Erosion and deposition as the swell rises

Late Cret. and Paleocene outcrops near coast due to isostatic rebound of eroded area

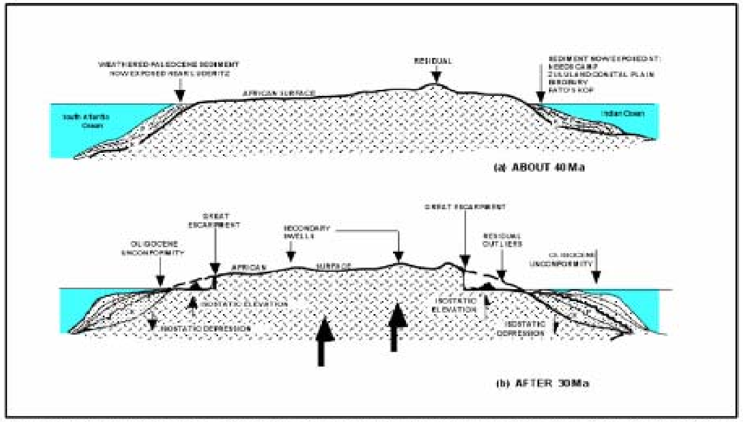

Figure 26 Sketch cross-sections illustrating the topography of southern Africa (a) at about 40 Ma, before the African Plate came to rest over the mantle circulation, and (b) after ~30 Ma, the time at which the plate stopped moving with respect to at least part of the mantle circulation. In the upper figure, the African surface is shown as lying close to sea level without many or prominent residual elevations. Cretaceous and Paleogene sediments (K and P) are indicated at the rifted margins of the continent. In the lower figure, the African surface is shown as elevated on the Great Swell of southern Africa whose uplift is represented by two large black vertical arrows. Two secondary or subswells are indicated. The Great Escarpment is beginning to cut back into the continent and sediments are beginning to be deposited offshore above the mid-Oligocene unconformity. Offshore, the newly accumulated sediments cause isostatic depression and onshore, removal of load by erosion causes isostatic elevation. Contemporary effects of world-wide sea level change and flexural effects (Mc Ginnis *et al.*, 1993), which amplify the results of uplift of the Great Swell of southern Africa near the coast, are not indicated separately in this sketch.

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Drainage changes as basins and swells began to form.

Southwest is Mainly based on Mike de Wit in Econ. Geol. 1999

Benguela Current, a cold current, began to flow to the north when an ice-sheet first formed in Antarctica (ca.35 Ma). Namib desert formed and persists.

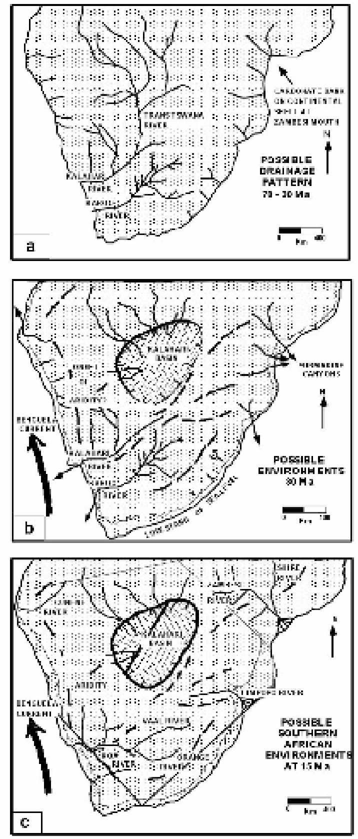

Figure 28. Sketch maps illustrating possible drainage systems and related environments for southern Africa at three times: before 30 Ma, at ~30 Ma, and at ~15 Ma. These figures are largely based on information in Dardis *et al.* (1988) and de Wit (1993), interpreted here using the ideas (1) that the uplift of the Great Swell of southern Africa began at about 30 Ma when the African Plate stopped moving over the mantle circulation, and (2) that the Great Escarpment has developed since that time. In Figure 28a, the drainage of the southern continent is shown as dominated by Trans Tswana and Karoo river systems. The coastline shown is that of today except at the mouth of the Zambesi where post 30 Ma rapid deltaic progradation (Droz & Mougenot, 1987, figure 13) has drastically changed the shape of the coastline. The existence of a carbonate bank at the Zambesi mouth in Paleogene time was suggested by De Buyl & Flores (1986, figure 19 and p. 417). Figure 28b represents conditions at about 30 Ma when sea level was low worldwide, the African continent began to be elevated and the Benguela current had begun to flow (Siesser, 1978) leading to the onset of aridity in the southwestern part of the continent. Submarine canyons were probably abundant and the positions of a few are indicated. The Kalahari Basin of interior drainage had begun to develop. Possible axes of subswells are indicated by dashed lines. Figure 28c shows conditions intermediate

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Du Toit discerned sub-swells in 1934

