metres (Haq *et al.*, 1987) for this transgression is too great, or that since the Pliocene the Namib coastal plain has sunk by 40 metres rather than been uplifted. With presently available evidence it does not seem to be possible to solve this conundrum.

There can be little doubt that global scale eustatic changes in sea-level are responsible for producing the elevated marine deposits along the coast of south western Africa. The coincidences in the number and timing of these events in the Namib and western Australia (Quilty, 1977) provide strong evidence for this. What is almost sure, is that epeirogenic uplift of the continent has also occurred and that this has affected the altitudes (usually increasing them) at which the various littoral marine deposits occur today. Among other authors, Haughton (1928, 1931) considered that the Namaqualand marine terraces had been subjected to tilting since their incision, but the evidence is equivocal and difficult to interpret. In some parts of the subcontinent, such as in the northern Transvaal, there was subsidence of the land during the Pliocene (Partridge *et al.*, 1995b). Parts of the Cape appear to be lower now than they were in the past, with Miocene terrigenous deposits now occurring 50 metres below sea-level (Partridge & Maud, 1987). In any case, the epeirogenic movements vary from

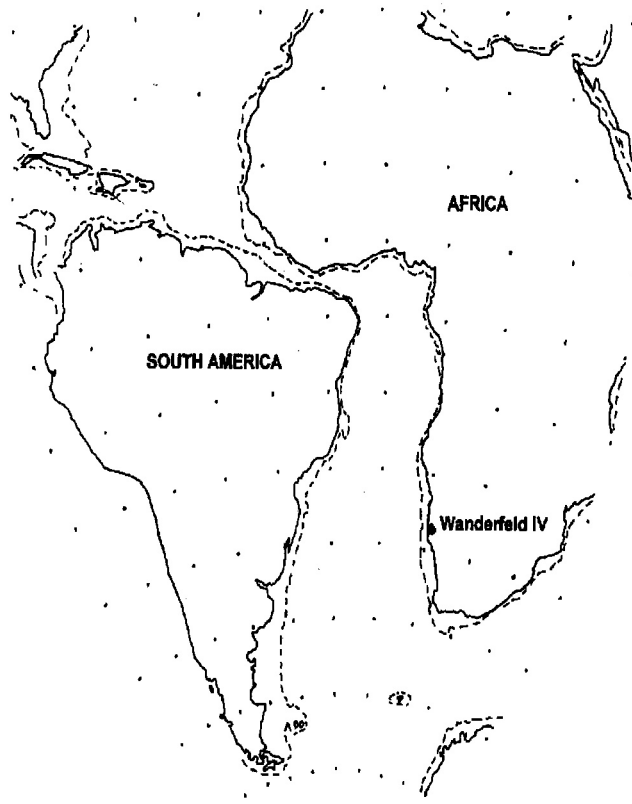
ly after break-up of Pangaea there was considerable rifting activity which Light *et al.*, (1992, 1993) have subdivided into two main phases, Synrift I starting in the Jurassic, and Synrift II (Valanginian to Hauterivian) which was followed by a transitional tectonostratigraphic phase which ended in the mid-Aptian. From Late Cretaceous times, the tectonic activity of the Namibian continental margin has been dominated by thermal sag.

The three maps, based on Owen's (1983) atlas of continental displacement, reveal that at the time of deposition of the Etjo and other Cretaceous aeolianites of Namibia, the geomorphological setting of the region was totally different from the setting in which the Neogene Namib aeolianites accumulated. It would therefore be inappropriate to link the two aeolianite systems together and from this to conclude that desert conditions have persisted in Namibia from the Cretaceous to the Present (Late Mesozoic-Cenozoic Model in Ward & Corbett, 1990). It is now clear that the two desert systems, albeit having similar geographic coordinates, are separated in time by about 100 million years. The Cretaceous Etjo Sandstones and those under the sea at Kudu Field (Light *et al.*, 1992, 1993) were very probably graben aeolianites (Frostick & Reid, 1987) of the type that occur today in East Africa and, like them, are associated with lacustrine and alluvial fan facies.



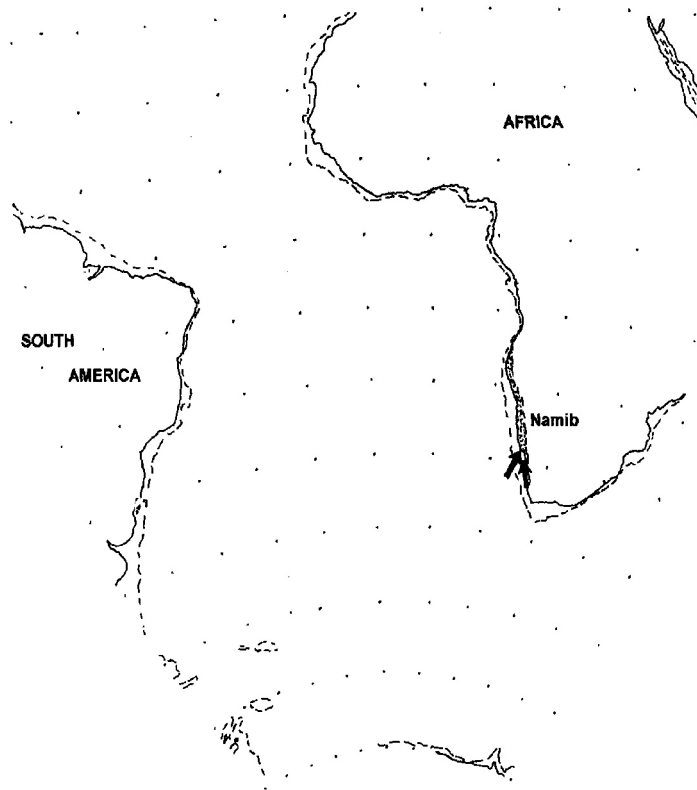
Depositional situation of Cretaceous aeolianites of Namibia (Kudu & Etendeka, ca 120 Ma)
Arrow shows main vector of prevailing wind. The South Atlantic has barely started to form

Figure 4-34.- The nascent south Atlantic immediately after the onset of continental break-up. At this stage the region was a rift valley in which various lacustrine and subaerial sediments accumulated, including aeolianites. These Cretaceous aeolianites are not precursors of the Namib aeolianites as has been thought in the past (map from Owen, 1983).



The South Atlantic at the time of deposition of the Wanderfeld IV Beds (ca 90 Ma) Namibia

Figure 4-35.- The South Atlantic at the time of deposition of the Wanderfeld IV beds (ca 90 Ma, Mid-Cretaceous) (map from Owen, 1983).



Depositional situation of the Namib sand sea (Middle Miocene to Recent)
Arrows show main vector of prevailing wind

Figure 4-36.- The regional depositional setting of the Neogene Namib aeolianites is completely different from that of the Cretaceous Kudu and Etendeka aeolianites (map from Owen, 1983).

At the time of deposition of the Wanderfeld IV beds (Late Cretaceous) the south Atlantic was considerably narrower than it is today and it is doubtful that the regional oceanic and atmospheric climates had much in common with those of the present day. Even if the South Atlantic anticyclone were located over the South Atlantic as it is today, then its effects on the wind regimes in the neighbouring continents would have been very different from what they are today (fig. 4-37) (Bigarella, 1970) with the prevailing winds blowing inland towards the heart of the African continent, whereas, at present (fig. 4-36) the prevailing winds along the coast of Namibia are more or less parallel to the coast-line (fig. 4-5).

4.10 BIOSTRATIGRAPHY

Since 1992, the NPE has found terrestrial fossils in well over 100 localities in the Namib Coastal Plain. Prior to this only a handful of fossil sites was known in fluvial strata ranging in age from Early to Middle Miocene. Of particular interest has been the discovery of diverse faunal remains in the Tsondab and Rooilepel Aeolianites which have yielded abundant mammal remains and bird eggshells. It is now known that aeolianite deposition started in the Early Miocene and has continued ever since.

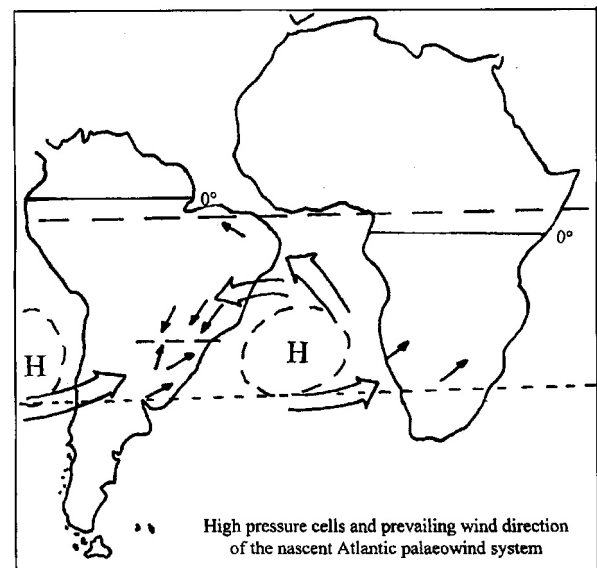


Figure 4-37.- Reconstruction of palaeoclimatic conditions in the South Atlantic towards the end of the Cretaceous (from Bigarella, 1970) to show how the onshore wind vectors would have been rather different from their modern conformation, blowing inland rather than along shore.

Marine fossils have been collected from many points along the coastal plain, and it was soon realised that molluscan faunas had changed dramatically over geological time. What was not known, however, were the ages of the various faunas, even though the sequence in which they occurred was well established by the late 1960s. PESA has found sufficient mammal fossils in the marine terrace deposits of Namaqualand to provide reliable age estimates for them. Hitherto considered to be of Pliocene and Pleistocene age, the deposits are now known to be considerably older, ranging back into the Early Miocene.

Fossils from sediments intercalated with the Kaukausb Travertine indicate a Pliocene age for these sediments which were previously considered to be Miocene or even older.

The NPE and PESA have thus considerably modified the dating of geological events in the Namib Coastal Plain. The ages of various localities is summarised in figure 4-38 together with proposed correlations to biostratigraphic successions in other parts of Africa.

4.10.1 LITTORAL MARINE FAUNAS

Figure 4-39 provides a summary of the geochronology and biostratigraphy of the littoral marine and fluvial deposits of the Namib Coastal Plain.

The Ryskop mammalian assemblage is clearly of late Early Miocene age, ca 18 Ma, based on comparisons with East African faunas. The closest matches are with Rusinga Island, Kenya, Faunal Set II of Pickford (1981) and Arrisdrift, Namibia, (Faunal Set IIIa). The Ryskop diamond-bearing gravels are probably equivalent in age to the so-called 90 metre package and the Grobler Terrace of various authors. Sea level at this time was at least 50 metres above modern sealevel.

Below the Ryskop diamond gravel horizon, is a channel cut into kaolinised bedrock to a depth of at least 9 metres, which was filled with peaty clay and sand with cobble horizons and intraformational conglomerates.

Lenses of the sand have been ferruginised, and blocks of reworked iron-cemented sands occur in the Early Miocene diamond-bearing gravels. These often contain the imprints of marine molluscs which are due to very localised solution and redeposition of iron salts near the surface of the blocks. Apart from these imprints and rare internal moulds of molluscs from the same deposits, all the marine molluscs in the 90 metre package have been destroyed by leaching.

At Ryskop, the *Kenyasus/Nguruwe* package is overlain by the *Donax haughtoni* (50 metre) sediment package, the base of which, locally known as the "suspended gravels", is 52 metres above sea level. At Ryskop and Hondeklip Bay, the 50 metre package has yielded mammalian remains similar to fossils from Langebaanweg, and these levels are thus of Latest Miocene to basal Pliocene age. Terrigenous

sands at the top of the 50 metre package at Ryskop yielded a bovid molar similar to material from Langebaanweg. M. Mittelmeyer's discovery of the suid *Nyanzachoerus kansasensis australis* in Zone 4a at Hondeklip Bay also provides evidence of a Late Miocene to Basal Pliocene age for the 50 mP. As Pether (1994) says of the provenience of the *Nyanzachoerus* jaw, it has a "matrix of barnacle-plate-rich, coarse sand. It is certainly closely associated with the 50 m package". Pether (1994) concluded that the 50 metre package was Early Pleistocene on the basis of the last known occurrence of the genus *Nyanzachoerus*, but the Hondeklip fossil is a primitive member of the genus closely similar to material from Langebaanweg, and is not similar to the youngest known species from East Africa. The 50 metre package is thus of Latest Miocene to basal Pliocene age.

Above the 50 metre and 30 metre packages there are various terrigenous deposits which have yielded remains of *Equus capensis*. These deposits, mainly aeolianites, have suffered more or less pedogenic activity. The latter processes have given rise to reddened horizons, occasionally with murrain nodules, and calcreted aeolianites. These are respectively Middle Pleistocene (with Acheulean artefacts) and Late Pleistocene to Holocene in age (with Middle Stone Age artefacts).

Finally, there are three raised beaches which contain cold water molluscan faunas. These represent the sub-10 metre packages, or raised beaches of Late Pleistocene to Holocene age.

4.10.1.1 Comparison between littoral successions north and south of the Orange River

Haughton (1931) was the first to make a detailed comparison between the molluscan assemblages in Namibia and Namaqualand. He recognised 5 zones which he called A-E from youngest to oldest. Zone E, the earliest was only represented at The Point (near Olifants Rivier) but was poorly fossiliferous, the sample consisting of the internal moulds of molluscs and isolated teeth of sharks and marine fishes. Zone D, the so-called Oyster Line association, yielded the index fossils *Donax rogersi*, *Chamelea krigei* and *Fissurella robusta*. Taken at face value these names would suggest that Haughton sampled parts of the *Donax haughtoni* (50 mP) and *Donax rogersi* (30 mP) packages, with *Chamelea krigei* representing the former and *Donax rogersi* the latter, as these two taxa are restricted in their geochronological ranges (Kensley & Pether, 1978; Pether, 1994). The subsequent discovery that Haughton's sample of *Donax rogersi* also contains specimens of *Donax haughtoni* (Carrington & Kensley, 1969) confirms the mixed nature of his zone D fauna which, as a consequence, is a melange of fossils from the 50 mP and the 30 mP. More recent work reveals that Haughton's zones A, Band C are not clearly separable on malacological grounds as he thought, since most, if not all of the species are extant ones. They are separable on geomorphological (altitudinal) grounds (Kensley & Pether, 1986) however.

AGE Ma	NORTHERN AFRICA	ARABIA	TROPICAL AFRICA	CHAD	SOUTHERN AFRICA	AGE Ma
0	Djebel Ressay 4 Djebel Ressay 7 Djebel Ressay 2, 3		Ngaloba		Etaneno Berg Aukas MM7 Asis Ost, Namib IV	0
1	Oued Kremia Djebel Ressay 5, 6, 8 Djebel Ressay 1		Olpira	O M	Berg Aukas MM6 Aigamas Nosib	1
2	Ain Boucherit Jebel Orousse, A. Brimba		Naidabad Ndolanya	O -	Jägersquelle Berg Aukas MM5	2
3	Lac Ichkeul, Jebel Mellah Saiz, Amama 3		Kaiso Village U.Laetoli	G R	Kaukausib, Hondeklip (30 mP) Makapansgat, Ngami Sterkfontein (inferieur)	3
4	Ain Guetarra, Argoub Kemelal Hamada Damous Oued Athmenia		L.Laetoli Kyeoro Kanapoi	O U P	Atoumanga Bochianga Kolinga, Moualla	4
5			Warwire		Chiwondo Rooilepel (daberas) Karingarab (daberas)	5
			Athi, Lower Nyaburogo		Berg Aukas MM4	
6	Khendek el Ouaich Wadi Natrun Sahabi, Menacer	Dubai	Kazinga, Ishasha Nkondo, Lukeino, U.Oluka Sinda, Kanam	Agranga	Langebaanweg Klein Zee, Hondeklip (50 mP)	6
7	Amama 2		Mpesida Lothagam			7
8	Mascara Rabat, St Donat, Sidi Salem Gafsa, Segui		Nyamavi, Karugamania L.Oluka		Rooilepel (laini) Karingarab (laini)	8
9	Djebel Krechem, Kechabta Amama I, Oued Zra Mdilla, Douaria		Luanda Nakali, Samburu Hills Ngeringerowa		Harasib 3a Berg Aukas MM3	9
10	Beni Amir, Khenchella Jebel Semmene, Bou Hanifia Assif Assermo, Conde Smendou		Kakara Chorora, Ngorora "E" top		Rooilepel (wardi), Prospect Hill Karingarab (wardi) Berg Aukas MM2	10
11	Cherichera, Sbeitla Bled Douarah Supérieur, Hakima		Ngorora 'E' base			11
12	Bled Douarah Inferieur, Tozeur Nementcha, Farafra Oum Douil, Sehib Beni Mellal	Al Jadidah	Ngorora 'C-D' Kisegi Ngorora 'A-B'		Hondeklip Bay (basal gravels) Rooilepel (corbetti) Berg Aukas MM1 Rooilepel (oshanai)	12
13	Pataniak 6, Testour		Tambach Kapsibor, F.Ternan, Serek			13
14					Karingarab (oshanai)	14
15	Foum el Guelta		Kirimun Majiwa, Maboko Kaloma, Nyakach Nachola			15
16		Ad Dabtayah As Sarrar Rotem Yerovem	Muruyur Moruorot, Moroto		Bosluis Pan	16
17	Gebel Zelten Kabylie, Kouif	Jabal Midra	Kalodirr Buluk, Kajong		Arrisdrift	17
18	Wadi Faregh Wadi Moghara Siwa	Wadi Sabya Ghaba	Rusinga, Karungu, Chianda Bukwa, Adi Ugri		Auchas (AMSE), Ryskop Auchas (AM02) Zebra Hill (Aepyornithoid) Langental E-Bay, Fiskus, Bohrloch Grillental, Elisabethfeld	18
19			Loncherangan Napak, Koru, Songhor Chamtware			19
20						20
21						21
22			Meswa Bridge			22

Figure 4-38.- Ages of fossiliferous deposits in northern, tropical and southern Africa based on mammalian biostratigraphy. Prior to the work of the NPE and PESA, very few sites of Middle and Late Miocene age were known in the southern half of the continent.

