

BRITISH GEOLOGICAL SURVEY
INTERNATIONAL BUSINESS DEVELOPMENT

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GEOLOGY OF THE
EASTERN PART OF THE
CHIMALA SHEET (246)

by

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1. INTRODUCTION

The geological survey of southeastern part of the 1: 100 000 sheet number 246 (Chimala) was undertaken under the auspices of the British Geological Survey's (BGS) "Geoschool" training programme which was run by R.J. Thomas from BGS, Keyworth between August 24 to September 24, 2009. The course was entitled "Large-scale regional geological mapping in high grade basement terranes".

The course commenced with 2 days preparations in Dodoma, followed by three weeks in the field based at the Chimala Mission hospital in the village of Chimala, some 70 km east of the regional centre of Mbeya, on the Tanzam Highway. Compilation and reporting took place during the last week. The area mapped comprised some 600 km². It was bounded in the east by the edge of sheet 246, in the north by the Quaternary alluvium of the Buhoro Flats, in the west by the unconformity with the overlying Bukoba Supergroup and in the south by approx northing 9010000, to the south of which, no vehicular access was found (Fig. 1).

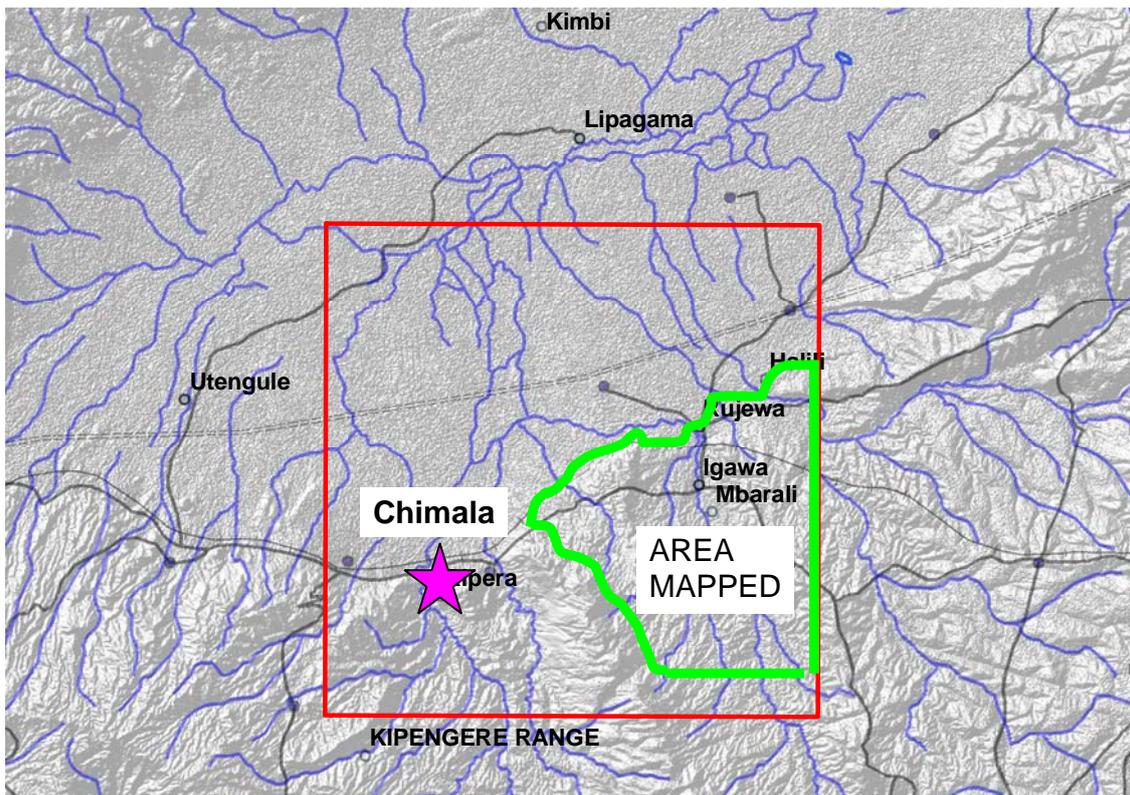


Figure 1. Location of the Chimala area in SW Tanzania, shown of Aster DEM image. Mapped area is outlined in green. The red square, which measures ca. 55 x 55 km, is the 1: 125 000 area of the published geological map of Harpum and Brown (1958).

2. METHODOLOGY

The mapping followed standard regional geological mapping procedures. In addition, and prior to departure from UK, an Arc9.2 GIS project was assembled of the area with layers for: 125 000 scale published geological map (Harpum and Brown, 1958), Landsat imagery, Aster DEM and Shuttle DEM. The GIS project was loaded onto a GETAC tablet computer with built-in GPS and the BGS "MIDAS" digital field data storage system added to Arc9.2. All field data were captured on this system in addition to manual data input onto GST (Geological Survey of Tanzania) custom-built field sheets. The 3 teams of 2 geologists each and the course leader had the use of two 4x4 Toyota Land Cruiser station wagons. Due to the size of the area to be mapped, most traverses took place along minor bush tracks passable by the vehicles, with short foot traverses to visible outcrops. The regional trend of the local Ubendian rocks is broadly north-south, so where possible, east-west, across-strike traverses were made. Representative samples of all lithologies were collected for petrographic analysis, including large samples of critical igneous lithological units for possible future geochronological studies.

3. PHYSIOGRAPHY

The area is characterized by well-vegetated low hills, koppies and ridges, formed from variably resistant paragneiss sequences (especially marbles, amphibolites and quartzites), separated by flatter thorn bush and savannah country, occupied by less resistant paragneiss lithologies and orthogneiss units. The Bukoban rocks form a prominent high escarpment and high plateau country. To the north lies the Quaternary Buhoro Flats, an extremely flat, alluvium-covered plain. August-September is in the dry season and only a few of the larger perennial streams were flowing. Daytime maximum temperatures were around 35 degrees C. The area is sparsely inhabited bush country, with human habitation restricted to villages along the main Dar-es-Salaam to Malawi/Zambia road (Tanzam highway). Limited agriculture is practiced along the road and in some irrigated areas, such as south of Igawa.

4. REGIONAL GEOLOGY

The area falls on the published 1: 125 000 geological sheet Chimala (Harpum and Brown, 1958). In regional terms, the sheet is purported to be situated at the junction between the Lupa and Mpangwa terranes of the Palaeoproterozoic Ubendian belt and the broadly coeval Usagaran granitoid terrane to the NE (e.g. Muhongo et al., 2002). It was not clear from the fieldwork to which of these terranes the mapped area belongs, but it is certain that no major Ubendian tectonic zones were encountered and the area must fall within a single tectonostratigraphic entity. The Ubendian rocks are intruded by a number of igneous suites of unknown age and are unconformably overlain by Neoproterozoic Bukoba Supergroup clastic cover rocks. The basement area is bounded immediately to the north by the extensive Quaternary alluvial deposits of the Buhoro Flats. Little, if any, other published work appears to be available on the specific area and no age determinations have been carried out.

5. LITHOSTRATIGRAPHY

In this report we have adopted the IUGS-approved lithostratigraphic scheme of rock unit nomenclature. This means that such terms such a “Series”, “System” etc. are not used and are replaced by ”Supergroup-Group-Formation-Member” etc for bedded and/or layered rocks and “Complex”, “Suite” etc for intrusive igneous rocks, prefixed by a geographic location (“Type Area”) and/or a lithological qualifier (e.g. “Limestone”, “Marble”, “Gneiss”, “Granite”) where appropriate. The units mapped and their possible age-connnotations are shown in (Fig. 2)

	Supracrustal rocks	Intrusive igneous rocks
Quaternary	Alluvium (15)	
	Talus (16)	
Jurassic?		Dolerite dykes, gabbro (10)
Neoproterozoic?		Kangaga porphyritic granite (8)
Mesoproterozoic?		Chimala potassic granite (14)
Weakly foliated to unfoliated, age completely unknown		Msusule tonalite, granodiorite (9)
		Biotite diorite (18)
Strongly foliated, probably Palaeoproterozoic		Hornblende gabbro, leucogabbro (13)
		Igawa dioritic orthogneiss (12)
		Granitoid orthogneiss (19)
		Leucocratic tonalitic orthogneiss (20)
		Ultramafic rocks (17)
Ubendian, presumed Palaeoproterozoic	Marble, calc-silicate rocks (1)	
	Biotite gneiss, sillimanite-gamet quartzite, Fe-quartzite, two-mica gneiss, biotite amphibolite (5)	
	Amphibolite, hornblende gneiss, calc-amphibolite (3)	
	Interlayered biotite gneiss and hornblende gneiss (7)	
	Grey quartz-feldspar-biotite gneiss/migmatite (4)	
	Leucocratic quartzo-feldspathic gneiss (2)	

Figure 2. Lithostratigraphy of the Chimala (East) mapped area.

6. UBENDIAN SUPERGROUP

The Ubendian Supergroup can be subdivided into a number of lithological units, which mainly comprise distinctive lithological packages or assemblages which can be recognised and mapped at the 1: 50 000 scale of the current mapping. The units form a series of interlayered supracrustal gneisses, migmatites and minor schists, some of which

are clearly of meta-volcanosedimentary origin (paragneisses). No age relationships between the mapped packages could be recognised. The packages can be viewed as “formations” though no formal names or Type Areas were identified, so are referred to by their lithological names in the following descriptions.

