THE DROWNED VALLEYS ON THE COAST OF KENYA.

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In his report on the Geology of the East Africa Protectorate (Col. Rep. Misc. No. 45, Cd. 3828, London, 1908), Mr. H. B. Maufe pointed out that the tidal creeks on the coast of Kenya, the rock floors of which are far below sea level, originated as land valleys, which are now " drowned." He also indicated that the sub-aerial erosion which produced or rejuvenated these valleys must have taken place subsequent to the formation of the raised coral reefs of Pleistocene age which form the existing coastal strip including most of Mombasa Island.

Although much is still obscure, light has been thrown in recent years on the oscillations of relative level between sea and land on the East African coast. Amongst the writings which bear on this matter are Stockley's report on the " Geology of the Zanzibar Protectorate " (London, 1928) with the associated report on the " Palaeontology of the Zanzibar Protectorate " by various specialists (London, 1927), Monograph No. IV of the Hunterian Museum, Glasgow University, containing various reports on geological collections from the coast lands of Kenya Colony made by Miss McKinnon Wood, and various papers and other publications recording the results of research work in other parts of the world on the relative level of land and sea during Quaternary times, the factors influencing coral growth, the solution of limestones by sea water and other phenomena. Borings carried out from time to time for the purpose of obtaining information relating to foundations for bridges and other structures, and to find water, have yielded evidence which is not without significance in the consideration of the history of these submerged valleys.

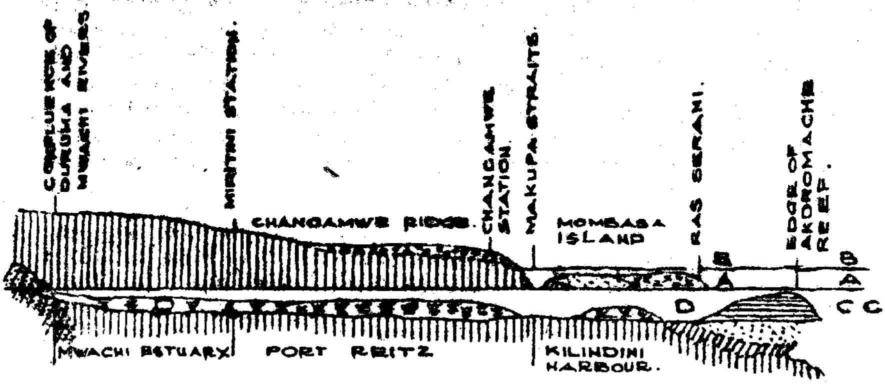
Even from topographical considerations alone, the similarity between the wide expanses of Port Reitz, Port Tudor, and Kilifi Harbour, with their narrow winding deep-water passages leading to the sea and partly blocked by submarine shelves of recent coral growth where they pass through the fringing reefs, cannot fail to excite interest regarding the origin and history of these creeks. If one also examines the other creeks penetrating the coast-lands, one finds that they are similar in type, but that some of the former land-locked harbours have become filled up from their rock floors with recent alluvium. Should one pursue the investigation further and examine the geological structure of the coast-lands, the conclusion is inevitable that these creeks were in existence as land valleys, subsequent to the formation of the coral reefs of Pleistocene age, which, with the breccia resulting from them, now form the fringe of the coast-lands, rising to some 80 feet above present low water at ordinary spring tides. These former valleys are now " drowned " beneath the sea.

Such submerged land areas and raised sea beaches, due to slow oscillations of level of land or sea or both during Pleistocene and Recent times are, of course common throughout the world. The British Isles themselves afford excellent examples, and much work has been done in recent years which bears on the fluctuations of level and their causes. There is much diversity of opinion as to whether such variations of relative level are due in whole or in part to oscillations of sea level relative to the land or oscillations of land level relative to sea level. The expressions of opinion at the Geographical Congress at Cambridge in 1928 were mostly in favour of the latter view, but much of the research work carried out in America favours the former opinion. As will be indicated later in this paper, the study of the phenomena in low latitudes may yield evidence which is less complicated and easier of interpretation in this respect than that obtainable from high latitudes.

