Geology of the Taita Hills
(Coast Province/Kenya)

(with coloured geological map, topographic Sheet 189/4)

by

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Errata:

On the geological section, the symbol for graphite gneiss at "Chawia Graphite Prospect", should replace the ultramafic rocks and the symbol for quartz-feldspar gneiss the one for graphite gneiss.

Several minor bands of gneiss do not appear on the section.

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Abstract

The Taita Hills in southern Kenya are situated in the Mozambique Belt, a major upper Proterozoic to lower Paleozoic structural/metamorphic unit extending along the east coast of Africa.

The Taita Hills are composed of Precambrian paragneisses, which represent metamorphosed pelitic, arenaceous and calcareous sediments with intercalations of basic igneous rocks. This volcano-sedimentary sequence was subject to amphibolite facies metamorphism. Ubiquitous anatectic mobilization during metamorphism resulted in the development of banded gneisses, augengneisses, migmatites and anatectic pegmatoid segregations. Intensive plastic deformation took also place. The foliation, however, is characterized by a remarkably constant strike (020/20 approx.) throughout the entire Taita Hills.

Tectonically emplaced ultramafic rocks form narrow belts, aligned sub-conformably to the foliation; these belts are situated at or near the contact between two litho-stratigraphic groups of different lithological facies and metamorphic sub-facies (Kasigau Group and Kurase Group).

The structural evolution of the Taita Hills took place in three deformation phases. The earliest, pre-migmatitic flexural-slip folds were almost entirely obliterated by superposed para-migmatitic slip and flow folds, which plunge uniformly towards NNE. Postmigmatitic open flexures, associated with post-crystalline cataclasis represent the last tectonic phase. Large N-S trending lineaments presumably are young tension structures with little – if any – vertical displacement, related to the evolution of the East African rift system.

Mineral occurrences of economic significance in the Taita Hills are restricted to industrial minerals such as graphite, asbestos, mica, kaolin, marble and corundum/ruby.

Zusammenfassung

Der Gebirgstock der Taita Hills liegt im südlichen Kenya zwischen dem Tsavo West Nationalpark und der Straße Mombasa – Nairobi. Die Taita Hills werden von präkambrischen Metamorphiten des „Mozambique Belts“ gebildet, einem Orogen, das sich entlang der afrikanischen Ostküste erstreckt.

Die Taita Hills bestehen aus einer Wechsellagerung von Paragneisen, im wesentlichen Bändergneise und leukokrate Gneise, mit Einschaltungen von Amphiboliten und Marmoren. Metamorphose der Amphibolitfazies erfaßte die ursprüngliche vulkano-sedimentäre Serie; damit verbundene anatektische Mobilisation verursachte die Entwicklung von Migmatiten und anatektischen pegmatoiden Segregationen. Tektonisch eingeschleppte ultramafische Gesteine bilden schmale, sub-konkordant zur regionalen Schieferung angeordnete Zonen. Diese Zonen liegen nahe beim oder direkt am Kontakt zweier litho-stratigraphischer Gruppen verschiedener Lithologie und metamorpher Sub-Fazies.

Die Schieferung streicht im gesamten Bereich der Taita Hills bemerkenswert konstant (etwa nach 020/20). Die strukturelle Entwicklung hingegen erfolgte in drei Deformationsphasen. Frühe, prä-migmatitische Biegegleitfalten werden von späteren para-migmatitischen Scher- und Fließfalten fast bis zur Unkenntlichkeit überprägt. Die Achsen dieser jüngeren Falten fallen uniform flach nach NNO ein. Post-migmatitische weitgespannte offene Flexuren stellen die letzte Deformationsphase dar, mit der auch weitverbreitete post-kristalline Kataklasis verbunden ist. Bedeutende N-S

streichende Lineamente sind wahrscheinlich junge Zerrstrukturen mit geringen vertikalen Sprunghöhen, die mit der Entstehung des ostafrikanischen Riftsystems verbunden sind.

Bedeutendere Mineralvorkommen in den Taita Hills beschränken sich auf Industrieminerale wie Graphit, Asbest, Glimmer, Kaolin, auf Marmor und auf Korund/Rubin.

1. Introduction

1.1 General

The geological survey of the Taita Hills was implemented during 1975 as part of the Kenya–Austria Mineral Exploration Project, a bilateral technical co-operation project funded by the governments of Kenya and Austria. AUSTROMINERAL Ges. m. b. H., Vienna, represented the Austrian government, the donor. AUSTROMINERAL authorized and sponsored the present publication, which is most gratefully acknowledged by the authors. AUSTROMINERAL also provided the coloured geological map of the Taita Hills; this map was originally contained in AUSTROMINERAL's report „Results on the Geological Survey of the Taita Hills Region", submitted to the Kenyan government in late 1978. The authors would also like to acknowledge the cooperation and support received from the heads and the staff of the Ministry of Natural Resources and the Mines and Geological Department, Nairobi. The Mines and Geological Department kindly permitted the publication of the present paper.

The geological survey of the Taita Hills aimed at providing an up-dated geological base for a systematic assessment of the mineral potential of the area. Such an assessment was considered justified,

- as exploration and small-scale mining of industrial minerals repeatedly took place in the Taita Hills during the past;
- as the recent discovery of significant gem stone deposits in the immediate vicinity of the Taita Hills (POHL & NIEDERMAYR 1978) aroused in addition considerable interest in the economic potential of the area; and
- as the existing outdated and cursory geological surveys were insufficient for systematic mineral exploration.

The technical staff provided by AUSTROMINERAL did include A. Horkel (field geology and preparation of the present report), W. J. Nauta (hydrology), G. Niedermayr (examination of thin sections), and W. Pohl (field geology). Messrs. R. E. A. Okello and J. K. Wachira (both field geology) were seconded by the Mines and Geological Department.

Subsequent to the present survey, a groundwater exploration project, funded by the Governments of Kenya and Austria and also carried out by AUSTROMINERAL Ges. m. b. H., Vienna, commenced in the same area in 1977.

An airborne magnetic survey of the Taita Hills was carried out by Terra Surveys Ltd. in 1977 under a contract financed by the Canadian International Development Agency (CIDA). A preliminary edition of the resulting map is provided as fig. 3.

1.2 Topography

The Taita Hills, situated between longitudes 38°15' and 38°30' E and latitudes 2°15' and 2°30' S, rise abruptly from a vast semi-arid peneplain, which extends over most of southern Kenya. The hills consist of fertile highlands (average elevation about

1500 m), and are topped by peaks, up to 2150 m high, and covered by remnants of mist forrests. POHL & NIEDERMAYR (1979) describe physiography, climate and vegetation in more detail.

The physiographical evolution of the Taita Hills is characterized by several erosional cycles and resulting erosion surfaces. Preserved relics of such surfaces include (SAGGERSON 1962 and 1963, SANDERS 1963, and WALSH 1960 and 1963):

- Cretaceous (?) surface at elevations of approximately 1500 m; older surfaces may possibly exist at higher elevations;
- End-Cretaceous surface at approximately 1300 m;
- Mashoti surface at approximately 1100 m;
- Mwangare surface at approximately 940 m;
- Sub-Miocene surface at about 800 m, the only surface correlated with erosion levels marked elsewhere in Kenya by fossiliferous sediments;
- End-Tertiary (upper Pliocene ?) surface, comprising most of the gently undulating peneplain surrounding the Taita Hills.

The topographic sheet Y 731 – 189/4 "Taita Hills", scale 1:50,000, served as base for the geological survey. Air photographs (approximate scales 1:30,000 and 1:60,000) covering the Taita Hills entirely were used to support and complement the regional geological mapping.

1.3 Access

The Taita Hills are immediatly west of the main road and railway from Nairobi to Mombasa on the Indian Ocean. A railway line and paved road which lead to Tanzania branch off at Voi, a few km east of the Taita Hills quadrangle, and pass through the SE-corner of the quadrangle. Wundanyi, the center of the district administration in the Taita Hills, is linked with this road by a paved mountain road, while numerous all-weather dirt roads provide access to all parts of the densely populated Taita highlands. Roads serving the lowlands are, however, rather scarce.

2. Previous Geological Investigations

PARKINSON (1947) provided the first cursory geological description of the Taita Hills, accompanied by an incomplete reconnaissance map, scale 1:250,000. The paragneisses, assigned to the "Basement System", then considered of Archean age, were already divided (according to the prevailing lithologies of the original sediments) into an arenaceous and an argillaceous group.

FARQUHAR (1960) rendered a more detailed account of the northern Taita highlands. Emphasis centered, however, on ultramafic rocks containing asbestos mineralizations.

Since then, no regional geological investigations were conducted in the Taita Hills. SHIBATA (1975) determined Rb/Sr ages of 827±55 m.y., which were then interpreted either as age of high-grade metamorphism or as the age of sedimentation, while K/Ar ages of 498±15 m.y. for biotite and 519±16 m.y. for hornblende respectively, were assigned to the main phase (?) of the Mozambiquian orogeny.

The areas adjoining the Taita Hills were surveyed geologically, scale 1:125,000, by BEAR (1955), SAGGERSON (1962), SANDERS (1963) and WALSH (1960), who also enumerate the previous investigators since the time of the early explorers. AUSTRO-

MINERAL also surveyed the areas north and south of the Taita Hills at scale 1:50,000 (AUSTROMINERAL 1978 a, b).

BEAR (1955) describes from the area to the west poorly exposed Mozambiquian gneisses, basic to intermediate charnockitic rocks, and ultramafic rocks.

SAGGERSON (1962) differentiated two litho-stratigraphic units in the area to the southwest:

- Kasigau Series, and
- Kurase Series.

The Kasigau Series, overlying the Kurase Series, is dominated by various biotite-hornblende and quartz-feldspar gneisses; its thickness exceeds 3,500 m. The Kurase Series, of which only the uppermost 2,400 m are exposed, is characterized by variegated biotite-hornblende (-kyanite, -graphite, -garnet) gneisses with intercalated marbles. The deformation pattern of the two series differs; open folds prevail in the Kasigau Series, whilst isoclinal overturned folds characterize the Kurase Series. This difference of the structural pattern was attributed to disharmonic folding, as no evidence for a discordance between the two series was found. Feldspar porphyroblasts from the Kasigau Series yielded K/Ar ages of 490 ± 25 m. y. and 425 ± 25 m. y. respectively.

SANDERS (1963) divided the paragneisses east of the Taita Hills into two units comprising various migmatitic biotite-hornblende gneisses; the "Sobo formation", a third unit situated towards east, was described as consisting of variegated, non-migmatized garnetiferous schists and paragneisses, amphibolite, quartzites and marble. Potassium feldspars from a pegmatite yielded a K/Ar age of 560 ± 50 m. y. (HOLMES & CAHEN 1955).

WALSH (1960) describes the area south of the Taita Hills as consisting of various paragneisses of the "Basement System", forming an overturned, northward plunging anticlinorium.

3. Litho-Stratigraphy

The Taita Hills are part of the Mozambique Belt, a major structural/metamorphic unit extending along the east coast of Africa from Malagasy and Mozambique into the Sudan and possibly into Egypt and Arabia; it represents one of the fundamental geological features of Africa (HOLMES 1951, CAHEN 1961, CLIFFORD 1970, KRÖNER 1978).

