British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Geology of part of the eastern margin of the Tanzanian Craton in the Mpwapwa area and its relationships with an off-craton, high-grade supracrustal gneiss sequence (Mpwapwa Group) of possible Palaeoproterozoic age

International Programme

Open Report OR\10\059

BRITISH GEOLOGICAL SURVEY

INTERNATIONAL PROGRAMME

OPEN REPORT OR\10\059

Geology of part of the eastern margin of the Tanzanian Craton in the Mpwapwa area and its relationships with an off-craton, high-grade supracrustal gneiss sequence (Mpwapwa Group) of possible Palaeoproterozoic age

Thomas, R.J.[1], Bushi, A.M.[2], Juma, Y.[2], Kalimenzi, J.[2], Kankila, A.[2], Lukas, P.[2], Macqway, M.[2], Maganga, Z.[2], Maulide, H.[2], Moye, C.[2], Msabi, M.[3], Notke, N.[2], Pius, R.[2] Shine, Y.[2] and Tulibonywa, T.[3]

[1] British Geological Survey, Keyworth, Nottingham NG125GG, UK

[2] Geological Survey of Tanzania, Dodoma, Tanzania

[3] Department of Geology, University of Dodoma, Dodoma, Tanzania

Bibliographical reference

Geology of part of the eastern margin of the Tanzanian Craton in the Mpwapwa area and its relationships with an off-craton, high-grade supracrustal gneiss sequence (Mpwapwa Group) of possible Palaeoproterozoic age. *British Geological Survey Open Report*, OR\10\059. 53pp.

Keyworth, Nottingham British Geological Survey 2010

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Contents

Figures

Table and Figures

Abstract

A number of traverses have been undertaken across a ca. 45 km section of the north-south oriented eastern margin of the Tanzanian Craton between Dodoma and Mpwapwa, Central Tanzania. The boundary is a SE-dipping zone of high strain between about 1 and 2 km wide. The rocks of the eastern craton are uniformly composed of coarse-grained grey granodioritic, migmatised orthogneisses which are heterogeneous at outcrop scale, but are regionally homogeneous. The orthogneisses have no regionally consistent fabric and foliations are variably oriented at outcrop scale. However, there is a gradual increase in strain eastwards towards the edge of the craton, manifest as an increasingly strong, regionally consistent, SE-dipping foliation. This strain increase eventually leads to mylonitic and porphyroclastic planar fabrics and strong, uniformly SE-plunging, linear fabrics. The kinematics of the high-strain mylonites show a consistent top-to-the-NW sense of movement. The frontal thrust zone grades laterally into steep sinistral and dextral oblique strike-slip shear zones to the north and south respectively. The contact is a single wide thrust zone in the north and south section of the studied area, with an imbricate belt in the central part.

To the east, the cratonic rocks are in contact with a high-grade supracrustal succession, termed here the Mpwapwa Group in the light of uncertain regional correlations (= "Isimani Suite"?). It consists of a thick sequence of leucocratic quartzo-feldspathic gneisses and migmatites, semi-pelitic two mica-kyanite-garnet schists/gneisses, quartzites, marbles and calc-silicate rocks and abundant metabasic layers. There appears to be an east-west zonation of Mpwapwa Group lithological units, with most of the quartzites, calcareous rocks and pelitic schists/gneisses tending to occur close to the craton margin, with semi-pelitic gneiss/migmatite to the east, along with interlayered repetitions of bimodal acid, quartzo-feldspathic leucogneisses and mafic gneisses (amphibolite, mafic garnet amphibolite).

Mineral assemblages, as evidenced by garnet-kyanite in pelitic rocks, garnet-clinopyroxene in some metabasites suggest metamorphism under moderate to high pressure amphibolite facies, as might be expected at the base of a thrust stack and resulting crustal thickening. Possibly, therefore, the Mpwapwa Group was deposited in a rifted passive-margin setting at the edge of the Tanzanian Craton, with shallow marine environments at the immediate continental margin and bimodal volcanic rocks more distally. During collision orogeny, thrusting took place at this rifted margin, inverted the Mpwapwa Group basin and transported the supracrustal rocks over the craton margin, an event which telescoped, but did not obliterate the original depositional zonation. The group may thus be viewed as a parauthochthonous succession. The rocks were intruded by plutons of largely unfoliated biotite granite, two-pyroxene charnockite and tonalite, the ages of which are unknown. With the above hypothesis and uncertainties in mind, a suite of samples are undergoing U-Pb zircon dating in order to constrain the timing of these events.

Introduction

The purpose of the research in the Mpwapwa area, east of Dodoma was two-fold:

1) To try to ascertain the nature of the eastern boundary of the Tanzanian Craton east of Dodoma;
2) To try and establish the relationships of the craton with its eastern envelope: a sequence of high-grade supracrustal gneisses of unknown age which outcrop SE of the craton around Mpwapwa.

The area under investigation comprises the central part of the Mpwapwa-South (B37/M1), half-degree (36° to 36°30'E /6° to 6°30'S) 1: 125 000 series geological map (Temperley et al., 1953) and described in Temperley (1938) (Figure 1). According to the compilation map of Pinna et al. (2004) the boundary between the eastern margin of the Tanzanian Craton and the Palaeoproterozoic Usagaran belt runs N-S across the area. The region is one of heavily bushed hill ranges and isolated koppies, surrounded by flat, sandy areas with almost no outcrop. In particular, the cratonic area to the west is characterised by low isolated koppies of Archaean granitoid, with rounded, bouldery tor-like outcrops. In contrast the eastern area, underlain by a sequence of high-grade supracrustal gneisses ("Mpwapwe Group"), is characterised by heavily bushed rounded hills and ridges, rising to high mountains east of the boundary zone, north of Mpwapwa.