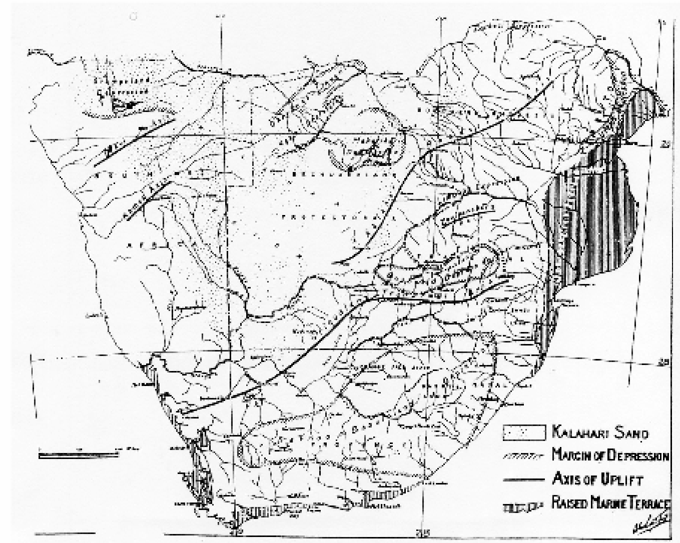

Figure 27 Figure reproduced from Alex L. du Toit's Presidential Address to the Geographical Society of South Africa (du Toit, 1933). The figure shows axes of uplift which correspond to the subswell crests of this paper. Du Toit was impressed by evidence of Quaternary tectonism.

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North and West Africa

Swells are smaller, but it rained more until the Sahara first formed at 2.8 Ma.

Sandstone Escarpments are a feature.

Bauxites, formed on the low-lying equatorial surface 100 Ma- 30 Ma, are now Elevated to varied extents

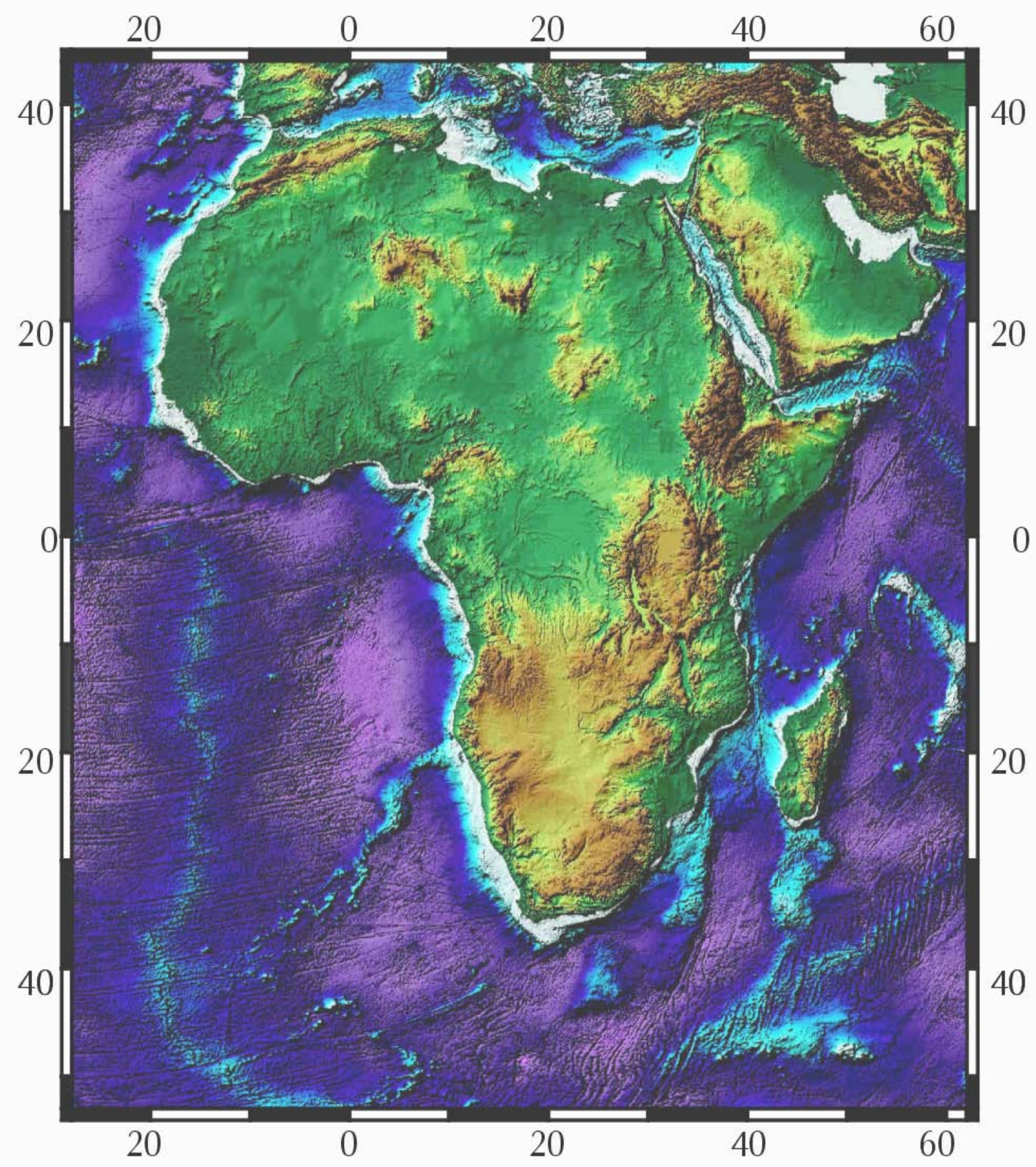

Image courtesy of NOAA and USGS.

