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## Notes on the Geology and Mineral Resources of the Mtito Andei-Taita Area (Southern Kenya)

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with the collaboration of

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With 2 Figures, 4 Tables and 1 Plate

### Abstract

The Mtito Andei-Taita area in southern Kenya is situated within the Mozambique Belt, a major Proterozoic structural/metamorphic unit extending more than 5000 kms along the eastern coast of Africa. The metamorphic lithologies of the Mozambiquian in the area include paragneisses, schists, marbles and amphibolites, considered to be originally mio- and eugeosynclinal volcanic and sedimentary rocks. Ultramafic rocks and poly-metamorphic charnockites and granulites are thought to represent respectively dismembered ophiolites and ancient sialic crust. They were tectonically emplaced during an early deformation phase. Subsequently a major orogenic episode affected all the rocks mentioned at about 800 m.y., producing the Barrow-type metamorphism noted which reached the highest amphibolite facies.

The structural evolution involved at least three phases of plastic deformation: final cratonization was achieved during the Pan-African orogenesis. Mio-Pliocene ruptural deformation associated with the extrusion of phonolites and basalts is related to the development of the East African rift system. Economic mineral

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deposits exploited at present are gemstone deposits, of which the most important are rubies which occur in association with ultramafic rocks, and strata-bound green grossularites ("Tsavorite") occurring in a particular graphite gneiss horizon. An economically promising graphite deposit has been located at Chawia. Certain horizons within the volcano-sedimentary suite are considered prospective for syngenetic base metal deposits. Of less imminent interest are small deposits of iron ore, kaolin, graphite, magnesite, and asbestos. Local requirements for bulk commodities such as sand, structural stone and limestone can be met from the known sources.

### Zusammenfassung

Das Mtito Andei-Taita Gebiet im Süden Kenyas liegt im „Mozambique Belt“, einem proterozoischen Orogen, das sich über mehr als 5000 km entlang der afrikanischen Ostküste erstreckt.

Die Paragneise, Schiefer, Marmore und Amphibolite, welche das Gebiet aufbauen, werden als ehemalige vulkano-sedimentäre eu- und miogeosynklinale Sedimente gedeutet. Ultramafite und poly-metamorphe Granulite und Charnockite wurden wahrscheinlich während der frühen orogenen Phasen tektonisch eingeschleppt und können als Ophiolite bzw. altes sialisches Grundgebirge angesehen werden. Die strukturelle Entwicklung erfolgte in mindestens drei Deformationsphasen und wurde während der pan-afrikanischen Orogenese abgeschlossen. Die Extrusion miozäner Phonolitlaven und pliozäner bis quartärer Olivinbasalte war mit der Entwicklung des ostafrikanischen Grabensystems verbunden.

In Abbau befindliche Lagerstätten sind hauptsächlich Edelsteinvorkommen: Rubine sind an Ultramafite gebunden; grüne Vanadiumgrossulare („Tsavorite“) kommen in einem bestimmten Graphitgneisshorizont vor. Bei Chawia wurde ein wirtschaftlich interessantes Graphitvorkommen gefunden. Bestimmte Horizonte innerhalb der vulkano-sedimentären Folge enthalten reichliche Indikationen für syngenetische Buntmetallagerstätten. Kleinere Vorkommen von Eisen, Kaolin, Graphit, Magnesit und Asbest sind wirtschaftlich wenig versprechend. Marmore, Basalte, Gneise und Lapilli genügen für die Deckung des lokalen Bedarfs an Bausteinen und Schotter.

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## 1. Introduction

Small deposits of graphite, magnesite, mica, magnetite and asbestos have been known to exist in the Mtito Andei-Taita area in southern Kenya for a long time. The discovery in 1971 of important deposits of ruby and high-quality green "Tsavorite" garnet enhanced considerably the economic interest in this area (BRIDGES 1974).

A systematic regional mineral exploration programme was therefore implemented from 1975–1978 within the framework of a bilateral technical assistance project funded by the governments of Austria and Kenya.

The general geological concept provided in this paper served as a basis for a systematic appraisal of the mineral potential of the area; it is derived from new geological mapping of 1 : 50.000 scale and was also based on the pre-existing geological data (PARKINSON 1947, FARQUHAR 1960, SANDERS 1963, WALSH 1960 and 1962, BEAR 1955 and SAGGERSON 1962 and 1963). The maps 1 : 50.000 have been compiled for the present paper into a generalised map at a scale of 1 : 250.000 (plate 1).

## 2. Regional Geology

### 2.1 General Geological Setting

The Mtito Andei-Taita area is situated within the Mozambique Belt, a major structural/metamorphic unit which extends along the African east coast from Mozambique and Malagasy into the Sudan and possibly as far north as Egypt and Arabia; it represents one of the fundamental geological features of Africa (HOLMES 1951, CLIFFORD 1970, KRÖNER 1977 and 1979). The belt consists typically of high-grade metamorphic rocks, characterized by K/Ar-ages of 400–600 m.y. (CAHEN 1951). Three major units were recognized in southern Kenya (POHL & NIEDERMAYR 1979):

Relics of older-metamorphic basement occur as wedges and slices of charnockites and granulites, tectonically emplaced within meta-sediments.

Variegated mio-geosynclinal meta-sediments, consisting of marbles, quartzites, graphite and kyanite (-sillimanite) gneisses and schists,

	Kasigau Group	Kurase Group
Metamorphism	amphibolite facies; (kyanite-almandine- muscovite sub-facies)	amphibolite facies approaching granulite facies; (kyanite-almandine-muscovite and sillimanite-almandine- orthoclase sub-facies)
Dominant deformation pattern	open folds	recumbent isoclinal folds with superimposed open folding
Litho-facies	monotonous; quartz-feldspar- hornblende/biotite gneiss with intercalations of epidote ortho-amphibolite	complex; marbles, banded biotite gneiss, graphite schists, kyanite/sillimanite gneiss, quartzites; acidic granulites, felsic gneiss, amphibolite

Table 1 — Main features of Kasigau and Kurase Groups

biotite (-hornblende) gneisses and amphibolites which were deposited as a sedimentary cover with volcanic intercalations upon the basement. SAGGERSON (1962) described this suite as the "Kurase Series".