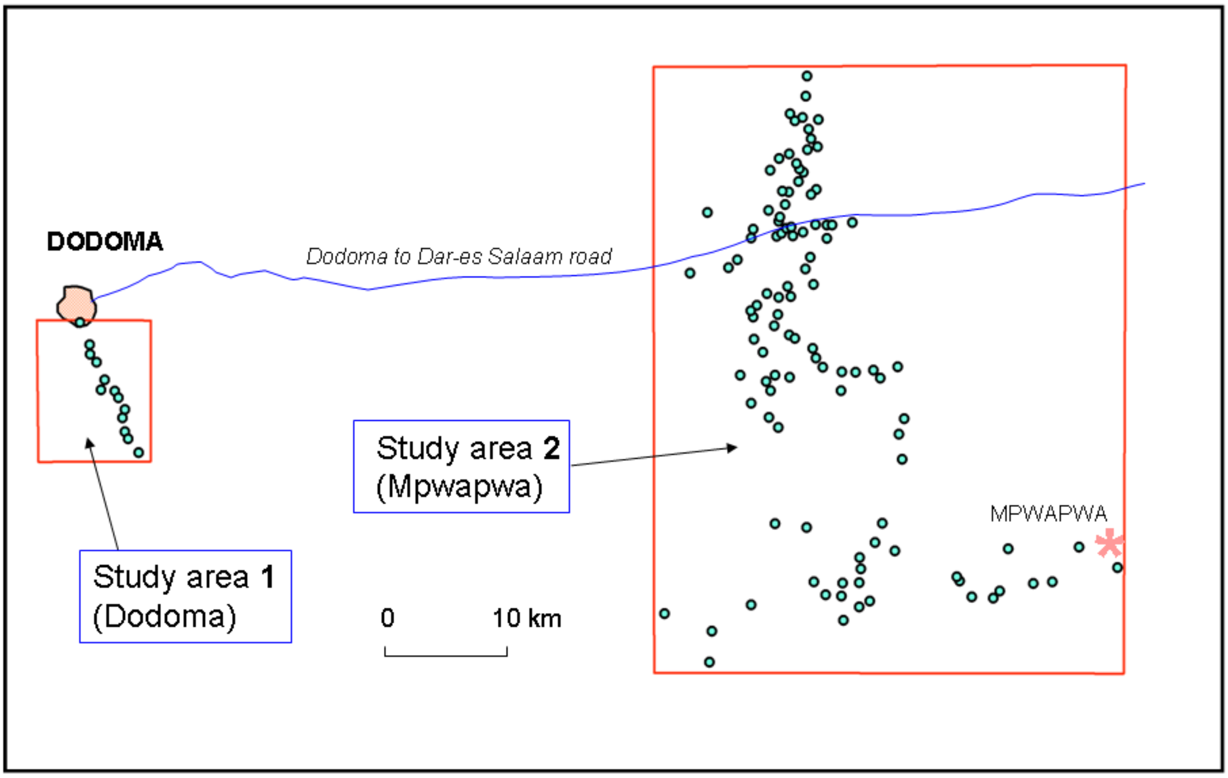


Figure 1. *The two study areas of the 2010 field season. The craton margin study area (2) is west and north of Mpwapwa. Blue dots are observation points.*

Tanzanian craton margin

The craton extends some 55 km east of Dodoma. A series of traverses across the margin were undertaken (Figure 2).

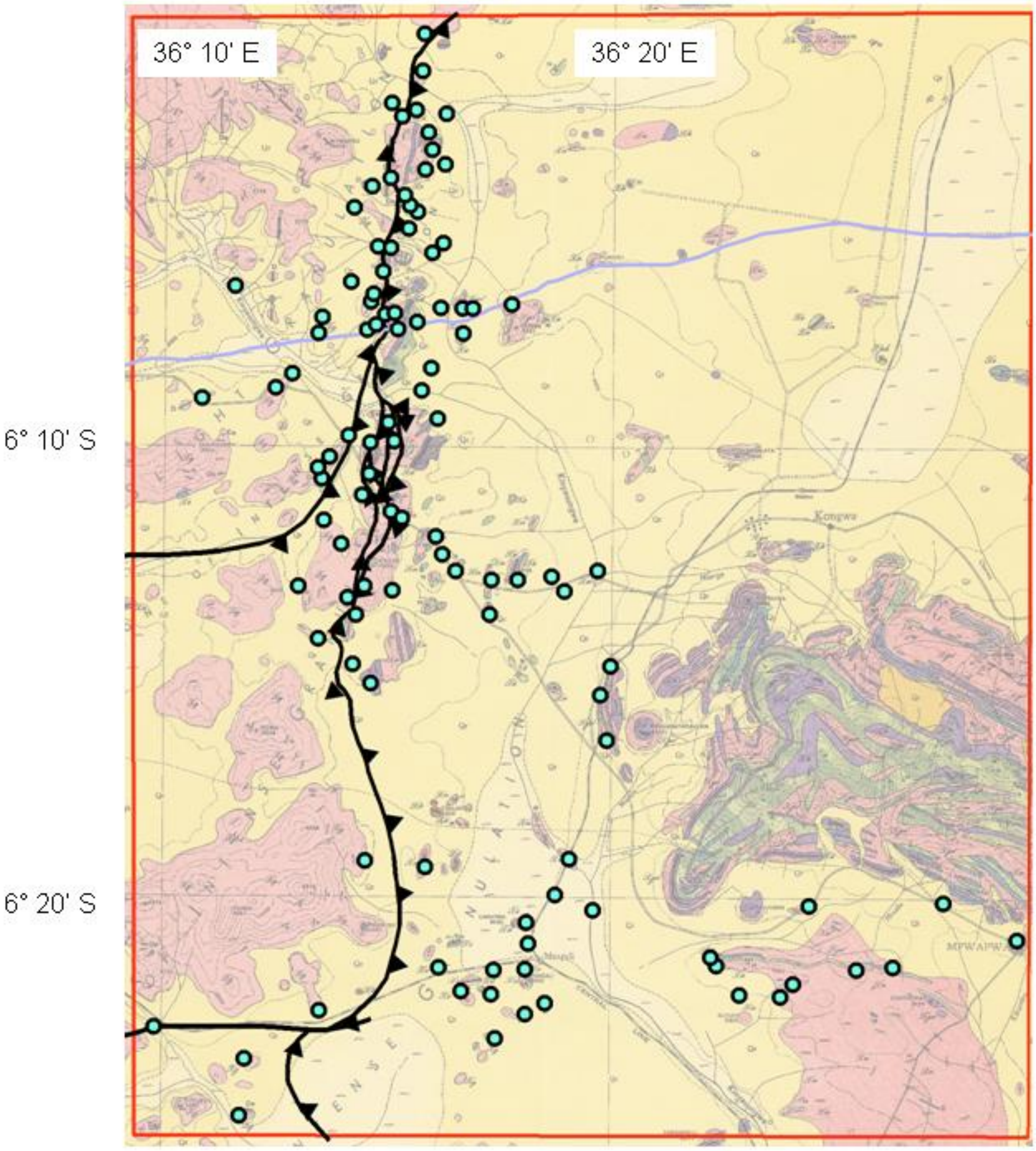
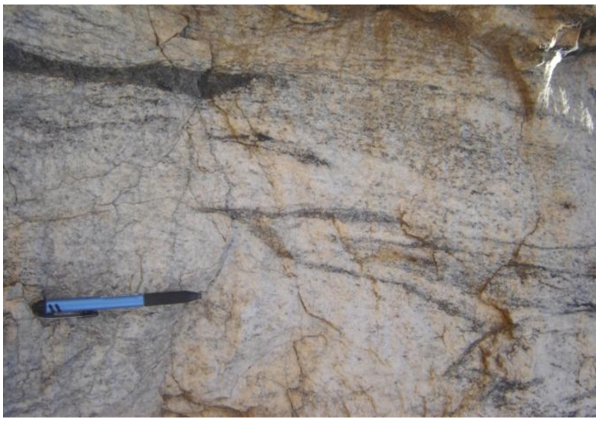