In Zanzibar and Pemba, Stockley's survey has shown that the Azanian series (Pleistocene limestones corresponding palaeontologically with the raised coral reefs and breccia of the Kenyan coastlands) extend to 75 feet in elevation above present sea level. An old beach level occurs at 30 feet. In Pemba, the corresponding levels are 40 feet and 25 feet. The Zanzibar creeks are comparatively shallow, while in Pemba they reach 39 fathoms (234 feet), a depth only exceeded in the Kenya Harbours between Lamu and Manda Islands. The difference between Zanzibar and Pemba in these respects is ascribed by Stockley to Pemba being a horst (separated from the mainland in Miocene time) and therefore liable to be subjected to differential movements, while Zanzibar was separated from the mainland in Pleistocene time, its separation being due to subaerial and submarine erosion uninfluenced by tectonic causes. Teale has observed that Dar es Salaam harbour as well as all the East African creeks are drowned valleys, and regards them as having been eroded when the sea level was some 120 feet lower than to-day. Bornhardt (1900) regarded the evidence in Zanzibar as leading to the conclusion that there were three transgressions of the sea (two of which were oscillatory) and four recessions, the maximum transgression amounting to several hundred metres above present sea level. The final regression (which gave rise to the drowned valleys) amounted, in his view, to perhaps 40 metres. Gregory (1921) has expressed the opinion that the variations in height of the raised coral reefs in different parts of the East African coast are so irregular that they must have been due to movements of the land and not alterations of the ocean surface. The maximum elevations above sea level, as recorded by various observers, are 25 feet at Mozambique, 130 feet at Lindi, 50 feet at Dar es Salaam, 80 feet at Mombasa, and 40 feet at Malindi. It is not established, however, to what extent sub-aerial denudation has lowered the levels in some places more than in others, nor whether the recorded levels relate to the reefs themselves or to the coral breccia.

As an example of these submerged valleys on the coast of Kenya, the creek comprising the estuary of the Mwachi River, Port Reitz, Kilindini Harbour, and the channel between the Andromache and Leven Reefs may be taken as an example. The outline of the geological sequence is now well established. The south-eastern half of Mombasa Island, and the mainland on each side, is composed of coral reef and coral breccia, of which about 80 feet in thickness are exposed above low water. This carries a fossil fauna from which Miss McKinnon Wood collected 136 species of which six only are extinct. (Monograph IV of the Hunterian Museum.)

SECTION ALONG PORT REITZ AND KILINDINI HARBOUR (WITH CHANGAMWE RIDGE AND MOMBASA ISLAND BEHIND) TO INDICATE PROBABLE VARIATIONS OF SEA LEVEL IN RELATION TO LAND LEVEL DURING PLEISTOCENE TIME.



RECENT	ALLUVIA	PLIOCENE	NORTH MOMBASA CRAG
	CORAL		MAGARINI SANDS
PLEISTOCENE	CORAL	JURASSIC	SHALES AND LIMESTONES
	SANDSTONE AND SANDS	TRIASSIC	SANDSTONES AND GRITS

AA SEA LEVEL AT PRESENT DAY

B B PROBABLE MAXIMUM SEA LEVEL WHEN THE PLEISTOCENE CORAL WAS FORMED

C C PROBABLE MINIMUM SEA LEVEL DURING THE TIME WHEN THE LAND VALLEY DD CC WAS ERODED

HORIZONTAL SCALE 1 IN 250,000 (APPROXIMATELY 4 MILES TO AN INCH)

VERTICAL SCALE 100 FEET TO AN INCH

Underlying the coral, and comprising most of the remainder of the island, the Kilindini sands, with a somewhat inconstant bed of tough sandstone near the top, have yielded a marine fauna apparently identical with that of the overlying coral and therefore also Pleistocene in age. These sands and sandstones are exposed in most of the railway cuttings on the Island and in the cliff overlooking Kilindini Wharf. The abutments of Nyali Bridge on both sides of Mombasa Harbour rest on the sandstone bed just below low water level, the cliffs above being composed of the coral. North-west of Shimanzi and also on the north side of the Island, the Kilindini Sands rest on the North Mombasa Crag, a shelly limestone carrying a marine Pliocene fauna similar to that of the Zanzibar series (Chlamys werthi beds). The shelly crag rests against a sea cliff of Jurassic shale (Changamwe Beds of Kimmeridgian age) on the Island side of Makupa Straits, the shale forming the shore of the Pliocene sea on which the shell bed was deposited. The marine Jurassic series (Bajocian to Kimmeridgian), overlain on some ridges by sands of terrestrial origin (Magarini Sands) extend from Makupa Straits to the confluence of the Mwachi and Duruma Rivers at the head of the Mwachi Estuary near the Suspension Bridge, where they give way to the underlying Triassic Sandstones (Duruma Sandstones) of terrestrial origin. Into these sandstones, shales and limestones the Mwachi River and its tributaries have cut deeply in the past, their lower reaches now being choked with mud and sand brought down by the rivers, often giving rise to mangrove swamps.