The metamorphic rocks of the Taita Hills are essentially a metamorphosed volcano-sedimentary sequence, originally comprising arkoses, greywackes, and marls, interbedded with limestones, shales and sandstones, and with intercalated basic lava flows, sills or tuffaceous layers. The entire sequence can be divided into two lithological units characterized by different facies and metamorphism. These units roughly correspond with PARKINSON's (1947) "arenaceous" and "argillaceous" units and also with SAGGERSON's (1963) Kasigau and Kurase Series. In accordance with modern nomenclature, they are referred to in the present report as "Kurase Group" and "Kasigau Group". The two groups are characterized by:

	Kasigau Group	Kurase Group
Metamorphism	amphibolite facies; kyanite-almandine-muscovite sub-facies	amphibolite facies; sillimanite-almandine-orthoclase sub-facies
Lithology	monotonous; quartz-feldspar gneisses and epidote amphibolites dominant; marbles very subordinate	complex; marbles, banded biotite gneisses and variegated sillimanite kyanite or graphite gneisses

The Kasigau Group is characterized by a thick, monotonous sequence of massive quartz-feldspar gneiss with intercalated epidote amphibolites. It overlies the lithologically more complex Kurase Group which was sub-divided further by POHL & NIEDERMAYR (1979) into several formations. In the Taita Hills, the following litho-stratigraphic units were discerned (from top to bottom):

Mugeno Formation, characterized by marble with intercalations of various biotite (-hornblende, -sillimanite/kyanite, -garnet and graphite) gneisses;
Mwatate Formation, mainly composed of monotonous banded biotite gneiss;
Mgama-Mindi Formation, of which only marbles are exposed.

Ultramafic rocks (serpentinite, dunite, and magnesium pyroxene-amphibole rocks) were tectonically emplaced during an early deformation stage at or near the contact between Kasigau und Kurase Group.

Summarizing POHL & NIEDERMAYR's (1979) detailed litho-stratigraphic description of the Kurase Group, the Mugeno Formation at the top of the group extends from the tectonic contact with the Kasigau Group to the lowermost reasonably continuous marble horizon. Marble bands, several tens of meters thick, characterize this formation. Intercalations of thin and impersistent bands of variegated biotite gneisses, sillimanite/kyanite (-garnet, -graphite) gneisses or garnetiferous quartz-feldspar gneisses occur frequently.

Characteristic for the Mwatate Formation are monotonous, uniform, banded migmatitic biotite gneisses which contain variable amounts of hornblende and garnet. Minor bands of plagioclase amphibolite, marble, quartz-feldspar gneisses and graphite gneisses are common intercalations. Mugeno and Mwatate Formation are ocasionally interfingering laterally; contacts are also frequently gradual. The two formations therefore may represent merely two contemporaneous sedimentary facies.

The limestones of the Mugeno Formation, interbedded with impersistent, rapidly changing sands and aluminous clays, are considered to represent the facies of a swell. This swell sloped into a basin, where the thick sequence of monotonous clays and marls of the Mwatate Formation did accumulate. Marbles associated with quartz-feldspar gneisses and sillimanite/kyanite gneisses in the northwestern Taita Hills may indicate a recurrence of the swell facies. Organic sediments, now present as graphite gneisses were deposited especially in the transitional zone between swell and basin.

Poorly exposed marbles at the bottom of the lithological sequence of the Taita Hills are correlated with the higher part of the Mgama-Mindi Formation (AUSTROMINERAL 1978 b). Accordingly, various biotite and/or graphite gneisses are presumably intercalated. Due to the absence of exposures, however, this is merely speculative.

4. Detailed Geology

4.1 Mozambique Belt ("Basement System")

Petrological data for the following brief descriptions of the metamorphic rocks of the Taita Hills were obtained mainly by macroscopic field observations supplemented by the examination of only some 140 thin sections. No diagnostic mineral assemblages or whole rocks were chemically analyzed, except for some electron microprobe analyses of pyroxenes and amphiboles of ultramafic rocks, and of plagioclase, tourmaline and corundum in plumasitic pegmatites. Also no data concerning the element distribution ratios of garnets, biotite and amphiboles do exist, although such data might substantially contribute to a better understanding of the lithological paragenesis. Petrological conclusions therefore have to be considered as preliminary, although they certainly do provide a general outline of the petrological/geological conditions in the Taita Hills.

Rock existing in both litho-stratigraphic groups are not separately described; some petrological units are not sufficiently large for appearing on the 1:50,000 scale geological map.

4.1.1 Quartz-Feldspar Gneiss (and Felsic Granulites ?)

In the Kurase Group, quartzo-feldspathic gneisses (frequently grading into leucocrate biotite gneisses) usually occur as fine- to medium grained, well foliated but occasionally also compact, light coloured rocks. They are intercalated as continuous bands or narrow impersistent lenses into biotite gneisses, graphite gneisses and marbles. Partial anatexis and alkali metasomatism with subsequent recrystallization have obliterated nearly all the sedimentary structures, except for occasional laminations. Felsic granulites, although not observed, are possibly also present (AUSTROMINERAL 1978 b).

Characteristic for the Kasigau Group are thick compact bands of massive, poorly foliated, fine to medium grained and light coloured quartz-feldspar gneisses. Epidote amphibolites, and to a lesser extent small, impersistent quartzite lenses are intercalated. These quartz-feldspar gneisses probably represent metamorphosed,thickly bedded greywackes and arkoses.

Macroscopically, quartz and feldspars are the main constituents of the gneisses, accompanied by biotite, hornblende and garnet. Garnet particularly is abundant in quartz-feldspar gneisses interbedded with graphite gneisses or marbles. Idioblastic magnetite, in octahedrons attaining several mm diameter, is a conspicuous accessory in quartz-feldspar gneisses of the Kasigau Group.

In thin sections, both the proportions of quartz and feldspar and the ratios of alkali feldspar to plagioclase vary widely. Quartz is usually xenomorphic and commonly has undulatory extinction. Although generally occuring as granoblastic mosaic, occasional flattening of the quartz grains leads in some specimens to an incipient granulitic texture. Microcline with quadrille structure is the dominant alkali feldspar; microcline perthite is less common. Plagioclase, occurring twinned or untwinned, is usually an oligoclase. Biotite usually occurs as stable flakes; muscovite, however, is generally altered. This may evidence p-T conditions near the boundary of medium- to high-grade metamorphism, as the reaction

$$\text{muscovite} + \text{quartz} = \text{orthoclase} + \text{sillimanite} + H_2O$$

takes place either roughly at the boundary between amphibolite and granulite facies, or within the amphibolite facies.

Garnet, frequently occuring as cataclastic idioblasts, apatite, graphite, zircon and magnetite are common accessories or minor constituents.

4.1.2 Quartzite

Light grey quartzites occur sporadically in the Kasigau Group. They appear mainly in the Mugeno Formation as narrow, impersistent lenses, and are interbedded with marbles, kyanite/sillimanite gneisses and quartz-feldspar gneisses. In the Kurase Group, quartzites form minor intercalations in quartz-feldspar gneisses. Quartzite lenses are usually too small for appearing on the geological map.

In thin section, quartzites consist of an interlocking mosaic of sutured quartz crystals with equigranular, interlobate, granoblastic texture. Poikilitic porphyroblasts of garnet and antophyllite and occasional mica or graphite flakes occur as accessories.

4.1.3 Graphite Gneiss

Graphite gneisses, mainly quartz-feldspar gneisses with increased contents of accessory graphite, are almost entirely restricted to the Kurase Group. Graphite gneisses generally occur as well foliated, light coloured rocks, and form several horizons intercalated into banded biotite gneisses, marbles and quartz-feldspar gneisses. Individual horizons are some six to ten meters thick; they consist of bands of graphite gneiss, a few cm to two or three meters thick, which alternate with various paragneisses.

Graphite gneisses exhibit in thin section a distinct gneissose texture. Disseminated graphite occurs in large flakes, up to 5 mm in diameter, in aggregates of mesocrystalline flakes and in spherical aggregates of microcrystalline acicular graphite; it constitutes up to approximately 10 % of the gneiss. Quartz with intense undulatory extinction occurs as single platy grains or as distinctly layered clusters. Alkali feldspar, mainly microcline, is more common than plagioclase. Quartz and plagioclase frequently exhibit myrmekitic textures. Graphite and occasionally occurring biotite flakes, associated with intensely altered muscovite, accentuate the foliation.

Also mapped as graphite gneiss is a distinct suite of highly tectonized paragneisses, which surrounds ultramafic rocks. This suite is composed mainly of graphitic gneisses and schists with intercalated thin bands of garnetiferous quartz-feldspar gneisses and biotite gneisses.

Fine grained graphite gneisses and graphite schists contain up to 20 % graphite as fine flakes and as micro-crystalline graphite aggregates. They occur as numerous layers, 0,5 to some three meters thick, and frequently grade into garnetiferous graphite gneisses or quartzites.

Desilication of these paragneisses took place at contacts with the ultramafic rocks; it resulted in the growth of vermiculite rims at the contacts. These rims contain occasionally ruby/corundum. Corundum was also observed in graphite schists near ultramafics, containing occasionally accessory kyanite. Larger corundum porphyroblasts also occur in a desilicated biotite-kyanite gneiss in contact with ultramafic rocks at Kishushi.

4.1.4. Banded Biotite Gneiss

Bandes biotite gneisses occur mainly in the Kurase Group and are particularly characteristic for the Mwatate Formation.

Biotite gneisses, including biotite-garnet gneisses and biotite-hornblende gneisses are usually well foliated, fine grained and generally of grey colour. Laminae rich in biotite and hornblende, alternating with quartzo-feldspathic laminae produce a conspicuous banding, which partly may reflect variations of the original composition, although in most cases it is caused by mobilization of felsic constituents during metamorphish.

Although generally of rather uniform appearance, biotite gneisses occasionally vary considerably regarding grain size, proportions of biotite and hornblende present, and intensity of migmatization. Felsic types change gradually into leucocrate biotite gneisses (mapped as quartz-feldspar gneisses) as the contents of biotite and particularly hornblende decrease further. Mafic biotite-hornblende gneisses and hornblende gneisses frequently grade into plagioclase amphibolites.

Typically, biotite gneisses contain in thin sections quartz, feldspar (mainly oligoclase and alkali feldspar), biotite and garnet. Garnet occurs either as minute idiomorphic grains or as large poikilitic porphyroblasts, which are usually somewhat cataclastic, and is occasionally present in considerable quantities. Tschermakitic or barroisitic hornblende in hornblendic gneisses is accompanied by scattered biotite flakes. Epidote-clinozoisite, zoisite, sphene, and apatite, as well as in places magnetite and graphite, are major accessories.

4.1.5 Kyanite/Sillimanite (-Garnet-Biotite) Gneisses

Metamorphosed aluminous pelitic sediments, now present as variegated kyanite/sillimanite gneisses are restricted to the Kurase Group, where they occur particularly in the Mugeno Formation. Kyanite/sillimanite gneisses are generally closely associated with marbles or quartzites.

These gneisses commonly have a schistose to gneissose texture and are composed mainly of quartz, feldspar, poikiloblastic kyanite and almandine garnet. Flakes of biotite and subordinate muscovite aligned along the foliation planes accentuate the schistosity.

In thin sections, alkali feldspar is present as both orthoclase and microcline. Plagioclase, quartz with undulatory extinction, biotite, almandine and kyanite are major constituents, accompanied by sillimanite, unstable muscovite and occasional corundum. Apatite, rutile, zircon and opaque grains are common accessories.

Sillimanite replaces biotite and corrodes kyanite marginally. It appears as regularly distributed single or clustered fibres, or as discoidal or elongated aggregates and usually is intimately intergrown with quartz. Additional clusters of small, sub-parallel sillimanite needles appear as inclusions in quartz grains.

4.1.6 Marble

Marbles are present in all the formations of the Kurase Group, but occur especially in the Mugeno and Mgama-Mindi Formations. They are derived from impure dolomitic limestones and are usually interstratified with narrow, rapidly changing bands of impersistent quartzites, quartz-feldspar gneisses and various biotite-, graphite-, and kyanite/sillimanite gneisses.

Marbles usually have a granoblastic texture, are white to grey coloured, and coarsely crystalline. Most marbles contain minor amounts of silicates such as diopside and tremolite, plagioclase, quartz, or graphite flakes. These impurities are frequently aligned along s-planes and produce together with varying crystallinity a faintly visible banding.

The MgO-content of three specimens, collected at Kenya Carboxide, squarry, (p. 26), oscillated around 18 % MgO; specimens collected by PARSONS (1943) along the Voi-Taveta road assayed between 5.8 and 20.7 % MgO, with an average of 14.7 % MgO.

