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Notes on the Geology and Mineral Resources of the Southern Kenyan Coast

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with the collaboration of

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With 2 plates

Abstract

The rifting and break-up of the Gondwana continent dominate the sedimentary and structural evolution of the southern Kenyan coast. Jurassic rifting transformed an intracratonic Permo-Triassic basin filled with continental clastics into a marginal marine basin located at the trailing edge of the African plate. An alkaline intrusive complex is related to structures which suggest that a failed rift arm of a triple junction formed in association with the opening of the Indian Ocean.

The mineral deposits, characteristic of the metallogenetic environment commonly associated with rifting, and include apart from insignificant sedimentary mineral occurences a major Nb-rare earth deposit associated with a carbonatite complex as well as several minor vein-type Pb-Zn-Ba mineralizations.

Zusammenfassung

Das Riften und Auseinanderbrechen des Gondwanakontinents sowie das Öffnen des Indischen Ozeans beherrschen die sedimentäre und tektonische Entwicklung der kenyanischen Küstenregion südlich von Mombasa.

Ein intrakratonisches permo-triassisches, mit kontinentalen Sedimenten gefülltes Becken wird im Zuge des Riftens von Gondwanaland in ein marines Randbecken umgewandelt. Strukturen, die an ein nicht voll entwickeltes Grabensystem einer „Triple Junction“ erinnern, kontrollieren einen intrusiven Alkalikomplex.

Die Lagerstätten entsprechen der generell mit Grabensystemen verbundenen metallogenetischen Fazies. Neben unbedeutenden sedimentären Vorkommen vorwiegend von Steinen und Erden existieren eine bedeutende Niob-Seltene Erden Lagerstätte in einem Karbonatit-Komplex sowie mehrere gangförmige Blei- Zink-Schwerspat-Vererzungen.

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1. Introduction

The Kenyan coast south of Mombasa contains one of the world's major potential niobium/rare earths deposits and several mineral occurences of lesser importance. Past mineral exploration was restricted to exploration of this Nb/rare earth prospect, to diamond exploration, and to some limited mineral reconnaissance for base metal deposits. Systematic regional mineral exploration was therefore justified and a pertaining programme was implemented to this end from 1976–1978 within the framework of a bilateral exploration project funded by the governments of Kenya and Austria, with AUSTROMINERAL acting as executing agency.

The general geological concept of the metallogenetic environment presented in this paper served as basis for the systematic appraisal of the area's mineral potential (AUSTROMINERAL 1978); it is derived from a compilation and review of the previously existing geological data (BAKER 1953 who focussed on the igneous rocks in the area, CASWELL 1953 & 1956 who dealt extensively with stratigraphy, sedimentology and paleontology, COETZEE & EDWARDS 1959), supplemented by regional geological mapping (shown in Plate 1).

2. Regional Geology

2.1 General Geological Setting

The regional geological and metallogenetic setting of the southern Kenyan coast is dominated by the rifting and break-up of the Paleozoic Gondwana continent and the development of the Indian Ocean (EMBLETON & VALENCIO 1977).

Proterozoic gneisses of the Mozambique belt (POHL & HORKEL 1980) form the basement of an intracratonic basin, filled with continental Permo-Triassic clastics.

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Rifting during the early to middle Jurassic, presumably preceeded partly by updoming along the incipient rift, transformed it into a marine marginal basin at the trailing edge of the African plate. An alkaline intrusive complex in the south is closely associated with structures suggestive of a failed rift arm of a minor triple junction, formed as a consequence of the opening of the Indian Ocean. General stratigraphy and tectonic evolution are summarized in Plate 2.

2.2 Stratigraphy and Sedimentology

2.2.1 Duruma Group (Permo-Triassic)

Most of the area is underlain by continental Permo-Triassic sediments assigned to the Duruma Group ("Duruma Sandstone Series" CASWELL 1953), which is generally considered as the Kenyan equivalent of the Karroo system of southern Africa. The Duruma sediments essentially comprise clastics (grits, arkosic sandstones, and shales), accumulated under lacustrine, sub-aerial conditions with minor marine ingressions in a broad, roughly NNE–SSW trending intracratonic trough, which formed towards the end of the Paleozoic within the Proterozoic gneisses of this part of the Gondwana continent.

During the initial development stages of this trough, downwarping was fairly rapid, and the basal *Taru formation* (exposed inland of the area investigated) consists mainly of coarse-grained, poorly sorted arkoses. Intercalated shales contain fresh water fauna. Intraformational reworking and sedimentary structures are widespread, and indicate rapid denudation and short transport with subsequent re-deposition in a high-energy lacustrine environment.

