Geology of the Mwatate Quadrangle (Sheet 195/2) and the Vanadium Grossularite Deposits of the Area

(with coloured geological map)

by

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Abstract

Within an Austrian Technical Assistance Programme to Kenya, executed by AUSTROMINERAL Ges. m. b. H., Vienna, Austria, between 1975 and 1978, the Mwatate Quadrangle (1:50.000 sheet 195/2) has been geologically mapped at a scale of 1:50.000. The map originally was submitted in AUSTROMINERAL's report „Geological Prospecting and Economic Assessment of the Gemstone Belt in Southeastern Kenya" in 1978. Special emphasis was given to the deposits of green vanadium grossularite, which is being exploited as a gemstone and at present constitues the only mineral production of the area.

The Mwatate area lies within the Mozambique Orogenic Belt; with the exception of soils and alluvium all rocks encountered are of Pre-cambrian age. They are mainly part of the rock pile generally termed Usagaran Metasediments (HEPWORTH 1971), including metamorphosed pelitic, arenaceous and calcareous sediments with intercalated bands of basic magmatic rocks and some unascertained acidic volcanics. Very small lenses of metamorphosed and highly altered ultramafic rocks occur in the south of the area. A large charnockite complex was mapped in the center of the area. In a wider sense it is thougt to represent the basement onto which the sediments were laid down.

The rocks are part of the Kurase Series (SAGGERSON 1962), here renamed Kurase Group. The original sedimentary environment was mainly shallow water and marine, with highly variable facies laterally as well as vertically. On this base several lithostratigraphic formations are differentiated. A distinctive rock suite within one of the formations containing the green grossularite deposits is defined as a member.

Structures observed point to a threefold deformation: Pre-migmatic isoclinal folds of NNW axial direction are overprinted by paramigmatic isoclinal or tight folds with northerly plunging axes, and post-migmatic open flexures. Generally, however, the lithostratigraphic suite strikes west of north and dips to the east, except in the northern center of the sheet, where a large monoclinal antiform plunging at a low angle to the north causes a more northerly direction of the dips. The latter is predominant in the Taita Hills immediately north of the present area. The ultramafites are thougt to mark a thrust system involving basement (charnockites) and the meta-sedimentary cover. The thrusts were possibly contemporaneous with F_1-deformation, and would have been folded and obscured by the later tectonic phases.

Metamorphism is of high grade: amphibolite facies and granulite facies mineral assemblages and rock textures have been observed in thin section. Anatectic mobilization of felsic rocks or rock components is wide-spread, and leads to the formation of banded gneisses, migmatites, and anatectic pegmatites. A very pronounced hiatus exists between the granulite facies basement (the charnockites) and the amphibolite facies cover rocks.

Five green vanadium grossularite deposits („tsavorite") are being exploited at present in the area. These gems have been formed by the concurrence of a combination of suitable material, colouring rare metals, and high grade metamorphism. Other minerals occurring in the area were found to be of less immediate economic potential. Among others they include red corundum (ruby), green tourmaline, blue zoisite (tanzanite), kyanite, magnetite, graphite, marble (limestone), uranium and thorium.

Zusammenfassung

Im Rahmen eines Projektes der Österreichischen Technischen Hilfe in Kenya, durchgeführt von AUSTROMINERAL in den Jahren 1975 bis 78, wurde das Kartenblatt Mwatate im Maßstab 1:50.000 geologisch aufgenommen. Die geologische Karte wurde 1978 im AUSTROMINERAL-Bericht „Geological Prospecting and Economic Assessment of the Gemstone Belt in Southeastern Kenya" überreicht.

Eingehend untersucht wurden die Lagerstätten von grünen Vanadiumgrossulargranaten, welche als Edelsteine gewonnen werden.

Es handelt sich hier um einen Teilbereich des Mozambique Gürtels, der seine letzte orogene Prägung an der Wende Proterozoikum/Phanerozoikum erfuhr. Metamorphe klastische Sedimente und dolomitische Kalke mit eingeschalteten basischen und sauren (?) Vulkaniten vertreten einen Teil der „Usagara-Metasedimente". Ein großer Charnockitkörper, der von den Metasedimenten eingehüllt wird, könnte in weiterem Sinne älterem Grundgebirge entsprechen, auf das die Sedimente abgelagert wurden. Kleine Linsen von Ultramafiten markieren vermutliche Aufschiebungen, an welchen das tiefere Stockwerk in einer frühen tektonischen Phase aufgeschleppt worden sein dürfte.

Die Deckengesteine gehören der Kurase Gruppe an, welche hier in mehrere lithostratigraphische Formationen unterteilt werden kann. Die sedimentäre Umgebung war randlich marin, mit horizontal und vertikal (zeitlich) rasch wechselnden Fazies.

Eine dreiphasige orogene Verformung ist gesichert: Vormigmatische isoklinale Falten (F_1) mit NNW-Richtung werden durch paramigmatische isoklinale und enge Falten mit nördlichem Achsenabtauchen (F_2) überprägt. Weitwellige Biegefalten sind die jüngste Verformung.

Die Metamorphose der Deckengesteine hat die höchste Amphibolitfazies erreicht. Anatektische Mobilisation von saurem Material ist allgegenwärtig, so daß Bändergneise, Migmatite und Pegmatite auftreten. Ein Metamorphosesprung ist zum charnockitischen Grundgebirge feststellbar, welches der Granulitfazies zugehört.

Mehrere aktive Minen in der Region bauen grünen Vanadiumgrossular ab. Die Lagerstätten liegen in einem bestimmten lithostratigraphischen Niveau der Metasedimente, und werden vor allem durch den ursprünglichen Gesteinsbestand sowie die geochemische Besonderheit dieser Gesteine kontrolliert.

1. Introduction

1.1 General

The Mwatate quarter degree sheet area is situated between latitudes 3°30' South, and 3°45' South, and longitudes 38°15' and 38°30' East in the southern Taita-Taveta District, Coast Province (see location key on geological map).

Since the discovery of gem-quality vanadium grossularite (green garnet, „Tsavorite") in its western and southern part in 1971, the area has gained considerable economic interest. Although a printed geological map was available (J. WALSH 1955), this was of limited use to gemstone prospectors and miners because of its scale (1:125.000).

Accordingly, it was decided to include mapping of the area at 1:50.000 among the tasks of the Kenya-Austria Mineral Exploration Project (1975–1978). The aim of this regional work was to locate the gemstone deposits and occurrences on a geological map of sufficient detail to understand the regional controls governing their distribution. In addition, detailed studies at the actual deposits were to allow a better understanding of their nature, thus assisting in a more rational approach to prospecting and mining.

The Austrian Government furnished technical assistance by providing expert personnel, laboratory/field equipment, and transport. The Kenyan Government supplied through its Mines and Geological Department counterpart personnel, laboratory/office/camp and transportation facilities as well as operating expenses. AUSTROMINERAL was the executing agency on the behalf of the Austrian Government.

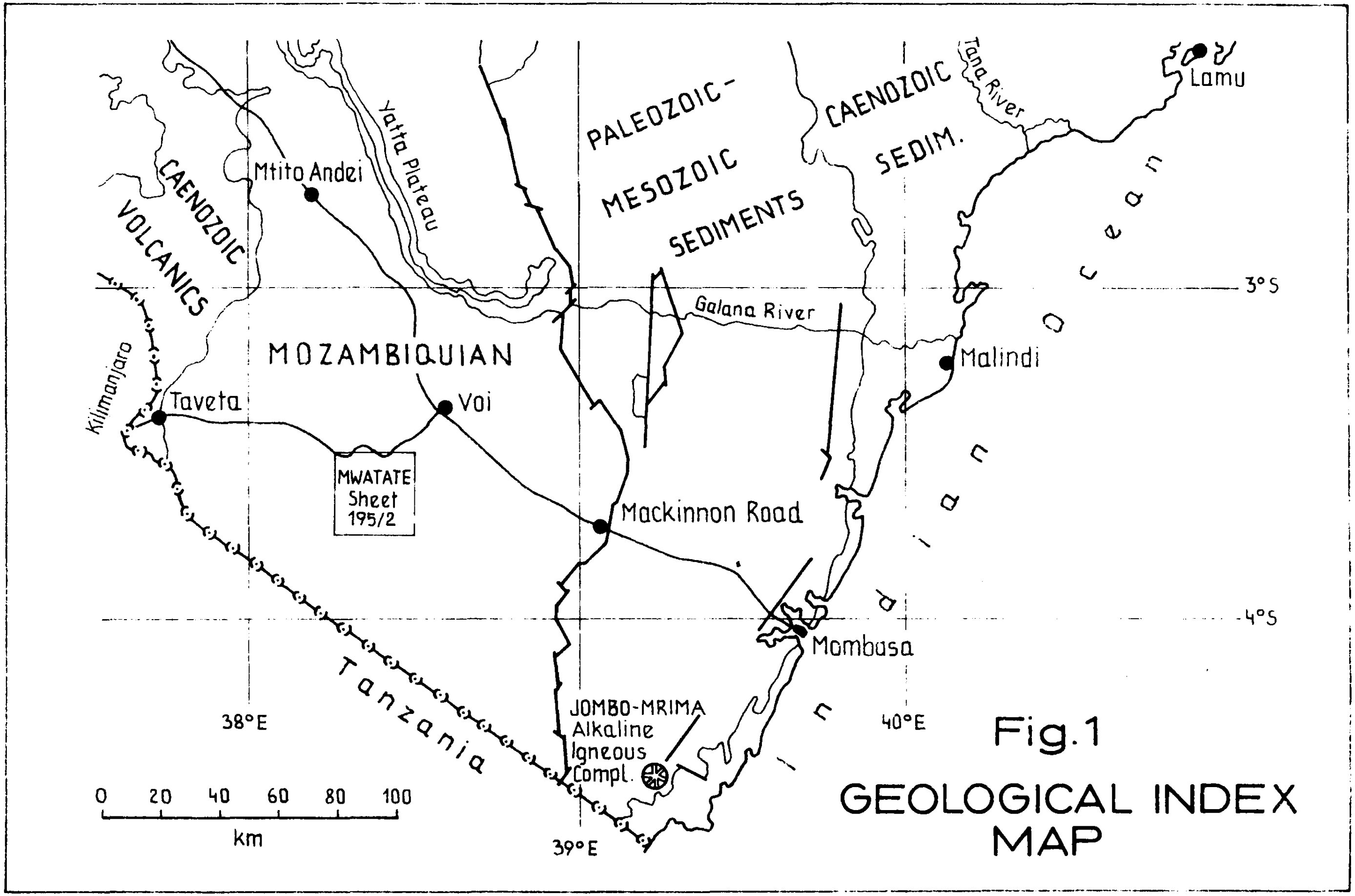

Fig.1

GEOLOGICAL INDEX MAP

The project personnel involved was as follows:
From the Government of Kenya (Mines and Geological Department):
Mr. D. B. Dow, Chief Geologist, till end of 1977
Mr. W. J. Wairegi, Project Co-Manager, Chief Geologist from beginning of 1978
From the Austrian Government (AUSTROMINERAL Ges. m. b. H., Vienna)
Dr. W. L. Werneck, Project Manager/Mining Engineer
Dr. W. Pohl, Senior Geologist – All field geology (September to November 1977 intermittently) map preparation and report writing (February – March 1978)
Dr. G. Niedermayr, Petrologist/Mineralogist – Examination of rocks and minerals, and preparation of an internal petrological report (January to March 1978).

The authors served as consultants of AUSTROMINERAL both in the field and in report writing.

Also in mid-1977, an airborn magnetic and radiometric (spectrometer) survey covering the entire Mwatate area was carried out by TERRA SURVEYS Ltd., under a contract financed by the Canadian International Development Agency (CIDA). A geological interpretation of the aeromagnetic contour map (fig. 12) is presented in chapter 7.2 of this report. The results of the radiometric survey are briefly described in chapter 7.7.

A water research project funded by the Kenyan and Austrian governments and managed by AUSTROMINERAL commenced in 1977. It's aim is a new evaluation of the Taita – area's water potential utilising as a base the detailed geological maps produced by the Kenya-Austria Mineral Exploration Project. Hydrogeological data on the Mwatate quadrangle collected until September 1978, and their interpretation as to the groundwater potential of the area presented in chapter 7.8 of this report. This chapter as well as fig. 13 was contributed by W. J. NAUTA, Senior Hydrogeologist of AUSTROMINERAL Ges. m. b. H., who is in charge of the Kenya-Austria Groundwater Project.

1.2 Access

The area lies immediately to the south of the partly surfaced main road from Voi to Taveta, as well as the railway line passing the same way. Both connect at Voi with the major traffic ways from Nairobi to Mombasa.

The Mwatate trading center lies at the northern edge of the sheet on the western bank of Mwatate River; it can be reached from Nairobi at a distance of 346 kms, from Mombasa at 166 kms.

The village Bura lies some 7 kms to the west, on the eastern bank of Bura River.

From those two settlements unsurfaced dirt roads and tracks suitable for four-wheel-drive vehicles mainly allow access to all parts of the area. Especially the sisal-plantations south of Mwatate, but also cattle ranches situated further south and to the West, have built a system of roads providing reasonable access by car to all parts of the sheet.

Only during heavy rains may traffic by vehicle be restricted by adverse road conditions.

1.3 Climate and Vegetation

Most of the area is part of the great tract of semi-arid plainland lying between the Coast Ranges and the highlands of the Taita Hills.

High mean temperature and low annual rainfall give rise over the plains to a bush vegetation consisting of different species of Acacia, Commiphora and Euphorbia.

Lime-rich soils over marble bands frequently carry almost impenetrable thickets of bush undergrown by Sansevieria while much of the plains are expanses of open grassland with scattered bushes or stunted trees.

The larger hills and some of their slopes in the area were covered earlier by open forests of hardwood trees, but extensive charcoal burning has left only remnants of this vegetation in less readily accessible parts.

The courses of Bura and Mwatate rivers are marked by fringes of tall trees (mainly the ,,fever tree", Acacia Xanthophloae) in their northern, upper reaches. Towards the south, these rivers gradually cease to carry surface water, although their alluvium contains groundwater much further. There, their beds are characterised by large streches of black ,,cotton soil" supporting a lush grass cover.

1.4 Physiography

The highest point in the area is Alia Hill at 4369' (1332 m); it is part of Mgama Ridge, representing the major physiographic feature of the area. Lower and more isolated hills occur to the east and south, where an almost featureless plain streches towards the south-east. It reaches there a minimum altitude of 2250' (686 m).

Most of the hills are aligned along the regional strike of the rocks, which is generally just west of north.

Several erosion surfaces have been differentiated earlier (WALSH 1960:5) in the wider area:

- End-Cretaceous Surface at 4300' (1310 m); here occurring only at Alia and Kide Hills on Mgama Ridge
- Mashoti Surface at 3500' (1070 m); widely existent on hills in the north-west and north of the sheet, forms summits of Sembi, Naoni, Mkengereni and Mikeli
- Mwangare Surface at 3100' (940 m); marked shelves on most higher hills and summits of Pusa, Mtonga, Kore and Mindi
- Sub-Miocene Surface at 2600' (790 m); dipping at 9' per mile to the south-south-east.

Most of the higher surfaces carry little soil-cover, so that the hills and their slopes provide reasonable rock outcrops. Lower slopes are occasionally covered by talus; very thick talus and soils are typical for the pediment areas surrounding the hills, as well as for the plains.

With the exception of Bura and Mwatate Rivers, the only watercourses are mere gullies which dissect the steeper hill-sides and the pediment areas, but disappear where they come into the plains. These gullies do not carry water expect during very heavy rains.

Waterholes occur in the plains at places where rain water collects in little ponds due to more impervious soil or rocks underneath. Such water is not an indication of a shallow water table; therefore the water-holes fall dry by evaporation during the dry season.

2. Previous Geological Work

The Mwatate quadrangle was included in the 1:125.000 scale geological map by J. WALSH 1960.

The rocks of the ,,Basement System" were then considered to be of Archaean age because of their high-grade metamorphism. WALSH mapped these rocks as a series of paragneisses, including granitoid gneisses, crystalline limestones, graphite gneisses and schists, as well as biotite gneisses.

The general structural pattern of the area was recognized as that of a series of folds overturned towards the west and plunging northwards.

A metamorphism of amphibolite facies grade followed by intense alkali metasomatism and granitization were deduced from the study of thin sections of the rocks.

Since then little geological work has been done in the quadrangle.

In 1971 deposits of green vanadium grossular garnet of gemstone quality were found in the west and south of the area (BRIDGES 1974). This prompted an inrush of prospectors and miners, and the setting up of the present project to assist those people by providing geological information to guide their work.

Mineralogical studies of the newly found garnets were published by SWITZER (1974) and in 1975 by GÜBELIN & WEIBEL; the authors describe physical properties, list chemical analyses, and communicate microscopic observations of the new garnet variety.

The region adjoining the Mwatate quadrangle is covered by the following publications:

To the east and north-east SANDERS (1963) described a suite of banded migmatites, microcline-rich granitoid gneisses, biotite gneisses intercalated with garnetiferous, calcareous and graphitic gneisses, crystalline limestones and amphibolites, dipping steeply to the west.

Three partly informal lithostratigraphic units are described:

- a westernmost series of garnetiferous and graphite gneiss interstratified with hornblendic and hornblende garnet gneiss west of the Tsavo – Athi rivers confluence; to the south massive hornblende-garnet and hornblende-biotite gneisses prevail in the hills around Voi and on Sagala range; tight isoclinal and some more open folds are typical structures.
- to the east continuing to Ithangethi on Galana river banded and contorted hornblende migmatites are common, axialplane folding and boudinage are predominant.
- east of Ithangethi the migmatites give way to a non-migmatised assemblage, formally named the Sobo Formation. It consists of garnetiferous schists and granulites, thin quartzites, abundant crystalline limestones, fissile hornblendic gneisses and dark garnet amphibolites. The Sobo Formation forms a wide open syncline with foliation dips generally less than 30°; the western boundary is considered as being faulted on thrusts dipping 35° west.

Potash feldspars from a pegmatite outcropping one mile south of Tsavo gave a K/Ar-age of 560 ± 50 m. y. (HOLMES & CAHEN 1955:12).

To the east and south-east SAGGERSON (1962) defined and named formally two lithostratigraphical units: the Kasigau Series, and the unterlying Kurase Series.

The Kasigau Series consists of hornblende-biotite gneisses, kyanite-biotite gneisses, quartz-feldspar gneisses, calcareous and granitoid gneisses of an approximate thickness of 11.000' (3.500 m); the top, however, was nowhere seen.

Typical structures are open folds with a northerly pitch; migmatization is only locally intense.

Of the Kurase Series only the uppermost 8000' (2400 m) are observable; rocks found are kyanite, graphite and quartz-rich gneisses and crystalline limestones. Metamorphism is of amphibolite facies grade (sillimanite – almandine subfacies), alkali metasomatism is widespread. Folds are overturned to the west, with a north-northwesterly plunge.

Although the difference in tectonic style suggests a discordance between the two Series, this was explained by disharmonic folding. However, the difference in nature and direction of both sets of folds is interpreted as being due to two phases of deformation: A first one producing overturned and recumbent tight folds of NNW direction mainly in the Kurase Series, and a second one causing open folds plunging northwards and affecting both Series.

K/Ar-age determinations on feldspar porphyroblasts from Maungu and Nyangala (Kasigau Series) gave 490 ± 25 and 425 ± 25 m. y. respectively.

At Mangari, south of the Mwatate quadrangle, a deposit of gem-grade rubies was discovered in 1973. A yet unpublished report on the nature of this and associated deposits was prepared in the course of this project (POHL et al.: Kenya-Austria Mineral Exploration Project, Rpt. 9, 1977). The rubies are products of desilication of alumina-rich country rocks or pegmatitic fluids caused by ultramafic rocks. These rocks were recognized to occur in lenses forming a belt along strike within the Kurase Series. They were originally dunites and pyroxenites, which were affected by at least the later phase of deformation and metamorphism.

West of the Mwatate quadrangle the crystalline rocks are poorly exposed (BEAR 1955) except around Taveta, at Murka-Loosoito, and in the Longalonga hills. Of interest are garnet-biotite gneisses, quartz-feldspar gneisses, basic to intermediate charnockitic rocks and ultramafic bodies around Taveta, kyanite quartzites and schists from Murka and Loosoito, and graphite-kyanite-muscovite assemblages with fuchsite and apatite at Longalonga. Regional strikes are west of north, dips moderate to steep to the east.