In thin sections, granoblastic calcite/dolomite is accompanied by minute grains or coarser blades of tremolite and of occasionally twinned diopside. Additional accessories include quartz, plagioclase, muscovite and phlogopite.

4.1.7 Calc-silicate Rocks

Calc-silicate rocks occur as numerous small lenses, seldom exceeding 0.5 m thickness and generally too small to appear on the geological map. They form impersistent intercalations in marbles or occur marginally at marble/gneiss contacts; they are, however, also found within migmatized successions of biotite gneisses and then probably represent impure calcareous sediments in the original stratigraphic sequence, subsequently altered by migmatization and accompanying metasomatism.

Calc-silicate rocks usually exhibit a granoblastic texture. Mineralogically, they are rather complex; diopside, tremolite-actinolite, phlogopite, scapolite, garnet and plagioclase are the main constituents. Calcite occurs only rarely. Zoisite, biotite, muscovite and alkali feldspar are common accessories.

4.1.8 Amphibolites

Most of the amphibolites occurring in the Taita Hills were presumably intercalations of basic volcanic material in the original sedimentary sequence, although quartzose and calcareous types may represent para-amphibolites derived from dolomitic marls and related sediments (ORVILLE 1969).

Amphibolites occur in the Kurase Group as compact, dark green plagioclase amphibolites, which generally contain no epidote, but are occasionally garnetiferous. The amphibolites form conformable lenticular intercalations in the paragneisses and usually have clear-cut contacts. Individual lenses are usually not more than some five to ten meters thick and therefore do not appear on the geological map.

Plagioclase in thin sections is xenomorphic to idiomorphic labradorite–bytownite, occurs twinned or untwinned and is then zoned. Relictic diopsidic pyroxene is as a rule altered to tschermakitic hornblende. Occasional garnet occurs as reddish-brown poikiloblastic crystals, partly with inclusions of hornblende and zoisite. Sphene, biotite, apatite and magnetite are common accessories.

Distinctly different amphibolites are characteristic for the Kasigau Group. There, dark, coarse grained and occasionally garnetiferous epidote amphibolites form major conformable intercalations in quartz-feldspar gneisses and probably represent basic sills, lava flows, or tuffaceous layers in a psammitic sedimentary sequence, although also para-amphibolites may occasionally be present. In thin sections, the epidote amphibolites are coarse textured, granoblastic and consist of calcic plagioclase, epidote and barroisitic hornblende.

4.1.9 Ultramafic Rocks

Ultramafic rocks form three narrow belts in the Taita Hills; probably they were tectonically emplaced into the metamorphic volcano-sedimentary sequence at or near the contact between Kasigau and Kurase Group during an early deformation phase.

The ultramafic rocks occur as numerous lenses, most of them already described by FARQUHAR (1960), are aligned sub-conformable to the regional strike of the foliation along definite horizons and are enveloped by a characteristic sequence of mainly graphitic paragneisses. Contacts with the country rock are usually strongly tectonized.

Lenses of ultramafic rocks are between one to some ten to fifty meters thick and are composed of serpentinites, pyroxene-amphibole felses and amphibole schists of variable composition; they are probably derived from dunites, peridodites, and pyroxene peridodites grading into pyroxenites.

High primary Cr and Ni contents, e. g. 1200 ppm Ni and 1900 ppm Cr in a bronzite-antophyllite fels (AAS-analysis by the Mines & Geological Dept., Nairobi), evidence an igneous origin of the ultramafic rocks. Serpentinites derived from carbonate sediments contain usually less than 20 ppm Ni and 100 ppm Cr, whilst corresponding values in serpentinites derived from igneous rocks exceed 400 ppm Ni and 1000 ppm Cr (BENSON 1918, FAUST & al. 1956).

Hydrothermal solutions originating during metasomatism or possibly derived from the water content of the original sediments in which the ultramafic rocks were emplaced, subsequently altered the originally anhydreous igneous mineral assemblages, which remained preserved only as relics. This alteration at high temperatures and moderate pressure created the now dominant mineral assemblages with serpentine group minerals, chlorites, talc, antophyllite (accompanied by tremolitic amphibole if sufficient calcium was available) and magnesite. Relictic ortho-pyroxenes of enstatitic to bronzitic composition are partially replaced by ortho-amphibole, mainly a low-Al antophyllite.

Larger ultramafic complexes consist of a core of dunite or serpentinite, occasionally veined by magnesite or asbestos; smaller ones are essentially composed of antophyllite-bearing amphibole-pyroxene felses. The serpentinite cores are as a rule unfoliated and not affected by tectonic stress of subsequent deformation phases (Cap. 5); they are surrounded, as also some of the smaller ultramafic lenses are, by strongly tectonized rims of fine-grained antophyllite schists, which are occasionally graphitic. Such schists form in addition small independent lenses, sub-conformably emplaced into the various paragneisses.

4.1.10 Migmatites and Migmatization

Partial anatexis during metamorphism of the volcano-sedimentary rocks of the Taita Hills caused widespread migmatization which affected nearly all the metamorphic rocks to some extent. In the initial stages, migmatization resulted in the development of augengneisses with microcline porphyroblasts and of banded gneisses.

Such migmatitic banded gneisses (refer also to cap. 4.1.4) are widely distributed in the Taita Hills and consist of numerous bands or laminae, a few mm to cm thick, rich in biotite (-hornblende-garnet), which alternate with quartzo-feldspathic bands. Increased migmatization, which is particularly manifest in the Kurase Group, led to the contortion of these bands, accompanied by increased feldspar porphyroblastesis, the disruption of mafic bands and the injection of leucosome. Further mobilization of the leucosome material eventually obliterated all earlier structures and produced proper migmatites, composed of mafic "restite" schlieren in highly deformed felsic mobilizates (metatects).

The migmatization process is mainly characterized by localized small-scale metasomatism and by additional "lit-par-lit injection" of leucosome produced by partial anatexis and differential fusion of the gneisses. Gneisses exhibiting different degrees of migmatization are occasionally closely and at random associated. This is attributed to local variations of the H_2O-contents of the rocks during metamorphism and also of the chemical bulk composition.

Alkali feldspar in migmatitic gneisses is usually perthitic microcline with faintly to well developed grid-iron twinning. However, in pelitic gneisses and schists associated with the more quartzose gneisses, orthoclase is mainly present. This may either reflect different primary compositions of alkali feldspars in different rocks or selective retrogressive changes. Microcline occurs in places as fine to medium grained replacements of plagioclase, orthoclase and muscovite or as large anhedral to nearly euhedral porphyroblasts. Most of these porphyroblasts are aligned sub-parallel to the foliation. The mafic minerals, mainly biotite and hornblende, are usually concentrated in dark streaks, bands and schlieren.

Increasing mobilization of leucosome eventually leads to the obliteration of the gneissose texture and creates gneisses of granitic appearance. However, no proper granites, even of palingenetic origin, were observed in the Taita Hills area.

Alkali feldspar in such „granitoid" gneisses has conspicuously increased and is usually microcline with associated micro-perthite. Plagioclase, mainly twinned or untwinned oligoclase, is frequently myrmekitically intergrown with quartz. Biotite is strongly pleochroitic and occurs with minor amounts of relictic accessory muscovite.

4.1.11 Anatectic Pegmatites and Pegmatoid Segregations

Partial anatexis and wide-spread mobilization of the felsic constituents of the various gneisses under varying p-T conditions and H_2O pressures during metamorphism led not only to migmatization but also to the formation of

- anatectic pegmatoid segregations,
- crossing-line pegmatites, and of
- quartz veins.

Anatectic pegmatoid segregations are ubiquitous in all the metamorphic rocks except marble and ultramafic rocks, but occur particularly in biotite gneisses. The segregations are found essentially as sub-conformable leucocratic quartzo-feldspathic bands, usually between 5 mm and some 50 cm thick. Normally, these bands are not folded, although boudinage, flow folding and even ptygmatic structures occur quite frequently. Occasional rims of mafic minerals (biotite and hornblende) accentuate the usually distinct, but occasionally also diffuse contacts of these segregations to the non-mobilized country rocks.

Anatectic pegmatoid segregations have mineral assemblages similar to the host rocks from which they are derived, except for higher contents of alkali feldspar, and a granoblastic, rather coarse grained texture. Segregations with quartz cores have developed particularly in amphibolites.

Crossing-line pegmatites, cutting across foliation planes, are mainly emplaced along hol-planes or ac-planes of the metamorphic rocks. These pegmatites are frequently zoned. A quartzo-feldspathic core (frequently with graphic texture) is surrounded by a marginal zone containing in addition dark brown to black tourmaline and books of muscovite or occasional biotite. Apatite is a common accessory.

Contrary to anatectic pegmatoid segregations, these pegmatites were not mobilized from the immediatly adjacent metamorphic rocks; they were also presumably emplaced during a rather late tectonic phase, as they were not affected by tectonic deformation and cut across deformed mobilizates.

Pegmatites cutting across ultramafic rocks became partially desilicated and were transformed into corundum-bearing plumasitic pegmatites (DEER 1963, FARQUHAR 1960). Plumasitic pegmatites have an equigranular texture and consist almost solely of plagioclase, accompanied by accessory tourmaline, corundum and rarely muscovite or alkali feldspar.

Plagioclase, usually in the oligoclase-andesine range is as a rule polysynthetically twinned. Zoning is, however, particularly well developed in untwinned crystals. Slightly bent twin lamellae probably evidence postcrystalline tectonic stress. Incipient sericitization along cracks is common.

The usually idiomorphic tourmaline is mainly of dravite composition. Dravite is frequently indicative for metasomatic/metamorphic mineral assemblages. The Mg in the dravite presumably has derived from the ultramafic country rocks by metasomatic diffusion ;boron became mobilized from the adjacent metamorphosed sediments.

Corundum, characteristic for plumasitic pegmatites, occurs as large, slightly corroded, colourless to faintly pinkish crystals with distinctly developed twin lamellae. If corroded, corundum is surrounded by muscovite; otherwise, muscovite occurs only as minor accessory constituent. Occasional accessories include also kyanite, diaspore, graphite flakes and calcite. Sporadic alkali metasomatism is evidenced by equigranular plagioclase intergrown with large perthitic alkali feldspar.

Quartz veins occur mainly in the Kurase Group as narrow (usually some 5 cm maximum thickness) and only a few meters long lenses and stringers; they are usually composed solely of compact, dense quartz, and are generally aligned sub-conformable to the foliation. Occasionally, however, undeformed quartz veinlets cut across foliation planes and thus evidence an origin during the later phases of metamorphism.

4.1.12 Metamorphism

Amphibolite-facies metamorphism with associated migmatization transformed the original volcano-sedimentary rocks into the paragneisses now present in the Taita Hills.

Mineral assemblages characteristic of the sillimanite-almandine-orthoclase sub-facies of the amphibolite facies (WINKLER 1967) occur in metamorphosed aluminous sediments in the Kurase Group; such sediments are the most sensitive indicators of p-T conditions during metamorphism. Amphibolites and other hornblende-bearing mafic rocks in the Kurase Group contain a tschermakitic hornblende and no epidote, whilst hornblende of rather barroisitic composition and abundant epidote characterize similar mafic rocks in the Kasigau Group. The metamorphites of the Kasigau Group were therefore assigned to the kyanite-almandine-muscovite sub-facies, although no proper aluminous paragneisses for substantiating this were observed.

Sillimanite present in aluminous paragneisses of the Kurase Group is only very rarely altered. P-T conditions sufficient for the reaction

quartz + muscovite = potassium feldspar + sillimanite (Fig. 1)

were therefore reached in alumina-rich rocks that responded little to migmatization.