LITTORAL MARINE AND FLUVIO-LACUSTRINE DEPOSITS OF THE CENTRAL AND SOUTHERN NAMIB				
AGE Ma	ROOIKOP	SPERRGEBIET	NAMAQUALAND	SALDANHA
0	<i>Donax serra</i> Package	<i>Donax serra</i> Package	<i>Donax serra</i> Package (sub-10 m Package)	<i>Donax serra</i> package
1				
2	Rooikop Gravels with <i>Donax rogersi</i>	<i>Donax rogersi</i> Package	<i>Donax rogersi</i> Package (= 30 mP)	<i>Donax rogersi</i> Package
3		Meso-Orange Terrace III		
4				
5				
6	<i>Donax haughtoni</i> Package	Meso-Orange Terrace II	<i>Donax haughtoni</i> Package (= 50 mP)	<i>Donax haughtoni</i> Package
7				
8				
9				
10				
11			<i>Agnotherium - Tetralophodon</i> Package (sub-50 mP Gravels)	<i>Diamantornis wardi</i> coastal aeolianite (Prospect Hill)
12				
13				
14				
15				
16				
17		Proto-Orange Terrace I		
18			<i>Kenyasus - Nguruwe</i> Package (= 90 mP)	
19		Langental, E-feld, Fiskus, Grillental		
20				
21				
22				

Figure 4-39.- Age relationships of littoral marine and fluvial deposits of the Namib Coastal Plain based on mammalian biostratigraphy. Instead of being randomly dispersed through the geological column, fossil deposits are grouped into four or five time slices which correspond more or less closely to periods of high sea-level.

Nevertheless, Haughton's results will go down in the annals as ground breaking work which revealed the utility of molluscs for local and regional biostratigraphy. Whilst many of the generic and specific names have undergone revision since 1932, rendering his faunal lists somewhat out-of-date (tables 3-13 and 3-14), Haughton's findings remain, in essence, of great scientific value and historical interest even though he remained reluctant to estimate the ages of his various zones beyond including them in the Late Tertiary and Recent.

The pioneering work of Haughton was extended by Carrington & Kensley (1969) who described 20 species hitherto unknown from the littoral deposits of south western Africa. 17 of these were new species or subspecies. They placed the entire succession along the coast into the Pleistocene, apparently being convinced that the raised beaches formed during the glacial period. They recognised 7 fossil beaches in Namaqualand at the following altitudes: - 75-90 (oldest), 45-50, 29-34, 17-21, 7-8, 5 and 2 metres above sea level and they proposed that these could be correlated to the Pleis-

tocene strands along the Atlantic coast of Morocco, the oldest (highest) transgression complex being correlated to the Basal Pleistocene. The main thrust of their research appears to have been of a taxonomic nature rather than biostratigraphy. Nevertheless, Carrington & Kensley were the first to notice that the large *Donax* specimens from Namaqualand fell into two groups which they accordingly separated into two species, *Donax rogersi* and *Donax haughtoni* and they also noted that the two species did not occur in the same sediments which would have been the case if the latter species were merely the juvenile stage of the former as suggested by Haughton (1931). *Donax haughtoni* was recovered from the 45-50 m strand line, while *Donax rogersi* was confined to the 17-21 m beach. They also reiterated Haughton's findings concerning the warm water affinities of the earlier molluscan assemblages.

It was Kensley & Pether (1986) who confirmed that the distribution of molluscs in the various Namaqualand sediment packages varied in a regular way, and they were thus enabled to refine the preliminary biostratigraphic schemes

of Haughton (1931) and Carrington & Kensley (1969). They recognised three major molluscan assemblages, two of which contained several extinct species (the 50 mP and 30 mP faunas) and one of which contained only extant species. They recognised three beach deposits (8 metre, 5 metre and 2 metre beaches) all of which contained Recent molluscs. Like their predecessors, Kensley & Pether (1986) thought all their fossil samples were Pleistocene. The 90 metre package (mP) yielded few identifiable mollusc remains (mainly internal moulds) and "its age remained uncertain although on geomorphological and stratigraphic grounds it has always been considered to be older than the 50 mP. Kensley & Pether estimated its age as Early Pliocene.

Study of fossil mammals associated with the various sediment packages reveals however, that there has been a consistent bias in estimations of the ages of littoral strata in Namaqualand and neighbouring Namibia. The belief that the various raised beaches resulted from the waxing and waning of polar ice caps during the Quaternary (Carrington & Kensley, 1969; Kensley & Pether, 1986) was deep seated and proved resistant to eradicate, especially when correlations to global-scale sea level curves seemed to lend support to the correlations (Hendey, 1981; Kensley & Pether, 1986). The barely fossilised appearance of many of the specimens also played a role in convincing authors that their samples were relatively young (Carrington & Kensley, 1969).

It is now evident, on the basis of mammalian biostratigraphy, that the 90 mP is of late Early Miocene age (ca 18 Ma), the 50 mP is Late Miocene to Basal Pliocene in age (ca 7-5 Ma) while the 30 mP is early Pleistocene (ca 3-2.5 Ma). Thus, although the sequence of geological events in the littoral of Namaqualand has in general been well worked out, the timing of these events has consistently been underestimated.

4.10.1.2 The CDM beaches north of Oranjemund

The diamondiferous beaches north of the mouth of the Orange River have yielded relatively few fossils. Haughton (1931) recorded various species including the extinct bivalves *Chamelea krigei* and *Donax rogersi*. Uncritical acceptance of these identifications would suggest that he sampled parts of the 50 mP and the 30 mP of Pether (1994). Fowler (1976) confirmed that these two taxa occurred in beaches D, E and F, but were absent from beaches A, Band C. Kleinjan (1971) had previously recorded *Donax rogersi* in beaches C and D. There thus exists a discrepancy between the results of the latter two authors, but it is not known whether this is due to a change in nomenclature of the various beach deposits (Kleinjan does not mention beaches E and F) or whether Fowler missed *Donax rogersi* in beach C. What is relatively sure, is that some of the CDM beach deposits are equivalent in age to the 50 metre package of Namaqualand (ca 7-5 Ma) and some are equivalent to the 30 mP (ca 2.5 Ma). There are also remnants of younger beach deposits in the region. Corvinus (1983) recorded the presence of diverse lithic

implements in some of the raised beach outcrops north of Oranjemund.

4.10.2 TERRESTRIAL FAUNAS

The group of fossils that has proved the most useful for determining the ages of Namibian strata has been the mammals. Many of the species and genera found in Namibia belong to widespread lineages found not only in other parts of Africa, but also sometimes in Europe. Of particular importance is the East African faunal succession, especially that of Kenya which spans most of the Neogene and has been well calibrated by numerous radioisotopic dates. The most important mammals for intracontinental correlations are the rodents, suids, proboscideans and ruminants while the most useful groups for intercontinental correlations are the carnivores and creodonts. However, whenever the fossil data warranted it, comparisons were made with East African, North African and Eurasian faunal successions. By this means we have been able to propose detailed correlations with a time resolution of the order of ca 1 million years.

Figure 4-38 presents the preliminary results of these correlations for North, East and Southern Africa. Hitherto the faunal succession of southern Africa was extremely limited, with a few Early Miocene, one Middle Miocene and one Late Miocene faunal assemblages, plus a few Pliocene sites. The number of sites has grown substantially and the spread of sites is now more complete for the Miocene and Pliocene. Included in the figure are the fossil sites discovered in the Otavi karst field as well as those from the coastal strip of Namibia and Namaqualand.

4.10.3 AVIAN EGGSHELLS

Having calibrated the Namibian faunal sites using mammals, it has then been possible to determine the ages of Namibian lineages that are not well represented elsewhere, in particular avian eggshells and marine molluscs. Having been calibrated, the sequence of eggshells can then be used for local correlations within the subcontinent.

Figure 4-40 summarises the sequence of eggshell morphologies worked out for the Namib aeolianites (Tsondab and Rooilepel Sandstones). There are eight major struthious eggshell morphological types ranging from about 15 Ma to the present (Senut *et al.*, 1994a, b, c, 1995; Dauphin *et al.*, 1995, 1998). The most useful aspect of the fossil eggshells is that with a practiced eye, they can be used while the geologist is still on outcrop, meaning that determination of the age of the strata can be made in real time. The two most striking factors are the surface morphology of the eggshells, including the size, distribution and outline of the pore complexes, and the thickness of the shells (more variable but still useful for broad correlations). In addition to the struthious eggshells, the Early Miocene deposits in the Sperrgebiet have yielded eggshells of aepyornithoid type, but these may well also occur in the Middle Miocene and later deposits and are thus less useful for refined biostratigraphy.

BIOSTRATIGRAPHY OF NAMIB AEOLIANITES BASED ON STRUTHIOUS EGGSHELLS


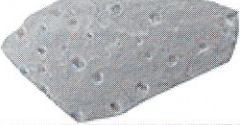


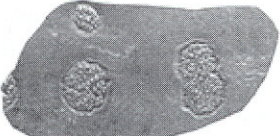
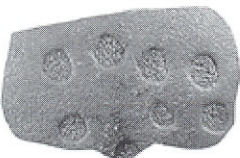



Approx. age Ma	Eggshell morphotypes	Species	Type Locality	Other Localities
0-2		<i>Struthio camelus</i>	None	E-Bay Bosluis Pan
2-5		<i>Struthio daberensis</i>	Daberas Duine	Awasib upper levels Karingarab upper Fiskus, Laetoli Kolmanskop
5-8		<i>Struthio karingarabensis</i>	Karingarab	Awasib upper levels
8-10		<i>Diamantornis lalini</i>	Target Pan	Rooilepel upper Awasib middle levels Tsaus Karingarab middle
10-12		<i>Diamantornis wardi</i>	Rooilepel middle	Prospect Hill Schmidtfeld Awasib lower levels Karingarab lower Vreemdelingspoort Tsaus
12-14		<i>Diamantornis spagglarii</i>	Karingarab	GP Pan North
14-15		<i>Diamantornis corbetti</i>	Rooilepel lower	West Pan Rooilepel West Elim, Diep Rivier Awasib lower levels Tsaus
15-16		<i>Namornis oshanae</i>	Etosha	Rooilepel base Karingarab base Awasib base
16-20		Aepyornithoid	None	Zebra Hill, Tsauchab Paradys Valley Langental Grillental Elisabethfeld

Figure 4-40.- Biostratigraphy of Namib Aeolianites based on struthious eggshells. Age control is provided by mammals found associated with the eggshells (scale of all photographs is x 1 except for that of the aepyornithoid which is x 17).

The discovery of *Diamantornis wardi* eggshell fragments in aeolianites at Prospect Hill, Saldanha, South Africa (Roberts pers. comm.) has led to revision of the local stratigraphic sequence there. Previously all the aeolianites at Saldanha were included in the Pleistocene Langebaan Formation, but the discovery of the *D. wardi* eggshells means that there are late Middle Miocene aeolianites in the region as well, and that therefore this formation is a composite unit. Struthious eggshells found in aeolianites at Bosluis Pan, South Africa, permitted the Pleistocene to Recent age of these sandstones to be established (Senut *et al.*, 1996). Fossil eggshells from the Late Miocene of the Arabian Peninsula are typical of *D. laini* (M.P. pers. obs.) and those from the Middle Pliocene of Laetoli are similar to those of *Struthio daberensis* (M.P. pers. obs.). Thus eggshells are proving to be of importance for intra- and intercontinental correlations.

Correlation of the Namibian succession to the East African and European faunal sequences is summarised in figure 4-41.

4.10.4 CONTINENTAL CORRELATIONS

The most secure basis for correlating Namib strata consists of its mammalian faunas. Various fossil sites in the Sperrgebiet, the Namib aeolianites and Namaqualand have yielded mammals that have also been recorded from East Africa, North Africa and even, in some cases, from Europe. The East African faunal succession (Pickford, 1981; Pickford & Morales, 1994) has been calibrated with the aid of radioisotopic dates obtained on volcanic rocks that are intercalated between fossiliferous beds, or are from the fossil beds themselves.

Figure 4-38 provides a preliminary correlation between southern African, east African and north African localities. The quantity and chronological spread of fossiliferous sites in Southern Africa is now an order of magnitude greater than it was even a few years ago. Prior to the NPE and PESA, there was only a handful of Miocene sites known in southern Africa, whereas there are now over 100. Whilst refinement of the faunal succession will undoubtedly con-

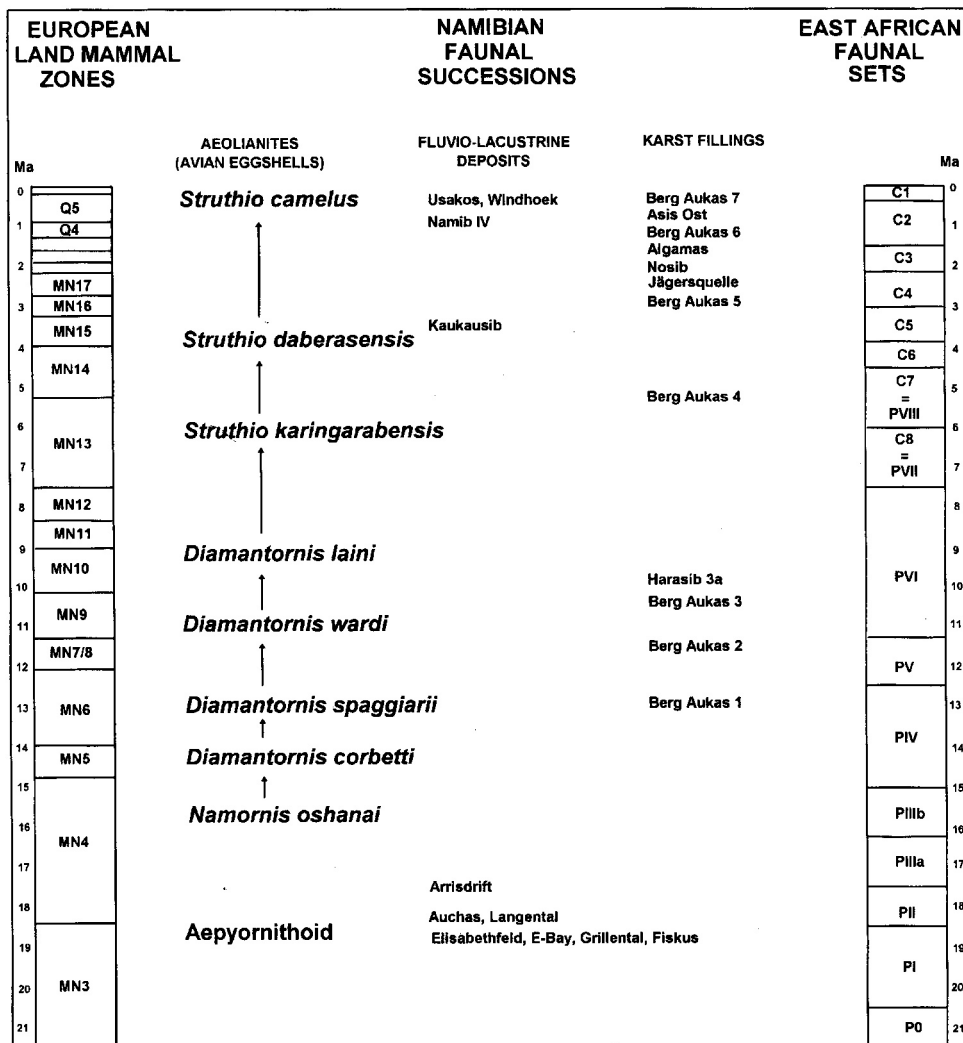


Figure 4-41.- Summary of biostratigraphic correlations of fossiliferous sites in Namibia, including the Otavi Mountains, with European and East African faunal sequences (MN zones from Mein, 1990).

tinue in the future, the broad brush strokes of the faunal succession in southern Africa are now in place.

It is worth reiterating that the flood of geochronological information now available for the Namib has led to a comprehensive reappraisal of the timing of geological events in the region, and in some cases has even led to revision of the sequence of events, for example, the relative positions of the Tsondab Sandstone and the fluvial deposits at Elisabethfeld, Grillental and Langental.

Summary charts of the geological history of Namaqualand and the Sperrgebiet, based largely upon the above biogeochronology, are presented in tables 5-1 and 5-2. Comparison with previously published geological histories of the region will reveal many differences in the timing of events, and sometimes of the succession of events (figs 4-1 and 4-2 and 5-1).

4.11 BIOGEOGRAPHY

4.11.1 MARINE LITTORAL BIOGEOGRAPHY

Haughton (1928, 1931) noted that the raised beach deposits of Namaqualand contained several molluscs that are normally found in warmer waters than occur along the Namib coast today. Tankard & Rogers (1978) provided more details, recognising eight species of molluscs that had a wider latitudinal distribution during the period of deposition of the 50 metre and 30 metre packages than they do today. At the time of their study, these deposits were thought to be Late Pleistocene, but they are here redated to Late Miocene and Late Pliocene respectively.

Figure 4-42 shows the extent of the distribution of several of these warm water taxa. Most of the warm water species found in Namaqualand are from the west side of Africa, but one of the taxa (*Tellina ponsonbyi*) is from the Indian

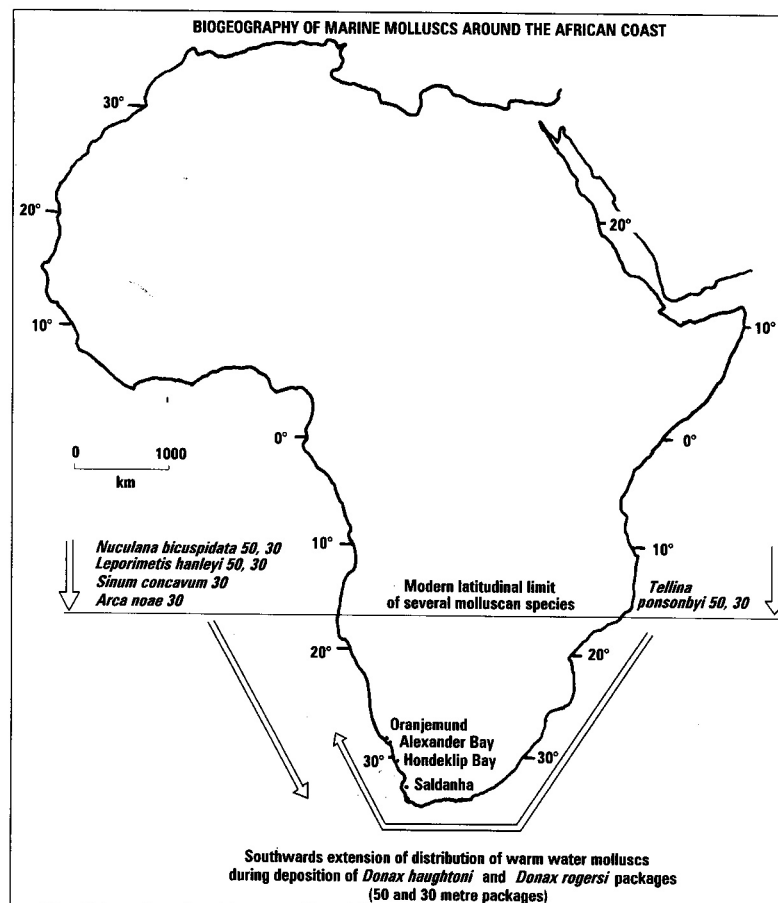


Figure 4-42.- Biogeographic relations of some marine molluscs found as fossils in Namaqualand. There can be little doubt that the coastal waters of the southeast Atlantic were appreciably warmer during the Miocene and Pliocene than they are today.