The region north of Mwatate was described in a very general way by PARKINSON (1947). A more detailed account of the geology of the Taita Hills but centering on their asbestos occurrences was given by FARQHAR (1960). SHIBATA (1975) determined Rb/Sr ages of 827 ± 55 m. y. on whole rocks from the Taita Hills (isochron disturbed), while K/Ar ages are 498 ± 15 (biotite only) and 519 ± 16 (hornblende) respectively.

Geological maps at 1:50.000 scale of the Taita Hills, Maktau, Kangetchwa and Manyani quadrangles (Rpts. 1–4) and of the Mtito Andei area (Rpt. 5) with the respective reports were produced by the Kenya – Austria Mineral Project in 1976. In the Taita Hills a lower hornblende-biotite gneiss unit with minor marbles, kyanite and graphite gneisses was differentiated from a higher quartz-feldspar gneiss unit with numerous concordant bands of plagioclase-epidote amphibolites. The contact between the two units is marked by a series of ultramafic bodies, which have been introduced before at least a later metamorphic event. They have frequently serpentinite cores surrounded by amphibole asbestos (-talc, -carbonate) rims.

They were interpreted as having been intruded along a regional thrust-plane with the same strike and dip as the foliation of the metamorphic rocks. From petrological studies two metamorphic events were assumed, an earlier regional one of amphibolite facies grade, and a later more thermal metamorphism of the same facies. Structures are very simple; foliation planes dip generally 20° to the north in the central part of the hills, but dip more steeply to the northeast and east in the west as well as the extreme east of the quadrangle.

A coloured geological map 1:50.000 and an updated report on the Taita Hills quadrangle is being published contemporaneously by the same publishers (A. HORKEL, G. NIEDERMAYR & W. POHL, 1979).

3. Summary of Geology

The Mwatate area lies entirely within the Mozambique Orogenic Belt, which extends from Madagascar and Mozambique through Eastern Africa into the Sudan and possibly to Egypt and Arabia. The Mozambique Belt was first described and named by HOLMES (1951); this belt consists of high-grade crystalline rocks, has an approximate north-south orientation over its whole length, and is characterised by ages in the range of 400–700 m. y. (CAHEN 1961). It certainly contains rocks of many different ages, and is essentially a zone of old basement with a sedimentary cover which together suffered several phases of deformation and metamorphism (HEPWORTH 1971). The last overprinting occurred during the Pan-African (or Damaran – Katangan) Orogeny, which took place around the turn of the Proterozoic to the Phanerozoic (550 ± 100 m. y. according to CLIFFORD 1970).

The crystalline rocks of the Mwatate area are metamorphosed pelitic, arenaceous and calcareous sediments with intercalated thin bands of basic sills or lava flows, some small lenses of ultramafic rocks emplaced along certain lithohorizons, and a large charnockite body. With the exception of the latter they are all part of the Kurase Series (SAGGERSON 1962), which in accordance with modern nomenclature (HEDBERG 1976) should better be named „Kurase Group“.

The meta-sediments and the enclosed meta-volcanic strata are part of the Usagaran Metasediments (HEPWORTH 1971), generally accepted as constituting a sedimentary suite laid down on older cratonic basement. The charnockite of the present area (possibly comparable to the Eastern Granulites/HEPWORTH 1971) may represent part of this basement.

The following lithostratigraphic succession has been established in the quadrangle (see also table 1):

	estimated thickness in metres
Mugeno Formation Characterized by numerous bands of crystalline limestone, intercalated with biotite (-garnet, -sillimanite, -graphite, -kyanite) gneiss and quartzfeldspar (-garnet) gneiss	900 + (top not defined)
Mwatate Formation Essentially thick and uniform biotite (-garnet) gneisses, banded gneisses, partly migmatized, alkali-feldspar growth widespread, with important layers of plagioclase amphibolites, and some minor bands of quartz-feldspar (-garnet) gneiss, marble, and kyanite (-sillimanite, Mn-) quartzite	4000

Mgama Mindi Formation	estimated thickness in metres
The lower part of this formation is characterized by graphite (-sillimanite) gneisses and schists, which are intercalated at a scale of metres or tens of metres with bands of granitoid gneiss, quartz-feldspar (-garnet) gneiss, crystalline limestone, amphibolite, and which toward the base contain some small bodies of ultramafic rocks as well as numerous very small lenses of (at the surface) gossanous material with elevated geochemical values of Ni, Co, Cr, V, Cu and Zn. These rocks may be called the	5000
Lualenyi Member	1000
of the Mgama-Mindi Formation. This member is the host to the green vanadium grossular garnet deposits at Mgama Ridge, as well as presumably at Mindi Hill. The higher part of the Mgama-Mindi Formation is poorly exposed; only thick bands of crystalline limestones can be mapped over considerable distances. They are probably intercalated with soft, deeply weathered biotite + and/or graphite gneisses. These rocks envelop the	
Mtonga-Kore Charnockite Complex	
which is possibly an older basement to the metasediments; the exposed parts are mainly uniform gneissose rocks consisting of plagioclase, potassium feldspar, hornblende, diopside, hypersthene, apatite and magnetite. This mineral assemblage points to an originally dioritic composition. The probable extensions of the complex are about 12 by 4 kms, its longer axis being parallel to the regional strike of the surrounding rocks. Foliation orientation within the body does not differ from the one of the enclosing units. The contacts with the country rocks are	

nowhere exposed; locally discordant boundaries can therefore only be assumed from the distribution of the enclosing marble bands.	
Mtongore Formation This formation is only partially exposed, and its base remains undefined, as it is outside the Mwatate quadrangle; biotite (-garnet) gneiss bands seem to be the characteristic rocks.	2000 + (base not defined)

Structures observed in the Mwatate quadrangle point to a history of three phases of deformation. At outcrop scale, pre-migmatic isoclinal axial plane folds (F_1) are followed by moderately tight to isoclinal para-migmatitic folds and boudinage (F_2). A third, probably post-migmatic phase of deformation (F_3) created wide open flexures of wave-lengths of several 100 metres to a few kilometres and probably caused also post-crystalline jointing, wide-spread cataclasis, and local faults.

F_1 fold axes plunge at moderate angles to the northwest and are asymmetric or overturned to the west, while F_2 and F_3 folds are north-south oriented and dip northwards. Variance of the stated direction and angles of axial plunge is important. This may partly be understood as rotation and resultant scattering of earlier linear structures by later folding as described by SANDER (1948:177–178), and also as dependance of second and third folds for their axial orientation on the attitude of s on which they formed (WEISS 1959:95–102).

The most conspicuous foliation planes are nearly always parallel to the observable boundaries between different rock types (S_0=S_1), although traces of a transverse „s" have occasionally been seen, both as a para-crystalline transverse direction of the orientation of biotite flakes (S_2 associated with F_2) as well as post-crystalline fracture cleavage (S_3 associated with F_3).

Foliation dips are generally at medium or moderate angles to the eastnortheast. F_1 and F_2 folds caused a left-hand displacement of continuous lithohorizons along strike, while F_3 folds led to medium and large scale warping of previous structures.

The existence of a large anticlinorial structure in the area as suggested by WALSH (1960) could not be confirmed by the present mapping. Although axial plane folding at minor and medium scale has been observed, and some repetition of lithostratigraphic sections certainly exists, the repetition of such sections at a regional scale seems unprobable in view of the now detailed knowledge of the lithostratigraphy of the area.

In a regional outlook, the deformation pattern recognized in the present area may compare to the ones described from NE-Tanzania (HEPWORTH 1971) and western Kenya (SANDERS 1965) as follows:

	Kasigau Group (identical with „Kasigau Series“/SAGGERSON 1962)		estimated thickness/metres
METASEDIMENTS	Kurase Group (identical with „Kurase Series“) SAGGERSON 1962	Mugeno Formation (marble, biotite-garnet-kyanite-sillimanite-graphite and quartz-feldspar-garnet gneisses)	900 + (probably around 4000)
		Mwatate Formation (biotite-garnet gneisses, banded gneisses, migmatite, plagioclase amphibolites, minor marbles and kyanite-sillimanite-quartzite)	4000
		Mgama-Mindi Formation (? biotite-graphite gneisses, thick bands of marble = higher part) envelops the	5000
		- - - - - - - - - - - - - - - - -	
		Mtonga-Kore Charnockite Complex (intermediate to basic charnockite, plagioclase gneiss)	
USAGARAN		(lowermost part of formation = graphite-sillimanite gneiss, with bands of granitoid and quartz-feldspar-garnet gneiss, marble, amphibolite; high geochemical values in Ni, Co, Cr, V, Cu and Zn =	
		Lualenyi Member (host to green grossularite deposits of the area)	1000
		Mtongore Formation (biotite-garnet gneiss, banded gneiss, marbles, quartz-feldspar-garnet gneiss)	2000 +
		base yet undefined	

Table 1 – Summary of the lithostratigraphy of the Mwatate quadrangle.

W-Kenya	NE-Tanzania	Mwatate area
B_2[x] (overturned to WNW; minor fold axis and lineations; axial plunge to NNE).	Bongan deformation (flexures at all scales, upright to slightly overturned; no axial plane foliation; axial plunge to NE)	F_3 deformation (upright flexures; axial plunge E of N)
B_1 (strongly defined; axial strike NW/SE; in parts strongly overturned to SW)	Kondoan deformation (intense main deformation; tight, reclined folds; penetrative foliation and lineation; axial plunge to SE; 700–900 m. y.)	F_2 and F_1 (?) (axial plane and tight folds; overturned to reclined towards WSW; axial plane foliation; axial plunge NW to N)

Metamorphism is of high grade; mineral assemblages indicative of both amphibolite facies and granulite facies have been determined. Rocks of suitable composition show anatectic mobilization of felsic material and growth of potash-feldspar to form typical banded gneisses. Migmatisation, however, involving blotting out of earlier structures at outcrop scale, is quite localised. Venites, agmatites, and nebulites have been observed.

More than one phase of metamorphism are thought to have occurred in the area. One phase may have taken place contemporaneously with F_1 deformation, possibly associated with intrusion or tectonic emplacement of the ultramafic rocks. At the present stage of knowledge, nothing can be added on the nature of a possible early metamorphic phase.

The major metamorphic phase in the area is associated with F_2 deformation. We find mineral assemblages indicating high pressures and high temperature, including the kyanite-almandine-muscovite subfacies and the sillimanite-almandine-orthoclase subfacies of the amphibolite facies. Some of the felsic gneiss bands within the metasedimentary suite, and the rocks of the Mtonga-Kore Charnockite Complex show granulite facies features; the felsic granulites by the typical discoidally flattened quartz grains, while the latter are charnockites proper, containing hypersthene besides diopside, hornblende, both feldspars, and some quartz.

The pt-conditions may have reached 7 kilobar and 700°C; this caused anatectic mobilisation of felsic material, and a widespread potassium metasomatism, which apparently reset the K/Ar radiometric ages.

The F_3 phase may have been accompanied by the more thermal phase concluded from the observation of sillimanite replacing kyanite. Penetrative pegmatites, consisting mainly of quartz-feldspar-muscovite-tourmaline are thought to have originated during this latest phase.

The formation of the green vanadium grossularite has taken place during the main metamorphic event wherever suitable material was available; a weak retrograde phase may have caused the kelyphitic rim around the garnets consisting of epidote, scapolite, clinopyroxene, and spinel.

Soils are generally residual, of reddish colour, and sandy. Light grey, shallow calcareous soils occur above crystalline limestone bands; calcrete layers may underly such soils, but frequently form a hard crust with little cover. Black cotton soils are found covering some low lying areas, but typically form a blanket above the alluvium

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[x] It should be noted, however, that SANDERS considered B_2 to be pene-contemporaneous cross folds to B_1.

PHANEROZOIC	Erosion and peneplainisation Deposition of Karoo-sediments ? Uplift and erosion	Segmentation of the crystalline rocks along regional zones of cataclasis (lineaments)
PRECAMBRIAN	F_3-deformation	(open, undulating folds with northerly trend; „penetrative“ pegmatites? more thermal metamorphic event, cataclasis)
	F_2-deformation	(axial plane folds with northerly trend, amphibolite/granulite facies, metamorphism, anatexis, migmatisation)
	F_1-deformation	(axial plane folds with NNW-trend, metamorphism?, regional thrusting with obduction/intrusion of ultramafic rocks?)
	Sedimentation of Kurase Group on a basement, which may be represented by the Mtonga-Kore Charnockite Complex.	

Table 2 – Summary of geological events in the Mwatate area

of the streams and rivers. This is thought to consist of gravel and sand, although it was rarely seen exposed due to the small amount of actually flowing water in the rivers.

4. Lithostratigraphy and Petrology

4.1 Lithostratigraphy

The Mwatate quadrangle is completely within the domain of the suite of meta-pelites and meta-calcareous rocks named Kurase Series by SAGGERSON (1962). This lithostratigraphic unit could be mapped similarly in the Taita Hills (NIEDERMAYR et al., 1976) as predicted by SAGGERSON (ibid.), and further to the northwest (HORKEL & ELLIOTT, 1976).

Accordingly, the unit is confirmed as being of regional importance. It should, however, be renamed

„Kurase Group“

according to modern lithostratigraphic nomenclature (HEDBERG 1976).

The present mapping in the Mwatate quadrangle was of sufficient detail to allow a further subdivision of the Kurase Group in the area. New lithostratigraphic units of the rank of formations could be defined, as well as one economically important member of one of the formations (see table 1).

4.1.1 The Mugeno Formation is the highest lithostratigraphical unit in the area; only its lowermost part lies within the Mwatate quadrangle, exposed on Mugeno Ridge in the north-eastern corner of the sheet.

Here, numerous marble bands with thicknesses up to several tens of metres are intercalated with biotite (-garnet – kyanite – sillimanite – graphite) gneisses and schists, and the occasional band of typically white or buff quartz-feldspar (-garnet) gneiss.

The base of the Mugeno Formation is taken as the lowermost reasonably continuous marble band on the western foot of Mugeno Ridge. The top of the formation is outside (to the east) of the Mwatate sheet; it is considered to be the major lithostratigraphic hiatus between Kurase and Kasigau Groups, now well known from recent mapping in the Taita Hills (NIEDERMAYR et al., 1976).

About 900 m of the lowermost part of the Mugeno Formation lie within the Mwatate quadrangle; the total thickness may be up to 4000 m.

The type-section of this formation would conveniently be chosen across the strike at Mugeno Hill.

4.1.2 The Mwatate Formation is poorly exposed; most of the flat areas in the north and east of the quadrangle are thought to be underlain by biotite (-garnet) gneisses and schists, banded gneisses and migmatites, with bands of plagioclase amphibolites, marble, quartz-feldspar (-garnet) gneiss and kyanite (-sillimanite – muscovite – Mn) quartzite.

Good and reasonably continuous outcrops of these rocks exist only on the hills both west and east of the northern Mwatate River valley. The northern tip of Naoni Hill is the best exposure of a migmatite proper in the quadrangle, with irregular obliteration of the banding in biotite gneisses by mobilized felsic material. Elsewhere, at Naoni, banded biotite (-garnet) gneisses and feldspar augen gneisses are intercalated with plagioclase (-garnet) amphibolite. Typical is intensive folding at all scales, as well as fragmented thin bands of amphibolite in migmatitic biotite gneiss bands, the fragments showing internal earlier folding (F_1) and later fragmentation and rotation, probably contemporaneous with F_2.

On Zongoloni Hill, identical more or less mobilized biotite (-garnet) gneisses contain bands of plagioclase amphibolite, marble, thinly foliated quartz-feldspar (-garnet) gneiss, quartz-feldspar augen-, and granitoid gneiss. At two localities on the hill occurs an important band of kyanite (-sillimanite – muscovite – Mn) quartzite; this is possibly one horizon repeated by overfolding. Outcrops, however, do not allow a positive statement.

Graphite is virtually absent from rocks of this formation, except a very minor content in marbles, and one small occurrence of soft graphite gneiss on the hill Tasha north of Mkengereni.

Towards the north-west, the lower part of the Mwatate Formation characterised by thicker amphibolites seems to wedge out between the massive biotite gneisses of the south-western Taita Hills and the marbles of the Mgama-Mindi Formation.

The formation's lithostratigraphic extent is determined by the base of the overlying Mugeno Formation, and the top of the Mgama-Mindi Formation underneath. The latter is considered to be above the remarkable marble bands enveloping the Mtonga-Kore Charnockite Complex. The thickness of the Mwatate formation may accordingly reach 4000 metres. However, repetition by axial plane folding could exaggerate considerably the true thickness.

It is not possible to consider one single section for a type-section of the Mwatate Formation; for convenience a longitudinal section along Zongoloni Hill to Sembi for the lower part, and along the Mwatate-Wundanyi road (in the Taita Hills, sheet 195/4) for the higher part may be used.

4.1.3 The Mgama-Mindi Formation is in contrast to the rather monotonous Mwatate Formation characterized by a wide variability of meta-sediments, which in addition lodge a variety of felsic (?) intermediate, mafic and ultramafic meta-igneous rocks.

Its higher part is poorly exposed with the exception of several conspicuous marble bands, which enclose the Mtonga-Kore Charnockite Complex. These marble bands may be intercalated with biotite and/or graphite schists and gneisses, but without any outcrop data this can only be guessed. No type section can be proposed for the same reason.

The basement character of the Mtonga-Kore Charnockite Complex has been recognized by the present survey. The main rock type, exposed in the hills Mtonga, Kore, and to the east in patchy exposures under shallow soil, is of intermediate, calc-alkalic composition. Contacts with the country rocks are nowhere exposed; from the geological map it may be deduced, that the complex is generally concordant. This could be primary, but is most probably due to tectonic readjustement in the sense of RAMSAY (1967). The internal structure of the complex seems to conform to the deformation pattern of the surrounding rocks (see chapter 5).

Below the calcareous upper **Mgama – Mindi Formation** follows a horizon characterized by preponderance of quartzo-feldspathic rocks, including a fine-grained, thinly foliated, white to buff quartz-feldspar gneiss (possibly a meta-rhyolitic tuff), a medium grained, rather massive quartz-feldspar gneiss (could be a metarhyolite), and granitoid gneiss bands (coarse volcanogene meta-agglomerate or greywacke ?). These possible meta-volcanics are at Mgama and at Mikeli Hills associated with a quartzitic rock containing (mainly Fe-) sulfides, and with marble bands, graphite gneisses and schists. Biotite (-garnet) gneiss bands and amphibolites are almost absent in these beds.

The base of this conspicuous quartzo-feldspathic horizon possibly representing a meta-rhyolitic body and its volcanosedimentary equivalents which forms Mairimba hill, the tops and the eastern slopes of Kide and Alia hills is the higher lithostratigraphic boundary of the **Lualenyi Member**.

The base of this member is identical with the base of the Mgama-Mindi Formation, considered to be situated at the western foot of Mgama Ridge. The member draws its name from the important green vanadium grossularite exploitations of the Lualenyi mine, situated within its higher part on Kide hill.

Characteristic rocks of the Lualenyi Member are graphite (-sillimanite – muscovite) gneisses and schists, intercalated at a scale of metres or tens of metres with numerous thin bands of granitoid gneiss, quartz-feldspar (-garnet) gneiss, marble, and occasionally biotite (-garnet-kyanite) gneiss, and amphibolite. Small gossans at some localities and numerous finds of gossanous float in soil above this member point to the existence of small lenses and pods of sulfides in unweathered rocks. In many instances cavities partly filled with such ironhydroxides have been seen in anatectic, concordant pegmatoids – indicating mobilization of the sulfides during high-grade metamorphism. Geochemical assays of gossanous material have shown that Ni, Co, Cr, V, Cu and Zn are present in anomalous quantities (see chapter 7.3).

The deposits and occurrences of green vanadium grossularite known until now are invariably situated within a higher horizon of the Lualenyi Member.

The lowermost parts of the member as exposed at the western foot of Mgama Ridge show a gradual lithological change to rocks containing more biotite than graphite, and thicker as well as more numerous marble bands. This is taken as an indication of the nearby but unexposed base of the member.

The ultramafic rocks mapped at Mikeli, and at Mindi occur near the base of the Lualenyi Member; they are considered to represent a regional thrust or suture. Another small occurrence of altered serpentine west of Kambanga would then imply a stratigraphically higher thrust within the Mgama-Mindi Formation. From the present mapping it was not possible to reach definite conclusions concerning the mode of emplacement of these ultramafics. The time of emplacement, however, is clearly pre-migmatitic (pre- F_3 and F_2) because of the heavy alteration of the ultrabasics by acid fluids during high grade metamorphism.