Figure 2. *Geology of the study area: identified craton-edge thrusts superimposed on published Mpwapwa geological sheet (Temperley et al., 1938). The Tanzanian Craton lies west of the thrusts (pink colours); the Mpwapwa Group lies to the east (blue, green and pink colours). Observation points in blue. Blue line is main Dodoma to Dar-es-salaam road.*

Over this area, the rocks of the eastern Tanzanian Craton are uniformly composed of grey, coarse-grained but inequigranular, migmatitic, granodioritic orthogneiss (quartz-plagioclase-minor K-feldspar-biotite ± hornblende). The rocks are heterogeneous on a small-scale, but are very similar over a large area, imparting a marked regional homogeneity. Typically the fabric is characterised by an irregular to chaotic, diffuse, swirling, locally folded foliation with no consistent geometry and immeasurable at outcrop, separated by areas of more homogeneous granodiorite (Figure 3a). The irregular gneissic fabric is caused by differences in modal mineralogy, grain size and leucosome veins (Figure 3b). Unlike the cratonic granitoids south of Dodoma, the eastern granodiorite is not heavily contaminated, but some diffuse, deformed mafic enclaves and biotite schlieren and blebs are usually present, locally imparting a crude diffuse banding. In some areas, a coarse-grained, leucocratic facies of the orthogneiss is present, with diffuse, folded biotite schlieren (Figure 3c). Leucosomes are often speckled in appearance, with coarse hornblende spots about 1 cm in size, locally replaced by micas. In a few localities, regularly-spaced, post-foliation shear zone cleavage is developed as fold crenulations, occupied by minor amounts of secondary diffuse leucosome (Figure 3d).

a)

b)



c)

d)

Figure 3. *Characteristics of the cratonic migmatitic granodiorite orthogneiss in the study area east of Dodoma a) Typical outcrop of grey orthogneiss showing biotite-rich blebs and schlieren to left and right of more homogeneous granitoid in the centre, with dark biotite-rich inclusions (Locality BTHOMAS_535: 859225/9322287); b) Coarse-grained leucocratic facies of the orthogneiss with diffuse, folded biotite schlieren (same locality as a); c) Orthogneiss showing weakly banded nature in some places and irregular felsic leucosome (Locality BTHOMAS_537: 859113/9323532); d) Regularly spaced, post foliation shear zone cleavage developed as fold crenulations, occupied by minor amounts of diffuse leucosome (Locality BTHOMAS_513: 852060/9319271).*

Towards the east, the irregular foliation in the orthogneiss becomes progressively, drawn into parallelism, such that a regional pervasive, SE-dipping foliation becomes apparent. Further east, the strengthening foliation is joined by an irregularly-developed, SE-plunging stretching lineation as the craton-edge shear zones are approached. Finally, within the bounding shear zones, the granodiorite shows protomylonitic to true mylonitic/ultramylonitic and porphyroclastic fabrics which dip E or SE, with strong SE-plunging lineations (see structure section, below). On the SE side of the contact lie the rocks of the Mpwapwa Group. In some of the high strain zones within the granodiorite orthogneiss in the craton margin shear zones, structural domains with dominant intense S-fabrics alternate with domains where the foliation is tightly folded around fold axes which plunge down the regional lineation direction. This gives rise to constructional L-dominated domains, with proto-megamullions locally developed (Figure 4).

a)

b)

Figure 4. *L-dominated domains (proto-mullions) in the cratonic granitoid orthogneiss (Locality BTHOMAS_556: 859965/9317483). a) Mega proto-mullions developing in intermediate S-L structural domains; b) Tight constructional M-style folding of foliation normal to mullion extension direction (which plunges away from the picture).*

Mpwapwa Group

A sequence of high-grade metamorphic supracrustal rocks occur immediately to the east of the craton edge. It is not certain to which (if any) of the known supracrustal sequences these rocks belong. On the 1: 2 000 000 geological compilation of Tanzania (Pinna et al., 2004) the rocks are merely shown as “Usagaran”, and are thus interpreted to be of Palaeoproterozoic age. In order not to make any erroneous correlations with other sequences, the rocks are termed here the “Mpwapwa Group”. It was not the purpose of this study to make a detailed study or re-map the Mpwapwa Group – the rocks are mapped and described in detail in Temperley (1938) and Temperley et al (1953). However, the rocks were examined with a view to:

a) Assess any gross changes in lithostratigraphic assemblage from the craton margin to the east, away from the craton
b) Determine any age-constraints on the group
c) Determine if the large areas of granitoid interleaved with the Mpwapwa Group can be correlated with those of the Tanzanian Craton (as shown on Temperley, 1938) or not. This has obvious implications for the position of the craton margin.