Borings for foundations near the confluence of the Duruma and Mwachi Rivers and where the Mwachi Estuary debouches into Port Reitz have shown that the rock floor is 70 to 80 feet below low water level. Opposite Makupa Straits the maximum depth is 22 fathoms (132 feet), which corresponds closely with the depth of 130 feet to rock found by borings for foundations for Makupa Bridge, indicating that the rock floor of Makupa Straits is at about the same level in its deepest part as that opposite it in Port Reitz. The gradient of the old valley from the head of the Mwachi Estuary to Kilindini Harbour would therefore appear to have been about 7 feet per mile when erosion ceased. This gradient is not less than one would expect from a consideration of the existing gradients of the Mwachi and Manolo Rivers above high water level, those rivers being fairly mature as regards their hydrographic characteristics. The extensive series of borings carried out between Mbaraki and Makupa Straits for foundations for various harbour works have yielded results which are interesting but in many cases conflicting and difficult of interpretation. Except those close to the shore, few have been carried to solid rock. Depths of 100 feet have, however, been reached in mud, silt and sand with occasional boulders and pebbly beds. Vegetable matter was recorded from several holes as having been encountered, and in one case wood at a depth of 86 feet off Shimanzi. Borings at Mbaraki appear to indicate a thickness of coral limestone up to about 60 feet below low water and that the underlying formation is much more argillaceous than the Kilindini Sands into which those clays no doubt pass laterally.

From the bend round Mtongwe Point where Port Reitz converges into the narrows of Kilindini Harbour, up to the channel opposite Ras Serani, maximum soundings in cross sections, as indicated on the Admiralty chart, vary from 20 fathoms (120 feet) to 32 fathoms (192 feet) with one isolated maximum sounding of 35 fathoms (210 feet). A reduction to 16 fathoms (96 feet) on the seaward side of the mouth of Mueza Creek occurs. There is no definite information regarding the nature of the bed, but it is thought probable that the excessive depths may be due to tidal scour in soft strata and the shallows to an accumulation of material discharged from Mueza Creek. Where the channel passes between the Andromache and Leven Reefs the depth for about a mile is reduced to a maximum in cross sections of 6½ fathoms (39 feet). This reduction is clearly due to recent coral growth. A narrow bench varying from 20 to 30 fathoms in depth separates the recent growths from the edge of the continental shelf. The average gradient of the old river channel from Mtongwe Point may have been about 6 feet per mile.

It is clear that a winding creek of this kind, with its rock bed far below low water level, cannot have been cut out by marine erosion as a sea bay would be. Nor can solution by sea water have had any appreciable effect, for the rocks cut through below the coral limestone are nearly all either argillaceous or arenaceous. The only known agency by which it could have been eroded is river action, when the land stood at such a height relative to sea level that the whole bed of the river, as finally degraded, was above the sea.

Moreover, as the raised coral reefs of Pleistocene age are approximately horizontally bedded and similar in type on both sides of the winding creek (as they also are in the case of the other creeks on the coast), they formerly extended across the areas now occupied by the creeks. The fluviatile erosion was therefore at least later than Lower Pleistocene time. The existence under the coral limestone of the Kilindini Sands on the mainland south of Kilindini Harbour has not been definitely established, for no borings have been sunk on the Likoni side, but their occurrence can be inferred. No doubt they become more argillaceous in an eastward direction as they do beneath Mombasa Island. As already mentioned, they occur on both sides of Mombasa Harbour.