Eu-geosynclinal meta-sediments are considered to be represented by a thick suite of monotonous meta-greywackes (quartz-feldspar-biotite-hornblende gneisses) with bands of ortho-amphibolites, described by SAGGERSON (1962) as "Kasigau Series" immediately to the east of the Taita area. This unit probably was deposited on a continental margin.

Facies transitions between the two series suggest an approximate time equivalence. The present contact between the two groups is apparently concordant. It is marked by lenses of meta-dunites, peridotites and -basalts possibly representing dismembered ophiolites along a regional thrust.

## 2.2 Litho-Stratigraphy of the Mozambique System

The metamorphic rocks constituting the Mozambique Belt in this area are essentially a metamorphosed volcano-sedimentary sequence, originally consisting of arkoses, greywackes and marly shales, interbedded with limestones, thin sandstones and intercalations of acidic and basic lava flows, sills and tuffaceous layers.

The entire sequence is divided into two lithological units characterized by different litho-facies, metamorphic sub-facies and deformation patterns (table 1); they correspond roughly with SAGGERSON's (1963) "Kasigau Series" and

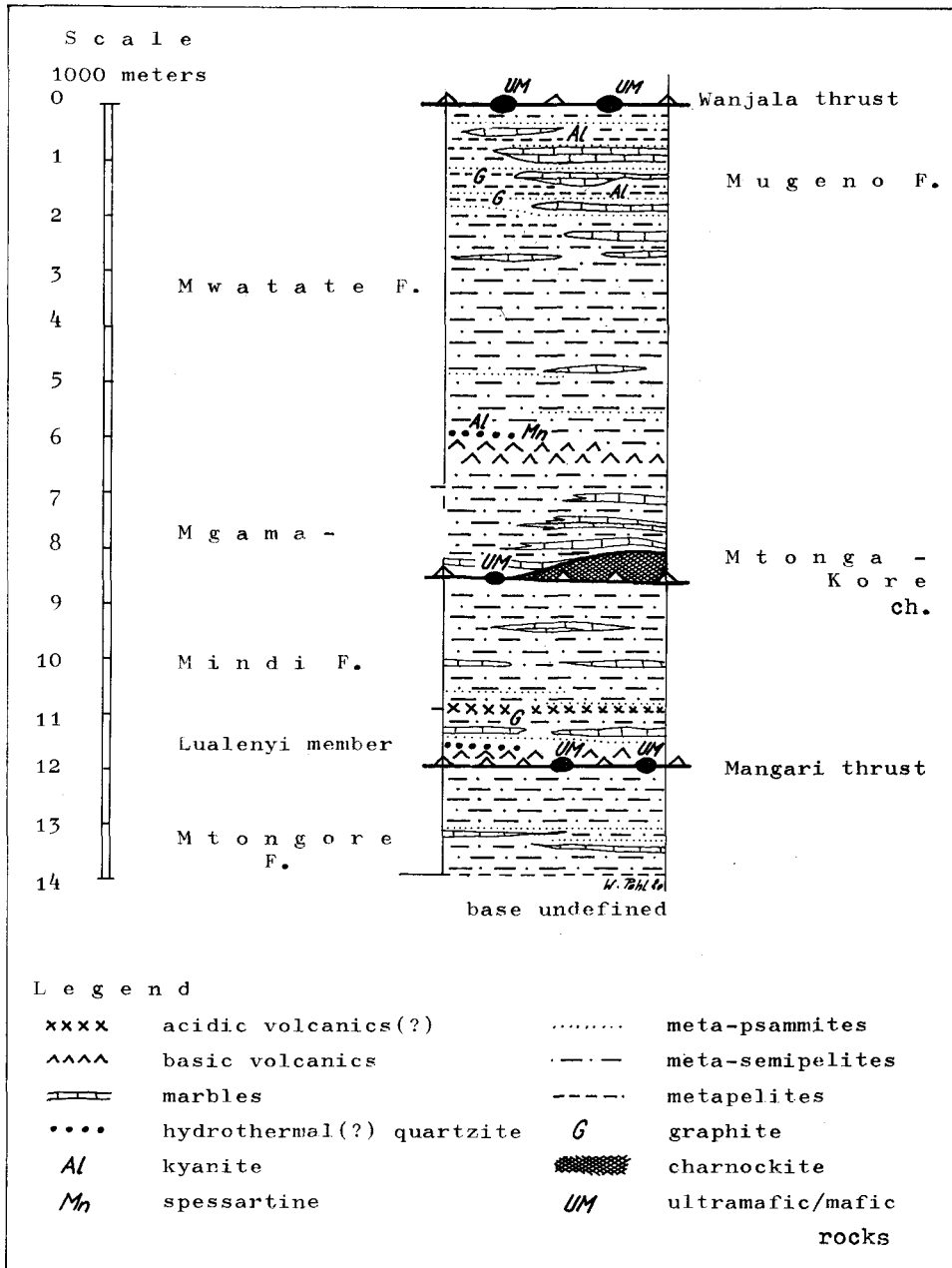


Fig. 1 — Schematic lithostratigraphic column of the Kurase Group in the Taita area.

“Kurase Series“ and are further described in accordance with modern nomenclature as the Kurase Group and the Kasigau Group.

Table 2 provides a sub-division of the Kurase Group. A graphical scheme of its lithostratigraphy is represented in Figure 1. The simplified lithologic column emphasizes the probability of repetition of parts of the rock suite by thrusting. However, poor outcrops do not allow continuous lateral mapping of thrusts and critical rock associations.