Towards the top, the grain size of the Taru sediments decreases, and the generally fine-grained *Maji-ya-chumvi formation* overlies the Taru sediments along a slight unconformity. Current bedding and ripple marks are common and indicate deposition in shallow water. A basal sequence, composed of fissile dark shales with thin intercalations of sandy siltstones, frequently shows rain pits and desiccation cracks together with appreciable amounts of precipitated salts. It therefore indicates a period of arid climate during which the trough apparently dried-up frequently. This facies is terminated by a marine ingression which deposited fish-bearing shales followed by flaggy, fine-grained argillaceous sandstones, siltstones, and shales with a wealth of sedimentary structures (cross-, current-, and convolute bedding, rippled laminations, slump folding, etc.); they contain Triassic fauna indicating the return of brackish and even fresh-water conditions.

During the deposition of the *Mariakani formation*, which conformably overlies the Mayi-ya-chumvi beds, erosion became more intensive and a rhythmic succession of fine to medium grained sandstones and impure shales was deposited, probably again under lacustrine conditions. Massive, fine-grained sandstones with distinct mottling prevail in the basal part of the formation, flaggy arkosic sandstones with usually well developed cross-bedding in the upper part.

More pronounced erosion persisted during the deposition of the *Mazeras formation*, which unconformably overlies the Mariakani formation. It starts with coarse-grained, cross-bedded arkoses, with lenses of grits and minor siltstone/shale

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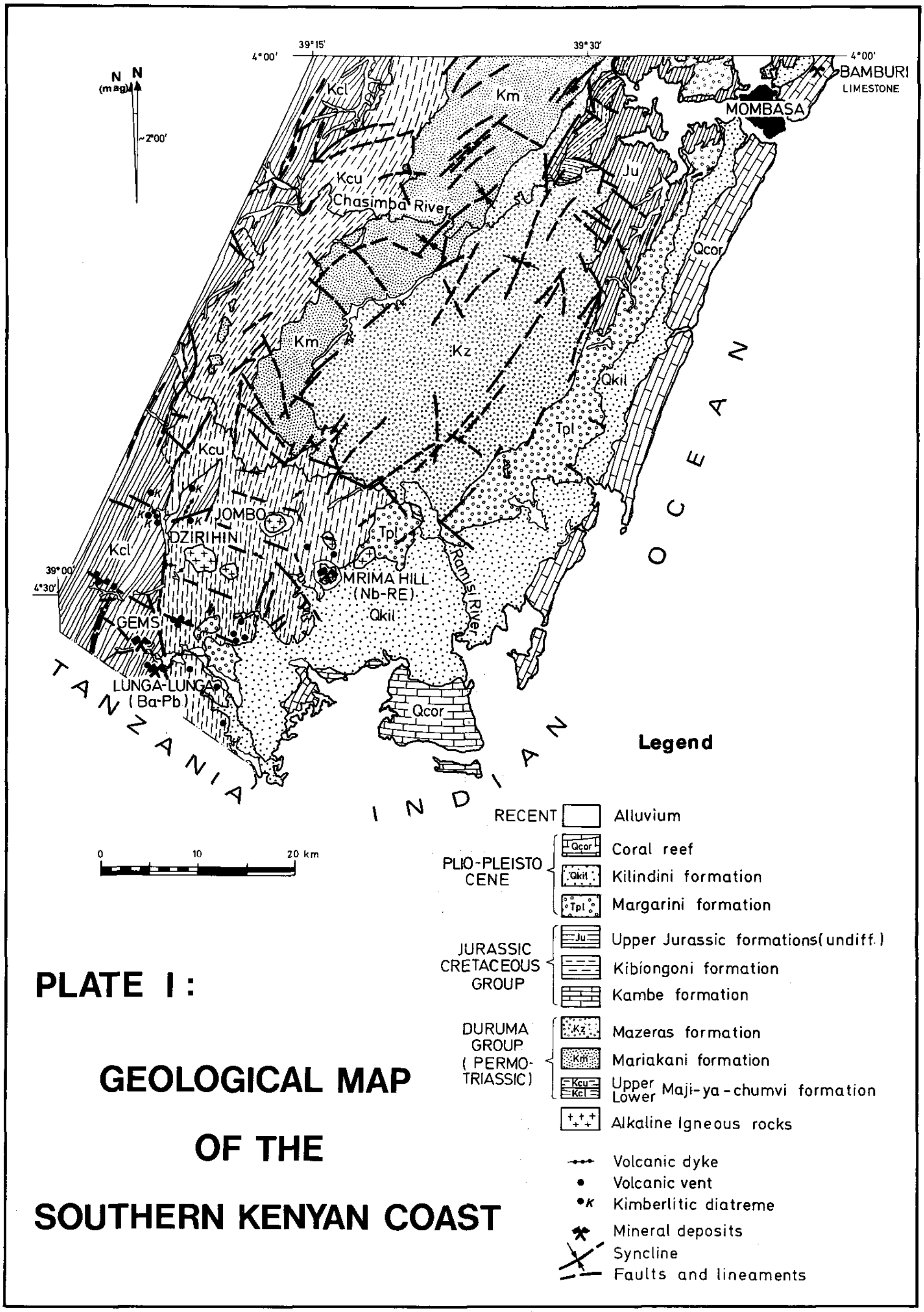