Before northern hemisphere ice sheets formed and related Sahara initiation(at 2.8 Ma) conditions year round were those of the two lower Figures. Rainfall on S. African swell Was mainly on S.E. coast where Great Escarpment is highest and offshore dip is higher

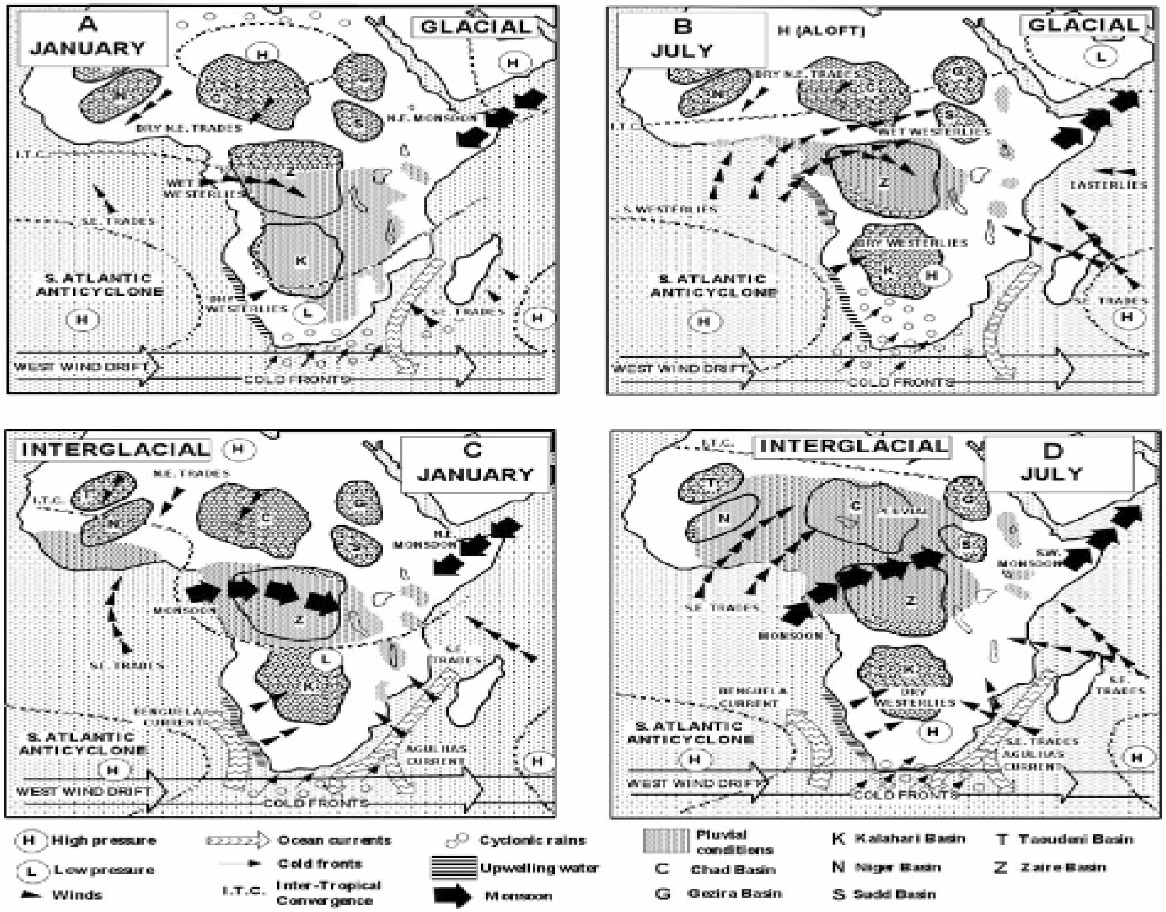

Figure 49 Figures indicating climatic variations in Africa related to changes in northern hemisphere glacial conditions (from Kroepelin, 1994, based on a figure by Shaw, 1985) incorporating the ideas of Van Zinderen Bakker (1976). Seven interior basins are indicated with checkerboard ornaments. Climatic variations have different effects in the various basins. For example, most of the Zaire Basin is subject to fluvial conditions, however the climate varies. Before northern hemisphere glaciation began at about 3 Ma, conditions similar to the interglacial conditions depicted in the lower two figures are likely to have obtained over the entire continent from about 35 Ma when the East Antarctic ice-sheet had formed and the Drake passage had opened.