The granulites and charnockites occurring in the Kurase Group as tectonically emplaced wedges and as one larger complex presumably represent an ancient sialic basement on which the Proterozoic Kurase sediments were deposited. The contacts between the individual formations are frequently gradational and the different facies interfinger laterally. This indicates a shallow marine paleo-environment with rapidly changing facies. On swells, limestones and thin impersistent beds of clastic sediments were deposited; the swells sloped into basins where thick monotonous sequences of semi-pelitic and pelitic sediments intercalated with organic muds accumulated. The volcanogenic rocks indicate dilation of the underlying sialic crust, possibly related to the initial stages of rifting. Hydrothermal systems initiated by volcanic processes may have produced syngenetic metal accumulations.

Mafic/ultramafic rocks (basalts, peridotites, pyroxenites, dunites and their metamorphic equivalents, mainly amphibolites, serpentinites and pyroxene-talc-amphibole rocks) were emplaced during an early deformational stage along thrusts and may represent dismembered and metamorphosed slices of oceanic crust.

### 2.3 Metamorphism

The rocks of the Mozambique Belt were subjected to regional Barrow-type medium to high-grade metamorphism, accompanied by migmatization and partial anatexis. However, no palingentic granites were recorded.

The mineral assemblages in metamorphites of the Kurase Group are indicative for the sillimanite-almandine-orthoclase sub-facies of the amphibolite facies (WINKLER 1967); only south of Mwatate and in the Longa-Longa Formation, mineral assemblages of the kyanite-almandine-muscovite sub-facies were recognized. The charnockites (plagioclase-potassic feldspar-hornblende-diopside-hypersthene rocks) are most likely the product of poly-cyclic anhydrous high-grade metamorphism, and thus differ distinctly from the enveloping migmatitic gneisses. This metamorphic hiatus supports the proposed basement/cover relationship between charnockites and para-gneisses.

Metamorphic rocks of the Kasigau Group contain mineral assemblages indicative for the kyanite-almandine-muscovite sub-facies of the amphibolite facies (WINKLER 1967). This points to a slight difference in metamorphic grade between Kasigau and Kurase Group.

Rb/Sr-ages of 827 m.y. (SHIBATA 1975) probably reflect the main metamorphism, as similar Rb/Sr-ages were obtained from Tanzanian granulites (SPOONER & al. 1970). Widespread K/Ar-ages of around 500 m.y. (SAGGERSON 1962, SNELLING 1964 and 1966) are considered to reflect resetting of radiometric ages during the Pan-African tectono-thermal event.

WEST	CENTRAL	NORTH-EAST
<p><b>LONGA LONGA FORMATION</b> marble, amphibolite, quartzite, kyanite quartzite and schist; spessartine quartzite-gondite?, graphite gneiss, biotite-hornblende gneiss, muscovite gneiss, porphyro-blastic hornblende-garnet gneiss</p>	<p><b>MUGENO FORMATION</b> marble, sillimanite/kyanite (-garnet) gneiss, variegated biotite gneiss, graphite gneiss; garnetiferous quartz-feldspar gneiss</p>	<p><b>ATHI FORMATION</b> banded biotite gneiss, marble, plagioclase (-biotite-garnet) amphibolite, graphite gneiss, quartz-feldspar gneiss; quartzite, hornblende-pyroxene gneiss and biotite-garnet-sillimanite gneiss/khondalite?</p>
	<p><b>MWATATE FORMATION</b> monotonous banded biotite gneiss, plagioclase amphibolite, quartz-feldspar gneiss, graphite gneiss, marble; kyanite/sillimanite gneisses, spessartine quartzite, base metals?</p>	<p><b>MGAMA-MINDI FORMATION</b></p>
<p>— Upper Member marble; biotite and graphite gneiss?</p>	<p>— Luanlenyi Member variegated graphite (sillimanite-muscovite) schist and gneiss, marble, quartz-feldspar(-garnet) gneiss; amphibolite; biotite-garnet-kyanite gneiss, quartzite, base metals?</p>	<p><b>MTONGORE FORMATION</b> banded biotite (-sillimanite-garnet) gneiss, marble, quartz-feldspar (-garnet) gneiss</p>

Table 2 — Provisional litho-stratigraphy of the Kurase Group (for details refer to HORTEL & al. 1979, POHL & NIEDERMAYR 1979, and AUSTROMINERAL 1978 a, b).

## 2.4 Post-Mozambiquian Rocks

Physiographical evolution after cratonization during the early Paleozoic took place in several erosional cycles and possibly also included the deposition of clastic Karroo sediments during a Permo-Triassic transgression. Relics of six erosion surfaces, dating from the Cretaceous to the upper Pliocene (?) were discerned by SAGGERSON (1962 and 1963), SANDERS (1963) and WALSH (1960 and 1963).

The Yatta Phonolite forms an unconformable capping, some 20 m thick, on a Miocene erosion surface above Mozambiquian gneisses. The phonolite lava presumably flowed along an old river bed incised in an older surface. Subsequent erosion of the adjacent gneisses resulted in the present reversed morphological feature of the Yatta Plateau (FUJITA 1977).

Lacustrine sediments, mainly calcareous silts, were deposited locally at Mzima Springs in depressions on the end-Tertiary erosion surface prior to the extrusion of Pleistocene basalts.

Extensive Quaternary basalts, mainly flows of olivine basalt, and volcanic cinder cones form a southward extension of the volcanic Chyulu Range. Intermittent volcanic activity commenced in the Pleistocene (SAGGERSON 1963) and continued into historic times.

Superficial deposits such as alluvium, colluvium and the mainly residual soils are the result of sub-aerial denudation under semi-arid conditions.