The former continuity of the marine Pleistocene deposits across what is now Kilifi Creek is borne out by the results of a number of boreholes sunk on both sides of the creek to find water. The sands and sandstones, which correspond stratigraphically with the Kilindini

Sands and Sandstones and directly underlie the coral, would appear to rest directly on the Jurassic shales at about the level of the bottom of the creek, 30 fathoms (180 feet) below low water level. As on Mombasa Island, they become argillaceous in a seaward direction and thin out westward, the thickness being probably about 105 feet below Kilifi Government Station with some clay beds intercalated. It is possible, however, that the base may be Pliocene in age and correlate with the North Mombasa Crag.

Although the creeks were cut through the Pleistocene marine series, the areas occupied by the present-day lagoons, such as Port Reitz and Port Tudor, behind the narrow creeks must have been occupied by sea bays in Pliocene time, for Miss McKinnon Wood collected fossil marine molluscs of Pliocene affinities from beds on the flank of the Mwachi Estuary and also from the valley of the Senawe River discharging into Takaungu Creek. During the deposition of these beds and the North Mombasa Crag, the sea level relative to the land would have been 50 feet or more higher than present-day level.

In early Pleistocene time there followed the deposition of the Kilindini Sands on the shelving floors of the bays, the sand changing to silt in deeper water. The sea must have stood at least 60 feet above its present level, relative to the land, at its maximum. The sand was brought down by the rivers and derived chiefly from the erosion of the Duruma Sandstones and no doubt also of the terrestrial deposits of Pliocene age known as the Magarini Sands. The sand would mostly be deposited in the bays near the river mouths. Deposition along the shore line generally would be likely to be more argillaceous because the sea cliffs at that time would be largely composed of Jurassic Shales, which would give rise to clays by marine erosion. The borings at Kilifi indicated an increase in clay content north and south of the creek.

A change in climatic conditions involving warmer sea and less rainfall supervened, and coral reefs started to grow at the mouths of the bays and along the coast generally reaching on the average three or four miles inland from the present sea shore line. The maximum thickness of the coral and breccia formed from it would appear to be in excess of 135 feet, judging by the boreholes at Mbaraki and Kilifi. Of this, some 60 feet are now below present ordinary low water spring tide level and 75 feet above it. It is probable, however, that the portion above water level has been much reduced in thickness by sub-aerial degradation. The bays at the mouths of the rivers became blocked with coral reefs, the drier coastal climate greatly reducing the discharge of the rivers and allowing the reefs to form in the clearer water.

The Tana and Sabaki Rivers discharging water from the highlands appear to have continued to exercise their influence in the then more extensive Formosa Bay, though to a lesser degree, for coral formed a few miles inland from the present Sabaki mouth. Hobley has pointed out (The Tana River, *Geogr. Journ.*, Jan., 1915) the effect which the Tana River has exercised by deposition of sediments opposite its delta and the fact that the edge of the continental shelf is some 23 miles outside the present shore line at the Tana mouth.

Following the formation of the Pleistocene coral, an elevation of the land or retreat of the sea is clearly indicated. The emerging coral reefs and underlying sands, sandstones and clays, which preceded the coral in formation, were broken through in all the present-day creeks, under wet climatic conditions, the rate of erosion probably keeping pace with the rate of emergence. At maximum, the difference of level between land and sea must have been greater than 130 feet and probably less than 190 feet more than at present.

The sub-aerial degradation of the surface of the land during these pluvial conditions must have been of consequence. The limestone of the raised coral reef and breccia would have been subjected to continuous alteration and solution by acids, and the soil which would result from decomposition would itself be continuously lowered by erosion as new soil formed beneath. The reduction in general land level may have been considerable. Until there is more exact evidence regarding the elevation of the sea beach at the time of maximum transgression by the sea, it can only be said with certainty that it was in excess of 80 feet above existing sea level. Stockley records (Geology of Zanzibar Protectorate, 1928) that the sea may have advanced to 150 feet O.D. during the Pleistocene transgression but that the evidence is not clear. He, however, states that it is likely that all localities (in Zanzibar) above the present O.D. were land.

Although the two major movements, one of transgression and the other of regression, are well defined and their extent determinable within limits, other oscillations and rest levels still present much uncertainty. The rest level which caused the old sea shore on which Mombasa Golf Links exists is well known, and this old sea beach some 30 feet above existing sea level is clear at intervals along the coast and at the mouths of the creeks. It seems likely to have occurred subsequent to the recession of the sea at the maximum of a temporary rise of level. On Zanzibar Island the old beach occurs at the same level. Evidence of a comparatively recent rest level can also be seen not infrequently at some 15 feet above existing sea level, lines of sea caves and beach deposits occurring at intervals. It corresponds with the recent 14 feet rest level recorded by Stockley in Zanzibar.