Basins and Swells of the past 30 million years in the North-west

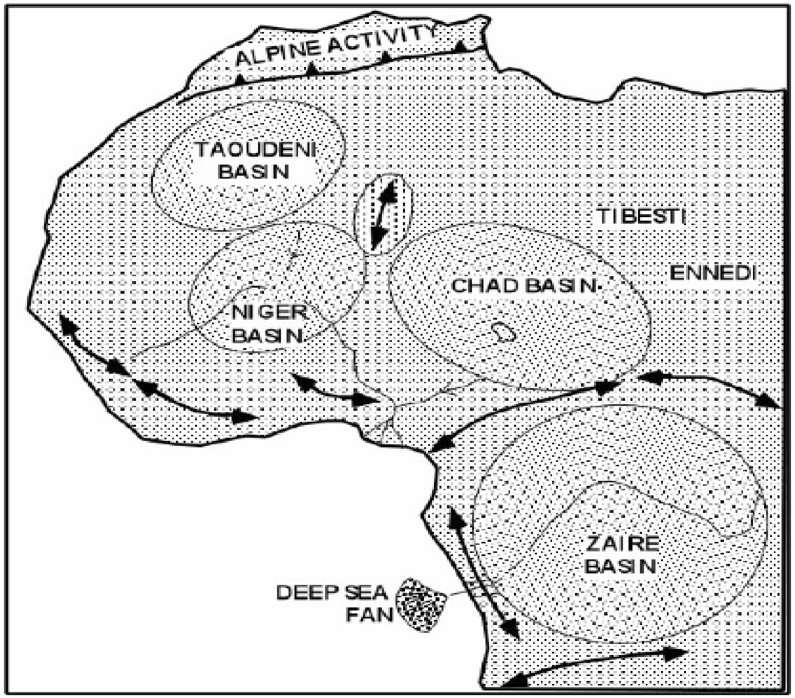

Figure 30 Interior basins and swells of northern and western Africa. The plate boundary zone of the Atlas Mountains on the northern border of the continent is not discussed in this paper. Summerfield (1996) has emphasised the importance of uplifts (indicated by lines with arrows at both ends) close to the coast which are particularly prominent in the region sketched on this map. The Zaire Basin is similar to the interior basins, but river capture has linked it to the ocean where a spectacular submarine canyon and deep sea fan have developed.

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Image courtesy of The Geological Society of South Africa.

between those of 30 Ma and the present as the Great Escarpment was in retreat and drainage development approached that of today.

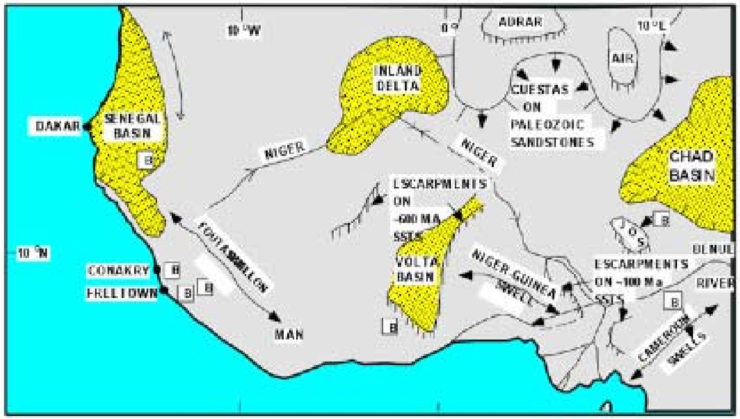

Figure 29 Basins and swells of West Africa. The interior basins of the Inland delta region of the Niger (Reclus, 1888) and the Chad Basin (Figure 20), as well as the coastal Senegal Basin, are set among 30 Ma and younger swells. Swells include the Fouta Djallon, the Niger-Guinea watershed, the Cameroun chain of several discrete swells, as well as the interior Jos (Figure 15), Air and Adrar swells. Because the uplifts of the swells have not been as intense as in much of eastern and southern Africa, escarpments and cuestas are developed around gently dipping sedimentary rock piles of various ages. The Benue and Niger rivers dominate drainage. The latter sometimes flows no farther than the inland delta and its middle reaches may flow in either direction. Localities marked with the letter B are bauxite localities, mainly from Egbogah (1975).

EAST AFRICAN RIFT SYSTEM

Active extent from 30 Ma until Now:

From Dead Sea transform (active since 15 Ma) through Suez and the Red Sea to the Ethiopian and East African swells, the Malawi rift and the offshore rift east of

Mozambique on the site of the Davie FZ. (Definitions of the EAR vary greatly)