## 3. Structural Geology

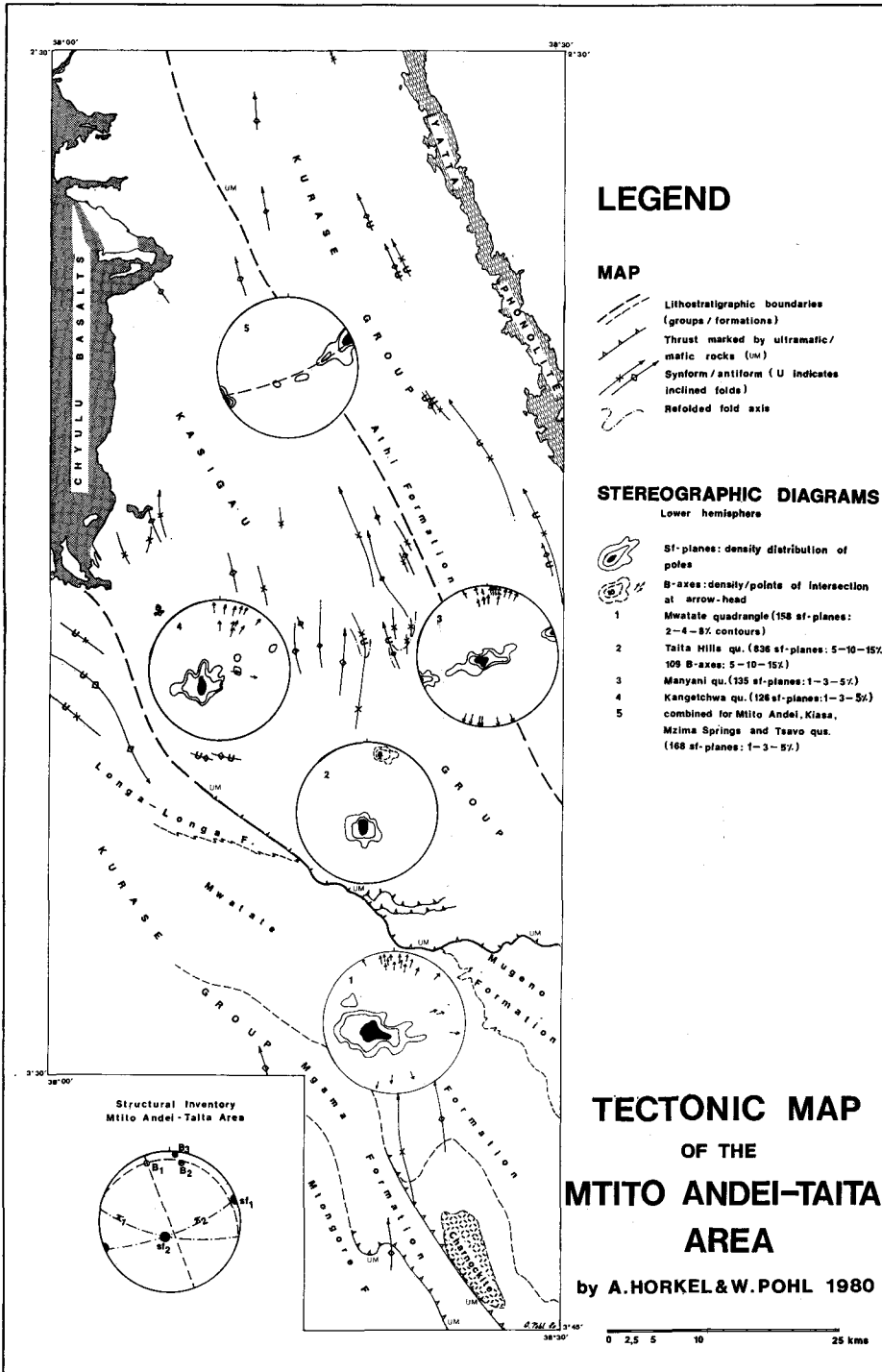
### 3.1 Folding

The major structural features in the Mtito Andei-Taita area are the result of intense plastic deformation, which affected all metamorphic rocks to some extent. Recumbent isoclinal folds characterize the Kuruse Group, while open folds seem to prevail in the Kasigau Group. In both groups at least three phases of plastic deformation are superposed on each other and produce a complicated poly-cyclic deformation pattern. Their structural inventory is provided in fig. 2.

The earliest deformation phase ( $F_1$ -deformation) preceding the migmatization of the metamorphites created mainly flexural-slip axial-plane folds; their axes plunge generally towards NNW. The foliation (sf 1) and other meso-structures related to  $F_1$ -deformation were widely obliterated by later deformation.

The next deformation phase ( $F_2$ -deformation) took place during migmatization of the metamorphites; it is characterized by highly mobile slip folds (shear folds) which with increasing anatectic mobilization occasionally grade into flow folds.  $F_2$ -foliation planes are commonly parallel to lithological contacts; incipient transverse foliation is somewhat younger. Conspicuous  $F_1$ -meso-structures include boudinage structures, minor folds and lineations, and pygmatic folds. Refolding of pre-existing  $F_1$ -folds by  $F_2$  caused in certain areas typical "mushroom" inter-





## LEGEND

### MAP

- Lithostratigraphic boundaries (groups/formations)
- Thrust marked by ultramafic/mafic rocks (UM)
- Synform/antiform (U indicates inclined folds)
- Refolded fold axis

### STEREOGRAPHIC DIAGRAMS

- Lower hemisphere
- S<sub>i</sub>-planes: density distribution of poles
  - B-axes: density/points of intersection at arrow-head
  - 1 Mwalale quadrangle (158 st-planes: 2-4-8X contours)
  - 2 Taita Hills qu. (836 st-planes: 5-10-15X; 109 B-axes: 5-10-15X)
  - 3 Manyani qu. (135 st-planes: 1-3-5X)
  - 4 Kangetchwa qu. (128 st-planes: 1-3-5X)
  - 5 combined for Mtito Andei, Kiassa, Mzima Springs and Taavo qu. (168 st-planes: 1-3-5X)

## TECTONIC MAP OF THE MTITO ANDEI-TAITA AREA

by A. HORTEL & W. POHL 1980

ference patterns. Incipient cross-folding with axes nearly perpendicular to the main axes was recognized in the south of the area.

