LINEAMENT AND PEGMATITE MAPPING USING LANDSAT TM IMAGERY AND AERIAL PHOTOGRAPH DATA

Kaseba-Katota Area, Serenje District, Central Zambia

By

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DECLARATION

This dissertation was written and submitted in accordance with the rules and regulations governing the award of Master of Mineral Sciences Degree of the University of Zambia. I further declare that the dissertation has neither in part nor in whole been presented as substance for award of any degree, either to this or any other University. Where other people's work has been drawn upon, acknowledgement has been made.

Signature of author: ....

Date: December 2001

APPROVAL

This dissertation of Simon Nkemba is approved as fulfilling the requirements of the Degree of Master of Mineral Science in Geology by the University of Zambia.

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ABSTRACT

The Kaseba-Katota area is part of the Mesoproterozoic Irumide fold belt trending in a northeast – southwest direction and covers part of the Eastern and Central provinces of Zambia.

Outcrops in the area include metasediments, which have been subjected to intense deformation resulting in strong foliation, recumbent and overturned folding. In places, the rocks seem to have undergone anatexis as indicated by ductile flow structures and heavily silicified layers. The general trend of foliation and schistosity is northeast - southwest. Foliation planes are mainly vertical or dip steeply to the east. The northeast - southwest Irumide structures are in places interfered by northwesterly trending structures of the Pan African Lufilian Orogeny. The rocks are characterised by vertical faults and joint patterns. The dominant joint pattern strikes between 30° – 80°.

Pegmatites in the Kaseba-Katota area commonly occur as lensoids and rarely form extensive and continuous tabular bodies. Most of the pegmatites in the belt are small, varying from 10 to 50 m in length and usually form small hills rising above the general surrounding up to about 6 m high. The pegmatites are associated with migmatites, schists, and micaceous quartzites. The contacts between the pegmatites and the host rocks range from very sharp to gradational. Chief minerals of the pegmatites are quartz, feldspar and mica. Most of the pegmatites have been exploited commercially for aquamarine, beryl, tourmaline and garnet.

Although the pegmatites host abundant muscovite and feldspar, these have not been exploited.

A digital database of the Kaseba - Katota area consists of geology, lineaments, faults (interpreted from Landsat Thematic Mapper (TM) image and aerial photographs), joints and foliation traces (mapped in the field).

Remote sensing techniques, Geographic Information Systems (GIS) as well as statistical analyses applied to this digital database and the resulting maps show that the strike of economical important pegmatites is parallel and controlled by NNE to ENE – trending lineaments, foliation and joints in the area.

The conceptual model shows that the rifting of the continental crust started around 1700 Ma followed by tectonic events some of which were responsible for the emplacement of the pegmatites and ended in the Pan-African Orogeny.

This thesis therefore, applied remote sensing techniques and GIS techniques for lineament mapping and generation of a conceptual model as a tool for delineating target areas for pegmatite exploration.

ACKNOWLEDGEMENTS

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CHAPTER 1

1.0 INTRODUCTION

The Kaseba-Katota area is endowed with abundant mineral resources, which if evaluated can contribute to the Country's export earnings. Most of these mineral resources are hosted by pegmatites, which are in turn hosted mainly by migmatitic gneisses, schists, and foliated quartzites.

The pegmatites are small, varying from 10 to 50m in length and usually form small hills rising above the general surrounding up to about 6m high. The pegmatites are suitable for small- and medium-scale workings mainly for aquamarine, beryl, tourmaline and garnet. Although the pegmatites host abundant muscovite and feldspar, these have not been exploited. The widespread illegal mining that has been going on in the study area has made it difficult to estimate the extent of small-scale mining and it's impact on Zambia's economy and environment. There has been very little detailed documentation on the locations, quantity and types of reserves of the pegmatites.

Deformation and metamorphic episodes have shaped the Kaseba-Katota area leading to a complex structural and metamorphic history. It is through interpretation of features such as lineaments, faults, joints and foliation that the nature of pegmatites could be understood. It is in this regard that Remote Sensing and Geographic Information Systems (GIS) were applied to map the lineaments and pegmatites in this area.

1.1 Location

The Kaseba-Katota area is located within Serenje District in Central Province of Zambia (Fig. 1.0). It lies 20 km to the south-east of Serenje Town, 20 km south of Kanona Town and about 36 km northwest of Chisomo Village. Access to the area is by an all-weather gravel road passing through Chisomo Village, about 70 km south-east of Serenje Town (Fig. 1.0). The study area is bound by longitudes 30° 20'E and 30°42'E and latitudes 13° 10'S and 13° 35'S (210000mE and 250000mE, and 8490000mN and 8540000mN) (Fig 1.1). For a lager scale map of the same area, see pocket at the back of this thesis.

1.2 Regional Structural and Geologic Setting

The Kaseba-Katota area is part of the Irumide Belt (Fig. 1.2). The northeast-southwest trending Irumide Belt is an intracratonic mobile belt of Mesoproterozoic age (Daly, 1986). The belt occupies most of central-eastern Zambia and is truncated by the Pan-African Zambezi Belt to the south-west, which separates the Irumide Belt from the broadly coeval Choma-Kalomo Block (Fig. 1.2). To the west, the Irumide Belt is bound by the Lufilian Arc and to the north-east by the Paleoproterozoic Ubendian Belt which was reactivated in the Meso- and Neo-proterozoic era. The polycyclic Mozambique Belt occurs to the east and south-east

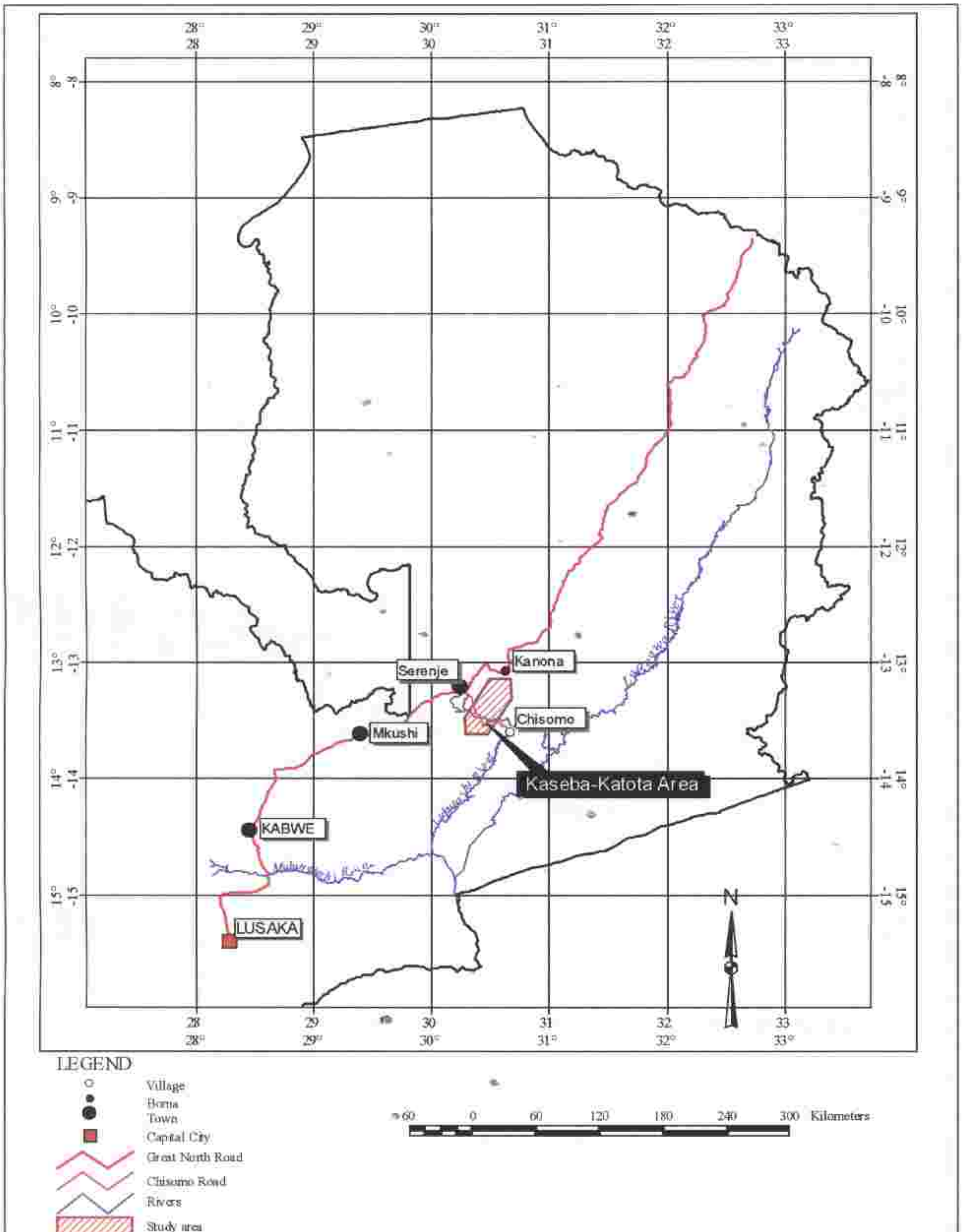


Fig. 1.0: Location Map of Kaseba - Katota Area in Central Zambia

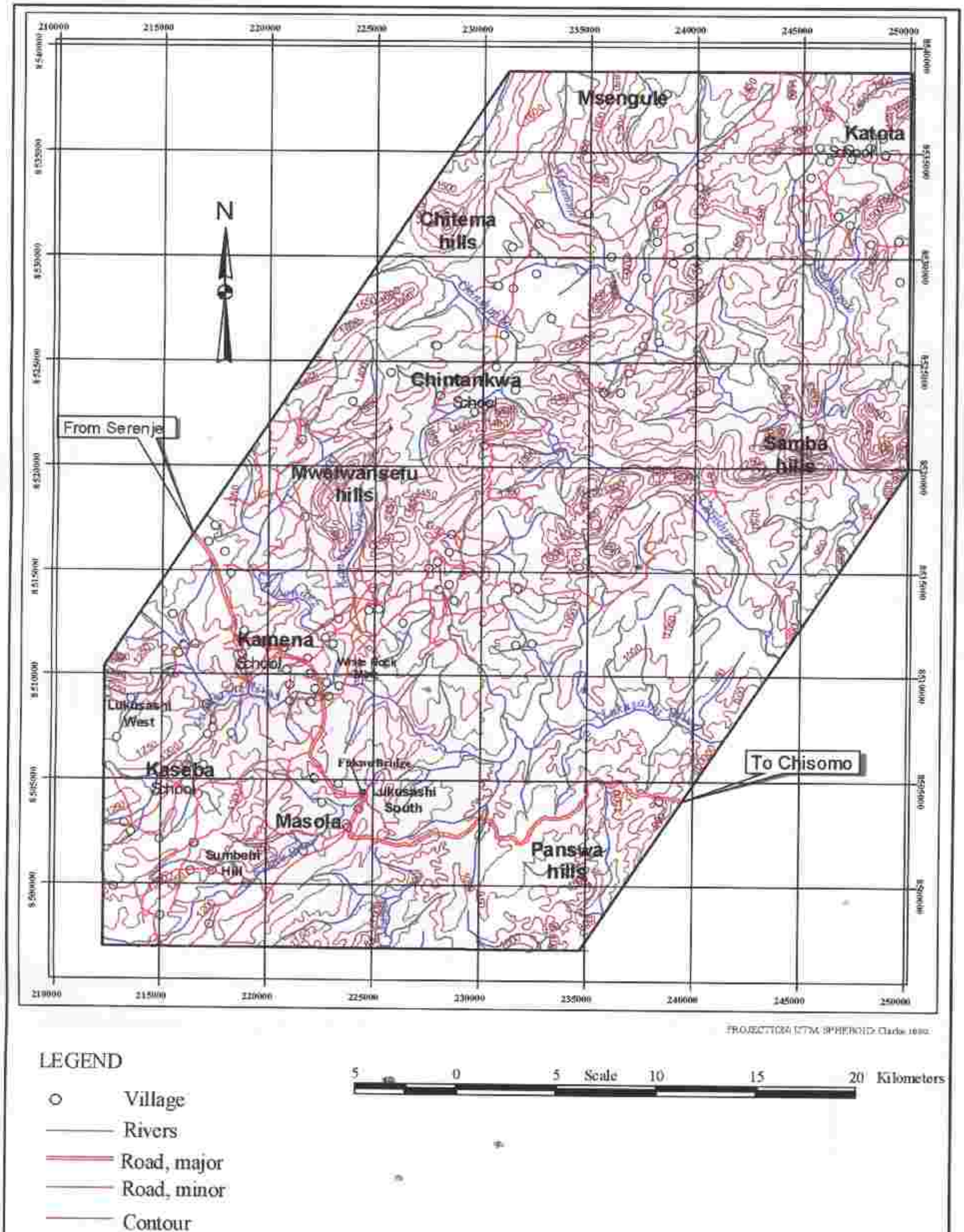


Fig. 1.1: Detailled Location Map of the Kaseba-Katota area showing Geography and the Serenje-Chisomo road.

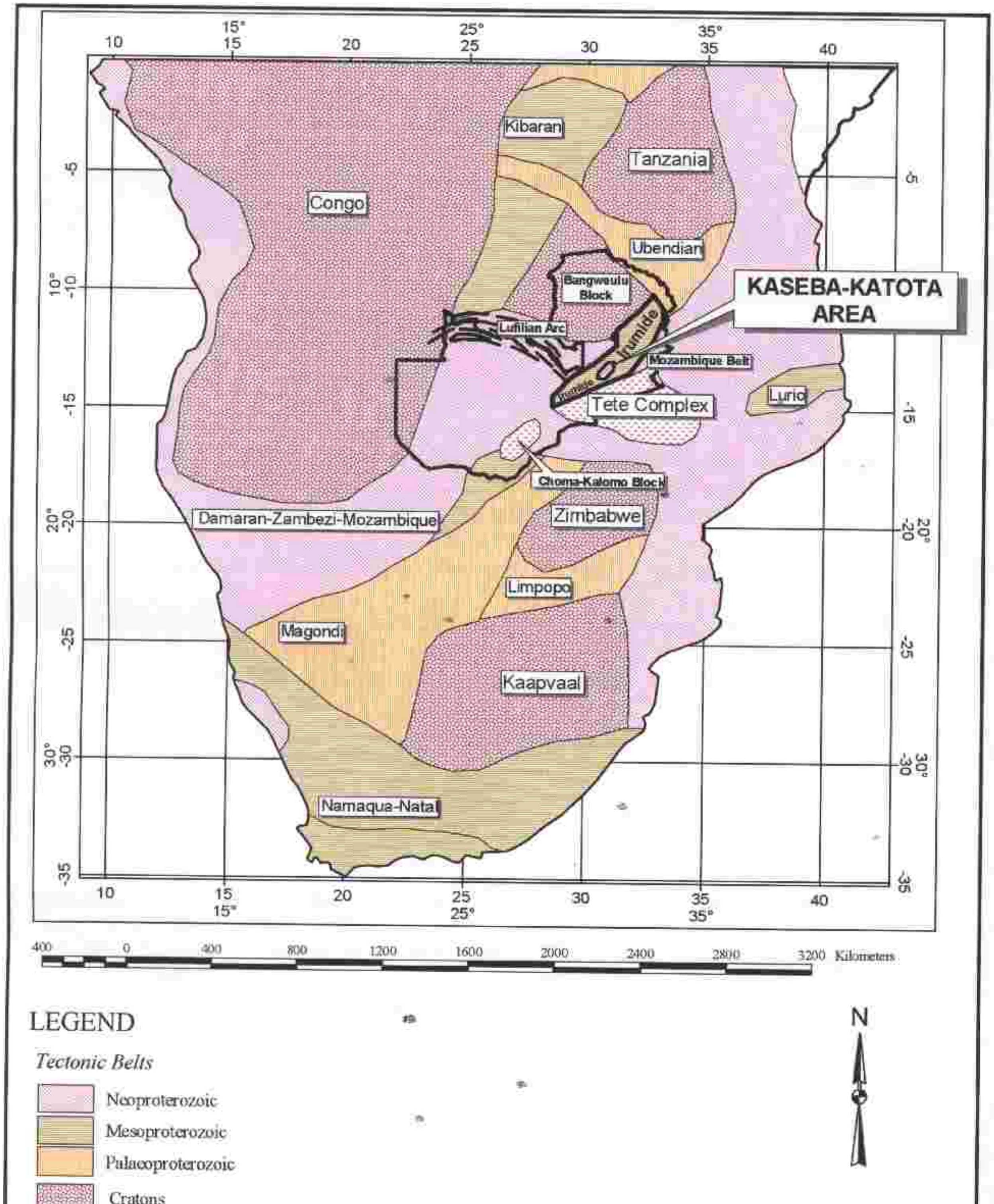


Fig. 1.2: Regional Structural and Geological Setting of the Irumide Belt in Southern Africa (modified from Cahen et. al., 1984)

whereas the Paleoproterozoic rocks of the Bangweulu Block occur to the northwest.

The Irumide Belt was first described by Ackerman (1950) as consisting of an older granitic complex (Die Mkushi Gneiss) and a younger metasedimentary sequence called the Muva. The northern and north-western part of the Irumide Belt consists of unmetamorphosed clastic sediments, which constitute a foreland basin (Daly and Unrug, 1982). Further east and in the central part of the belt, deformation becomes complex and metamorphic grade increases from low greenschist to sillimanite and kyanite grade in the central part of the belt.

The central part of the belt is characterised by highly deformed basement gneisses and metasediments overlain by younger metasediments that preserve sedimentary features. The Irumide Belt is also characterised by the lack of extensive carbonates as those present in the Lufilian Arc, Zambezi and Mozambique belts. The lack of thick carbonate sequences and presence of predominant clastic metasediments in the Irumide Belt implies that the basin never attained stability during deposition (Daly and Unrug, 1982).

Previously the Irumide Belt was considered to have recorded little crustal shortening. However subsequent work has shown that there is considerable crustal shortening in the Irumide Belt both in the foreland region and in the central part of the belt (Mapani and Moore, 1995).