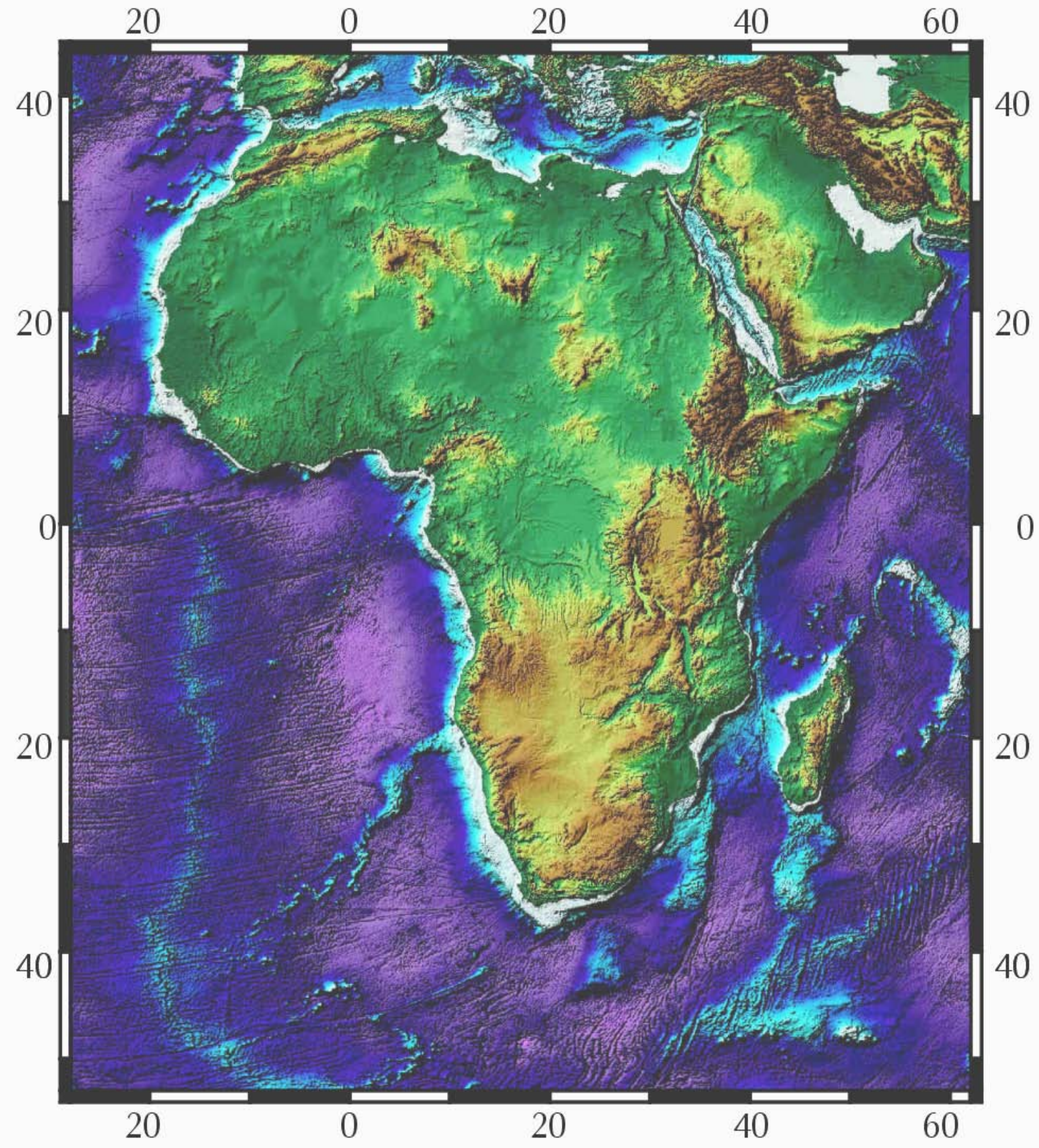

Image courtesy of NOAA and USGS.

EAR NOT YET FORMED
Mwadui and Uweinat ages are Wrong.

Possible Migration of 45-35 small Plume from S. Ethiopia to W of Lake Turkana

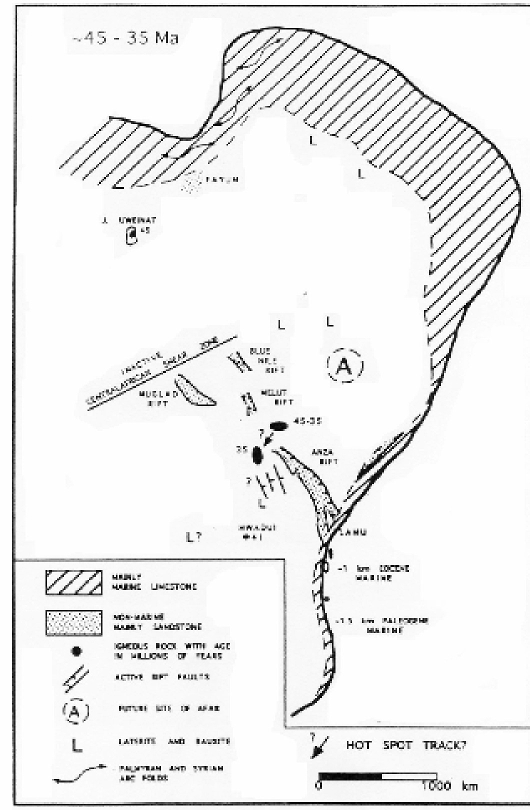

Figure 31 Sketch map showing the area over which the East African Rift System would develop starting at ~30 Ma. Arabia at this time formed a promontory of the African continent. This map illustrates conditions during later Eocene times between ~45 and ~35 Ma. Four Mesozoic rifts continued to receive sediments and some rift faults were active. Most of the interior of the continent was low-lying, and laterites (L), which formed at this time or somewhat earlier, are locally preserved. Kimberlite was erupted at Mwadui and granite was emplaced at Jebel Uweinat. Plume generated flood basalts were erupted in an area in S. Ethiopia over most of the 45 Ma to 35 Ma interval. By 35 Ma, a plume—possibly the same plume—was beginning to erupt basalt in an area in Lokitipi where eruptions have continued ever since. Palmyran and Syrian arc folds had just ceased to be active in Eygpt and the Levant. Shallow-water marine sandstones and limestones are widely but sporadically distributed over the northeast corner of the continent and a well-developed shoreline is exposed at Fayum. On the east coast of the continent thick Paleogene sections off Tanzania may indicate the existence of a river system draining the interior of East Africa. The future site of impact from below the Afar plume is indicated.