A type section for the Lualenyi Member would best be combined of a profile along E/W coordinate 9601 from the foot to the top of the unnamed broad hill north of Kide for some 600 metres of the member immediately below the productive green garnet horizon, and a profile through Luanlenyi Mine No. 2 to the top of Kide hill comprising the uppermost 100 metres to the overlying quartz-feldspar gneiss horizon.

4.1.4 The Mtongore Formation is again only partially exposed; it is considered to extend westwards from the western foot of Mgama Ridge. Its top is marked by a change in the rock-character from the graphite (-muscovite) – rich gneisses and schists of the Lualenyi Member to biotitic gneisses. The base of the formation is west of the Mwatate quadrangle in very flat, featureless terrain, and will probably be determined with great difficulties only.

The available exposures show biotite (-sillimanite – garnet) and banded gneisses predominantly, with important beds of marble; quartz-feldspar (-garnet) gneiss and granitoid gneiss are of less importance. The thickness of the member represented along profile A-A on the geological map is taken as about 2000 m.

4.2 Petrology

For a petrological description of the rocks mapped in the Mwatate quadrangle the following groups are differentiated (however, not all of these groups are mappable units in the area):

Meta-sediments: granitoid gneiss
quartz–feldspar gneiss
quartzite
biotite (-garnet) schist and gneiss
graphite (-muscovite) schist and gneiss
sillimanite (-graphite) schist and gneiss
muscovite schist and gneiss
crystalline limestones
calc-silicate rocks

Meta-igneous rocks: meta-rhyolites, rhyolitic tuffs and agglomerates (?)
charnockites
plagioclase amphibolites
garnet amphibolites
ultramafic rocks

Anatectic mobilisates, migmatite

The weakness of such a classification is well realized, namely the difficulty to differentiate with certainty between felsic rocks of igneous or sedimentary origin. Doubtful attributions will be declared as such in the following.

4.2.1 Meta-sediments

Granitoid gneiss is a field term for coarse-grained rocks of quartzo-feldspathic composition, which occur in thick bands of tens of metres in the northern Mgama Ridge; thin bands of the same rocks are intercalated throughout the Lualenyi Member of the Mgama-Mindi Formation. These rocks typically form positive outcrops, and may serve as marker horizons in field as well as photo mapping.

At outcrop and handspecimen scale, foliation is frequently obliterated by an almost total mobilization during metamorphism. They grade imperceptibly into anatectic pegmatoids which may then accumulate in lenses along strike of a bed, thinning out in between.

The rocks are of granoblastic texture, frequently with large (up to 100 mm long) partly idiomorphic microcline porphyroblasts; they contain xenomorphic quartz with undulatory extinction, potash feldspar (mainly microcline with quadrille structure, partly perthitic), twinned or untwinned plagioclase, partly zoned and filled, and muscovite. Biotite (P 104 8)* graphite and sulfides (P 1015) have occasionally been observed in addition. Graphic intergrowths of quartz and feldspar occur in more pegmatitic parts of granitoid gneiss bands.

Granitoid gneisses may grade into biotite or graphite gneiss or Fe-sulfide quartzite if the respective minerals occur in higher quantities; with finer grain size they may approach quartz-feldspar gneiss. With these latter rocks a gradual relationship has been observed in the field at outcrop scale; sharp boundaries, however, between beds of both rocktypes are not infrequent either.

Granitoid gneiss could be the metamorphic equivalent of coarse volcanogene agglomerates or greywacke.

Quartz-feldspar gneiss is a medium – or fine-grained, white or yellowish buff, usually well foliated rock. Some types show a lamination at mm- to cm-scale, which is here interpreted as an inherited sedimentary structure. These laminations appear to be due to variations of the quartz-feldspar ratio only; doubtful graded bedding could be observed at one locality.

Quartz-feldspar gneiss bands form some of the most remarkable rock-walls in the Mwatate quadrangle at Kide and Mairimba. They are generally resistant to weathering, and serve as marker horizons similarly to granitoid gneiss bands.

The predominant constituents are quartz and feldspar, with small amounts of muscovite, biotite, sillimanite, graphite; the texture is granoblastic, although gradational flattening of quartz (approaching typical discoidal shape) leads to granulitic textures. In some bands of the Lualenyi Member, and in the Mugeno Formation, garnets may occur in considerable quantities.

Quartz is xenoblastic as a rule, with undulatory extinction. In some specimen from Mairimba, however, larger quartz-graints show rounded and embayed edges, which may be remnants of grain surfaces typical for felsic effusive rocks (N 123, 124). Feldspars show mostly quadrille structures; orthoclase is usually perthitic; placioclase is andesine – labradorite twinned and zoned. Biotite and muscovite are rare, the latter is obviously unstable at the metamorphic conditions reached. Sillimanite occurs in single needles, bundles of fibres, and small recrystallized knots arranged along foliation planes (P 1070 and 1076). Garnet forms idioblasts, frequently strongly ruptured. Accessories are zircon, rutile, apatite, and small ore grains. Some zircons examined were of typically metamorphic roundish shape.

Gradual changes to granulite, graphite and/or sillimanite gneiss and to Fe-sulfide quartzite (at Mikeli) may occur.

The medium-grained, massive quartz-feldspar gneiss at Mairima may present an acidic lava sheet, while the finegrained laminated gneiss at Kide and the sulfide quartzite at Mikeli and Mgama could be of volcano-sedimentary origin (tuffs and mineralized chert respectively). The coarse grained granitoid gneiss bands at Mgama may similarly be derived from greywacke or arkose of volcano-sedimentary derivation. Thin and laterally little continuous bands of quartz-feldspar (-garnet) gneiss, however, are interpreted as psammitic intercalations in a generally pelitic sedimentary rock suite.

Quartzites are subordinate in the Mwatate quadrangle.
Two types may be differentiated:

Iron-sulfide quartzite – occurring within the predominatly quartzo-feldspathic

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*Sample numbers cited in brackets refer to rock samples stored with Mines and Geology Dept., Nairobi.

horizon above the Lualenyi Member at Mikeli and the Mgama north-slope (P 1015)

Sillimanite-kyanite quartzite – as a mappable unit only found at Zongoloni hill (P 1099–1105), although thin bands of such rocks have also been sampled north of Mindi (N 125) within graphite-sillimanite gneiss.

The iron-sulfide quartzites are light-grey rocks, coarsely crystalline with interlocking quartz-grains; ordinarily the sulfides are almost completely leached from the rock at the surface, so that the quartzite is vuggy and irregularly covered by limonitic crusts. In addition, the rocks carry a distinctively poor vegetation. They may be metamorphic cherts associated with volcanism.

Sillimanite-kyanite quartzites at Zongoloni are light-grey, weathering to a very rugged local relief covered with a dense, thorny bush; the exposed rock is overgrown profusely with a species of lichen. At places, the quartzite contains pods of coarsely crystalline blue kyanite. These are small individually (up to a maximum of one cubic metre) and constitue less than 1 % of the rock-mass.

Quartz occurs in large grains, partly filled with sillimanite needles; sillimanite is distributed in the rock as single needles and elongated bundles of fibres; graphite and rutile are accessories, limonite fills cracks and stains the intergranular matrix. Untypical for the whole is a specimen of Fe-quartzite with spessartine from southern Zongoloni (P 1104), although Fe-rich, dark quartzite is more common in the northern band.

Biotite (-garnet) gneisses and banded biotite (-garnet) gneisses probably are the most widely distributed rocks in the Mwatate quadrangle. Their tendency to weather easily, however, makes outcrops of these rocks quite rare. Larger outcrops exist only on the hills Pusa, Zongoloni, Mkengereni and Naoni along Mwatate river; elsewhere, bands of biotite gneiss intercalated with other rocks have been mapped at Mugeno, the western foot of Mgama Ridge, and Mtongore/Kasindano. These rocks are thought to represent about one third of the Mugeno Formation, more than two thirds of the Mwatate Formation, possibly up to 50 % of the Lualenyi Member, and more than half of the Mtongore Formation.

In fresh outcrops and hand-specimen, they are well foliated, grey rocks, usually banded by interstratified lighter and darker laminae, at a scale of cms to tens of cms. Some of this banding may well be inherited from sedimentary stratification (S_0 or S_1 – see chapter 5), while other types are clearly caused by mobilization of felsic material during high-grade metamorphism (S_2).

The biotite gneisses are essentially a very uniform group of rocks with little variation in composition. Typically (P 1049, 1055, 1107, 1116, 1145), they contain xenomorphic quartz, little if any potash feldspar, plagioclase (oligoclase–bytownite, idiomorphic to subidiomorphic, twinned and zoned), biotite, and garnet (reddish brown, poikilitic; wherever an internal s has been observed in the garnets, this was not displaced against the s of the rock). Felsic and mafic minerals are alternatively enriched in successive bands, to give the banding characteristic for the rocks. Accessories are apatite, zircon, tourmaline locally, and fine ore-grains.

Where biotite gneisses are interstratified with other rock types, their mineralogy may vary more widely. At Mgama they have been observed to grade into granitoid gneiss (P 1048) and quartz-feldspar gneiss (P 1056); at Mtongore they contain sillimanite (P 1080); at Naoni mobilization of felsic material leads to migmatite (P 1107), others aregranulitic(P 1120) and contain hornblende (P 1090).

Graphite schists and gneisses have been observed almost exclusively in the Lualenyi Member of the Mgama-Mindi Formation, although it is suspected that such rocks form also an important part of the higher succession of this formation. As they are very soft rocks as a rule and are easily weathered, natural outcrops are rather rare. Only the gneissic and alumosilicate-rich rocks may be found outside of artifical exposures. Rock-colours are buff, light grey, yellowish or greenish dependant on the rock-forming minerals. Graphite rarely determines the colour, as it hardly occurs in higher percentages.

Three distinct varieties of graphite bearing rocks can be differentiated, although transitional types are not infrequent:

Quartz-feldspar (-muscovite) – graphite gneiss – with xenomorphic quartz, some orthoclase and microcline, but mainly plagioclase; graphite mostly below 2 % (E 16 R, P 1021, P 1023, P 1036, P 1065). Bands consisting of graphite-muscovite-microcline have been noted (P 1030).

Quartz-muscovite-sillimanite-graphite schist – this is the prevailing type; xenomorphic, often flattened quartz-grains; muscovite in bands marking the foliation; graphite and sillimanite occur similarly, or sillimanite may form nodules giving the rock a macroscopically remarkable knotty texture (P 1043, P 1057, P 1065, P 1096, P 1125). Accessories are rutile, apatite, tourmaline, and sulfide ore grains.

(Quartz) – calcsilicate – graphite schists – form thin bands or more frequently and typically „boudins" (see chapters 5 and 7 for details) in certain lithohorizons; the quartz-content is variable and may be completely absent, the main calcsilicates are clinopyroxene, clinoamphibole, scapolite and epidote; grossularite deposits are intimately associated with these rocks (see chapter 7).

The graphite content in these rocks is mostly around 2–5 %; only a few specimen from the top of Mgama Ridge at coordinate 9601.8 have been observed to contain more graphite.

Mapping has shown, however, that graphite-rich rocks occur as minor bands or lenses too thin to warrant further investigation.

The graphite schists and gneisses typically contain numerous small bands, lenses or pods rich in Fe-sulfides with elevated geochemical values of Zn, Cu, Cr, Ni and V (see chapter 7). This points to their origin as bituminous clays, which are commonly enriched in V, Mo, U, Cu and As (WEDEPOHL, 1969). By decreasing graphite contents these rocks may grade into quartz-feldspar gneiss, muscovite–sillimanite schist, etc.

Sillimanite (-muscovite) schists and gneisses have been found as bands alternating with other rocks of the Lualenyi Member. They are mostly soft, light brown or yellowish, well foliated rocks of gneissic to schistose appearance.

These rocks consist of variable amounts of quartz, alkali-feldspar (orthoclase, microcline), plagioclase, muscovite, kyanite (unstable, corroded by sillimanite), sillimanite and occasionally some graphite (P 1017, P 1043, P 1057, P 1065, P 1069, P 1070, P 1073, P 1076, P 1096, P 1125). Accessories are apatite, anatase, rutile, tourmaline, zircon, and opaque matter (pyrite mainly).

Gradation of these high-alumina rocks into quartz-feldspar gneiss or graphite schist is common.

Meta-calcareous rocks present in the Mwatate quadrangle are almost exclusively dolomitic crystalline limestones; calcsilicate rocks have been observed as thin bands within other meta-sediments or as marginal facies of marble bands only.

Crystalline limestones have been mapped in all formations within the quadrangle; however, only in the Mugeno Formation, the upper Mgama-Mindi Formation, and the southern facies of the Lualenyi Member marbles constitute an important part of the lithological column.

These rocks are of white or grey colour, frequently banded, coarsely crystalline, with single xenomorphic calcite grains reaching more than 1 cm diameter. Most marbles exhibit a strong H_2S – smell when freshly parted with the hammer. Texture is granoblastic; banding is usually recognizable only on weathered outcrops. It is produced either by variation in grain size or by predominance of calcite on one hand and calcsilicates, graphite, muscovite, quartz, alkalifeldspar, and pyrite on the other hand in alternating layers (P 1040).

Five specimen of crystalline limestone have earlier been analysed for their calcite: dolomite ratio (WALSH 1960:23); the dolomite content was then found to vary from 35 to 45 % in four samples, while a specimen from south of Kambanga only contained 5 % dolomite.

Calcsilicate rocks have rarely been observed in bands thicker than 1 metre, either as intercalations in meta-pelites, or as a transitional facies between silicic rocks and crystalline marbles. They may represent impure marbles, but some are certainly the product of mobilization of solutions and reaction of those rocks with each other during high-grade metamorphism.

The calcsilicate rocks of the Mwatate quadrangle have a complex and variable composition. Mineral assemblages observed in thin sections are:

P 1138: quartz – diopside – garnet (-calcite)
P 1135: plagioclase – diopside – tremolite – calcite/dolomite
P 1016: quartz – plagioclase – orthopyroxene – tremolite (-biotite, -calcite)
P 1028: (quartz – plagioclase – orthopyroxene) tremolite (-scapolite)
P 1141: tremolite – graphite.

A convergence exists between meta-pelites with calcsilicates (quartz – calcsilicate – graphite schists), meta-calcareous rocks derived from impure limestone/dolomite, and metamorphic reaction products between both rock groups.

Certain calcsilicate rocks in the area attain a special interest as they are intimately associated with the deposits of green vanadium grossular garnet (see chapter 7).

4.2.2 Meta-igneous rocks

Meta-igneous rocks within the Mwatate quadrangle were not described by earlier investigators. This is in part due to better outcrops existing today after the prospecting and mining boom of the last years, and partly to a different interpretation of the origin of certain rocks by better methods of examination, and the general advance of science. Even so, some of the following attributions of rocks to the meta-igneous group are still conjectural. This is especially true for the felsic rocks, where geochemical methods helpful with the more basic rocks are less decisive.

Meta-rhyolite and -rhyolite tuffs are thought to be represented by the quartz-feldspar gneisses of Mairimba, Mikeli, and Kide.

The meta-rhyolites (?) are light, massive rocks, forming important natural outcrops. They have granoblastic or granulite texture. Their main constituents are quartz (mainly xenomorphic, platy; sub-idiomorphic grains with embayed, rounded edges occur also); alkali feldspar (abundant microcline, orthoclase), plagioclase (andesine labradorite; twinned and zoned, corroded by alkali feldspar), muscovite (strongly altered, unstable), and biotite (rare). Accessories are zircon, rutile, apatite, and opaque matter. Specimen attributed to this group are P 1095, P 1130, N 123 and N 124.

Meta-rhyolitic tuffs (?) are whitish to buff, thinly laminated rocks, mapped at Kide (N 122), Mikeli, and Mindi (N 126). They show granoblastic to granulitic texture with xenomorphic, partly platy quartz (large grains with embayed edges rare), orthoclase and microcline, plagioclase (andesine to labradorite, twinned, partly zoned), biotite and muscovite (the latter pale green due to a certain Cr-content). Accessories are rutile, zircon, apatite, graphite, and opaque matter.

Charnockite constitutes the hills Mtonga and Kore west of the Mwatate River valley. There, medium grained, well foliated, brown, and very uniform gneisses form conspicuous boulder outcrops.

Under the microscope, these rocks show granoblastic texture. The mineral assemblage is quartz – alkali feldspar – plagioclase – hypersthene – diopside – hornblende (P 1083, 1084). Quartz is subordinate at about 5 % of the rock. Both feldspars, alkali feldspar (at about 15 %) and plagioclase (60 %) may be recognized. Alkalifeldspar proved to be orthoclase, commonly perthitic with film-, braid-, and string-microperthites. Plagioclase is in the range of oligoclase – bytownite, twinned or untwinned, and partly zoned. Bent twin lamellae reflect post-crystalline deformation. Hypersthene and diopsidic clinopyroxene are grouped together, in about equal amounts (5 % each). Diopside exhibits occasionally distinct exsolution lamellae of orthopyroxene. Olive brown to dark olive green tschermakitic hornblende (6 %) surrounds clinopyroxene in clusters arranged parallel to the planes of foliation. These clusters may be remnants of mafic phenocrysts in the original igneous rock. Apatite, zirkon, and magnetite as accessories, sum up to about 4 %. A whole rock analysis of charnockite from Mtonga is presented in table 3.

	P 1084	N 130	N 131	N 132
SiO_2	60,7 %	59,71	47,07	68,94
Fe_2O_3	6,78 %	4,75	14,87	2,80
Al_2O_3	16,1 %	17,51	13,35	14,87
TiO_2	1,17 %	0,80	2,38	0,23
CaO	4,48 %	2,80	6,00	0,98
MgO	nil	2,75	11,00	0,30
MnO	nil	– not determined –		
K_2O	5,0 %	6,50	0,97	7,50
Na_2O	5,38 %	4,25	3,00	3,00
P_2O_5	0,07 %	0,18	0,66	0,02
moisture	0,24 %			
ign. loss (excl. moisture)	0,03 %	0,36	0,36	0,62
Total	99,95 %	99,61	99,66	99,26

Table 3 – Chemical composition of charnockites (samples P 1084, N 130 and N 131) and granulite (N 132) from Mtonga and Kore Hills
Assayed by the Chemical Laboratory, Mines and Geological Department, Nairobi; Analyst: Omboke

The predominant rock type at Mtonga (P 1084) contains less hornblende and orthopyroxene, than the one at Kore (P 1083 – described above). The main charnockite at Mtonga forms an anticline, in the core of which more felsic as well as more mafic granulitic rocks have been sampled.

The mafic rock is very fine grained, dark grey, nearly schistose (P 1085). It consists of plagioclase, hypersthene, partly altered to diopside, hornblende, apatite, and magnetite.

The more felsic types have been determined as plagioclase (-orthoclase – quartz – biotite – apatite – rutile) gneiss (P 1086) and microcline (-quartz – plagioclase – biotite – garnet) migmatitic gneiss (P 1088). This variability of the composition of the felsic rocks seems to point to a sedimentary origin; the mafic charnockite of P 1085, however, is most probably consanguinous with the main rock mass.

Amphibolites have been mapped within the lower part of the Mwatate Formation mainly; there, at the hills Naoni, Mkengereni and Zongoloni, thick layers of black, frequently banded, foliated amphibolites are well exposed.

In thin section, these rocks consists of plagioclase, pyroxene, hornblende, apatite, and opaque matter (P 1114). Plagioclase is labradorite to bytownite, idiomorphic to xenomorphic, twinned, zoned if intwinned. The pyroxene is pale green diopside in relictic grains surrounded by hornblende. The latter is idiomorphic to subidiomorphic, strongly pleochroitic from yellow-green to dark olive green.

Trace metal assays of two samples (P 1114, 1119) of amphibolites from Naoni are listed among others in table 4. The high values of Ni and Cr are interpreted as an argument for an igneous origin of these rocks.

At Mgama Ridge, amphibolite bands with a thickness up to a few metres are implied by float in slope-scree. Outcrops of these rocks are very rare and small, as they occur towards the base of the Lualenyi Member only, which means at the same time the western foot of the ridge. Here, both plagioclase amphibolites and garnet amphibolites have been found.

Under the microscope, the garnet amphibolites consist of plagioclase (oligoclase – andesine, twinned and zoned), idiomorphic to subidiomorphic tschermakitic hornblende, and pale reddish-brown poikilitic garnets, partly with inclusions of hornblende, zoisite, and opaque matter in parallel arrangement. Only opaque matter was observed as an accessory mineral (P 1029, P 1060, P 1077). – On the base of trace metal values (table 4) the Lualenyi amphibolites are thought to be derived from igneous material.