Plate 1: Geological map of the Southern Kenyan Coast

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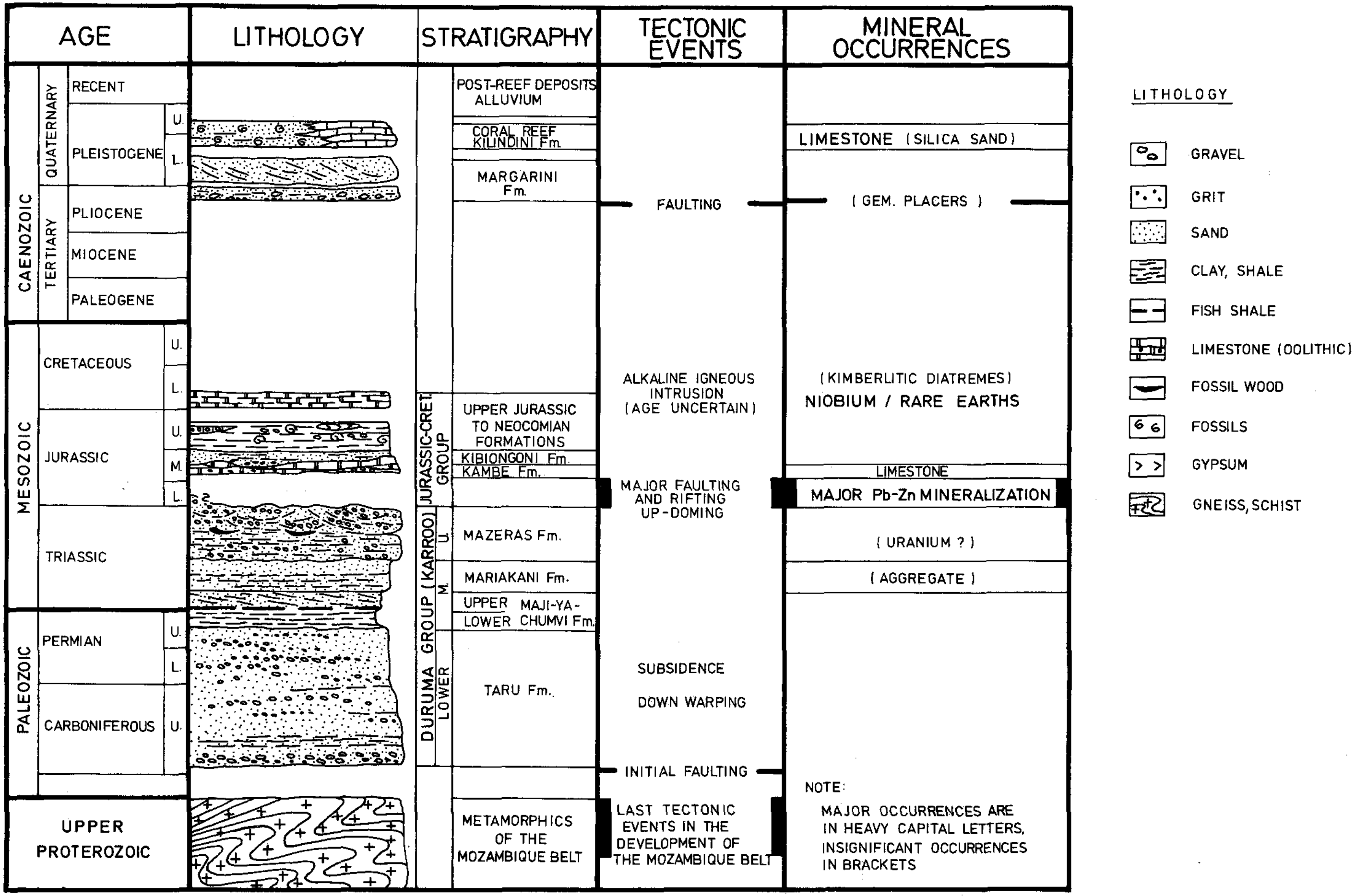