The Mpwapwa Group is characterised by a thick, strongly foliated, highly diverse meta-sedimentary sequence (paragneisses), interlayered with thick basic meta-igneous units. It is impossible to estimate the relative abundances of the rock-types that make up the Mpwapwa Group, as the exposed areas on ridges and hills are made up of resistant lithologies such as quartzites and metabasic rocks, while the extensive, lower, unexposed areas rarely are seen to be underlain by less resistant mica-rich metapelites for example. They were metamorphosed under amphibolite grade conditions, but most of the rocks are not as extensively migmatised as those of the craton. Below are brief descriptions of the lithologies encountered.

Quartzite

Quartzite units are abundant in the Mpwapwa Group. They are probably over-represented in terms of outcrop due to their resistance to weathering and, as such, they tend to form the spines of many of the rounded ridges which abound. Many are coarse-grained, glassy white to pale-grey or dark grey rocks with little fabric. Other units are finer-grained, often micaceous and with layering on a mm to few cm scale due to grain size differences and darker, heavy mineral layers (Figure 5a). In locality BTHOMAS_521 (862491/9312143), primary cross-bedding was observed in layered quartzites with sub-vertical foliation and fine dark layering, probably due to heavy mineral concentrations (Figure 5b). Some quartzites are kyanite-bearing, with kyanite occurring in coarse bladed aggregates (Figure 5c). Tight to isoclinal folding of the layering is seen in some high strain domains (Figure 5d). Typically, the rocks are feldspar-free mature orthoquartzites with >95% of strongly stretched, strained and crenulate quartz, muscovite (ca. 2%) as strongly oriented flakes thin aggregated foliae with sparse opaque mineral and traces of apatite and zircon (see Appendix).

a)

b)

c)

d)

Figure 5. *Quartzites of the Mpwapwa Group. a) Thinly-laminated quartzite, with heavy mineral layers; b) Primary cross-bedding in well-layered quartzite (a and b both from Locality BTHOMAS_521: 862491/9312143); c) Coarse-grained glassy white recrystallised quartzite with pods of coarse, bladed kyanite (Locality BTHOMAS_553: 861751/9318416; d) Tight folding in grey and white quartzite (Locality BTHOMAS_610: 861269/9328649).*

Kyanite rocks

Kyanite is the common metamorphic indicator mineral of aluminous rocks of the Mpwapwa Group, being present in many meta-pelitic and some quartzitic rocks. In one locality, BTHOMAS_569 (872979/9296235) spectacular kyanite-pyroxene-amphibole rocks were found, but unfortunately not totally *in situ*. At the western tip of a prominent E-W ridge are loose boulders of coarse-grained grey glassy quartzite, accompanied by abundant boulders of massive, heavy coarse-grained bluish-green pure kyanite rocks ± clinopyroxene and clino-amphibole (Figure 6a), along with rare marble fragments. In thin section a sample showed that the rocks are composed of large euhedral blades of kyanite (50%), euhedral pale green clino-amphibole (probably actinolite), grains up to about 1 to 2 mm, pale green euhedral diopside grains < 1 mm across, set in a fibrous and radiating interstitial groundmass of chalcedonic quartz (20%) (See Appendix). The kyanite rocks presumably occur as large blebs within the metasedimentary sequence. They must have been formed from the metamorphism of rocks with an unusual protolith composition, such as peraluminous ashy siliceous tuff?

Pelitic schist and gneiss

Mica-rich schists and gneisses ± garnet and kyanite occur extensively within the paragneiss sequence. For example at Locality BTHOMAS_543 (861553/9325230), two- mica garnet schists are interlayered with coarse-grained glassy quartzites and actinolite amphibolites. Pelitic rocks probably constitute a larger proportion of the Mpwapwa Group, especially near the craton margin than is apparent from outcrop abundance alone, as they are easily weathered and only tend to occur where in immediate contact with more resistant layers such as quartzite and marble. Kyanite is also locally abundant, for example at Locality BTHOMAS_547 (862784/9322922), poor outcrops of coarse-grained pelitic gneiss have quartz-feldspar-biotite-muscovite-garnet-kyanite parageneses (Figure 6b). The kyanite forms bluish-green blades up to 1 cm in length, while garnet porphyroblasts of smaller dimensions occur in some layers. In thin section, feldspar is seen to be very minor and the major phases are accompanied by accessory opaque mineral, zircon and apatite (see Appendix). In the detailed section, west of Locality BTHOMAS_610, there is a thick (several hundreds of metres exposed) sequence of slabby grey semi-pelitic gneisses, with layers with very coarse garnet porphyroblasts over 1 cm across (Figure 6c). In western part of this sequence, very close to the boundary with the craton, is a dark grey heterogeneous layer several metres thick, which is made up of various exotic rounded clasts of granitoid and other lithic fragments, in a scaly micaceous matrix with garnet, which is a possible interlayered diamictite bed (Figure 6d). The section also includes one light green actinolite amphibolite layer up to 5 m thick.