A hornblende gneiss found on the dump of an excavation in the extreme southeast of the sheet (P 1091) is probably meta-igneous also in view of its high trace metal values (see table 4). This rock consists of (quartz-) plagioclase – diopside, which is mainly altered to actinolitic hornblende, calcite, and zoisite. On the dump, it was associated with garnet–biotite gneiss.

Ultramafic rocks have been mapped only at Mikeli, Mindi, and to the west of Kambanga. The three occurrences are all situated in the southern part of the Lualenyi Member, which is more meta-calcareous-pelitic than the northern part. The latter contains more quartzo-feldspathic (meta-psammitic) horizons.

Sample No.	Rock	Ni	Co	Cu	Pb	Zn	V	Cr
P 1075	Amphibolite	1000	125	20	100	90	400	485
P 1077	Amphibolite	1000	125	25	100	80	350	410
P 1084	Charnockite	1000	65	20	125	80	50	280
P 1091	Amphibolite	1500	100	10	100	100	200	425
P 1114	Amphibolite	1510	115	90	85	140	1100	500
P 1119	Amphibolite	1500	110	88	130	165	1240	500
P 1127	Ultramafite	1100	105	63	83	115	170	1200
P 1131	Ultramafite	1475	70	85	185	145	290	2500
P 1143	Ultramafite	700	70	135	123	95	210	1800
N 130	Charnockite	400	65	10	80	80	50	90
N 131	Charnockite	350	100	20	100	100	550	150

Table 4 – Trace metal content in meta-igneous rocks of the Mwatate 1:50.000 sheet area (AAS assays after hot leaching in HF/HCl by the Chemical Laboratory, Mines and Geological Department, Nairobi – Analyst: E. P. Mwaniki).

In the field, ultramafic rocks do not form natural outcrops. At the locations cited they could only be observed in prospecting pits. As far as these exposures allowed, the following observations were made: The ultramafites form lenses of rather irregular shape in graphite-sillimanite gneiss and/or schist with bands of quartz-feldspar gneiss. They may also be in contact with marble. The size of the single bodies is estimated as varying between 10 (at Mikeli and Kambanga) and 100 metres (at Mindi) of the long axis. Contacts with the country rocks may be concordant or discordant, in all cases vivid chemical interactions along contacts during high grade metamorphism as described by POHL & NIEDERMAYR (1977) at Mangari have been proved by field observations.

In handspecimen, these rocks are dense, non-foliated, of greenish or yellowish brown colour. Under the microscope, they prove to consist mainly of orthopyroxene (enstatite – bronzite) and edenitic hornblende. In minor quantities have been determined in addition: quartz (P 1097), muscovite (P 1097, P 1143), pyrite, corundum (ruby), rutile (N 12), kornerupine (N 127) and spinel (P 1127). Limonitic staining in fissures and cavities, and a clay matrix are omnipresent.

Trace metal analyses of such rocks have shown an elevated content in Ni, Co, Cu, Pb, Zn, and V (see table 4). This is considered as proof of an igneous origin of these rocks. Drawing conclusions from comparison with very similar rocks from the Taita quadrangle (NIEDERMAYR et al., 1976) and Mangari (POHL & NIEDERMAYR, 1977), these rocks may have been dunites (serpentinites) and pyroxenites originally, altered by high grade metamorphism and penetrating pegmatitic solutions to their present state. These alterations and interactions with country-rocks may be summarized by

recrystallisation
silication
hydration, and
carbonisation of the original ultramafic igneous rock, and
desilication, and
enrichment in Mg and Cr of the country rocks.

At Mangari, this process led to the formation of corundum (ruby) and green Mg-Cr-tourmalines. In the Taita Hills, deposits of anthophyllite asbestos have been produced.

In the Mindi and Mikeli areas, the ultramafites have been found to contain tiny grains of red corundum (ruby). Larger, salable stones, however, have not yet been discovered.

4.2.3 Anatectic mobilisates, migmatite

High-grade metamorphism caused wide-spread mobilization of felsic rock constituents in the Mwatate quadrangle.

Evidence for this are migmatites as well as pegmatoid bands and veins present in all suitable rocks. Exeptions are rocks of a composition making them resistant against total or partial melting at the pt-conditions reached (ultramafic and metacalcareous rocks; amphibolites, quartzites, etc.), and notably the rocks of the Mtonga-Kore Charnockite Complex.

Partial mobilization of different rocks under variable pt-conditions and H_2O-pressure led to a variety of mobilisates in the Mwatate quadrangle:

- quartz veinlets
- quartz-potash feldspar-plagioclase bands and veinlets („pegmatoids“)
- quartz-potash feldspar (-plagioclase) - biotite „pegmatoids“
- quartz-potash feldspar-muscovite-tourmaline pegmatites (penetrative over larger distances, graphic intergrowth of quartz and feldspar)

Quartz veinlets occur mainly in the graphite gneisses and schists of the Lualenyi Member. They are always thin (usually less than 20 cms thick) and relatively short lenses (up to several metres length). Both concordant and folded as well as discordant and unfolded veinlets have been observed, the latter occasionally cutting F_2 folds. This proves, that more than one generation of such veinlets exist in the area. In addition, some of the earlier quartz-veinlets have diffuse margins, while the supposedly later ones show sharp boundaries.

Quartz (-potash feldspar) - plagioclase pegmatoids are ubiquitous in the biotite gneisses. Typically, they form thin concordant bands and discordant veinlets in the rocks here termed „banded gneisses“ (see chapter 4.2.1). The structures of these pegmatoids are very variable, reaching from simple unfolded bands through shear- and flow-folds to ptygmatic folds and boudinage. This indicates locally highly differing conditions of deformation, probably controlled both by the nature of the original rock as well as the amount and nature of the mobilisate. Diffuse and sharp boundaries of these rocks towards the unmobilized bands have been observed. Occasionally, a local enrichment of dark minerals (mainly biotite) along the boundaries is very conspicuous.

Quartz-potash feldspar-(plagioclase-) biotite (-garnet) pegmatoids occur essentially in the same way as the ones just described. They show, however, a tendency to cloud earlier structures in a diffuse penetration. Accordingly, they are here considered to be a later pegmatoid generation. Their dimensions are frequently similar to the earlier pegmatoids. Where this type of mobilization reaches outcrop-scale, and earlier structures are hardly recognizable, the rocks are called migmatites in this report.

Quartz-potash feldspar-muscovite-tourmaline pegmatites seem to be of a more „igneous“ nature, contrary to the pegmatoids obviously derived from their immediate countryrocks. The pegmatites are penetrative, cutting rocks of different composition, and show graphic intergrowth of quartz and feldspar. They are especially frequent in the Lualenyi Member of the Mgama-Mindi Formation, but occur principally everywhere within the quadrangle.

The pegmatites in the Lualenyi Member are characterised by fuchsite besides muscovite and green tourmaline, both due to the generally high rare metal background in the country rocks. Locally, they may contain graphite in large rosettes, sheafs of sillimanite, bluish kyanite, sulfides (mainly pyrite), and rutile. Very often, a quartz-core is developed, or quartz-veinlets cut the pegmatite, indicating a late hydrothermal stage. The above mentioned late quartz-veinlets cutting folds and other early structures may be consanguinous with this post-pegmatitic quartz-deposition.

At Mtonga Hill pegmatites cut the felsic gneisses in the core of the anticline, but also the main charnockite near the northern limit of the hill. Both are rather uniform in composition, consisting of large microcline porphyroblasts, some plagioclase, quartz, and magnetite in coarsely crystalline pockets. The northern pegmatite can be followed more than 100 metres along strike, at near vertical dip, and on average 2 metres thickness. It is thus the largest pegmatite seen in the quadrangle.

Migmatites develop from banded gneisses, where mobilization has obliterated earlier structures so far, that neither the nature of the original rock nor its banding is recognizable except in traces. A large outcrop of migmatites is the rocky northern promontory of Naoni Hill. There, general growth of feldspar-blasts and penetration by quartz-feldspar-biotite mobilisates has created „nebulites“ (granitoid rock with mafic schlieren) and „granites“ with hypidiomorphic texture.

Similar rocks have been observed in smaller outcrops elsewhere at Naoni and at Zongoloni. This pattern of distribution of highly mobilised migmatites is here interpreted as being due to local variation of pt, pH_2O and the composition of the original rocks. A systematic, regional pattern of higher and lower temperatures reached cannot be implied from this observation. Other highly mobilized rocks include the granitoid gneisses, some banded quartz-feldspar gneisses, and the almost ubiquitous banded biotite gneisses. As mobilization was very local in these cases, and the original metamorphic rocks is well recognizeable, the application of the term „migmatite“ would only lead to confusion. It was therefore restricted to the rocks described above.

5. Structures

All metamorphic rocks of the Mwatate quadrangle are heavily deformed. As a rule, the main foliation is parallel to lithologic layering in the rocks (premetamorphic $S_0 = S_1$). In addition, crystallisation has taken place along planes transverse to S_1 (creating a para-metamorphic, transverse S_2), while post-metamorphic deformation created ruptural planes of discontinuity in some instances (S_3 = joints).

Folding has affected all formations differentiated in the area in a comparable manner: F_1-folds are axial plane folds affecting S_0/S_1, and plunge to the north-west. F_2-folds are paramigmatitic, and affect earlier structures as well as pegmatoid mobilisates cross-cutting F_1-folds. F_2-folds are highly variable as may be expected from the extreme mobility of many rocks which are affected: predominantly, similar (shear-) folds have been observed, but these may grade into „flow folds“ and ptygmatic folds. Boudinage is a common phenomenon during this stage of deformation, affecting both thin, competent beds in the lithological suite (amphibolites, calc-silicate rocks, quartz-feldspar gneiss, etc.) and pegmatoid veinlets and veins. F_3-folds are post-migmatitic; they share a northnortheasterly axial strike with the F_2-generation, but are mostly upright, asymmetric or symmetric open flexures. This deformation ends in post-crystalline jointing and widespread cataclasis.

Most rocks are strongly lineated, either by linear groovings, the axes of minor folds, or the parallel elongation of biotite and hornblende. The lineation is a b lineation, created by both F_1- and F_2-folds.

Faults are apparently not common in the area, although this may partly be due to the paucity of outcrops. Sharply linear features, like the Mwatate river valley and the western-slope of Mgama ridge, may be due to faulting. In view of the mappable continuation of lithohorizons across these features in the Taita Hills (NIEDERMAYR et al., 1976), they are best explained as zones of more intense facturing and cataclasis, but without actual displacement.

5.1 Folds

The three principal fold-types differentiated in the Mwatate area are schematically illustrated in fig. 2. They are superimposed on each other, producing complicated features of refolding. A well exposed example of refolding of a F_1-synform by F_2-folds is reproduced in fig. 3. Ordinarily, however, outcrops do hardly ever allow actual observation of such features, and interpretation of incomplete data is necessary to arrive at the structural model proposed.

Overturned to recumbent, tight and axial plane folds with a northwesterly to north-northwesterly strike are the oldest deformational features recognised in the area (F_1-folds). They occur everywhere in the quadrangle at outcrop scale, and were mapped at Mgama and Mindi in larger dimensions. From this it is not assumed, that the latter are restricted to the lower formations, the reason being supposedly only the paucity of outcrops in the east. The F_1-folds affect material inhomogenies (layering considered to represent the original sedimentary features). At outcrop scale, such folds are cut by migmatitic mobilisates.

The migmatic mobilisates cutting F_1-folds are themselves folded into tight or axial plane, recumbent to overturned folds along northerly axes (F_2-folds). This folding is at places accompanied by shearing creating an S_2, which is now represented by planes of biotite growth transverse to the lithological layering of the rocks. Where mobi-

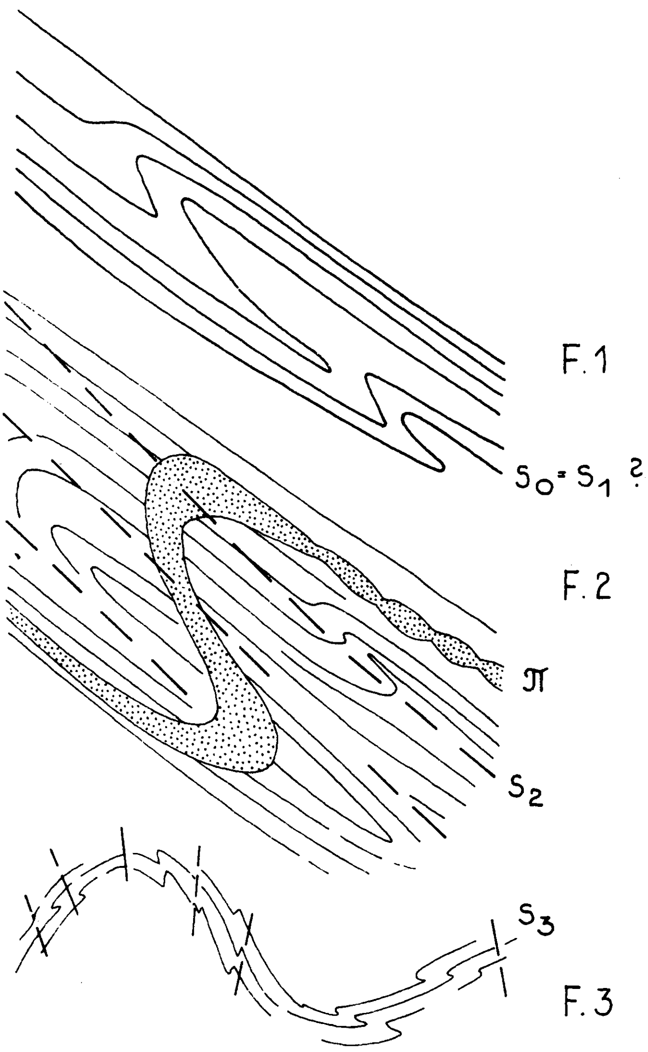

Fig. 2: SCHEMATIC SKETCHES OF PRINCIPAL FOLD TYPES DIFFERENTIATED IN THE MWATATE AREA

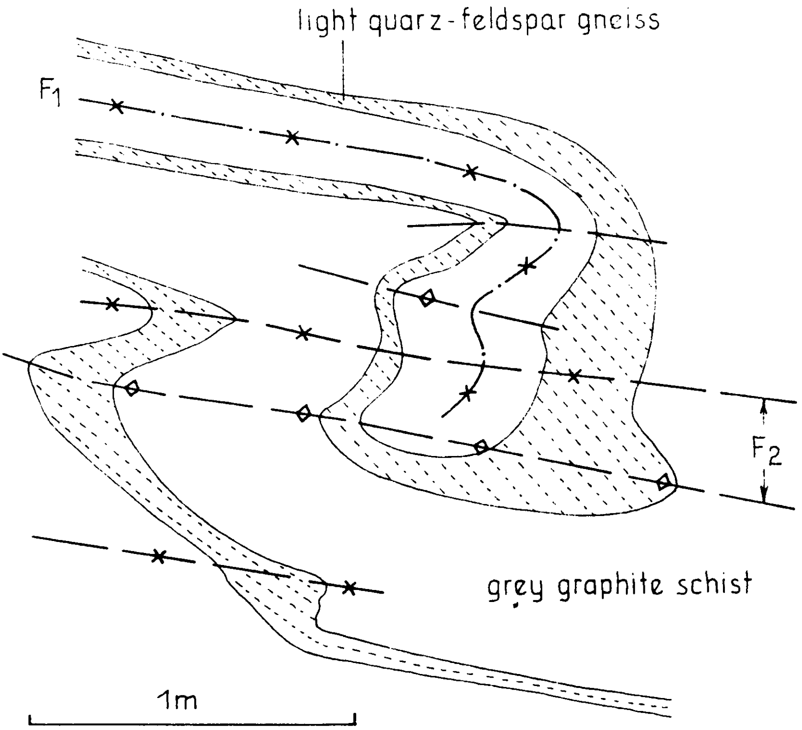

Fig. 3: SKETCH OF EXPOSURE AT MINDI / GG1-MINE: F_1 synclinal fold refolded by F_2

lity was too high to allow shearing, „flow folds" and ptygmatic folds are developed. To which extent F_2-folds of larger dimensions than some tens of metres wavelength as observed at Mgama Ridge may exist, is at present difficult to decide. The assumption is, however, that such folds are generally of small to medium dimensions.

The wide, open, symmetric or asymmetric F_3-folds, however, have been mapped ranging from several tens of metres to several kilometres wavelength. They plunge to the north, generally with about 10°.

Cross-folds at approximately right angles to F_1-folds occur in the northern Mgama Ridge. They are wide, open undulations plunging at 30—40° north of east, accompanied by minor crenulations of S_1. These transverse compressional features are considered to have resulted from a local restraint of the elongation parallel B_1. The reason for this restraint, however, cannot be defined at present.

5.2 Faults and lineaments

One fault only appears on the geological map of the Mwatate quadrangle, cutting marbles in the northern Mgama Ridge. Minor fractures of dimensions which cannot be represented at 1:50.000 scale are numerous, however. Comparison with the Taita Hills, where outcrops are more continuous, does not suggest the existance of many faults of larger extent and displacement in the area.

Similarly, the impressive linear features of the Mwatate river valley, and the west-slope of Mgama Ridge, are most probably not faults, but zones of pronounced fracturing, jointing and cataclasis with little if any displacement. The Mwatate Lineament extends northwards into the Taita Hills, and southwards into the Kinjaro quadrangle, with an overall length of around 50 km.

5.3 Mtonga-Kore Charnockite Complex

Few structural data can be collected at the exposures of this complex, and these hardly allow a rational interpretation of the internal structure of the complex. It may be assumed from these data, that the complex has been affected by F_1- to F_3-folding; the former is represented by a constructed axis (β) dipping 03° to 160°, while F_2 is thought to be responsible for the strong lineation imprinted on the charnockites plunging 10° to the north. F_2-folds may well be present, but cannot be recognised because of the absence of migmatitic mobilisates. The complex does not seem to be structurally different from its country rocks, although it is considered probable, that it represents a tectonically emplaced basement to the Kurase Group.

5.4 Tectonic significance of the ultramafites: The Mangari thrust system

Small bodies of ultramafic rocks have been exposed by prospecting pits at Mikeli, Mindi, and west of Kambanga. This distribution is here tentatively interpreted to reflect intrusion or obduction along a thrust system, which may have been formed contemporaneously with F_1-deformation. The thrusts would have been folded by later tectonic phases.

Supposedly, the thrusts ly underneath the Mtonga-Kore Charnockite Complex, and to the west at the approximate lower boundary of the Mgama-Mindi Formation. About 20 kms along strike to the southeast of Mindi occur the important ultramafics of Mangari, which carry mineralisation of red corundum and ruby (POHL & NIEDERMAYR, 1977). In view of the economic significance of these deposits, the thrust system will be called here „Mangari thrust system".

5.5 Minor structures

Boudinage is common throughout the area. Thin bands of more competent rocks (amphibolite in biotite gneiss, quartz-feldspar gneiss, granitoid gneiss, and marble in graphite gneiss and schist, calcsilicate bands in graphite schist, etc.) form ellipsoid rafts in their incompetent country rocks. The spaces between adjacent bodies may be filled by pegmatoid mobilisate (see chapter 7), or the country rock surrounds them completely. Frequently, the boudins are internally folded and rotated in relation to their country rocks, which is considered due to shearing parallel to layering in the country rocks. The calcsilicate boudins in graphite schist, associated with the deposits of green grossularite, have rarely been found to have a welldefined longitudinal axis. At Mindi/GG1-mine, however, such axes have been measured to dip with 40°

to 040°, approximately parallel to the above mentioned cross-folds. In addition to pre-existing layers in the rocks, boudinage affected also veins and veinlets of the pegmatoid mobilisates. Therefore it is contemporaneous with the F_2-deformation, and para-crystalline.

Late-crystalline deformation is indicated by bent twin lamellae in feldspar and in calcite in many specimen throughout the area.

Post-crystalline cataclasis has affected rocks throughout the area, resulting in highly cracked feldspars and garnets, which in some specimen are set in a finely crushed matrix.

6. Metamorphism

The metamorphic rocks of the Mwatate area are the product of high-grade regional metamorphism. Most mineral associations found indicate amphibolite facies, as already noted by J. WALSH (1955:17). During the present survey, the occurrence of granulite facies rocks was recognized, and more details were added to the understanding of the metamorphic history of the area.

6.1 Progressive Metamorphism

The Mtonga-Kore Charnockite Complex exhibits clearly a higher metamorphic grade than the enveloping gneisses of the Kurase Group. While in the former ortho- and clinopyroxene together with orthoclase, plagioclase, hornblende and quartz coexist, greenish hornblende with plagioclase characterizes amphibolites contained in the latter. This observation of a metamorphic hiatus clearly supports the proposed cover/basement relationship between both units.