Ocean and presumably got to Namaqualand by way of the Cape. There can be little doubt that, from the point of view of marine molluscs, the coastal waters of the Namib were more tropical during the Miocene and Pliocene than they are today. The change from warm to cold waters took place during the Pleistocene, as shown by the presence of exclusively cold water species in the sub-10 metre raised beach deposits of the region. This change accords reasonably closely in time with the plunge in ocean temperatures that occurred at the onset of the Quaternary (fig. 4-29) deduced from oxygen isotope studies.

4.11.2 TERRESTRIAL BIOGEOGRAPHY

The fossil mammals of the Namib succession from the Early Miocene to recent have close relationships with mammals from Neogene deposits in other parts of Africa and in cases even with Europe. This suggests that the mammals recovered were not stenotopic, but were able to adapt to a variety of habitats. This fact enables palaeontologists to carry out biostratigraphic correlations between southern, eastern and northern Africa, but at the same time it does not reveal much about the biogeographic affinities between the various areas, except to show that the Namib faunas have not been separated from those of the rest of Africa for any lengthy period of time. There are various mammal lineages in the Namib succession that are traditionally considered to have originated in Eurasia including the Suidae, hornless ruminants, Amphicyonidae, Mustelidae and lagomorphs, but none of them is known exclusively from the Namib, all of them being known from East Africa as well. There are some endemic species and even genera of mammals, but these are still in the process of being studied. The climacoceratids from Arrisdrift represent an endemic genus and one or two of the smaller carnivores may have been endemic. The bulk of taxa from Arrisdrift are however close to or identical with species known from Kenya (Pickford *et al.*, 1996).

Thus, during the Cenozoic, the Namib mammals participated fully in the evolutionary activity of the Ethiopian Zoogeographic Region, meaning that gene flow between East Africa and the Namib was never seriously interrupted during this period. A similar situation pertains today, with several mammal lineages being common to the arid parts of East Africa and the Namib.

Two of the fossil land snails (*Dorcasia*, *Trigonephrus*) of the Namib belong to the endemic family Acavidae, while the third (*Xerocerastus*) belongs to an endemic genus of Subulinidae and all of them occur in Namibia today. In East Africa, fossil land snails from Cenozoic deposits are all closely related to lineages that occur in the same region today (Pickford, 1995c). Thus, in strong contrast to the widespread distribution of Namib mammal lineages, the land snails were restricted in their distribution without a single species being common to the fossil records of the two regions. Likewise the fossil land snails of North Africa are closely related to extant lineages that occur there today, and they have nothing in common with the East African or Namibian species. This speaks eloquently for a

certain degree of permanence in the geographic distribution of land gastropods.

Fossil macrobotanical remains have only been found in any abundance in the Namib at Auchas an Early Miocene site, and in this case the affinities of the assemblage are with the Zambezian Regional Centre of Endemism and the Kalahari - High Veld Regional Transition Zone (fig. 2-8). By the end of the Miocene there is evidence that fynbos was growing in northern Namaqualand, at Swartlinterjies, indicating a change towards closer affinities with the Karoo Namib Regional Centre of Endemism (fig. 2-8). Near Vredendal, South Africa, petrified wood of tropical species has been recovered (Bamford, pers. comm.) but its age is not known.

Thus the biogeographic affinities of the Namib vary depending upon which group one examines. There are lineages such as the mammals which are pan-Ethiopian in distribution, there are others, including the molluscs and the Late Miocene plants which are more restricted in their ranges being confined to the southern African region. There can be little doubt that during the Miocene the biogeographic affinities of the Namib have fluctuated, being predominantly Kalaharian to Transvaalian and Zambesian in the sense of Deacon & Lancaster (1988) (fig. 2-6) during the Early and early Middle Miocene, whereas from the Late Miocene to present they have been predominantly Karoo- Namaqualian.

The results of Coetzee (1986) based on the palynology of the coastal strip of the Western Cape reach comparable conclusions, revealing a Transvaalian (warmer, more humid) influence during the Miocene and Cape and Karoo-Namaqualian affinities in Pliocene and Pleistocene times.

There can be little doubt that the shifts in biogeographic affinities that have been documented for the Namib resulted mainly from changes in climate, from subtropical with summer rainfall in the Early Miocene and early Middle Miocene to temperate with winter rainfall later in the Middle Miocene until the present day (fig. 4-28).

4.12 PALAEOCLIMATOLOGY

4.12.1 KAOLINITE

The kaolin-rich weathering horizon which occurs widely throughout Namaqualand, attests to a tropical or subtropical humid climatic regime at the time of its formation (Robert & Kennett, 1992). Early Miocene and basal Middle Miocene faunas and floras from southwestern Africa indicate that tropical or sub-tropical conditions persisted in the same region until about 16-15 Ma but that the climate was not as humid as it had been before. After this time, temperate conditions were established, and the onset of desertification occurred in the Central Namib which culminated in the accumulation of the thick aeolianites of the proto-Namib (Rooilepel and Tsondab Sandstones). South of the Orange River, in the Southern Namib, regional aeolianite deposition did not commence until the

Plio-Pleistocene. There are, however, quite extensive sediment deposits in the Knersvlakte and elsewhere, which overlie kaolinised bedrock and which are probably of Tertiary age. These consist of fluvial and floodplain deposits, often with gypsum concentrations rich enough to be exploited by open cast mining methods. These deposits are locally overlain by a thin ferruginous horizon which has yielded fossil wood of tropical trees, which is in turn overlain by aeolianites with fossilised termitaries and recent sands.

4.12.2 MARINE FAUNA

4.12.2.1 Fishes

The marine fish fauna is still under study, but previous researchers have recognised the presence of various sharks and fishes in the samples from Namaqualand. The abundance of labrid tooth complexes in many samples from Namaqualand indicates that the coastal waters at the time of deposition (Late Miocene and Late Pliocene) were likely to have been warm, because these fishes are today confined to the tropics.

4.12.2.2 Mollusca

Haughton (1928, 1931) was the first to notice that the raised beach complexes of Namaqualand yielded warm water species of marine molluscs. Subsequent researchers have confirmed Haughton's insight (Carrington & Kensley, 1969; Tankard & Rogers, 1978; Pether, 1994) and it is now accepted that the southeastern Atlantic coastal waters were relatively warm at the time of deposition of the 50 mP and the 30 mP.

In sharp contrast, molluscs from the sub-10 metre beaches of Namaqualand contain exclusively cold water species of molluscs. The available evidence suggests that the change from warm to cold waters along the Namaqualand and Namibian coasts took place later than the Early Pleistocene, and once having changed they remained cold.

4.12.3 TERRESTRIAL FAUNA AND FLORA

The terrestrial faunas and floras from the Namib throw some light on palaeoclimatic conditions. The Early and Middle Miocene assemblages found at Ryskop, Hondek-lip Bay and further north at Auchas, Baken and Arrisdrift, as well as in the high plateau at Bosluis Pan, all attest to the existence of tropical to subtropical semi-arid to sub-humid climatic conditions in the sub-continent during the early part of the Neogene. Crocodiles have been found at Bosluis Pan (Senut *et al.*, 1996) and in the Orange River Valley (Arrisdrift, Auchas, Baken) (Pickford, 1996) and these provide good evidence of tropical to sub-tropical conditions at the time of deposition (Pickford *et al.*, 1995b). The fossil wood from the Orange River Valley and from Vredendal belong to tropical hard woods (Bamford, pers. comm.).

In the Central Namib major changes occurred during the Middle Miocene, when arid to hyper-arid conditions set in which resulted in the proto-Namib Desert. At Swartlinterjies, Late Miocene clays have yielded plant fossils which indicate that the fynbos was already established in the region by the end of the Miocene suggesting a temperate climate with winter rainfall. By Pleistocene times changes had occurred to the extent that calcretes and murram palaeosols began forming in the Namib.

4.12.3.1 Plants

Macro- and micro botanical fossils have thrown some light on the palaeoclimatology of the Namib. Fossil pollen and spores have been recorded from Kareedornvlei (Rogers *et al.*, 1990), Noup, Graafwater and Henkries (Scott, 1995). Little is known about the Kareedornvlei sample (fig. 4-4) which is supposedly of Early Cretaceous (Neocomian) age. The Noup sample of Tertiary age indicates that channel clays accumulated while the climate was moist and the regional vegetation composed of woodland and forest, in complete contrast to the extant fynbos vegetation of the area. Later than the Noup sample, there are pollen spectra from Graafwater and Henkries which contain mainly Asteraceae and other fynbos pollen types. Thus the few Namaqualand pollen spectra available, confirm that there were major changes in the climate of the region during the Tertiary, with more tropical, humid conditions early on, followed by more arid temperate conditions.

Macrobotanical remains from the Orange River and Swartlinterjies reveal very much the same story, even if the amount of data is limited. In the Proto-Orange terraces, fossil wood of Early and basal Middle Miocene age belongs to taxa which indicate that sub-tropical, semi-arid to sub-humid climatic conditions prevailed at the time of deposition. In Late Miocene clays at Swartlinterjies in contrast, fossil plants belong to typical fynbos morphotypes, with small, thickened leaves suggesting that by about 7 Ma the climate of Namaqualand was already temperate with winter rainfall. Presumably the climatic change occurred some time during the Middle or Late Miocene, but available evidence does not permit a more precise determination of when the climate changed.

4.12.3.2 Mollusca

Four genera of terrestrial molluscs have been found in the Namib fossil record. The most abundant of these is the acavid snail *Trigonephrus* which is today confined to the southwestern corner of Africa (Van Bruggen, 1969) (fig. 4-43). Ward *et al.*, (1993) suggested that the ubiquitous presence of this snail in the deposits of the Sperrgebiet from Early Miocene time onwards, indicated that the region has been subjected to a winter rainfall regime since the end of the Early Miocene. This species has now been found in Early Miocene sediments at Grillental, which increases its stratigraphic range downwards into a period during which it is thought, on the basis of other evidence, that the Namib was sub-tropical to tropical with summer

rainfall. Today this genus does not occur north of the Lüderitz-Aus road, and it has never been recorded in the sediments north of this road either.

The acavid snail *Dorcasia* has been found in Early Miocene sediments at Grillental and Glastal. It does not occur in the aeolianites of the Sperrgebiet, but it is relatively common in Middle Miocene dunes of the Saldanha area. At present the genus is confined to Namibia (fig. 4-43) and the extreme north of Northern Cape Province, South Africa. Thus during the Middle Miocene its distribution extended appreciably further south than it does today. This genus is tolerant of quite a variety of arid to semi-arid habitat types, but is limited eastwards by the Kalahari (fig. 4-43). Its present range almost coincides with the 21°C isohyet.

The third land snail found in the fossil state in the Sperrgebiet was recovered in large numbers from the Pleistocene Obib dunes. It is *Xerocerastus*, a subulinid snail with wide distribution in Namibia, Botswana and northern South Africa (fig. 4-44). It is essentially a snail adapted to semi-arid habitats and has evolved a variety of behavioural ploys to survive in rather harsh environments which are subject to rapid seasonal changes. In areas that are season-

ally flooded, it shelters under stones and fallen trees during the dry weather, but it will climb onto any outstanding substrate such as exposed rocks or tree trunks during the wet weather when the ground becomes waterlogged, where it will fix itself to wait until it can descend to dry ground again, sometimes several weeks to months later. In places enormous concentrations of these snails can be found aestivating several feet above the ground. In situations where there are few exposed supports, the snails will climb on each other and form clumps of snails almost like bunches of grapes. The shells of these snails are brilliant white and are relatively thick, presumably so that the maximum amount of the sun's energy is reflected away from the shell in their exposed resting places and to minimise evaporation of the body fluids. This genus does not appear to occur in the Namib Desert proper and its presence at Obib on the edge of the Sperrgebiet is perhaps somewhat unexpected. However, it occurs not very far east of the Sperrgebiet and a relatively minor climatic change might allow it to colonise the desert margins.

Finally, the internal shell of a slug (Urocyclidae) was recovered at site GT 6 in the upper Grillental, in association with an Early Miocene microfauna. At present, the near-

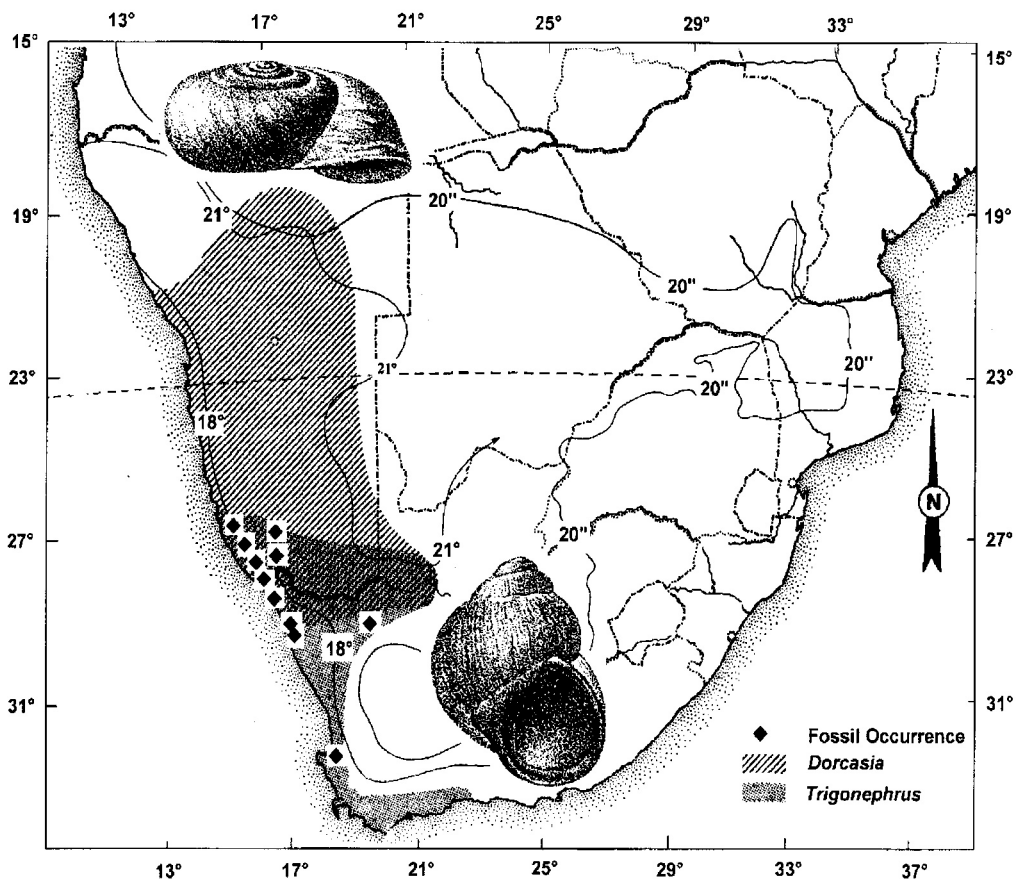


Figure 4-43.- Distribution of extant and fossil acavid snails, *Dorcasia* and *Trigonephrus*. Fossil *Trigonephrus* has much the same distribution in the Early and Middle Miocene as it does today, but *Dorcasia* occurred considerably further south during the Middle Miocene than it does at present. (Map from Van Bruggen, 1969).

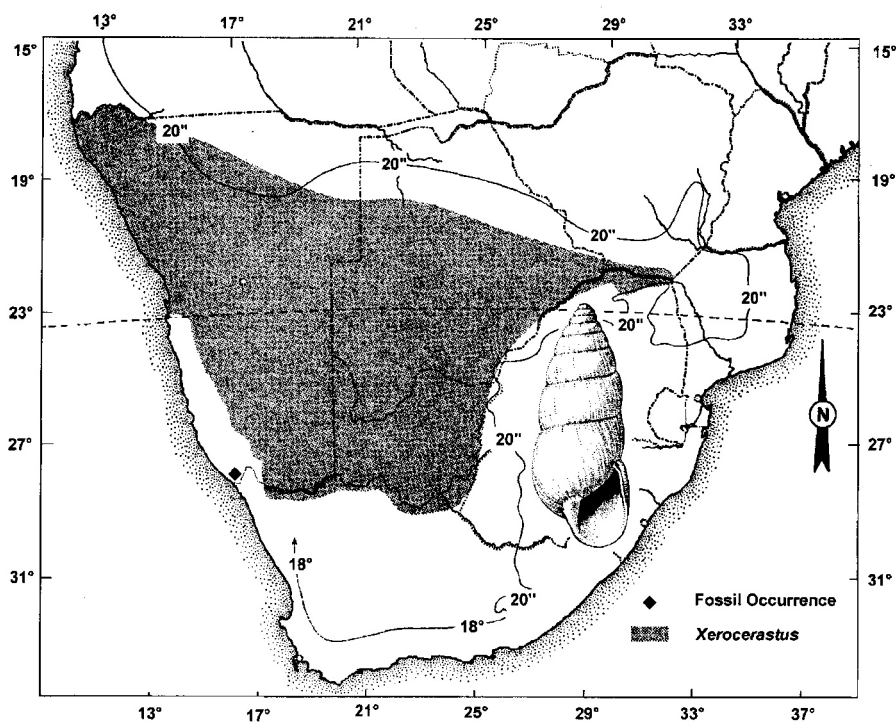


Figure 4-44.- Modern and fossil occurrence of the subulinid snail *Xerocelestus*. Usually rare to non-existent in the true Namib Desert, being predominantly an inhabitant of semi-arid steppe and savanna subject to summer rainfall, it has been found in the fossil state in the Pleistocene Obib aeolianites. (Map from Van Bruggen, 1969, modified to take into account the more accurate data presented in Van Bruggen, 1964).

est urocyclids to Grillental occur in the eastern part of the continent in Natal and Moçambique, and its presence in Namibia is indicative of a relatively humid, tropical and well vegetated environment (Pickford, 1995).