1.3 Previous Work

All previous investigations in the pegmatite belt were carried out to locate mica-bearing pegmatites. The British South Africa Company initiated a co-operative scheme with independent local operators to produce mica. In December 1964, the Geological Survey Department assumed responsibility for operating the scheme, but the results of prospecting during 1965 indicated that reserves were limited and continued production would become increasingly uneconomical. The scheme was terminated at the end of June, 1966 (Cvetkovic, 1973).

In June and August 1968, most of the pegmatites occurring in Kamena area (see Fig. 1.1) were visited, but only two occurrences, known as Lukusashi West (~5 km west of Kamena) and Lukusashi South (Masola area), were selected for detailed investigations due to clear zonation, good mineralisation and thin overburden. In addition to the two localities mentioned, samples were taken at others, but a number of pegmatites were not sampled because of the thickness of overburden or the dangerous condition of old excavations. The pegmatites were previously prospected for mica, but the feldspar content was not examined in detail.

1.4 Present Investigations

Present investigations involved location of pegmatites in the field, detailed geological description of their cross-sections, structural mapping and application of Remote Sensing and Geographic Information Systems. Description of the cross-sections was done in trenched pegmatites left unfilled by previous workers and local illegal miners. For details on the methods used in the study, refer to Section 1.8. About 106 pegmatites were recorded during fieldwork (see Chapter 4).

Data from field investigations was integrated into a Remote Sensing and Geographic Information Systems (GIS) database. Remote Sensing techniques (see Chapter 5) were applied to the Landsat TM image of Kaseba-Katota area and Geographic Information Systems (see Chapter 6) was used for spatial analysis to determine how geological and structural trends in the study area are related to the age, strike, and mineralisation of the pegmatites.

A conceptual model has been generated to illustrate the processes that led to the formation of pegmatites in the study area.

1.5 Climate

The climate in the Kaseba-Katota area is typical of the central African Plateau, with the year divisible into three seasons; a rainy season from November to April; a cool, dry winter from May to August; and a hot, dry period of September and October. The dry period becomes progressively more humid until the rains, which are usually preceded by severe thunderstorms. The average annual rainfall over the past 8 years has been 1066mm. The mean maximum temperature in the hottest months has been 31^{0}C, and the minimum 16^{0}C. The diurnal range of temperature is 4.4^{0}C. In the cool months temperatures frequently fall below 4.4^{0}C.

1.5.1 Soils and vegetation

Plateau soils constitute the major soil type, underlying a woodland flora. The soils are pallid sandy soils of a highly leached type, with pale brownish to white colour. Fine to coarse soils, with a fine silt or clay fraction, which tend to cement the sand together, increase in proportion towards the deeper horizons. In the Katota area, red earths in scattered areas are lithologically controlled variants of the plateau soils. The soils are deep red with an orange to brownish tone, and have a clay-loam texture (Fig. 1.3a and b).

Vegetation is composed of variable woodlands of uniform growth (Fig.1.3c), with rather limited undergrowth, which become very short and mixed in upland areas, where they contain large proportions of such trees as *Monotes, Protea,* and *Uapaca.* Due to limited undergrowth, the pale brown soil in Fig. 1.3c, is visible under the woodlands near the bottom centre of the picture. In the flatter areas *B. floribunda* and *B. longifolia*, together with *I. paniculata* are present (Trapnell and Clotheir, 1957). The rest of the area is generally covered by *Isoberlinia paniculata-Brachystegia* woodlands, which are taller woodlands with rather sparse undergrowth of small trees, typically dominated by *Isoberlinia* and *B. longifolia* (Trapnell and Clotheir, 1957).

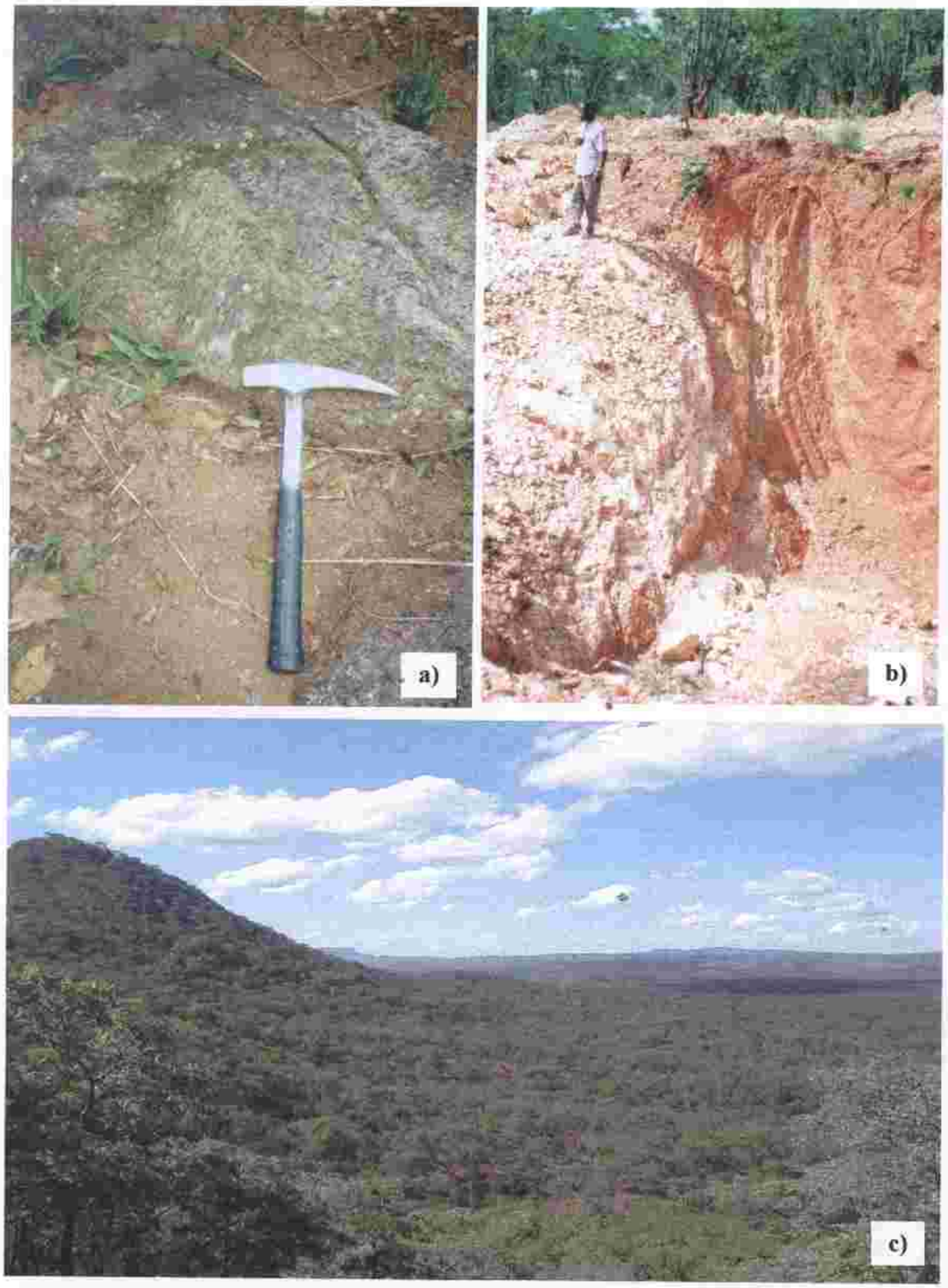


Fig. 1.3: a) Plateau, pallid sandy soils with pale brownish colour, Kamena area. b) Horizons of red plateau soils with an orange to brownish tone, and a clay-loam texture, Kamena area. c) Woodlands of uniform growth, with limited undergrowth. The woodlands are mixed and contain large proportions of such trees as *Monotes*, *Protea*, and *Uapaca*, Panswa Hills. Notice the undulating topography and canopy.

Indigenous agriculture on the plateau soils follows the Chitemene pattern of agriculture, a method involving cutting the branches of the trees, burning and cultivation (Fig. 1.4). The Chitemene pattern is a shifting cultivation from which the natural vegetation takes several years to recover. Too frequent cultivation has resulted in the development of stunted shrubs, with little shade and heavy undergrowth over much of the reserve. In the north, much of the woodland is preserved on plateau soils, but the normal indigenous agriculture is again a type of Chitemene, with cassava and finger millet as the chief crops. The more fertile Upper Valley soils of dambo fringes and the small *Chipya* patches (Trapnell and Clotheir, 1957) are heavily cultivated to produce vegetables and maize. These areas are, however, relatively small, and the agriculture in the reserves is still at subsistence level.

1.5.2 Topography and Drainage

The whole area comprises gently rolling plateau country at about 1,200 metres, with very low relief except for a few persistent quartzite ridges, which generally rise to 120 m above the plateau level. The ridges do not show a consistent summit level and do not appear to be relics of an older erosion surface but are simply the expression of resistance to weathering and erosion.

The area between Kamena and Chintankwa has a rugged topography produced by the differential erosion of a complex folded sequence of quartzites and schists. Erosion of the schists in the core of this structure has produced a long stretch of relatively level

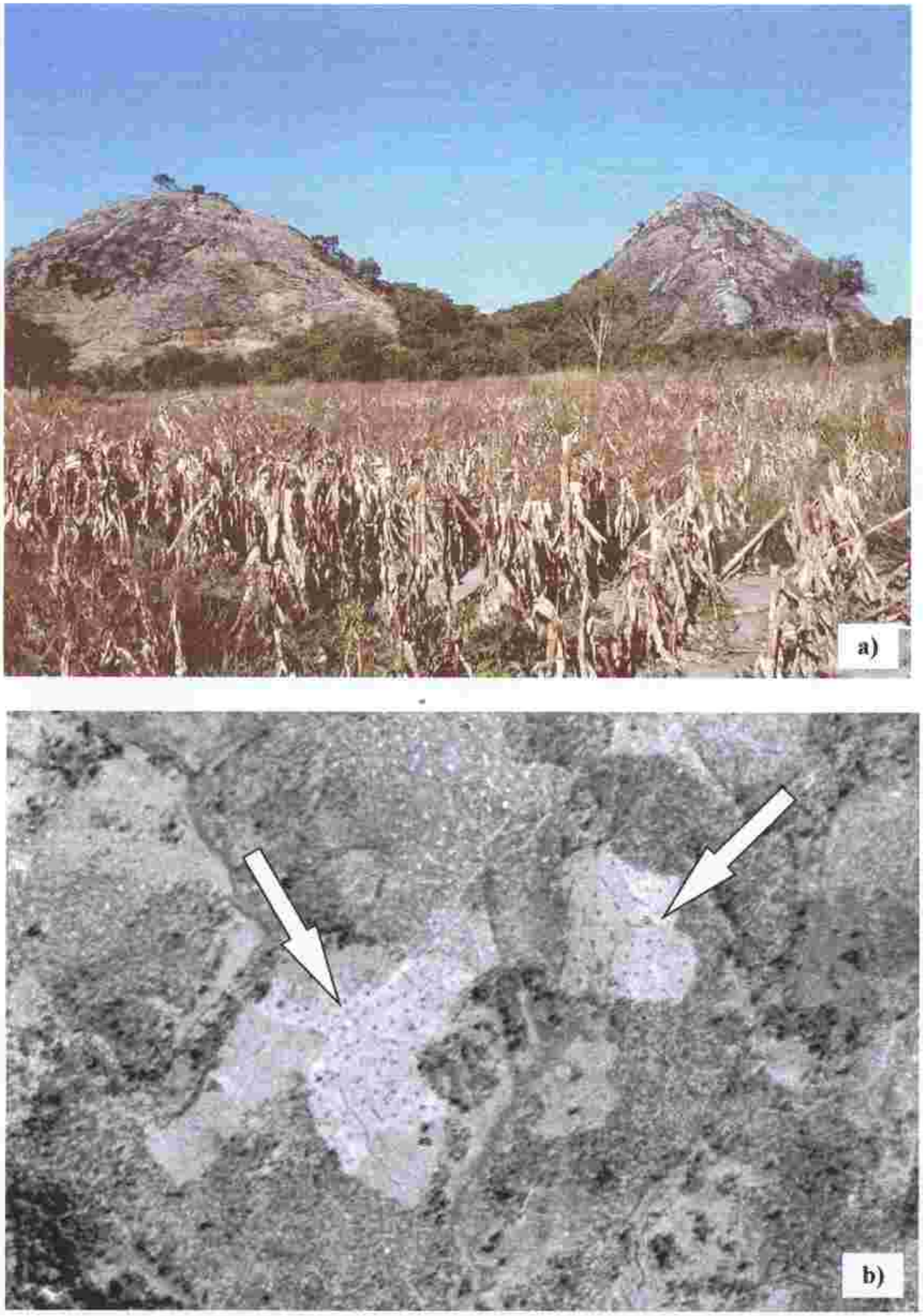


Fig. 1.4: Indigenous agriculture on the Plateau soils. a) A maize field near granite hills in Kamena area. The picture is about 400 m across near the foot of the hills. b) Chitemene pattern (see arrows), a method involving cutting and burning the branches of the trees for the cultivation of finger-millet. The Chitemene cultivation has resulted in the development of stunted shrubs with little shade and heavy undergrowth over much of the forest. The photo is 3 km across.

ground crossed by few streams. To the south and southwest of the Katota School, granites and gneisses form a gently rolling country broken only by the parallel quartzite ridges.

The Kaseba-Katota area is drained by the Lukusashi River and its generally southerly- and northerly-flowing tributaries.

1.5.3 Weathering and Erosion

The major rivers such as Lukusashi, Chipendezhi and Masola (see Fig. 1.1), maintain well-defined courses and flow perennially, but the remaining streams are largely dambos (water logged areas), with only indistinct drainage lines and intermittent flow. However, these streams have strong transporting power, and the major movement of material is effected by gully erosion during the rainy season. Thus areas in the Mwelwansefu and Panswa hills (see Fig. 1.1) are capped by a thin immature soil profile. Chemical weathering has taken place, in the Chintankwa-Katota area, producing a sandy soil, which passes down to an iron-rich illuvial horizon, generally situated at a depth of 0.6 to 1.8 m.

The regime of chemical weathering, aided by the constant removal of decomposed material, has resulted in almost complete lack of exposure in areas underlain by schists, and there are only a few scattered outcrops of the very extensive gneisses. The gneisses form low domes or slightly beveled pavements, usually with a weathered skin from a few millimetres to a few centimetres thick lying as exfoliated slabs on the surface.

1.6 Aims

The aims of this study are:

a) Mapping, geological description and economic potential assessment of pegmatites in the Kaseba-Katota Area.

b) Undertake a detailed satellite image study of the Kaseba-Katota area, including fieldwork to generate a conceptual model for economically important pegmatites using Remote Sensing and Geographic Information Systems (GIS) technology. Emphasis is put on digital enhancement of satellite images for visual interpretation and analysis of structural data (e.g. lineament mapping).

1.7 Significance of the Study and Scientific Contribution

Gemstone mining plays an important role in the economy of Zambia since the 1960s, providing employment and source of income particularly for small-scale miners, export earnings and increased self-reliance. According to an European Union study undertaken recently, Zambia could be earning over US$200,000,000.00 per annum in contrast to US$10,000,000.00 per year (Nyambe, 2000) if legal conditions were fulfilled. A good understanding of the type and nature of pegmatites and their relationship with the general structural setting of the area will aid in well-targeted field mapping of the pegmatites. By bringing into play the role of Remote Sensing and Geographic Information Systems technology, geological mapping will often be cost-effective and time-efficient since information about vast regions can be derived much more quickly than by traditional methods. Through this study, field mapping has contributed to the improvement and extension of the geological maps of the study area and updated information on pegmatites and associated mineralisation.

1.8 Methods used in the Study

Field and laboratory methods were used in this study. All relevant information derived from these methods were entered in a GIS database for analysis.

1.8.1 Field Methods

Field methods involved reconnaissance study, followed by geological mapping.

1.8.1.1 Reconnaissance

Reconnaissance work was intended for familiarisation with the study area and for marking prominent structural features such as granitic intrusions and bedding scarps.

1.8.1.2 Geological Mapping

Note books, pencils, markers, stereo pairs, a geological hammer, a compass and sample bags were prepared for geological mapping. Two working topographic maps, several pairs of aerial photographs and a hard copy Landsat TM image of the study area were prepared for use in the field. Planned systematic traverses of the study area were taken to establish geological boundaries, and to locate pegmatites. Local people assisted in locating mined pegmatites and mineral deposits. Representative samples of different rock types were numbered and taken for further study.

1.8.2 Laboratory Methods

Laboratory methods involved Remote Sensing, Geographic Information Systems (GIS) technologies and petrographic work.

1.8.2.1 Remote Sensing Techniques

Landsat Thematic Mapper image of August 1998 covering Mkushi and Serenje districts was radiometrically corrected and geographically registered (see Chapter 5) using PCI Image-Works Version 7 software (2000). The Kaseba-Katota area was spatially subsetted from the Mkushi-Serenje image. Bands 4, 5 and 7 were overlaid in red-green-blue (RGB) space to make a false colour composite to be used as the basis for image interpretation, because it gave the best combination for geological interpretation. 'Warping' of the image was done to fit a map base using a set of ground control points recognisable on both the image and the map. Map locations (eastings and northings) were entered automatically via the digitising table. Corresponding screen locations were identified using the cursor and automatically recorded in pixel co-ordinates (sample and line). During warping, the program determines polynomial equations to convert original pixel locations to new locations to suit the given map projection.

Visual image interpretation was carried out on the geo-referenced image. This was done both by on-screen digitising using PCI Image-Works Version 7 software (2000) and tracing on transparent paper using hard copy images.

Classification was performed on multi-band images of the study area to define a series of classes corresponding to spectrally discrete surface materials including granitic intrusions, excavations of pegmatites and sharp lithological boundaries. Both 'unsupervised' and 'supervised' classifications were carried out and the results compared.

Linear features were interpreted on both aerial photographs and on the Landsat Thematic Mapper image covering Kaseba-Katota area. Lineament analysis were used to interpret regional structure, to aid in locating buried structures and to map fractures.