Amphibolite facies mineral assemblages are widely developed in meta-sediments and meta-volcanics of the Kurase Group. Meta-pelites are characterized by kyanite and/or sillimanite, the latter sometimes replacing the former, biotite and orthoclase, which may partly have originated by the reaction

muscovite + quartz + plagioclase → orthoclase + sillimanite + more calcic plagioclase + H_2O (MIYASHIRO 1973:226)

except in the absence of quartz.

Orthoclase is frequently corroded and replaced by microcline. Partial melting of the rocks is ubiquitous.

Meta-basites of the cover consist of hornblende, plagioclase and variable but smaller amounts of clinopyroxene, biotite, and garnet. The amphibolites at Mgama Ridge contain hornblende with brown or olive brown colours in Z, while those south and north of the Mtonga Kore Charnockite Complex are green. It is not clear, whether this observation reflects a different metamorphic grade or an originally different bulk composition.

Meta-calcareous rocks in the area are composed of calcite, dolomite, quartz, diopside, tremolite, rarely zoisite and grossularite. The absence of wollastonite in the presence of grossularite suggests, that the high-temperature stability limits of the latter mineral (MIASHIRO 1973:275) were not reached.

Meta-psammites and metamorphic, originally felsic igneous rocks consist mainly of microcline and quartz, with variable amounts of plagioclase, orthoclase, muscovite, biotite, garnet and sillimanite. Flattening of quartz-grains at some exposures leads to granulitic textures; the mineral assemblages, however remain within the amphibolite facies type. Muscovite is replaced by orthoclase except in quartz-free schists at

Mgama Ridge. Orthoclase in turn is corroded or replaced by microcline. Partial melting is highly variable from an almost total mobilisation (granitoid gneiss) to the absence of observable mobilisates at outcrop scale (quartz-feldspar gneiss derived from ? rhyolites).

The observations cited allow the following conclusions: Progressive metamorphism of the
kyanite – almandine – muscovite subfacies
was followed by a phase of still higher temperature, of the
sillimanite – almandine – orthoclase subfacies
of the amphibolite facies, as described by WINKLER (1964).

Accordingly, extreme conditions of the amphibolite facies have been reached. The coexistence of kyanite, sillimanite and quartz, widespread partial melting and the absence of staurolithe and cordierite prove that relatively high pressures have been reached at a high temperature level. Metamorphism was of the Barrow-type, or the „medium pressure type“ as defined by MIYASHIRO (1973:74).

Granulite facies rocks form the Mtonga-Kore Charnockite Complex. The main mass consists of oligoclase, orthoclase/microcline, brownish-green hornblende, diopside, hypersthene and some quartz. Minor bands at Mtonga vary towards more felsic or more basic composition. The uniformity of the Complex as well as the nearly total absence of anatectic mobilisates are a striking feature. It is conceivable, that the complex may represent a dry intermediate intrusion into the Kurase Group, which because of impermeability to access of H_2O during metamorphism recrystallized into a granulite facies mineral assemblage. This is considered to be one way of granulite-formation by WINKLER (1964). More probable, however, appears to us granulitisation after expulsion of water from the rock mass during one or more earlier metamorphic phases. However, only radiometric age-determinations on specific minerals within the complex and in the cover rocks will allow a definite statement on this subject.

The conspicuous metamorphic disconformity between the charnockites and their country rocks does not favor a relationship proposed by BAGNALL (1964) in the neighbouring N. E. Tanzania: There, BAGNALL (loc. cit.) proposed the formation of both metamorphic zones by one process. Diffusion from the granulite facies rocks of K, Si, Al and O would have caused a migmatite front in the overlying amphibolite facies rocks.

Typical mineral assemblages observed in thin section and reactions considered indicative for the conditions of progressive metamorphism in the area are shown in fig. 4. The relatively wide range from 3 to 7 Kbar and 600–700°C illustrates the complexity of the metamorphic history of the rocks in the area.

6.2 Retrogressive Metamorphism

All metamorphic rocks of the area exhibit features of partial adaption to lower p/t conditions following the peak of progressive metamorphism.
We include here tentatively the formation of

- microcline at the expense of orthoclase
- hornblende at the expense of diopside
- the kelyphitic shell around grossularites
- muscovite in granitoid gneiss and graphite schists of Mgama Ridge

in rocks of the Kurase Group, and

- hornblende and biotite at the expense of pyroxene in the charnockites.

6.3 Correlation of metamorphic and structural history

Unfortunately, the application of radiometric dating methods during the present survey was not possible. Accordingly, the following correlation is based on geological reasoning only, and has to be understood as a preliminary approach.

Mtonga-Kore Charnockite Complex		Kurase Group
	cataclasis retrogressive reactions F_3-deformation (more thermal amphibolite facies, penetrative pegmatites)	
granulitisation ? (low pH_2O)	F_2-deformation	amphibolite facies metamorphism, anatexis and migmatisation (high pH_2O)
	F_1-deformation (Mangari thrust system;	enplacement of ultramafics; lower grade metamorphism ?)
		Sedimentation
denudation uplift presently unknown structural and metamorphic events		

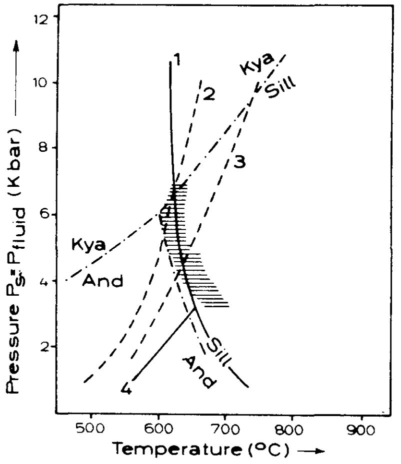

Fig. 4 CONDITIONS OF METAMORPHISM IN THE MWATATE QUADRANGLE DEDUCED FROM MINERAL ASSEMBLAGES AND INDICATIVE REACTIONS (SHADED AREA). Reaction curves and phase boundaries of Al_2SiO_5 minerals after WINKLER 1974.

1 albite+potassium feldspar+quartz+ H_2O = melt
2 tremolite+calcite+quartz+talc+dolomite
3 diopside+tremolite+calcite+quartz
4 muscovite+quartz+potassium feldspar+ sillimanite

7. Mineral Deposits and Occurrences

7.1 General

Until quite recently, no mineral deposits of economic significance were known in the Mwatate sheet area. The 1:125.000 geological map (J. WALSH, 1955) notes three occurrences of kyanite and sillimanite, while the accompanying text describes localities with elevated contents of common garnet and of graphite, and a number of crystalline limestone analysis. Since then, the discovery of gemquality green grossularite at Mgama and at Mindi has changed the area into one of the important gemstone producers within East Africa.

Mapping of the area within the Kenya—Austria Mineral Exploration Project, described in this report, served to investigate the geological controls of the gemstone deposits, in order to assist prospectors and miners in their task. In addition, several new mineral occurrences of red garnet, turquoise, blue zoisite (tanzanite), green tourmaline, red corundum (ruby), kyanite, magnetite, spinel and rutile could be found or recorded.

The CIDA aerial survey 1977 covered the Mwatate sheet totally, both with a radiometric and a magnetic survey along flight-lines spaced at 1 km distance. The magnetic contour-map produced by the survey is geologically interpreted in the following chapter 7.2, while remarks on the radiometric results may be found under 7.7.

An economic appraisal of the area is contained in AUSTROMINERAL's report „Geological Prospecting and Economic Assessment of the Gemstone Belt in Southeastern Kenya“. The authors views expressed in the following pages does not necessarily reflect AUSTROMINERAL's opinion.

7.2 Interpretation of the Aeromagnetic Data

A regional trend of the magnetic field in the area is indicated by the following observations: values are generally below 34 100 gammas in the SW, and above the mark in the NE. Single rock bands are certainly not traceable on the map, the structural grain however, is well represented by the predominant direction of isolines along strike. By visual interpretation four domains may be differentiated within the quadrangle: the southeast, the Mgama Ridge area, the Mwatate antiform with the northeast, and the singular feature of the Mtonga anomaly in the center.

In the southeast, a regular pattern of highs and lows is arranged parallel to the presumed regional SE-NW strike of the rocks. In this area, thick soil blankets cover totally the crystalline rocks, and the significance of the different field values cannot be ascertained.

The magnetic pattern over the Mgama Ridge area shows well the general northnorthwesterly trend of the rocks. The highs and lows are not attributable to specific rock units mapped in the area.

The Mwatate antiform is well traceable by the arrangement of the magnetic contour lines. The amphibolites mapped at the hills Naoni, Mkengereni and at Zongoloni appear to be represented by flat lows. The discordance between Mwatate Formation and Mgama-Mindi Formation suggested by the outcrop pattern northnorthwest of Mtonga is similarly reflected in the pattern of the magnetic contours. In the northeast of the map area, the supposedly low dip of the rocks and partly lobate rock boundaries in conjunction with apparently little variability in rock susceptibilities generate a more irregular pattern. Contours over the Mugeno Formation are very flat and are not arranged parallel to the main strike.

The positive Mtonga anomaly is elongated in a north/south direction; highest values measured were 34625 gammas, the lowest 33920 gammas. To the north, a gradual decrease of the values takes place, while the eastern and western flanks are quite steep, the western one slightly more so. To the south, the anomalous values decrease abruptly north of Kore Hill. The positive peak of the anomaly lies just southwest of Mtonga Hill. To the Southwest of Kore Hill, itself reflected by nearly background values, an impressive negative anomaly occurs. This is elongated in a direction which seems to cross the regional strike in that area. It is difficult to evade the conclusion, that an intimate relationsship exists between the Mtonga Kore Charnockite Complex and this unique magnetic feature. However, the shape and the configuration of the anomaly are not in accordance with shape and internal structure of the Charnockite Complex. The source of the anomaly is different of the rocks which can be observed at the surface. As to its nature, only speculations are possible at the present stage. Most probably, a considerable concentration of magnetite will be the reason for the high values.

7.3 Green Vanadium Grossularite

Green vanadium garnets were first located in 1971 at Mindi and Mikeli Hills. Little later, the Mgama Ridge deposits were found, and actual production of the gemstone commenced in 1973. It has since attained the following values:

Value in	1973	1974	1975	1976	1977
Ksh	640.794	1,616.818	831.774	1,391.902	1,391.948

The figures were supplied by the Mines Department, Nairobi.

The important new find of gemstones in Kenya soon aroused the interest of gemmologists, and results of several very involved mineralogical examinations were published within a few years (SWITZER 1974, GÜBELIN & WEIBEL 1975, SCHMETZER et al. 1975). From these publications, the mineralogical characteristics of the green garnets may be summarized as follows:

7.3.1 The mineralogical characteristics

The green garnets are grossularites, which theoretically have the formula $3\ CaO\ .\ Al_2O_3\ .\ 3\ SiO_2$. The chemical composition of a well-coloured stone from Lualenyi-Mine/Pit No. 1 was found to be (GÜBELIN & WEIBEL 1975):

CaO	35,1 %	(37,3 %)
Na_2O	0,1 %	
MgO	0,5 %	
MnO	0,75 %	
FeO	0,05 %	
Al_2O_3	20,9 %	(22,6 %)
V_2O_3	3,3 %	
Cr_2O_3	0,19 %	
TiO_2	0,25 %	
SiO_2	38,7 %	(40,1 %)

Note: values in brackets are theoretical contents of chemically pure grossularite

Internally, the vanadium grossularite contains liquid inclusions and minute crystals of different composition; among others, quartz, calcite, and tremolite („byssolite") have been made probable. Externally, idiomorphic crystals or irregular nodules

(„potatoes“) of these garnets are surrounded by a kelyphitic shell, consisting of epidote, clinopyroxene, spinel, quartz and scapolite.

7.3.2 The geological controls

Of the geological controls governing the distribution of the green garnet deposits very little has been published earlier. It had been recognized, however, that the Vanadium as the main colouring agent was most probably derived from originally bituminous substances in the country rocks (GÜBELIN & WEIBEL 1975). During high grade metamorphism, the bitumen was transformed to graphite, while the trace-metals were mobilized and could enter minerals then being formed. The basic lithological controls – marble bands in graphite gneiss – had been established before (BRIDGES 1974).

During this survey, all producing green garnet mines of the quadrangle were visited and essential geological features were mapped in detail (figs. 5–10).

Minkenco-mine (fig. 5)

The mine lies on the west-slope of Mgama ridge. A highly variable series of muscovite-graphite-sillimanite schists and gneisses with quartz and pegmatoid lenses and intercalated quartz-feldspar and granitoid gneiss bands form the higher slope of the ridge around the mine. The rocks dip quite uniformly 40/090. In the opencut, a band of graphite schist with layers of yellowish, weathered, originally pegmatoid boudins* has been found to contain green garnets along its footwall. The productive horizon is the lower one of the boudin layers; here, the boudins are less than 40 cm thick and 70 cm long; they do not have defined long axes, but are more or less round viewed vertically to the foliation. They consist of nontronite and some limonite; green vanadium grossularite is being found in rim of single boudins or in the space between adjoining ones. There, quartz occurs together with calcsilicates (grossularite, tremolite). The enclosing graphite schist contains several percent of sulfides (mainly pyrite, specimen P 1096).

The exposures at Gitshure-mine, situated about 2 km south of Minkenco-mine, are nearly identical to the ones just described. Accordingly, they are not illustrated here.

Lualenyi mine no. 1 (fig. 6)

This mine is situated on the steep western slope of Kide hill. Here, the rocks mapped in the surroundings are graphite-sillimanite-muscovite schists and gneisses, with bands of granitoid and quartz-feldspar gneiss, as well as several intercalations of crystalline limestone. Generally, these rocks dip eastwards with 40–50°.

In the opencut, very complicated relations have been found. The remarkable wall forming the near-vertical east-slope of the cut is a pegmatite vein cutting across all other rocks; it is bordered by a strongly weathered fault-breccia to the east, which then grades into folded graphite schist with intercalations of quartz-feldspar gneiss and marble, heavily deformed by axial plane folds of wave-lengths of a few metres.

West of the fault-filling pegmatite, an anticlinal structure can be recognized by the attitude of two quartz-feldspar/granitoid gneiss bands, which is then followed by a syncline formed by graphite schists with quartz-veinlets and kyanite-graphite lenses. These schists are intensely folded, as illustrated in fig. 5.

These observations are interpreted to reflect a geological history of disharmonic

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*Note: The term „boudin“ here and in the following is used in a descriptive way; it is not necessarily implied that these bodies comply with the genetical meaning of the term.

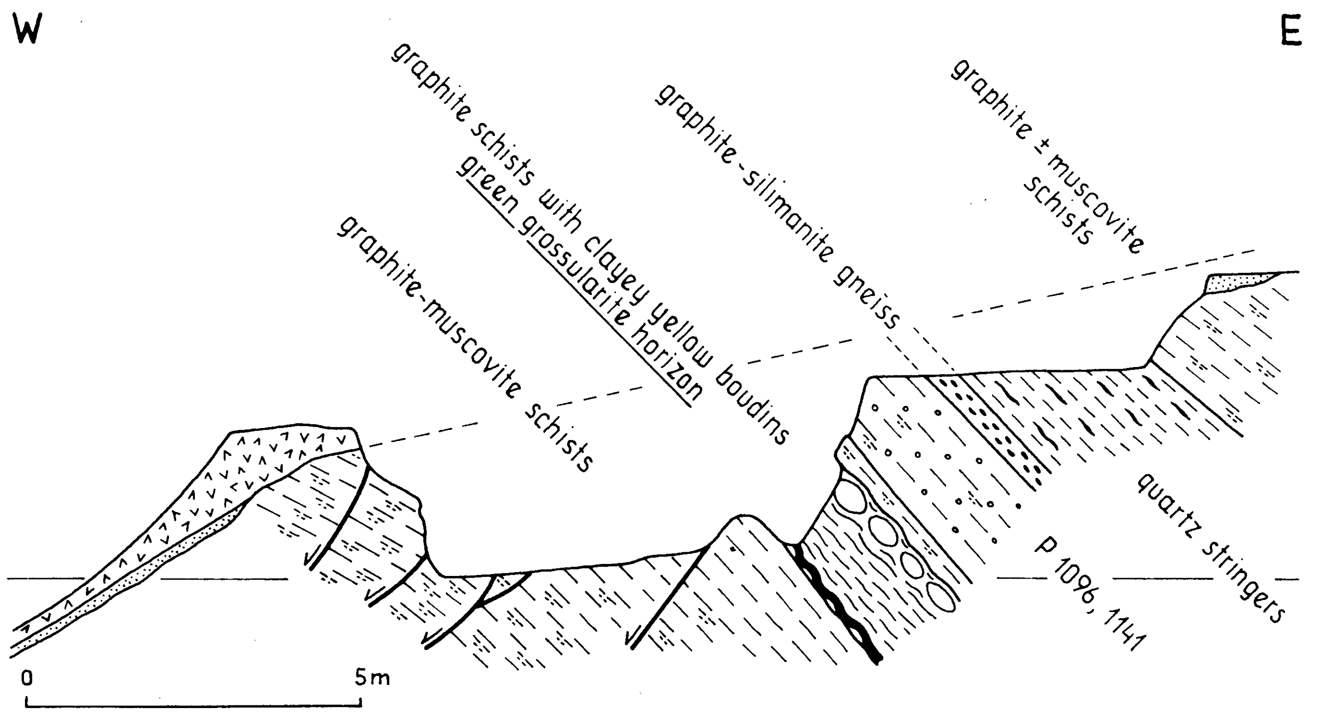

Fig. 5: SECTION ACROSS MINKENCO-MINE OPENCUT (MGAMA NORTH)

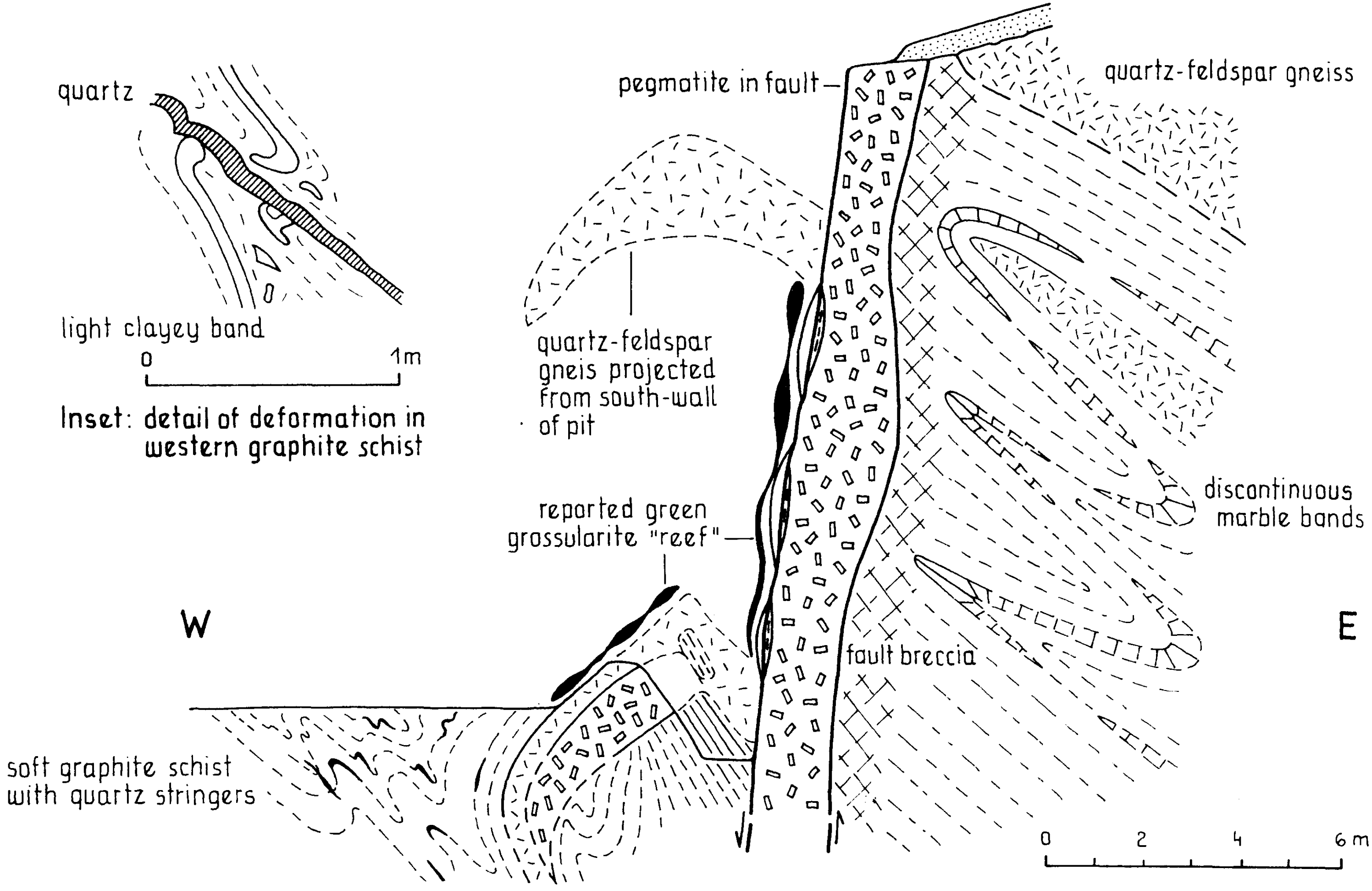

Fig. 6: SCHEMATIZED SECTION ACROSS LUALENYI MINE No.1 OPENCUT

folding, faulting + pegmatite intrusion, and again faulting (brecciation). The present outcrops, however, do not allow a clear representation of these processes in time and space.