6.1. Marbles and calc-silicate rocks

Metamorphosed calcareous rocks form two major prominent, N-S-trending belts within the area. The rocks are generally more resistant to erosion than the surrounding gneisses and tend to form positive topographic features. Consequently, their distribution is quite accurately portrayed on the published geological map. The marbles form two distinct belts. The most extensive of these, in the west, is over 2 km wide in the north and can be followed for over 20 km along strike. A thinner belt in the east (12 x 0.5 km) occurs within a distinct paragneiss sequence. The western belt is discontinuous, however, having been disrupted in several places by shearing and boudinage. It is composed of mixed marbles and calc-silicate rocks. Pure white marbles are found locally, and have been exploited for dimension stone in a number of quarries (e.g. 643591/ 9028396). These may be calcite or dolomite-dominated – the composition of the carbonate was not clear from the field investigations. The pure carbonate rocks contain variable proportions of silicate minerals and grade into calc-silicate rocks, with increasing SiO₂ and other elements. In impure siliceous dolomitic marbles, minerals such as tremolite (crystalline to asbestiform), forsterite, wollastonite, garnet, diopside and titanite were noted. Some facies of the marble unit contain irregular calc-silicate masses with epidote-actinolite-diopside-andradite assemblages (Fig. 3a, b, c.).

The eastern belt of this unit contains calcareous metamorphic mélanges of impure marble and calc-silicate rocks (e.g. at 655994/ 9028522). The mélanges are composed of “clasts” of two types in a calcareous matrix. Firstly, greenish calc-silicate metamorphic segregations of quartz-epidote-amphibole-garnet +/- diopside form irregular, angular and dismembered chaotic masses from a few cm to over a metre in size. The second type consists of rounded pebble-like inclusions of hornblende gneiss and amphibolite, or rare quartzite. These well-rounded clasts appear to have been water-worked prior to inclusion in the original limestone – it is hard to envisage that they could have been derived from the surrounding amphibolites in such a form. This has the important implication that they were derived from an older, pre-Ubendian (i.e. Dodoman, Archaean) source. The calc-silicate segregations appear to have locally been nucleated on the amphibolite clasts. Both inclusion types are set in a mass of recrystallised marble. The extreme viscosity contrast between the competent calc-silicate clasts and the incompetent matrix has caused the disruption of the clasts and the production of the chaotic mélanges (Fig. 3d, e, f.).



Figure 3. Field photographs of the marbles and calc-silicates of the Ubendian Supergroup. a) Idiomorphic tremolite porphyroblasts in siliceous dolomite; b) Layering in siliceous dolomite in abandoned quarry; c) Asbestiform tremolite vein; d) garnet porphyroblast in marble matrix with small garnet and diopside grains of metamorphic calc-melange; e) Rounded (water-worked?) amphibolite “pebble” in calc-melange; f) Green epidote-rich irregular calc-silicate “clasts” in calc-melange.

6.2. Paragneisses

Apart from, and associated with, the marble/calc-silicate rocks, a number of interlayered gneiss units are also clearly of paragneissic origin. These tend to occur in association with the calcareous rocks in immediately adjacent belts. A number of narrow, individual continuous paragneiss units are shown on the map of Harpum and Brown (1958), but our work has shown these units to be laterally discontinuous and lensoid in form. Consequently, it is not practical to show the detailed distribution of all the lithotypes individually at 1: 50 000 scale and we have grouped them into a single “paragneiss” unit on the map, with the following lithological types:

Sillimanite-garnet quartzite: These were encountered on one of the paragneiss ridges east of the most easterly marble unit (656300/9024338). It comprises some 3 to 5 metres of rusty-brown weathering, fine-grained, highly foliated quartzitic gneiss, with abundant layers rich in red garnet, acicular sillimanite and a high proportion of sulphides. The latter produce a strong sulphurous smell under the hammer, although much of the original sulphide (mainly pyrite) has been oxidized to limonite, goethite and haematite. The garnet is pinkish and could be manganiferous (spessartine), in which case, these rocks might have an exhalative “coticule” type genesis.

Fe-quartzite: Dark grey quartzites were observed in a number of localities, where they form small hill or ridge features. They occur in much smaller bodies than shown on Harpum and Brown (1958), and many of the quartzites shown on the published map turned out to be amphibolite on checking in the field. Quartzites thus represent a volumetrically very minor constituent of the paragneiss package. The rocks are coarse-grained, recrystallised and massive to weakly layered. Layering is usually seen as alternating grey and pinkish bands on the 1 to 2 cm scale. In some such areas, metre-scale tight to open concentric folds were seen (Fig. 4a). Some rocks are foliated, with the planar fabric defined by micaceous specular haematite. Other rocks contain layer parallel concentrations of fine-grained magnetite up to 5 cm thick (Fig. 4b). The rocks are rarely seen totally *in situ*, but as lines of bouldery sub-outcrop, aligned parallel to the strike of the regional fabric orientation. Some of the less well-layered Fe-quartzites might have an exhalative, rather than a clastic origin.

Two-mica paragneiss/schist: These rocks are rather poorly exposed in the SE part of the area, where they tend to crop out in the topographic lows between ridges of more resistant lithologies. They are layered, with coarse-grained quartz and feldspar-rich layers a few mm in thickness alternating with those rich in biotite and muscovite. The most micaceous rocks can be termed schists. The rocks tend to be strongly weathered, but nevertheless form an important part of the paragneiss sequence. In one locality (653411/9015386) the rocks showed evidence of post-tectonic secondary muscovite growth, with idioblastic white mica growing across the regional fabric (Fig. 4c). This texture may be a thermal (contact) metamorphic effect of an adjacent granite pluton. Some outcrops of the schists show a second, crenulation cleavage developed at a high angle to the regional foliation (e.g. at 657386/9019742).

Biotite amphibolite: Amphibolitic rocks forms an integral and important part of the Ubendian Supergroup sequence in this area and larger areas of such rocks are indicated separately (see 6.3, below). However, a 3 m thick layer of notably biotite-rich, mafic gneiss occurs adjacent to the garnet sillimanite quartzite unit (see above). The gneiss is not notably banded, but very strongly foliated. This is significantly different from the “standard” amphibolites in the area and is thought to represent a mafic paragneiss (metavolcanic?) with an unusually potassic composition.

Biotite gneiss: Grey biotite-rich gneiss forms a significant component of the paragneiss sequence. It is composed of quartz-feldspar and biotite and differs from the more heterogeneous grey quartz-feldspar-biotite +/- muscovite gneiss/migmatite (see 6.4 below), in that it is more uniform and not notably layered or migmatitic. However, in some areas, considerable compositional banding was observed (659577/9020069: Fig. 4d).