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Image courtesy of The Geological Society of South Africa.

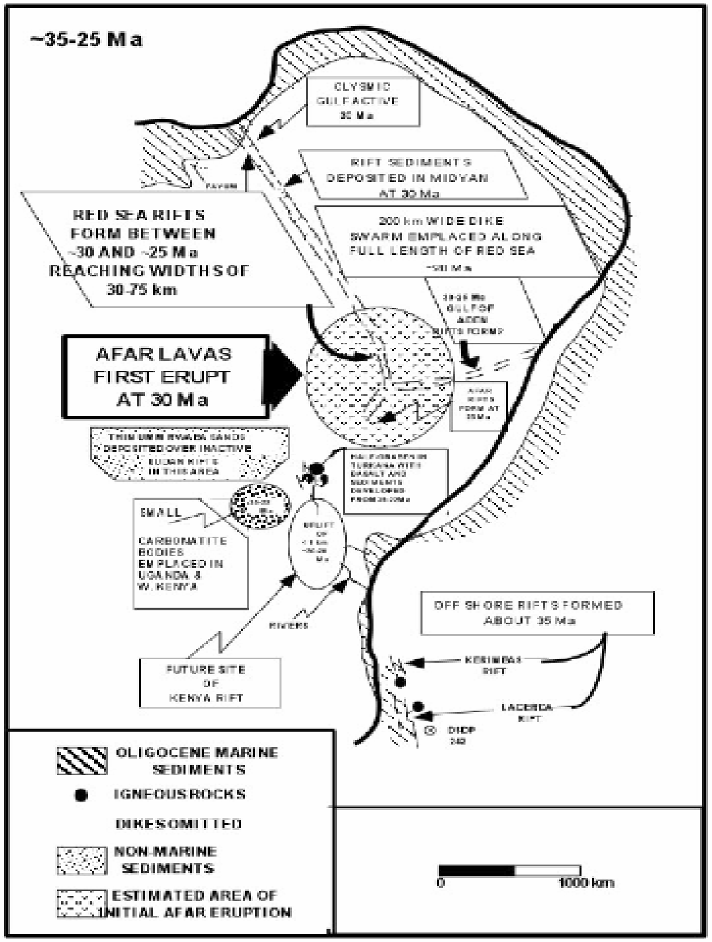

Figure 32 Sketch map showing the inception of the East African Rift System during the 10 My interval 35 to 25 Ma. The critical event may have been the eruption of the Afar plume at ~30 Ma to form the Ethiopian traps. The Afar plume has been persistently active at the same site ever since. The Red Sea Rift, including Suez, formed at ~30 Ma and both rift sediment deposition and the emplacement of a dike swarm accompanied early rift development. Rifts in the Afar had formed by 25 Ma and the Gulf of Aden Rift may have formed simultaneously. In Turkana half-graben with basalts and sediments developed over the site of the Lokitipi eruptions and also over the Anza Rift. Other Mesozoic rifts in Sudan became inactive and were overlain by thin sands of the Umm Rwaba formation. A Kenya dome of moderate elevation formed and products of erosion from that dome may be represented in the Turkana grabens and in the coastal rift basins of Tanzania. Offshore the Kerimbas and Lacerda Rifts formed in water depths of 1 km and the igneous rocks of Paisley and St. Lazare seamounts in those rifts were erupted.

Afar plume
erupted at 31 Ma.
Cracks that
formed in
an attempt to
relieve stress
modification in
a newly formed
~ 1km high
dome propagated to:
1.Rt-angled bend
in Levant corner,
2.to volcanic
area of S. Ethiopia
3. on Gulf of Aden site.