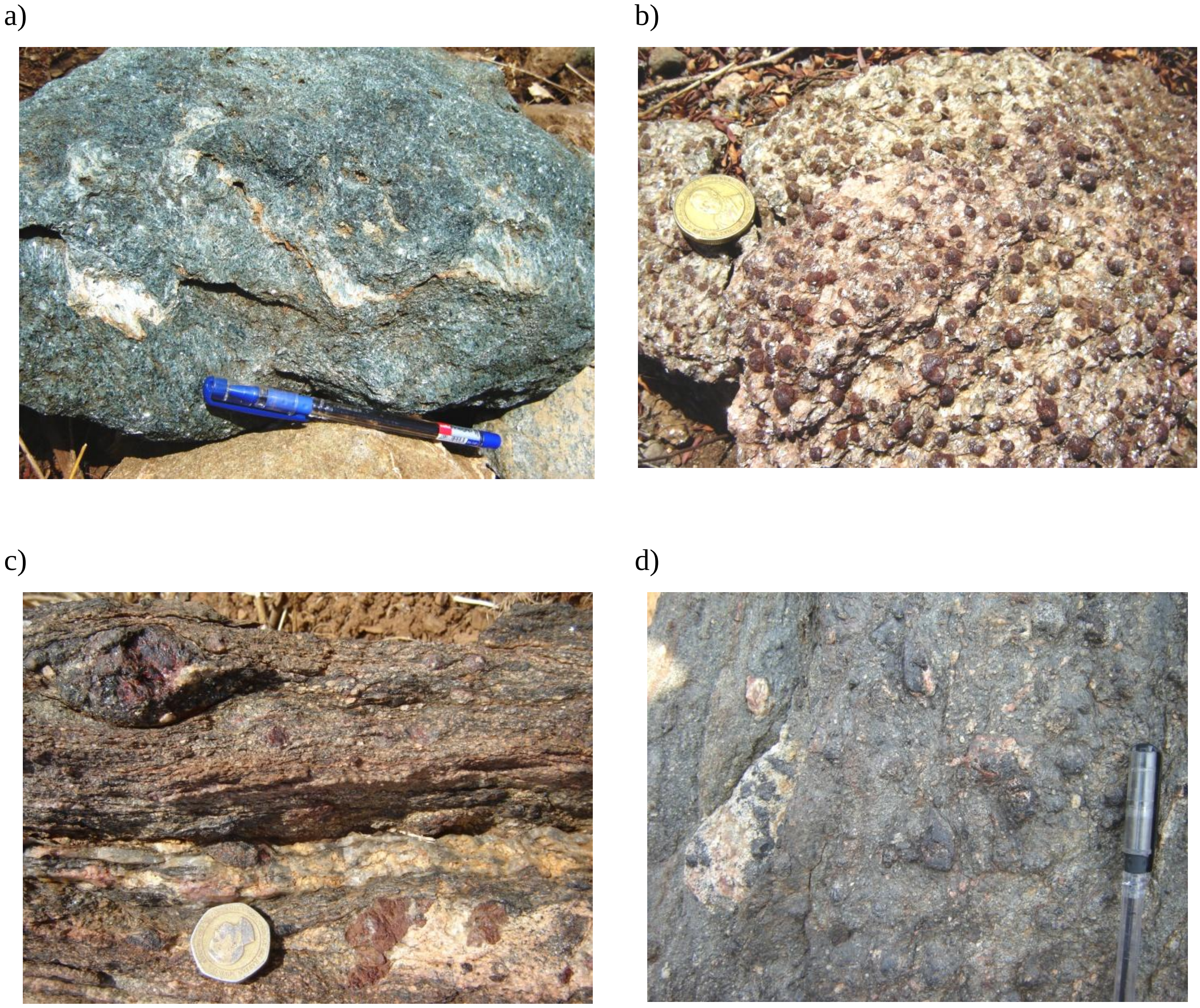


Figure 6. *Aluminous rocks in the Mpwapwa Group. a) Coarse-grained bladed kyanite rock (Locality BTHOMAS_569: 872978/9296235); b) Two mica schist/gneiss with abundant almandine garnet (Locality BTHOMAS_543: 861553/9325230); c) Coarse garnet porphyroblasts in semi-pelitic gneiss; d) possible coarse diamictite layer with rounded granitic clast? (left) in "dirty" grey, heterogeneous, inequigranular matrix, within the pelitic schist/gneiss sequence (c and d from part of section west of Locality BTHOMAS_610: 861269/9328649) .*

Semi-pelitic gneiss and migmatite

These rocks are less micaceous than the true pelitic rocks and tend to be garnet and kyanite-free, though the latter was seen in a few places. Excellent outcrops of these rocks can be seen on the main Dodoma to Dar-es-Salaam road (Locality BTHOMAS_550: 864799/ 9323099). The northern part of the section, at base of the hills is made up of very heterogeneous, well-banded, biotite- and muscovite-rich pelitic stromatic migmatite with tight folding of banding (Figure 7). The banding is mainly caused by coarse quartz-feldspar leucosome veins one- to a few cm thick and biotite-rich restitic melanosomes which form lensoid clots in minor fold closures. Going south, up the hill, the strain increases, so that at the top the gneisses have a much more regular, straight planar banding with a strong foliation and lineation. At this locality, some biotite-muscovite rich layers contain sparse blue kyanite, but garnet was not seen.

a)

b)

Figure 7. *Two examples of semi-pelitic migmatite of the Mpwapwa Group, with deformed, largely, stromatic leucosomes (Locality BTHOMAS_550: 864799/9323099).*

Marble and calc-silicate rocks

Low volumes of calcareous and calc-silicate rocks are relatively common along the western marginal outcrop of the Mpwapwa group, but less common to the east. They are not particularly well exposed, but at Locality BTHOMAS_517 (861679/9313573) a small disused quarry exposes marble layers several metres thick, along with interlayered calc-silicate rocks, including rocks with quartz-calcite-dolomite-tremolite-diopside assemblages. Most of the marbles are coarse-grained, but very inequigranular pale-grey to white, strongly recrystallised, with strongly foliated domains separated from coarse crystalline, more massive layers. It appears to be rather impure, being locally micaceous and with quartz-rich clots. The marble is interlayered with other paragneisses. The structural base of the succession in the quarry is marked by a quite pure white equigranular micaceous quartzite, followed by thin (about 1 m) greenish actinolite amphibolite, overlain by about 2 m of fine- to medium-grained grey biotite granular schist/gneiss (similar to those seen near Dodoma: meta-greywacke/dirty sandstone?). Above lies the marble which is ca. 15 m thick, in turn overlain by a grey-weathering sugary quartzite. At locality BTHOMAS_552 (861100/9319576) and amphibolite-paragneiss sequence contains a 0.5 to 1.5 m thick layer of pink (dolomitic?) coarse-grained layered marble, folded around an open synformal structure some 5 m across (Figure **8**a).