1.8.2.2 Geographic Information Systems (GIS) Application

GIS applications were used for data capturing, manipulation, spatial analysis and representation. Data capturing was done with ARC/INFO V7.1.2 (1994), via the digitising tablet. Manipulation and spatial analysis of the data was done with ArcView GIS V3.2 (2000). Numerical data in Microsoft Excel 2000 spreadsheets was imported into ArcView and converted to shape files for analysis. The final stage consisted of combinations of various maps that provided relative favourability for pegmatites occurrences.

In situ data of the study area, particularly around Masola area and Sumbeni Hill, Chibolele Mine and Katota area (see Fig. 1.1) was further carried out to ascertain the results of laboratory study.

1.8.2.3 Petrographic work

Representative samples for different rock types in the study area were prepared for further laboratory study. A maximum of three thin sections of each rock type were made for study under electronic microscope. Photographs of interesting structures and mineralogy in the thin sections were taken (see Chapter 2). The data generated from thin section interpretation were combined with that from remote sensing techniques, GIS and the field for compilation of this thesis.

Figure 1.5 below shows a summary of the methods and stages taken in this study.

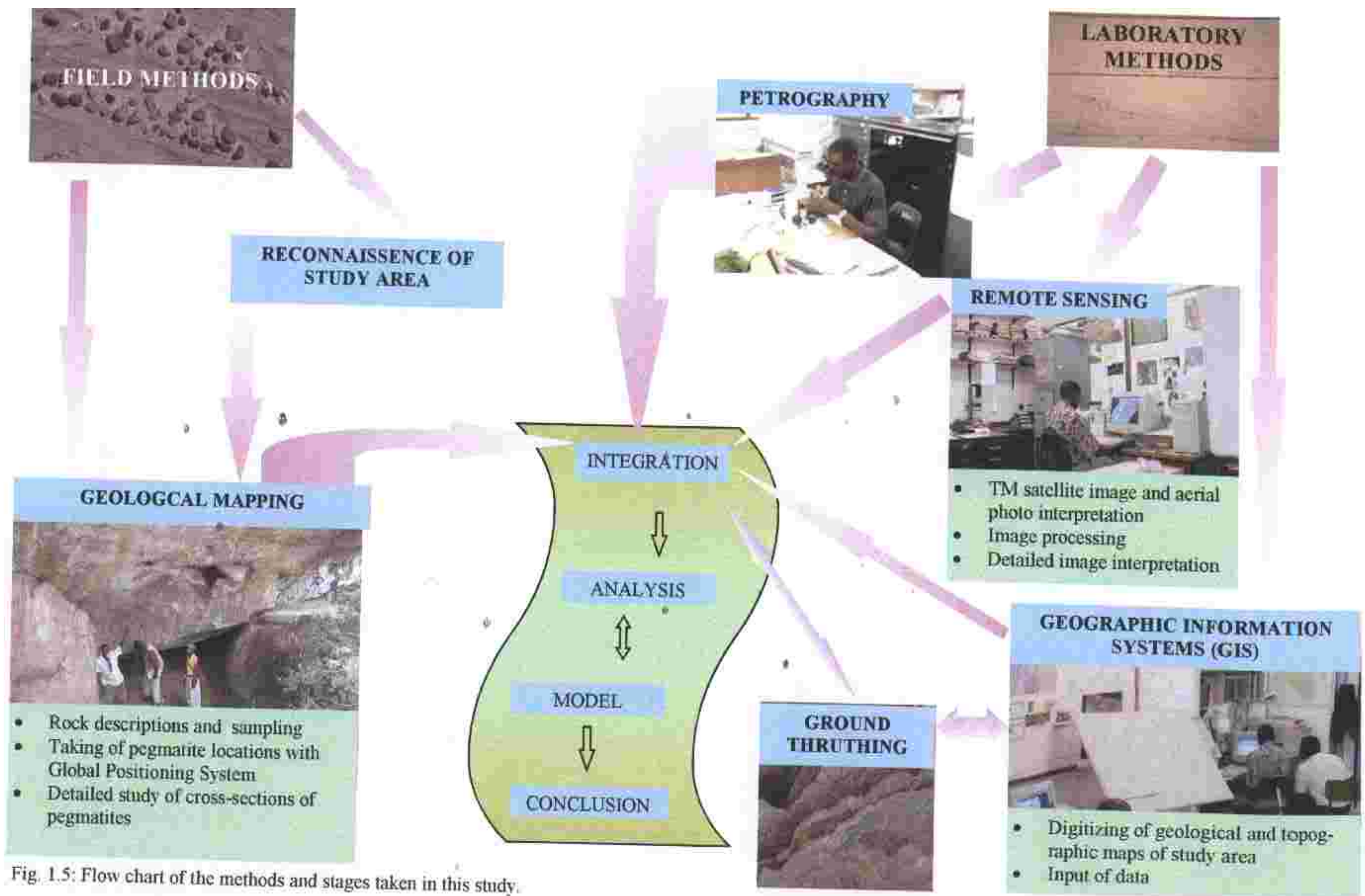


Fig. 1.5: Flow chart of the methods and stages taken in this study.

CHAPTER

2

2.0 GEOLOGY

2.1 General

The Kaseba-Katota area is underlain by the Muva Supergroup of the Mesoproterozoic age. The supergroup is subdivided (Mapani and Moore, 1995) into Serenje and Gneiss groups (Table 1). The Serenje Group, which occupies the central and north-western parts of the study area, is subdivided into Lower Pelite, Quartzite and Upper Pelite formations. The Gneiss Group, which constitutes more than 60% of the study area (Fig. 2.1), consists of granites, gneisses and migmatites, intruded by pegmatites and dolerites.

2.2 Serenje Group

The Serenje Group is represented in the study area by conspicuous ridges trending mainly in a northeast-southwest direction. The group comprises the Lower Pelite, Quartzite and Upper Pelite formations.

2.2.1 Lower Pelite Formation

The Lower Pelite Formation in the Kaseba-Katota area comprises crenulated fine- to e 1: Stratigraphy of the Kaseba-Katota area (modified from Mapani and Moore, 1995)

ERA	SUPERGROUP	GROUP	FORMATION	LITHOLOGY
MESOPROTEROZOIC	MUVA	Gneiss	Gneiss	*Dolerite, Pegmatite*
				Migmatite
				Porphyroblastic gneiss. Medium- to coarse-grained Mesocratic gneiss and Leucocratic gneiss
				Coarse-grained porphyritic granite with thin bands of foliated micro-granite
				Weakly foliated, coarse-grained and granular mesocratic and leucocratic granites, composed mainly of quartz, microcline, biotite and plagioclase
		Serenje	?	*Pegmatite –foliated and zoned Amphibolite*
			Upper Pelite	*Thin fine-grained micaceous quartzite*
			Quartzite	*Quartzite – coarse-grained and massive*
				Quartzite – foliated
			Lower Pelite	*Reddish–brown and weakly crenulated (locally) porphyroblastic schist with porphyroblasts.*
				Crenulated fine- to medium-grained, reddish-brown to grey schist.

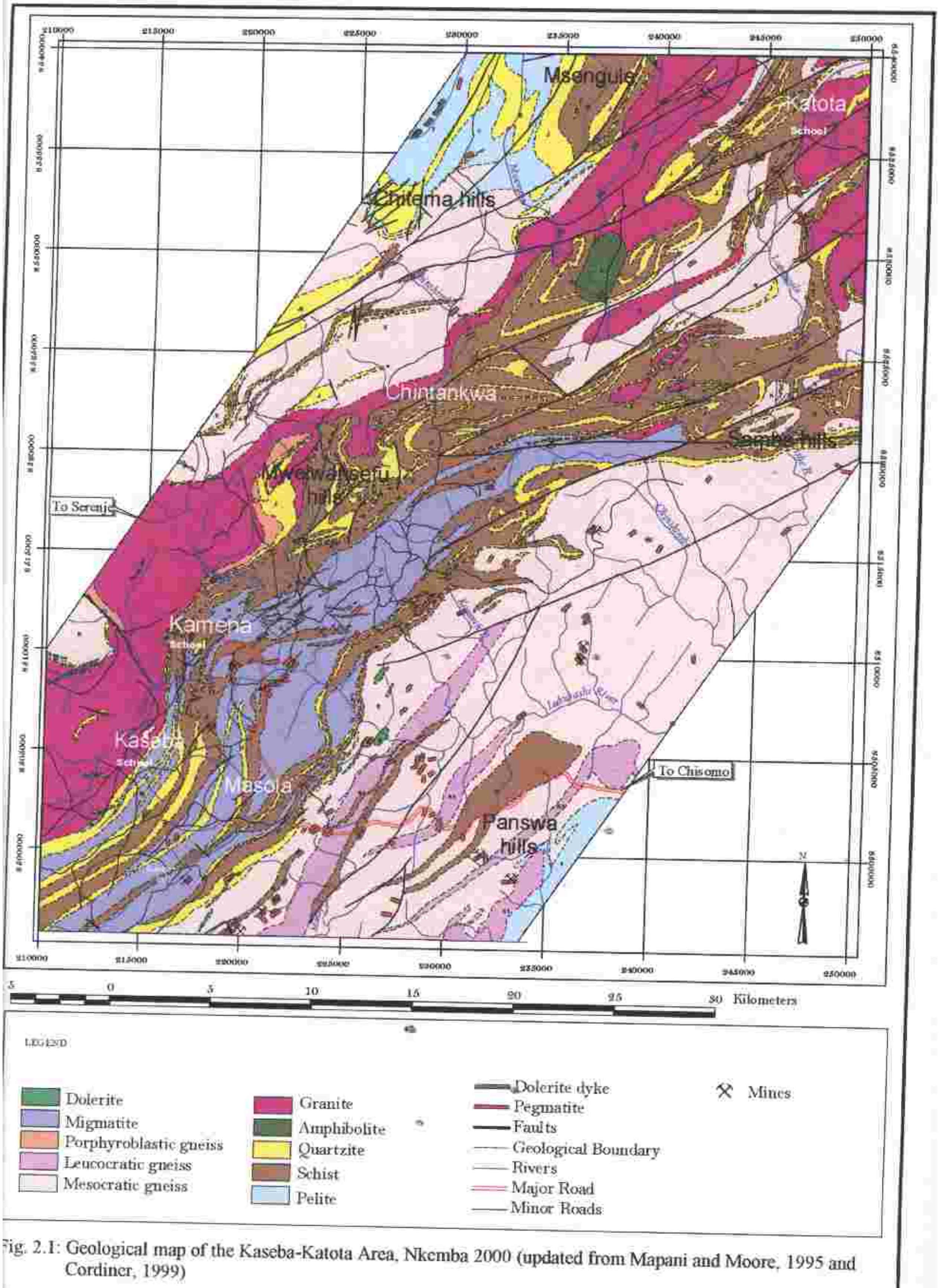


Fig. 2.1: Geological map of the Kaseba-Katota Area, Nkemba 2000 (updated from Mapani and Moore, 1995 and Cordiner, 1999)

medium-grained, reddish-brown to grey schist and a reddish–brown, weakly crenulated (locally) porphyroblastic schist. Outcrop sizes in this formation range from a few centimetres to 8m in width and from 0.5m to over 50m in length.

2.2.1.1 Crenulated Schist

The crenulated schist is reddish-brown to grey and fine- to medium-grained (Fig. 2.2a). Good outcrops of this facies lie 2.5 km south-west of Masola Bridge (see Figs. 1.1 and 2.1), within 1 km south and north-east of Kamena School and 3 km west of Katota School (see Fig. 1.1). Generally the outcrop size ranges between 0.5m to 15m in width and 1m to 50m in length. The schist south-west of Masola Bridge is strongly foliated and recorded three phases of deformation. In hand specimen, the schist consists of mica, quartz, garnet and sillimanite. Kyanite constitutes an accessory amount in the schists south of Katota School (see Fig 1.1). To the west of Fukwe Bridge (see Fig. 1.1), the schist consists a considerable amount of magnetite.

In thin section, the schist is medium-grained (Fig. 2.2b). It is composed of parallel flakes of muscovite, biotite, needle-shaped sillimanite and recrystallised quartz. Biotite replaces sillimanite in places. Accessories are fractured garnet.

Magnification x 2.5 XPL **b)**

Fig. 2.2: a) Outcrops of reddish-brown to grey, fine- to medium-grained crenulated schist, Kaseba area. Hammer is 30 cm long. The crenulations have been folded with fold axes dipping 5° to the northwest. b) Photomicrographs of the crenulated schist in (a). Chief minerals are muscovite, quartz, biotite and minor sillimanite. Muscovite displays decussate texture consisting of randomly oriented interlocking platy elongate crystals. Visible accessory mineral is garnet.

Qtz = quartz; Sili = sillimanite; Musc = muscovite; Bio = biotite; Gnt = garnet.

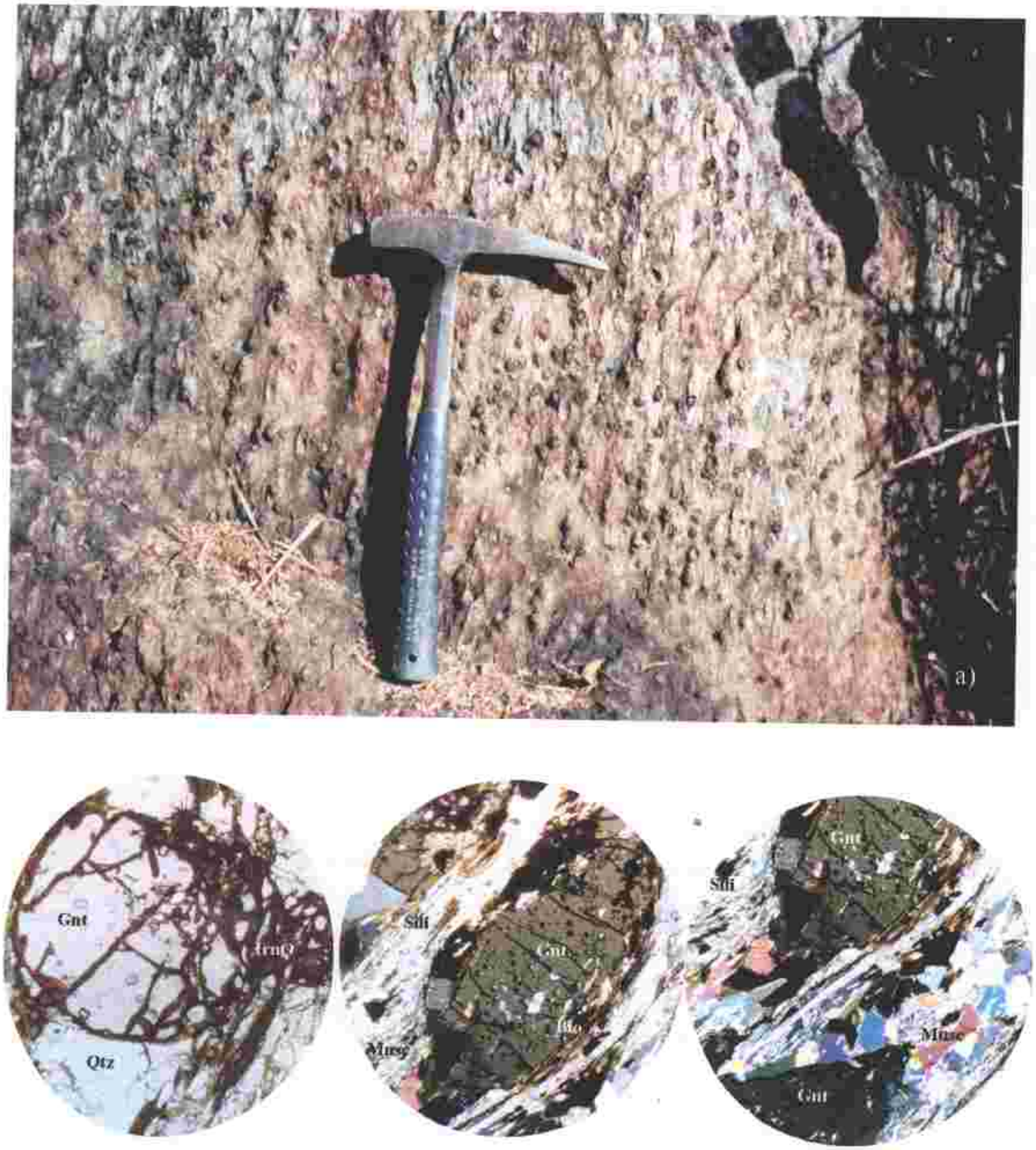
2.2.1.2 Porphyroblastic Schist

The porphyroblastic schist is reddish–brown and weakly crenulated locally (Fig. 2.3a). The schist in contact with the migmatite shows increasing coarseness of garnet porphyroblasts towards the contacts. Outcrop of porphyroblastic schist are generally small and scattered (0.5m x 1m) except the areas west and south of Katota School, east of Kaseba School and in Masola. Outcrops in these areas form ridges ranging from 6m to 20m in width and 10m to 200m long. In many places, vegetation grows along joints.

In hand specimen, the schist consists of garnet and quartz porphyroblasts in a muscovite rich matrix. To the west of Katota School, the schist consists of a considerable amount of tourmaline (~30%) near its contacts with pegmatites. Thin sections of the schist (Fig. 2.3b) are medium- to coarse-grained, with porphyroblasts of garnet and quartz embedded in foliated matrix of muscovite, sillimanite and quartz. Garnet is heavily fractured and rimmed by iron oxide. Some of the garnet porphyroblasts contain inclusions of biotite and quartz. Some garnet porphyroblasts are rotated at an angle to the main foliation whereas others are stretched parallel to foliation. Fine-grained quartz crystals are concentrated in pressure shadows and occur interstitially to sillimanite and biotite. Biotite is seen to replace sillimanite whereas kyanite occurs as an accessory.

2.2.2 Quartzite Formation

The Quartzite Formation mainly occupies high topographic areas forming long traceable outcrops ranging from a few centimetres to 10m wide and from 15m to 500m in length.