4.12.3.3 Reptiles

Chelonians are frequently found fossilised in Miocene deposits of the Namib. In Early Miocene strata at Elisabethfeld, Grillental, Fiskus, and Langental and at Middle Miocene deposits at Arrisdrift, large tortoises of the genera *Geochelone* and *Chersina* have been reported (Stromer, 1926; Meylan & Auffenberg, 1986). The large size of these tortoises indicate optimal growth conditions, including an equable climate and a rich source of vegetation. The present day climate of the Sperrgebiet is unsuitable for tortoises of such large size. The largest specimens found today in the region are an order of magnitude smaller than the fossil specimens.

Crocodiles are very abundant as fossils at Arrisdrift, and they have also been found at Auchas, Baken and Bosluis Pan (Pickford, 1996) but they have not been recorded from sites in the northern Sperrgebiet. As Pickford pointed out, crocodiles are today restricted to tropical and sub-tropical environments because the temperature at which eggs are incubated is crucial for the survival of the species. At temperatures one or two degrees lower than the optimal incubation temperature (31.5° to 32.5°C) all the eggs will hatch as females, whereas one or two degrees above this

temperature they will hatch only as males. Eggs exposed to temperatures more than 2° to 3° from optimum will not hatch at all. Thus, the presence of abundant crocodiles, including hatchlings at Arrisdrift and elsewhere in the Proto-Orange deposits, provides reliable evidence concerning the temperature during the crocodile breeding season in the Early and Middle Miocene of southern Africa.

4.12.3.4 Mammals

Mammals are generally not considered to be useful for throwing light on palaeoclimates. However, diversity of mammals at a fossil locality may provide some information about latitude, and by inference climate. This is because the diversity of most groups of organisms is highest in the humid tropics and decreases as latitude, altitude and aridity increases and mammals are no exception to this general rule. The faunas from the Early Miocene of the northern Sperrgebiet and from the Middle Miocene of Arrisdrift are reasonably diverse, but are not exceptionally so. Arrisdrift is now known to have at least 30 species of mammals which compares poorly with similar aged sites in East Africa which can have up to 68 species (at Rusinga, Hiwegi Formation, for example (Pickford, 1986b)). However, if consideration is taken of the fact that the taphonomical processes in the two regions were markedly different, being very favourable for fossil preservation in East Africa, and less favourable in Namibia, then the discrepancy in diversity may be more apparent than real. However, given the

uncertainties involved in this type of investigation it would be unwise to try to obtain detailed palaeoclimatic information from this kind of data.

4.12.4 AEOLIANITES

The aeolianites of the Central and Southern Namib provide good evidence for past arid to hyper-arid conditions. During the Early Miocene, prior to the accumulation of the first aeolianites, there is no evidence that the Namib was hyper-arid. Instead it was inhabited by a diversity of mammals and reptiles which suggest that it was tropical to subtropical with a healthy vegetation cover of savanna to woodland type with gallery forests fringing water courses (Hendey, 1978; Pickford *et al.*, 1996). The discovery of urocyclid sIUGS at Grillental accords with this scenario, yet the presence of feldspathic grits in the Early Miocene deposits would suggest instead the presence of a more arid climate. Perhaps the climate was sub-tropical and sub-humid to semi-arid, with groundwater forests in places in which sIUGS could survive. Today in southern Africa, similar sIUGS are only found in the eastern parts of the subcontinent, notably in Natal (Connolly, 1939).

By about 15 Ma aeolianite deposition started in the Namib, and from then onwards the region has been arid. The transition from savanna-like to desert conditions occurred at the same time that there was a plunge in the global ocean water temperature curve (figs 8-28, 8-29) and it seems likely that the two phenomena are related to each other.

4.12.5 CALCRETES

The Namib coastal plain is well endowed with calcrete. Near the Great Escarpment, thicknesses of up to 20 metres of calcreted conglomerates have formed close to drainage lines, but these horizons thin laterally between drainages and away from the escarpment. Fossils found in the calcreted at several sites are all of Pleistocene to recent species. The thick layers of calcrete at Kamberg (Yaalon & Ward, 1982) are probably of Pliocene age, but no direct evidence of their age has been found. They predate incision of the Kuiseb Canyon and deposition of the Oswater Conglomerate, the latter unit probably correlating to the 30 metre littoral marine package.

Nearer the coast, calcrete pedogenesis also occurred, but the products of this process are not the same as those near the escarpment. Often it is no more than a calcification of exposed sediments, and the colour of the pre-existing sediment is usually inherited. Thus, calcreted at Trigieville, north of Oranjemund are pink to red, as are those at Kalkrücken. Elsewhere in the Sperrgebiet, such as at Buntfeldschuh, Pomona, Elfert's Tafelberg and Chalcedon Tafelberg the calcreted are brown, sandy and extremely well indurated.

Thus from 15 Ma until the Pliocene, conditions suitable for calcrete pedogenesis did not occur in the Namib. Then

during the Pliocene and the Late Pleistocene the climate ameliorated enough for this kind of deposit to form. In the Namib it implies that annual rainfall increased compared with previous fully desertic conditions. Calcrete formation appears to have slowed down at present, compared to the rates of formation during the period of maximal development. In some areas, such as near Kamberg, there are two or three calcrete terraces, suggesting that calcreted formed episodically and were subjected to erosion in between periods of formation, implying that the climate fluctuated in a cyclic way during the Pleistocene. Not enough is known about these deposits however, to make any sweeping correlations to glacial and interglacial cycles for example.

4.12.6 GYPCRETES

The main climatic significance of the Namib gypcreted, is that they imply the presence of fogs along the coast. Today fogs are frequent along the Namib coast (up to 180 days each year), but the absence of gypcreted of any substantial age might suggest that fogs did not greatly affect the coast in pre-Pleistocene times. It is already known from the study of molluscs in the 50 metre and 30 metre packages of Namaqualand that the coastal waters of the Namib were relatively warm compared with those of the sub-10 metre raised beaches which contain cold water molluscan lineages. The available evidence would suggest that the Namib coast did not become foggy until the Pleistocene at the earliest.

A summary of African Miocene palaeoclimatic data is given in figure 4-45, which reveals that there have been considerable changes through the Neogene. Where today there is the world's largest desert used to be forested during the Miocene, whereas the region that is now covered in tropical rain forest used to be dune desert with sand sheets up to 250 metres thick.

4.12.7 ECOCLIMATIC BELTS OF THE WORLD

Encircling the globe in bands that are more or less parallel to the equator are broad ecoclimatic belts ranging from the Polar regions with their arctic climates to the equator with its tropical belt. In between are the Taiga, Boreal, Temperate and Sub-tropical zones. Although the boundaries between neighbouring zones are gradational, the belts are nevertheless measurable and describable entities in terms of the climatic conditions that prevail in them as well as the main vegetation types that grow in them. With the passage of geological time it is clear that the positions of the boundaries between the various belts have not remained static. There have been many latitudinal fluctuations in their position (Pickford & Morales, 1994) partly due to Milankovich scale fluctuations (a few degrees of latitude) and partly due to larger scale changes in the Earth's atmosphere and hydrosphere. There are two main possibilities regarding the positions of these ecoclimatic belts at the surface of the Earth. The most commonly invoked explanation is known as the accordion model, in which the latitudinal width of the various belts

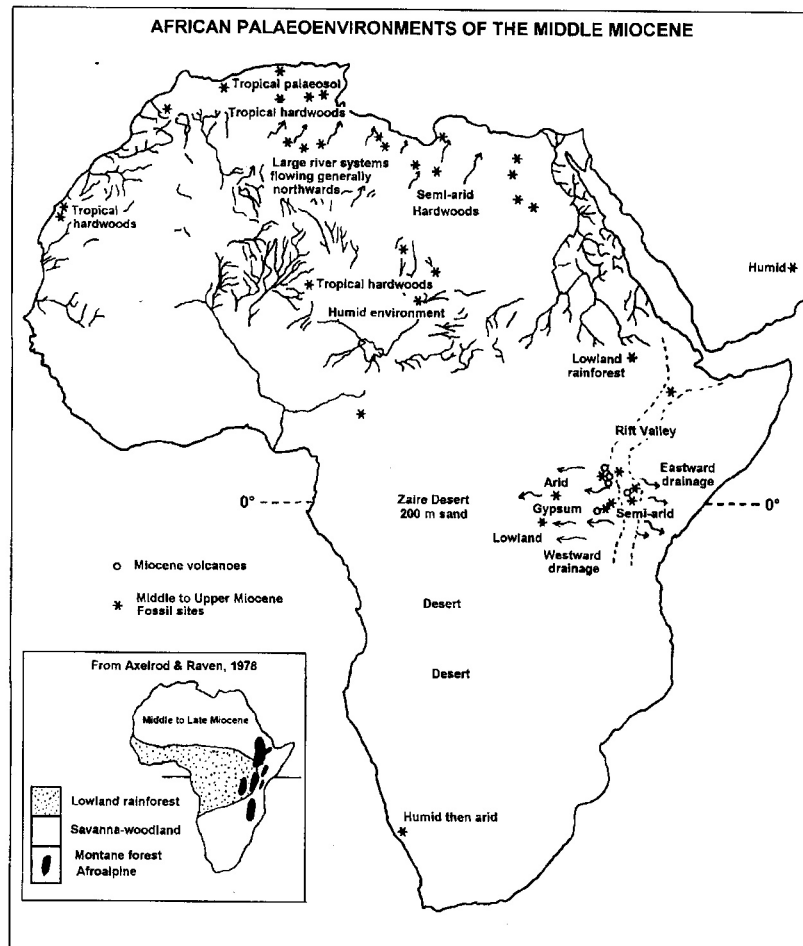


Figure 4-45.- Summary of Middle Miocene palaeoecological indications in Africa. The distribution of permanent rivers, forests and deserts was completely different during the Middle Miocene from what it is today. The accordion hypothesis of ecoclimatic belts, which is implicit in the figure from Axelrod & Raven (1978) does not accord with the available fossil and geomorphological evidence.

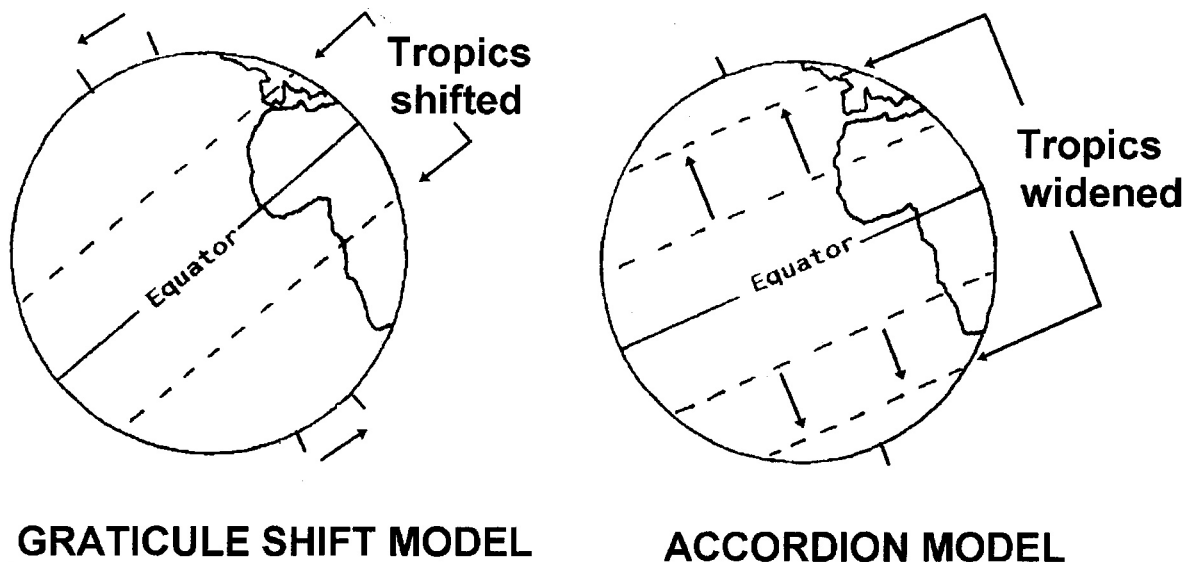


Figure 4-46.- Comparison of two hypotheses of ecoclimatic belts of the world. In the graticule shift model, the widths of the belts need not change a great deal, but their position on the globe shifts as the pole positions change. The accordion model posits a fixed equator and substantial changes in the widths of the various ecoclimatic belts. The debate is currently not settled, even though the majority of palaeoclimatologists assume that the equator has been fixed in position throughout geological history. Note that in both of these examples, Europe is tropicalised. However, in the graticule shift model southern Africa would become temperate whereas in the accordion model it would become more tropical.

changes symmetrically about a fixed equator (fig. 4-46). Less commonly encountered in the literature is the graticule shift model in which the position of the equator and the ecoclimatic belts move as the axis of rotation of the globe changes (Marchal, 1996).

There is great reticence on the part of many geotectonicians and geologists to accept that changes in the axis of rotation of the globe are possible (Pickford, 1996). However, in a fluid rotating planet such as the Earth, in which the distribution of mass at its surface is changing not only laterally (with continental shift) but also vertically (with uplift of vast areas such as the East African Dome and the Tibetan Plateau), it has been calculated that polar shifts amounting to tens of degrees would occur (Marchal, 1996, 1997). The movements would take place at virtually the same rate as the tectonic activity, implying a shift of some 10° of latitude in 2-3 million years.

The available climatic data from the Namib indicates that there were indeed major changes in the position of ecoclimatic belts during the Neogene. For example, during the Early Miocene the Namib lay within the sub-tropics and probably had summer rainfall, whereas during the Middle Miocene there was a switch to a temperate climate with winter rainfall. This evidence indicates that at the latitude of southern Namibia (29°S latitude) the subtropical belt moved equator wards between 16 and 14 Ma. In the

northern hemisphere at the latitude of Spain (40°N latitude) there is evidence that the boundary between the Palaeartic and Ethiopian Biogeographic Realms also moved equator wards during this time span (Pickford & Morales, 1994). This coincidence would tend to support the accordion model of ecoclimatic belts rather than the graticule shift model. However, more complete data is required from the southern hemisphere in order to understand more fully the history of the ecoclimatic belts and to evaluate the impact of the two models on the world's palaeoclimates.

4.13 PALAEOENVIRONMENTS

4.13.1 MARINE LITTORAL

4.13.1.1 Molluscs

Haughton (1931) was the first to notice that some of the molluscs from Namaqualand denoted warmer coastal waters than occur there today. Subsequent studies by Tankard & Rogers (1978), Kensley & Pether (1986) and Pether (1994) have confirmed Haughton's insight, and have extended both the data base and the interpretations. In the samples available to Kensley & Pether (1986) there are nine species with West African to Mediterranean zoogeographic affinities (table 4-3). Some of these are eurytopic, being tolerant of wide ranges of temperature, while others are more stenotopic, occurring mainly in warm tropical to

TABLE IV-3

ZOOGEOGRAPHIC AFFINITIES OF NAMAQUALAND MOLLUSCS
(from Kensley & Pether, 1986)
(50 = 50 mP, 30 = 30 mP)

West African-Mediterranean	W and E coasts of southern Africa	East coast of Africa
<i>Arca noae</i> 30	<i>Afrocominella capensis</i> 50	<i>Calyptrea helicoidea</i> 30
<i>Barnea truncata</i> 50, 30	<i>Amblychilepas scutellum</i> 50, 30	<i>Melliteryx capensis</i> 50
<i>Cantharidus striatus</i> 50	<i>Bullia annulata</i> 50	<i>Nassarius kochianus</i> 30
<i>Crepidula porcellana</i> 50	<i>Bullia digitalis</i> 50, 30	<i>Oxystele sinensis</i> 50, 30
<i>Leporimetis hanleyi</i> 50, 30	<i>Bullia laevis</i> 50	<i>Ringicula turtoni</i> 50
<i>Nuculana bicuspidata</i> 50, 30	<i>Burnupena papyracea</i> 50	<i>Arca avellana</i> 50
<i>Natica cf adansonii</i> 30	<i>Conus mozambicus</i> 50, 30	<i>Striostrea margaritacea</i> 50, 30
<i>Sinum concavum</i> 30	<i>Diodora elevata</i> 50, 30	<i>Tellina ponsonbyi</i> 50, 30
	<i>Fissurellidea aperta</i> 50	<i>Tugali barnardi</i> 50
	<i>Fusus faurei</i> ?50	<i>Turritella declivis</i> 50
	<i>Gibbula zonata patula</i> 50	<i>Cylichna tubulosa</i> 50
	<i>Nucella dubia</i> 50, 30	
	<i>Ocenebra purpuroides</i> 50	
	<i>Patella argenvillei</i> 50, 30	
	<i>Patella barbara</i> 50, 30	
	<i>Patella granatina</i> 30	
	<i>Patella miniata</i> 30	
	<i>Tricolia capensis</i> 50	
	<i>Turbo cidaris</i> 50, 30	
	<i>Turritella carinifera</i> 50, 30	
	<i>Aulacomya ater</i> 50, 30	
	<i>Choromytilus meridionalis</i> 30	
	<i>Perna perna</i> 50, 30	
	<i>Phaxas decipiens</i> 50, 30	
	<i>Scissodesma spengleri</i> 50	
	<i>Tellina trilatera</i> 50, 30	
	<i>Tivela cf compressa</i> 50, 30	
	<i>Venus verrucosa</i> 50, 30	
5/8 in 50 mP 6/8 in 30 mP	24/28 in 50 mP 17/28 in 30 mP	9/11 in 50 mP 5/11 in 30 mP

sub-tropical waters.