A final deformation phase ( $F_3$ -deformation) after migmatization is mainly reflected by large open folds and gentle flexures with axes sub-parallel to the  $B_2$ -axes. These structures seem to control the emplacement of late pegmatites, and, most importantly, the joint pattern in the area.

### 3.2 Emplacement of Granulites, Charnockites and Ultramafic Rocks

Mafic and ultramafic rocks were presumably emplaced prior to  $F_2$ -deformation along low angle thrusts (HORKEL & al. 1979, POHL & NIEDERMAYR 1979). Some of these rocks may represent oceanic crust which was largely destroyed during the early history of the Mozambique Belt. Intense shearing during  $F_2$ -deformation caused the predominant re-alignment of the now dismembered metamorphosed and tectonized mafic/ultramafic complexes in sub-conformity to the  $sf_2$ -planes (HORKEL & al. 1979).

Small wedges of granulites and charnockites as well as the large Mtonga-Kore charnockite complex as a rule are aligned sub-conformably along regional  $F_2$ -structures. Although  $F_1$ -meso-structures were occasionally recognized, granulites exhibit as a rule intense  $F_2$ -deformation. They were thus presumably tectonically emplaced during the earliest deformation stages and subsequently subject to intense plastic deformation.

### 3.3 Faulting

Most of the faults and fractures in the area are post-crystalline ruptures generated during or shortly after the last phase of plastic deformation. They are mainly near-vertical hol-planes, hko-planes and ac-planes related to the dominant axes. Displacements as a rule are small. Post-crystalline ruptural deformation accounts also for the widespread cataclasis of the metamorphites, affecting particularly the porphyroblasts.

Large north-south trending lineaments in the south represent a different type of ruptural deformation. These lineaments, extending occasionally over more than 50 km are interpreted as major tensional structures with no significant vertical displacement (HORKEL & al. 1979). They are presumably related to the evolution of the East African rift system. Crustal movements taking place up to the present day are indicated by numerous earthquakes with epicenters near the Taita Hills (LOUPEKIN 1971).

Minor post-Miocene (?) faulting recorded in the Yatta phonolite represents probably reactivation of post-crystalline ruptures. The eruption centers of Quaternary basalt flows are also aligned along NNE-SSW trends, which similarly may reflect pre-existing zones of crustal weakness, re-activated during the evolution of the rift system.

### 3.4 Structural/Metamorphic Evolution

From the geological data acquired during mineral exploration and regional geological reconnaissance, a provisional correlation of depositional, structural and metamorphic events is provided in Tables 3 and 4.

TIME SCALE

BROAD ENVIRONMENT

550 m.y. Pan-African Event	final cratonisation	F <sub>3</sub> -open flexures about NNE-axes; thermal metamorphism (M <sub>3</sub> ), microcline growth, setting of K/Ar-ages, intrusion of pegmatites; retrograde metamorphism (M <sub>4</sub> )	
1200 to 800 ? (Kibaran)	continental collision	F <sub>2</sub> -main phase: tight to isoclinal, overturned folds with NNE-axes, crossfolds with easterly plunge; medium-pressure/high temperature metamorphism of Barrow-type (M <sub>2</sub> ), anatexis and migmatisation	
	suturing	F <sub>1</sub> -tight to isoclinal, overturned folds with NNW-axes, emplacement of ophiolites along regional thrusts, green-schist metamorphism (? M <sub>1</sub> )	
< 2000 m.y.	rifting/closure	Deposition of mio- and eugeosynclinal groups miogeosynclinal: meta-carbonates, -Mn/Fe-quartzites, -sandstones, -pelites (graphite- sillimanite schists)	eugeosynclinal: meta-greywacke, -arkoses, -basalts
> 2500 m.y.	older basement	two-pyroxene granulites (charnockite)	

Table 3 — Tentative summary of Mozambiquian history in the Mtito Andei-Taita Area.

TIME SCALE		BROAD ENVIRONMENT	
PALEOZOIC MESOZOIC CENOZOIC	Tertiary Quaternary	Holocene	Soils, colluvium and alluvium
		Pleistocene	rift-related fracturing and volcanism Chyulu basalts (pleistocene to recent) Mzima Springs sediments
		Neogene	Yatta phonolite
		Paleogene	erosion, earliest land-surfaces preserved in Taita Hills earliest kaolinitic soils in the Taita Hills, land forms of humid tropic climate
		erosion in the NW, in the SE deposition of Karoo-sediments (?) at present no Karroo-sediments known, but a former extension into the study area seems possible	
		uplift and erosion	

Table 4 — Summary of post-Mozambiquian history in the Mrito Andei-Taita Area.

## 4. Economic Geology

The present mineral production of the Mtito Andei-Taita area is confined to gemstones, mainly rubies associated with ultramafic rocks and strata-bound green grossularites ("Tsavorite"). The production of graphite, particularly from the Chawia deposit may also prove economically feasible. Less promising mineralizations, mainly with a potential for domestic markets, are magnesite and asbestos occurrences in ultramafic bodies or kaolin and magnetite deposits. The development of bulk commodities such as marble and structural stone depends mainly on an adequate local market potential.

In general, the geological environment of the Mozambiquian is considered unfavourable for deposits of metallic ores: The rock suites consist mainly of originally clastic meta-sediments; intrusive rocks with potential for mineralization are absent and the mafic/ultramafic rocks are practically devoid of metals. This observation agrees well with the general concepts of the minerogenetic pattern of the Mozambique Belt. However, the present mapping and exploration campaign has resulted in indications for syngenetic base metal mineralizations in the south of the Taita area, which are associated with basic volcanic rocks, Fe/Mn-quartzites, and graphitic schists showing small gossans with anomalous base metal values. In contrast to those discoveries in the Kurase Group south of the Taita Hills, a systematic geochemical stream sediment survey covering the eight northern quadrangles at an average density of 1.5 samples per square kilometer did not result in any prospective exploration targets.