Magnification x 2.5 XPL

b)

Fig. 2.3: a) Reddish brown, porphyroblastic and weakly crenulated schist, Kamena area. Hammer is 30 cm long. b) Photomicrographs of the porphyroblastic schist in (a), with heavily fractured garnet filled and rimmed by iron oxide. Fine-grained quartz crystals are concentrated in pressure shadows and occur interstitially in silimanite and biotite. Flakes of biotite and needle-shaped sillimanite wrap around the porphyroblasts and define a strong foliation. Garnet porphyroblasts contain inclusions of biotite and quartz.

Qtz = quartz; Sili = sillimanite; Musc = muscovite; Bio = biotite; Gnt = garnet; IrnO = iron oxide.

Quartzite can be divided into two categories based on their structure and mineralogy namely: foliated and massive quartzite.

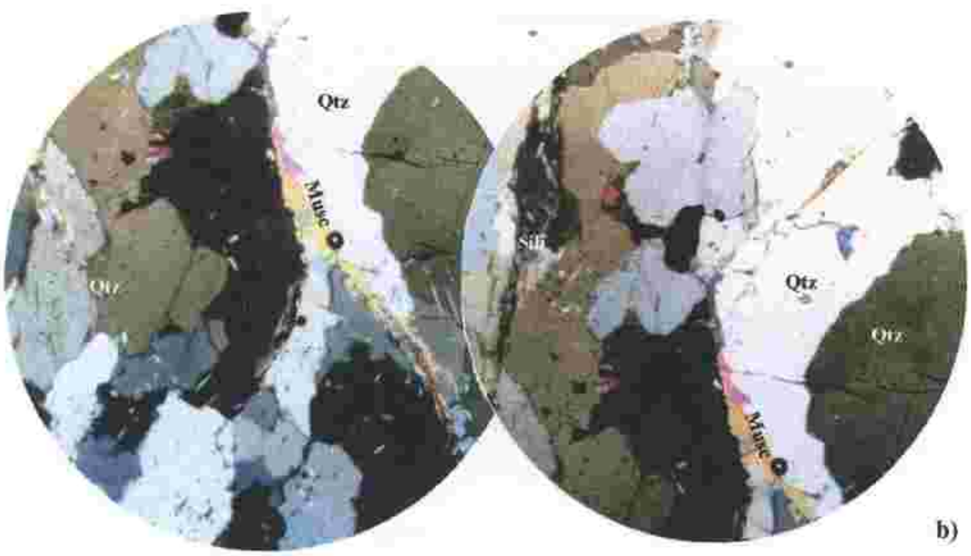
2.2.2.1 Foliated Quartzite

Outcrops of foliated quartzite are more abundant and extensive than those of the massive quartzite (see Section 2.2.2.2). The sizes of these outcrops range from 0.5 m to over 10m in width and from 15 m to over 200m in length. The foliated quartzite (Fig. 2.4a) is pale yellow to white, fine-grained, hard and brittle. It consists of quartz, muscovite and sillimanite. Quartz is usually recrystallised and elongate. Muscovite and sillimanite define the foliation. In strongly foliated quartzites, hand specimens split along foliation planes.

In thin section, the foliated quartzite is medium-grained and composed of quartz and sillimanite, with accessory muscovite and biotite. Quartz crystals are sub-equant with penetrating grain boundaries. Sillimanite is randomly oriented to sub-parallel. In places sillimanite forms aggregates. Muscovite and biotite flakes occur in inter-grain spaces of quartz (Fig. 2.4b).

2.2.2.2 Massive Quartzite

The massive quartzite is white and coarse-grained (Fig. 2.5a). The quartzite is strongly deformed in Chintankwa, Katota and Kamena areas (see Fig. 1.1) leading to recumbent



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2.4: a) Pale yellow to white foliated micaceous quartzite. Muscovite and sillimanite rich bands define the fo-
n. The quartz-rich bands are fine-grained and sugary in texture. Hammer is 30 cm long. b) Photomicrographs
e foliated quartzite in (a), with a medium-grained texture and composed of quartz, sillimanite and muscovite
accessory biotite. Quartz crystals are sub-equant with penetrating grain boundaries. Sillimanite is randomly
ted to sub-parallel. In places sillimanite forms aggregates. Muscovite and biotite flakes occur in inter-grain
s of quartz.

= quartz; Sili = sillimanite; Musc = muscovite

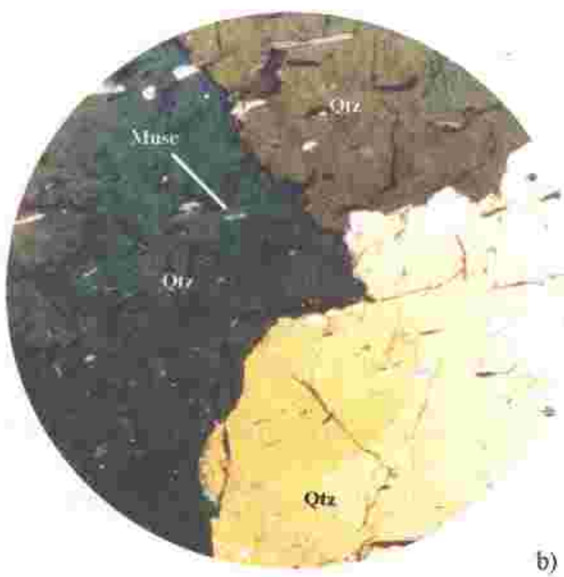

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Fig. 2. 5: a) Folded micaceous quartzite west of Kamenã School. Compass is 5 cm long. b) Photomicrograph of coarse-grained massive quartzite consisting almost entirely of quartz. Crystals of quartz are equigranular and show triple boundaries. Accessory minerals are muscovite, silimanite and garnet. Muscovite and silimanite are parallel oriented.

Qtz = quartz; Musc = muscovite.

and overturned folds. The outcrop size ranges from 1m to over 10m in width and from 5m to over 150m in length. Thin sections of the massive quartzite are fine-grained, massive and consists almost of pure quartz (Fig. 2.5b). Crystals of quartz are equigranular and show triple junctions. Accessory minerals are muscovite and garnet.

2.2.3 Upper Pelite Formation

The Upper Pelite Formation was described by Mapani and Moore (1995) to consist of thin-banded metasiltstone intercalated with fine-grained quartzites, cross-stratified locally. Pelitic bands are present in both the banded metasiltstones and the quartzites. The metasiltstones are colour banded, probably representing sedimentary bedding. The bands range from 3 to 5 cm thick lying within quartzites. The banding typically consists of alternating metasiltstone and thin, 2 cm-thick layers of quartz-muscovite schist.

2.3 Gneiss Group

The Gneiss Group has a granite-gneiss complex intruded by pegmatites and mafic intrusives (Table 1). In the central parts of the area, deformation and anatexis led to the formation of migmatites. The group covers over 50% of the Kaseba-Katota area (see Fig 2.1).

2.3.1 Granites

Granites occupy a major part of the Kaseba-Katota area (see Fig. 2.1). The granites form a continuous trend of outstanding dome- to cone-shaped hills of up to 400m long, 200m across and 80m above the ground (Fig. 2.6). The granites tend to have a northwest vengeance between 30° and 70°.

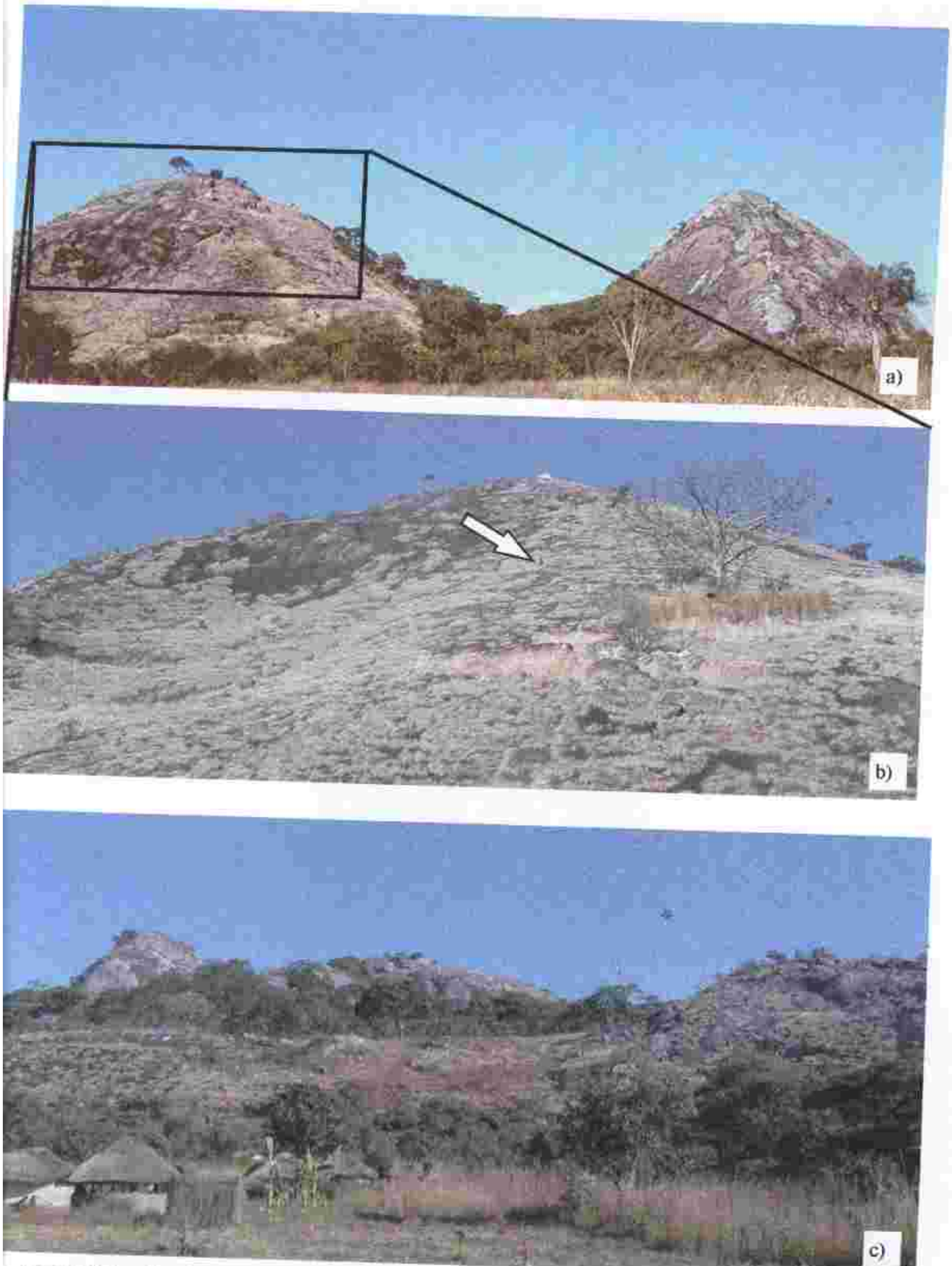
In outcrop, the granites vary in nature and can be divided into two complexes based on their structure and mineralogy namely Mesocratic and leucocratic granite and porphyritic granite complexes.

2.3.1.1 Mesocratic and Leucocratic Granites

The outcrops of the mesocratic and leucocratic granite complex (Fig. 2.7a and b) have surfaces coated black to different shades of grey with characteristic spheroidal weathering on bare surfaces. Outcrop size ranges from 1m x 2m to 75m x 150m. Colour ranges from dark to light grey and grain size from medium- to coarse-grained. The granites show foliation foliation striking east and northeast. The foliation is defined by mica and is usually vertical or steeply dipping to the southeast. Hand specimens are dense and

compact, consisting of quartz, feldspar, biotite, muscovite and accessory garnet and hematite.

In thin section, the granite is coarse-grained and granular, composed mainly of quartz, microcline, biotite and plagioclase (Fig. 2.7c and d). Accessory minerals include garnet, sericite and iron oxide. Quartz occurs as euhedral to subhedral crystals. Some quartz crystals show undulose extinction and share inter-fingered boundaries. Microcline occurs as subhedral crystals with albite and pericline twinning in places.



g. 2.6 a) Outstanding dome- to cone-shaped granite hills about 1.2 km north-west of Kamena School. b) A ailed part of the hill in (a) with a person (see arrow) for scale. c) A continuous trend of granite hills east of se shown in (a). Huts for scale.

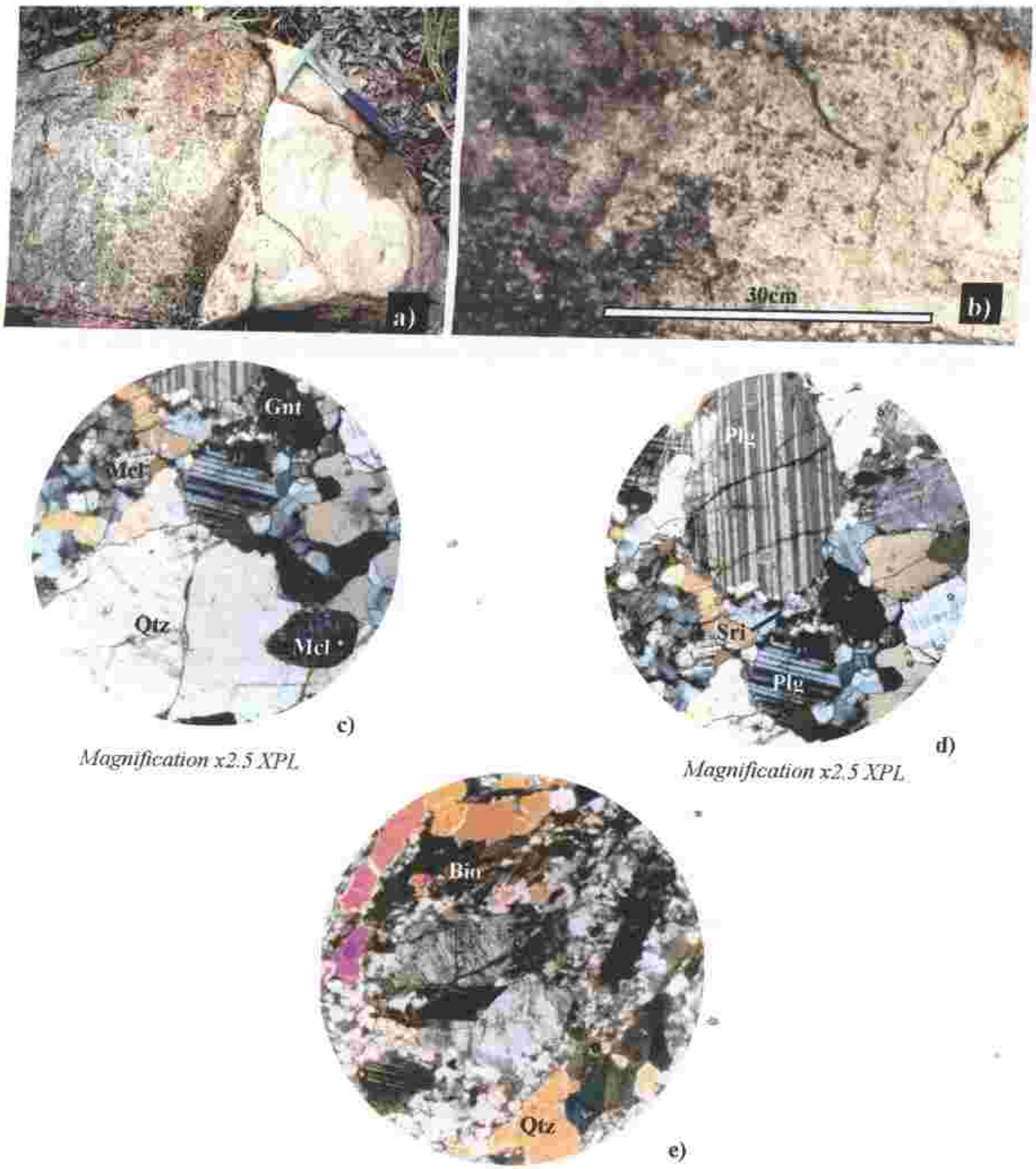


Fig. 2.7: a) Outcrops of medium- to coarse-grained leucocratic and mesocratic granite complex, surfaces are coated brownish to different shades of grey with characteristic spheroidal weathering on the surfaces, Kaseba area. Hammer is 30 cm long. b) Outcrops of mesocratic granite with medium-grained texture. The granites are weakly foliated striking east and northeast, Kaseba area. c and d) Photomicrographs of leucocratic granites. The texture is coarse-grained and granular, composed mainly of quartz, microcline, and plagioclase. Accessory minerals include garnet and sericite. Quartz occurs as subhedral crystals and share inter-fingered boundaries. Microcline occurs as subhedral crystals with albite and pericline twinning in places. Plagioclase is subhedral with very distinct albite and lamella twinning. Plagioclase is altered to sericite. e) Photomicrograph of mesocratic granite. The texture is medium– to coarse-grained and foliated. The gneiss is composed of recrystallised elongate quartz, biotite and plagioclase. Biotite flakes are subhedral and random to sub-parallel to each other.

Qtz = quartz; Mcl = microcline; Bio = biotite; Plg = plagioclase; Gnt = garnet; Sri = sericite.

Plagioclase is subhedral with very distinct albite and lamella twinning. It is altered to sericite. Biotite flakes are random to sub-parallel, subhedral to euhedral. Biotite wraps around quartz and feldspars but also forms parallel flakes defining a weak foliation.

2.3.1.2 Porphyritic Granite

Porphyritic Granite is the most common type of granite in the study area. Its outcrops are usually dome-shaped with surface areas ranging from 10m x 15m to 100m x 300m and heights from 2m to 80m (see Fig. 2.6). The outcrops of the porphyritic granite (Fig. 2.8a-d) are coated black and occasionally vegetated along deep cracks. In the Kaseba area, the porphyritic granite contains thin bands of foliated micro-granite with sharp contacts. The porphyritic granite contains lens-shaped xenoliths of gneisses and schists sub-parallel to the phenocrysts.

Hand specimens of the porphyritic granites are dense, compact and consist of preferred oriented subhedral phenocrysts of quartz and K-feldspar set in a fine- to medium-grained mafic-rich matrix. The granite is intruded by pink to white, fine-grained aplites to the southwest of Kaseba (see Section 2.3.7).