As reported by the mine-manager, green vanadium grossularite (with quartz, tremolite, zoisite, etc.) was found in a „reef" within soft graphite schists along the pegmatite wall and continuing several metres below the present pit-floor, where it was lost at the bottom of a small shaft. Around the nose of the anticline formed by the quartz-feldspar gneiss, a less productive branch of the reef was followed for several metres. At present, however, no green garnet can be seen in this mine, the production being stopped.

Lualenyi mine no. 3 (fig. 7)

Situated in the upper reaches of a small valley running from north of Kide hill to the north-east, this mine extends over a considerable horizontal and vertical distance. One productive horizon exists here, but a considerable part of the production was reportedly found in near-surface bluish clayey pods, clearly a product of weathering. The primary horizon seems to be quite poor, and has hardly been followed to more than a few metres depth. It is a band of small boudins again, found in a dark-grey, sandy graphite schist, which in its turn is intercalated in a series of muscovite-graphite schists with quartz-stringers and pegmatoid lenses, and occasional bands of quartz-feldspar and granitoid gneiss. All these rocks dip with about 40° to the east or north-east.

Lualenyi mine no. 2 (fig. 8)

Located only about 1 km north of Lualenyi mine no. 1, this open cut lies most probably in the same lithostratigraphic horizon as mines no. 1 and 3. The cut exposes muscovite-graphite schists with quartz-stringers and pegmatoid bands, intercalated with quartz-feldspar and granitoid gneiss bands, the latter grading into pegmatites. These rocks dip generally with 40–50° to the east; axial plane folds of all scales up to about 10 metres wave length are observable. Folding is disharmonic, the incompetent graphite schists being more intensely deformed than the competent felsic gneisses.

In the section surveyed, four horizons containing green grossularite have been recognized, although horizon no. 4 was the most productive one. To the north, these horizons merge into one. To the south, they cease to be productive. The vanadium grossularite is found in pockets or lenses within the productive horizons, which are probably associated with boudins as described above for Minkenco mine. The distribution of such pockets is irregular, however, although the boudin beds are continuous.

GG3-mine / B-workings (fig. 9)

The rocks around this mine are from top to bottom

10 m	quartz-feldspar gneiss (fine – to medium grained, partly laminated, light)
20 m	marble
100 m	muscovite-graphite schists with quartz-veinlets and pegmatoid segregations, graphite-sillimanite-, marble-, quartz-feldspar- and granitoid gneiss bands as well as small lenses (?) of ultramafic rock towards the base
50 m	marble with pods of quartz, muscovite, and diopside.

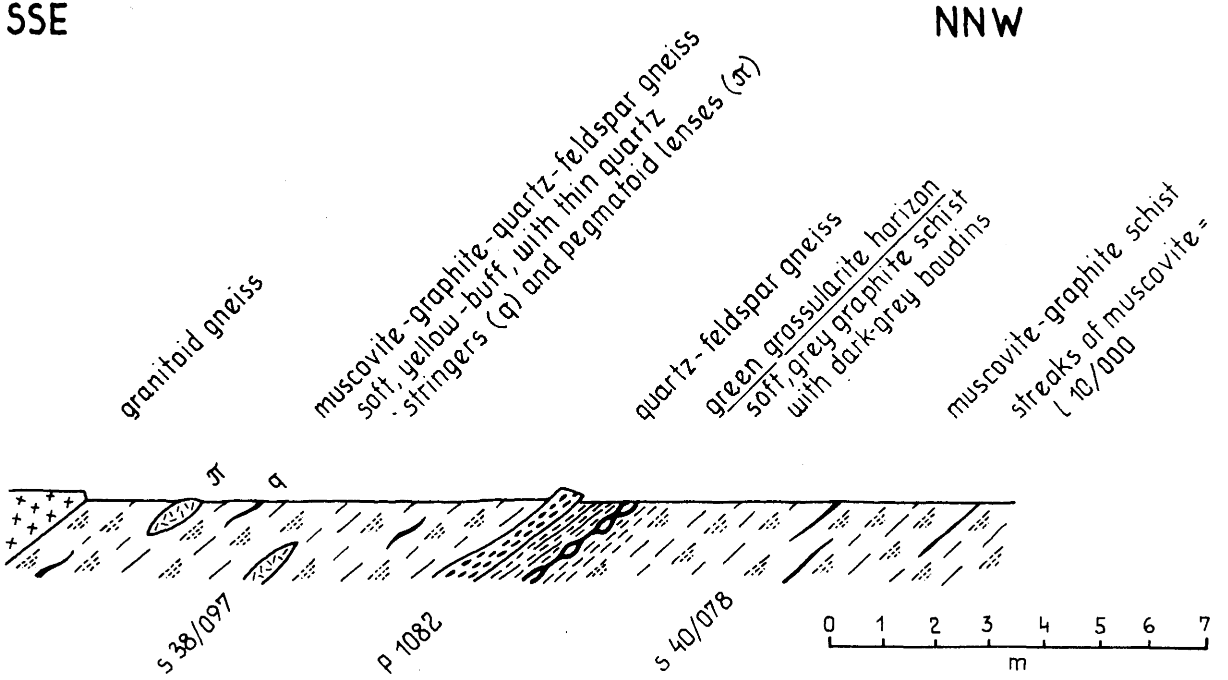

Fig. 7: SECTION ACROSS PRODUCTIVE ZONE IN LUALENYI MINE No. 3

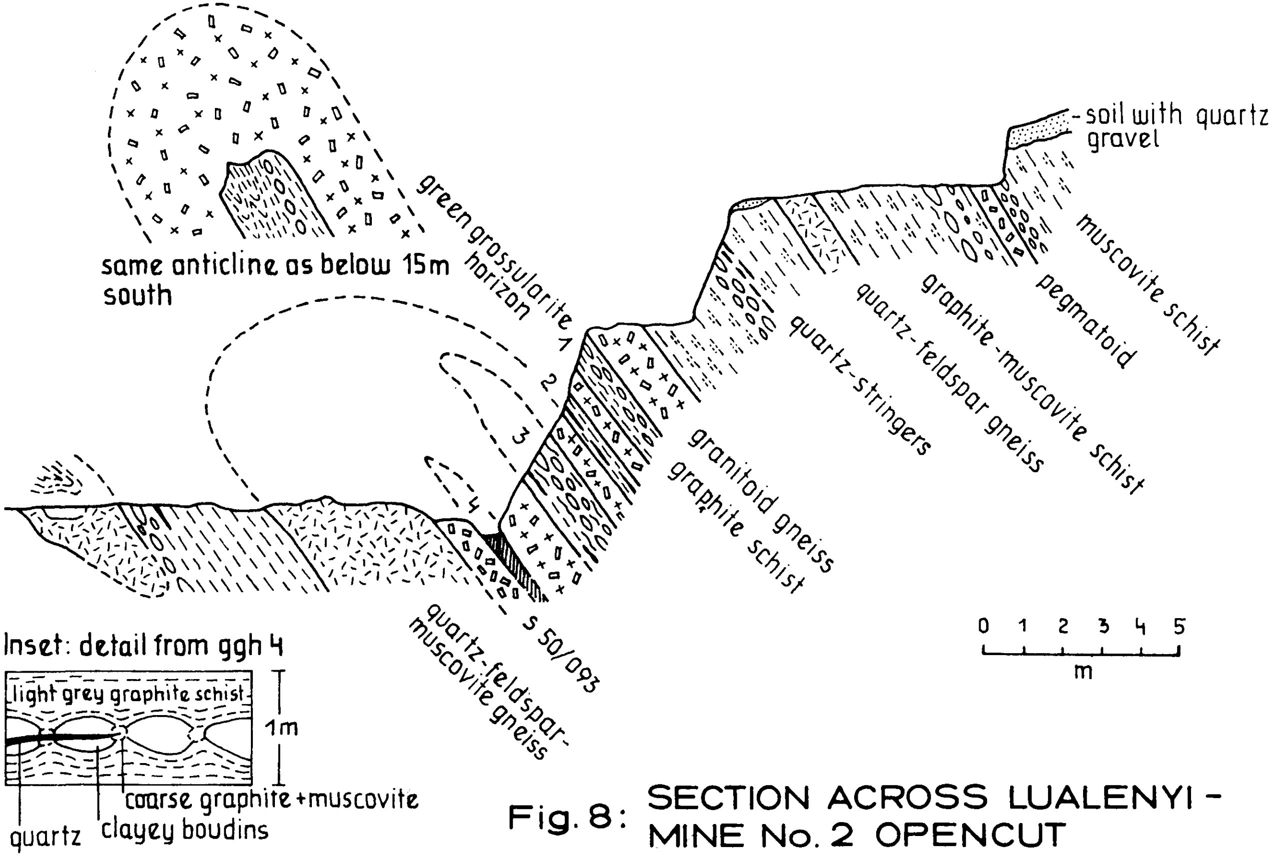

Fig. 8: SECTION ACROSS LUALENYI - MINE No. 2 OPENCUT

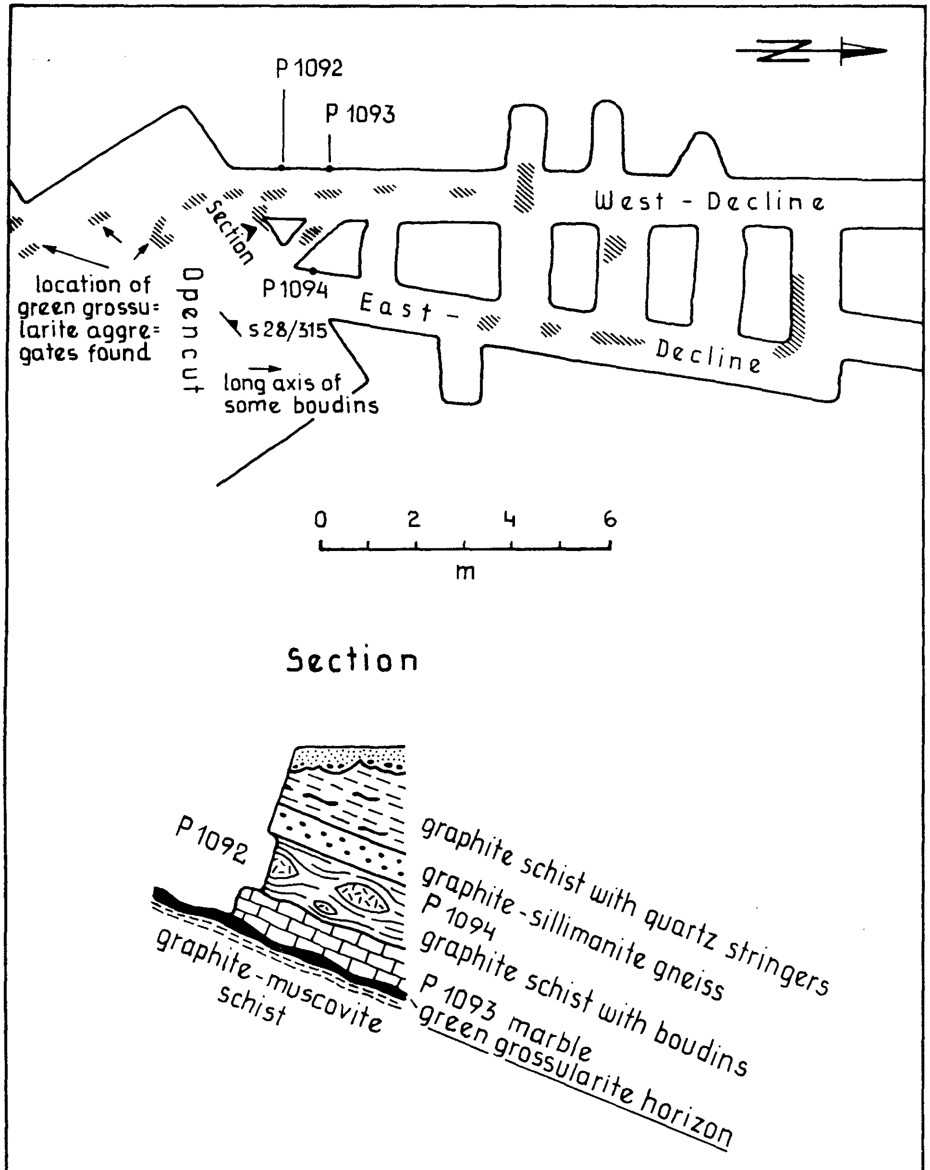

Fig. 9: PLAN AND SECTION OF GG 3 - MINE / B-WORKINGS (MIKELI)

The different workings of the GG3-mine are all situated in the higher part of the thick muscovite-graphite schists, only a few metres below the higher marble bed. In it's lower part, lenses or irregular bodies of ultramafic rocks have been located by systematic prospecting. These contain tiny red corundum crystals (see below 7.2.).

The GG3-mine / B-workings provided the occasion to map the distribution of green vanadium garnet nodules on a partially exposed plane of the productive horizon, as pointed out by the mine-manager. In our opinion, there is no tectonic control of their location. The nodules seem to occur irregularly and unpredictably, wherever the original rock may have had a suitable composition.

The section of fig. 9 shows, that the green grossularite horizon here is at the base of a marble bed in the uppermost part of muscovite-graphite schists. This is notably different from previously described mines.

GG1-mine / Mindi Hill south (fig. 10)

The excavations of this mine lie westwards of the rounded summit of a small hill south of Mindi Hill. The summit is formed by a thicker marble bed, which is underlain by graphite-muscovite schists with an occasional intercalation of graphite-sillimanite gneiss and lenses or irregular bodies of ultramafic rocks. The graphite-muscovite schists in turn are underlain towards the western base of the hill by biotite-garnet gneiss. General dip is with 30° to 40° to the northeast.

Two larger trenches have been opened to a depth of about 8 metres below the surface, both with short declines as depicted in fig. 10. Green grossularite was produced from one horizon in both cuts; the geological situation suggests, that the two exposures represent the limbs of an F_1-fold (an antiform with a northerly plunge).

The productive horizon in both cuts is exposed on the western flank of the workings, so that the distribution of accumulations of green grossularite as marked by the mine-manager could be observed. Again, their location was found to be irregular.

The green grossularite horizon at GG1-mine consists of a bed of boudins, which viewed vertically to the horizon are mostly round; some have pronounced long axes, which have been measured to plunge parallel with the dip of the foliation.

Summing up the results of detailed mapping, the following geological controls could be established for the presently known occurrences and mines of green vanadium grossularite in the Mwatate quadrangle:

– regional lithostratigraphy

All presently known green garnet locations lie in the higher part of the Lualenyi Member of the Mgama-Mindi Formation. This is not by chance, as understood at present, but may be explained by the geochemical and lithological characteristics of the rocks concerned.

– lithology

Green garnets are invariably found in graphite gneiss and schist, either in originally more calcareous beds or at the contact between such beds with the graphitic rocks. In both cases, the availability of silica, alumina, and lime for the formation of grossularite during metamorphism was given.

– availability of colouring trace-metals (geochemistry)

The above cited analysis of a green grossularite from Lualenyi shows the colouring metals to be

Vanadium (V)
Manganese (Mn)

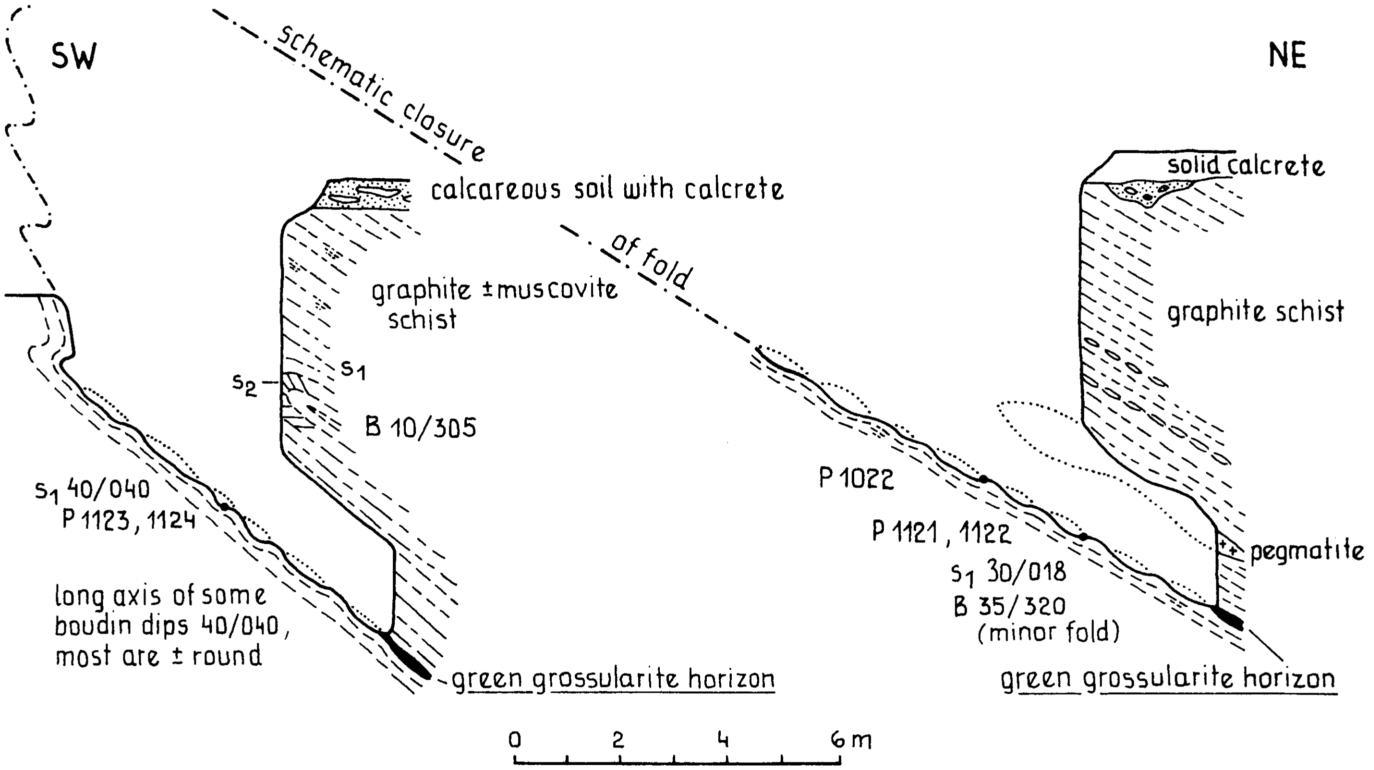

Fig. 10: SECTIONS ACROSS GG1-MINE OPENCUTS (MINDI SOUTH)
Note: horizontal distance not to scale

Titanium (Ti)
Chromium (Cr)
Iron (Fe)

Others may yet be determined by further analytical work. Accordingly, the availability of these metals has to be considered as one of the controls:

Iron is present in most rocks in sufficient quantity, as well as Manganese and Titanium. The high Vanadium and Chromium values are due to the content of organic matter in the original sedimentary rock. Organic matter, especially of bituminous nature, scavenges many metals. Vanadium and Uranium are among the best known examples of metals enriched with organic matter to deposits of economic size, but many others may similarly occur in unusual high traces. In the Mgama area, the original bituminous matter was transformed into graphite during high-grade metamorphism. This obviously liberated and mobilized the metals contained, which then either formed own minerals or entered other minerals being formed, like grossularite or tourmaline. Mapping revealed the existence of numerous small gossans in Mgama ridge and Mindi; the largest of those was found at Mikeli south, with an exposed length of about 30 m at 2 m thickness (samples P 1067 and 1068). These gossans represent weathered outcrops of sulfide rich graphite gneiss or schist. Samples of gossans or gossanous float were analysed for the elements Ni, Co, Cr, V, Cu, Pb and Zn (see tables 5 and 6). A sample of a small pyrite pod found in quartz-feldspar gneiss at Tree House hill, Mindi, yielded the following trace metal values (in ppm):

	Ni	Co	Cu	Pb	Zn	V
P 1126	160	145	25	115	20	nil

Although the analyses show the variability of the trace metal content within the Lualenyi Member, they prove the wide availability of the metals colouring the green grossularite.