Kyanite represents in such paragneisses an earlier mineral paragenesis, dominated by high pressure; the development of sillimanite followed during a more thermal metamorphic phase, possibly related to SHIBATA's (1975) late-orogenic event which rejuvenated the K/Ar systems of biotites and hornblendes about 500 m. y. ago. Rb/Sr ages of 827 m. y. are considered to represent the main metamorphism as similar Rb/Sr ages were obtained also in northeastern Tanzania (SPOONER & al. 1970); the widespread K/Ar ages of 500 m. y. (SAGGERSON 1962, SNELLING 1964, 1966) apparently reflect a late-orogenic thermal event involving a major part of the Mozambique Belt.

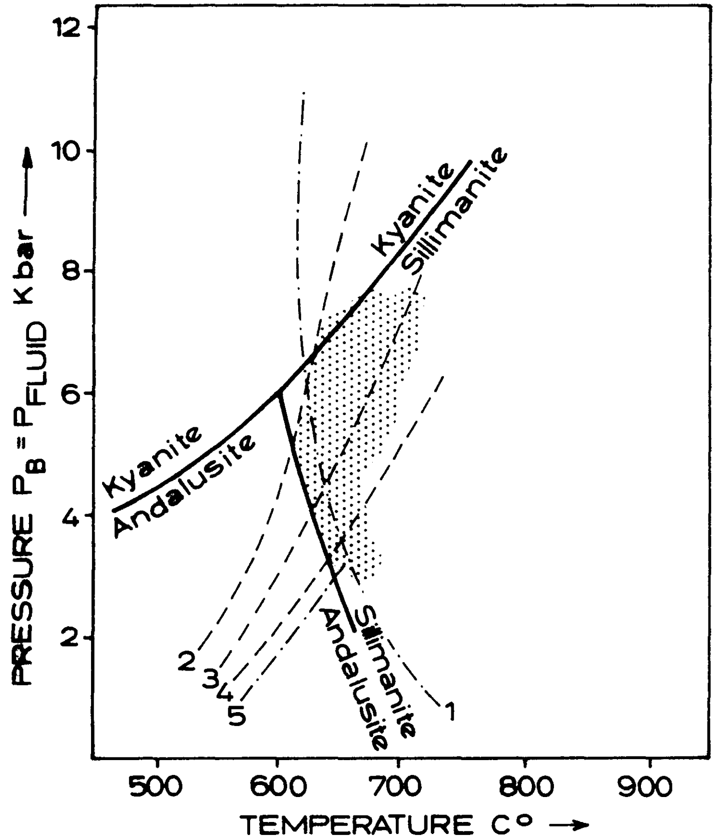
According to the mineral assemblages and reactions indicative for the metamorphic grade (Tab. 1 and Fig. 1) temperatures of about 630° C to 700° C and pressures of 3.5 to 7.5 kbar were probably reached during metamorphism. Thus, the rocks fall into the high temperature part of the medium pressure type amphibolite facies (MIYASHIRO 1973) of "Barrow type" metamorphism. The remarkably spacious pressure field presumably reflects the different metamorphic grade of Kasigau and Kurase Groups, but possibly also two metamorphic events with p-T conditions shifting from the kyanite to the sillimanite field.

The contact between Kurase and Kasigau Groups may represent a major structure which separates two litho-stratigraphic groups of slightly but significantly different metamorphic grade, and which is moreover marked by tectonically emplaced ultramafic rocks.

Kurase Group	
Psammitic meta-sediments	quartz + alkali feldspar + plagioclase + biotite ± muscovite ± garnet ± sillimanite quartz + alkali feldspar + plagioclase + graphite quartz + plagioclase + graphite ± alkali feldspar ± biotite ± muscovite ± garnet quartz ± plagioclase ± muscovite quartz + diopside ± tremolite + calcite quartz + anthophyllite + graphite ± plagioclase ± garnet quartz + hornblende + magnetite
Semi-pelitic meta-sediments	quartz + plagioclase ± biotite ± alkali feldspar ± muscovite ± garnet quartz + plagioclase + hornblende ± biotite ± garnet quartz + alkali feldspar + plagioclase + hornblende ± biotite ± garnet
Pelitic meta-sediments	quartz + alkali feldspar + sillimanite ± plagioclase ± biotite ± muscovite ± garnet ± kyanite plagioclase + biotite + kyanite ± quartz ± garnet ± sillimanite ± staurolite quartz + garnet + sillimanite ± biotite ± muscovite ± kyanite ± corundum
Calcareous meta-sediments	calcite + diopside + tremolite ± quartz ± plagioclase ± phlogopite ± scapolite calcite + diopside + tremolite ± muscovite ± wollastonite calcite + diopside + quartz ± tremolite ± garnet quartz + alkali feldspar + plagioclase + diopside + hornblende + garnet (calc-silicate rock)
Amphibolite	plagioclase + hornblende ± quartz ± diopside ± olivine plagioclase + alkali feldspar + hornblende ± biotite diopside + hornblende ± calcite

Kasigau Group	
Psammitic meta-sediments	quartz + alkali feldspar + plagioclase + muscovite ± biotite quartz + garnet + magnetite ± hornblende
Semi-pelitic meta-sediments	quartz + plagioclase + hornblende + garnet + biotite + muscovite quartz + plagioclase + hornblende ± alkali feldspar + biotite ± garnet garnet ± hornblende
Pelitic meta-sediments	not observed
Calcareous meta-sediments	quartz + plagioclase + diopside + tremolite + mica + scapolite (calc-silicate rock)
Amphibolite	plagioclase + hornblende + epidote hornblende + garnet + zoisite ± plagioclase

Tab. 1: Mineral assemblages in the Taita Hills.



1 Ab+Ksp+Qz+H_2O = melt
2 Tr+Cc+Qz+Ta+Do
3 Di+Tr+Cc+Qz
4 Fo+Tr+Cc+Do
5 Mus+Qz = Ksp+ alumo-silicate

Fig. 1: Mineral assemblages and reactions indicating p-T conditions in the Taita Hills Quadrangle. The various reaction curves and the approximate phase boundaries kyanite / sillimanite and kyanite / andalusite appearing in this figure were obtained from WINKLER (1974)

Regressive changes of previously existing stable mineral assemblages by retrograde metamorphism during late stages of metamorphism are reflected for instance by alterations of orthopyroxene to clinopyroxene and of clinopyroxene to amphibole.

4.2 Superficial Deposits

Soils, alluvium and colluvium result mainly from sub-aerial denundation under semi-arid to semi-humid conditions during the Plio-Pleistocene.

4.2.1 Alluvium

Alluvium extends along the main rivers. Typically it sonsists of unconsolidated gravels, silts an sands. Exposures are generally rare. Sandy alluvium, occasionally containing streaks of black magnetite-garnet sand, prevails in the semi-arid northern Taita Hills where drainage takes place mainly as short floods after heavy rains. In valleys draining the more humid southern part of the area, seasonal swamps or stretches of marshy water-logged "black cotton soils" have developed. Black cotton soils also characterize areas with impeded drainage.

4.2.2 Colluvium

Thick fan-type colluvial deposits surround the Taita Hills; they are absent only in the south. Talus slopes of the denudated gneiss mountains pass into the colluvial deposits accummulated at their foot. The colluvium, which is frequently heavily gullied, slopes genty into the surrounding pediplain.

4.2.3 Soils

Autochthoneous, residual kaolinitic or light-coloured sandy soils have developed in the humid Taita highlands. The c-horizon of these soils consists of weathered gneiss; relicts of the original petrological textures remained frequently preserved.

Residual, ferralitic reddish sandy soils exist in the semi-arid pediplain surrounding the Taita Hills and at the foot hills in the extreme northwest. Sporadically these soils contain concretions of lateritic ironstone. Caliche (calcrete) occurs wide-spread, either as nodular concretions in the soil or as a compact hard layer at its base. Such hard caliche crusts have developed particularly above marbles but also on amphibolites, and along river banks (due to evaporation of ascending capillary solutions). The extensive caliche crusts concealing larger marble outcrops are covered by grey calcareous soils which markedly contrast with the brick-red ferralitic soils concealing most of the other metamorphic rocks.

5. Structural Geology

5.1 Folds

The structural pattern of the Taita Hills is dominated by plastic deformation which affected all the metamorphic rocks in a similar manner. Different deformation phases are superposed on each other and produce a complicated poly-cyclic pattern.

The usually conspicuous foliation is poorly developed only in marbles and in compact quartz-feldspar gneisses of the Kasigau Group. The foliation coincides with the original sedimentary bedding, preserved as lithological contacts and as boundaries of material changes. The uniform E-W strike and constant shallow dip of the foliation in the entire Taita Hills are one of the most striking structural features of the area (Fig. 2). Transverse shears create occasionally an incipient para-metamorphic transverse foliation, whilst post-crystalline ruptural deformation resulted in cataclasis and jointing.

The structural evolution of the general area (AUSTROMINERAL 1978) took place in three phases; their structural inventory appears in Fig. 2.

The earliest deformation (F_1-deformation) did preceed migmatization; it caused in adjacent areas open or isoclinal flexural-slip folds plunging towards NNW (AUSTROMINERAL 1978 a). In the Taita Hills, however, F_1-folds are virtually entirely obliterated by later deformation and occur only sporadically as poorly preserved relics. F_1-deformation does not even appear in the spatial distribution of the foliation planes which are elsewhere partially aligned along the π_1-circle (AUSTROMINERAL 1978).

Para-migmatitic deformation (F_2-deformation), the next tectonic phase, created mainly highly mobile slip folds (shear folds), which grade occasionally into flow folds and ptygmatic folds. The strong, homogenous stress field of F_2-deformation controlled the entire deformation pattern of the Taita Hills.

F_2-deformation took place as shearing along previously established, reactivated flat lying F_1-foliation planes. These foliation planes form in the stereogram one well accentuated maximum located at the intersection of the π_1 and π_2-cercles (Fig. 2).

Numerous F_2-structures are conspicuous in outcrops; they include mainly microfolds or boudinage of anatectic mobilizates or of thin competent beds in lithological successions, and lineations (mainly b-lineations) such as elongated mineral grains, fold axes or groovings and crenulations on s-surfaces.