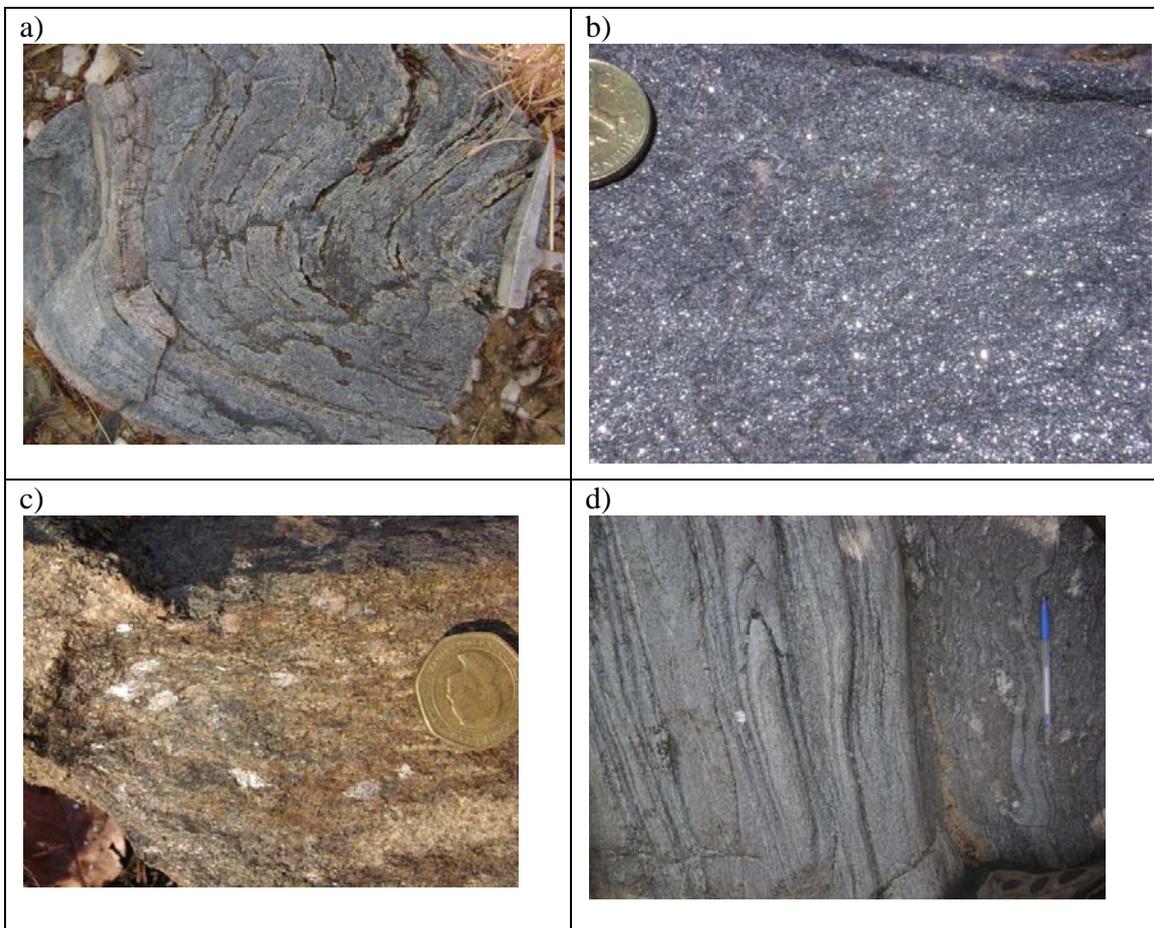


Figure 4. Field photographs of various paragneiss units of the Ubendian Supergroup. a) Tight, concentric, metre-scale minor folds in layered grey quartzite; b) Specular haematite in Fe-quartzite, of exhalative origin?; c) Late muscovite porphyroblasts (shiny) in 2-mica gneiss/schist, possibly representing static, post-tectonic growth due to thermal metamorphism associated with a nearby granitoid intrusion; d) Biotite gneisses, showing compositional banding and isoclinal minor folds.

6.3. Amphibolite, hornblende gneiss, calc-amphibolite

Mafic gneisses and amphibolites form an important component of the Ubendian in the area. The most extensive belt, in the eastern part of the area can be traced for over 20 km along a N-S strike east and west of Igawa village. Thinner belts crop out west of the “main” marble unit, and beneath the unconformity at the base of the Bukoba Supergroup in the west. In addition, prominent pods and lenses (“mega-boudins”) up to several hundreds of metres in length are present in many other areas most particularly associated with the paragneisses, where they form resistant, heavily-bushed hills and ridges.

The most common lithology is made up of well-banded hornblende gneiss, with alternating layers of fine- medium and coarse-grained, dark hornblende-dominated and light plagioclase-dominated layers, typically on a mm- to few cm-scale (Fig. 5a, b). Within these layered gneisses, more massive pods, boudins and lenses of coarse-grained massive hornblende-rocks (mela-amphibolite) are common, as low-strain boudins. Other variants include coarse-grained hornblende-plagioclase gneisses with an igneous (orthogneissic) appearance. These latter sometimes contain mafic inclusions which could represent enclaves in a meta-gabbroic host or even volcanic fragments in a tuffaceous protolith. The hornblende gneisses of all types appear to be largely biotite-free. They probably represent mafic volcanic/volcaniclastic protoliths.

One of the most characteristic features of the mafic gneisses, particularly in the widely-distributed mega-boudins, is the development of spectacular agmatites. Agmatite masses form a many low, dark koppies throughout the Ubendian Supergroup, commonly within the quartz-feldspathic gneiss unit. Many of these are shown as quartzite on the map of Harpum and Brown (1958). The agmatites are coarse-grained amphibolite breccias, with disoriented, angular to sub-rounded mafic “clasts” of coarse hornblendite, actinolite-hornblende rocks and amphibolite (hornblende-plagioclase rocks) from a few centimeters to up to a metre in size, net-veined by a ramifying stockworks of coarse feldspathic leucosome (646938/9029164: Fig. 5c, d). Typically, no foliation is present, though in some high-strain zones the entire mélange is flattened parallel to the regional fabric. A sub-variant of the agmatite is seen as rough-weathering bodies of agmatitic Ca-rich amphibolite with calc-silicate mineralogy and affinities (e.g. at 647703/9029467). These rocks are dark in colour and composed of hornblende-actinolite-diopside-epidote-titanite assemblages and might represent an original sedimentary protolith such as a calcareous marl.

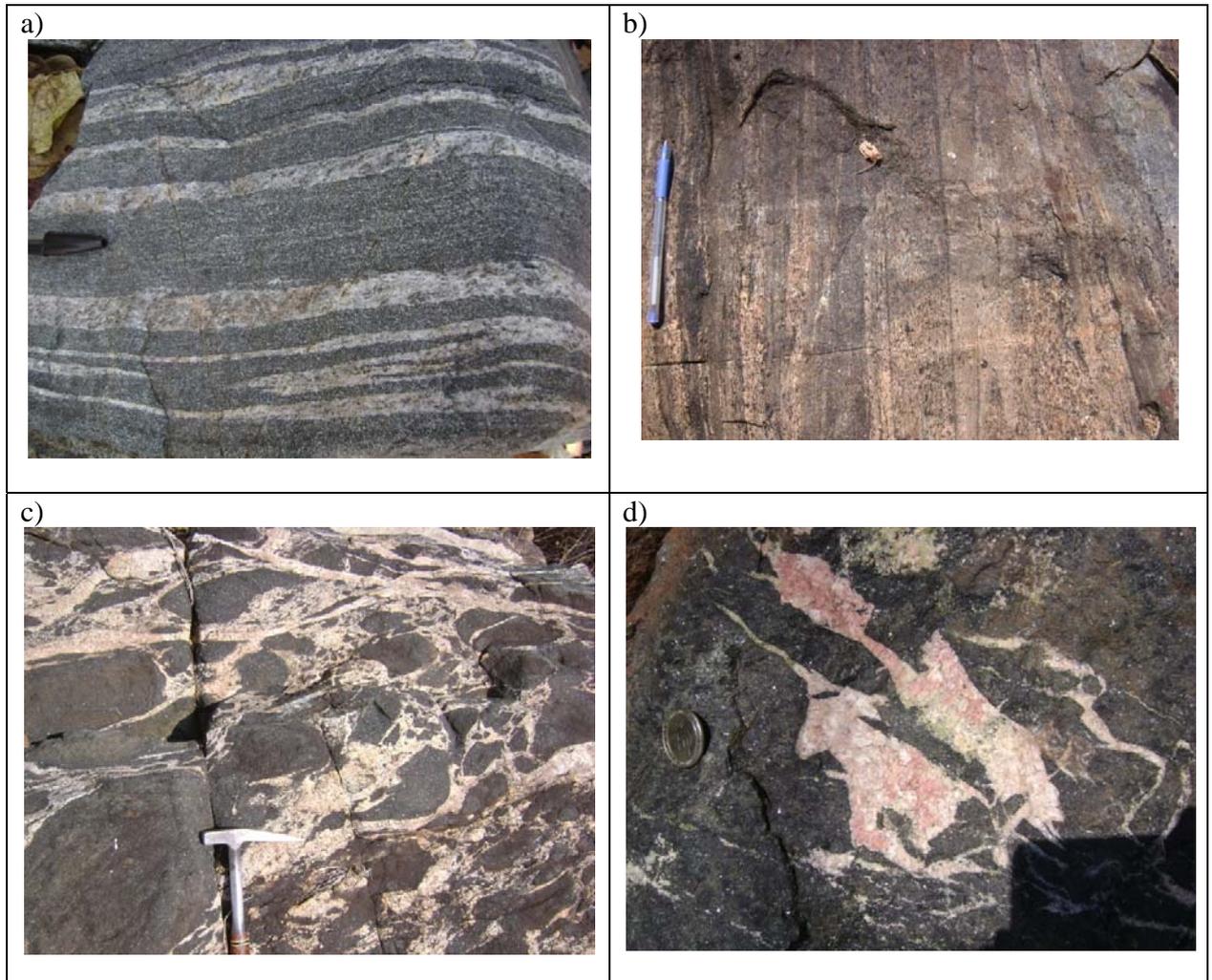


Figure 5. Typical hornblende gneisses from the Ubendian Supergroup. a) Banded amphibolite with isoclinally folded leucosomes (bottom); b) banded amphibolite showing great inequigranularity between layers; c) Agmatitic amphibolite with stockworks of leucosome veins between mela-amphibolite blocks in a low-strain mega-boudinage area; d) Close up of agmatitic leucosome, with some pink K-feldspar.

Locally, the amphibolitic gneisses contains pods and discontinuous layers of dark green "knobbly-weathering" porphyroblastic gneiss. The porphyroblasts are up to 1 cm in size and altered to chlorite-actinolite (?), but may have originally been garnet. These rocks contain a high proportion of prismatic actinolite due to later retrogression.

6.4. Grey quartz-feldspar-biotite +/- muscovite gneiss/migmatite

The grey quartz-feldspar-biotite gneiss unit occurs in the eastern part of the area, immediately west of the Kanganga porphyritic granite. It forms a N-S-trending belt some 18 km long by a maximum width of about 3 km in the south, narrowing to 0.5 km in the north. The unit was previously mapped by Harpum and Brown (1958) as "Biotite - muscovite gneiss, migmatitic in part" with many magnetite quartzite lenses. The rocks

outcrop quite extensively, often forming slabby “tombstone” exposures defined by the strong, usually sub-vertical foliation (Fig. 6a).