Plate 2: General Stratigraphic and Tectonic Evolution of the Southern Kenyan Coast

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intercalations. The sedimentation rate eventually surpassed the rate of subsidence of the trough, and dry areas covered by *Dadoxylon* forest emerged, as evidenced by a well-defined horizon containing abundant fossil wood. Coarse-grained, massive arkoses and grits of terrestrial origin with infrequent sub-aqueous intercalations terminate the Mazeras formation. This decline of the subsidence rate possibly already indicates incipient up-doming prior to the Jurassic rifting of Gondwana (NEUGEBAUER 1978).

2.2.2 *Marine Jurassic – Cretaceous Sediments*

After the termination of the Duruma sedimentation, major faulting and rifting led to the break-up of Gondwanaland; it caused a fundamental facies change from a continental cratonic trough to a marginal marine basin with neritic sediments, located at the trailing edge of the continent. This transition is marked by a middle Jurassic (Bajocian) marine ingression.

The basal Bajocian sediments of the *Kambe formation* were deposited under near-shore neritic and estuarine conditions. Basal transgression conglomerates, largely composed of Duruma detritus, are overlain by impure micritic limestones, occasionally with small bioherms, and near-shore oolithic limestones, which were deposited in a shallow shelf environment with only moderate terrigeneous contamination.

The *Kibiongoni formation*, comprising shales, sandy siltstones, impure sandstones and grits, represents a partly contemporary estuarine facies with strong terrigeneous influence. Apparently seaward drainage was restricted by coastal ranges, probably resulting from up-doming prior to rifting. Clastic detritus was thus transported into estuaries just by a few rivers breaching this coastal range whilst the limestones of the Kambe formation formed in the clean, agitated sea between the estuaries. With increasing denudation of the coastal range, they were partly later covered by estuarine Kibiongoni sediments.

Kambe and Kibiongoni formations are overlain by a monotonous sequence of fossiliferous *Upper Jurassic* calcareous *shales* and mudstones with occasional thin lenses of impure or oolithic limestones. Four formations extending from the Calloway into the Kimmeridgian were discerned on a biostratigraphical basis by CASWELL (1953 & 1956). The fauna of the basal shales is characteristic of muddy deeper water deposits. This facies, however, did not persist and Argovian sediments again include oolithic limestones and even a horizon with gypsum concretions, indicating the return of shallow-water conditions. Sedimentation apparently continued without a break into the middle Kimmeridgian. Upper Kimmeridge to Purbeck are absent; a small occurence of impure Neocomian limestone has faulted contacts.

2.2.3 *Plio-Pleistocene Deposits*

Erosion prevailed during the Tertiary until the Upper Pliocene, when tectonic reactivation resulted in increased erosion from structural highs. Fluviatile pebble beds, gravels and sands of the *Margarini formation* were deposited on down-faulted and eroded Jurassic and Duruma sediments. After a regression during the lowest Pleistocene, dunes which form the bulk of the Margarini formation were blown-up.

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The younger Pleistocene was marked by eustatic fluctuations of the sea level, by the erosion of the Margarini sediments, the growth of a *coral reef* and the deposition of the associated lagoonal sands and backreef deposits of the *Kilindini formation.*

2.3 The Jombo-Mrima Alkaline Complex

The generally close relationship of continental rifting with alkaline magmatism is documented at the southern Kenyan coast by the Jombo-Mrima alkaline complex, tentatively dated as Cretaceous (WALSH 1969).

The major alkaline intrusions of Jombo Hill and Dzirihini consist of cores of nepheline syenites surrounded by mafic alkaline rocks (malignites, ijolites, melteigites, juvites, and foyaites). Associated with them are the carbonatite complex forming Mrima Hill as well as agglomerate vents, kimberlitic diatremes, and minor volcanic vents. Lamprophyric dykes (monchiquites, vogesites, camptonites, and tinguatites) as well as nephelinite and syenite aplites cut across the igneous rocks and the surrounding Duruma sediments, which show in places intense fenitization by in-situ alkali metasomatosis. Active hot springs are recent vestiges of volcanic activity.

2.4 Structural Geology

The general structural pattern of the area is rather simple. Vertical faults, striking parallel with the coastline, displace the generally flat SE-dipping sediments downward to the east. The major faults, along which rifting and break-up of Gondwana did occur are located offshore (KENT & al. 1971, RABINOWITZ 1971).