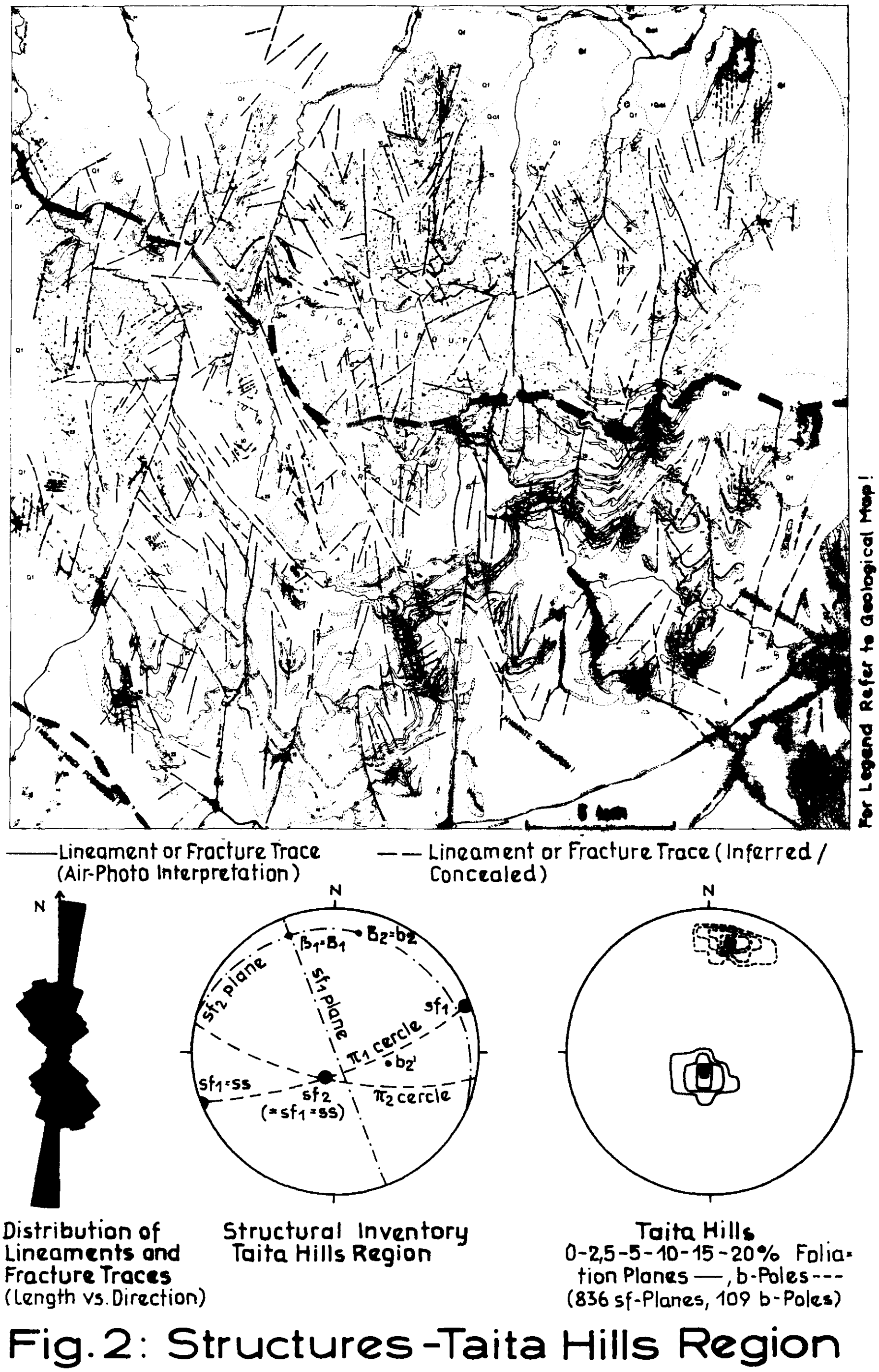
These b-lineations plunge towards NNE; their maximum, however, is aligned slightly elongated along the sf_2-circle between the $beta_1$ and $beta_2$ poles. This pattern may possibly reflect continuous rotation of the B-axes in the axial plane during progressive deformation (SAGGERSON 1973), while the regional stress field changed continuously from F_1 into F_2-deformation. F_1 and F_2 deformation would then merely constitute individual phases of one event of progressive deformation.

The last phase of plastic deformation (F_3-deformation) resulted in gentle asymmetric folds that are essentially open flexures plunging sub-parallel to the B_2-axes.

5.2 The Emplacement of the Ultramafic Rocks

Ultramafic complexes are aligned along specific horizons, sub-conformable to the regional strike of the foliation, and situated at or close to the contact between Kasigau and Kurase Group. This contact apparently constituted a major mechanic inhomogeneity or structure separating two litho-stratigraphic units of different lithological and metamorphic facies. The emplacement of the ultramafic rocks was presumably controlled by major s-parallel zones of crustal weakness, developed along this contact. Overthrusting after the main metamorphism may have accentuated the difference between the metamorphic grades of Kasigau and Kurase Groups.

The emplacement of the ultramafic rocks was probably prior to F_2-deformation, as their marginal zones were already subject to intense F_2-deformation. Most likely, the emplacement took place during the earlier stage of folding. Subsequent F_2-deformation strongly affected the ultramafic bodies; these were probably originally similar to the elliptic Kinyiki ultramafic complex further north (AUSTROMINERAL 1978 a), which remained better preserved due to a diminished intensity of the F_2-stress field.



Distribution of Lineaments and Fracture Traces (Length vs. Direction)

Structural Inventory Taita Hills Region

Taita Hills 0-2,5-5-10-15-20% Foliation Planes —, b-Poles --- (836 sf-Planes, 109 b-Poles)

Fig. 2: Structures-Taita Hills Region

Tectonic stress and aqueous solutions released during migmatization transformed their marginal zones, smaller ultramafic complexes even entirely, into strongly tectonized antophyllite schists.

5.3 Faults

Ruptural deformation controls the deformation pattern not as strikingly as plastic deformation. Faults and joints, which control the marked rectangular drainage pattern of the Taita Hills, appear on aerial photographs as straight alignments of drainage segments, morphological features, vegetation, etc.

Most of the joints and fractures probably originated as post-crystalline ruptures during the last deformation phase (F_3-phase). Geometrically, they mainly are near-vertical h0l-planes, ac-planes and hk0-planes related to F_3-deformation. These structures are usually too small to appear on the geological map or on the structural map (Fig. 2). Post (F_3)-crystalline deformation also created bent twin lamellae in calcite and feldspar porphyroblasts and wide-spread cataclasis of garnets and other porphyroblasts.

Impressive N-S trending lineaments, the largest forming the Mwatate valley and extending over some 50 km towards south on Landsat imagery, characterize a second type of faults. These faults appear in Fig. 2 as a distinct N-S peak in the distribution of orientation vs. length of lineaments. No complimentary maximum, which would represent the second set of non-distortion planes of the strain ellipsoid, did, however, develop. Such a geometrical configuration is characteristic of tension structures (MÜLLER 1963). The N-S lineamtens are therefore interpreted as extensive tensional fracture zones with little – if any – vertical displacement. The respective phase of ruptural crustal deformation is tentatively correlated with the evolution of the East African rift systems as crustal movements taking place to this present day are evidenced by numerous earthquakes with epicenters located in or near the Taita Hills (LOUPEKINE 1971). However, no time marks for dating this deformation phase more exactly do exist.

5.4 Structural/Metamorphic Evolution

The data available at present are not yet sufficient for an exact reconstruction of the structural/metamorphic evolution of the Taita Hills. The few radiometric age determinations available (SHIBATA 1975) particularly are of a mere reconnaissance character.

General geological considerations, requiring substantiation by further detailed research, do therefore mainly provide the base for a correlation of structural and metamorphic events (Tab. 2).

Deformation Phase	Tentative Age (after SHIBATA 1975)	Metamorphic Event	Structural Event
			Tensional structures (related to the evolution of the Rift System during the Neogene ?)
			Uplift and denudation (several erosional cycles)
F3	approx. 500 m.y.	Retrograde metamorphism Late-orogenic thermal event (development of sillimanite)	Post-crystalline ruptural deformation and cataclasis Open flexures Emplacement of penetrative crossing-line pegmatites?
F2 continuous	approx. 830 m.y.	Barrow-type amphibolite-facies metamorphism, anatexis and migmatization	Tectonic reactivation and thrusting along the Kurase-Kasigau contact Para-migmatitic slip (shear) and flow folds
change ? F1			Emplacement of ultramafic rocks along or close to the contact between Kurase and Kasigau Group Pre-migmatitic flexural-slip folds
		Sedimentation of Kasigau Group and Kurase Group Major unconformity Pre-Mozambiquian basement (hypothetic)	

Tab. 2 – Structural/Metamorphic Evolution of the Taita Hills

6. Economic Geology

The present geological survey, also conceived as assessment of the mineral potential of the Taita Hills, did include
- appraisals of the individual mineral occurrences known at present;
- regional mineral exploration, aimed at discovering new mineral deposits and at a general appraisal of the mineral potential; and
- an assessment of the hydrogeological potential of the Taita Hills.

An overall appraisal of the mineral potential of the Taita Hills is contained in AUSTROMINERAL's report "Results on the Geological Survey of the Taita Hills Region". It has to be emphasized that the following assessment does not necessarily reflect the opinion of AUSTROMINERAL Ges. m. b. H.; it is an independent attempt of the authors to contribute towards a better understanding of the mineral potential of the area.

6.1 Mineral Deposits

Most of the numerous mineralizations recorded during or prior to the present exploration programme are merely of academic interest owing to poor grades and/or insufficient reserves, and have no economic potential. Only major mineral occurrences or prospects appear on the geological map. Reference to the location of insignificant prospects and mineralizations is only made with Mercator-grid co-ordinates.

6.1.1 Graphite

Graphite occurs as disseminated flakes in graphite gneisses. The strata-bound deposits usually consist of several lenticular horizons of graphite gneiss intercalated into various paragneisses. Individual horizons are usually some three to eight meters thick. They comprise numerous bands of graphite gneiss, varying between a few cm and some two to three meters thickness, and with barren intercalations of banded biotite gneiss, quartz-feldspar gneiss and anatectic pegmatoid segregations. The paragneisses frequently contain poikilitic garnet and feldspar porphyroblasts.

Graphite is present either as flakes or as spherulitic aggregates. Besides large flakes attaining up to 3 mm diameter, mesocrystalline flakes which form quartz-graphite aggregates, some 2 mm by 0.3 mm large, do exist. Spherulitic graphite aggregates (diameter approximately 0,15 mm) are composed of numerous microcrystalline crystallites, approximately 20 μm large.

Of the numerous occurrences of graphite gneiss in the Taita Hills, particularly in the Mwatate and Mugeno Formations, only two mineralizations are large enough to be of commercial interest. Grades and/or reserves of all the other graphite occurrences are insignificant; these occurrences are therefore not described further.

6.1.1.1 The Chawia Graphite Prospect

The Chawia graphite prospect (co-ordinates 4284/96162) was discovered during the present survey and is the sole mineral deposit in the entire Taita Hills with an economic potential sufficient to justify a detailed mining pre-feasibility study (AUSTROMINERAL 1978 a).

The main graphite horizon at Chawia attains some six to ten meters thickness and possesses remarkable continuity along strike. It dips uniformly with some 10° to 20° towards NNE, and is exposed along a dip-slope. Therefore, large quantities of graphite gneiss became amenable to weathering. The resulting kaolinization of the feldspars creates a friable ore, facilitates comminution and liberation of undamaged graphite flakes from the gangue, and renders an economic beneficiation of the graphite ore possible.

The data for an estimation of the reserves available at present are restricted to surface exposures and a few shallow exploration pits. Based on these data, inferred reserves of weathered graphite ore were estimated at 1,200,000 metric tons (for details refer to AUSTROMINERAL 1978 a: 372 ff.). One bulk sample collected for beneficiation tests assayed 13 % C.

Laboratory beneficiation tests ascertained that graphite concentrates containing in excess of 90 % C could be obtained by flotation of the weathered ore at a recovery of approximately 48 %.

A pre-feasibility study on a mine model with an annual capacity of 48,000 tons (metric) rund of mine and 3,360 tons graphite concentrate was therefore drawn up by AUSTROMINERAL Ges. m. b. H. (for details refer to AUSTROMINERAL 1978 a; 366–431).

The mining operation is planned as conventional open cast mine. Top soil and friable graphite ore are removed by bulldozer stripping and scraping, loaded onto trucks and hauled to the plant. Beneficiation commences with primary crushing in an impact crusher for selective comminution, operating in closed circuit with a screen. The screen underflow is ground in a ball mill and passes through a spiral classifier into the rougher flotation circuit. After wet re-grinding of the rougher concentrate in a ball mill, the rougher concentrate is cleaned in a second flotation circuit, dried, bagged and transported by rail to the sea-port for shipping.

According to the financial analysis, the mine could achieve a satisfactory return oninvestment; further exploration of the prospect appears therefore justified.

6.1.1.2 The Mwatate Graphite Prospect

Graphite mining at the Mwatate prospect (co-ordinates 4309/96177) commenced in 1953 but was discontinued already after one year during which approximately 400 tons of flake graphite concentrate were recovered.

The strata-bound mineralization exploited by this short-lived operation is identical with the one at Chawia. Only small quantities of graphite gneiss were, however, exposed in the outcrops and became thus amenable to supergene alteration. The tenor of the mineralization is also not as high as at Chawia. An average grade of 7 % C is deduced from unpublished production reports; no definite figures are, however, stated. The reserves of weathered gneiss are by now virtually entirely depleted; only unweathered graphite gneiss, apparently not amenable to economic beneficiation does remain. Open cast mining would immediatly encounter large and rapidly increasing stripping ratios; underground mining would cause prohibitive production costs. The economic potential of the prospect appears therefore little promising.