Regionally, the calcareous rocks tend to be associated with quartzites, calcareous paragneisses, calc-silicate rocks and garnet-free calc-amphibolites ± epidote and titanite. The latter tend to be clinopyroxene and epidote-bearing and grade into siliceous calc-silicate rocks with increasing silica content. Calc-amphibolites often have a characteristic “pitted” weathered appearance (where the pits are often spongy clinopyroxene porphyroblasts) and are locally agmatitic. Local segregations of coarse garnet-quartz rocks and epidote pods were noted in some grey medium-grained calc-silicate gneiss outcrops, as for example at the large calc-silicate koppie at BTHOMAS_562 (861779/9295854) (Figure **8**b). At this locality, grey, medium-grained equigranular calc-silicate gneisses are interlayered with calc-amphibolites with amphibole porphyroblasts up to 5 cm in size and green epidote-rich rocks (Figure **8**c). This outcrop forms such a prominent feature, rising above the adjacent sandy plains that it probably forms a resistant mega-boudin amongst other, unexposed, softer paragneisses.

Exposed marble and calc-silicate outcrops are often accompanied by the overlying development of quite extensive surficial calcretes, as a replacement feature under and within the soil profile. The calcrete can be up to a metre thick in places and is composed of rounded masses of calc-cemented grit (Figure **8**d). The underlying presence of marble can probably be inferred in some unexposed areas by extensive surface calcrete development.

a)

b)

c)

d)

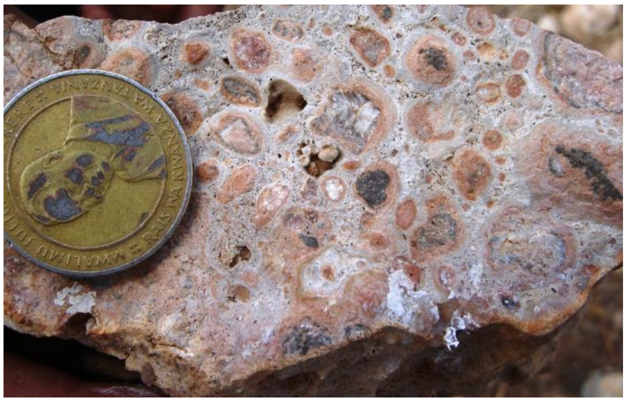


Figure 8. *Calcareous and calc-silicate rocks in the Mpwapwa Group. a) Layered coarse-grained pink (dolomitic?) marble within paragneiss sequence (Locality BTHOMAS_552: 861100/9319576); b) Grey calc-silicate gneiss (quartz-plagioclase-diopside) with amphibolitic blebs (Locality BTHOMAS_562: 861778/9295854); c) Mixed calc-silicate mafic gneiss, diopside amphibolite (dark grey) and epidote-amphibolite (green) (Locality BTHOMAS_610: 861269/9328649); d) Detail of gritty calcrete which is typically developed in the surface profile above calcareous rocks (unmarked locality: 861927/9318803).*

Quartzo-feldspathic gneiss

Probably one of the more abundant lithotypes of the Mpwapwa Group, these rocks are intimately associated with amphibolite gneisses. They are, medium- to coarse-grained, usually pinkish-weathering, saccharoidal, very leucocratic gneisses composed of quartz-feldspar with very little biotite (CI typically <5%). They are locally inequigranular, with scattered large K-feldspar augen (Figure 9a). Locally very small amounts of muscovite are present, and very sparse, tiny, clear pink garnets about 1 mm in size or less. The rocks are typically strongly foliated and lineated and intense ribbon-quartz fabrics are present in sheared rocks close to the craton margin (Figure 9b). Sometimes, thin (cm -scale) quartz veins are seen, parallel to foliation (e.g. Locality BTHOMAS_557: 859724/9318241). The rocks are locally migmatitic, with coarse-grained, usually layer-parallel, often tightly to isoclinally folded, leucosome veins and blebs up to a few cm thick (Figure 9c). This lithology often forms rods and mullions in L-dominated structural domains (Figure 9d). The gneisses are composed of strongly parallel-oriented quartz (35%), K-feldspar (orthoclase: 40%), sodic plagioclase (20%), with sub-equal biotite and muscovite (together 5%) in thin foliae and trace amounts of zircon. The texture is extremely inequigranular, with K-feldspar grains up to about 2 mm in size and quartz forming elongate aggregates. The strong foliation defined by parallel alignment of minerals (especially micas, quartz aggregates) and grain size variations in the mineralogy. Most of the “granitic” rocks on the map of Temperly et al. (1953), east of the craton margin, are made up of this unit.

a)

b)

c)

d)

Figure 9. *Quartzo-feldspathic gneisses of the Mpwapwa Group. a) Inequigranular rather heterogeneous Q-F gneiss, with feldspar porphyroblasts and strong planar fabric (Locality BTHOMAS_572: 876352/9295133); b) Detail of quartz-feldspathic gneiss in high strain zone, showing typical quartz-ribbon fabric (Locality BTHOMAS_557: 859724/9318240); c) Thin folded leucosomes in otherwise rather homogeneous gneiss (Locality BTHOMAS_570: 874163/9294700); d) L-tectonite (mullions) developed in quartzo-feldspathic gneiss in L-dominated domains (Locality BTHOMAS_545: 859316/9325480).*