The *Donax haughtoni* and *Donax rogersi* packages both contain warm water marine faunas with West African affinities, whereas the sub-10 metre *Donax serra* beaches yield cold water molluscs with affinities to the Modern faunas of the region (Pether, 1994). Thus, through the Late Miocene and early Pleistocene, the coastal waters of Namaqualand were relatively warm, whereas by the Middle Pleistocene they had become cold.

4.13.1.2 Phosphorites

Tankard (1975) and Tankard & Rogers (1978) have linked the genesis of phosphorites along the coast of southwestern Africa to the upwelling of cold phosphate-rich waters along the coast which precipitated phosphates in the littoral zone as the waters became warmer in the vicinity of the coast and as the pII increased shorewards. The Namaqualand phosphates (Watkins *et al.*, 1995) which are mostly of mid to Late Miocene age would thus indicate that upwelling of cold waters began during the Middle Miocene, which accords with estimates made by other workers (Siesser, 1980). There is also agreement between the presence of warm water molluscs in the Miocene littoral sediments and the precipitation of phosphates in the same general region. By the Pleistocene however, the near-shore coastal waters had become cold and the precipitation of phosphorites decreased or stopped altogether.

4.13.2 TERRESTRIAL

4.13.2.1 Molluscs

Fossil terrestrial molluscs are very common in the Namib Coastal Plain deposits. The most commonly found is the genus *Trigonephrus* which is today confined to the southwest corner of Africa where the climate is temperate with winter rainfall (fig. 4-43). Ward *et al.*, (1993) suggested that the presence of this snail in the fossil record of the southern Namib indicated that winter rainfall had characterised the region since the beginning of the Middle Miocene.

The genera *Dorcasia* and *Xerocerastus* are much less commonly found in the Namib deposits, but they suggest sub-tropical to warm temperate environments, with summer rainfall. *Dorcasia* occurs today in the Orange River Valley, but it is a diminutive form at the edge of its range of distribution. The fossil *Dorcasia* from Grillental and Glastal are large specimens which resemble extant subtropical species from upland Namibia. *Xerocerastus* is a savanna form the distribution of which is confined to regions which receive summer rainfall. In the Namib it has only been found as a fossil at Obib, where it occurs in large quantities suggesting a short-lived incursion of summer rainfall to the edge of the Namib during the Pleistocene, in accord with other evidence such as calcrete pedogenesis.

4.13.2.2 Flora

Palaeobotanic remains have been found at several places in the Namib, but their stratigraphic representation is incomplete. Fossil wood is common at Auchas in the Proto-Orange deposits of Early Miocene age and the assemblage of genera (*Combretum*, *Terminalia*) is indicative of sub-tropical woodland and savannah (Pickford *et al.*, 1995) similar to the vegetation that grows today in the mopane woodlands of southern Africa (Zambezi Regional Centre of Endemism (II in fig. 2-8) and the Kalahari-High Veld Regional Transition Zone (XIV in fig. 2-8). Along the Proto-Orange, the vegetation might have been more luxuriant, as is suggested by the diversity and types of fossil fauna found at Auchas (Pickford *et al.*, 1995b) and the nearby site of Arrisdriest (Hendey, 1978).

At Swartlinterjies (Block 9) green clays of Late Miocene age (with the proboscidean *Anancus*) contain fossil leaves and plant stems that resemble those of extant fynbos vegetation (small, thick fleshy leaves, diminutive leaf size). If the determinations are correct, then it would imply that fynbos vegetation was established in Namaqualand by about 7-5 Ma. This in turn would indicate that there must have been a major climatic and vegetation change in the Namib some time during the Middle or Late Miocene from subtropical with summer rainfall before to temperate with winter rainfall afterwards.

Coetzee (1977, 1978, 1980, 1986), who examined the palynology of Tertiary strata of southwestern Africa reached a similar conclusion, though it must be admitted that the timing of events remains unclear, even if the sequence of events that he reconstructed is assured.

4.13.2.3 Fauna

The Early and Middle Miocene faunas of the Sperrgebiet indicate that the environment was open and relatively dry, such as savanna and woodland. Along water courses there would undoubtedly have been denser vegetation forming riparian forests (Hendey, 1978). Mammals from the Tsondab and Rooilepel Sandstones consist mainly of small forms (rodents, macroscelidids) but there are fragmentary remains of larger species such as gomphotheres, giraffids and carnivores. It is probable that taphonomic factors have played an important role in destroying large mammal skeletal remains, thereby skewing the Namib fossil record, but in any case the diversity and biomass of large mammals was probably always restricted in the Namib once desert conditions prevailed. Microfauna in contrast is rich and sometimes well preserved, indicating that, like today, the Namib has always been a living desert.

Virtually every outcrop of aeolianite in the Namib is riddled with trace fossils (Plate 5). Although many of these are of botanical origin (rhizoliths), it is clear from their morphology that a lot of them were made by faunal elements that burrowed into the sands before they were heavily indurated. Whilst it is difficult to identify what animals manufactured each type of trace fossil, it is clear that mammals, reptiles, molluscs and insects were all active in producing these traces. By analogy with traces made by present day inhabitants of the Namib, such as the

golden mole (*Eremitalpa*), the lizards, the tenebrionid beetles and termites (*Psammotermes* and *Hodotermes*) it has been possible to infer what kind of animals made the ichnofossils in the aeolianites. From this it is evident that for the past IS Ma, burrowing fauna has comprised an important element of the Namib habitat.

4.14 TAPHONOMY

4.14.1 SCATOLOGICAL ORIGIN OF SMALL MAMMAL CONCENTRATIONS IN THE EARLY MIOCENE OF ELISABETHFELD, NAMIBIA

In the red limey silts at Elisabethfeld there are rich but scattered concentrations of small mammal remains. In several of these patches, bone-rich carnivore coprolites are well preserved along with partly dispersed fossil scats and a spread of dispersed bones and teeth (Plate I, fig. 1, Plate 3). Many of the latter show characteristic erosion of the outer surfaces of the sort that occurs in the coprolites, indicating that these isolated fossils have also passed through the digestive tract of a small carnivore (Plate I, figs 3-5, Plate 2, figs 1-7). The fossiliferous coprolites collected at Elisabethfeld, numbering over a dozen, are all about the same dimensions as the scats of the extant Black Backed Jackal (*Canis mesomelas*) (Plate I, fig. 2) which occurs in the area today. The only known fossil carnivore from Elisabethfeld is the creodont *Metapterodon kaiseri* which was approximately the same size as a jackal, and could represent the agent responsible for the fossil concentrations.

There are three main features of interest, apart from the identification of the mode of concentration of the micromammals at the site. The first is that the patchy, but highly concentrated nature of the micromammal assemblages along with complete and partly dispersed scats suggests that the accumulating agent returned repeatedly to the same precise spot to defecate. This behaviour is characteristic of many carnivores which use such 'latrines' as a way of marking their territories. If so, then the Elisabethfeld occurrence would provide a glimpse into the possible behaviour of a lower Miocene carnivore of small to medium size.

Secondly, study of the microfossils using the scanning electron microscope reveals several different kinds of damage to the micromammalian fossils. The most obvious damage, visible even under a low power microscope, consists of etching of enamel and bone, probably by digestive enzymes. In teeth, the etching is concentrated preferentially in the enamel, but it can also affect cementum, as for example in lagomorph cheek teeth (Plate 2, fig. 1). In bones, acid attack affects both spongy and compact bone (Plate I, figs 3-5), but many of the bones are not affected, as though they were not in contact with digestive juices for very long, or were somehow protected from attack. A closer look reveals that it is only the bones exposed at the surface of the coprolites that show strong signs of

etching, while those in the centre of the coprolites show minimal etching. It would thus appear that in some cases the coprolite itself protected the unetched bones and teeth. This would indicate that some of the etching took place in the large intestine, well beyond the influence of stomach acids.

All the skulls and long bones of the micromammals are broken, but smaller bones such as vertebrae, phalanges, carpals and tarsals tend to be entire. The scanning electron microscope reveals that the broken long bones often possess scratch-like marks with depressed fractures (Plate 2, fig. 7), probably caused by biting or chewing with sharp pointed cusps of the cheek teeth. However, skulls and long bones are not broken into smithereens indicating that chewing was not prolonged and was not aimed at reducing the bones to a pulp. Instead, it would appear that the carnivore responsible for producing the coprolites would chew the prey item a few times to break the skull and long bones, after which it would swallow the specimen whole or in two or three chunks. The result is that each scat contains the remains of one or two, rarely three individual small mammals. Such a way of dealing with small mammal prey items is used by jackals, bat-eared foxes (*Otocyon megalotis*) and viverrids.

Thirdly the coprolites reveal something about the diet of one of the Early Miocene predators at Elisabethfeld. They have yielded a variety of small mammals and birds. Rodents (*Apodecter* sp.) were the most important prey species, whilst the small macroscelidid *Myohyrax* was a common element of the diet. The lagomorph *Austrolagomys inexpectatus* occurred rarely in the scats, as did the pedetid *Parapedetes namaquensis* and the large macroscelidid *Protypotheroides*, suggesting that these slightly larger mammals only formed an occasional item in the predator's diet. A few bird and lizard bones were found in some of the coprolites, while one yielded several snake vertebrae. Occasional bones and teeth of a small bovid (*Namibiomyx senuti*) and a juvenile individual of the hyracoid *Prohyrax tertarius* were found in the same scatters as the microfauna, and, judging from the etching that these have undergone, these relatively large mammals (body weight up to 3 kg) were also eaten by the predator.

Stromer (1926) thought that the micromammal concentrations at Elisabethfeld may have resulted from the activities of owls, but the coprolites collected by the Namibia Palaeontology Expedition have none of the hallmarks of owl pellets (complete skulls and limb bones, minimal etching of bone surfaces) but are instead typical of scats produced by small carnivores.

One of the fossil-rich patches at Elisabethfeld contained an extraordinary concentration of skeletons of small to medium mammals. Among the sample there were 13 individuals of a large species of *Protypotheroides*, several large rodents such as *Diamantomys luederitzi* and *Bathyergoides neotertarius*, some small rodents such as *Apodecter* sp., and *Protarsomys* sp., two small bovid individuals (*Namibiomyx senuti*), a hyracoid (*Prohyrax*

tertiarius), a bunodont macroscelidean (*Palaeothentoides* sp.) and a creodont (cf *Metapterodon kaiseri*). Many of the specimens were complete, but disarticulated and intermingled with each other. The form and restricted nature of this fossil concentration (30 cm diameter, 20 cm deep) suggests that the bones may have accumulated at the bottom of a burrow. Unfortunately, post-depositional compaction has fragmented many of the bones, jaws and teeth, making it difficult to extract entire specimens without them disintegrating into small pieces. At present they are being held together by a thin coating of calcareous crust which has formed around the material, thereby binding the separate fragments together.

A further peculiar point about the taphonomy of the Elisabethfeld site, is that several of the large rodent specimens, such as *Parapedetes namaquensis* occur as articulated skeletons. Stromer (1926) described one such specimen, the holotype of the species. The NPE found parts of two more individuals in articulation. It would appear that this was a burrowing rodent, and that the specimens found had died and been fossilised within their burrows. However, at the discovery sites, there were no obvious signs of burrow

structures, although the overbank deposits in which they occur show mottled colours which indicate the occurrence of slight pedogenesis.

The picture that emerges is that the red silts at Elisabethfeld accumulated in a floodplain setting between the branches of two streams. Flooding occurred only occasionally, so that pedogenic activity could proceed to the point where mottled soil structures resulted. The area was suited for burrowing mammals and was the preferred habitat for small carnivores and micromammals which left their calling cards on the surface of the soil. Larger denizens of the region included tortoises, ruminants (climacoceratids and bovids), hyracoids and the ratite *Struthio coppensi*. The high proportion of small mammals with hypsodont dentitions (*Myohyrax* sp., *Protypotheroides* sp., *Austrolagomys*) indicates that the main vegetation cover was grass, while the browsing ruminants and hyracoids indicate the presence of low bushes and trees. The floodplain was traversed from time to time by proboscideans which left their footprints in some of the shaley facies of the red silts (fig.4-47).

Nearby, fluvial sands and conglomerates have yield-

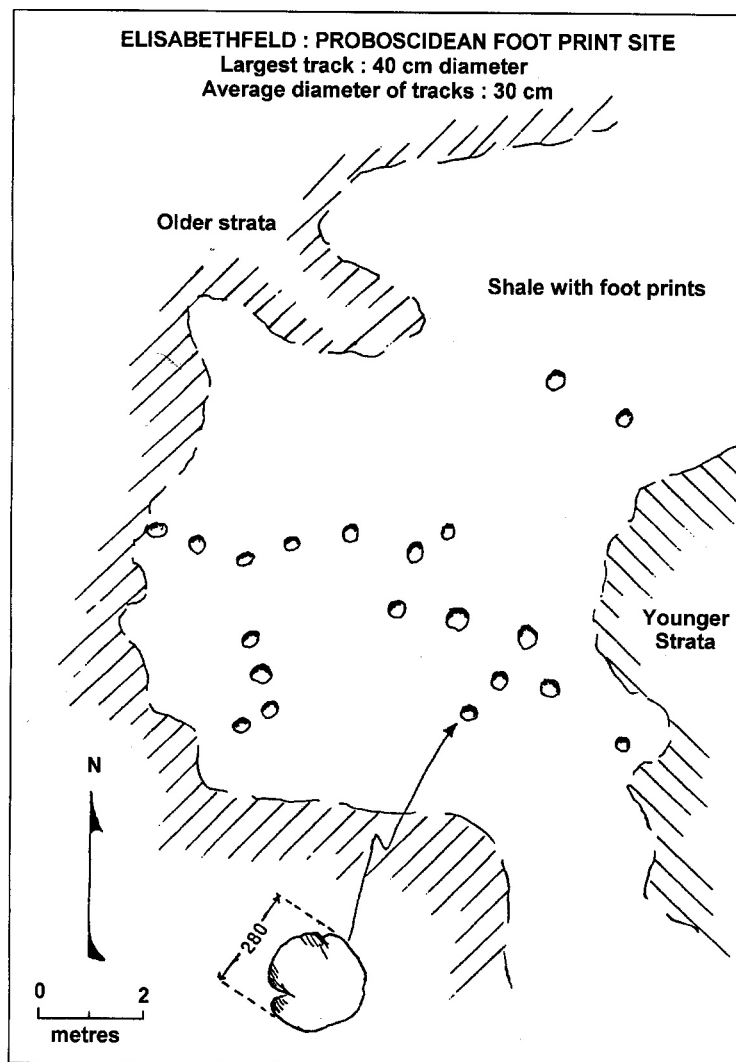


Figure 4-47.- Proboscidean trackway in Early Miocene shales at Elisabethfeld, Northern Sperrgebiet.

ed the remains of medium sized mammals such as small climacoceratids, suids, bovids and hyracoids. These remains tend to be scattered and sometimes abraded, but one specimen, a small climacoceratid, consisted of an articulated skeleton. The skeleton was partly buried in a shallow channel at the time of deposition, and only the parts that were buried survived. The broken and weathered ends of bones poke upwards into the overlying stratum, but nothing substantial occurs in the younger bed. It would appear that bones exposed at the surface at Elisabethfeld did not last very long. The exposed ends of the ruminant bones are chalky and highly fragmented, being typical of bone that has been exposed to the sun and has developed extensive cracking and fissuring to the point of disintegration. In contrast, bones that were quickly buried are well preserved.

4.14.2 ARRISDRIFT

Arrisdrift fossil site is located in a lateral channel of the proto-Orange River. As such, the fossil assemblage exhibits many of the taphonomical features associated with fluvial strata: disarticulated skeletons, abraded and broken bones and teeth and some evidence of reworked fossils. Many of the bones, especially long bones and mandibles, are distorted due to differential sediment compaction. Very few complete skulls occur at the site, they have usually been broken into fragments, partial maxillae being the best represented portions. Several bones and teeth have been attacked by gypsum crystal growth which usually destroys them. One hyracoid jaw was unusual in having the mandible faithfully replaced by gypsum while the teeth remained unaffected. A few long bones of ruminants were completely destroyed by gypsum formation, but not before the medullary cavity had been filled by calcite. The result was an accurate mould of the medullary cavity.

Examination of the collection reveals that several ruminant specimens possess bite marks of the sort made by crocodiles: well spaced puncture marks in line, puncture marks with characteristic 'croc-tooth' outlines. This would suggest that one of the main predators of the Arrisdrift ruminants was the crocodile. Crocodile bones and teeth comprise more than 10% of the fossil sample at Arrisdrift, counted as numbers of specimens. The discovery of a jaw of a hatchling crocodile indicates that they were breeding close to or at Arrisdrift.

Despite the fluvial nature of the Arrisdrift site, other than crocodiles there are very few aquatic vertebrates in the collection. Fish vertebrae are rare and no freshwater turtles have been recovered. No molluscs are preserved at the site, but serpulid worm tubes are extremely common, forming individual tubes and conjoined masses or reefs. The latter suggest that the environment was brackish water and near sea level.

The fine preservation of vertebrate remains at Arrisdrift is undoubtedly due in part to the nature of the underlying bedrock - metavolcanics of the Grootderm Formation - which is rich in calcite. In East Africa sediments rich in calcite tend to be the richest in fossil remains (Pickford, 1986b).

4.14.3 AEOLIANITES

The Rooilepel aeolianites are richly fossiliferous. The commonest fossils are termite structures, such as foraging tunnels, hives, nursery chambers and so on. Internal moulds of the snail *Trigonephrus* are also extremely abundant as are eggshell fragments of struthious birds. Vertebrate fossils are common, but are often difficult to see on account of the fact that many of them occur in nodules of sand. The occurrence of articulated skeletons or parts of skeletons is common, suggesting that the individuals were not greatly disturbed by post-mortem processes. Among the taxa found in articulation were pedetids, thryonomyids, dendromurids, and an orycteropodid. These were all probably burrowing mammals, and it is likely that they often died inside their burrows and were thus protected from damage.

A serious question that had to be addressed was whether the fossil mammals were 'intrusive' into the Rooilepel Aeolianites. If it could be demonstrated that the mammals were burrowing into the sands a long time after their deposition, then the resultant fossils would not be of direct use in determining the age of deposition of the sands, but only of the time that the mammals were burrowing into them. Even today, mammals are burrowing into the Rooilepel aeolianites.