6.1.2 Mineral Deposits Related to Ultramafic Rocks

All the ultramafic rocks are mineralized to some extent with asbestos, magnesite, vermiculite and also corundum. Most of these occurrences were already investigated by SANDERS (1953) and FARQUHAR (1960).

6.1.2.1 Antophyllite Asbestos

Major asbestos mineralizations occur at the Mackinyambu prospect (co-ordinates 4234/96327), smaller deposits at "Grennan's Claims" (co-ordinates 4219/96328 and 4241/96319).

Asbestos mineralizations consist of lenticular bodies of antophyllite asbestos within the various serpentinite complexes. Antophyllite generally is associated with some talc and vermiculite, and occurs essentially as slip-fibre. Cross-fibre asbestos and frequently also crypto-crystalline magnesite form veinlets ramifying through serpentinite. The asbestos ore bodies are generally aligned conformable to the regional foliation. Slip-fibre, although appearing oriented at random, is usually aligned to some extent along the regional B-axis.

The initial development of the Mackinyambu and Grennan's Claims deposits took place during the early 'fifties but was soon abandoned without any significant production. The Mackinyambu prospect, by far the largest and most promising deposit, was explored again by CIDA in 1967 and 1968 (KAYE 1968). Based on a core drilling programme comprising four holes with a total footage of 144 m, ore reserves were estimated at:

proven:	937,440 tons (short)
probable:	302,250 t
possible:	1,000,000 t
total:	2,239,690 tons (short)

The ore, as determined on the drill core, contains 5 % antophyllite fibre.

The antophyllite asbestos is, however, of excessive brittleness, low tensile strength, poor flexibility and spinnability, of low resistance to acids (TURNER & NEWALL 1968) and thus of a quality unsuitable for any industrial application. Despite substantial reserves, the asbestos deposits warrant therefore at present no further exploration.

6.1.2.2 Ruby/Red Corundum

Corundum occurs sporadically in plumasitic pegmatites or in desilicated gneisses at the contacts with ultramafic rocks. Gem-quality corundum, however, was only discovered at the Kishushi ruby prospects in the extreme northwest of the Taita Hills (between co-ordinates 4170/96358 and 4192/96340), where it occurs in plumasitic pegmatites cutting across ultramafic rocks, in silica-deficient reaction rims or zones at the contact of ultramafic rocks with gneisses, or as porphyroblasts in desilicified paragneisses. In reaction zones, corundum is mainly embedded into vermiculite pockets.

After the discovery of the prospects in 1973 and 1974, unknown amounts of rubies, most likely only of cabochon quality or even mere red corundum, were recovered from numerous small diggings. The claims are at present virtually abandoned, as the easily and cheaply exploitable mineralizations are exhausted. However, systematic exploration may still result in economic discoveries.

6.1.2.3 Magnesite

Crypto-crystalline magnesite, occurring as reticulate irregular narrow veins usually only some few cm thick, is nearly ubiquitous in the serpentinites of the Taita Hills. The magnesite mineralizations generally have no economic potential owing to poor grades and insignificant reserves. However, one deposit (co-ordinates 4429/96272) is intermittently exploited on a small scale for the local manufacturing of fertilizer for magnesia-deficient soils.

6.1.2.4 Vermiculite

Vermiculite deposits occur as pockets and rims lining the contacts of ultramafic rocks with the country rocks or with cross-cutting pegmatites. The vermiculite mineralizations are small; the maximum dimensions observed were 0.4 m by 0.2 m. Owing to these minute reserves, the vermiculite deposits are of no economic significance.

6.1.3 Kaolin

Numerous kaolin occurrences, already known prior to the present survey (PARKINSON 1947) result from in-situ weathering of small anatectic pegmatites. Owing to minute reserves, this type of mineralization has only a very limited economic potential.

One extensive kaolin mineralization, the Mgambonyi prospect, was discovered during the present survey in the northern Taita highlands.

This mineralization is related to a thick sequence of quartz-feldspar gneiss, underlying an old erosion surface, where deep reaching intense kaolinitic weathering took place. Subsequently, when erosion was rejuvenated, steep valleys were incised into the kaolinized gneiss, which remained preserved only as isolated cappings on ridges and hills.

These kaolinitic cappings occupy a total area of approximately 8.2 km^2. In the few exposures available the depth of supergene kaolinization exceeds five meters. Resources are therefore very substantial. Samples collected at Mwarungu (co-ordinates 4271/96275) where kaolinized gneiss is quarried as a local building stone, contained 25.6 % and 41.1 % kaolin.

The kaolin, however, is of poor quality and unsuitable for most industrial applications owing to insufficient albedo and excessive coarse grain (for the paper industry), prohibitive Mn-contents (for the rubber industry), and high quartz contents and unacceptable color (for application in paints). High thixotropy, quartz contents and also the small amount of the dispersable fraction in addition prevent the use of the kaolin in foodstuffs, pharmaceuticals, cosmetics, insecticides and in industrial manufacturing of ceramic articles. The sole possible application suggested is as medium quality fire-clay. Small amounts of higher grade kaolin available in weathered anatectic segregations could provide the raw material for a cottage pottery industry.

Owing to the poor quality of the kaolin, the economic potential of the prospect appears at present rather low despite the considerable resources available.

6.1.4 Muscovite

Small muscovite books occur widespread in penetrative tourmaline pegmatites. Small quantities of muscovite were even mined briefly during 1944 at the Mgange prospect (co-ordinates 4180/96320).

Muscovite occurs at Mgange in a zoned pegmatite, some 30 m long an 2 m wide. The core of the pegmatite is rich in quartz and tourmaline. Microcline and muscovite prevail in the marginal zones. Individual stained muscovite books attain up to 30 cm diameter.

Approximately 70 kg dressed mica were recovered from some 500 tons of pegmatite worked (i. e. approx 0.15 kg dressed mica per ton pegmatite). One sample of dressed mica sent to prospective purchasers for an appraisal was determined as „good stained ruby mica“, whilst the waste was described as „cross-grained and useless“ (PARKINSON 1947).

The reserves remaining at the Mgange prospect amount to some 600 tons pegmatite; the economic potential of the prospect is therefore rather low.

6.1.5 Semi-precious Stones, Abrasives and Ornamental Stone

6.1.5.1 Garnet

Brown to pinkish garnets are common constituents of the metamorphic rocks and numerous small unregistered diggings, now all abandoned,were recorded.

Garnets occur as large poikilitic porphyroblasts or as small clear idiomorphic crystals in the metamorphites; they also form some insignificant placer deposits.

Exploitation of garnet as semi-precious stone is, however, hampered by the small size of clear crystals or crystal fragments and the intense cataclasis of the garnets. Crystals suitable for facetting are therefore very scarce. Mining of abrasive-grade garnet is considered uneconomic because of the small size and the rather low tenor of the mineralizations.

6.1.5.2 Tourmaline

Minor amounts of green tourmaline are occasionally associated with black tourmaline in pegmatites. The stones generally are of low quality owing to an unpleasant brownish pleochroism. As reserves are also minute, the economic potential of the mineralizations is unpromising.

6.1.5.3 Ornamental Stone

Granoblastic garnet-kyanite rocks, suggested for application as ornamental stone occur at the Kishushi ruby prospect as a band, 30 m long and 1 m thick. Thinnes and jointing of this band prevent the recovery of larger slabs suited as ornamental stone for construction purpose. Smaller pieces, however, might serve for hand crafting artesan articles. However, as the kyanite-garnet rock is brittle and difficult to polish, the economic potential of this deposit is probably low.

6.1.6 Marble

The extensive marble outcrops in the southeastern Taita Hills were already prospected by PARSONS (1943). At present, some estimated ten to twenty tons of marble are quarried per day by Kenya Carboxide Ltd. near the main road (co-ordinates 4431/96189), and supply the local demand for quick lime and limestone.

The MgO-content of the marbles, determined by PARSONS (1943), ranged between 5.8 % and 20.7 %. Grab samples collected at the Kenya Carboxide quarries during the present survey assayed:

	CaO (%)	MgO (%)	SiO_2 (%)
I	32.2	18.2	1.0
II	32.48	17.8	1.12
III	32.48	17.6	1.56

(Analysis by the Mines & Geol. Department).

The marble is therefore unsuited for manufacturing cement, and only usable for quick lime and as building stone. Ample reserves close to road and railway are readily available if the local demand should increase.

6.1.7 Iron

Magnetite occurs as common accessory constituent in quartz-feldspar gneisses, amphibolites and in anatectic segregations derived from such rocks. Individual magnetite octahedrons, occasionally attaining up to 3 cm diameter aroused some interest in the past (KARANJA 1974); the mineralizations, however, have no economic potential at all.

Minute grains of pyrite, sporadically disseminated in anatectic segregations are also merely of academic interest.

6.1.8 Kyanite and Sillimanite

Several bands of paragneisses with kyanite and/or sillimanite as rock-forming minerals exist in the Taita Hills. None of these occurrences, however, including those already mentioned by PARKINSON (1947) and TEMPERLEY (1953) is sufficiently rich or extensive to warrant further exploration.

6.1.9 Alumn

An alumn mineralization in alumn-sulphur-graphite gneiss was reported by HOBDEN (1954). Its location is unknown. The mineralization intermittently extends over 90 m along strike and is 0.9 m thick. It has to be considered as a mineralogical curiosity of no economic potential.

6.2 Regional Mineral Exploration

The regional mineral exploration programme carried out in the Taita Hills did comprise

- a regional geochemical drainage survey, and
- an airborne magnetometric survey.

6.2.1 Geochemical Drainage Survey

6.2.1.1 General Information

The geochemical drainage survey covered the Taita Hills at an average sample density of approx. 1 sample per 1.2 sq. km. This density is sufficient to provide detailed information on the location of mineralized zones and even of individual larger deposits (BARRINGER 1972).

As standard sample served the minus 80 mesh fraction of active drainage sediments, analyzed with an atomic absorption spectrometer for the elements

Cr, Ni, Cu, Zn and Co

after hot digestion with 6n HCl.

No confidence levels were calculated for the analyses: the precision of the analytical method was controlled by periodic analyses of standards.

6.2.1.2 Drainage Pattern

Gradients and maturity of the drainage system of the Taita Hills vary considerably. In the Taita highlands, the remarkably rectangular drainage pattern is controlled by tectonic lineaments. Gradients generally are steep. Typically, drainage sediments consist of coarse to medium grained sands with small amounts of finer grained material. Lowest-order tributaries frequently contain also dark, organic alluvial soils.

The lowlands are characterized by mature drainage systems with moderate gradients. Drainage sediments are mainly sandy and usually contain sufficient amounts of the finer sized fractions. Seasonal swamps or flood plains without properly defined active drainage channels, which occur frequently, were excluded from sampling.

6.2.1.3 Interpretation

The geochemical data aquired were interpreted using the uni-variate graphical method of LEPELTIER (1969) for each element (for details refer to AUSTROMINERAL 1978 a) separately.

The geochemical anomalies in the Taita Hills occur either scattered or as clusters.

Ultramafic rocks are merely reflected by two small clusters of minor Ni-anomalies. Cr-anomalies are absent. Despite high primary Cr and Ni contents of the ultramafic rocks, only small amounts of Ni and the rather immobile Cr became apparently available for secondary dispersion, due to the small size of the individual exposures. The amounts of Cr and Ni released during weathering were insufficient to create significant geochemical drainage anomalies.

One major and clusters of numerous minor Zn-anomalies, are related to compact quartz-feldspar gneiss of the Kasigau Group, apparently with Zn contents significantly exceeding regional treshold levels. These Zn-anomalies may be indicative for intercalations of orthogneisses, derived from acid effusiva in a meta-psammitic sequence, apparently, however, not for zinc mineralizations. Minor copper anomalies, occasionally associated with minor Zn-anomalies, may reflect amphibolites with excessive lithological Cu contents, wich are intercalated into Zn-rich quartz-feldspar gneiss. Some isolated anomalies possibly are related to insignificant disseminated sulphide mineralizations similar to the ones described by SANDERS (1963) further north.