– high grade metamorphism

High grade metamorphism is certainly one of conditions for the green grossularite formation, but is so general in the East-African Mozambique Belt, that there is no practical value in stating it as one of the controls. The reactions grossularite = wollastonite + anorthite + gehlenite

and

grossularite + quartz = wollastonite + anorthite (as shown by MIYASHIRO 1973:275) may help to exclude areas, where grossularite would have been unstable at slightly higher temperatures of metamorphism then the ones realized in the Mwatate area. However only research at regional scale may allow definite conclusions, whether areas containing wollastonite should be excluded from prospecting for grossularite.

– tectonics

The deformation of the rocks containing green grossularite before, during, and after metamorphism is in our opinion not a direct control. An exception may be cases, where limestone has been brought into direct contact with clayey rocks by early faulting, such as possibly at Lualenyi mine no. 1, or at GG3-mine/A-workings (not illustrated here).

Where the distribution of green grossularite within the productive horizon could be mapped, no coincidence with lineation or fold axes was found.

The frequent occurrence of green grossularite within beds formed of ,,boudins“ (lenticular bodies in cross-section) leads to the question of the origin of those structu-

SAMPLE No.	Ni	Co	Cr	V	Cu	Zn
P 1012 R	105	43	70	275	198	7250
P 1024 R	300	50	200	460	93	2100
P 1027 R	4175	103	70	85	55	3500
P 1050 R	33	8	25	80	20	78
P 1052 R	195	55	170	575	28	8750
P 1054 R	53	5	23	10	13	185
P 1066 R	105	45	215	625	48	7500
P 1067 R	178	50	173	425	38	11750
P 1068 R	80	48	143	175	55	700
P 1079 R	103	65	43	175	180	19250
P 1082 R	195	30	148	1400	63	403
P 1089 R	90	75	63	700	15	16500

Note: All values in ppm

Table 5 – Trace metal content of samples from Mgama Ridge (AAS assays after hot leaching in HF/HCl by the Chemical Laboratory, Mines and Geology Dept., Analyst E. P. Mwaniki).

P 1012, 1024, 1027, 1052, 1066 and 1079 = gossanous float
P 1050 = sheared granitoid gneiss
P 1054 = vuggy, limonitic quartz
P 1067 = graphite gneiss with limonite
P 1068 = limonite with quartz and graphite
P 1082 = bluish grey clay filling joints above the green garnet horizon at Lualenyi Mine No. 3

SAMPLE No.	Ni	Co	Cu	Pb	Zn	V
P 1104 R	2935	76	63	100	405	85
P 1128 R	1050	85	810	78	975	1100
P 1133 R	420	155	85	650	30	2000
P 1138 R	2000	80	185	475	275	nil

Note: All values in ppm

Table 6 – Trace metal content in gossanous float from Zongoloni (P 1104 R) and the Mindi area (AAS assays after hot leaching in HF/HCl by the Chemical Laboratory, Mines and Geological Department, Nairobi – Analyst: E. P. Mwaniki).

res: The data and observations collected so far do not support a tectonic origin, as most of them are rounded in all directions. According to the sensu strictu use of the term, however, boudins should be clearly elongated parallel to contemporeaneous fold-axes. It appears, that these structures may be inherited from the original sediments, and may represent large, more calcareous concretions, or possibly be of direct biogenic derivation. Further research into this matter is suggested.

7.3.3 Prospecting

Prospecting for green grossularite deposits may involve the following methods:

Direct methods = to examine rocks, gravel, calcrete, soil and alluvium for traces of green garnet

Indirect methods = to search minerals (calcsilicates), rocks (graphite gneiss and schist with marble or calcsilicate bands), gossanous lenses, boudin structures, or favourable geological conditions in a general sense (belts of graphitic rocks interstratified with marbles, and with elevated rare metal content).

From the last methods listed to the former one may consider this a succession to be employed from the first planning of a prospecting campaign (selection of an area on the basis of known geology) through early stages of field work (location of possible host rocks) to detailed prospecting (location of calcsilicate bands or boudins in trace metal rich graphite gneiss) to finally finding chips of green grossularite. – Obviously, however, one or more of these stages may be skipped depending on available time, resources, and prior information.

Direct methods of green garnet prospecting are simple. They include visual inspection of soil, rock outcrops, alluvium, calcrete, and ant hills for tiny chips of the mineral while traversing prospective areas. Much more involved and time-consuming is the sieving of soil, in order to separate the grain size which most probably contains green garnet chips from larger rock fragments and the fine dust. Generally the fraction between 0,2 and 2 mm diameter will be most advantageous. Sieving should preferable be carried out in water (for example in a 200 l drum cut in half and filled with water), as the colour of the tiny chips will then be more readily recognized.

Samples for wet-sieving can be collected from the base of the humic soil layer (mostly less than 10 cm in the area) or slightly deeper (from the bottom of a pit as deep as a shovel's blade). If the size of the samples is uniform, grid-pitting and counting of garnet-chips per sample may lead to maps of the distribution of green grossularite in the soil, which will help to place prospecting pits and trenches more intelligently. The distance of sampling could be wide for a preliminary survey (about 20 m square along the prospective horizon), and much smaller (down to 3 m) once a prospective area has been located and pitting or trenching is indicated. The economy of the method should be obvious when comparing the amount of labour necessary to dig only one short and shallow trench, to the quick and easy sampling of sandy soil at 20–40 cm depth, and wet-sieving about one kilogram of the material collected.

Adverse geological conditions, however, may lead to errors when applying the method indiscriminately: A soil-cover not representing the local nature of the rocks underneath, but transported from elsewhere, may effectively obscure even the richest green grossularite deposit underneath. In such a case, only geological reasoning, or wild-cat pitting and/or trenching may be successful in finding the deposit.

Important is the point, that prospecting should be most intensive along strike (laterally) of a once recognized productive horizon. Here is the best chence to find more enriched parts.

Indirect methods for green grossularite prospecting may be simple and straight forward, as the use of calcsilicate bands or boudins in graphite schist as an indication of favourable environs. More involved tools which may conceivably contribute include a variety of geochemical and geophysical prospecting techniques.

The use of minerals which are in a wider sense associated with the geological environment favourable for green grossularite deposits („indicator minerals") applies the same practices as outlined above for the direct search. Minerals which may be considered to indicate green garnet potential are:

epidote, chlorite, zoisite, tremolite, diopside, greenish muscovite (fuchsite), green tourmaline.

The first minerals indicate the calcsilicate environment, while the two last ones reflect the elevated trace-metal content in the rocks.

„Indicator rocks“ are sulfide-rich graphite schists and gneisses, preferably with marble and calcsilicate bands and/or boudins. Unfortunately, these rocks as well as the indicator minerals are little resistant to weathering. They will hardly be recognized in natural outcrops, but rather in pits and trenches.

Geochemical prospecting methods may contribute during a first, regional stage of prospecting, when areas of higher trace metal background are being south. This is conceivable within a large scale prospecting campaign, but will contribute nothing once a prospective area has been recognized.

Similarly, geophysical prospecting methods might be used to locate the graphite-rich rocks. Applicable could be

aerial electromagnetics (graphite !)
aerial radiometrics (higher uranium background in graphitic rocks)
ground electromagnetics, resistivity methods
ground radiometrics

Although an application of these methods may be useful in large, virgin areas, they cannot be recommended generally.

Geological mapping may in many cases give the same results, although slower, and will in addition produce a wealth of useful data, which may be quite important at a later, more local stage of prospecting and mining.

A possible program for a green grossularite prospecting campaign could consist of the following phases and activities:

1st phase – choosing the area

Work during this phase will center on scanning geological reports and maps (available from the Mines and Geological Department) for the location of variegated graphitic/carbonatic metamorphic rocks.

2nd phase – regional prospecting

The area considered favourable from a general literature survey may now be prospected by aerial geophysical surveys, regional geochemical ground surveys, by car and foot traverses in order to locate siutable host-rocks, indicator minerals, and, though not to be excepted at this stage, green grossularite.

3rd phase – detailed prospecting

The prospects found by earlier work now have to be subjected to detailed search for green grossularite deposits. Methods used would be wet-sieving of soil samples, pitting and trenching at regular intervals whereever chips of the mineral have been found. Every green-garnet occurrence located will primarily be developed along strike, in order to get data on the location of the richest parts.

This phase of detailed prospecting will pass into mining, whereever marketable material is encountered.

7.3.4 Mining of green grossularite

The nature of the deposits of green grossularite predetermines the possible methods of exploitation. Restraints are added in the area by the absence of abundant and cheap water.

Present conditions in the area allow the application of simple open-pit and under-

Indirect methods = to search minerals (calcsilicates), rocks (graphite gneiss and schist with marble or calcsilicate bands), gossanous lenses, boudin structures, or favourable geological conditions in a general sense (belts of graphitic rocks interstratified with marbles, and with elevated rare metal content).

From the last methods listed to the former one may consider this a succession to be employed from the first planning of a prospecting campaign (selection of an area on the basis of known geology) through early stages of field work (location of possible host rocks) to detailed prospecting (location of calcsilicate bands or boudins in trace metal rich graphite gneiss) to finally finding chips of green grossularite. – Obviously, however, one or more of these stages may be skipped depending on available time, resources, and prior information.

Direct methods of green garnet prospecting are simple. They include visual inspection of soil, rock outcrops, alluvium, calcrete, and ant hills for tiny chips of the mineral while traversing prospective areas. Much more involved and time-consuming is the sieving of soil, in order to separate the grain size which most probably contains green garnet chips from larger rock fragments and the fine dust. Generally the fraction between 0,2 and 2 mm diameter will be most advantageous. Sieving should preferable be carried out in water (for example in a 200 l drum cut in half and filled with water), as the colour of the tiny chips will then be more readily recognized.

Samples for wet-sieving can be collected from the base of the humic soil layer (mostly less than 10 cm in the area) or slightly deeper (from the bottom of a pit as deep as a shovel's blade). If the size of the samples is uniform, grid-pitting and counting of garnet-chips per sample may lead to maps of the distribution of green grossularite in the soil, which will help to place prospecting pits and trenches more intelligently. The distance of sampling could be wide for a preliminary survey (about 20 m square along the prospective horizon), and much smaller (down to 3 m) once a prospective area has been located and pitting or trenching is indicated. The economy of the method should be obvious when comparing the amount of labour necessary to dig only one short and shallow trench, to the quick and easy sampling of sandy soil at 20–40 cm depth, and wet-sieving about one kilogram of the material collected.

Adverse geological conditions, however, may lead to errors when applying the method indiscriminately: A soil-cover not representing the local nature of the rocks underneath, but transported from elsewhere, may effectively obscure even the richest green grossularite deposit underneath. In such a case, only geological reasoning, or wild-cat pitting and/or trenching may be successful in finding the deposit.

Important is the point, that prospecting should be most intensive along strike (laterally) of a once recognized productive horizon. Here is the best chence to find more enriched parts.

Indirect methods for green grossularite prospecting may be simple and straight forward, as the use of calcsilicate bands or boudins in graphite schist as an indication of favourable environs. More involved tools which may conceivably contribute include a variety of geochemical and geophysical prospecting techniques.

The use of minerals which are in a wider sense associated with the geological environment favourable for green grossularite deposits („indicator minerals") applies the same practices as outlined above for the direct search. Minerals which may be considered to indicate green garnet potential are:

epidote, chlorite, zoisite, tremolite, diopside, greenish muscovite (fuchsite), green tourmaline.

The first minerals indicate the calcsilicate environment, while the two last ones reflect the elevated trace-metal content in the rocks.

„Indicator rocks" are sulfide-rich graphite schists and gneisses, preferably with marble and calcsilicate bands and/or boudins. Unfortunately, these rocks as well as the indicator minerals are little resistant to weathering. They will hardly be recognized in natural outcrops, but rather in pits and trenches.

Geochemical prospecting methods may contribute during a first, regional stage of prospecting, when areas of higher trace metal background are being south. This is conceivable within a large scale prospecting campaign, but will contribute nothing once a prospective area has been recognized.

Similarly, geophysical prospecting methods might be used to locate the graphite-rich rocks. Applicable could be

aerial electromagnetics (graphite !)
aerial radiometrics (higher uranium background in graphitic rocks)
ground electromagnetics, resistivity methods
ground radiometrics

Although an application of these methods may be useful in large, virgin areas, they cannot be recommended generally.

Geological mapping may in many cases give the same results, although slower, and will in addition produce a wealth of useful data, which may be quite important at a later, more local stage of prospecting and mining.

A possible program for a green grossularite prospecting campaign could consist of the following phases and activities:

1st phase – choosing the area

Work during this phase will center on scanning geological reports and maps (available from the Mines and Geological Department) for the location of variegated graphitic/carbonatic metamorphic rocks.

2nd phase – regional prospecting

The area considered favourable from a general literature survey may now be prospected by aerial geophysical surveys, regional geochemical ground surveys, by car and foot traverses in order to locate siutable host-rocks, indicator minerals, and, though not to be excepted at this stage, green grossularite.

3rd phase – detailed prospecting

The prospects found by earlier work now have to be subjected to detailed search for green grossularite deposits. Methods used would be wet-sieving of soil samples, pitting and trenching at regular intervals whereever chips of the mineral have been found. Every green-garnet occurrence located will primarily be developed along strike, in order to get data on the location of the richest parts.

This phase of detailed prospecting will pass into mining, whereever marketable material is encountered.

7.3.4 Mining of green grossularite

The nature of the deposits of green grossularite predetermines the possible methods of exploitation. Restraints are added in the area by the absence of abundant and cheap water.

Present conditions in the area allow the application of simple open-pit and underground mining methods only. The resulting labour-intensiveness, however, cannot a priori be considered as a disadvantage in a developing country. The careful observation of almost each shovel of material while being handled will ensure, that no material of value is lost.

Heavy earth – and rock – moving equipment would of course allow the quick removal of large quantities of overburden, and in this way a much higher production could certainly be achieved. The reaction of the overseas market for the gems, however, might be unfavourable to a large quantity of the material.

Exploitation of green garnet from deposits in the Mgama-Mindi area involves the following steps:

- removal of overburden/or driving underground along the productive horizon
- mining of the rock containing green grossularite
- preliminary sorting to remove larger nodules or aggregates of green garnet
- (wet) sieving of the finer material, removal of the grain size – 1 mm, sorting out all green grossularite grains and chips
- cleaning of the green garnet from it's matrix (tools used may be a small hammer, chisels, princers, wire brush, etc.)
- sorting of the green grossularite according to colour, transparency, and size. Well crystallised specimen may find a better market among mineral collectors, and should not be destroyed before a careful evaluation as to where a higher return may be realized.

7.3.5 Marketing

The above cited production figures illustrate the difficulty to produce a steady supply of well balanced quality from the irregular deposits of green grossularite. In order to achieve the best prices

- a steady supply of reasonably comparable quality, and
- well sorted parcels, not run-off-the-mine material

are considered advantageous. Of course both demand considerable resources and experiences on the side of the miners.

Faceted green grossularites with a diameter of more than 3 mm, or a weight of more than 3 carats are quite rare, and command special prices, which are fixed between buyer and seller for each specimen. The majority of the gems trade at the following approximate prices (European market, 1977):

	good colour		poor colour
1 carat	2400	–	10 ksh/carat
1–2 carats	4000	–	300 ksh/carat
2–3 carats	6000	–	300 ksh/carat

7.4 Red Corundum (Ruby)

Tiny grains of red corundum (ruby) have been found at the following localities:

- 2 km south of Alia peak, Mgama ridge (E 180 R). Here, the mineral occurs together with red spinel in a marble horizon within the Lualenyi Member. The occurrence has been extensively examined by trenching to several metres depth, and was found to be uneconomic, as no ruby of sufficient size to be marketable was found.
- GG3-mine, Mikeli

  Ultramafic rocks, now consisting of pyroxene and amphibole, are in contact with felsic rocks. In the soil above the contact, tiny chips of red corundum have been found. Extensive pitting to examine the contacts at depth remained without success.

- 1 km north of GG1-mine, Mindi (P 1097 R)
  Ultramafic rocks similar to the ones at Mikeli, are cut by minute veinlets of pegmatoid nature. Red corundum and spinel (?) in very small grains occur in these veinlets. The occurrence has been prospected by trenching and pitting to the bedrock, with a negative result.
- 1,5 km south of Kambanga (P 1134 – 36 R)
  A pit has been opened here to a depth of 6 metres in graphite schist with bands of marble and calcsilicates, as well as pegmatoid segregations. During this survey, red corundum could not be seen in the pit; fragments were located on the dump, however.
  Although ultramafites have been mapped at a locality only about 2 km along strike to the northwest (P 1131 – 33 R; here without corundum), such rocks could not be found in the diggings near Kambanga. It is assumed, that the chips of gem-corundum found on the dump originated from the marble bands.

In spite of the non-economic results of all prospecting for gem-corundum in the Mwatate area until now, further work is certainly recommended. Until now, only a few occurrences of ultramafic rocks have been found. It may be expected, that with additional finds more prospects and possibly deposits of the Mangari type (see POHL & NIEDERMAYR 1977, for more details) will be located.

7.5 Other Coloured Gemstones

In addition to green grossularite and red corundum, green tourmaline, red garnet (rhodolite), blue zoisite (tanzanite), turquoise, and red spinel have been found in the Mwatate sheet area.

Green tourmaline is common throughout the Lualenyi Member, where it occurs in numerous pegmatoid segregations, and in pegmatites. To the knowledge of the author, only a very few pockets of green tourmaline have been mined in the area. All occurrences known are too small and too irregular to be able to support a proper exploitation.

Red garnet (rhodolite) is exposed in a small pit in the northwest corner of the sheet, and is widely found on the western flank of Mindi. The stones are invariably very small and rarely of reasonable quality. Therefore, they could not be exploited and sold at a profit on the market. Future, better finds cannot be excluded.

Blue zoisite (tanzanite) occurs in minute traces at Lilani. There, a thick marble horizon forms an open syncline with graphite schist in the core. The marbles contain concordant pegmatite lenses with green tourmaline; impure bands in the marble are rich in grey zoisite and show locally tiny blue grains of tanzanite. Extensive trenching at the locality did not reveal any economic accumulations of the mineral.

Turquoise forms thin veinlets in sillimanite-graphite gneiss at Kavishoi, north of Mindi. The occurrence is very small, and the mineral rather pale coloured. No economic significance may be attributed to the find.

Red spinel was determined mineralogically in the marbles containing red corundum at Mgama Ridge (E 180 R). No economic value can be attributed to this occurrence.

7.6 Industrial minerals

Under this heading graphite, crystalline limestone, apatite, and kyanite/sillimanite can be listed at present.

Graphite is common throughout the Lualenyi Member. Bands rich enough in the mineral to warrant mining and concentrating are rare, and too thin to support an open pit operation. For underground exploitation, the contents are too small. No exploration effort for this mineral can be recommended.

Marble (crystalline limestone) occurs throughout the Mwatate area, and could be exploited at many localities. Generally, a high Magnesia-content is probable for most of the occurrences in the area. If chemically pure limestone should be needed for a future project, detailed prospecting should be carried out.

Kyanite and sillimanite as rock-forming minerals are locally developed at Mgama Ridge. There, contents may reach 10 % of the rock mass. The extensions of the alumo-silicate strata are too small for any exploitation. Sillimanite occasionally forms pockets in pegmatoid mobilisates (N 121 R) which are of mineralogical interest only. At Zongoloni, kyanite (-muscovite) pods occur in quartzite. Unfortunately, the hard country rock did not weather away as at Murka (west of the Taita Hills), where rich secondary accumulations of kyanite boulders supported a sizable mining operation. At Zongoloni, the size of the pods as well as the frequency of their occurrence within the rockmass are far below economic limits. Until now, the pods have been superficially prospected by locals who suspected the kyanite to be a precious mineral. The present survey excludes any economic potential of the occurrences, except possibly to supply a small collectors market.