Thin sections of the porphyritic granite have very coarse-grained porphyritic texture (Fig. 2.8 e and f). The granites are mainly composed of quartz, albite, orthoclase, microcline, plagioclase and accessory biotite and sericite. Quartz and feldspar form myrmekitic texture (Fig. 2.8g). The groundmass is medium-grained and composed of quartz, feldspar, sericite and biotite.

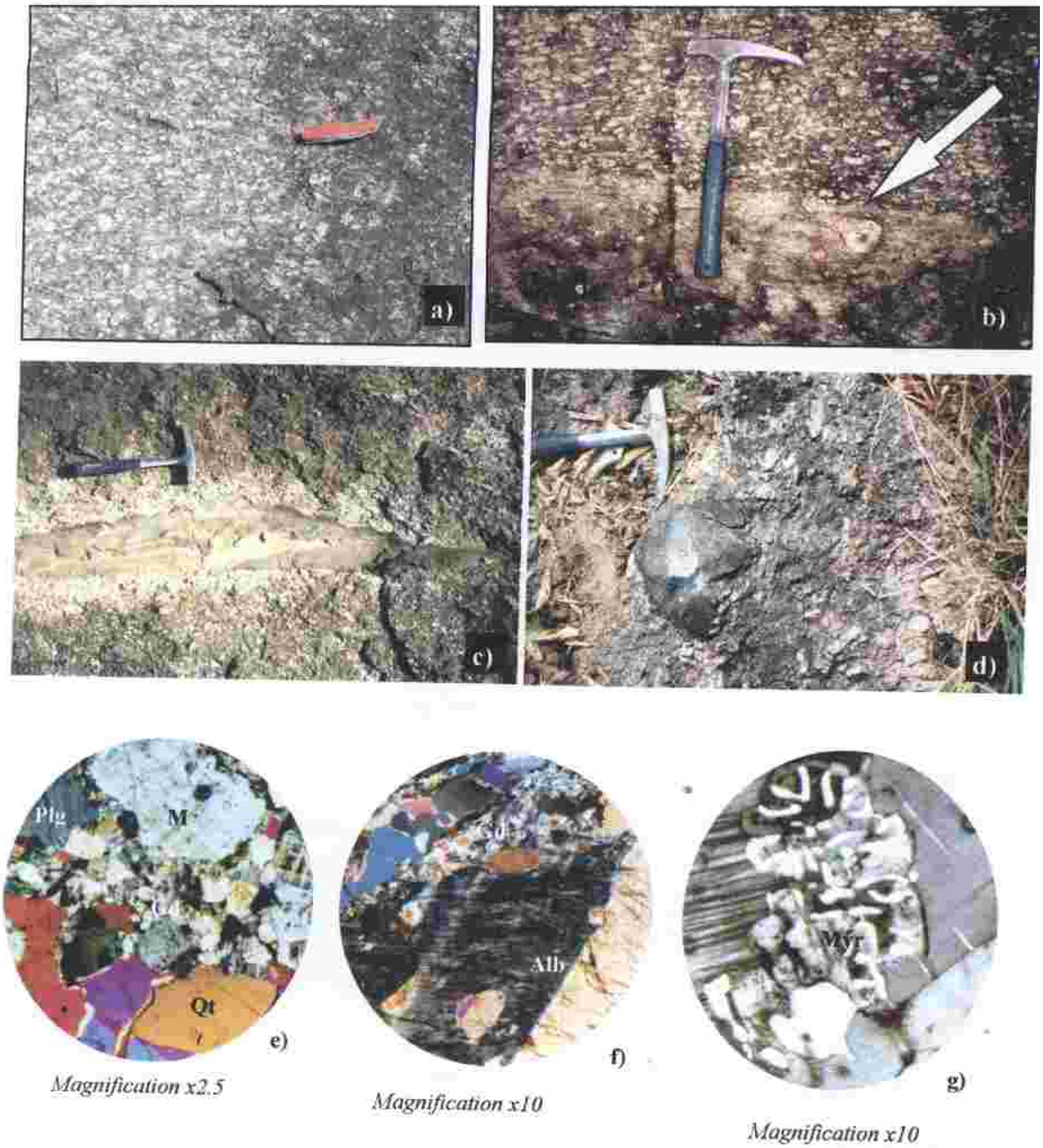


Fig. 2.8: a) Very coarse-grained porphyritic granite coated grey, Kamena area, the knife is 8 cm long. b) Porphyritic granite containing thin bands of foliated micro-granite with deformed and rotated feldspar crystals (see arrow), Kaseba area, hammer for scale. c) Porphyritic granite containing lens-shaped xenolith of mesocratic gneiss sub-parallel to the phenocrysts, Kaseba area. Hammer for scale. d) Porphyritic granite containing oval-shaped xenolith of gneisses, Kaseba area. Hammer for scale. e and f) Photomicrographs of porphyritic granite with very coarse-grained porphyritic texture. The granite is mainly composed of quartz, albite with albite twinning, microcline with cross hatching, plagioclase and accessory biotite and sericite The groundmass is medium-grained and composed of quartz, feldspar, sericite and biotite. g) Photomicrograph of porphyritic granite showing myrmekitic texture between quartz and feldspar.

Qtz = quartz; Mcl = microcline; Plg = plagioclase; Gdm = ground mass; Alb = albite; Myr = myrmekitic texture.

2.3.2 Gneisses

Gneisses occupy another major part of the Kaseba-Katota area (see Fig 2.1). The gneisses are characterised by an undulating landscape south-east of the study area near the escarpment and south of Katota area. Outcrops sizes range from 0.5m x 1m to 100m x 200m. Thin units of schist and amphibolite about 1m thick and up to 150m long, occur as intercalations within the gneisses. Locally, the gneisses grade into migmatites with assimilated boundaries.

In outcrop, the gneisses can be divided into three types based on their structure and mineralogy. The first and most abundant type in the study area is the medium- to coarse-grained mesocratic gneiss. The second type of gneisses and next in abundance is fine- to medium-grained leucocratic gneiss. The third type of gneisses is dark-grey with coarse-grained porphyroblastic texture.

2.3.2.1 Mesocratic Gneiss

The medium- to coarse-grained mesocratic gneiss (Fig. 2.9a and b) commonly forms extensive flat outcrops (50m x 150m), which are well exposed in the south and south-east of Masola and around the source of Manda River (see Fig. 1.1). Most of the outcrops of the medium- to coarse-grained mesocratic gneisses are fresh with a distinctive dark and medium grey colour and intruded with quartz veins which are 1-20 cm thick and 5-150 cm long.

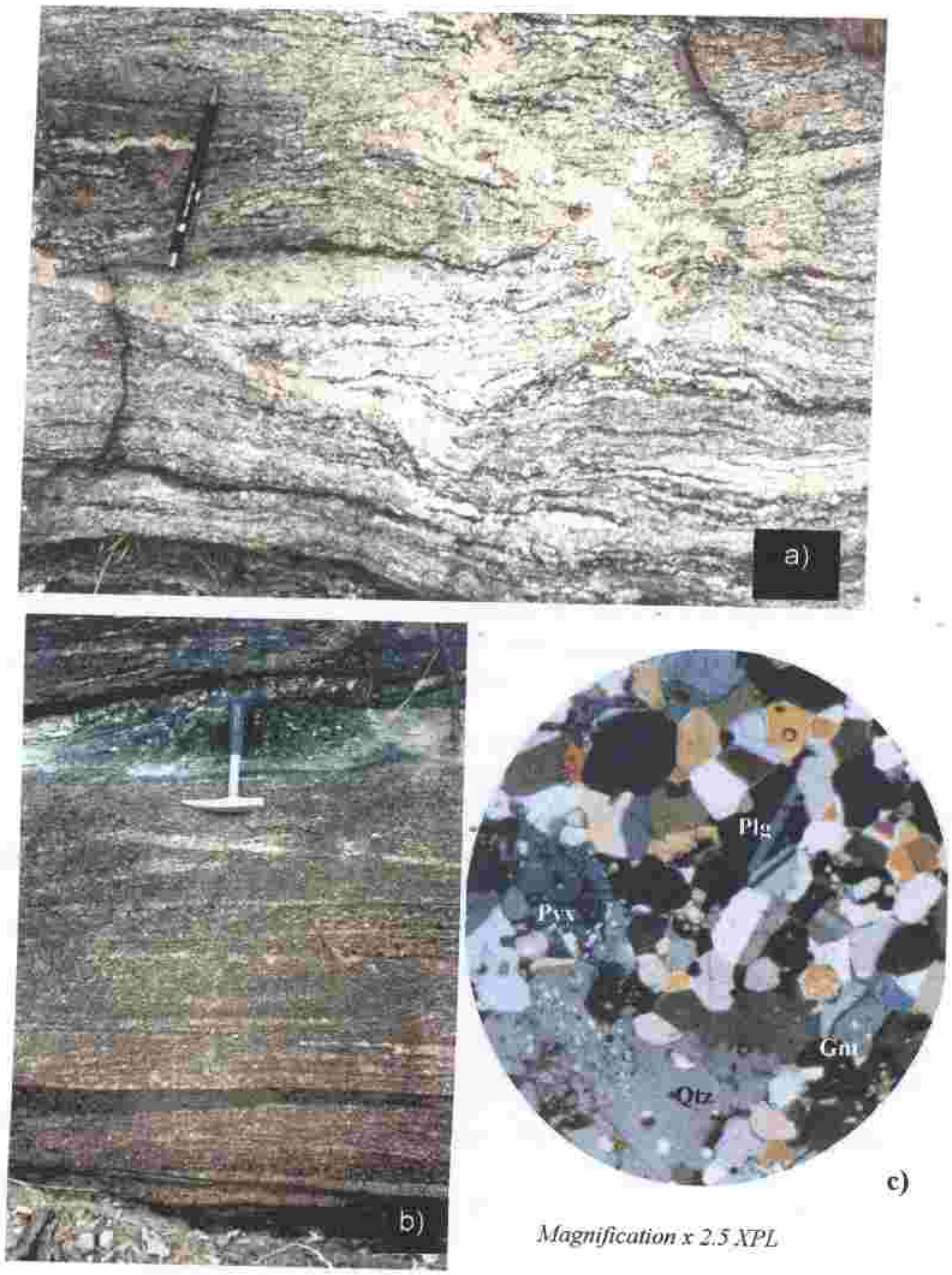


Fig. 2.9: a) Outcrop of garnet-rich mesocratic gneiss with flow banding. Pencil is 15 cm long. b) Outcrop of medium- to coarse-grained mesocratic gneiss with stretched quartz crystals and quartz veins. The quartz vein (below hammer handle) is 1-5 cm wide and more than 5 cm long. Hammer is 30 cm long. c) Photomicrograph of medium-grained mesocratic gneiss in (b). The mesocratic gneiss is mainly composed of quartz, plagioclase, pyroxene and garnet. Quartz crystals are subhedral with strain boundaries at triple junctions. Pyroxene crystals show two cleavage directions and alteration around the rims. Garnet occurs as euhedral to subhedral prisms.

Qtz = quartz; Plg = plagioclase; Pyx = pyroxene; Gnt = garnet.

In thin section (see Fig. 2.9 c and d), the gneiss is medium-grained. It is composed of recrystallised elongate quartz, K-feldspar, plagioclase, pyroxene and garnet. Quartz crystals are subhedral with strain boundaries at triple junctions. Plagioclase is recrystallised to subhedral crystals. Parallel small inclusions of quartz are present in the feldspars. Garnet occurs as euhedral to subhedral prisms. Pyroxene crystals show alteration around the rims.

2.3.2.2 Leucocratic Gneiss

The leucocratic gneisses (Fig. 2.10a) are more resistant in contrast to the mesocratic gneisses. In the south-east of Kaseba the leucocratic gneisses form isolated rectangular blocks measuring 10m long, 1-2m thick and up to 2m high. Leucocratic Gneiss constitutes a major portion of Panswa hills (see Fig. 2.1) with outcrops measuring 50m x 100m. The gneiss also occurs as thin units (0.5m x 15m) in the medium- to coarse-grained mesocratic gneiss.

In thin section, the gneiss is coarse and granoblastic in places. The main minerals are quartz, orthoclase with accessory plagioclase. The rocks are composed of alternating biotite-rich and quartz-rich bands defining gneissosity (Fig. 2.10b). The minerals are mainly equigranular but quartz crystals are elongated and fractured. Among quartz crystals are fibrous aggregates of sillimanite. In places, plagioclase is altered to sericite.

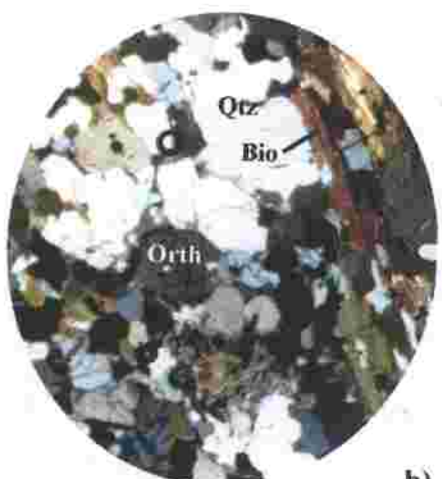


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Fig. 2.10: a) Medium-grained leucocratic gneiss with very strong foliation. b) Photomicrograph of the leucocratic gneiss. The leucocratic gneisses have coarse-grained texture. The main minerals are quartz, biotite and orthoclase with accessory plagioclase. The rock is composed of alternating biotite-rich and quartz-rich bands defining gneissic foliation.

Qtz = quartz; Plg = plagioclase; Orth = orthoclase; Bio = biotite; Pyx = pyroxene.

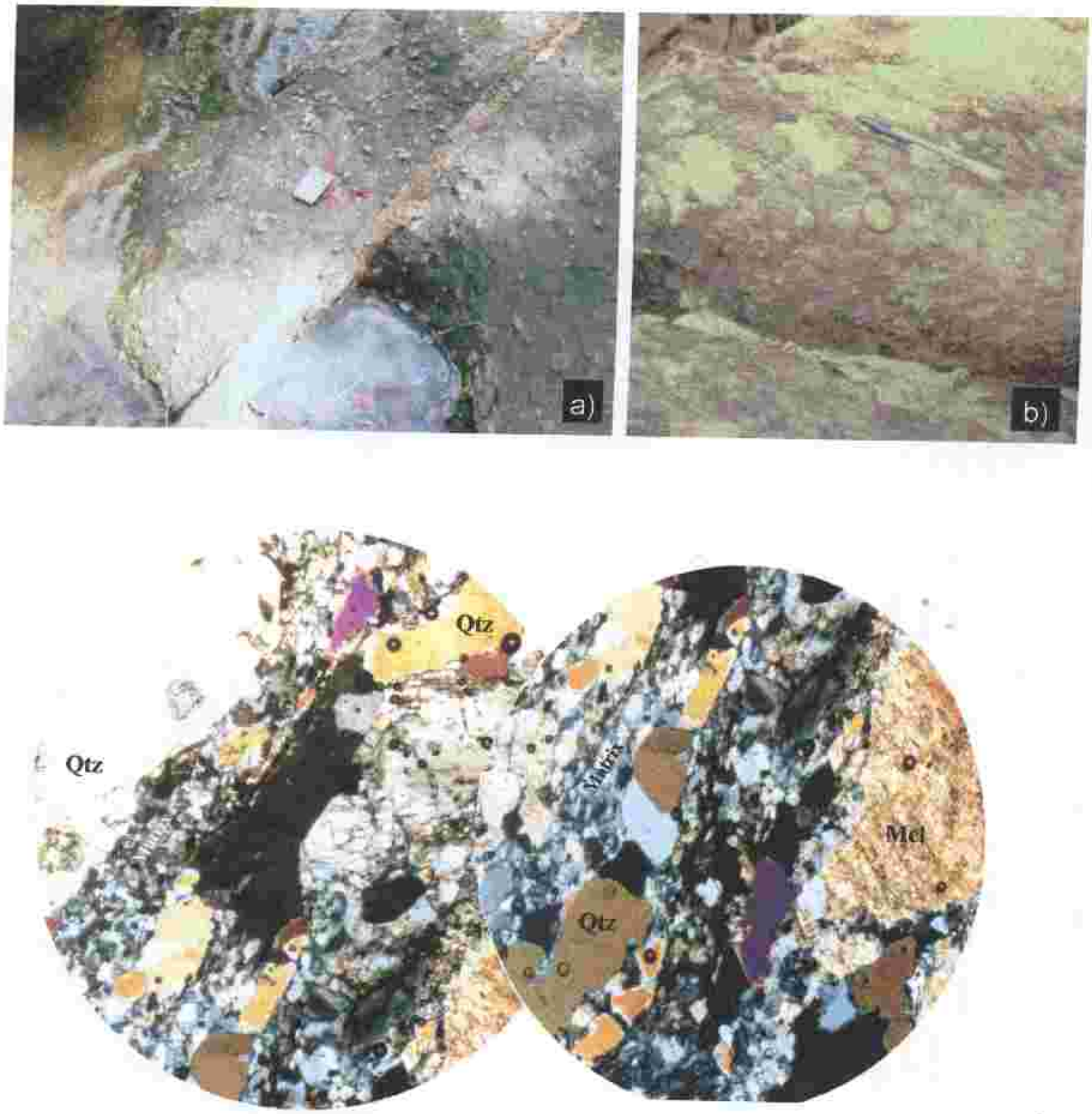
2.3.2.3 Porphyroblastic Gneiss

The porphyroblastic gneiss occurs as intercalations (5m x 15m) in the porphyritic granite in Kamena area and Mwelwansefu hills (see Fig. 2.1). In outcrop the gneiss is usually coated with varying shades of grey (Fig. 2.11a and b). Fresh surfaces show anhedral porphyries of pink feldspar and quartz embedded in a fine- to medium-grained feldspar-quartz-mica- rich matrix. Decompression texture, resulting from garnet porphyroblasts breaking down to quartz and feldspar, occur in the porphyroblastic gneiss south of Masola Bridge (see Fig. 1.1).

In thin section, the gneiss has very coarse-grained porphyroblastic texture (Fig. 2.11c). Quartz and microcline augens form the porphyroblasts, which are commonly rimmed by fine-grained microcline and quartz.