The study of the relationship between climatic conditions in high and low latitudes during Pleistocene and Recent times, the influence of glacial and inter-glacial periods in causing fluctuations of sea level and the glacial control theory in relation to the formation of coral reefs have received much attention in recent years. The binding up of large volumes of water in terrestrial ice sheets, thousands of feet thick, in the higher latitudes of the northern and southern hemispheres cannot have failed to influence profoundly the ocean level, especially if one can assume that maxima of the major glaciations in all regions were approximately synchronous. Research in the United States (American Geog. Research Series No. 17, The Last Glaciation, Ernest Anster, 1928) places such high values on the thicknesses of ice sheets in various parts of the world during maximum glaciation that a lowering of sea level of 305 feet is indicated. Nansen's calculation that the average elevation of the land above the sea was increased by more than 400 feet is quoted by C. E. P. Brooks (Climate through the Ages, 1926) as a conservative one. Many authorities are not prepared to accept such considerable thicknesses as, for instance, 18,000 feet for the Kewatin and 14,000 feet for the Labrador ice sheets. Park, however (Text Book of Geology) quotes thicknesses of 5,000 feet for the Scottish ice sheet, 7,000 feet for the Scandinavian and New Zealand ice sheets, and in North America from 7,000 feet to 15,000 feet. Whatever the maximum thicknesses were, it is generally agreed that they were considerable, and a lowering of ocean level in excess of 130 feet seems very probable. A reduction of the mean temperature of the oceans would also cause a lowering of sea level to the extent of about one foot per degree Fahrenheit.

Moreover, the weight of the ice sheets would affect the isostatic balance in high latitudes. Some depression or other dislocation of land areas in those latitudes would seem probable unless either compensation kept pace or crustal strength and rigidity above the layer of flow were adequate to take up the stresses without distortion. Neither alternative would seem likely, though no doubt adjustments of whatever character might be expected to lag, in some measure, behind their causes. In his study of the Great Ouse Basin, however, Professor Marr (Pleistocene Deposits of the Great Ouse Basin, *Quart. Journ. Geol. Soc.*, LXXXII, 1926) finds emergences of land to coincide with each of the two major Pleistocene glaciations recognised in England and a submergence during the interglacial period. On the other hand, evidence in the Oxford District leads Dr. Sandford (*Quart. Journ. Geol. Soc.*, LXXXV, 1929) to postulate a considerable submergence during the earliest glaciation. Whatever the result, at any particular time, of adjustments of relative level between land and sea may have been in high latitudes, one might therefore expect tropical regions to have been comparatively free from complications; the fluctuations of sea level, which would be free from lag, would be the only appreciable factor, other than such independent crustal movements as may have occurred.

It seems not unreasonable, therefore, to postulate that the emergence of the land, when the drowned valleys were eroded during a pluvial period, was due principally to glaciation in high latitudes. The formation of the Pleistocene coral preceded this and took place during a dry period with warm seas coincident with a transgression of the sea over the land. One would place this epoch during the preceding interglacial period. It would seem probable that the deposition of the Kilindini Sands, which antedated the coral reefs and occurred during a time of high rainfall without coral formation, correlated with the earlier glacial episode. Adopting the Alpine sequence, one might speculate further and regard the deposition of the Kilindini Sands and Sandstone as contemporaneous with the Gunz-Mindel glaciations, the formation of the coral limestone and breccia as having taken place during the long warm interglacial period between the Mindel and Riss, and the erosion of the drowned valleys as coincident with the Riss and Wurm glaciations. On these suppositions, the submergence which gave rise to the 30 foot shelf would seem likely to have been contemporaneous with the comparatively short warm Riss-Wurm interglacial; the formation of the 15 foot beach would have been coincident with the Climatic Optimum, which is believed to have culminated about 4,000 years ago when the Arctic Ocean is regarded by C. E. P. Brooks (Climate through the Ages, 1926) as having been free from ice. The formation of the sand dunes, which occur at intervals along the coast and are now covered with vegetation, would also seem likely to date from that warm dry and recent period.