### 4.1 Gemstones

#### 4.1.1 Ruby and Sapphire

Ruby and sapphire deposits in the area are of the following types:

- Desilicated plumasitic pegmatites cutting across ultramafic rocks;
- Desilication zones at the contact of ultramafic rocks with paragneisses;
- In metamorphic aluminous sediments (mainly kyanite schists and quartzites);
- As accessories in marbles, associated with red spinel;
- In placer deposits derived from any of the above mentioned primary mineralizations.

However, only the deposits associated with ultramafic rocks and eluvial placers are actually of economic significance.

The important ruby deposits at M a n g a r i result from complex desilication processes between small ultramafic bodies (intensely altered talc-enstatite-tremolite/antophyllite-chlorite rocks) and intrusive pegmatites or paragneisses. Ruby occurs in plumasitic pegmatites (plagioclase-mica rocks with accessory tourmaline and kyanite) which form irregular near-vertical veinlets in the ultramafics and are surrounded by phlogopite-vermiculite-antophyllite alteration zones. Ruby occurs also in clustered kyanite/sillimanite-tourmaline-mica aggregates developed in desilicated felsic gneisses. Rich eluvial placers formed by disintegration of the near-surface parts of the primary ruby deposits and subsequent enrichment in a gravel zone near the base of the soil cover.

Small deposits of low-quality pinkish ruby were briefly worked at *Kishushi* (HORKEL & al. 1979). There, ruby occurs in plumasitic pegmatites and in vermiculite pockets developed at desilicated contacts of felsic gneisses with serpentines and antophyllite rocks. Desilicated paragneisses also contain metasomatic tourmaline and corundum.

At *Kinyiki Hill*, desilicated reaction rims at the contacts of rafts of amphibolites or biotite-hornblende gneisses within serpentinites contain pockets of asbestose antophyllite and vermiculite, in which large poikilitic corundum crystals with occasional patches of clear sapphire are embedded. Most gem-quality sapphires were reportedly recovered from colluvial gravels which accumulated at the foot of *Kinyiki Hill*.

#### 4.1.2 Green Grossularite Garnet ("Tavorite")

Deposits of gem-quality green vanadium grossularite, marketed as "Tavorite" occur at *Mgama Ridge* in certain scapolite-bearing graphite schists in the upper part of the *Lualenyi Member* (for details refer to POHL & NIEDERMAYR 1979). The green grossularite occurs among other calcsilicate minerals as scattered porphyroblasts with kelyphitic rims; it has been formed by metamorphic processes from thin, more calcareous beds or concretionary lenses intercalated with the originally bituminous graphite schists and gneisses. The sedimentary environment may have been partly evaporitic (SUWA et al. 1979). Vanadium, the main colouring agent, was originally contained in bituminous matter. During metamorphism, this was transformed into graphite, and the mobilized vanadium entered the grossularite garnets then being formed. Tectonic structures exerted apparently no control on the genesis of the "Tavorite" garnets.

Intense cataclasis affected the frequently poikilitic garnet. Gem-quality rough stones are therefore rather small and good gems weighing more than three carats are exceptionally rare.

#### 4.1.3 Other Gemstones

Small quantities of green tourmaline are occasionally associated with common tourmaline in zoned pegmatites and rarely pegmatoid segregations; it occurs mainly together with ruby in plumasitic pegmatites and desilicated gneisses. The tourmaline is rarely of marketable quality.

Red and pinkish garnets occur locally as large poikilitic crystals in metamorphic rocks. Owing to intense cataclasis, clear stones or crystal fragments are usually small. Most garnets in the area, however, contain an important percentage of andradite; because of this and the heavy superficial alteration, concentrations suitable for the production of abrasives could not be located.

Traces of blue zoisite ("Tanzanite") occur occasionally with common zoisite in impure marbles.

Red spinel is associated as an accessory with small ruby crystals in some marbles.

Minute quantities of low-quality turquoise form thin veinlets in sillimanite-graphite gneiss of the *Mgama-Mindi Formation*.

## 4.2 Graphite

Disseminated graphite flakes occur in quartzo-feldspathic para-gneisses, which are usually intercalated with garnetiferous biotite gneisses or marbles. Graphite gneiss horizons are composed of individual graphite gneiss bands with intercalations of barren gneisses or anatectic pegmatoid mobilisates. The horizons extend usually over considerable distances along strike. Graphite gneisses occur particularly at transitions between facies characterized by marbles and by thick monotonous biotite (-hornblende) gneisses respectively in the higher Kurase Group of the Taita Hills; they are, however, also associated with variegated garnetiferous paragneisses of the lower Kurase Group.

The Chawia and Mwatate deposits (HORKEL & al. 1979) consist of gently dipping horizons of leucocratic graphite gneiss, some six to ten meters thick, intercalated with biotite gneisses. The graphite gneiss at Chawia is exposed along a dip-slope. Large quantities of graphite gneiss have therefore been subjected to supergene alteration, which is crucial for rendering the graphite gneiss amenable to an economic concentration process. Inferred reserves of weathered graphite gneiss at Chawia amount to 1.2 million tonnes at a grade of approximately 13% C. Concentration tests yielded a coarse flake graphite. According to a pre-feasibility study (AUSTROMINERAL 1978 a) further exploration of the prospect is considered justified. The Mwatate deposit was exploited briefly, but operations ceased after the recovery of some 400 tonnes of flakes, when the reserves of weathered ore were nearly depleted.

Approximately 130 tonnes of graphite concentrate were produced 1943–1955 from the Tsavo graphite deposit. There steeply dipping bands of graphite gneiss, 2 m to 15 m thick, are intercalated conformably into garnetiferous paragneisses and amphibolites. Owing to the near vertical position of the beds, only small quantities of the graphite-bearing rock were subjected to supergene alteration. Reserves of an average grade of 6% C were therefore soon depleted.

## 4.3 Magnetite

At Wanjala, steeply dipping beds of compact, massive magnetite are intercalated conformably into a series of ortho-amphibolites. The ore-bodies vary in length between 10 m and 250 m and in thickness between 1 m and 7 m. The deposit is considered to be a metamorphosed submarine exhalative mineralisation associated with basic volcanics.