Fortunately, at Rooilepel and elsewhere there are lag deposits and interdune bedded sediments. These often weather out as plate-like slabs of sandstone rich in clasts (granules) that are larger than aeolian sand (microregs). These deposits are also fossiliferous, and the material is usually disarticulated and scattered on the bedding planes. The accumulation of these fossils was contemporary with that of the deposits. Comparison of samples of these fossils with those that occur as articulated specimens in nodules reveals that they comprise the same taxa, from which we conclude that the burrowing mammals preserved at Rooilepel were active at the time of dune formation. They can thus be used to determine the age of the aeolianites.

A feature of the vertebrate fossils found at Rooilepel and elsewhere in the aeolianites, is that the specimens are always small. Even proboscidean teeth are represented by fragmentary specimens only a few centimetres long. The reason appears to be that only small bones and teeth are easily buried in sand, large bones tend to remain on the surface and, as a result, are more prone to predator attention and the desiccating rays of the sun. Even today, as one traverses the desert, one sees large bones in various stages of decomposition lying on the surface of the dunes. In the Sperrgebiet a few years of exposure suffices for an equid skull to decompose into tiny fragments.

4.15 ICHNOFOSSILS

The most obvious palaeontological remains throughout the aeolianites of the Namib are ichnofossils and rhizoliths. Exceptionally well preserved examples occur in the

Bushman Hill to Elbow Dune sector of the Namib Desert. These fossils consist of indurated sandstone which preserves the shape of the original burrows made by invertebrates and vertebrates, structures formed by termites with faecal pellets which have been replaced by sandstone, and root systems of plants.

There are several generations of ichnofossils in the Awasib area. Firstly, there are structures that were formed soon after deposition of the sands. Secondly, there are many structures which long post-date the deposition of the sands, some of the Miocene aeolianites containing ichnofossils of Pleistocene or Recent age. Several burrow-like ichnofossils occur in the area including those made by invertebrates such as termites and ants, but also by beetles and spiders. Others were made by vertebrates such as rodents and dune moles. The only burrow makers that can be identified with confidence are the sand termite *Psammotermes* and the mound termite *Hodotermes*. Large diameter (5cm) burrows with internal «swim» structures were probably made by a small mammal similar to the dune mole *Eremitalpa*. Several spiral burrows were found, one of them closely resembling the ichnogenus *Gyrolithus* which is an open, cork-screw spiral ending downwards in a blind pocket, often with a secondary spiral offshoot. Others, *Daimonhelix*, are closed, screw-like spirals descending vertically into the aeolianite (Plate 5, fig. 4).

Numerous ball-like and tube-like ichnofossils occur throughout the Namibian aeolianites (Plate 5, fig. 2). These are most likely to represent structures made by *Psammotermes*, although some of the balls could represent fossilised dung balls deposited by dung beetles. Masses of fecal pellets deposited by *Psammotermes* occur in abundance, as do «sand flowers», also probably made by the sand termite (Seely & Mitchell, 1986). Traces made by *Hodotermes* are rare in the Awasib area, but a superb example of a termitary occurs in a cliff in the Southern Locality, while open tubes lined with white material occur in places. In Early Miocene deposits at Fiskus, Grillental and Gypsum Plate Pan, the calcified fungus gardens of *Hodotermes* are preserved, but the time when these structures were built is not known. They could be contemporary with the Early Miocene deposits, or they could date from more recent times.

At Elisabethfeld, there is an exposure of red shale which is covered with footprints of proboscideans (fig. 4-47). The tracks are on average about 30 cm in diameter but reach 40 cm in width. The layout of the tracks suggest that one, or perhaps two, individuals crossed the area, but not in a straight line. The footprints are slightly impressed into the underlying shale and there are raised rims where mud was squeezed upwards round the edges of the feet.

Heinz (1932, 1933) described some Holocene mammal footprints from the northern Sperrgebiet. Tracks included those of giraffe and elephant which no longer occur in the area as well as those of large antelopes and hyaenas which do. Late Pleistocene clays near the mouth of the Orange

River contain abundant footprints of large mammals (hippos, large ruminants, and perhaps humans) and ostriches.

4.16 NAMIB-BENGUELA INTERACTIONS

4.16.1 UPWELLING

Upwelling of relatively cold waters along the coast of southwestern Africa has been going on since at least the Late Miocene (Siesser, 1980) on the basis of evidence from ocean cores and may have started during the Oligocene (Van Zinderen Bakker, 1975). The genesis of widespread deposits of phosphorite in the region is undoubtedly related to the upwelling of cold, organic-rich water which warmed as it approached the coastline, precipitating phosphates as the temperature and pH changed (Tankard & Rogers, 1978; Watkins *et al.*, 1995). Whilst there has been some uncertainty about when phosphogenesis started and for how long it continued, mainly because there were differing opinions about the ages of the raised littoral marine deposits along the Namaqualand coast, it now seems clear that the Late Miocene was the main period of deposition. It continued until the Late Pliocene after which phosphogenesis diminished, especially after the coastal waters became cold during the Pleistocene.

There is no evidence in the Namib deposits that could be used to infer that upwelling of cold water occurred along the coast any earlier than the Middle Miocene. This is not to say that there was no upwelling during the Oligocene and Early Miocene (Van Zinderen Bakker, 1975, 1984a, b, c), rather it was either taking place well offshore or upwelling waters were relatively warm. Examination of figures 4-28 and 4-29 reveals that the main period of phosphogenesis in the southeast Atlantic took place after the Middle Miocene plunge in ocean temperatures deduced from oxygen isotope data, and before the Late Pliocene plunge that heralded the Glacial Period. Thus there was a period of some 13 million years during which phosphogenesis occurred (ca 15 Ma to ca 2 Ma). Prior to this ocean waters were too warm, whilst after this the coastal waters were too cold for precipitation of phosphates. The peak of activity seems to have occurred about 7-5 Ma when the coastal waters of the Namib were still relatively warm as shown by the molluscan faunas.

Interaction between the Benguela Current and the Namib Desert thus has a long history spanning at least 15 million years. From this it would be difficult to evade the conclusion that hyperaridity in the Namib Desert was magnified by upwelling of the Benguela Current along the coast of Southwest Africa in a region that was in any case semi-arid to arid on account of its mid-latitude position near the eastern edge of a persistent anticyclone system, the South Atlantic Anticyclone. The interaction appears to have been stable over geological time, but there is no doubt that there have been fluctuations in the position of upwelling cells and the impact that they have had on the climate of the coastal strip. Eustatic shifts in sea-level would have played a role in determining the position of upwelling cells, while other factors also led to latitudinal

changes in the position of the cells, just as they do today. Nevertheless, the system of upwelling cells has been stable since the Middle Miocene, as has the general area in which they have been active.

4.16.2 SOUTHERLY WINDS

At present, the southerly winds along the coast of Namibia are among the most persistent on Earth. So active and boisterous are these winds that in the north of the Sperrgebiet they have scoured the land surface to such an extent that the effects are clearly visible in satellite images of the region, especially in the sector between Bogenfels and Lüderitz. In places yardangs have been eroded into bedrock ridges. This and other effects of the southerly winds on Namib landforms have been well described by Corbett (1989, 1993). The question is whether such persistent and violent winds have always characterised the Namib. There can be no doubt that southerly winds have played over the Namib for the past 15-16 million years. The aeolianite evidence strongly points to such a conclusion (Ward, 1987; Ward & Corbett, 1990) especially the northerly oriented dune bedding that occurs throughout the Namib Sand Sea, with few localised exceptions. The evidence that winds have been excessively strong is less compelling. The granule ripples produced at present in the Sperrgebiet, especially in the Buntfeldschuh - Kolmanoskop sector are one of the most striking features of such wind activity. Similar coarse granule deposits do occur in the Namib, but none of them are older than the Pliocene as far as is known. The oldest examples encountered comprise the Fiskus Sandstone in the Elisabeth Bay - Kolmanoskop area. Other than these strata, the Namib aeolianites appear to be rather ordinary desert sandstones resulting from deposition in dune systems such as the Modern Namib Sand Sea.

4.16.3 BERG WINDS

Berg winds blow from the continental interior towards the Atlantic (Whitaker, 1984) (figs 3-10 and 3-11). Even though these winds occur only a few times per year, mainly during the winter months, the amount of geological work they accomplish, in moving sand, blowing dust out to sea and eroding ventifacts, is impressive (Selby, 1977a, b). Indeed, a strong East Wind can move more sand in one day than the normal southerly winds will move over a much longer time span (Corbett, 1989). In the region between the Swakop and Kuiseb Rivers in the central Namib, sandblasting of rock surfaces and pebbles is almost monodirectional (Selby, 1977b) with 93% of all ventifacts measured having facets that indicated that the dominant sand-blasting winds blew from the northeast (i.e. Berg Winds). Fewer than 5% were produced by sandblasting from the southwest, which is the predominant wind direction in terms of annual frequency and duration. The marked difference in etching of rock surfaces is undoubtedly due to the fact that the Berg Winds are usually of high velocity, whereas the southerly winds are less so, even if they persist for considerably longer.

Measurement of the dip direction of dune bedding in

the Tsondab and Rooilepel Sandstones reveals that the predominant winds responsible for moving the dunes of the sand sea have been consistently from the south and southwest. However, there are some dunes with bedding oriented at marked offsets from the northeast, and some of these could be due to the occasional Berg Wind that blew in the past. However, no systematic survey has been done and it would be difficult to be dogmatic about the possibility.

4.16.4 HYPERARIDITY AND COASTAL FOGS OF THE NAMIB

There can be little doubt that the Benguela Current has contributed to the aridity of the Namib since at least the Middle Miocene. The effect of the cold upwelling water is to modify the climate along the coastal strip, in general making the atmosphere drier than it would be were there no upwelling. During the Neogene, the aridity of the Namib probably increased in stepwise fashion. During the Early Miocene the coastal plain was semi-arid to sub-humid. Between 16 and 14 Ma there was an increase in aridity and the onset of desertic conditions took place, and this coincides reasonably closely with the onset of upwelling of organic-rich water as evidenced by phosphogenesis in the southeast Atlantic (Watkins *et al.*, 1995). Coastal waters remained warm however until the end of the Pliocene as shown by the littoral molluscan faunas (Haughton, 1928, 1931; Pether, 1994). During the Pleistocene the temperature of the coastal waters off the Namib decreased as shown by the colonisation of the region by molluscs adapted to cold water and the disappearance of those adapted to warm water. This change again modified the climate of the Namib, principally by promoting conditions suitable for the generation of coastal fogs on a frequent basis (tens to hundreds of times per year). Thus, even though the Namib remained hyperarid, much of the coastal strip up to 30-40 km inland was subjected to frequent nocturnal fogs - often containing sea spray - which were blown gently inland by onshore breezes. The formation of gypcretes in the coastal belt indicates that sea spray has commonly blown inland since the Pleistocene. Prior to the Pleistocene however, fogs were probably infrequent along the Namib coast, or did not occur at all.

4.17 RELATIONSHIPS OF THE NAMIB DESERT

4.17.1 AFRICAN DESERTS

A question that springs to many peoples' minds is whether all the African deserts have the same age. The simple answer is they don't, yet this needs to be explained so that the installation of the desert belts of Africa can be envisaged as part of the development of global climatic systems during the Tertiary and Quaternary (fig. 4-48). In short, the Sahara is considerably younger than the Namib Desert, aridification starting there towards the end of the Late Miocene or during the Pliocene (Tiedemann *et al.*, 1989) in contrast to the Namib which became arid at the end of the Early Miocene some 10 or more million years earlier. The study of the history of African deserts

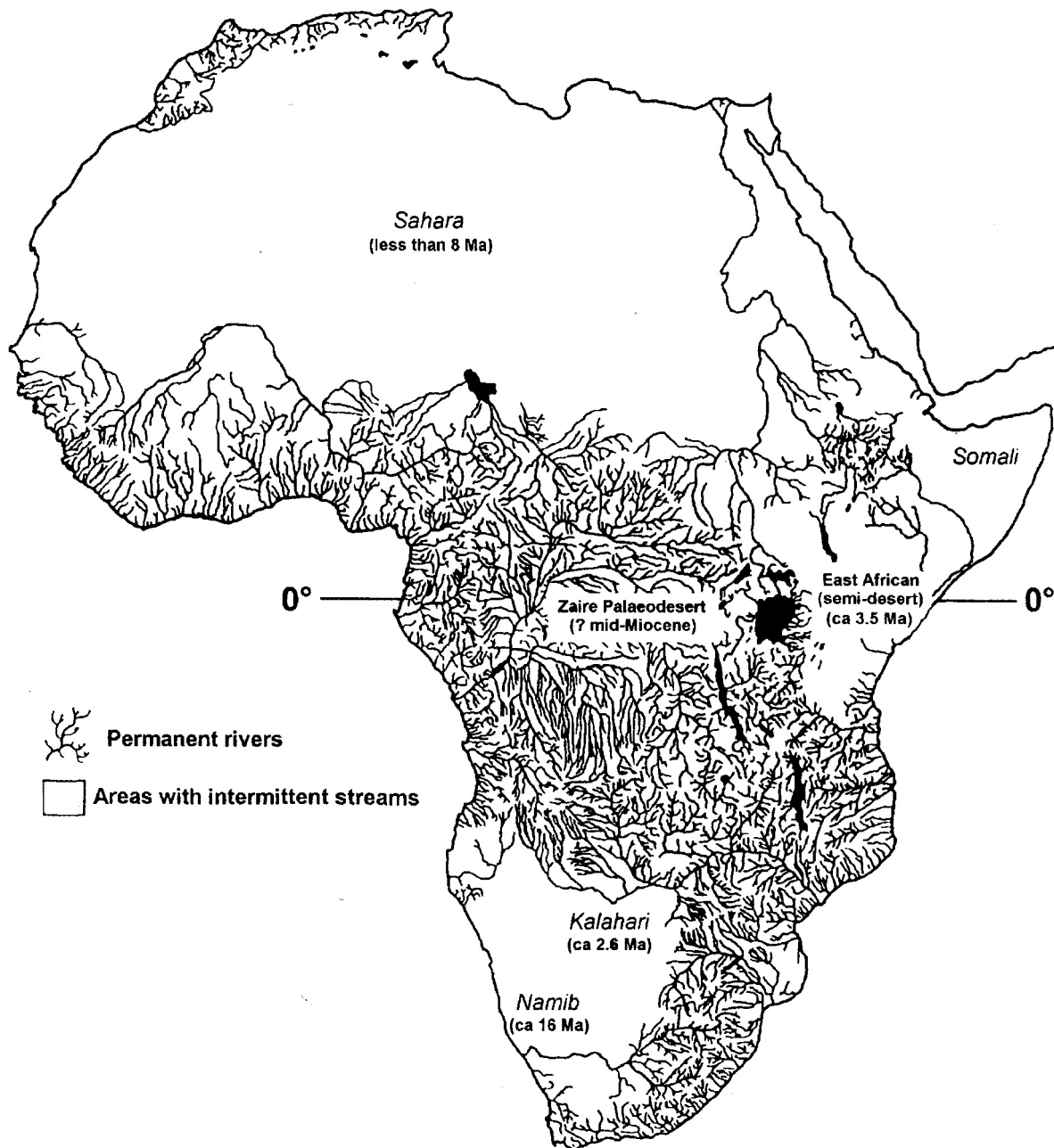


Figure 4-48.- Summary of the relationships between the arid zones of Africa, showing that they developed at different times during the Late Neogene. The Namib Desert dates from the beginning of the Middle Miocene or slightly earlier, whereas the Kalahari is essentially a Plio-Pleistocene desert. The Sahara became hyper-arid at the end of the Miocene and East African semi-desert was installed by about the Late Pliocene.

is complicated by the fact that there are vast expanses of aeolian sands where today there are tropical forests, such as in Gabon, Congo, Zaire and Angola (figs 4-45 and 2-7). The ages of these now defunct deserts are not well constrained, but the Zaire desert probably dates from the Middle Miocene and may have experienced a second pulse of aridity during the Pleistocene (Pickford, *et al.*, 1993). The Zaire Palaeodesert deposits blend southwards into the extant Kalahari Desert, and they may well belong to the same overall system of aridity, the geographic position of which

has shifted southwards over geological time. But there are widely differing opinions about the age and history of the Kalahari (Passarge, 1904; Thomas & Shaw, 1990). Leriche (1938) for example, concluded that the Kalahari Beds were Cretaceous on the grounds that the dinosaur *Kangnasaurus* occurred in fluvial sediments south of the Orange River thought to belong to the Kalahari Beds. However, the strata at Kangnas represent a crater filling of Cretaceous age (De Wit, *et al.*, 1992) and have nothing to do with deposition in the Kalahari Basin. Pickford (1990) concluded that de-

sertification of the western Kalahari, in the region of the Kwihaba Hills, began during the Late Pliocene to Early Pleistocene on the basis of the relationship between karst infillings and calcrete at Koanaka Caves. The period of cave formation, implying a climate appreciably more humid than today's, was Pliocene, whereas the main period of infilling with aeolian sands began in the early Pleistocene, virtually at the same time as the great sheets of calcrete were formed in the same region.

Even though the history of the Namib Desert is now relatively well constrained on the basis of fossil mammal biochronology, those of the Sahara and the former Zaire Desert are poorly known to unknown. It is therefore not possible to propose any robust climatic hypotheses which explain the development of all African Deserts. One is thus forced to look at the problem on a more parochial scale, and it would appear from this that the onset of aridification in the Namib at the end of the Early Miocene was related to the onset of continental scale glaciation in the Antarctic and one of its consequences, the upwelling of cold water along the coast of southwestern Africa.

4.17.2 WEST COAST DESERTS OF THE WORLD

If the onset of aridification in the Namib Desert was related to growth of the Antarctic Ice Cap and the related phenomenon of northwards flow of cold water which upwelled along the southwest coast of Africa, then it would appear to be likely that the coast of Africa would not be the only one affected. South America and Australia have coastlines between the 15°S and 30°S latitude and they also have west coast deserts, the Western Australian Desert in Australia and the Atacama Desert in South America. Even though the latitudinal spread of the deserts in these two continents is different from that of the Namib, because regions where the cold Antarctic waters well up depends on the topography of the ocean floor and on the strength and direction of winds that influence the coastal surface waters, it would appear that the west coast deserts in all three continents could indeed result from the same prime mover, the polar ice cap. One way to test this hypothesis is to determine the timing of the onset of aridity in the three deserts.