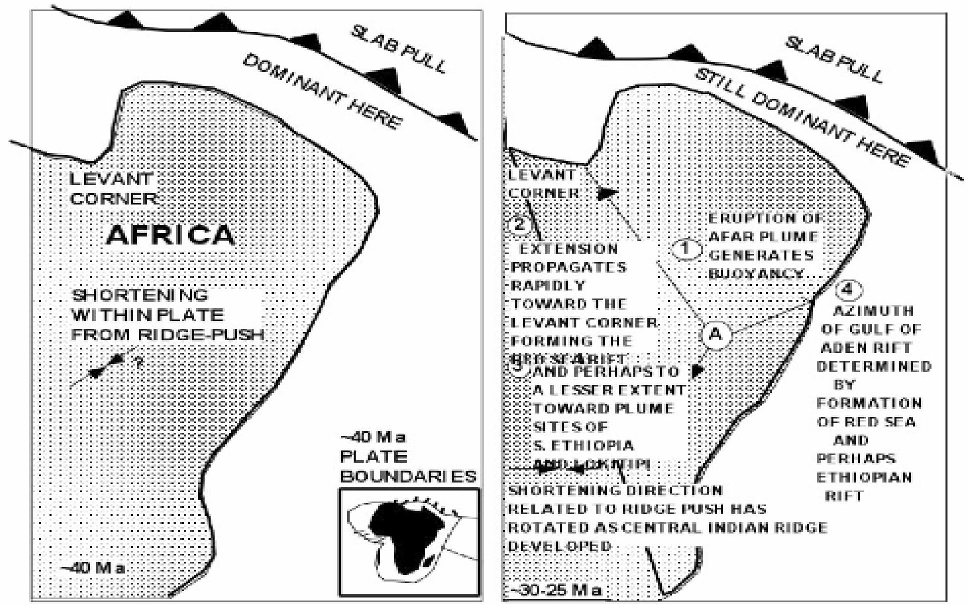

Figure 33 Sketch illustrating how the geometry of the Levant Corner may have played a critical role in the evolution of the Red Sea Rift. The stress field normally associated with rifted continental margins was amplified, because of the right angle, in the region of the Levant Corner. Eruption of the Afar plume generated buoyancy over an area perhaps 1000 km in diameter modifying the within-plate stress field. Propagation of the Afar extensional stress field, preferentially toward the Levant corner, led to formation of the exceptionally long and straight Red Sea Rift segment. Propagation of stress from the Afar in the direction of the Lokitipi plume may not have been throughgoing at this time but the azimuth of the Ethiopian rift may have been determined by that process. The azimuth of the Gulf of Aden Rift may simply record a direction dependent on the initiation of rifting in the Red Sea and the Afar.

Dikes emplaced in cracks accommodated initial extension in newly formed rifts that on the future Red Sea site had stabilized at 70 km wide by 25 Ma.

Image courtesy of The Geological Society of South Africa.

Offshore rift segment of EAR on site of Davie FZ. Reflector ages are tied to a DSDP hole. Mougenot et al. Nature (1986)

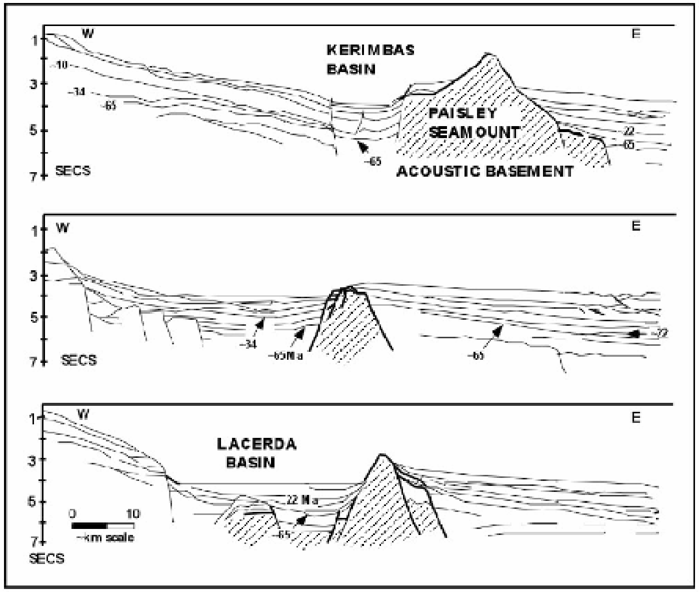

Figure 35 Cross-sections showing line drawings of seismic reflection lines through the Kerimbas and Lacerda basins to illustrate the style of active rifting. Figure redrawn from some of the lines illustrated in Mougenot *et al.* (1986, figure 2). Numbers assigned to reflectors are ages in My.

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Image courtesy of The Geological Society of South Africa.