Indicated and inferred magnetite reserves (including secondary colluvial deposits) amount merely to about 300.000 tonnes recoverable by open cast mining. The ore contains between 58 and 62% Fe; deleterious impurities such as P, Ti, As, Sn, and SiO<sub>2</sub> do not exceed the usual acceptable levels.

## 4.4 Base Metals

Insignificant disseminated copper mineralizations extend intermittently along the Athi river. They consist essentially of sulphide impregnations, mainly chalcopyrite, in amphibolites, gneisses and anatectic pegmatoid segregations. Outcrops of this mineralization covers areas of a few square meters. Supergene alteration

caused the development of conspicuous surface staining by malachite and some azurite along foliation planes and joints, but earlier examination of such prospects produced negative results (SANDERS 1963). Quartzite lenses and beds containing Mn, Fe, and kyanite associated with ortho-amphibolites of the Kurase Group south of Mwatate and with acidic meta-volcanics (?) at Mikeli (Mgama Ridge south) are interpreted as hydrothermal and syngenetic rocks. Gossanous rocks found in their environs contain high geochemical base metal values. Further investigations are therefore certainly justified.

#### 4.5 Mineralization Associated with Ultramafic Rocks

Other mineralizations genetically related to the ultramafic rocks apart from ruby and sapphire include magnesite, antophyllite, asbestos and vermiculite.

Kinyiki Hill which contains the largest known magnesite deposit in the area is essentially a lenticular dunite-serpentine complex enclosed within the amphibolites and biotite gneisses, which also form numerous rafts in the ultramafic rocks. Irregular veinlets of crypto-crystalline magnesite form a stockwork in the ultramafic rocks. The magnesite contains finely dispersed colloidal silica and chalcedony encrusts the walls of the veins. Reserves are estimated at approximately 3.3 million tonnes containing about 10%  $MgCO_3$ . The siliceous magnesite is merely suitable for low-quality refractories, and agricultural purpose. In view of these limitations of quality, grade and reserves, large scale exploitation of the deposit is not envisaged. Desilicated reactions rims at the contact of the ultramafites with gneisses, amphibolites and pegmatites are lined with vermiculite pockets and with cross- or slip-fibre antophyllite asbestos, intimately intergrown with green talc. Pegmatites cutting across the ultramafic complex contain feldspar, quartz (occasionally of piezo-quartz quality), vermiculite and common tourmaline. All these minerals have been and continue to be exploited on a small scale.

The asbestos deposit at Mackinyambu occurs in serpentine (SANDERS 1953, FARQUHAR 1960, HORKEL & al. 1979) and comprises lenticular bodies of antophyllite associated with some talc and vermiculite. Insignificant magnesite forms reticulate veinlets through serpentine. Reserves amount to some 2.2 million tonnes containing about 5% antophyllite fibre. However, owing to the poor quality of the fibres the asbestos is at present unmarketable.

#### 4.6 Kaolin

Supergene kaolin mineralization is restricted to the Taita Hills. Most occurrences resulted from weathering of small anatectic pegmatoid segregations and are therefore economically insignificant. Kaolinitic soils in the vicinity of Mgambonyi (HORKEL & al. 1979) developed on a thick sequence of quartz-feldspar gneisses resulted from deep humic weathering at an old and subsequently dissected erosion surface. The deposits now occur as isolated cappings of kaolinized gneiss. The kaolin content in the material is rather low, however, and even the concentrated kaolin is of low quality and merely suitable as fire clay. The potential resources, however, are very large.



#### 4.7 Muscovite

Muscovite occurs frequently in zoned tourmaline pegmatites, which typically consists of a quartz-rich core surrounded by a zone mainly composed of microcline and muscovite. Small quantities of mica were mined during World War 2 at Rhodesian Hill and Mgange. Some of these pegmatites could supply at a small scale quartz and feldspar for the glass and ceramics industries.

#### 4.8 Structural Stone

Marble is quarried east of Mwatate on a small scale. Owing to a high Mg-content, the rock is not suited for the manufacturing of cement, but merely for burning to produce lime, and as dimension stone or aggregate. Small quarries for basalt, gneiss and lapilli supply the local requirements for road metal and aggregate. Ample resources of these low-value bulk commodities are readily available for development if required by increased local demand.