Apatite was recognized as a primary accessory mineral mainly in the graphite schists of the Lualenyi Member, but also in the Mtonga-Kore Charnockite. Occasionally, as at Mgama east (P 1028 R), thin secondary coatings of apatite appear in joints of graphite schist. Similarly, turquoise fills thin fissures in graphite-sillimanite gneiss at Kavishoi. Contents observed are less than 3 % in all cases, to that no further work can be recommended.

7.7 Ores

Ores at present known in the Mwatate sheet area are of mineralogical interest only; they include magnetite, pyrite (with base metal sulfides in minor amounts), and rutile. Locally in the Lualenyi Member, elevated geochemical values of Uranium and Thorium are present.

Magnetite was found in lumpy aggregates in pegmatitic float at Mtonga Hill. It occurs also as an accessory to a content of several percent in the charnockites, and the fine black sand derived from those rocks characterises the soil-covered parts of the complex. Similar thin streaks of black sand were observed about 5 km west of Mindi over several square kilometres; due to the total absence of outcrops in this area the derivation of this magnetite cannot be ascertained. A specimen of magnetite from pegmatite at Mtonga Hill was analysed by the Chemical Laboratory of the Mines and Geological Dept., with the following results (figures in ppm):

	Ni	Cu	Co	Cr	V	Zn
P 1089	90	15	75	63	700	16500;

Non of the occurrences mentioned possesses any economic potential

The CIDA aerial magnetic survey has located a strong magnetic anomaly centered at Mtonga Hill. From it's shape, the source of the anomaly is considered to ly at considerable depth.

Accordingly, the nature of the source cannot be determined with certainty. It seems probable, however, that a considerable accumulation of magnetite would be the reason for the anomaly. Deep drilling could certainly elucidate the case, but the economics of mining iron ore at depth do hardly encourage such work.

Pyrite is ordinarily oxidised at the surface in the Mwatate area, and with the exception of a few localities (P 1015 R – Mgama north, and P 1126 R – Mindi/Tree House Hill, etc.) only gossanous float points to the occurrence of sulfide – lenses and/or sulfide-rich rocks. Except as a very minor accessory elsewhere, pyrite is restricted to rocks of the Lualenyi Member. Tables 5 and 6 (chapter 7.2.2) show that the sulfide lenses probably contain besides pyrite small amounts of Ni, Cr, V, Co, Cu and Zn-ores. In view of the small size of these lenses as well as their wide spacing within the rock-suite they are considered to be without any economic scope.

Rutile is widely distributed as an accessory in the rocks of the Mwatate quadrangle. Only at Mgama north the mineral was found in more than microscopic amounts, however: At the sample location P 1009 R rutile occurs in rounded grains together with quartz in calcrete; it is thought to be derived from a pegmatite underneath, while the calcrete originates from marbles immediately adjacent to the locality. At the sample location P 1061 R on the east slope of Mgama Hill, rutile fills intergranular spaces in a pegmatoid granitoid gneiss. Both occurrences of rutile are of mineralogical interest only.

Uranium and Thorium are thought to be present in higher geochemical values in the Lualenyi Member of the Mgama-Mindi-Formation. Actual analytical determinations of the metals have not been carried out, however, due to the non-availability of the necessary analytical apparatus.

On all traverses in the quadrangle, a spectrometer was carried along to discover any surface radioactivity. No economically promising concentration was found.

The CIDA radiometric survey in the gembelt area was originally designed to help define areas of more intense K-metasomatism, which were thought to possibly coincide with more frequent occurrences of penetrating pegmatites. Analysis of the data showed, that K-metasomatism is nearly ubiquitous in the area. K^{40} highs and lows are dependant on soil and rock types, but do not indicate accumulations of pegmatites. In spite of this failure, the survey discovered a number of U/Th-anomalies, mainly situated in graphite gneiss zones. The evaluation of these anomalies is not yet concluded.

7.8 Water – by W. J. NAUTA (AUSTROMINERAL Ges. m. b. H., Vienna, Austria)

Hydrology:

Surface water in the area mainly originates from the Taita Hills by means of the Mwatate River, and to a lesser extent from the Bura River, which flows along the western edge of this sheet. No constant river gauging records exist; occasional measurements give indications for minimum flows of a few liters per sec. in the northernmost section of the rivers in the dry season and maximum flows of close to 1000 l/sec. in prolonged wet rainy seasons (this does not concern short – period storm run-off).

No reliable rainfall figures are available for this area. Extrapolation from nearby stations give annual precipitation rates from 400 to 600 mm on the peneplains and slightly higher values for Mgama Ridge and other hills. Evaporation from open water surfaces is well over 2000 mm per year. Rainfall in the area only occasionally improves the water situation by filling isolated waterholes, from where most of the water evaporites. Rain on the hills runs down in gullies and rapidly dissipates in the accummulation pediments around the foot of the hills.

In the Mwatate River a dam was built for the Taita Estates Ltd. This dam has a designed storage capacity of 900.000 m^3.Further downstream a few very small dams exist. In the Bura River a dam was built for the Taita Hills Lodge, designed to a storage capacity of 190.000 m^3.

Hydrogeology:

Groundwater in the area in general occurs in the valley fill (alluvium) and valley connected fissure systems in the metamorphic rock. The alluvium is shallow and very clayey. Therefore groundwater recovery from it is not possible but must be sought in the fault and joint systems which cross the river valley.

Further away from the river chances for locating groundwater are remote. The metamorphic rocks have a very low porosity. Only fissures and fractures may contain water, combined with micro interstices caused by weathering. Karst-type sink holes have been observed one some hills with marble outcrops. In view of the low relief of the area it is not probable, however, that larger reserves of trapped water could be tapped. In addition, search for such water would prove to be most difficult and very costly.

Boreholes:

In this area 18 boreholes have been drilled. Of these 14 were sunk by the Taita Estates Ltd., many of them in the direct vicinity of the dam (table 7).

Most boreholes yield water with a certain degree of mineralization, some nearly fresh, some completely saline. Yields are variable but in general moderate to low. Only from the more recent boreholes chemical water analyses are available. Many of the older holes have been abandoned.

Table 7 shows that in most of the boreholes water was struck at more than one level, probably due to the borehole crossing several inclined fracture zones or more weathered rock.

Mineralization of groundwater (salinity):

This is due to weathering of the rocks and the relation between macro and micro pores systems. The mobility of groundwater in the metamorphic rocks is mainly determined by the macro porosity of the fissures; because of the relatively short contact with the rock mineralization remains low.

The water in the micro pores is of a very low mobility and becomes strongly mineralized by taking up salts produced by the weathering processes. Pumping from a new borehole first draws the mobile water from the macro pores. Subsequently, if insufficient recovery time is allowed, the micro pores will start yielding mineralized water to the macro pores systems, thus gradually turning the pumped water saline.

Geophysical prospecting:

Electro-resistivity work has been carried out in the area. Cross-soundings have been made near boreholes at Taita Estates of which accurate drill logs exist, in order to ob-

Borehole No.	year	location	ground elec.	total depth	over-burden	depth hard rock	WSL	WRL	yield liters/hour	water quality		remarks
										original	changed	
P 157	1931	Teita Estate sisal fields	799	28	?	?	9	4	4.360	?	?	abandoned
C 70	1938	Teita Estate west bank old factory	833	94	3	4.5	16 53 70 90–92	9	9.480	?	?	abandoned
C 71	1938	Teita Estate dam reservoir	824	32	10	10.5	7.6–10.4 20	3	18.750	?	?	now flooded by dam reservoir
C 301	1944	Teita Estate west bank	824	95	11	75	28 46 76	19.5	883	good	?	abandoned original BH No. 4
C 302	1944	Teita Estate east bank	814	134	7	29.3	31.4 51.2 106.7	11.6	4.100	good	?	abandoned original BH No. 5
C 347	1945	Teita Estate west bank	824	151	10.4	10.4	10 26.5 89.7 111.3 132.7	6.1	9.100	good	?	abandoned original BH No. 3
C 350	1945	Teita Estate west bank	824	61	7	11.6	10.7 21.4 55.8	6.4	4.754	good	?	abandoned original BH No. 2
C 520	1947	SW of Mwatate trade centre	928	122	8.5	22	63.4 73–76 115	40	5.005	good	?	abandoned
C 3588	1969	Kambanga, South Mwatate R.	703	109.5	21.3	33.5	32.3	25.6	dry	–	–	dry
C 3783	1969	Lualenyi, S Bura R.	775	106.7	37.5	98.2	58 85.4	49	9.750	good to taste	saline	
C 4202	1976	Teita Estate east bank new factory	824	89	16	72	3 8.4 72–83	5.1	4.500	saline	?	conductivity 2980 micro mhos/cm^3
C 4203	1976	Teita Estate west bank old factory	824	50	8	10	10 34 36	4.5	6.800	saline	?	conductivity 4400 micro mhos/cm^3
C 4216	1976	Teita Estate east bank sisal fields	869	78	8	12	2.5	–	dry		–	dry, abandoned
C 4218	1976	Teita Estate west bank old factory	824	30	14	20	6 20	5	18.830	very good	?	
C 4219	1976	Teita Estate west bank old factory	820	35	12	13	6 15	4.75	27.200	very saline	?	casing, corroded, pump stuck
C 4264	1976	Choke Ranch S Mwatate R.	744	80	10	16	12	7	5.300	brackish	?	no chemical water analyses available
C 4274	1976	Teita Estate near dam	826	65	8	17	9	5.7	6.000	good	?	

Note: 1. All depths in meters; 2. WSL = water struck level; 3. WRL = water rest level; 4. P 157, C 70 to C 520 incl. are the old borehole: their positions are indicated on the map, but not their data. 5. C 3588 to C 4274 incl. are the new boreholes; both their positions and data are indicated on the map.

Table 7 – water borehole records from the Mwatate quadrangle

tain specific resistivity values for lithology and aquifers. Treatment of the obtained results revealed a definite anisotropy of the resistivity pattern in the metamorphic rocks. Further south exploration work has been carried out by electro-resistivity sounding and profiling. However, the exceptional flood conditions of 1978 strongly limited the work.

Groundwater potential:

At this stage of research it is thought that the groundwater potential of the Mwatate Sheet area is very low, both quantitatively and qualitatively.

Quantitatively it is low since rainwater in the area itself hardly contributes to any recharge. Most recharge comes from Mwatate and Bura Rivers headwaters, but storage along these river valleys is limited.

Qualitatively it is low due to mineralization of water contained in the metamorphic rocks, as well as of water in parts of the alluvium because of the often highly alkalic „black-cotton"-type of soils.

Surface water potential:

The rare occurrence of flowing surface water in the lower Mwatate and Bura River valleys is no basis for the development of reliable water supply systems from surface water. Even the Taita Estates and Taita Hills Lodge dams in the northern parts of the sheet are of limited potential because of the high evaporation. The applicability of existing technical means to minimize evaporation, like floating plastic sheets, would have to be examined.

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1st Report: Results of the Geological Survey of the Taita Hills Region – 589 pp., maps, figures.
2nd Report: Geological Prospecting and Economic Assessment of the Gemstone Belt in Southeastern Kenya – 198 pp., maps, figures.
3rd Report: Geological Survey and Results of Mineral and Base Metal Prospecting in the Coastal Belt South of Mombasa (Kwale District) – 106 pp., maps, figures.
4th Report: Pre-feasibility study on the Murka Kyanite Deposit – 186 pp., maps, figures.

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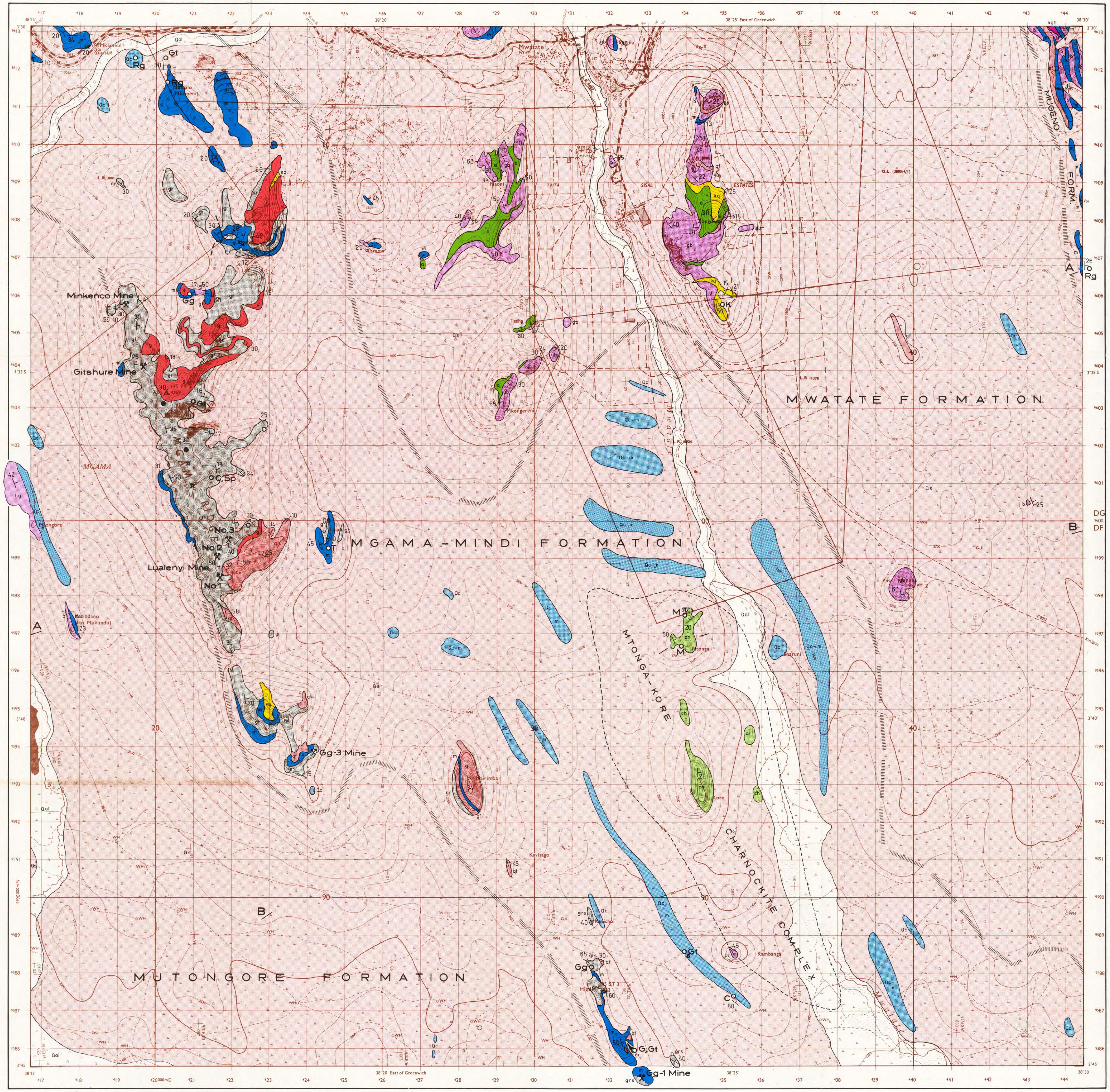
During a field visit to the area, Dr. Gabor GAAL from the University of Helsinki, Finland, provided most stimulating thoughts from his wide experience of the Precambrian geology of Northern Europe.

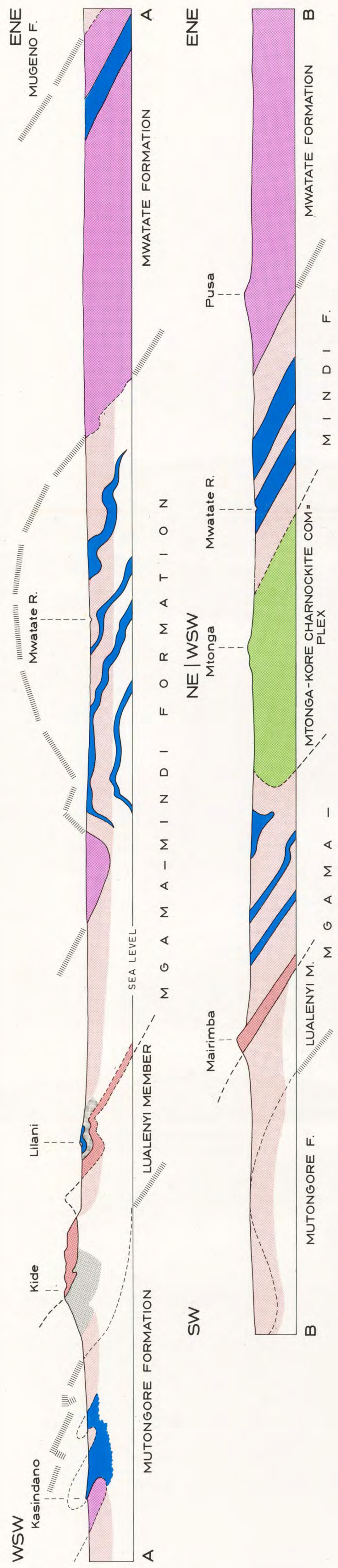
GEOLOGICAL MAP OF THE MWATATE QUADRANGLE

Geologically mapped in 1977 by W. POHL

KENYA - AUSTRIA MINERAL EXPLORATION PROJECT

AUSTROMINERAL





QUATERNARY / TERTIARY

- Qal Alluvium (mostly 'black cotton soil')
- Qs Soil (residual) overlying undifferentiated Precambrian
- Qc Calcrete and calcareous soil

PRECAMBRIAN

- g Granitoid gneiss
- qf Quartz feldspar gneiss and felsic granulites
- q Quartzite (k=kyanite, s=sulfides/limonite)
- b Biotite/banded gneiss (h=hornblende, g=garnet, m=migmatite and feldsp.-augengn.)
- gr Graphite gneiss (± muscovite, sillimanite always 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
- ch Charnockite
- a Amphibolite (± garnet)
- Ultramafic rock

- ||||||| Litho-stratigraphical boundary (inferred) formations
- ⊥30 Strike and dip of foliation
- Fault

⚒ Mine ● Prospect o Mineral occurrence

Gg = green grossularite (wherever not marked differently)
Rg = red garnet
T = tanzanite (blue zoisite)
Gt = green tourmaline
C = red corundum
K = kyanite
M = magnetite
Sp = spinel
R = rutile

0 1 2 km 3 4 5

Scale 1:50 000

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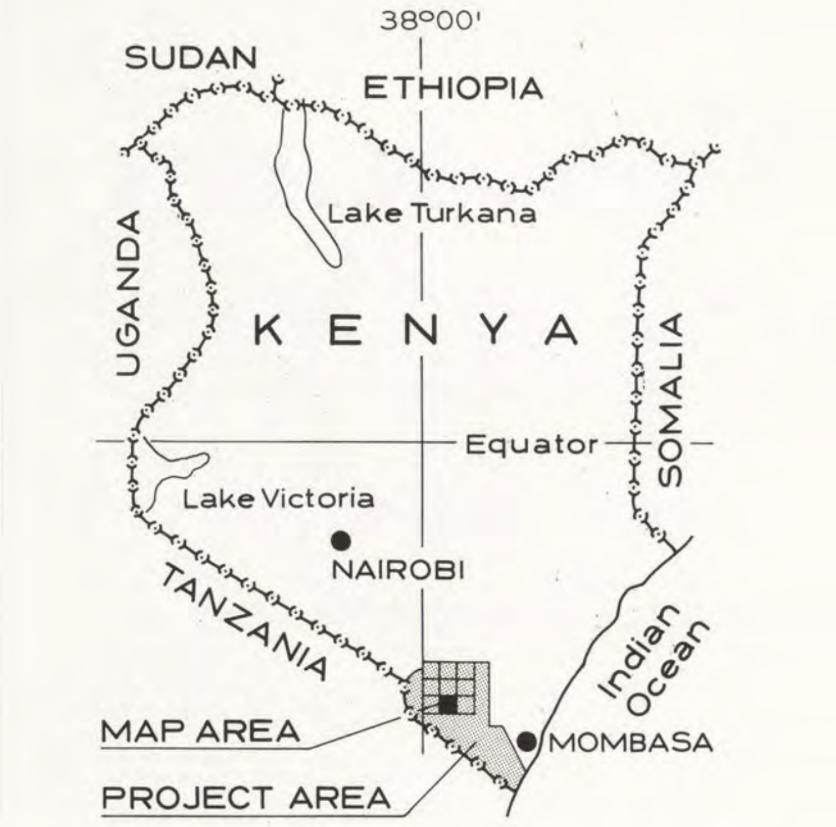

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