The Namib became hyperarid during the Middle Miocene. Desert conditions were also established along the southwestern coast of South America during the Miocene, but precisely when aridification started is not known. The timing of the origin of the Western Australian Desert is the least well known, and it is in any case poorly represented along the coast, being for the most part an inland desert which, in its geomorphological setting, is more akin to the Kalahari Desert than to a coastal desert such as the Namib. It is thus possible that at least the Namib and Atacama Deserts came into being at the same time, and therefore resulted from the same overall cause, which was probably growth of the Antarctic icecap to continental proportions during the Middle Miocene. The proximate

cause may well have been the upwelling of cold water along the respective coasts, but this cold water was ultimately derived from the high latitude regions surrounding Antarctica.

4.18 RATES OF EVOLUTION

Previous ideas about rates of evolution in the Namib fell broadly into two schools of thought. There were authors such as Koch (1962) who considered that the desert must be very ancient (Cretaceous) in order for the specialised fauna and flora of the region to have had time to evolve. For these scientists, the rates of evolution envisaged were extremely slow. For the second group (Endrödy-Younga, 1982) who considered that the desert was appreciably younger (Miocene), rates of evolution were postulated to have been much more rapid.

Now that we know that hyperaridity in the Namib is no older than the base of the Middle Miocene (ca 16 Ma) it is evident that rates of evolution have been orders of magnitude more rapid than considered possible by those who supported a Cretaceous age for the origin of the desert. This in turn implies more severe selection pressures and perhaps enhanced generation of genetic variability in desert environments, or a combination of both.

An unsatisfactory aspect of the debate about rates of evolution of the Namib fauna and flora, was that until recently its fossil record was non-existent. Thus there was no way of testing whether the specialised tenebrionid beetles found in the Namib have been there since the Cretaceous or only since the Miocene or later. Thus, proposals concerning rates of evolution were little more than personal opinions rather than being based on factual evidence. The fossil plant record of the Namib is still extremely poor, but there are some groups of vertebrates which have a better representation. In particular rodents and struthious bird eggshells are abundant and are present at many levels within the sequence of aeolianites. Both of these groups show rapid and dramatic evolution through the Namib geologic column. Although it is as yet difficult to quantify the changes because the studies of the material are still progressing, they are so clear that both groups are useful for biostratigraphic purposes.

Changes in the hypsodonty of pedetid cheek teeth have been demonstrated (Mein, in prep.) which permit four or five biozones to be distinguished in the Namib aeolianites. This represents a duration of about 3 million years per biozone. However, the evolution of the cheek teeth of pedetids appears to have been gradual rather than saltatorial, so that the boundaries of the biozones are not sharp. Fossil struthious eggshells evolved so rapidly that at least 8 biozones can be defined for the Namib aeolianite succession (Pickford *et al.*, 1995; Senut & Pickford, 1995b) which is a resolution of about 2 million years per biozone, or perhaps less than this if desertification began later than 16 Ma. As with the pedetid teeth, the changes in struthious eggshell morphology appear to have been gradual rather than saltatorial, but there is no doubt that

changes were rapid.

It would appear from the available fossils that the major force for evolutionary change in the Namib was severe natural selection acting upon normal amounts of biological variability rather than enhanced production of variability. The fossil eggshells in particular, reveal that at any particular stratum, variability was not very great, suggesting that the genome at any one stratigraphic interval was relatively homogeneous. Nevertheless there must have been genomic changes through geological time, but these could have occurred at similar rates to those that characterised struthious birds elsewhere in the continent.

4.19 ARCHAEOLOGY

Stone artefacts of various kinds occur throughout the Namib (Martin, 1957). The earliest identified tools consist of artefacts of Oldowan typology and Acheulean hand axes, cleavers and «bolas» stones (Corvinus, 1978b, 1983). Many of the hand axes are rather small (less than 10cm long). Acheulean sites are known at Obib and Swartlintjies. The latter site is associated with mammalian and chelonian remains and the stone tools in it are in mint condition.

Middle Stone Age lithic blades, arrow heads, scrapers and cores occur in many places in the desert. Some of the long slim blades show immense skill on the part of the knappers and a fine knowledge of the flaking properties of the different types of stone available. Late Stone Age implements

are rarer in the Namib, but a concentration of microliths was found near Zweikuppenberg (fig. 4-9).

Grind stones and rubbing stones occur in several places along the eastern edges of the Namib. The most impressive localities with grind stones are at Dead Tree Pan (west of Bushman Hill) at Tree Pan and at Elbow Dune (Southern Locality). At the latter site there are abundant bones, ostrich eggshells and stone tools at the bottom of a blow-out depression. The Elbow Dune locality contains several mortars and grind stones. The latter are unusual because of their small size and because they are worn at their ends and not their sides. These peculiar grind stones are so small that they must have been held in one hand.

Awasiib waterhole was evidently a major resource to ancient humans. There are immense quantities of stone tools and ostrich eggshells, some decorated, lying all over the place. In the Awasiib region there are elaborately constructed lines of stones used to direct game animals into areas where they could be hunted more easily than by following them in the plains. There are also stone mounds in various places, but little work has been done on these archaeological remains.

Dolomite outcrops near Daberas have been decorated with petro glyphs of various kinds at different times. The subjects consist mainly of pictures of animals, but there are also some geometric designs, perhaps representing structures such as buildings or game traps.

5. CONCLUSIONS

The Namib coastal plain of Namibia and South Africa possesses a heterogeneous cover of Cenozoic sedimentary and volcanic rocks overlying Late Proterozoic metamorphic and igneous bedrock. Sediments range in type from fully marine calcareous sediments of Cretaceous age, to littoral marine and terrestrial deposits of Eocene and Early Miocene to Recent age. The terrestrial deposits are highly diverse and include volcanic rocks, fluvio-paludal and pan sediments, crater infillings, palaeosols of various sorts, travertine, tufa and aeolianites. The last category is by far the most voluminous, covering about half the southern Namib to a depth of up to 200 metres.

By 1990 fewer than a score of fossiliferous localities had been recorded in the southern Namib. Apart from a few sites, most of these were poorly dated, their geochronological positions often being out by an order of magnitude or more. North of the Orange River most sediment units were thought to be considerably older than they actually are, whereas south of the Orange they were generally considered to be much younger than they really are. Some of the mammal sites, including Elisabethfeld, Langental and Arrisdrift have been reasonably well dated since their discovery, as have some of the more ancient marine faunal levels (Wanderfeld IV and Langental Eocene site). The outcome was that researchers were hampered in their efforts to determine not only the timing of geological events, but also the sequence of events, uncertainties which led to erroneous reconstructions of the geological history of the region being proposed. The NPE and PESA have documented well over a hundred localities in the Namib which have yielded faunas that allow biostratigraphic correlations to be made to calibrated successions elsewhere in Africa and even Europe. The fact that many of the Namib fossil mammals occur in the East African fossil record where the faunal sequence has been dated by radioisotopic methods, has allowed the ages of most of the Namib sediment bodies to be estimated with an accuracy of about 1 million years.

As a result, the biostratigraphic and geochronologic results of NPE and PESA have refined our understanding of the geological history of the region (Tables 5-1 & 5-2). Events such as the erosion of the Namib Unconformity Surface and the onset of desert conditions in the Namib that were previously considered to be of Late Cretaceous or Palaeocene age, are now known to date from the Early to Middle Miocene while some extensive calcrete deposits hitherto reported to be Middle Miocene are in fact Pliocene to Late Pleistocene. In some instances the sequence of events has been revised, especially the superpositional relationships between the Early Miocene fluvio-paludal deposits of the northern Sperrgebiet and the Tsondab Sandstones. Previously considered to be older than these fluvio-paludal deposits, the Tsondab Aeolianites are in fact younger than them, and as a consequence, they do not represent a pluvial phase in the history of the Namib Desert. In the Kuiseb Valley, in contrast, the Karpfenkliff Conglomerate probably represents a humid phase in the Namib early in the Pliocene (Ward, 1987; Ward & Corbett, 1990). In Namaqua-

land, faunal dating of the various littoral marine sediment packages has revealed that they are all considerably older than previously thought. The 90 metre package, hitherto correlated to the Late Pliocene or Early Pleistocene is Early to basal Middle Miocene in age. Gravels below the 50 metre package at Hondeklip Bay are late Middle to early Upper Miocene age while the 50 metre package itself, which was previously thought to date from the Pleistocene, is of Late Miocene to Early Pliocene age. The 30 metre package is Late Pliocene to Early Pleistocene rather than Late Pleistocene.

These revisions impinge on many other aspects of Namib geology, including palaeoecology, palaeo-climatology, geomorphology and palaeobiology. For example, rates of evolution in the Namib have been considerably more rapid than thought possible by authors such as Koch (1962) who concluded that the desert must have formed during the Cretaceous in order that the highly endemic beetle fauna could have had time to evolve. This evolution must now be envisaged as having taken less than 16-15 million years rather than 65 million years or more. Rates of erosion, in contrast, need not have been as rapid as previously thought, since the Namib Unconformity Surface dates from the Middle Miocene in its type area rather than from the Cretaceous or Palaeocene. Nevertheless, rates of erosion that we have been able to calculate in the vicinity of Chalcedon Tafelberg, can reach figures of 15 metres of vertical downwasting per million years which is rapid by any scale of measure. It should be pointed out however, that these figures may only apply to specific coastal zones of high intensity winds. In this particular case the erosion was predominantly by aeolian deflation processes, and these have undoubtedly played the most important role in recent geological times in concentrating the diamond placers of the northern Sperrgebiet (Corbett, 1989).

The history of eustatic change in Namaqualand has been revised by the new data. Historically there has been a tendency to underestimate the age of littoral sediment packages, with various attempts being made to correlate them to Quaternary fluctuations in sea-level brought about by the waxing and waning of polar ice caps. However, the removal of three of the sediment packages from the Pleistocene and their placement in the Miocene and Pliocene completely modifies previous concepts, and leads to a closer accord between the eustatic history of the southeast Atlantic and that of other parts of the world such as Australia.

Sea-level was considerably lower during the Oligocene than it is today, and all the major rivers and streams draining the Namib incised valleys into the coastal plain. These can be followed out to sea in some cases such as the Kaukausib and Orange. The Early Miocene was a period of transgression with sea-level culminating at least 50 metres and possibly 90 metres above Modern sea-level. The Middle Miocene was a period of regression during which the 90 metre package was deposited. This was followed by a transgression of late Middle Miocene age (12-10 Ma). The Late Miocene (7-5 Ma) was a further period of transgression to 50 metres

TABLE 5-1

SUMMARY OF THE MAIN GEOLOGICAL EVENTS IN THE NAMIB COASTAL PLAIN, NAMIBIA, SINCE THE SEPARATION OF SOUTH AMERICA FROM AFRICA DURING THE HAUTERIVIAN (* = diamondiferous strata)
<p>Sossus Sand Sea Russel's Perch aeolianite formed (Anntental) Sandstone) Modern beaches of the Sperrgebiet. Cold water fauna*</p> <p>Deposition of 2 metre raised beach* Marine transgression to 2 metres asl. Cold water fauna</p> <p>Deposition of 5 metre raised beach* Marine transgression to 5 metres asl. Cold water fauna</p> <p>Deposition of 8 metre raised beach* Marine transgression to 8 metres asl, installation of cold water molluscan faunas</p> <p>Widespread calcrete genesis in Namib Coastal Plain Obib Aeolianites accumulated</p> <p>Travertines and grits of the northern Sperrgebiet (Kaukausib, Grillental, Gamachab) ca 2 Ma Fiskus Aeolianites deposited</p> <p>Deposition of regressive marine <i>Donax rogersi</i> package ca 3-2.5 M* ?Deposition of Meso-Orange Terrace III? Marine transgression to ca 30 metres asl ca 3-2.5 Ma. Warm water fauna Arrival of <i>Equus</i> in the Namib</p> <p>Deposition of regressive marine <i>Donax haughtoni</i> package ca 7-5 Ma* ?Deposition of Meso-Orange Terrace II? Marine transgression to ca 50 metres asl ca 7 Ma. Warm water fauna</p> <p>Onset of phosphorite genesis (Rooikop)</p> <p>?Pomona silicified regoliths? Chalcedon Tafelberg siliceous/dolomitic strata accumulate in crater Pedogenesis and weathering of monchiquite Chalcedon Tafelberg crater formed ca 15 Ma</p> <p>Onset of arid to hyperarid conditions in the Central Namib (Rooilepel and Tsondeb Aeolianites)</p> <p>Proto-Orange Terrace I deposited (Auchas, Arrisdrift, Baken) ca 19-17.5 Ma* Backponding of valleys in the northern Sperrgebiet (Fiskus, Grillental, Elisabeth Bay, Elisabethfeld, Langental faunas) ca 20-19 Ma Marine transgression to ca 90 metres asl ca 20-17.5 Ma</p> <p>Deep incision of the Orange River Valley (to ca 40 metres below sea level) (ca Oligocene 27-22.5 Ma)</p> <p>Cessation of kaolinitisation in the Namib ca basal Miocene (ca 23 Ma) ?Skilpadberg Silcrete genesis? Kaolinitisation of bedrock cropping out at the Namib Unconformity Surface (ca Oligocene, 31-27 Ma)</p> <p>Langental Eocene marine deposits ca 34 Ma Klinghardt Phonolite eruptions ca 37 Ma Swartkop fluvial sediments (later silicified after being buried by phonolite flow)</p> <p>?Buntfeldschuh marine levels? (Bartonian ca 43 Ma)*</p> <p>Wanderfeld IV marine deposits in northern Sperrgebiet ca 95 Ma</p> <p>Onset of backwearing of the Great Escarpment and formation of the Namib Coastal Plain Separation of South America from Africa during the Hauterivian ca 120 Ma</p>

TABLE 5-2

SUMMARY OF MAIN GEOLOGICAL EVENTS IN THE NAMAQUALAND COASTAL PLAIN, SOUTH AFRICA, SINCE CONTINENTAL BREAK-UP IN THE HAUTERIVIAN

* = diamond-bearing sediments

<p>Swartduinen mobile dunes ca 10 Ka to 0 Ka Establishment of modern conditions along the coastline of southwestern Africa ca 10 Ka. Cold water fauna* Deposition of raised beach 2 metres asl* Transgression to +2 metres asl followed by marine regression. Cold water fauna.</p> <p>Deposition of 5 metre raised beach followed by marine regression* Transgression to +5 metres asl. Cold water fauna.</p> <p>Deposition of 8 metre raised beach deposits followed by marine regression.* Marine transgression to +8 metres asl. Cold water fauna First evidence of cold coastal waters in Namaqualand based on molluscan assemblages. Calcrete pedogenesis of littoral sands in Namaqualand (Swartduinen fauna) ca 20 Ka Aeolianite deposition in Namaqualand Coastal Plain</p> <p>Acheulean artefacts accumulate in murrum palaeosols (Swartlinterjies fauna and artefacts) ca 0.5 Ma Rubification of the sands of Namaqualand Accumulation of aeolianites throughout much of the Namaqualand Coastal Plain</p> <p>Deposition of terrigenous deposits associated with the <i>Donax rogersi</i> package (terrestrial fauna at Hondeklip Bay) Deposition of regressive littoral sediments of the <i>Donax rogersi</i> package* ?Deposition of Meso-Orange Terrace III? Marine transgression to +/-30 metres asl ca 3-2.5 Ma. Warm water fauna Arrival of <i>Equus</i> in Namaqualand ca 2.6 Ma</p> <p>Deposition of terrestrial sands associated with the <i>Donax haughtoni</i> package Onset of deposition of sediments at Areb (High Namaqualand) ca 6-4 Ma First evidence of fynbos vegetation in Namaqualand (Swartlinterjies) (could have been established earlier) Deposition of littoral strata of <i>Donax haughtoni</i> package some of which are silicified (H. Bay and Langebaanweg faunas) ca 7-5 Ma* ?Deposition of the Mesa-Orange Terrace II? Marine transgression to +/-50 metres asl, peak production of phosphorite, ca 7 Ma. Water water fauna.</p> <p>Deposition of coastal aeolianites in the Saldanha region (Prospect Hill <i>Diamantornis wardi</i> aeolianite) Arrival of <i>Hipparion</i> in Namaqualand ca 10.5-11 Ma <i>Agnotherium/Tetralophodon</i> at Hondeklip Bay (ca 14-11 Ma) Onset of phosphorite genesis in southeast Atlantic littoral settings</p> <p>Deposition of basal grits at Bosluis Pan (High Namaqualand) ca 16 Ma* Regressive littoral deposits of the <i>Kenyasus/Nguruwe</i> package (Ryskop fauna ca 18 Ma* Deposition of Proto-Orange Terrace I (Baken, Auchas, Arrisdriest faunas) ca 19-17.5 Ma* ?Deposition of gravels at Nuttabooi and Kommaggas some of which are silicified* Marine transgression to +/-90 metres asl ca 20-17.5 Ma</p> <p>Intraformational conglomerates deposited in Ryskop channel Accumulation of sands in palaeochannels at Koingnaas and Ryskop (sands ferruginised earlier than 18 Ma) Deposition of peaty clays in palaeochannels at Koingnaas and Ryskop (=?Elandsfontyn Formation ca 22 Ma))</p> <p>Cessation of kaolinitisation in Namaqualand ca basal Lower Miocene (ca 23-22 Ma) Incision of channels into kaolinitised bedrock (ca 23.5 Ma) Onset of kaolinitisation of bedrock and basal conglomerates in the Namaqualand Coastal Plain (ca Late Oligocene 31-27 Ma) Deposition of conglomerates in bedrock channels incising the Namaqualand Coastal Plain* Incision of the Namaqualand Coastal Plain</p> <p>Onset of backwearing of the Great Escarpment and formation of the Namaqualand Coastal Plain Separation of South America from Africa ca 120-130 Ma</p>

asl with the Pliocene being one of regression during which the 50 metre package accumulated. A further transgression to 30 metres asl took place at the end of the Pliocene. During the Pleistocene the three sub-10 metre raised beaches were formed.

With the rise and fall of sea-level, the base level of rivers draining into the Atlantic was altered. One result of this was the accumulation of fluvial strata during transgressive phases. Indeed, it is thanks to a major transgression during the Early Miocene that the Namib has such a good fossil record for this period, with several major localities in the northern Sperrgebiet and the Orange River Valley (the Proto-Orange Terrace). Among the faunas and floras collected in these fluvio-paludal deposits there are many new taxa of mammals, birds and reptiles. In particular the NPE has recovered abundant micromammals from several sites. Further marine transgressions occurred during the Late Miocene and Late Pliocene which led to the formation of the Meso-Orange terraces, but these are poorly fossiliferous.