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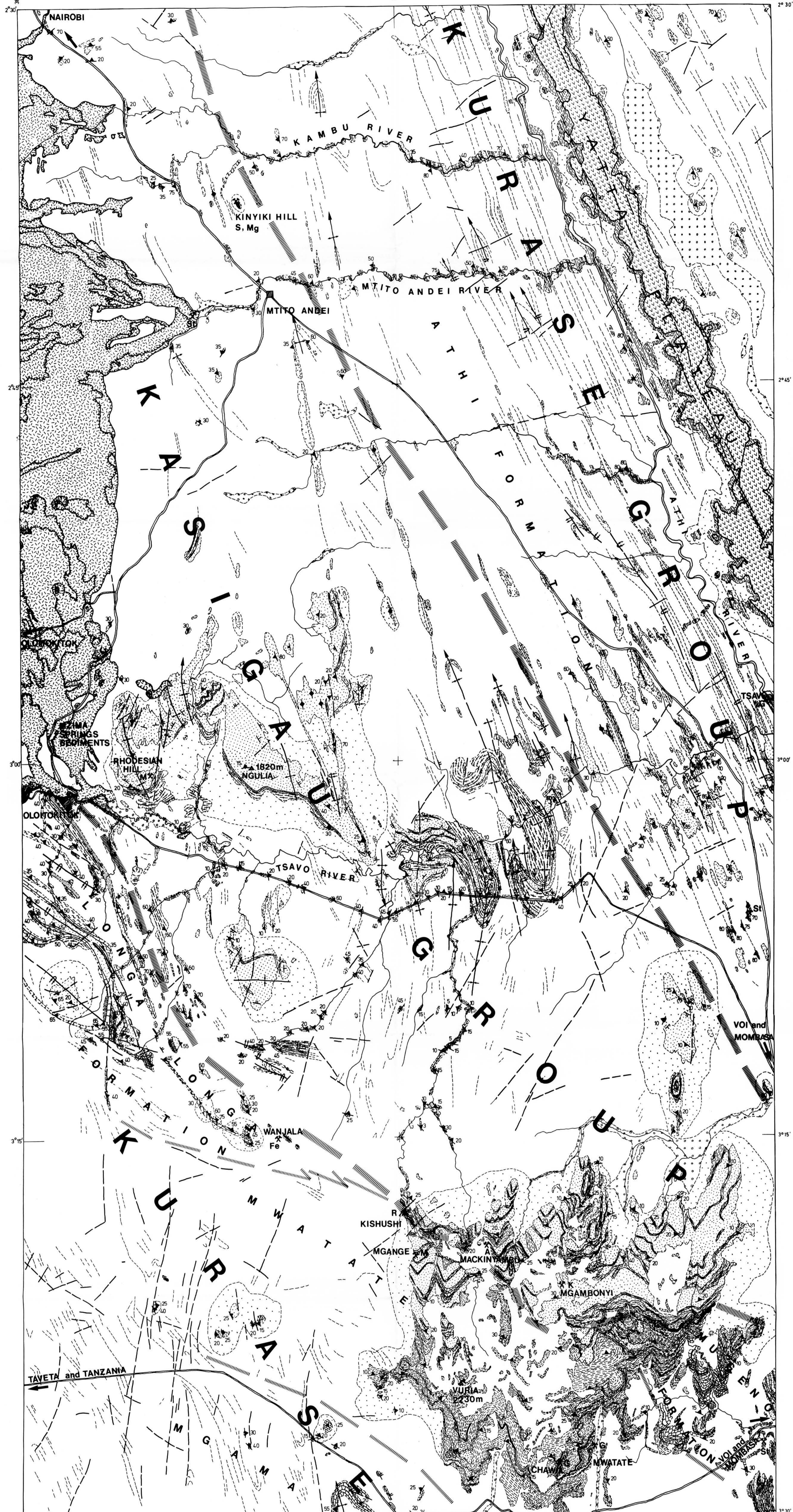
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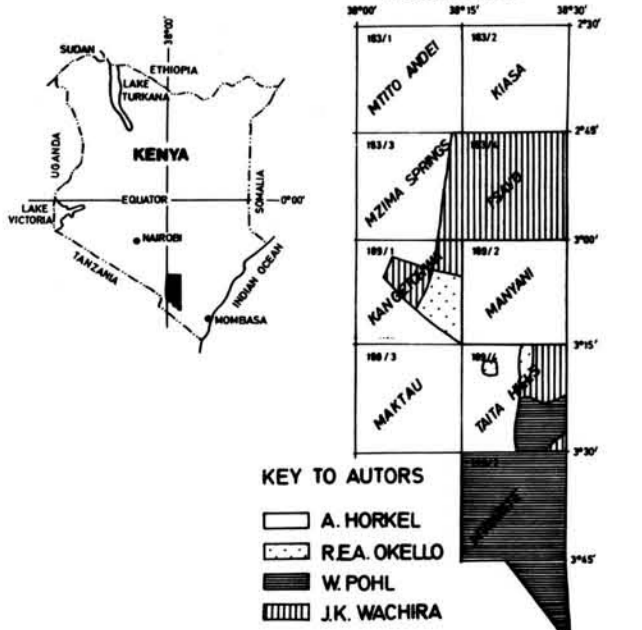
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**LEGEND**

- QUATERNARY / TERTIARY**
- SOILS (RESIDUAL) OVERLYING UNDIFFERENTIATED PRECAMBRIAN COLLUVIAL DETRITAL DEPOSITS
  - ALLUVIUM
  - BASALT / VOLCANIC CONE WITH LAVA FLOW
  - PHONOITE
- PRECAMBRIAN**
- QUARTZ - FELDSPAR GNEISS (WITH FELSIC GRANULITES IN THE KURUSE GROUP)
  - BANDED BIOTITE GNEISSES
  - KWANITE / SILLIMANITE GNEISSES AND QUARTZITES
  - GRAPHITE GNEISS
  - MICA SCHISTS, MICACEOUS GNEISS
  - QUARTZITE
  - MARBLE
  - AMPHIBOLITE
  - CHARNOCKITE
  - ULTRAMAFIC ROCKS
- BOUNDARIES AND STRUCTURES**
- GEOLOGICAL BOUNDARY (APPROXIMATE)
  - LITHO-STRATIGRAPHICAL BOUNDARY (INFERRED) GROUPS / FORMATIONS
  - FAULT OR LINEAMENT
  - STRIKE AND DIP OF FOLIATION (MEASURED) OVERTURNED / VERTICAL DIP
  - STRIKE AND DIP OF FOLIATION (AIR - PHOTO INTERPRETATION)
  - TREND LINE (AIR PHOTO INTERPRETATION)
  - ANTICLINE - OVERTURNED ANTICLINE (WITH PLUNGE OF AXIS)
  - SYNCLINE - OVERTURNED SYNCLINE (WITH PLUNGE OF AXIS)
- PROSPECT / QUARRY**
- IRON
  - RUBY / SAPPHIRE
  - TSAGORITE GARNET
  - GRAPHITE
  - MAGNESITE
  - ASBESTOS
  - KACOLIN
  - MICA
  - MARBLE, GNEISS, BASALT

**INDEX MAP**



**GEOLOGICAL MAP**  
OF THE  
**MTITO ANDEI - TAITA AREA**  
(SOUTHERN KENYA)

SURVEYED BY: A. HORNEL, R.E. OKELLO, W. POHL & J.K. MACHIRA

KENYA - AUSTRIA  
MINERAL EXPLORATION PROJECT

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