The gneisses are grey in colour and range from medium- to coarse-grained. Layering on all scales (mm-cm-decimetre scale) is typical, with differentiation into coarse leucocratic layers dominated by quartz and feldspar alternating with medium-grained more biotite (+/- muscovite) layers. The gneisses are locally slightly migmatized, with thin (cm-scale) stromatic leucosomes with thin biotite melanosome selvages (Fig. 6b).

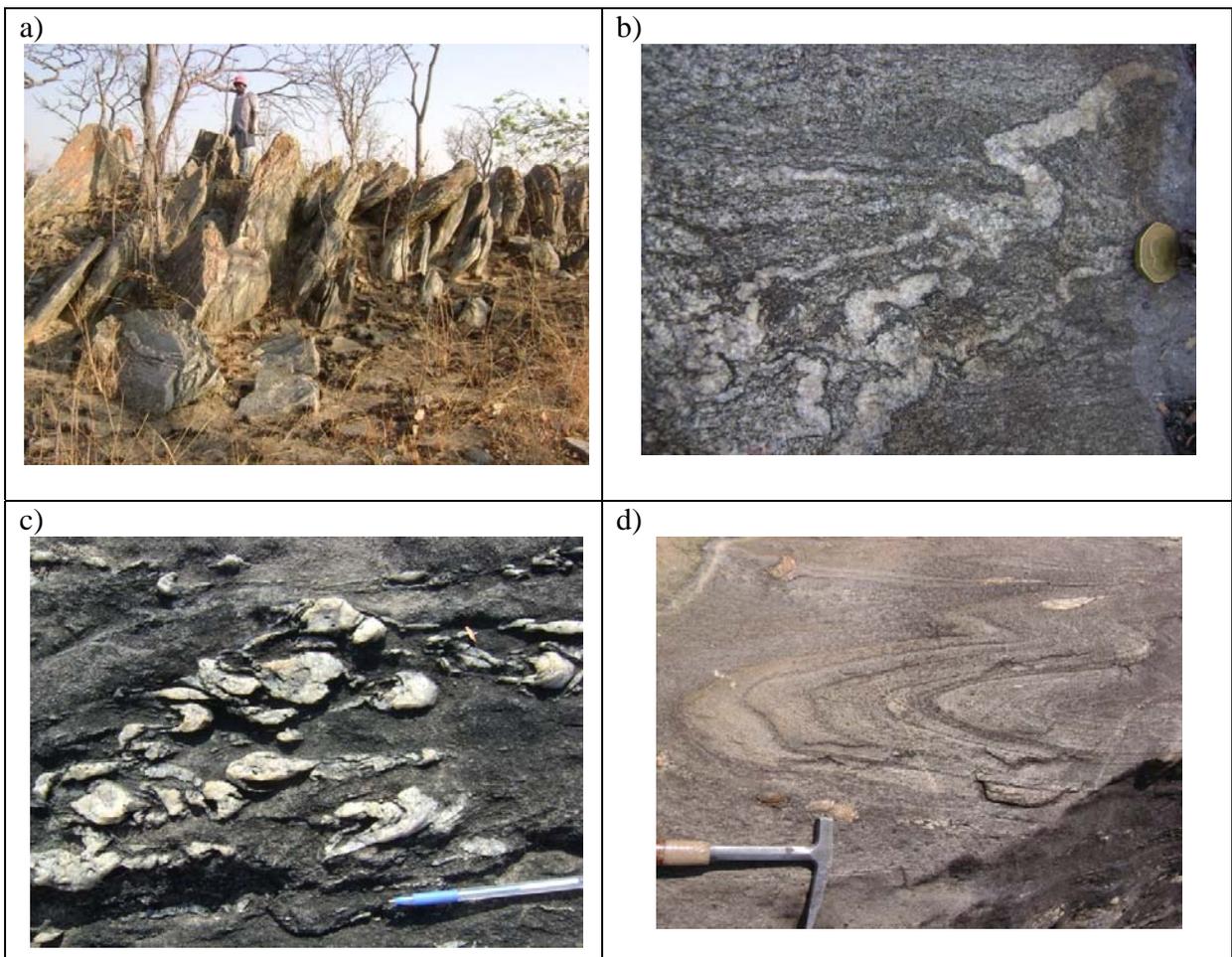


Figure 6. Grey quartz-feldspar-biotite +/- muscovite gneiss/migmatite. a) Typical strongly foliated slabby “tombstone” weathering of this unit; b) Thin leucosome veins with biotite-rich melanosome selvages and coarse quartz-feldspar leucosome; c) Early quartz veins folded and dismembered during deformation; d) Minor tight W/M folds in grey gneiss.

Particularly fine outcrops are present in the river section at 658196/9022071, where there are several hundreds of metres of fresh outcrop. In this section, the gneisses are well banded, but only weakly migmatitic, with local zones containing thin leucosomes with thin biotite selvages. However, there are zones rich in folded and disrupted non-migmatitic quartz veins, presumably remnants of early quartz veins

developed during prograde metamorphism at the greenschist facies stage (Fig. 6c). Minor tight folds have symmetrical “M-W” geometry and the outcrop is interpreted to occupy the hinge zones of a larger, regional-scale fold (Fig. 6d). The lithology of the gneisses is consistent over the wide cross-strike outcrop, which has an overall homogeneity. The protolith of the grey gneisses is interpreted either as an impure clastic sedimentary rock such as a greywacke, with or without a volcanic component.

6.5. Interlayered biotite gneiss and hornblende gneiss

This is a composite unit, formed by the interlayering of typical grey quartz-feldspar-biotite and hornblende gneiss/amphibolite. It forms an important belt west of Igawa, which measures some 14 x 4 km. In most outcrops, particularly in numerous road-cuttings along the Tanzam highway the proportion of the two rock types is ca 75:25, with the inter-layering occurring on a metre to few-metres scale. The same features seen in the individual gneiss units are as described above in the two relevant sections.

6.6. Leucocratic quartzo-feldspathic gneiss

The rocks of this unit are found extensively in the central and NW parts of the mapped area. The central area, south of Igawa, forms a N-S trending belt-like outcrop which was mapped for nearly 15 km along strike. In the west, the gneisses underlie a large area including the envelope to the Msusule tonalite pluton and the central pluton of the Mabadaga Suite. The unit also underlies a rather poorly-defined area east of the main northern marble outcrops.

The quartz-feldspathic gneisses does not outcrop particularly well, but locally forms areas of slightly elevated topography strewn with scattered debris. The rocks are cream, pinkish to light-grey in color, variable in grain size, but typically medium- to coarse-grained. They are composed of quartz, two feldspars, with very minor biotite and rarely, hornblende. The gneisses are strongly foliated and typically layered, and well exposed in a river section west of Igawa (641637/9026641: Fig. 7). The layering is mainly defined by grain size variations and minor compositional variation, with thin (mm-scale) more biotite-rich layers and schlieren. Some very fine-grained streaky pink gneisses, for example as exposed at 634635/9024240) may represent acid volcanic (rhyolitic) protoliths and, as such, might be suitable candidates to directly date the Ubendian Supergroup in this area. Migmatitic structures are locally seen, with thin quartz-feldspar leucosomes with thin biotite selvages. Harpum and Brown (1958), recognise this unit, but our mapping has shown it to be far more extensive

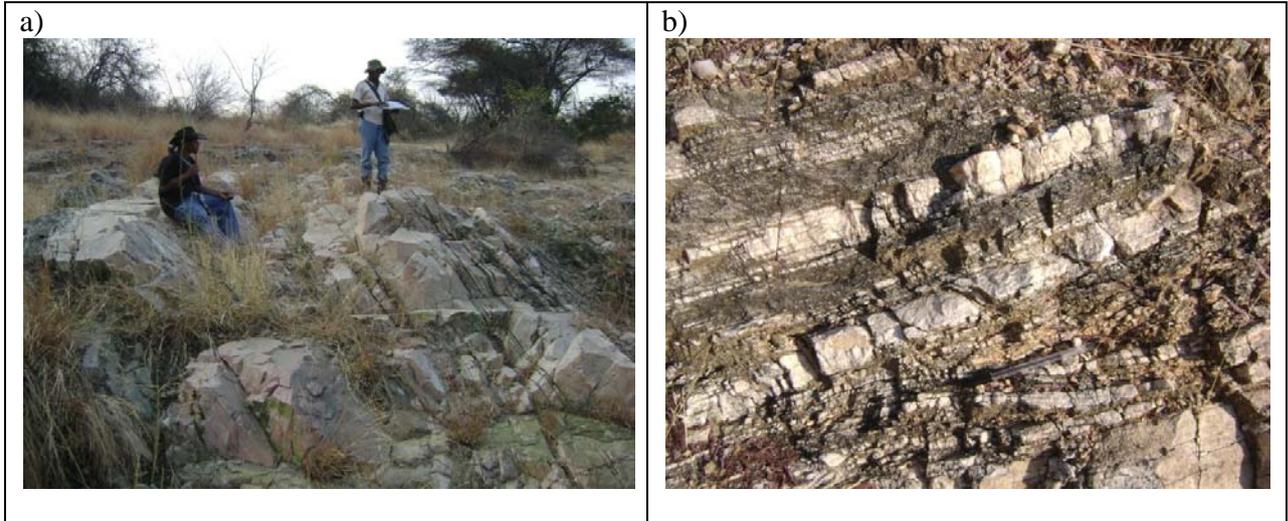


Figure 7. Leucocratic quartzo-feldspathic gneiss. a) Gneisses with extremely leucocratic, pale-grey quartz-feldspar layers up to ca. 1 m thick; b) Strong layering and inequigranular quartzo-feldspathic gneiss.