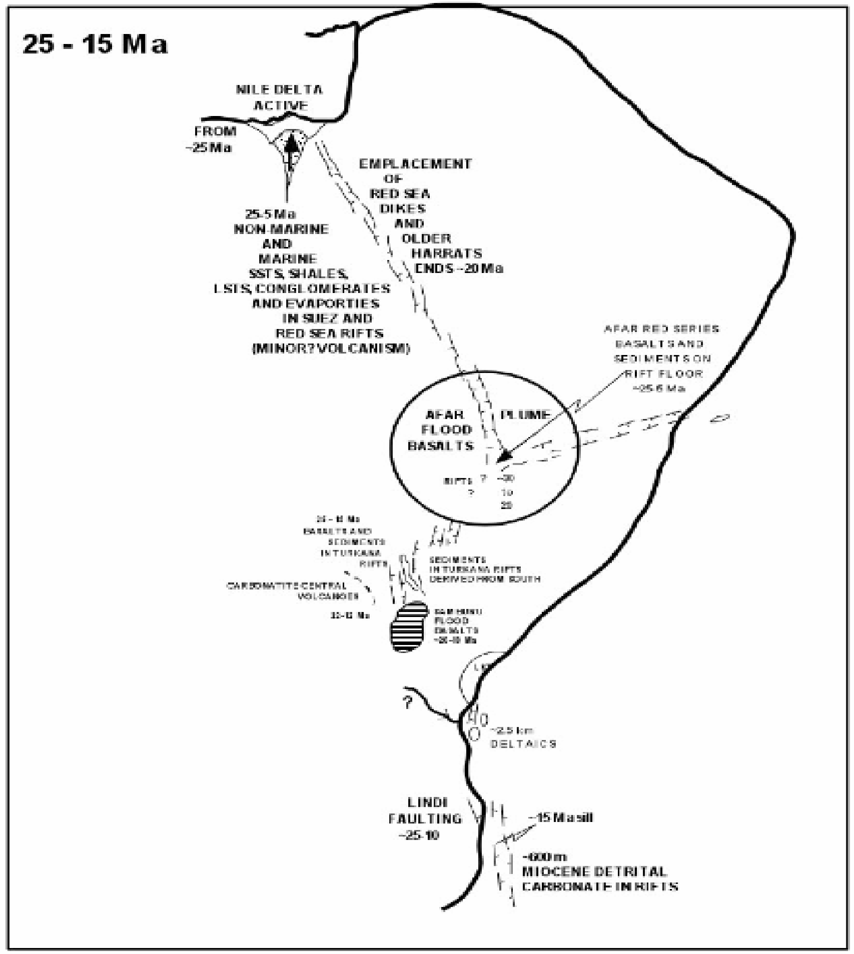

Figure 36 During the interval from 25 Ma to 15 Ma, the East African Rift System evolved without great change. The newly formed Nile river constructed a delta on the Mediterranean coast about 150 km south of its present location. Activity in Turkana persisted in its established style and the Samburu plume erupted about 1 km of flood basalt on the future site of the Gregory Rift. The coastal rift system of Tanzania continued to develop with a thick accumulation of deltaic sediments. Farther south the Kerimbas and Lacerda Rifts and their onshore neighbor, the Lindi fault system, continued to be active.

Image courtesy of The Geological Society of South Africa.

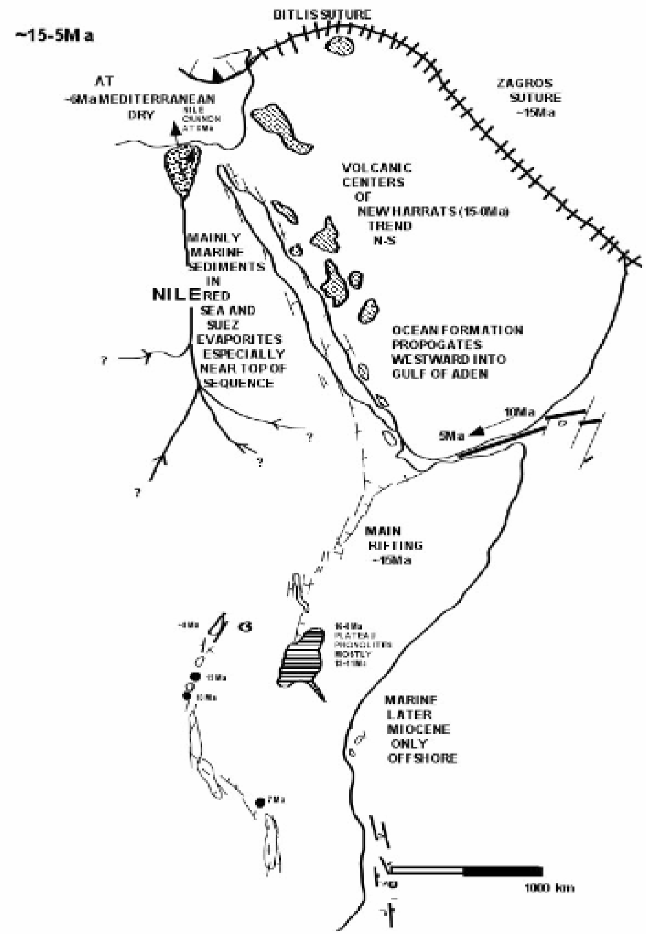

Figure 37 At 15 Ma the East African Rift System developed many features which persist today. The collision of Arabia with Asia was immediately followed by the first eruptions of the new harrats. North-south trending lines of volcanic cones indicate a new stress distribution in Arabia and the propagation of ocean floor formation into the Aden Rift for the first time at 10 Ma may be a related phenomenon. Within-rift sedimentation and volcanism in the Red Sea persisted without great change and the Nile delta continued to prograde into the Mediterranean. Main rifting in the Ethiopian Rift took place at 15 Ma but there was no great change in Turkana. The Samburu plume erupted a kilometer of plateau phonolites but the Gregory Rift was not yet a coherent structure, although establishment of the Elgeyo fault by 10 Ma provided a link between Turkana and the Gregory Rift area. The time of origin of the Western Rift is not well established. 15 Ma is chosen here as the time of origin because it is slightly older than the oldest dated volcanic rocks of the rift in the Virunga.