Amphibolite and hornblende gneiss

As noted above, clinopyroxene-bearing calc-amphibolites occur interlayered with calc-silicate rocks. Other prominent, typically garnet-free, foliated amphibolite gneisses with simple, sub-equal plagioclase-hornblende mineralogy, locally with epidote, occur as layers up to several tens and hundreds of metres thick within the quartzo-feldspathic gneisses. The amphibolites are usually strongly foliated, with layering due to grain size differences and slightly variable hornblende-plagioclase ratios (Figure 10a). Occasionally the amphibolites are weakly migmatitic with development of thin, sparse leucosome veins and blebs (Figure 10b). The observed felsic-mafic gneiss bimodality becomes a dominant feature of the Mpwapwa Group east of some 8 to 10 km east of the craton margin, at least as far as Mpwapwa.

a) b)

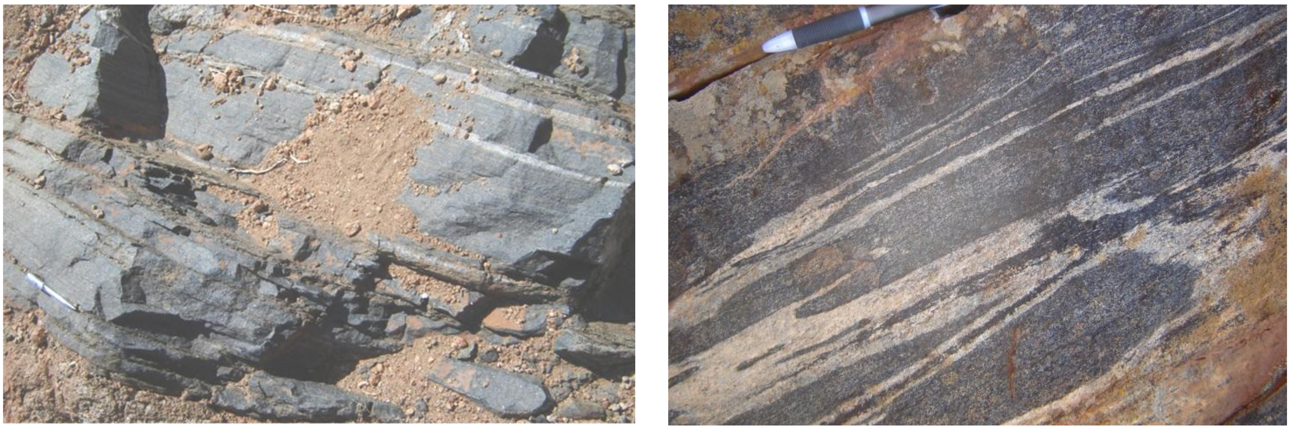


Figure 10. *Amphibolites in the Mpwapwa Group. a) Layered mafic hornblende gneiss, with thin, sparse plagioclase-rich layers (Locality BTHOMAS_513: 852060/9319271); b) Migmatised amphibolite, with deformed and stretched leucosomes: such rocks are not very common and probably represent calc-amphibolite agmatites flattened in the boundary shear zone (Locality BTHOMAS_530: 863894/9310347).*

Garnet-clinopyroxene amphibolite

The mountainous part of the Mpwapwa Group, which forms the high massif north of Mpwapwa contains multiple layers several tens of metres thick, of massive to poorly-foliated, dark-greenish grey, mafic garnet-clinopyroxene amphibolites, which are oriented parallel to the regional foliation. The layers tend to be separated by more weathered layers of quartz-feldspathic gneisses of similar thickness. The rocks are poorly-foliated and slightly layered, with the latter defined by differences in grain size and locally defined by trains of garnet grains of differing grain size (Figure 11a). In one locality (BTHOMAS_577: 882560/9298463), massive, to poorly foliated garnet amphibolite shows cauliform garnet porphyroblasts up to ca 1 cm across which grew across (later than) a set of very thin (migmatitic?), ptygmatically folded leucocratic veins (Figure 11b). In thin section, the rocks are seen to be composed of about 40% clear plagioclase, with abundant green hornblende (ca. 40%), anhedral clear pale green clinopyroxene (diopside?) and anhedral embayed and inclusion-filled garnet up to 3 mm in size. There are significant amounts (ca 1%) of rounded, subhedral titanite grains, often occurring in aggregates and “trains” aligned parallel to the foliation which is defined mainly by alternating plagioclase-rich and –poor layers and grain size differences. Some large ragged opaque mineral grains are sparsely present. In one locality (BTHOMAS_586: 860571/9326235), garnet amphibolite contains what appear to be grey orthogneiss xenoliths, suggesting that they are an intrusive lithology, possibly mafic sills? (Figure 11c).

a)

b)

c)

Figure 11. *Garnet-cpx amphibolite. a) Very mafic amphibolite, with weak planar fabric defined by aligned garnet grains (Locality BTHOMAS_577: 868874/9308211); b) Cauliform garnet porphyroblasts showing they grew later than emplacement of very thin felsic veins (Locality BTHOMAS_577:882560/9298463); c) Xenolith of grey hornblende-plagioclase gneiss sin garnet amphibolite suggest an intrusive origin for the latter* (*BTHOMAS_586: 860571/9326235*).