The quartz-feldspathic gneisses are invariably associated with small volumes of amphibolite and hornblende gneiss, occurring as metre-scale discontinuous layers, blebs and boudins, along with larger masses up to several hundreds of metres in length .

7. PLUTONIC ROCKS, INCLUDING INTRUSIVE ORTHOGNEISSES

7.1. Ultramafic rocks

Many of the hornblendite pods and mega-boudins seen throughout the area are, strictly-speaking of ultramafic compositions, but these are discussed under the amphibolites in section 6.3 above. The non-amphibolite ultramafic rocks are restricted to two occurrences. South of Msusulu (638371/9025296) are poor outcrops and much float of a variety of coarse-grained mafic to ultramafic lithologies, including grayish, massive serpentine and amphibole, green actinolite-rich rocks, Fe-rich ultramafics with rubbly weathering and rusty Fe-oxide crusts, rounded pods of concentric chrysotile asbestos (Fig 8a), along with coarse-grained gabbro (CI ca. 60) and coarser leucogabbro (CI ca. 30). This lithologically complex body has sheared, schistose margins, but outcrop is too poor to show the relationships between the various phases. The outcrop is interpreted as forming part of a mafic-ultramafic igneous complex.

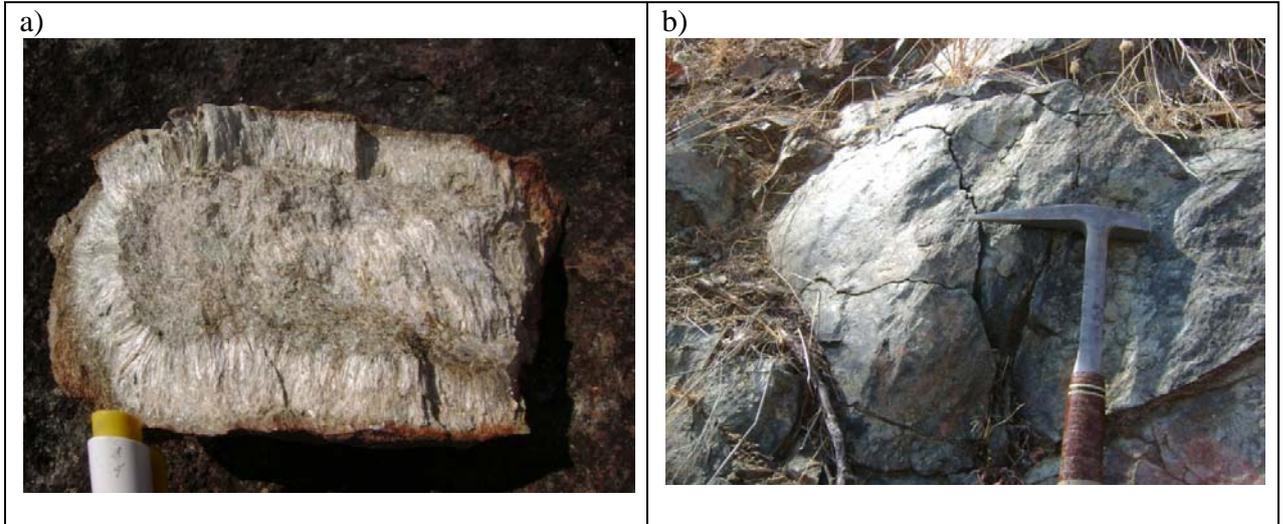


Figure 8. Ultramafic rocks a) Crysotile (?) asbestos pod in mafic-ultramafic complex south of Msusule; b) Chlorite sheen on rounded joint surfaces in chlorite-epidote-actinolite rock at Igawa railway cutting.

Secondly, in a railway cutting north of Igawa (651768/9033819), are exposures of homogeneous, massive, unfoliated, bluish-grey jointed ultramafic rocks. These are rather weathered, but with some fresh rock present between joints, composed of coarse-grained, bluish-green hornblende-actinolite-chlorite-epidote rock. The rocks are fractured and jointed, with scaly, curvi-planar joint surfaces coated with fine chlorite (Fig. 8b). The rock are intruded by irregular aplitic veins and networks of coarser-grained, weathered granitoid as sheet like masses up to 2 m across and forming a ramifying stockworks.

7.2. Leucocratic tonalitic orthogneiss

A number of previously-unrecognised sheet-like intrusions of white-weathering, coarse-grained, "flecky" leucotonalitic orthogneiss have been recognised in the area south of Msesule. The lithology has very high plagioclase content, but quite low quartz (ca. 10%). CI is ca 15-20 (i.e. leucocratic), with mafic minerals forming stretched aggregates of greenish actinolite and chlorite clots after original mafic phases (hornblende/clinopyroxene?). The mafic aggregates measure ca. 1 cm long, with larger plagioclase grains of similar dimensions. Rare mafic xenoliths were seen in some outcrops. In terms of age relationships, rocks of this unit occur as enclaves in the Msesule tonalite. The unit is intruded by deformed and metamorphosed amphibolite dykes (e.g. Fig. 9a).

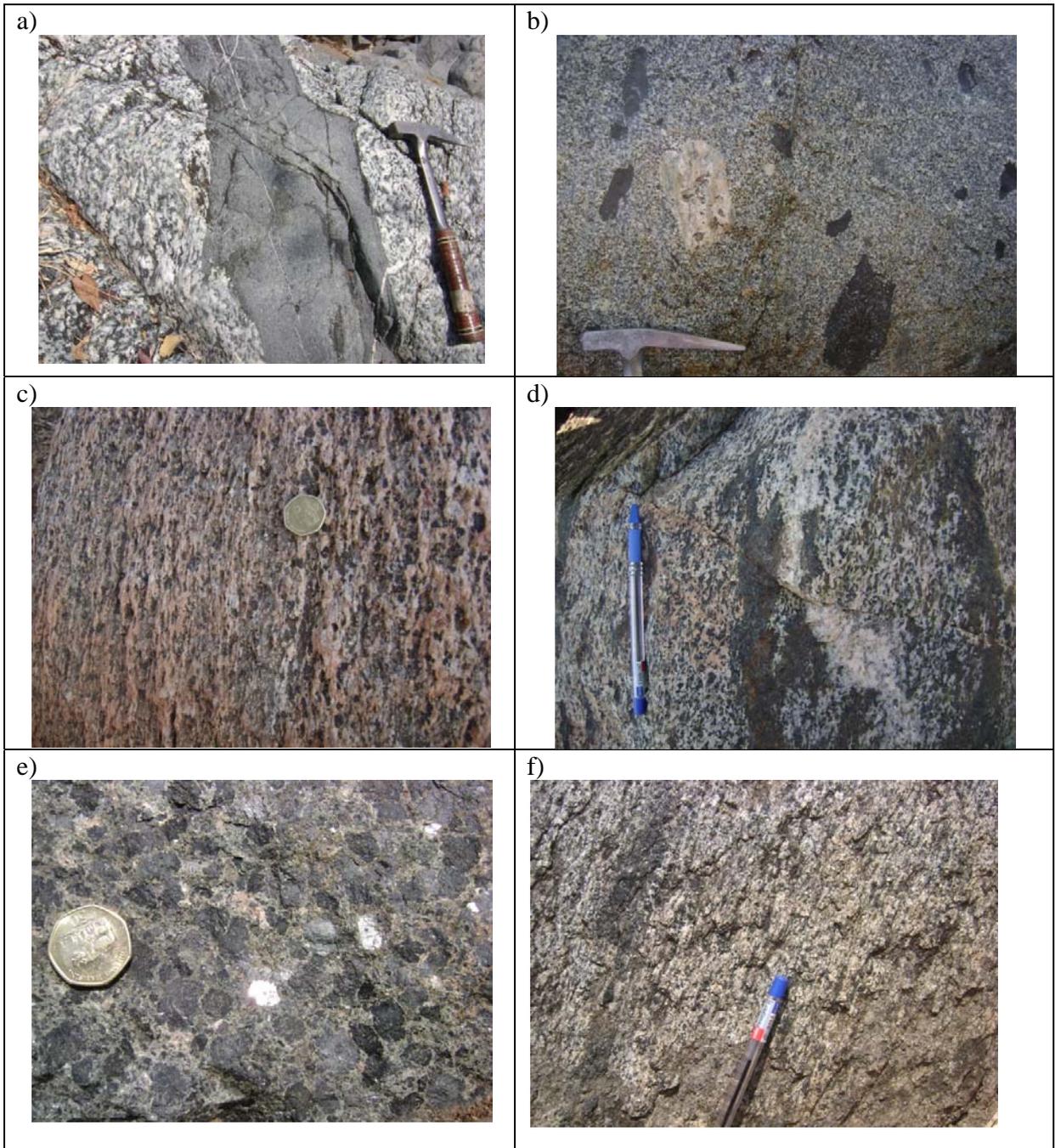


Figure 9. Orthogneisses intruding the Ubendian Supergroup. a) Coarse-grained leucocratic tonalitic orthogneiss, intruded by metamaic dyke; b) Enclaves of different types (felsic and mafic Ubendian gneisses) in an unfoliated zone of the granitoid orthogneiss unit; c) Strongly foliated Igawa dioritic/gabbroic orthogneiss (hornblende-plagioclase); d) Mafic (hornblende enclaves in the Igawa orthogneiss; e) Unfoliated very coarse-grained, equigranular, massive homogeneous hornblende mela-gabbro, with stumpy (equant) euhedral, randomly oriented hornblende crystals in coarse greenish matrix; f) Strong foliation and mineral lineation in the foliated biotite diorite.