6.2.2 Airborne Magnetic Survey

The results available at present from Terra Surveys Ltd. are restricted to a preliminary contoured map (Fig. 3). Except for the flight-line spacing (one km), no data on flight lines orientation and ground clearance in the mountainous terrain, or on data processing were communicated.

The survey was carried out with a proton free precession magnetometer installated in a Super Canso aircraft with perpendicular tie-in lines at 20 km intervals. The measurements of the total magnetic intensity were made in units of 0.5 gammas at intervals of 1.2 seconds. Location of the flight lines was determined from 35 mm tracking films exposed during the survey flights.

A preliminiary, qualitative evaluation of the airborne magnetic survey (Fig. 3) reveals generally low gradients and little correlation with the major geological features, although the dominant structural pattern is faintly recognizable.

A rather uniform field, oscillating around 34150 gammas and with gentle gradients characterizes the Kurase Group in the southern part. The few minor anomalies are mainly due to topographic effects, such as steep cliffs (for instance the "Bura Bluff") and to local enrichments of accessory magnetite in the metamorphic rocks.

Significantly increased gradients mark the zone of ultramafic complexes at the contact between Kurase and Kasigau Group.

Adjacent to the north, a major, E-W trending zone with alternating steeper and flatter gradients does occur. The anomalies are aligned parallel to the regional strike and reflect the thick complex of compact, magnetite-bearing quartz-feldspar gneiss and amphibolite at the base of the Kasigau Group. The northern sector of the map is dominated by random oriented, rather minor regional highs and lows, which are again attributed to varying contents of accessory magnetite in the metamorphites.

Summarizing this initial qualitative interpretation of the airborne survey, the magnetic field is characterized by rather random variations of the magnetic susceptibility of the metamorphites, most likely created by variations of the content of accessory magnetite. The few proper anomalies outlined, probably reflect mainly topographic effects and local enrichments of magnetite but no mineralizations of economic potential.

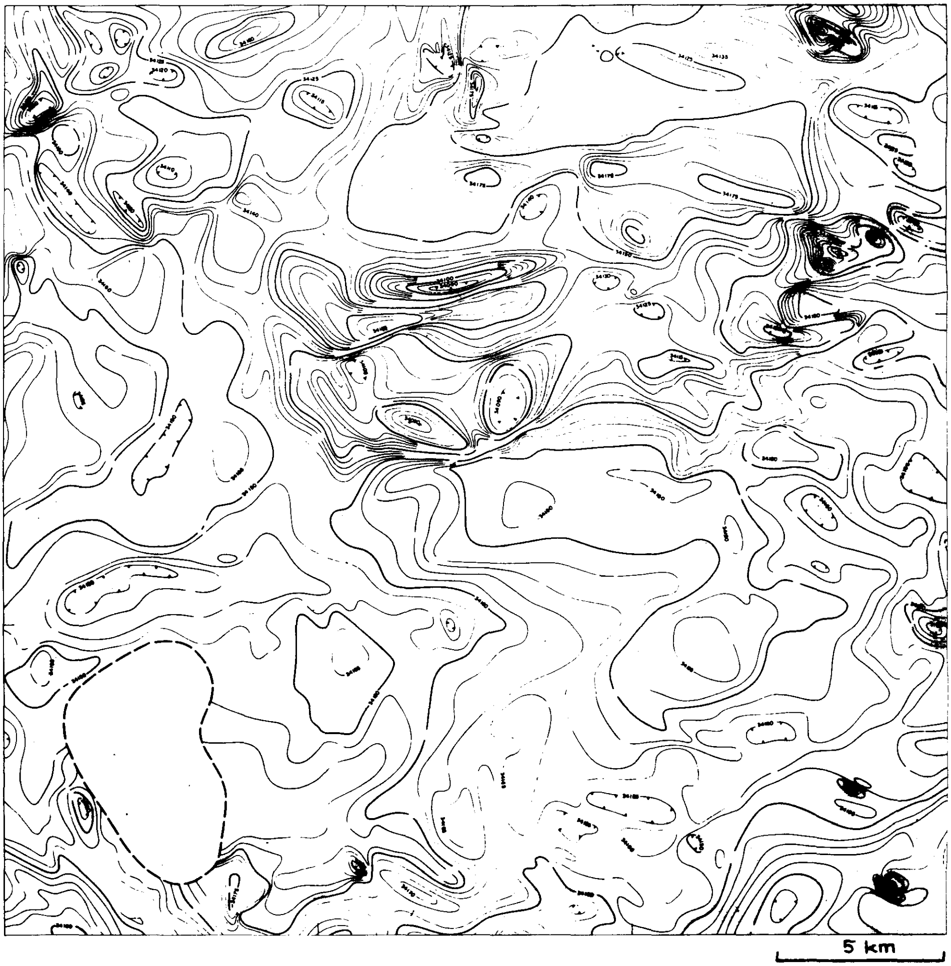


Fig. 3:

Aeromagnetic map of the Taita Hills

Surveyed in 1977 by Terra Surveys Ltd. under a contract by the Governments of Kenya and Canada.

6.2.3 Conclusions

The regional geochemical and geophysical surveys of the Taita Hills were mainly designated to locate base metal mineralizations and mineralizations associated with ultramafic complexes. Most of the anomalies outlined by these surveys, however, presumably reflect merely particular lithologies with trace element contents or magnetic susceptibilities respectively, significantly exceeding the regional backgrounds. As substantiated by the surface indications recorded, areas containing potentially economic base metal mineralizations apparently do not exist, nor are undiscovered major ultramafic complexes with their particular mineralizations (cap. 6.4.2) indicated by these surveys.

The general geological environment, comprising a highly metamorphosed, partially migmatitic volcano-sedimentary sequence, apparently devoid of metamorphosed syngenetic mineralizations or of late-orogenic granitoid intrusions, is moreover rather unfavourable for base metal mineralizations. Mineralizations related to ultramafic rocks are also of an economically little promising type (cap. 6.1.2).

Mineralizations of economic potential in the Taita Hills are restricted to industrial minerals and to types of mineral deposits to which geochemical and magnetic exploration methods generally are rather insensitive. The overall mineralization pattern agrees well with the general metallogenetic pattern of the Mozambique Belt, in which only deposits of industrial minerals and of gemstones are known so far.

6.3 Hydrogeology

6.3.1 Hydrology

The Taita Hills, which rise abruptly some 1300 to 1500 m above the surrounding peneplain, intercept the humid air masses carried inland from the Indian Ocean by the prevailing NE and SE winds. Orographic rains are the result. Annual precipitation in the humid central highlands varies between 1000 and 1500 mm; the northern highlands in the rain shadow and the foot hills receive 700 to 1000 mm annual precipitation, compared to 400 to 700 on the semi-arid peneplain. Annual evaporation amounts to 2200 to 2500 mm on the peneplain and to 1000 to 1500 mm in the hills. Based on extrapolation of existing data, evaporation equals precipitation at approx. 1500 m altitude.

The steep morphological relief, combined with deforestation, resulting soil erosion and insufficient soil conservation practices, cause a high run-off and considerably reduced infiltration, storage and retention capacities.

6.3.2 Aquifers

Unconsolidated or only slighty consolidated clastic sediments, such as valley alluvium, colluvium and even soils, which would provide the best aquifers because of high porosity and permeability, are generally too limited in extent and depth to be of significant potential as aquifers.

Exploitable aquifers are therefore only related to the generally low primary and secondary porosity of the metamorphic rocks. The secondary porosity is caused by systems of "macro pores" and "micro pores". Macro pores are fissures and fractures of structural origin. Micropores are interstices created by weathering. These two types of secondary porosity are usually closely related, as cracks and fissures facilitate the percolation of water and hence more intense weathering. Secondary porosity particularly controls the mineralization of the groundwater.

Bore-hole No.	year	location	ground level	total depth	over burden	depth hard rock	WSL	WRL	yield (gph?)	water quality		remarks
										original	changed	
P 81	1930	Kedai Sisal Estate	900	119	2	12	60 70	60	1.800	?	saline	abandoned
P 108	1930	Paranga Valley	783	39	3	22	12	12	5.400	brackish	saline	abandoned
P 113	1930	Paranga Valley	800	31	5	18	12	11	5.400	?	saline	abandoned
P 117	1930	Paranga Valley	816	31	2	19	12	11	11.250	?	saline	abandoned
C 477	1946	Kishusi Valley	914	49	4	20	17	10	7.280	slightly brackish	saline	abandoned
C 480	1946	Kishusi Valley	853	112	2	2	76	40	260	slightly brackish	?	abandoned upon completion
C770	1948	Kedai Sisal Factory	792	92	7	16	12	9	2.275	fresh	saline	abandoned
C 771	1948	Kedai Sisal Factory	853	40	5	25	17	12	5.460	slightly brackish	saline	abandoned
C 937	1949	Goshi Valley, Msau	701	47	4	15	6	6	8.200	fresh	saline	disused, pump still present
C 938	1949	Mbololo Valley Ghazi	732	43	6	?	18	7	114	?	?	not completed, running sand; handpump operatet for short time

Note: 1. All depths in meters 2. WSL = water struck level 3 WRL = water rest level

Table 3 – Water-borehole records from the Taita Hills

6.3.3 Groundwater Mineralization

All the boreholes drilled to date in valleys at the Taita Hills' footslopes (Tab. 3) had low to moderate yields; sooner or later the water turned brackish or saline, probably due to overpumping. The wells are now abandoned; no water analyses are available.

The increasing salinity of the groundwater is probably caused by particular interactions between macro and micropores systems. Macroporosity (fissures) mainly accounts for the mobility of groundwater in metamorphic rocks. The water stays in contact with the rocks for a relatively short period; hence, mineralization remains low. Mobility in micro pores, on the contrary, is very low. The groundwater in interstices becomes strongly mineralized by dissolving salts produced by weathering processes. Pumping from a new well first draws water from the macro pores. If overpumped, i.e. if pumped in excess of the recharge capacity of the macro pores system, the micro pores will yield mineralized water to the macropores system. Thus the water pumped turns gradually saline.

Detailed electro-resistivity surveys in major valleys of the Taita Hills, carried out within the framework of the bilateral Kenya-Austria groundwater exploration project, confirmed varying degrees of groundwater mineralization in and near all the fracture systems and weathered zones in the major valleys investigated.

6.3.4 Groundwater Potential

The groundwater potential of the Taita Hills, according to our present knowledge, is rather low. The accumulation of significant quantities of groundwater is obstructed by high run-off and poor infiltration, combined with unfavourable hydrogeological conditions, such as poor or heterogeneous porosity which limits the storage capacity of the aquifers. Also the potential for groundwater of higher quality is disappointing, as salinity resulting from weathering processes renders the water partly unfit for human consumption, for animal husbandry, agriculture and even for some industrial applications.

Areas with satisfactory storage and reacharge conditions are considered restricted to the upper reaches of the Mwatate and Bura valleys, where groundwater exploration should therefore concentrate. In addition, optimum use of surface water resources should be attempted by constructing dams for regulating run-off and for storing water.