The faults in the south of the area form the northward extension of the NNE-striking Tanzanian "Tanga fault belt" (KENT & al. 1971). North of the area of the alkaline complex, fault trends change to NE, whilst the alkaline complex itself is elongated WNW, a trend which also controls the alignment of clusters of volcanic diatremes, lamprophyric dykes and major faults. This structural pattern, characteristic of triple junctions, can accordingly be interpreted as an incipient triple junction with a failed WNW rift arm, which developed during the opening of the Indian Ocean.

3. Economic Geology

3.1 Sedimentary Mineral Occurences

Mineral production in the area described is presently restricted to small-scale quarrying of *Jurassic limestones* for aggregate and road ballast. Pleistocene *coral limestone* is utilized on a larger scale for manufacturing cement at Bamburi north of Mombasa, and also has a considerable economic potential in the area investigated.

Other mineral occurences of sedimentary origin comprise mainly industrial minerals, and in addition gravel and sand. None of these, however, are presently commercially exploited. *Silica sands,* resulting from the reworking of the dune sands of the Margarini formation in the swash zone of Pleistocene beaches are known to occur in the Kilindini formation, although no estimates of their economic potential are available. Insignificant placer occurences of *semi-precious stones,* mainly garnet,

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tourmaline and zircon, derived from the "gemstone belt" in Proterozoic gneisses further inland (POHL & HORKEL 1980), are associated with the basal fluviatile member of the Margarini formation. The facies of the Mazeras formation suggests a potential host rock for sandstone-type *uranium* mineralizations although no uranium indications have yet been reported. However, Zambian carnotite deposits occur in similar stratigraphic positions in arkosic Karroo sandstones and grits with a lithofacies closely resembling that of the Mazeras sandstones (MONEY & PRASAD 1977).

3.2 Hydrothermal Pb-Zn-Ba Mineralizations

Numerous minor vein-type galena-sphalerite-baryte mineralizations of the type commonly associated with continental rifting occur along the Kenyan coast. They are structurally controlled by the major pre-Bajocian faults along which rifting took place and occur exclusively within Duruma sediments. Bajocian sediments, even close to mineralized faults are as a rule not mineralized except for small sporadic galena or sphalerite crystals of diagenetic origin.

The largest base metal deposit of the Kenyan coast, mined on a small scale until 1977 and situated immediately north of the area described at Kinangoni, consists of a hydrothermally mineralized tectonic breccia in a fault zone complementary to the major faults forming the eastern margin of the Mazeras formation. Diamond drilling in this area also intersected sub-conformable disseminated sphalerite mineralizations, presumably selective impregnations in pervious sandstone horizons close to hydrothermal veins.

In comparison, the base metal mineralizations south of Mombasa have a rather insignificant economic potential. They are generally thin, impersistent Pb-Ba veinlets in fault breccias, reaching a maximum thickness of 3 m at the Lunga-lunga baryte prospect.

A geochemical stream sediment survey, covering the area with an average sample density of 0.9 samples per sq. km outlined 19 significant geochemical anomalies. However, follow-up exploration with geochemical soil surveys and ground geophysics indicated again only minor vein-type mineralizations and no promising major exploration targets.

3.3 Mineralizations associated with Alkaline Rocks

The *Mrima Hill Nb-Rare earths deposit* constitutes the most important mineral deposit in the area. Niobium and rare earths elements are enriched in a gossaneous manganiferous laterite which developed as residual soil on the karstic relief of a carbonatite. Although the prospect has substantial reserves and ranks amongst the major potential deposits of the world, the metallurgical complexity of the ore has so far prevented its development (COETZEE & EDWARDS 1959, MASON 1966, HEINRICH 1966).

Kimberlitic rocks have been prospected in the past for diamonds but proved to be barren. During the present survey, additional volcanic vents were prospected using geochemical methods, ground magnetics and heavy mineral spectra for diamondiferous kimberlites, but again with negative results.

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Minor *Cu-Pb* mineralizations of no economic potential occur occasionally in fault breccias at the margin of lamprophyric dykes. Some *alkaline rocks* could serve as raw material for ceramics and as cement additives (ALLEN & CHARSLEY 1969).

Owing to the absence of a well-developed surface drainage system, the alkaline complex was explored on a regional scale by a geochemical soil survey combined with a magnetic survey over an area of 225 sq. km at a grid spacing of 1000×200 m. Geochemical and magnetic anomalies, however, merely reflect different lithological backgrounds and possibly some insignificant vein-type mineralizations. They apparently do not reflect exploration targets with an economically significant mineral potential.

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