7.3. Granitoid orthogneiss

An extensive, possibly sheet-like body of granitoid orthogneiss has been mapped in the area south of Igawa. It was not recognised on the map of Harpum and Brown (1958). The best outcrop of this unit is found at the head of the Igawa irrigation scheme (652949/ 9024936) in river cascade outcrops. The lithology is a highly contaminated, coarse-grained, grey granodiorite with (at this outcrop) a sporadically-developed, weak sub-vertical foliation. The mineralogy comprises quartz (ca 20%), plagioclase (ca 45%), K-feldspar (ca 20% max, variable) + hornblende and biotite. It is slightly porphyritic in places with scattered, sparse, greyish-green plagioclase phenocrysts up to ca. 1 cm across. Enclaves are plentiful, with both xenoliths and autoliths present. Xenoliths of amphibolite, hornblende gneiss and felsic gneiss range from the cm-scale up to 30 cm long, and are locally flattened parallel to the weak foliation (Fig. 9b). Microdioritic autoliths are common, ranging from ca. 5 to 10 cm in size. The granodiorite is cut by late, thin, epidote-filled fractures. Elsewhere, the foliation is typically much stronger and the unit is orthogneissic, rather inequigranular, with diffuse mafic streaks. In some outcrops the orthogneiss is slightly cataclased, with broken feldspars.

7.4 Igawa hornblende diorite/gabbro orthogneiss

The Igawa gabbroic/dioritic orthogneiss comprises two intrusions centred on the village of Igawa on Sheets 246/2 and 4. The larger body measures some 7 x 3 km, while the smaller, to the west measures about 2 x 1 km. The unit is well exposed on the eastern side of Igawa (Locality 19: 652095/903436) where it forms a series of fresh and bouldery outcrops. The rock is dark grey in colour and contains hornblende and plagioclase as the major minerals in sub-equal proportions, with secondary throughout. The hornblende occurs as black prismatic crystals up to 1 cm in size with pale greenish-grey plagioclase slightly finer-grained. Quartz appears to be absent, so it is not possible from the mineralogy alone to deduce if the rocks have a dioritic or gabbroic composition.

The constituent minerals are strongly oriented, imparting a very strong foliation (Fig. 9c). The pervasive foliation is steeply-dipping and trends approximately N-S. The unit contains mafic enclaves, mainly hornblende xenoliths, streaked out parallel to the foliation and ranging in length 50 cm, most commonly around 10 to 15 cm (Fig. 9d). At some localities, the diorite/gabbro is cut by thin hornblende-bearing felsic and is cut by late epidote-filled fractures.

The Igawa orthogneiss is locally migmatized. For example, north of Igawa at Locality 22 (651604/9031661), coarse-grained, highly foliated dioritic orthogneiss, with mafic enclaves contains irregular leucocratic veins sub-parallel to the regional foliation which appear to be leucosomes. Such features are also seen at bridge over the Igawa River (Locality 62: 651599/9029995), where the orthogneiss is highly contaminated by elongated mafic enclaves. The unit was not recognized on the map of Harpum and Brown (1958) who grouped it within their "hornblende-biotite granitic migmatites" unit.

7.5 Hornblende gabbro, leucogabbro

A number of small intrusions of coarse-grained hornblende gabbro and associated leucogabbro were mapped. For example, east of the Msesule pluton, at 641582/9029655, a prominent dark, tree-covered koppie is composed of unfoliated, very coarse-grained, knobby-weathering, equigranular, massive homogeneous hornblende mela-gabbro, with stumpy(equant) euhedral, randomly oriented hornblende crystals over 1 cm in size, set in coarse greenish matrix (Fig. 9e). The gabbro is cut by thin aplite veins a few centimetres across. The outcrop is ovoid in shape, measuring ca. 300m N-S, by ca. 50 m E-W. The flat area surrounding the outcrop is poorly exposed; a foliated, coarse-grained leucogabbro phase is exposed along the NE side of the mela-gabbro. Clearly the regional strain has been partitioned into the leucogabbro phase (and surrounding quartzo-feldspathic gneisses), leaving the mela-gabbro unstrained.

7.6 Biotite diorite

Bouldery, fresh outcrops of coarse-grained, grey, massive to weakly foliated, mesocratic gabbro/diorite crop out at the edge of the Buhoro Flats, north of Igawa (652233/9034720). The outcrops are fairly homogeneous in terms of grain size and mineralogy with CI varying from ca. 40 to 60 over outcrop area. The mineralogy is hornblende + biotite and plagioclase +/- quartz (occurring as rounded xenocrysts). Hornblende locally forms multi-crystalline aggregates up to 8 mm across and small amounts of secondary epidote is present in most areas. Some foliated outcrops have strong, steep mineral stretching lineation (Fig. 9f). The diorite is cut by some late cross-cutting acid veins. Both xenoliths and autoliths are present in small quantities.

7.7 Mabadaga Suite

The Mabadaga Suite comprises three intrusive granitoid plutons. It includes the Msesule pluton, which was shown on the published geological map of Harpum and Brown (1958). In addition, the suite includes two similar granitoid plutons which were identified during the current survey. These previously unidentified plutons occur to the south of Igawa and appear to be of similar dimensions to the Msesule pluton, although their contacts were not followed laterally and they do not form notable features on the remote-sensing imagery.

The elliptical Msesule Pluton is the well exposed in numerous, rounded, tor-like outcrops along the Tanzam Highway east of Mubuyuni. It measures about 8 x 5 km in size and is slightly elongated E-W, parallel to the fabric in the country-rock quartzo-feldspathic gneisses, which wrap around the pluton. The tonalite is grey in colour, coarse-grained, equigranular and typically unfoliated and homogeneous. It is composed of quartz, plagioclase, hornblende and biotite ± minor K-feldspar, and secondly epidote. With slightly increased K-feldspar, some rocks are granodioritic. CI ranges from about 10 to 15.

Enclaves of two types are common: a) Irregular to angular xenoliths of country-rock amphibolite and hornblende gneiss up to 20 cm in size (e.g. 639606/9027160: Fig 10a) and b) lensoid microdioritic autoliths about 10 cm in size (Fig 10b). In many road-cuttings the tonalite is totally weathered, showing concentric exfoliation-weathering, sometimes with fresh corestones. The pluton is very homogeneous, with little variation in grain size and mineralogy and is cut by very few later acid veins. Some outcrops are cut by late, straight-sided, epidote-filled fractures.



Figure 10. Msusule tonalite. a) Irregular, angular amphibolite xenoliths in marginal zones of the Msusule pluton; b) Rounded autolith, with mafic reaction rim; c) elongated “trains” of microdiorite autoliths in lower parts of Msusule pluton.

The Msusule pluton appears to be tilted, so that lower levels of the intrusion are exposed along the SE margin. For example at the excellent stream outcrops at 638138/9025063, a deeper level is exposed, along with the contact zone with the country-rock gneisses. Here, the tonalite is weakly to moderately foliated and highly contaminated

with mafic enclaves (xenoliths and autoliths) elongated along the foliation direction (Fig 10c). The enclaves show all stages of assimilation, down to patches of slightly more mafic “ghosts” enclaves of almost totally digested mafic material. This implies that the Msesule tonalite has an hybrid origin, the evidence for which is not apparent at higher levels. The hybrid rocks send out dyke-like apophyses into a strongly foliated, layered quite heterogeneous mafic amphibolite-hornblende gneisses and leucotonalite orthogneisses which constitute the country-rocks at this outcrop.

The lithologically-similar plutons south of Igawa, show some mineralogical variation, with variable quartz content and feldspar ratios, giving rise to compositions ranging from tonalite to granodiorite to quartz monzonite and quartz monzodiorite and Colour Indices up to 40. The southernmost of the two plutons is erroneously shown by Harpum and Brown (1958) as an extension of the Kangaga porphyritic granite.

7.8 Chimala potassic granite

The Chimala granite was not studied in detail, as the emphasis of the mapping was to the east. The granite does not outcrop well at Chimala village, which lies upon a thick and extensive talus apron at the northern flank of the mountain front. Nevertheless, the talus fragments, up to several metres in size are comprised almost entirely of red-weathering, coarse-grained potassic granite, termed the Chimala Granite. The talus also contains fragments of granite porphyry, termed “pseudo-porphyry” by Harpum and Brown (1958), who grouped the granitoids into rocks of the “Ukinga Epoch”. The Chimala Granite outcrops in the Chimala River, for example at 612136/9018657. Here, the granite is massive, unfoliated, pink to red and very coarse-grained, but not porphyritic. Quartz content is high, with ca. 60% brick-red K-feldspar and hornblende, but no biotite noted. The granite is very homogeneous, with no veins or enclaves noted.