2.3.3 Migmatites

Migmatites occupy low-lying areas in the Kaseba-Katota area (see Fig. 2.1). The migmatites are deeply weathered and poorly exposed. Good exposures of fresh migmatites measuring between 2m x 5m and 5m x 15m occur where Lukusashi, Chipendezhi and Masola rivers (see Fig. 2.1) cut across contacts between the migmatite and other rock types. Two units are distinguishable in the migmatite namely, mesocratic and melanocratic migmatites. The mesocratic unit predominates the melanocratic gneiss. Fig. 2.12a and b shows mesocratic migmatites at the foot of Sumbeni Hill (see Fig. 1.1) where Masola crosses a contact between porphyroblastic schist and migmatite.



c)

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Fig. 2.11: a) Dark-grey coarse-grained porphyroblastic gneiss, coated with varying shades of grey. Porphyroblasts are composed of anhedral pink feldspar and quartz embedded in a fine- to medium-grained feldspar-quartz-mica- rich matrix. Silver compass is 5 cm long. b) Decompression textures in the porphyroblastic gneiss, Manda River area, south of Fukwe River Bridge. The pen is 10 cm long. c) Photomicrographs of the porphyroblastic gneiss in (a). Quartz and microcline augens form the porphyroblasts. The matrix is composed of fine-grained microcline and quartz.

Qtz = quartz; Mcl = microcline.

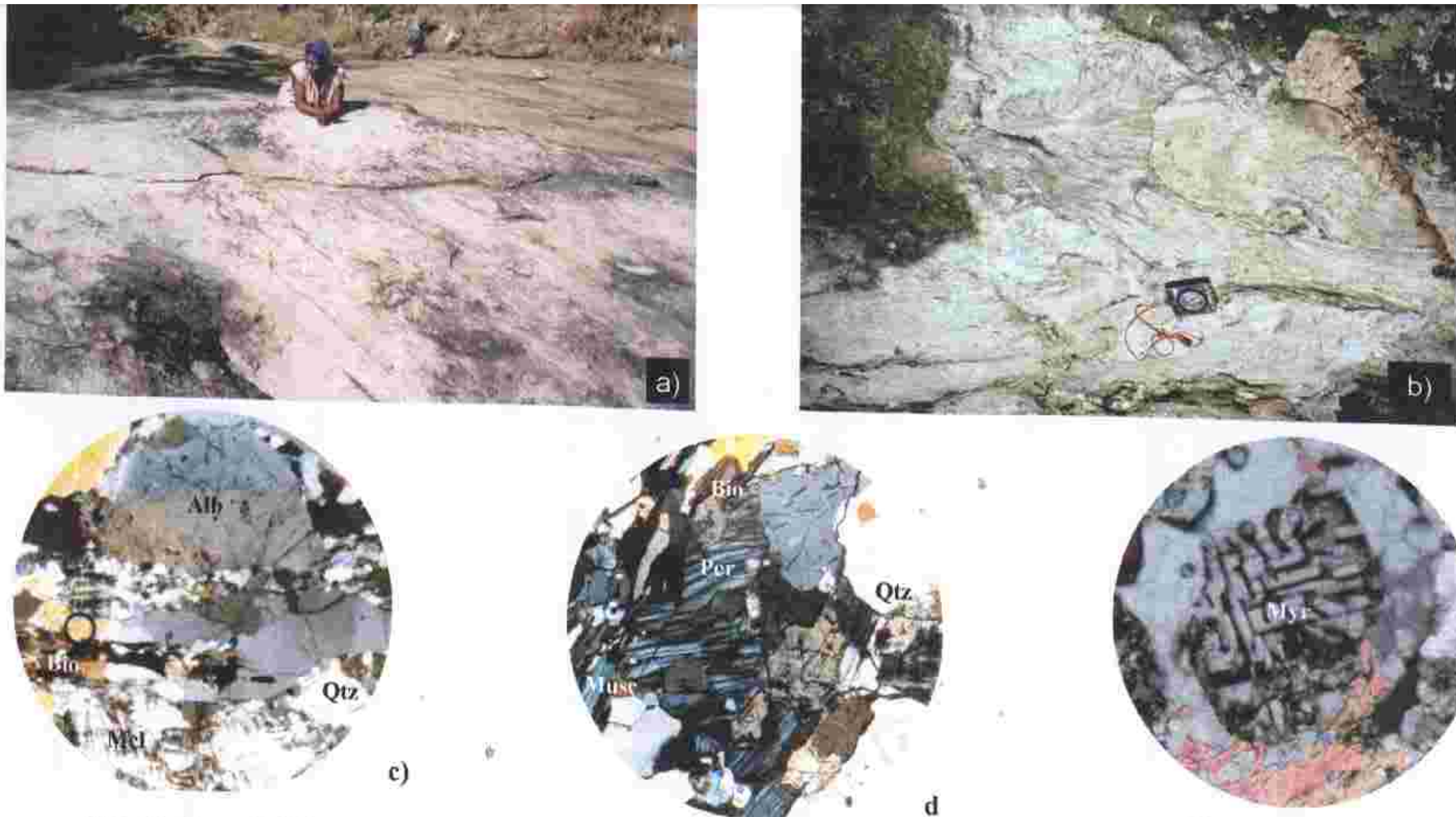


Fig. 2.12: a) Fresh mesocratic migmatite outcrops in the Lukusashi-Fukwe basin. Person for scale. b) Flow banding and ductile deformation in the mesocratic unit of the migmatite, in Chipendezhi River. Silver compass is 5 cm long. c) Photomicrograph of mesocratic migmatite. The migmatite is medium- to coarse-grained. The main minerals are quartz, albite and biotite. Quartz is recrystallised, fractured and elongate. Microcline is anhedral and elongate with distinct cross-hatching. Biotite is elongate, subhedral and parallel defining foliation. d) Photomicrograph of the mesocratic migmatite. The migmatite is couarse-grained and massive and alternates with the previous unit (c). d) Perthic texture between quartz and microcline. Iron oxide fills fractures in the rock. e) Myrmeckitic texture between quartz and microcline. Iron oxide fills fractures in the rock.

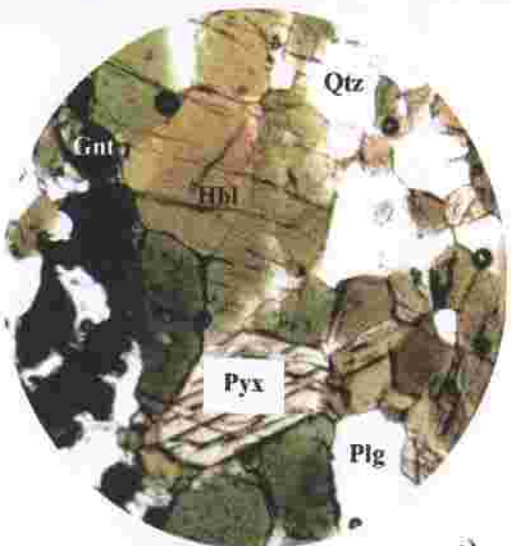
Qtz = quartz; Mcl = microcline; Plg = plagioclase; Per = perthite; Alb = albite; Myr = myrmekitic texture; Hbl = hornblende; Px

The migmatites are characterised by quartz-feldspar veins, ptygmatic folds, shlierine structures and rafts. Locally, the mesocratic gneiss has a sugary texture. Pegmatitic rocks occur in form of irregular pockets and stock-works within the mesocratic gneiss.

In thin section (see Fig. 2.12c and d), the mesocratic unit is medium- to coarse-grained and granoblastic. Fine-grained schistose layers are present in the unit and the main minerals are quartz, microcline, biotite, plagioclase and muscovite. Quartz occurs as anhedral grains with interpenetrating boundaries meeting at triple junctions. In the schistose layers, quartz is recrystallised and elongate, with fractures transverse to the long axes. Finer-grained quartz is polysutured. Microcline is anhedral and elongate with distinct cross-hatching. Microcline contains inclusions of biotite. Myrmekitic texture occurs between quartz and microcline. Biotite is subhedral and elongate, defining foliation. Plagioclase occurs as subhedral crystals with distinct lamella twinning. Symplecktic texture occurs where quartz and plagioclase are intergrown (see Fig. 2.12d). Sillimanite develops from biotite and occurs as parallel aggregates of fine needle-like crystals along biotite flakes. Garnet, staurolite, epidote are accessories. Garnet is highly fractured, rounded and contains inclusions of biotite.

The melanocratic unit (Fig. 2.13a and b) is fine- to medium-grained and foliated. Compositional banding and alignment of minerals define the foliation.

In thin section (Fig. 2.13c), the unit consists of hornblende, plagioclase, quartz and accessory iron oxide. Hornblende is subhedral to euhedral crystals, occurring in prismatic forms with perfect cleavages. The crystals are aligned parallel to foliation.



c)

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Fig. 2.13: a) Outcrops of melanocratic migmatites with folded and displaced quartz-feldspar veins. The pencil is 15 cm long. b) Fresh melanocratic migmatite outcrops along Lukusashi River. c) Photomicrograph of the melanocratic migmatite in (a), consisting of hornblende, pyroxene, plagioclase, quartz and accessory iron oxide. Hornblende and pyroxene crystals are subhedral to euhedral, occurring in prismatic forms with perfect cleavages. The crystals are aligned parallel to foliation. Plagioclase forms subhedral recrystallised crystals.

Qtz = quartz; Plg = plagioclase; Myr = myrmekitic texture; Hbl = hornblende; Pyx = pyroxene.

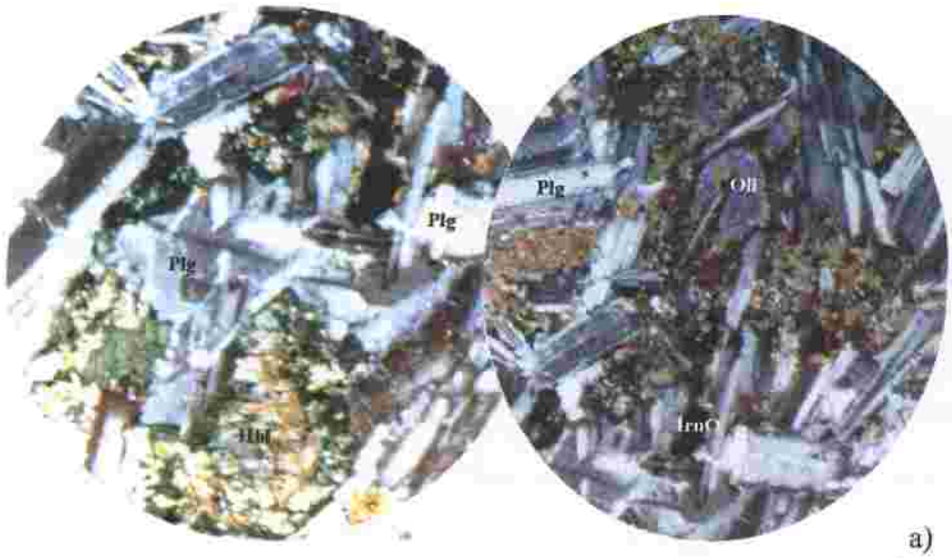
Plagioclase forms sub- to euhedral recrystallised crystals with distinct albite twinning. Iron oxide fills fractures in the rock.

2.3.4 Mafic Intrusives and Amphibolites

Mafic intrusives in the Kaseba-Katota occur in the form of loose boulders, which form narrow ridges 2 to 5m wide, 10 to 30m long and 3m high. The intrusives are dolerites intruding granites, gneisses, migmatites and schists.

In thin section, the dolerites consist mainly of plagioclase and pyroxene with minor olivine and iron oxide (Fig. 2.14). Plagioclase is coarse-grained with pericline and albite twinning. In places, the plagioclase is altered to scapolite. Pyroxene (augite) is rimmed by hornblende giving a corona texture. Hornblende occurs as pseudomorph of pyroxene.

Amphibolites are widespread in the northeast part of the Kaseba-Katota area. The amphibolites intrude granites, gneisses migmatites and schists, striking concordantly to the main Irumide foliation, but can form discordant lenses. The amphibolites range from a few centimetres to 200 cm wide and more than 200m long, and those occurring in the gneisses and granites are strongly foliated.



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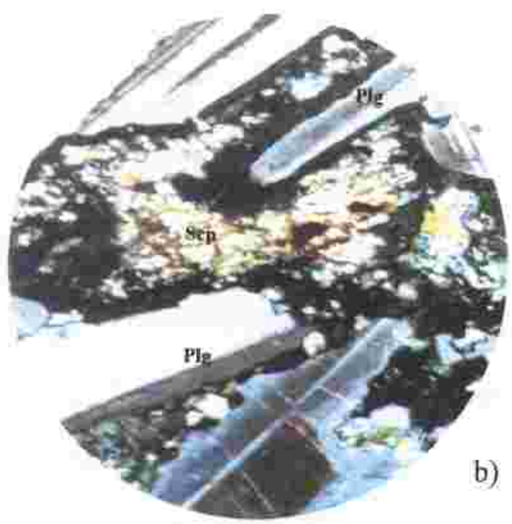

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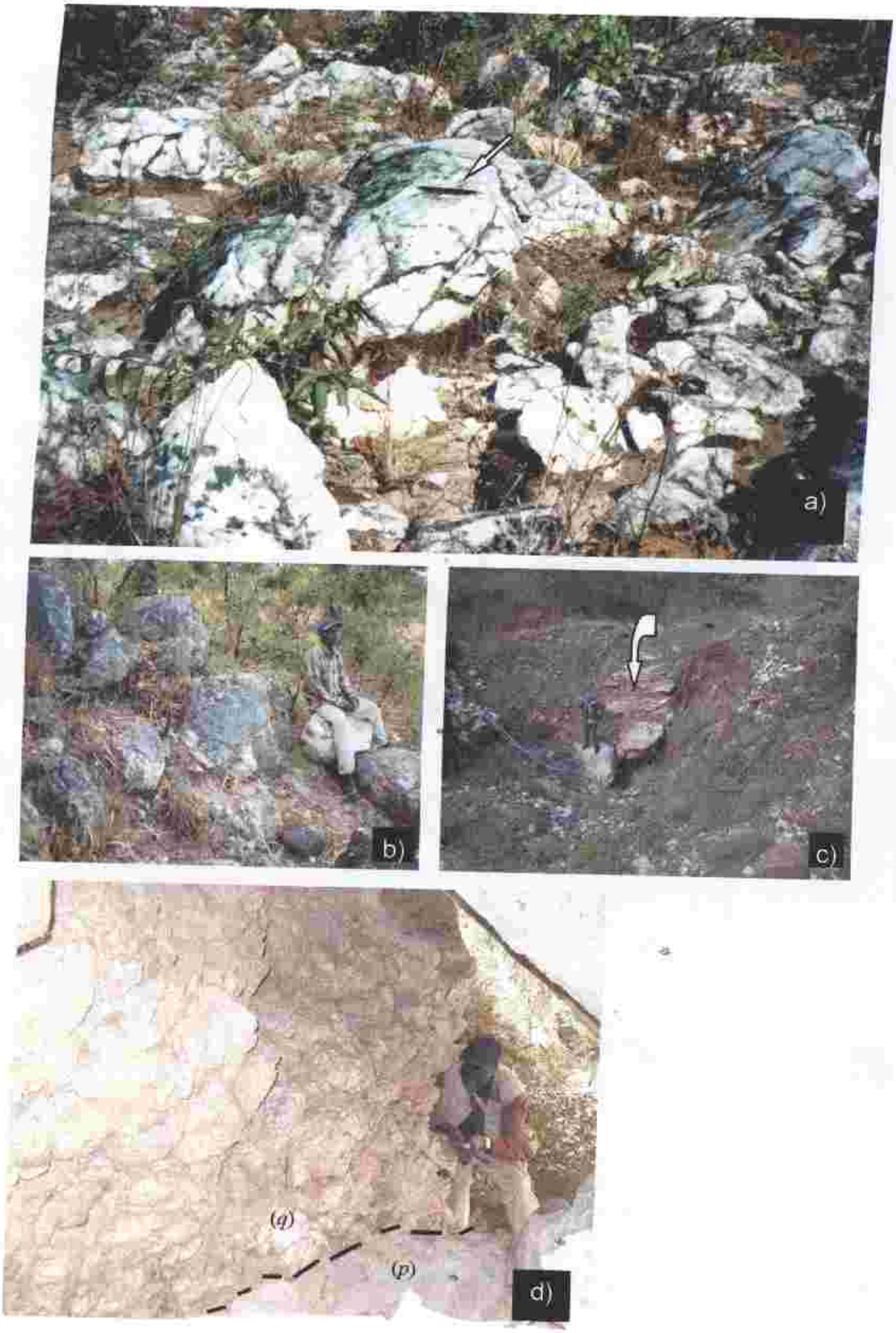
Fig. 2.14: a) Photomicrographs of dolerite consisting mainly of plagioclase, hornblende and pyroxene with minor olivine and iron oxide. Plagioclase is coarse-grained with pericline and albite twinning. b) Detailed Photomicrograph of dolerite showing plagioclase alteration to scapolite.

Plg = plagioclase; pyx = pyroxene; Hbl = hornblende; Scp = scapolite; Oli = olivine; IrnO = iron oxide.