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Fig. 4 **Quartz-Feldspar Gneiss** (specimen P 15).
Microcline with quadrille structure, quartz (white) and subordinate oligoclase, in places synplectitically intergrown with quartz.
Nicols X, length of figure approx. 2 mm

Fig. 5 **Quartz-Feldspar Gneiss** (specimen P 49/2).
Alkali feldspar (microcline) with characteristic quadrille structure replaces muscovite (grey).
Serizitization of oligoclase is apparent near the left upper corner.
Nicols X, length of figure approx. 2 mm

Fig. 6 **Kyanite-Sillimanite Gneiss** (specimen P 48).
Acicular sillimanite corrodes and replaces kyanite. Additionally quartz (white) and opaque grains do occur.
Nicols //, length of figure approx. 2 mm

Fig. 7 **Biotit-Garnet Gneiss** (specimen P 26).
Garnet deformed by synkinematic postcrystalline cataclasis, with biotite laths and xenomorphic feldspar postkinematic.
Nicols //, length of figure approx. 2.5 mm

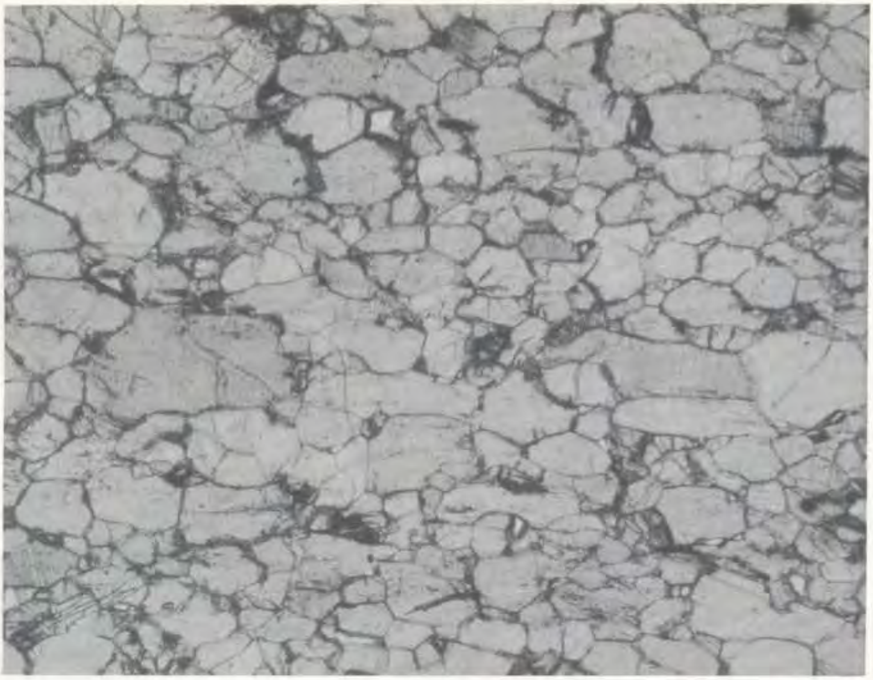

Fig. 8 **Antophyllite Rock** (specimen N 84)
Slender antophyllite prisms and blades with granoblastic, nearly equigranular texture; the fine polysynthetic twin lamellae may reflect tectonic stress related to F_2-deformation.
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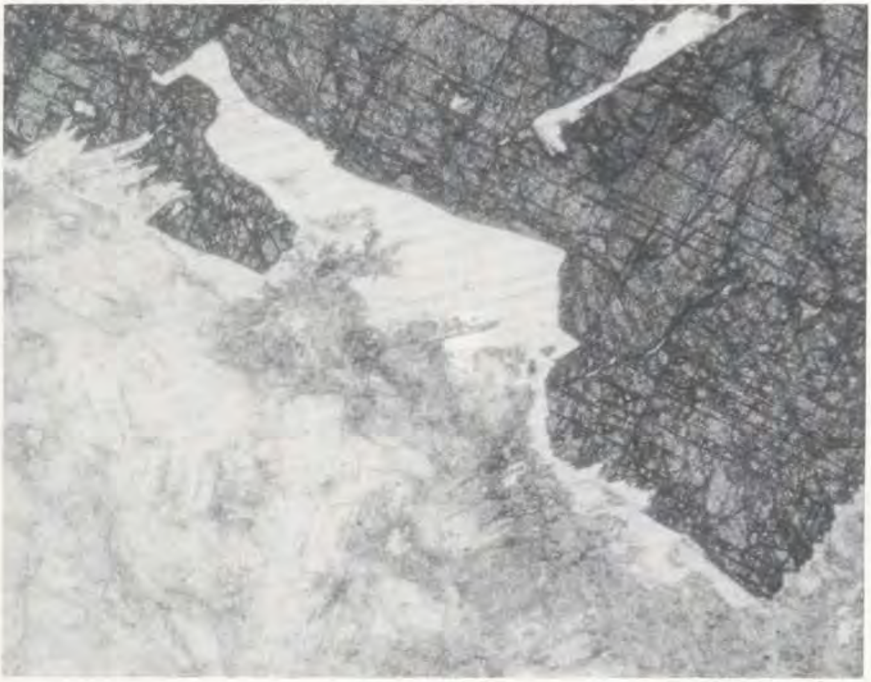


Fig. 9 **Plumasitic Pegmatite** (specimen N 42)
Corundum (dark) is marginally replaced by muscovite (white). Partially sericitized plagioclase (light grey) is in the oligoclase-andesine range.
Nicols //, length of figure approx. 2.5 mm

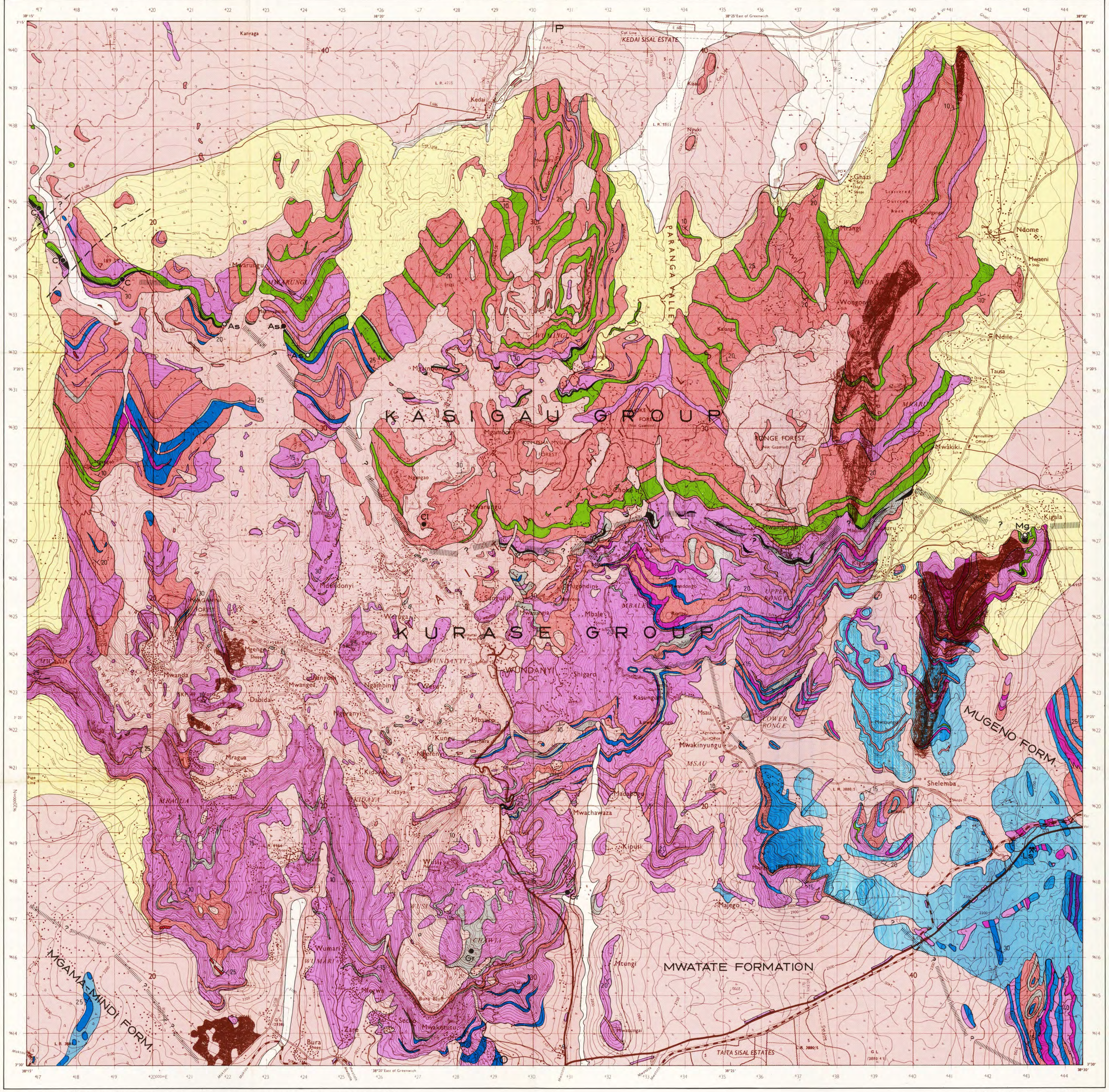
BEILAGE 3

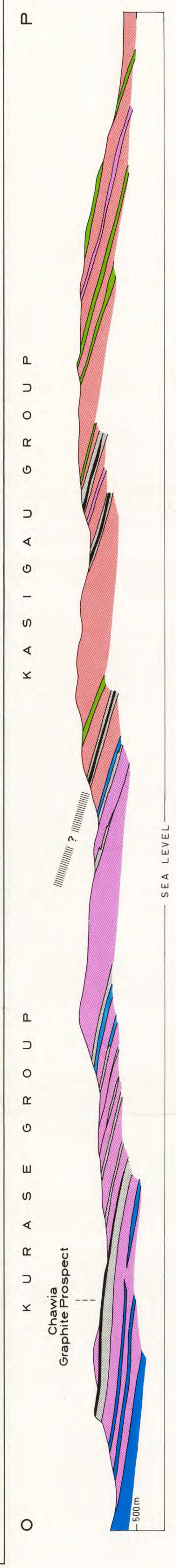
GEOLOGICAL MAP OF THE TAITA HILLS

Geologically surveyed in 1975 by A. HORKEL, R.E.A. OKELLO, W. POHL, J.K. WACHIRA

KENYA-AUSTRIA MINERAL EXPLORATION PROJECT

AUSTROMINERAL





QUATERNARY/TERTIARY

Qal	Alluvium
Qf	Colluvium
Qs	Soil (residual) overlying undifferentiated Precambrian
Qc	Calcrete and calcareous soil

PRECAMBRIAN

qf	Quartz-feldspar gneiss and felsic granulites
b	Banded biotite gneiss (h=hornblende, g=garnet, m=migmatite and feldsp.-augengn.
gr	Graphite gneiss (±muscovite, silimanite; interbedded with g, qf, m, π, and some bg, a)
kgb	Kyanite-garnet-biotite gneiss
m	Marble (typically with bands of gr and white qf
π	Pegmatite
a	Amphibolite (± garnet)
σ	Ultramafic rock

▥	Litho-stratigraphical boundary (inferred) groups
▥	Litho-stratigraphical boundary (inferred) formations
≺20	Strike and dip of foliation
- - -	Fault

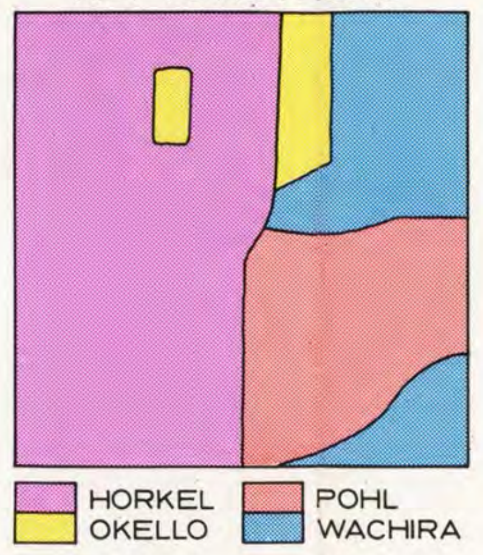
⚒ Mine ● Prospect o Mineral occurrence

C = red corundum
Gr = graphite
Ls = limestone
As = asbestos
Cl = kaoline
Mg = magnesite

0 1 2 3 4 5 km

Scale 1:50 000

KEY TO AUTHORS



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