Kaolinisation of bedrock and sediments in Namaqualand took place in pre-Miocene times on the basis of the discovery of Early Miocene mammals at Ryskop in sediments that unconformably overlie the kaolinites. In Namaqualand, the weathering that produced these kaolinites is considered to have occurred during the Oligocene, but in the Sperrgebiet kaolinisation occurred prior to the Lutetian (Middle Eocene). Previously this weathering was thought to have occurred late in the Cretaceous.

The onset of arid to hyperarid conditions in the Namib took place during the Middle Miocene some 16-15 Ma. Prior to this the region was semi-arid to sub-humid as shown by the fauna and flora from numerous localities and by the palaeosols that were formed. Thus in the Central and Southern Namib coastal strip, from the Late Oligocene to the Middle Miocene there was a trend towards increased aridity. Apart from minor fluctuations in climate which led to the production of calcrete horizons and travertine deposits during the Plio-Pleistocene, the Namib had been arid ever since the Middle Miocene.

Vegetation in the Southern and Central Namib changed dramatically during the Miocene. In the Early and basal Middle Miocene strata, the macrobotanical and palynological data indicate that the region enjoyed a tropical to sub-tropical climate with sub-humid to semi-arid conditions. The rainfall probably fell mainly during the summer months. By the end of the Miocene the region had become temperate with winter rainfall and the fynbos vegetation had been installed, as shown by fossil leaves at Swartlinterjies and pollen spectra from several sites. There was a brief amelioration of climate during the Pleistocene during which the Namib became more humid and possibly warmer, but this did not last very long.

Despite the aridity that the Namib has experienced for the past 16-15 million years, it has always been well endowed with fauna and flora. The extensive aeolian deposits that formed show abundant and ubiquitous signs of infaunal activity of many varieties (Plate 5). These range from rhizo-

liths, to insect and mammal burrows, to termite hives and foraging tunnels. Body fossils are common in the aeolianites, and reveal that the Namib has been home to micromammals and large mammals and birds since its inception (fig. 4-40). Many of the taxa discovered by the NPE in the aeolianites are new to science. Struthious birds have left behind an incomparable record of their presence in the form of thousands of eggshell fragments. Eight major eggshell types have been documented which always occur in the same stratigraphic order. The surface morphology and thickness of eggshells changed rapidly through time with the result that they form the basis for a local biostratigraphic scale with geochronological resolution on the order of 1.5 to 2 million years.

Coastal waters were warm throughout the Palaeogene and much of the Neogene as revealed by the nature of the molluscan faunas and other marine organisms including corals that occur in the littoral marine deposits. During the Pleistocene in contrast, the coastal waters of the Namib became cold and the region was colonised by cold water faunas (fig. 5-1). The climate of the coastal strip changed at this time, and the occurrence of fogs and sea spray became frequent as shown by the formation of gypcretes up and down the coastal plain. Prior to this, fogs were probably rare to non-existent along the Namib coast.

The formation of vast deposits of phosphorite in the south-east Atlantic coincides in timing with the period of desertification of the Namib, suggesting that the two phenomena were linked to the same overall cause. It has long been postulated that the upwelling of cold waters brought from polar regions by the Benguela Current contributed to the aridity of the Namib, and the new findings must remove much of the residual doubt that remains in the minds of those researchers who have considered that the two phenomena were seriously offset in time. The phosphorites formed throughout the Middle and Late Miocene and Pliocene from upwelling organic-rich waters that warmed up as they approached the Namib coast. During the Pleistocene, as the coastal waters became cold, precipitation of phosphorite slowed down considerably or even stopped altogether.

When the revised geological history of the Namib is compared to global geological history, there are several striking correlations to be found, including the eustatic events already noted. Detailed comparison of coastal water temperatures, even though the Namib record is by no means complete, shows a broad agreement with ocean water temperature curves based on oxygen isotope measurements of benthic foraminifera. Furthermore, major plunges in ocean water temperature that took place during the Middle Miocene and at the end of the Pliocene accord closely in time with major palaeoclimatic events in the Namib, namely the onset of hyper aridity in the Middle Miocene and the installation of cold coastal waters during the Pleistocene. Thus, Namib geological history was not delinked from that of the rest of the globe but is best understood within a global context, especially that of the world's oceans and atmosphere. Nevertheless, the Namib underwent many more localised processes such as travertine formation and calcrete pedogenesis, but even these can best be explained in terms of global scale climatic changes rather than as parochial events.

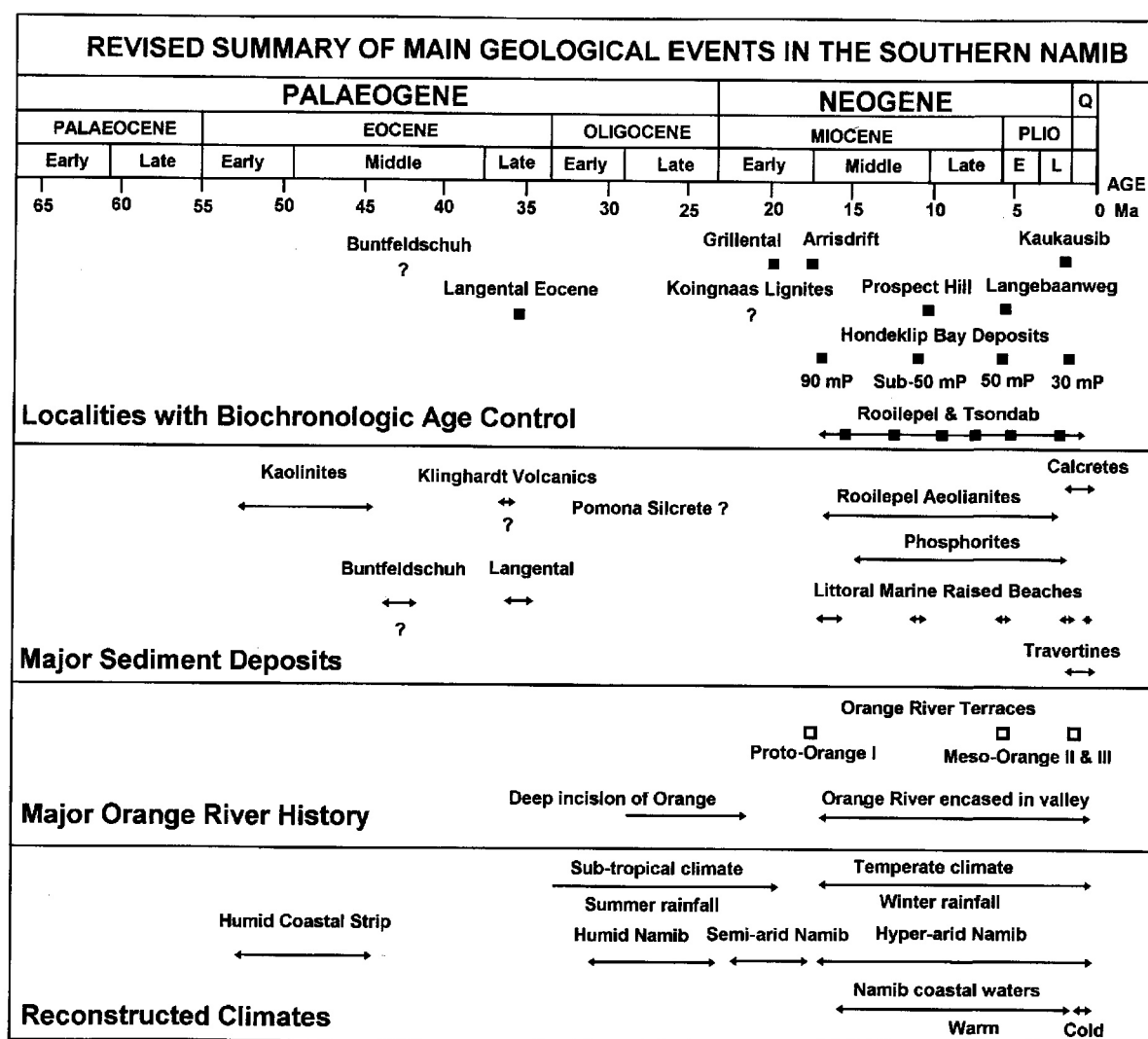


Figure 5-1.- Revised summary of some of the geological events that took place in the Namib during the Cenozoic. Compare this revision with that of Pether (1994) presented in figure 3-3.

There were however some genuinely local events, such as the Klinghardt volcanicity and the emplacement of the Chalcedon Tafelberg monchiquite and the subsequent infilling of crater with sediments.

In the Namib, there remain several major geological conundrums to be solved. Some of them are classic issues such as the age of the Bunfeldschuh sediments, the origin and age of the Pomona silicified regolith and the Kakoberg ferruginous deposits. Others are less well known but are nevertheless important, including epeirogenic movements of the crust which undoubtedly played a role in Namib geomorphology, but which have been difficult to pin down. The word "silcrete" raises many hackles among the fraternity of Namib geologists, and silicified sediments have been the subject of active debate in the literature. In fact, as was shown by Pether (1994) the pooling of all siliceous strata in the Namib into a single unit is surely unwarranted. These deposits formed by at least three different

processes at different times. Yet the timing of silicification has yet to be determined, with several major differences of opinion being voiced in the literature. It is now known that some of these deposits date from the Miocene or later (Chalcedon Tafelberg, The Point, Somnaas, Little Karoo) but others predate or coincide with the period of incision of the lower reaches of the Orange River (Oligocene) into its present valley. The precise ages of lignitiferous (peaty) deposits in channels of pre-Middle Miocene age at Koingnaas, Ryskop, Kareedornvlei, Noup and other sites need to be determined. At present they are considered to be of Late Oligocene or Early Miocene age, but no direct evidence as to their period of deposition has been forthcoming.

Finally, there can be little doubt that this revision of Namib geology will lead to a better appreciation of the timing and the processes of diamondiferous ore genesis in the southwestern African coastal strip, and their reworking by marine, fluvial and aeolian processes.

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PLATE 3

(scale bars 2 cm)

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(scale bar 2 cm)

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(scale bar 2 cm)

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PLATE 1



PLATE 2

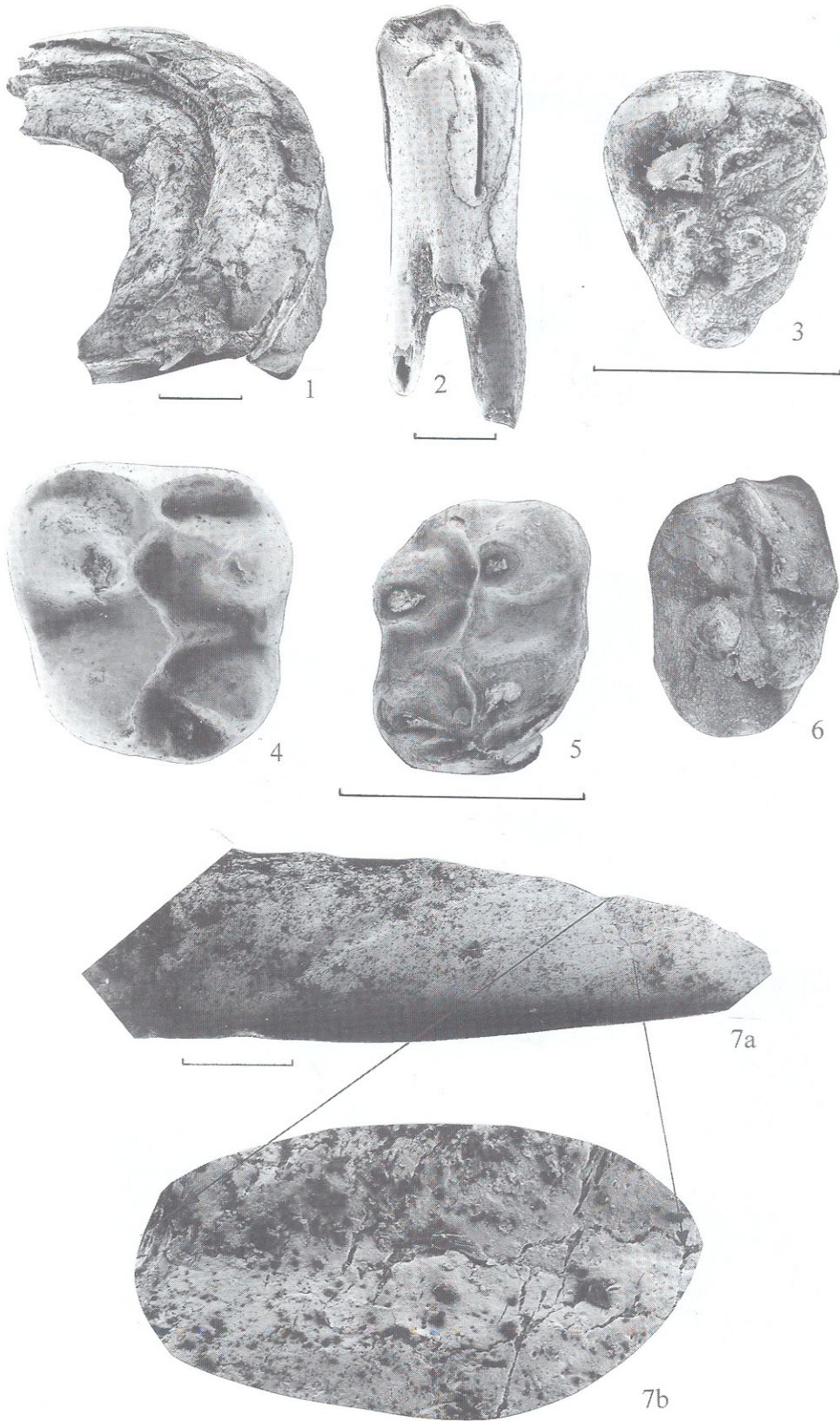
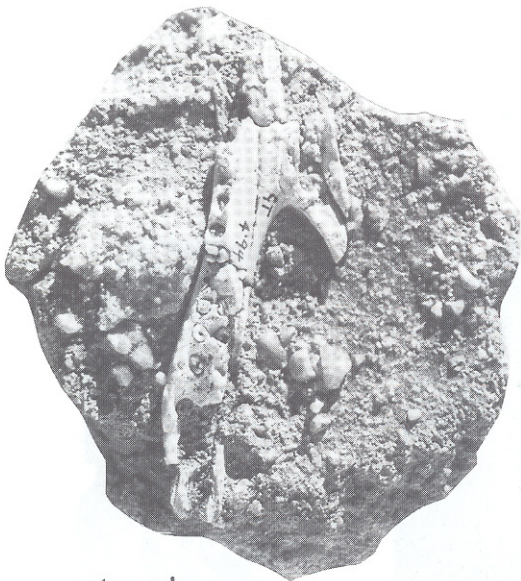


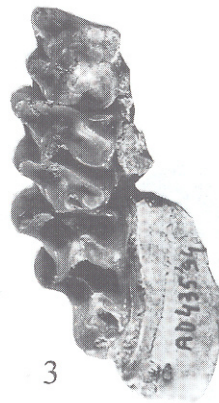
PLATE 3



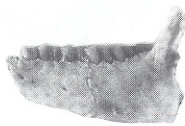
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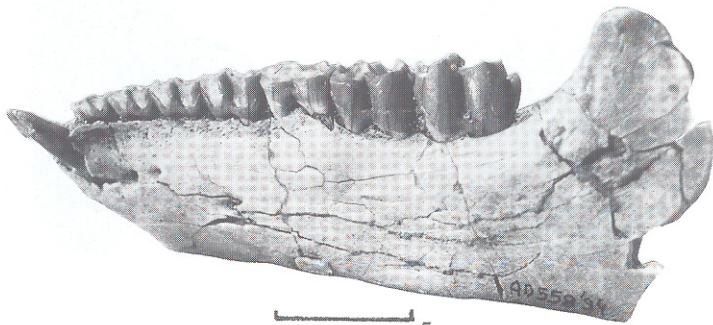
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PLATE 4

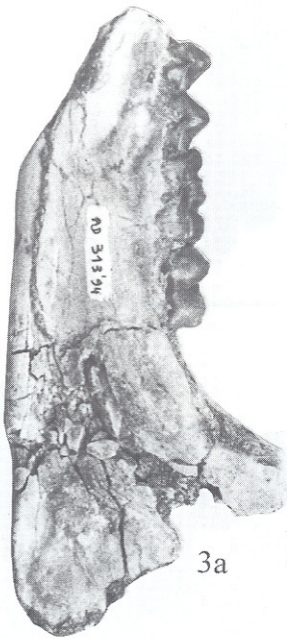
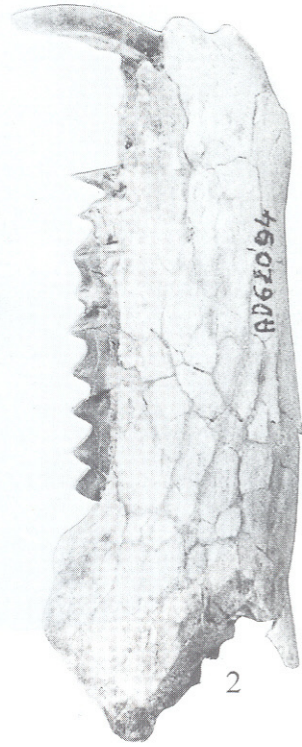
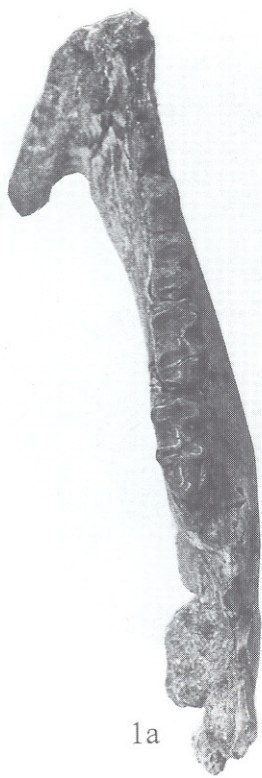


PLATE 5