7.9 Kangaga porphyritic granite

The Kangaga porphyritic granite is an extensive intrusive lithology located in eastern part of 246 sheets 2 and 4, where it covers an area of about 150 km². It tends to outcrop poorly and is only exposed in road cuttings, which tend to be highly weathered, and in rare river outcrops which can be fresh. It forms flattish plateau country characterised by coarse orange, gravelly soils. The lithology contains enclaves of Ubendian gneisses, particularly at its margins, demonstrating that it post-dates the Ubendian Supergroup. The contact with the Ubendian gneisses is complex and outcrops in the north show it to be a zone, at least several hundreds of metres wide which is dominated by aplite and pegmatite sheets, intruded parallel to the margins, and including rafts of country-rock material.

Generally, the granite is pale grey when fresh to pinkish when more weathered. It is relatively homogeneous, massive to weakly-foliated and coarse-grained. It is typically (though not exclusively) porphyritic, with euhedral pinkish K-feldspar phenocrysts measuring up to 2 x 1 cm in size. Locally the phenocrysts are crudely aligned parallel to the intrusion margins in what is interpreted as a primary igneous flow fabric (Fig. 11a).

The granite is composed of quartz (ca. 30%), K-feldspar (ca. 45%), plagioclase (10%), with biotite +/- hornblende. The colour index ranges from 10 to 20.

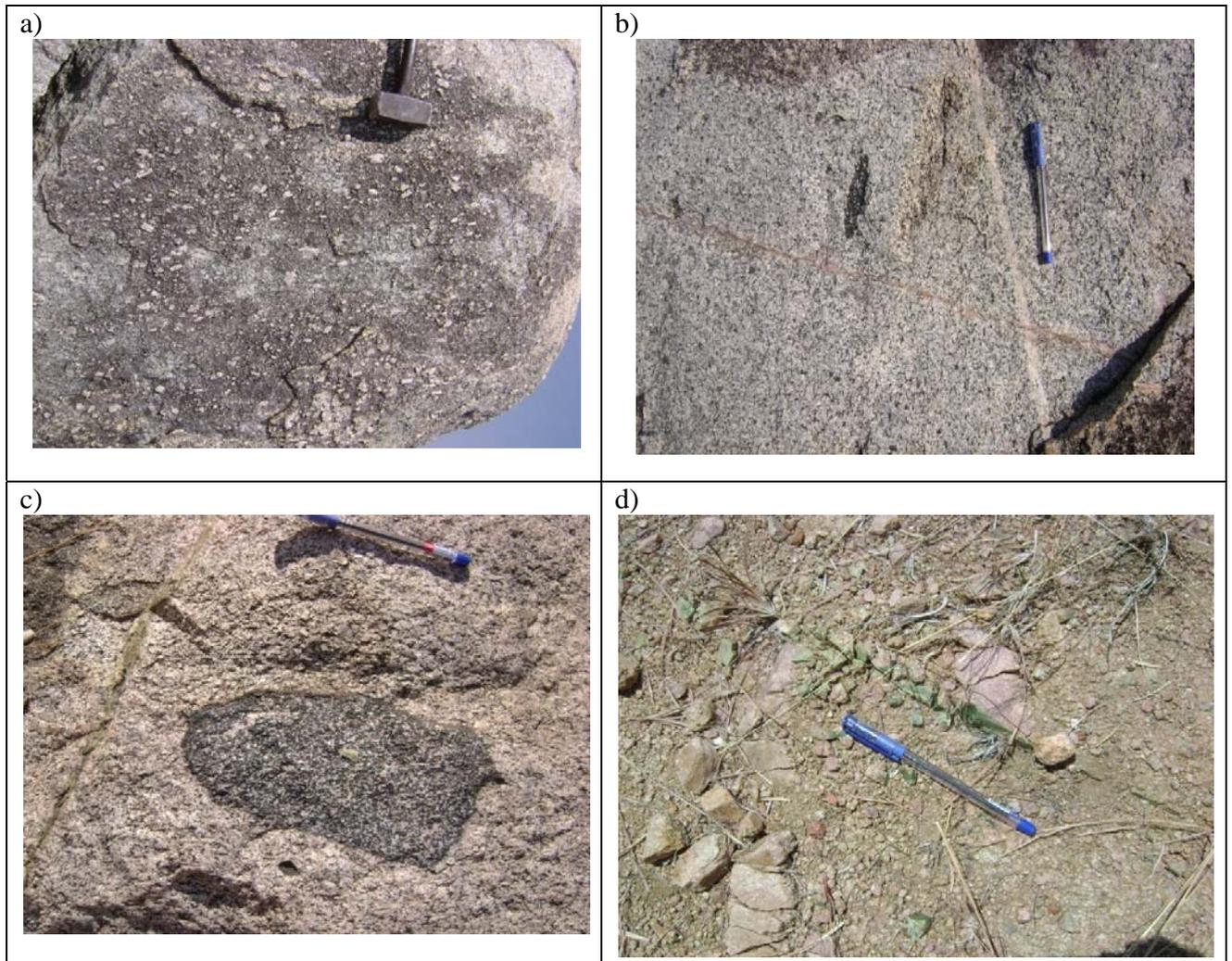


Figure 11. Kangaga porphyritic granite. a) Weak sub-parallel alignment of K-feldspar phenocrysts due to primary igneous flow; b) Flattened ellipsoidal mafic autolith aligned with the igneous fabric. Granite is non-porphyritic here and cut by this aplite vein and a late reddened-epidotised fracture; c) Blocky rounded hornblende gabbro xenolith; d) Late epidotised fracture shows apparent dextral displacement of an aplite vein in the granite

The granite contains both small (up to ca 10cm) discoid microdiorite autoliths which are aligned parallel to the igneous flow fabric, and more blocky, rounded hornblende gabbro xenoliths up to 20 cm across. (e.g. Locality 12: 660615/9026114, Figs 11 b and c). The granite is ubiquitously cross-cut by pegmatite and aplitic veins. In one locality (e.g. Locality 199: 660909/9021391), the pegmatite vein phase is seen to be older than the aplites, in a cross-cutting, dilational relationship. In most exposures the granite is cut by late fractures which are filled with epidote, surrounded by a reddened, Fe-rich halo. These fractures occur in conjugate sets and local small displacements were observed (Fig. 11d).

The extent of the granite as mapped, was similar to that portrayed on the published geological map in the north, though the western protuberance shown in the south, was found to be erroneous.

7.10 Karoo (?) dolerite

The geological map of Harpum and Brown (1958) shows a large number of dolerite dykes within the mapped area. Most of these were not seen during the present survey, even when apparently in the locations shown. A small number of dolerites were mapped, mainly occurring as lines of bouldery sub-outcrops, from which the dyke orientation can sometimes be measured. In most cases, the rocks are greenish-grey, medium-grained, aphyric dolerite/microgabbro, with sub-ophitic texture. Many larger dykes have coarser-grained (gabbroic) cores, with finer-grained chilled margins.

In one locality (658686/9020131) the Ubendian gneisses are intruded by a spectacularly plagioclase-porphyritic and locally vesicular dolerite dyke about 5 m wide (Fig 12a). Both phenocrysts and vesicles locally aligned by igneous flow, parallel to the dyke margins. Phenocrysts not regularly distributed however; they occur in swarms and some parts of the dyke are aphyric. The age of the dolerites are unknown, but they are similar to those of Karoo (Jurassic) age which are so characteristic and widespread throughout southern Africa.

8. QUATERNARY

8.1. Alluvium

Small amounts of coarse alluvium are found along some of the larger river courses, but the main accumulations are the extensive silty deposits which form the Buhoro flats region to the north of the mapped area.

8.2. Talus and colluvial deposits

Many of the larger hills and mountain ranges are surrounded by an apron of coarse angular talus. This is particularly apparent beneath the Bukoban escarpment, where coarse quartzitic talus of the basal Bukoba Supergroup forms a wide apron. The fault-bounded northern margin of the Bukoba Supergroup is also marked by a talus apron about 1km wide, and is well seen, for example, along the main road near the village of Mubuyuni where excellent sections through up to 8 m of talus are exposed in a gravel pit at 628799/9022805. In this outcrop, a 6 m thick vertical section of bedded talus overlies weathered Bukoba siltstones. The talus comprises a number of beds of variable grain size of loosely-consolidated, clast-supported breccia, with angular reddish Bukoba Supergroup fragments (Figs 12 c and d)