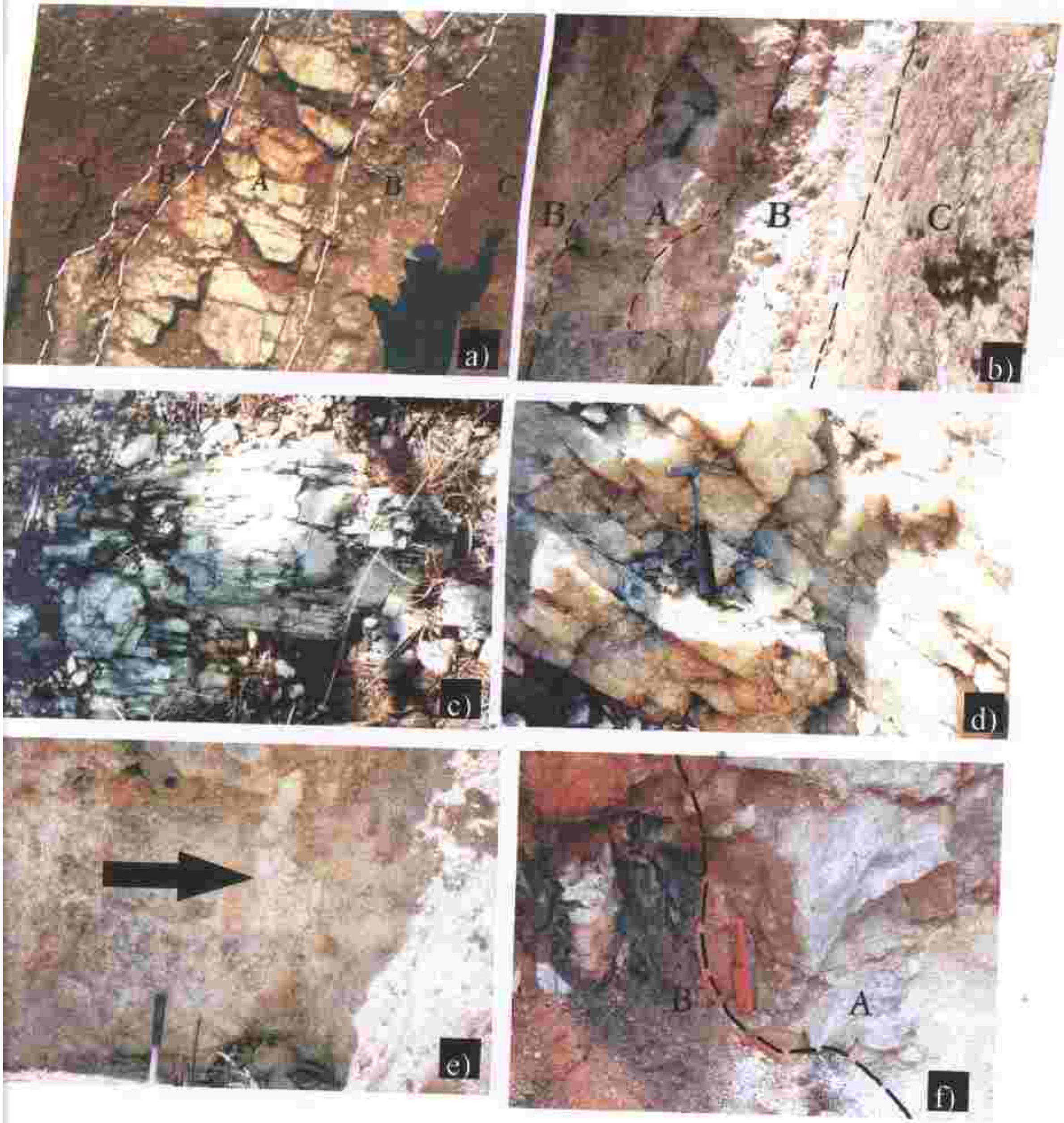
2.3.5 Pegmatites

Pegmatites occur as lensoids and dykes varying from 10 to 50 m in length, 0.1 m to 6 m in width and usually form small ridges rising above the general surrounding up to about 6 m high (Fig. 2.15). The pegmatites rarely form extensive and continuous bodies, but are associated with banded and migmatitic gneisses, schists and foliated quartzites. The *pegmatites are intermediate to felsic in composition and white to pink in colour.* Pegmatites occurring in the migmatites, gneisses and schists commonly host abundant 'books' of muscovite of up to 30 cm long, 15 cm wide and 15 cm thick (see Chapter. 4). The muscovite 'books' when exposed by weathering or mining, are a clue to the occurrence of pegmatites as they give a unique signature on the Landsat TM image provided there is little or no vegetation cover. The contacts between the pegmatites and the host rocks vary from very sharp to gradational.

Two generations of pegmatites can be distinguished based on age and their attitude, internal structure and nature of contacts with the host rocks. The earlier generation is of Mesoproterozoic Kibaran age (Mapani and Moore, 1995) and strikes between 20° and 80°, concordant to the major host rock structures and usually have assimilated boundaries. Mapani and Moore (1995) considered the earlier generation to contain beryl and aquamarine. Pegmatites of this generation are foliated, zoned and show three sets of joints, trending north-east, north-west and north respectively. Cross sections in the pegmatites show at least three zones (Fig. 2.16a and b) distinguished on basis of mineralogy, namely the core, intermediate and wall zones.



2.15: a and b) Loose boulders of pegmatite cores in the Kaseba-Katota area. The cores of the pegmatites nore resistant to weathering and stand out as small ridges of quartz boulders. Pencil (see arrow) is 15 cm in (a) and Person for scale in (b). c) An exposed pegmatite core (see arrow) in the Kamena area. Person cale. d) Very coarse-grained pegmatite, with a very sharp contact (see dotted line) between a quartz-rich (*p*) and a feldspar-rich intermediate zone (*q*), Panswa hills. Person for scale.



; 2.16: a) Cross section in the Kibaran pegmatite east of Masola area on the Chisomo Road (Fig 1.1). Three zones re distinguished as: A = core, B=intermediate zone, C=outer zone. Person for scale. b) Cross section in the Ki- an pegmatite, 3 km north of Kamena with three zones; A = core, B=intermediate zone, C=outer zone. Hammer is cm long. c and d) Foliated core zones in the Kibaran pegmatites consisting of recrystallised elongate crystals of rtz. Hammer for scale. e) Intermediate zone in the Kibaran pegmatite showing kaolinised portions (see arrow), th of Kamena. Hammer for scale. f) Intermediate zone showing tourmaline mineralisation in the Kaseba area. ife is 8 cm long.

The core in the Kibaran pegmatites is foliated and consists of recrystallised elongate crystals of quartz. The intermediate zone is composed of sub- to euhedral crystals of feldspar and recrystallised crystals of quartz (see Fig. 2.16c and d). Well-developed graphic intergrowths are common in the intermediate zone. The intermediate zone in most pegmatites of the older generation is kaolinised (see Fig. 2.16e). The kaolinisation results from weathering and erosion of feldspars which give a unique signature on aerial photographs. The outer zone consists of a homogeneous mixture of muscovite, feldspar and quartz. The grain size, particularly that of quartz and feldspar, increases towards the cores (2–100 cm) of the pegmatites.

Other minerals in the zoned pegmatites include garnet, hematite (in the core), chlorite, biotite, tourmaline (see Fig. 2.16f) and beryl (in the intermediate zones). Mica, feldspar and beryl are the principal commercial minerals recovered from zoned pegmatites (see Chapter 4). These minerals are concentrated in the intermediate zone.

A classic example of a zoned pegmatite is from Chibolele Mine (Fig. 1.17a) located 8 km south-east of Kamena School (see Fig. 1.1). The pegmatite is emplaced in the fine- to medium-grained leucocratic gneiss. Four trenches were made by earlier prospectors to intersect the pegmatite at an average spacing of 15m. The Mine has been exploited for beryl until February 1998. Four zones are present in Chibolele Mine. The core (Fig. 2.17b) is composed predominantly of white, milky megacrystals of massive and recrystallised elongate quartz and barren. On smooth fractured surfaces, the quartz crystals are striated. Isolated crystals of smoky quartz are also present. The contact between the core and the intermediate zones is very sharp. The intermediate zone is subdivided into two sub-zones based on texture and mineralogy: the inner and outer

ig. 2.17: a) Chibolele Mine quarry; approximately 15m wide (near the surface) and 6m deep. The quarry ex-oses pegmatite zones on its benches. The core does not contain economically important minerals. Person for ale. b) Pegmatite core composed predominantly of white, milky and recrystallised elongate quartz. Isolated ystals of smoky quartz are also present (see arrow). c) The inner intermediate sub-zone; composed of fractured ystals of feldspar (whitish) and quartz (blue). Pencil is 15 cm long. d) Outer intermediate sub-zone is brownish white, composed of very coarse-grained feldspar. The feldspar crystals are heavily fractured and strongly eaved. The picture is 1.8 m across. e) Wall zone composed mainly of weathered, coarse-grained, feldspar and eritic material. Picture is 3m across.

intermediate sub-zones. The inner intermediate sub-zone (see Fig. 2.17c) is yellowish brown to white and composed of heavily fractured crystals of feldspar and quartz. The sub-zone has blocks which contain very coarse graphic intergrowths of pink feldspar and glassy quartz. The inner intermediate sub-zone consists of a 10 cm thick feldspar-rich unit, a 10 cm thick muscovite-rich unit and a 30 cm thick feldspar-quartz-lepidolite unit with traces of black tourmaline.

The outer intermediate sub-zone (see Fig. 2.17d) is brownish to white, composed of very coarse-grained aggregates of feldspar, muscovite and quartz. The outer sub-zone is 50 cm thick and is separated from the inner sub-zone by a sharp contact.

A 5 cm thick, muscovite-rich rim separates the wall zone from the intermediate zone. The wall zone (see Fig. 2.17e) is whitish and composed of very coarse-grained white feldspar, medium-grained quartz and muscovite. The wall zone is 2m thick and heavily fractured.

The later generation of pegmatites is of Neoproterozoic Pan-African age and is oblique and perpendicular to the Kibaran pegmatites. The pegmatites of the Pan-African generation do not show any significant internal structures. The major joint set associated with this generation of pegmatites is north trending with vertical dips and a faint north-west trending set of joints.

2.3.6 Quartz veins

Quartz veins intrude all rocks in the Kaseba-Katota area. The quartz veins (Fig. 2.18) have various trends and sizes ranging in width from millimetre scale to about 6m. In length, quartz veins can be traced for hundreds of metres. Quartz crystals in the veins range from opaque milky to transparent.

2.3.7 Aplites

The aplites are intrusive into the porphyritic granite south and southwest of Kaseba School (see Fig. 1.1). The aplites occur in form of dykes measuring 15 cm across and at least 30 m long (Fig 2.19), and are commonly emplaced parallel to the orientation of the phenocrysts in the porphyritic granite. However some are perpendicular to foliation while others form stocks. In hand specimen, the aplites are yellowish white, fine- to medium-grained with a sugary texture. The mineralogy is predominantly quartz and K-feldspar.

g. 2.18: Stretched quartz veins in fine– to medium-grained banded gneiss. The quartz veins are emplaced ırallel to the host rock foliation at N52°E. Pen is 15 cm long. b) Folded quartz veins in the migmatite in lasola area. Hammer is 100 cm long. c) Folded quartz vein in the mesocratic granite in Kamena area. ammer is 30 cm long.

'ig. 2.19: a) Aplite dykes intrusive into the porphyritic granite south and southwest of Kaseba School. Hammer s 30 cm long. b) Aplite dyke emplaced discordantly to the orientation of the phenocrysts in the porphyritic grane. The foliation trend in the porphyritic granite is east-west parallel to the pencil. Pencil is 15 cm long.

CHAPTER

3

3.0 STRUCTURE AND METAMORPHISM

3.1 General

The Kaseba-Katota area has been shaped by a series of deformations and associated metamorphism. These have led to development of lineaments, faults and folds that can clearly be seen on the Landsat TM image used in this study (Fig. 3.1). Metasedimentary ridges of the Serenje Group stand out as lineaments, folded in the northern part of the image and faulted in the centre of the image (Fig. 3.1). The Gneiss Group is represented by round to oval-shaped granitic intrusions appearing as small dots in the image (Fig. 3.1).

Many authors have recognised at least four deformational episodes and four accompanying metamorphic cycles in the neighbouring areas. The metasediments in the adjacent areas of Kaseba-Katota (north and north-west of Serenje Town) were affected by four deformation episodes (Mapani and Moore, 1995; Cordiner, 1999). The D_1 phase produced F_1 folds with northerly trending axes. Axial traces of the F_1 folds wrap around the Sasa Dome (Fig. 3.1). East of Sasa Dome, the D_1 structures are sub-horizontal with northwest thrusting and recumbent folds. The S_1 foliation is observable in the Sasa Dome. The D_2 event affected narrow zones and back-thrusted D_1 structures, producing northeast-trending folds. The D_2 deformation episode is correlated with the main Irumide Orogeny which produced the main S_2 foliation in the rocks of the area. S_2 is

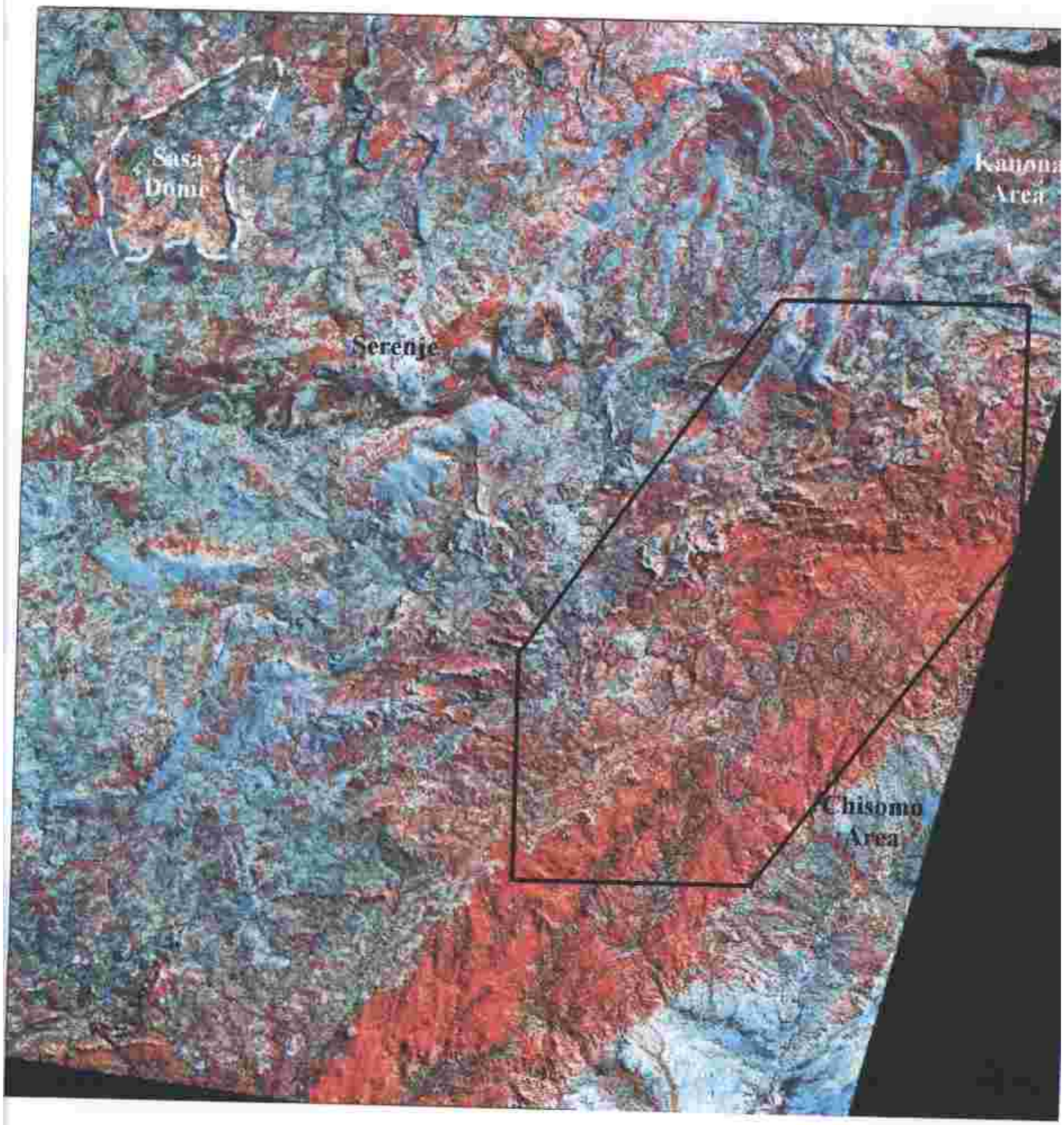


Fig 3.1: Landsat Thematic Mapper image of Serenje area of August 1998 in false colour composite (bands '4, 5 and 7) showing general structural features of the study area (black box) and the surrounding areas such as Sasa Dome, Kanona and Chisomo. The area shown is approximately 100 x 90 km.

characterised by tight to isoclinal folds with northeast axes, and vertical to sub-vertical fold hinges. The D_3 event is characterised by open folds with northwest axes, and is weaker than D_2. The D_3 deformation is correlated with the Lufilian Orogeny and is less represented in the Kanona area. S_3 is mainly a crenulation of S_2 cleavage. D_4 produced the faulting associated with the Karoo extensional tectonics. Klinck (in press) described three deformation episodes in the Chisomo area (see Fig. 3.1). The earliest deformation (D_1) resulted in north-north-westerly biotite schistosity. D_2 produced isoclinal and coaxial folds, whereas the D_3 event produced tight upright similar folds along northeast axes and is attributed to the main Irumide event. The D_4 event is characterised by open upright folds along northwest axes.

3.2 Structure

A succession of deformations and metamorphic episodes have shaped the Kaseba-Katota area leading to a complex structural and metamorphic history. Three deformation episodes, D_1, D_2 and D_3, associated with S_1, S_2 and S_3 foliations are observable in the Kaseba-Katota area.

3.2.1 Folding

The D_1 deformation phase produced northwest trending S_1 foliation. The S_1 foliation is faintly observable in the fine- to medium-grained leucocratic gneisses south of Katota School (see Fig. 1.1).

The D_2 deformation episode produced the main S_2 foliation in the Kaseba-Katota area. S_2 deformed the angular (Fig. 3.2a) isoclinal F_1 folds with northeast trending axial traces, and steeply plunging hinge lines. Mappable-scale F_1 folds are easily identified on aerial photographs and the satellite image (see Fig. 3.1).