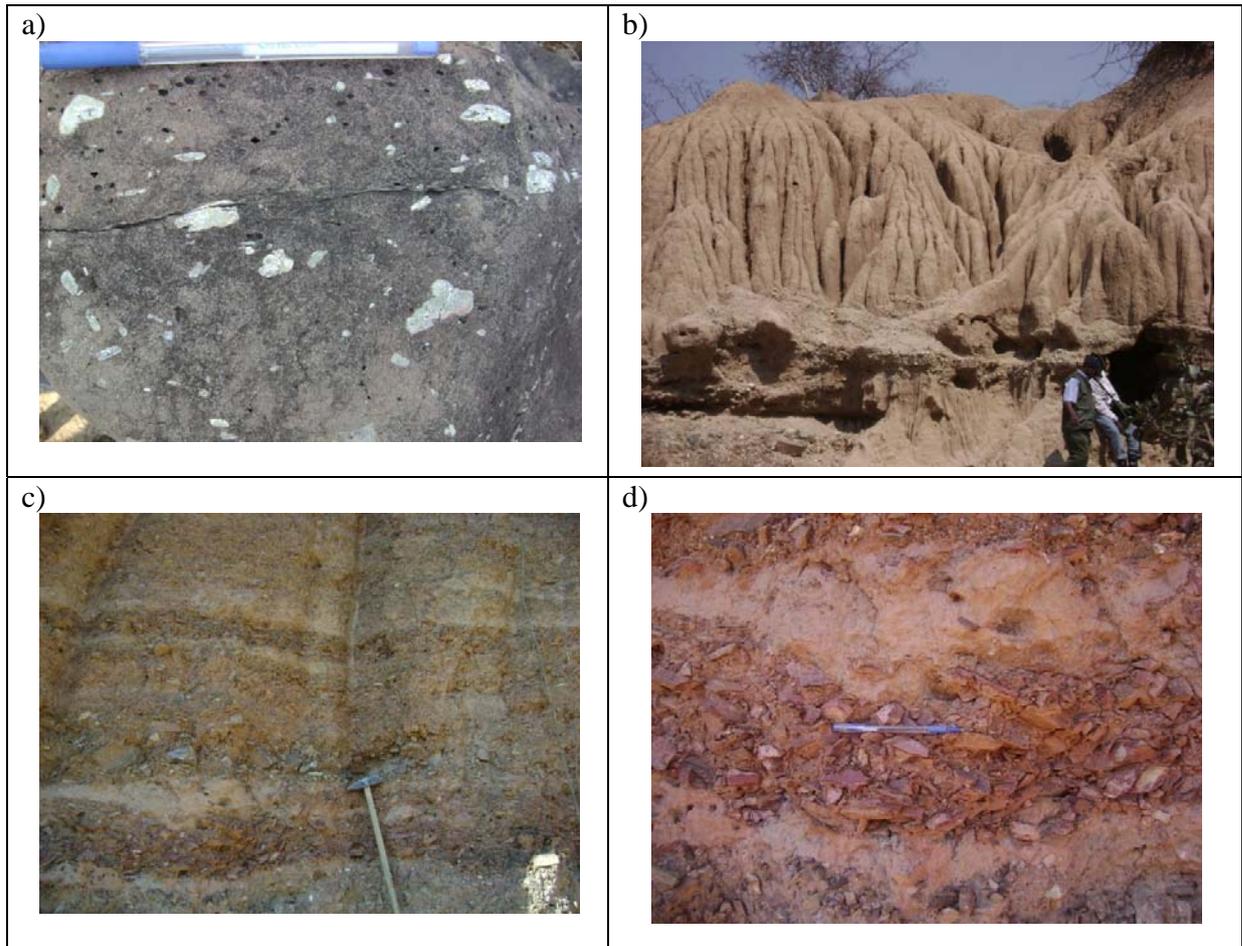


Figure 12. a) Plagioclase-porphyritic and vesicular dolerite; b) Localised colluvial deposit overlying the Msusule pluton, the 8m thick deposit is silty in nature, with a coarse-grained base (by the heads of the two figures); c) Bedded coarse-grained angular talus deposit which forms an apron at the northern, fault-bounded fringe of the mountains overlooking the Buhoro Flats to the north; d) Detail of angular component clasts of the talus which is made up of maroon siltstone fragments derived from the Bukoba Supergroup.

9. STRUCTURE AND METAMORPHISM

The structure of the supracrustal gneisses of the Ubendian Supergroup, and the early orthogneisses, in the area is dominated by a broadly N-S striking, generally steep to sub-vertical metamorphic foliation. The orientation of the foliation changes to a more E-W strike in the NW, where it swings around the Msesule pluton before being unconformably overlain by the Bukoba Supergroup in the west. The foliation is a transposed metamorphic fabric defined by mineral preferred orientation and metamorphic compositional layering/banding. No original volcano-sedimentary structures were observed. Nevertheless, the association of marbles, quartzites and other clear paragneisses, suggests that the sequence is derived from metasedimentary/metavolcanic protoliths. The large scale compositional layering seen, suggests that the metamorphic fabric may well be parallel to original (S_0) bedding, and that consequently the regional fabric is parallel to unseen large-scale isoclinal folds. The regional (S_1) fabric, is locally folded at the outcrop (sub-metre) scale. Minor similar folds tend to be tight to almost

isoclinal in geometry with plunges to the north and south. Most tend to have “W” and “M” profiles, showing them to occupy positions near the hinge areas of unseen, larger scale folds (Fig 13a). Relatively few “S” and “Z” geometry folds were seen, suggesting that high strain in the limb areas of larger scale folds may be zones of high shear strain, largely obliterating minor folds. In such limb areas, the strain can be high, with the development of steep protomylonite belts, with strong N- or S-plunging stretching lineations (Fig, 13b).



Figure 13. a) Minor tight “M” folds of the regional metamorphic fabric in biotite paragneiss; b) Intense, protomylonitic fabric in hornblende gneisses, possibly in sheared limb area of tight, regional-scale fold; c) Minor disharmonic ptygmatic folded leucosomes in fairly homogeneous layers of grey quartz-feldspar-biotite gneiss; d) Crenulation folds and incipient S_2 cleavage in two-mica schist from the Ubendian paragneiss sequence.

In certain competent layers, such as the grey quartzites, the minor folds are concentric in geometry (Fig. 4a). In notably incompetent-competent layers, and such as the calc-silicate marble units, deformation is dominated by disharmonic folds and metamorphic mélanges (e.g. Fig. 3f). Other examples of disharmonic folds are seen in ptygmatically folded leucosomes veins in some fairly homogeneous layers within the grey quartz-feldspar-biotite gneisses (Fig., 13c). The regional S_1 folds do not themselves have a strong axial-planar foliation development, although a weak fracture cleavage was noted in a few localities. However, the mica-rich schists of the paragneiss sequence do, locally show a secondary (S_2) crenulation (Fig, 13d).

The granitoid units such as the Igawa orthogneiss which are pre- S_1 in age have as strong foliation which is oriented parallel to the regional fabric. However, strong strain-partitioning is also widespread, such that, for example, the highly competent, pre- S_1 hornblende gabbros do not show any foliation, but occur as “megaboudins” with all the strain partitioned into the surrounding country-rock gneisses. The same phenomenon is also seen in the numerous hornblende-rich and amphibolitic pods (including amphibolitic agmatites) which are distributed widely throughout the area.

The deformation, presumed to be of Palaeoproterozoic age, took place under peak, amphibolite facies metamorphism. This is characterised by hornblende-plagioclase assemblages in meta-basic rocks, and garnet-biotite in some paragneisses. Muscovite is present in some lithologies, but sillimanite was also seen in some garnet-sillimanite quartzites, showing that peak metamorphism took place approximately at the sillimanite-muscovite transition. Supporting this, localized migmatization, as exemplified by agmatitic amphibolites and stromatic migmatites in the paragneisses suggest metamorphism at the partial anatexis threshold for metapelites, i.e. at ca 700° C under water-saturated conditions. Pressure estimates are more difficult, owing to a lack of distinctive assemblages, though localized garnet growth suggest metamorphism was attained under intermediate pressure conditions. Retrogression is widespread, and manifest as growth of actinolite, epidote and chlorite in rocks of the appropriate composition (primarily metabasites).

In one locality, a second phase of muscovite was seen overgrowing the foliation in two-mica gneiss/schist. This is attributed to the effects of a late, thermal event, possibly associated with a nearby granitoid intrusion.

A number of brittle faults were observed in outcrop. For example at 658713/9023609 a silicified fault breccia forms a prominent N-S-trending resistant ridge. Other examples of similar features were also noted. The map of Harpum and Brown (1958) implies that the southern margin of the Buhoro alluvial flats is a post-alluvial fault, i.e. is a neotectonic feature. In the gravel pit west of Mubuyuni (628799/ 9022805), Bukoban Supergroup siltstones are rotated from shallow N-dip to vertical to steep-south (overturned), due to drag folding/tilting by the major (otherwise unseen) fault in the area. However, the talus exposed at this site covers the rotated beds without break suggesting that the fault (at least here) is pre-talus in age and not the result of neotectonic movements.

10. ECONOMIC GEOLOGY

The current survey did not focus on economic geology. The only resources obviously encountered were the few dimension stone quarries and prospects on the marble ridges. Of these, only one has been worked economically in recent years, (at 643591/9028396), but this operation is now closed (at least temporarily) due to the 2009 global economic recession. Apparently, artiginal gold mining is taking place in the central part of the area but these workings were not visited and clearly occur in a relatively remote region. A few small pits marked as Au occurrences on the geological map of Harpum and Brown (1958) were encountered, but not investigated in detail. Some of the paragneiss sequences have been prospected as recently as 2002, as evidenced by prospecting permit beacons, but the results of these activities are unknown.

References

- Harpum, J.R. and Brown, P.E. (1958). Geological map of quarter degree sheet 71SW (Chimala). 1:125 000 scale geological map, Geological Survey Department, Dodoma.
- Muhongo, S. Tuisku, P., Mnali, S., Temu, E., Appel, P. and Stendal, H. (2002). High-pressure granulite-facies metagabbros in the Ubendian Belt of SW Tanzania: preliminary petrography and P–T estimates. *Journal of African Earth Sciences*, 34, 279–285.