Kink folds of chevron type are present in garnet-sillimanite schist (Fig. 3.2b and c) southwest of Masola Bridge (see Fig. 1.1). The presence of leucosomes and neosomes in the fine- to medium-grained gneisses shows that the D_2 deformation was associated with anatexis and migmatisation. The rocks of the Katota School and Manda River areas (see Fig. 1.1) may have undergone several deformation events, but only D_2 is clearly observable. The main structural feature of the Kaseba-Katota area trends east-northeast/west-south-west and is attributed to D_2, the main Irumide deformation. This event has almost obliterated all older structures in the area. The younger D_3 event is represented by weak open F_2 folds (Fig. 3.2d). The F_2 folds have northwest trending axial traces, and gently plunging hinge lines. The folds are observable in fine- to medium-grained leucocratic gneiss and the micaceous quartzite. The D_3 deformation is correlated with the Lufilian Orogeny and is not very distinctly represented in the Kaseba-Katota area. S_3 is mainly a crenulation of S_2 cleavage, it is well exposed in the schist south of Katota and north of Kaseba (see Fig. 2.1). Shear zones are associated with both D_2 and D_3 (Fig. 3.2e).

3.2.2 Faulting

The major faults mapped were located by aerial photograph and Landsat TM image interpretation. Metasedimentary ridges of the Serenje Group provided useful horizons

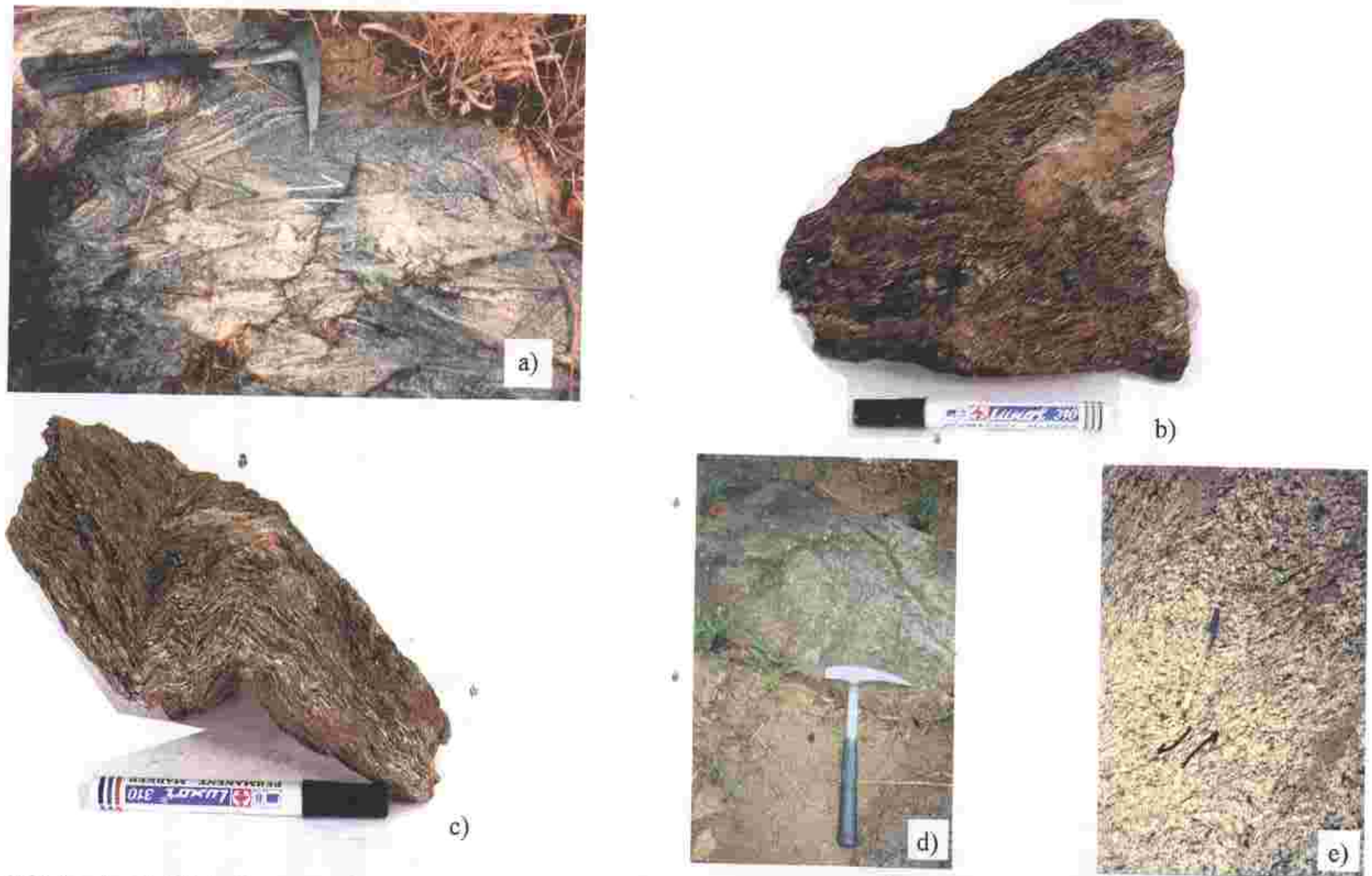


Fig. 3.2: a) Angular F_1 folds in the mesocratic gneiss with northeast trending axial traces, and steeply plunging hinge lines. Hammer is 30 cm long. b) Crenulations in the garnet-sillimatite schist southwest of Fukwe Bridge (Fig. 1.1). Marker is 13 cm long. c) F_1 Kink folds in the garnet-sillimatite schist southwest of Fukwe Bridge. The axes of folds plunge to the southwest between 30° and 70°. Marker for scale. d) F_2 folds have northwest trending axial traces, and gently plunging hinge lines. The F_2 folds are observable in fine- to medium-grained leucocratic gneiss and the micaceous quartzite. Hammer for scale. e) Shear zones (see arrow) in the medium-grained leucocratic gneiss. Pen is 15 cm long.

in the detection of strike-slip faulting. The Kaseba-Katota area is affected mainly by two sets of fault systems, one with north-west trend, the other with north-east trend.

The north-east - trending fault system resulted from the D_2 deformation episode and is more prominent between Mwelwansefu hills and Katota area and less prominent to the south of Mwelwansefu hills (see Fig. 2.1). This fault system has affected contacts between the Gneiss and Serenje groups. The quartzite and intercalated schists are locally sheared and granulated.

The north-west - trending fault system resulted from the D_3 deformation episode and mainly affected the Serenje Group to the south and southwest of the study area.

3.2.3 Jointing

Three sets of joints resulting from D_1, D_2 and D_3, deformation episodes respectively, are present in the Kaseba-Katota area. At the Landsat TM image resolution (28 m x 28 m), and aerial photograph scale (1:30,000), joints were not recognisable. However, field mapping revealed three joint sets. Foliated quartzites (Quartzite Formation) contain all the three sets of joints. J_1 joints appear faint and trends between north of northwest and north. The most prominent of the three is J_2 which trends N48°E (see Section 6.3) and is more or less concordant to the S_2 foliation and the axial traces of F_1 folds. J_3 set is common in the porphyroblastic gneisses, porphyritic granites and migmatites and has a north-west trend.

3.3 Metamorphism

Generally the metamorphic grade in the Serenje area, which includes the Kaseba-Katota area, increases from greenschist in the northwest to upper amphibolite in the south-east. Greenschist facies assemblages are characterised by chlorite-muscovite-quartz-talc in the metasedimentary rock episodes (Mapani and Moore, 1995; Cordiner, 1999). To the south-east, staurolite occurs with garnet, and farther southwards, cordierite and sillimanite are present. Migmatites have essentially garnet-biotite-plagioclase-sillimanite assemblage. Around Chisomo area, D_1 was accompanied by M_1 biotite-staurolite-garnet mineral growth in the upper amphibolite facies. The $M_{2\text{-}3}$ event continued through D_2 and D_3 in the upper amphibolite facies. The D_4 deformations were accompanied by widespread retrograde metamorphism during the M_4 metamorphic episode, forming biotite-chlorite-sericite assemblages of the greenschist facies. The calc-silicates of the Chisomo area, south-east of Kaseba-Katota area, show diopside-garnet-zoisite-plagioclase assemblages characteristic of the sillimanite zone to the northwest and the assemblage carbonate-edenite-plagioclase-diopside and biotite-diopside-edenite-scapolite-plagioclase with epidote to the south-east.

Within the Kaseba-Katota area, greenschist facies assemblages are apparent in the metasedimentary rocks of the Serenje Group to the north-west, which increase towards the south and south-east into amphibolite facies in the gneisses and migmatites (see Fig.2.1). The greenschist facies are characterised by muscovite-quartz in the Serenje Formation (see Figs. 2.3 and 2.5) and garnet-sillimanite-biotite in the Gneiss Formation (see Fig. 2.10).

The D_1 and D_2 events in the Kaseba-Katota area were accompanied by metamorphic mineral growth in the upper amphibolite facies. The Gneiss Formation shows typical mineral assemblages of muscovite-biotite-microcline-quartz in granites and gneisses with epidote in places. The Serenje Group metasediments between Kamena and Chintankwa area have assemblages of muscovite-kyanite-quartz. This suggests relatively high-pressure metamorphism. The D_2 deformation in the Katota School and Chipendezhi River areas (see Fig. 1.1) was accompanied by development of metamorphic assemblages of quartz-microcline-plagioclase-biotite-muscovite-epidote in the Gneiss Formation whereas in the Quartz, Upper- and Lower Pelite formations, muscovite-garnet-sillimanite mineral assemblage were developed. The D_3 deformation was accompanied by retrograde metamorphism during the M_3 metamorphic episode, forming biotite-chlorite-sericite assemblages of the greenschist facies.

CHAPTER 4

4.0 ECONOMIC GEOLOGY

4.1 General

The Kaseba-Katota area is endowed with abundant mineral resources suitable for small- and medium-scale mining which could be a source of employment, income and export earnings. The widespread illegal mining (Fig. 4.1) that has been going on in the Kaseba-Katota area has made it difficult to estimate the extent of small-scale mining and it's impact on the social, environmental and economic sectors. Economic minerals mined in the Kaseba-Katota area are aquamarine, beryl, feldspar, mica, tourmaline, quartz and Magnetite. About 106 pegmatites (Table 2) were recorded during fieldwork in the study area. Out of the 106 pegmatites mapped, 26 host economically important minerals. Gneisses host most of the economically important pegmatites.

4.2 Aquamarine

Most number of pegmatites in the Kaseba-Katota though heavily fractured, host pale blue aquamarine. Known pegmatites with unfractured pale aquamarine are located south of Katota School and near Panswa hills (see Fig. 1.1). A mining trench measuring 15mx2mx2m (LBH) at location 245450E, 8534133N (UTM ZONE 36) has been excavated in a pegmatite by illegal miners. Approximately 50kg of pale blue to

Fig. 4.1: a) Mining activity in the Masola area (Fig. 1.1). This trench is being deepened for the third time by local miners to exploit aquamarine. Gemstones were discovered from a depth of 50 cm and deeper. b) An aquamarine mine in Kaseba area (Fig 1.1). The mineralised intermediate zone of the pegmatite is 1.2 m. The pegmatite dips at 40° to the southeast (see arrow). Person for scale.

Table 2: Pegmatites mapped in the Kaseba-Katota area.

AREA	LOCATION		STRIKE	DIP	DIRECTION	HOST ROCK	MINERALOGY (Pegmatite)	ZONNING
	East	North						
Masola	224011	8501171	50			Gneiss?	Quartz & K-feldspar	unzoned
Masola	224325	8502378	60			Gneiss?	Quartz, K-feldspar & muscovite	unzoned
Masola	222123	8497841	60			Gneiss?	K-feldspar, muscovite & quartz	unzoned
Masola	221676	8509781	70	75	SE	Gneiss	Quartz, muscovite + feldspar	zoned
Masola	222855	8500350	50			Gneiss?	Quartz, muscovite	zoned
Masola	224411	8501525	184			Gneiss	Quartz, muscovite + rose	zoned
Masola	224064	8503964	40			Gneiss?	Quartz, K-feldspar, muscovite, tourmaline	zoned
Masola	225212	8504134	55			Gneiss	Quartz, K-feldspar, muscovite	zoned
Masola	221051	8503659	80			Gneiss	Quartz, K-feldspar, muscovite	zoned
Masola	228575	8500368	65			Gneiss	Quartz, K-feldspar, muscovite	zoned
Masola	224344	8503920	35			Gneiss	Quartz, K-feldspar, muscovite	zoned
Masola	223427	8501336	46			Migmatites	Quartz & K-feldspar	unzoned
Masola	222444	8498708	20			Schist?	Quartz	unzoned
Kamena	225990	8510733	0			Quartzite	Quartz, K-feldspar & muscovite	unzoned
Kamena	221844	8509140	80			Migmatites	Quartz + little K-feldspar & muscovite	zoned
Kamena	222352	8509301	32			Migmatites	Muscovite, K-feldspar, quartz	zoned
Kamena	219637	8509293	0			Schist	Quartz, muscovite & K-feldspar	zoned
Kamena	216929	8509736	0			Schist/Migmatite	Quartz, muscovite & K-feldspar	zoned
Kamena	216976	8510226	0			Schist/Quaretzite	Quartz, K-feldspar & muscovite	unzoned
Kamena	216240	8509466	40			Schist/Quaretzite	Quartz	unzoned
Kaseba	215797	8506574	42			Porphyritic Granite	Quartz & K-feldspar	unzoned
Kaseba	215336	8504913	324			Schist?	Quartz	unzoned
Kaseba	215496	8505735	30	70	SE	Porphyritic Granite/Quartzite	Quartz + little K-feldspar & muscovite	zoned
Kaseba	208995	8498568	110			Schist	Quartz, K-feldspar & muscovite	zoned
Kaseba	216487	8500584	180			Migmatites?	Quartz, K-feldspar & muscovite	zoned
Kaseba	213541	8506880	356			Gneiss	Quartz	unzoned
Kaseba	214455	8507536	300			Gneiss	Quartz	unzoned
Kaseba	215090	8507631	62			Porph. Granite	Quartz	unzoned
Kaseba	215512	8507721	100			Porph. Granite	Quartz	unzoned
Kaseba	212724	8501593	90			Migmatites	Quartz, K-feldspar + tourmaline	unzoned
Kaseba	219852	8506226	100			Migmatites	Quartz	unzoned
Kaseba	219279	8506287	30			Migmatites/schist	Quartz	unzoned
Kaseba	217017	8505950	128			Schist?	Quartz	unzoned
Kaseba	215904	8505612	48	90		Schist/Quartzite	Quartz	unzoned
Kaseba	216845	8501040	18			Migmatites	Quartz	unzoned
Kaseba	215439	8502484	54			Schist?	Quartz	unzoned
Kaseba	214641	8501754	0			Schist?	Quartz	unzoned
Kaseba	217280	8508062	186			Quatzite/Schist?	Quartz	unzoned
Kaseba	216051	8501173	190			Schist	Quartz	unzoned
Kaseba	211822	8499744	80			Quatzite/Schist	Quartz	unzoned
Katota	245450	8534133	75			Quartzite	Quartz, feldspar & muscovite	zoned
Katota	246618	8533464	145			Schist/Quartzite	Quartz, feldspar & muscovite	zoned
Katota	246838	8532015	50	45	NW	Quartzite	Quartz, K-flap & muscovite	zoned
Katota	246838	8532065	170			Quartzite	Quartz, K-feldspar & muscovite	zoned
Katota	246730	8530145	70			Schist	Quartz, muscovite	zoned
Katota	247232	8528155	150			Quartzite	Quartz, Muscovite, Feldspar	zoned
Katota	244618	8533390	5			Schist/Quartzite	Quartz, K-feldspar, muscovite	zoned
Katota	244637	8537900	75	76	NW	Porphyroblastic schist	Quartz, muscovite & K-feldspar	zoned
Katota	243475	8536125	75			Quartzite	Quartz	unzoned
Katota	241994	8536590	80			Quartzite	Quartz	unzoned
Katota	242327	8538078	100			Quartzite	Quartz	unzoned
Katota	244470	8534960	70			Quartzite	Quartz	unzoned
Katota	250151	8537069	80			Porph. Granite	Quartz	unzoned
Katota	250938	8537036	120			Porphyritic Granite/Quartzite	Quartz	unzoned
Katota	250016	8536120	65			Quartzite	Quartz	unzoned
Katota	241944	8538124	115			Porphyritic Granite	Quartz	unzoned
Lukusashi	228531	8504671	64			Gneiss	Quartz & feldspar	unzoned
Lukusashi	229145	8505056	82			Migmatites	Quartz	unzoned
Lukusashi	229100	8504200	40			Migmatites	Quartz	unzoned
Lukusashi	228686	8504173	40			Gneiss	Quartz & feldspar	unzoned
Lukusashi	219926	8514078	0			Schist	Quartz, K-feldspar & muscovite	zoned
Lukusashi	228662	8505012	18			Gneiss	Quartz, feldspar, muscovite	zoned
Manda River	223333	8500966	56			Gneiss?	Quartz	unzoned
Manda River	223333	8500966	120			Gneiss?	Quartz	unzoned
Manda River	221312	8497596	80			Gneiss?	Quartz, muscovite + K-feldspar	zoned
Manda River	219575	8496158	80	40	SE	Gneiss	Quartz, K-feldspar & muscovite	zoned
Manda River	225952	8501444	40	78	SE	Gneiss	Quartz, feldspar, mica	zoned
Manda River	225793	8501326	108			Gneiss?	Quartz	unzoned
Manda River	227560	8500805	330			Quartzite	Quartz	unzoned
Manda River	227752	8497923	100			Gneiss?	Quartz	unzoned
Manda River	227372	8497377	90			Migmatites	Quartz	unzoned
Mupombo Hills	228035	8511859	60			Schist	Quartz, muscovite	zoned
Mupombo Hills	226716	8511089	40			Schist	Quartz, muscovite & K-feldspar	zoned
Masola	229501	8501994	50			Migmatites	Quartz, feldspar	unzoned
Masola	229706	8501511	180			Gneiss?	Quartz	unzoned
Panswa Hills	239759	8500364	90	45	N	Gneiss	Quartz, K-feldspar & muscovite	zoned
Panswa Hills	231211	8500285	48			Schist	Quartz, feldspar & muscovite	zoned
Panswa Hills	232165	8499757	20			Gneiss	Feldspar, muscovite & quartz	zoned