Layered gneisses of tonalitic composition, origin uncertain

At the top of Laisanga mountain, above a series of poorly exposed paragneisses, (Locality BTHOMAS_570: 865382/9297691), are cuttings and outcrops of fresh, highly sheared, streaky grey gneiss. The rocks are coarse-grained, but very inequigranular, banded and blebby (Figure 12a). The banding on cm to 20 cm scale, between light-coloured coarse-grained quartz-feldspar-biotite gneiss and all intermediate compositions through to dark, hornblendic blebs. CI ranges from about 5 in most leucocratic layers, up to 90 in hornblendic blebs and almost everything in between. The banding is accentuated by grain size variations, but while the gneiss is sheared and heterogeneous, is not notably migmatitic (Figure 12b). The overall bulk composition is probably tonalitic, but the protolith is unclear; they could be orthogneisses. A weak, almost down-dip lineation is present and kinematic indicators such as asymmetrical amphibolite blebs give a give top-to-NW sense of shear (thrust). The ductile fabric is locally deformed into metre-scale, tight similar folds.

a) b)

Figure 12. *Gneisses of tonalitic bulk composition within the Mpwapwa Group – protolith uncertain (Locality BTHOMAS_580: 865382/9297691). a) Blebby grey gneiss with hornblende-rich mafic streaks; b) Leucocratic-melanocratic layering in the gneiss.*

Plutonic igneous rocks

The Mpwapwa Group appear to have been intruded by three different plutonic igneous rock types and fairly rare pegmatite bodies. The rocks occur in widely-spaced localities and were nowhere observed juxtaposed. The relationship with the Mpwapwa Group was not observed either except for possible xenoliths of Mpwapwa Group gneisses in one of the intrusions. Each has been samples for possible U-Pb zircon dating in order to give a minimum age for the Mpwapwa Group.

Biotite granite

Two outcrops of identical, pinkish-weathering, grey, almost unfoliated granite were found in the sand flats bordering the Kinyasungwe River (Localities BTHOMAS_531 and _532 (866974/ 9311312; 866452/9311901 respectively). They form a number of low small outcrops, scattered over few hundreds of square metres (Figure 13a), of fairly leucocratic (ca 8% biotite), coarse-grained, equigranular, homogeneous granite (fine-grained for a granite 2-4 mm average grain size). The mineralogy is of granite *sensu stricto* with quartz, pink K-feldspar, subordinate white plagioclase and biotite with sparsely scattered magnetite grains surrounded by leucocratic haloes. A typical modal mineralogy of the granite is quartz (35%: slightly strained grains up to 3 mm in size), unaltered microcline (45%), sodic plagioclase (15%), very dark brown unaltered biotite (5%), with accessory zircon and apatite and rare allanite (see Appendix). The granite is “clean”, with no xenoliths seen, but is intruded by a few thin pegmatites. It is very weakly foliated with what may be an igneous fabric.

Sheared tonalite (orthogneiss)

Highly sheared tonalite, now a strongly foliated orthogneiss was observed within the western part of mylonitic craton margin, within the Mpwapwa Group just north of the main Dodoma to Dar-es-Salaam road near Km 56 (Locality BTHOMAS_539: 859995/9322749). It is not known if the strong pervasive foliation is due entirely to its position within the shear zone. A few other outcrops of similarly orthogneissic rocks were found in the southern part of the area.

The rocks consist of highly foliated, lineated, tonalitic orthogneiss. It is coarse-grained in lower strain zones and finer-grained where intensely deformed. The lithology is an equigranular, dark grey, homogeneous, entirely non-migmatitic plutonic igneous rock composed of quartz, plagioclase, hornblende and biotite (Figure 13b). It is devoid of later veins or xenoliths. Much of the outcrop at BTHOMAS_539 is protomylonitc, with small hornblende augen throughout, strongly drawn out along the lineation direction and some hornblende porphyroclasts up to 3 cm across (Figure 13c). The mineralogy of the tonalite is marked by an unusual accessory mineral suite. It is composed of quartz (15%), plagioclase (65%, with periclinal twinning), minor microcline and very dark-green hornblende (12%; no biotite), with quite high quantities (total 3%) of accessory allanite (euhedral grains up to 0.8 mm, metamict, with by narrow halo of expansion cracks), titanite (subhedral grains up to 0.5 mm in length, aggregated with hornblende) and zircon (up to 500 μ) with a little secondary carbonate (see Appendix).

Charnockite

Dark greyish green two-pyroxene charnockite crops out in a disused quarry near Msagali (Locality BTHOMAS_563: 864042/9295752). Here, the main quarry face is composed of massive to poorly-foliated very dark grey charnockite, composed of pale blue, opalescent quartz, dark grey feldspars and pyroxene. In the lower part of quarry, the charnockite contains large rafts of quartzo-feldspathic gneiss, presumed to be belonging to the Mpwapwa Group country rock. This provides some evidence that the charnockite intruded the Mpwapwa Group. It may take the form of a sub-horizontal sheet as a flat-lying to shallow south-dipping foliation and leuco-veining/layering is present in upper parts of quarry. At Locality BTHOMAS_601 (866149/9294387), rounded outcrops are worked by locals for stone. The lithology is very coarse-grained, K-feldspar porphyritic, dark greyish-green charnockite, with grey euhedral K-feldspar phenocrysts up to 3 cm in size (Figure 13d). Over most of outcrop, there is a weak fabric (igneous?) with sub-parallel orientation of “matchbox” feldspars, but elsewhere, and parallel, porphyroclastic protomylonitic fabrics are developed. The charnockite is homogeneous and contains no recorded xenoliths or veins.

The felsic minerals of the charnockite comprises quartz (30%), as clear grains up to 3 mm across, unaltered orthoclase (32%) which is locally micro- string perthitic and subhedral plagioclase (25%) which occasionally shows patch antiperthitic texture. Some sub-solidus inter-feldspar reaction has produced myrmekite. Mafic phases comprise orthopyroxene (4%) as euhedral to subhedral grains up to 2 mm, altered along cleavage and prism-perpendicular cracks to a greenish serpentine mineral, anhedral, pale green clinopyroxene (4%), occasionally showing exsolution lamellae and dark brown biotite (4%), in slightly oriented mafic aggregates with pyroxenes. Accessory apatite, zircon and opaque mineral complete the mineralogy. It is interesting to note that the porphyritic charnockite is lithologically identical to those dated between ca 530 and 500 Ma in Madagascar and Mozambique respectively.

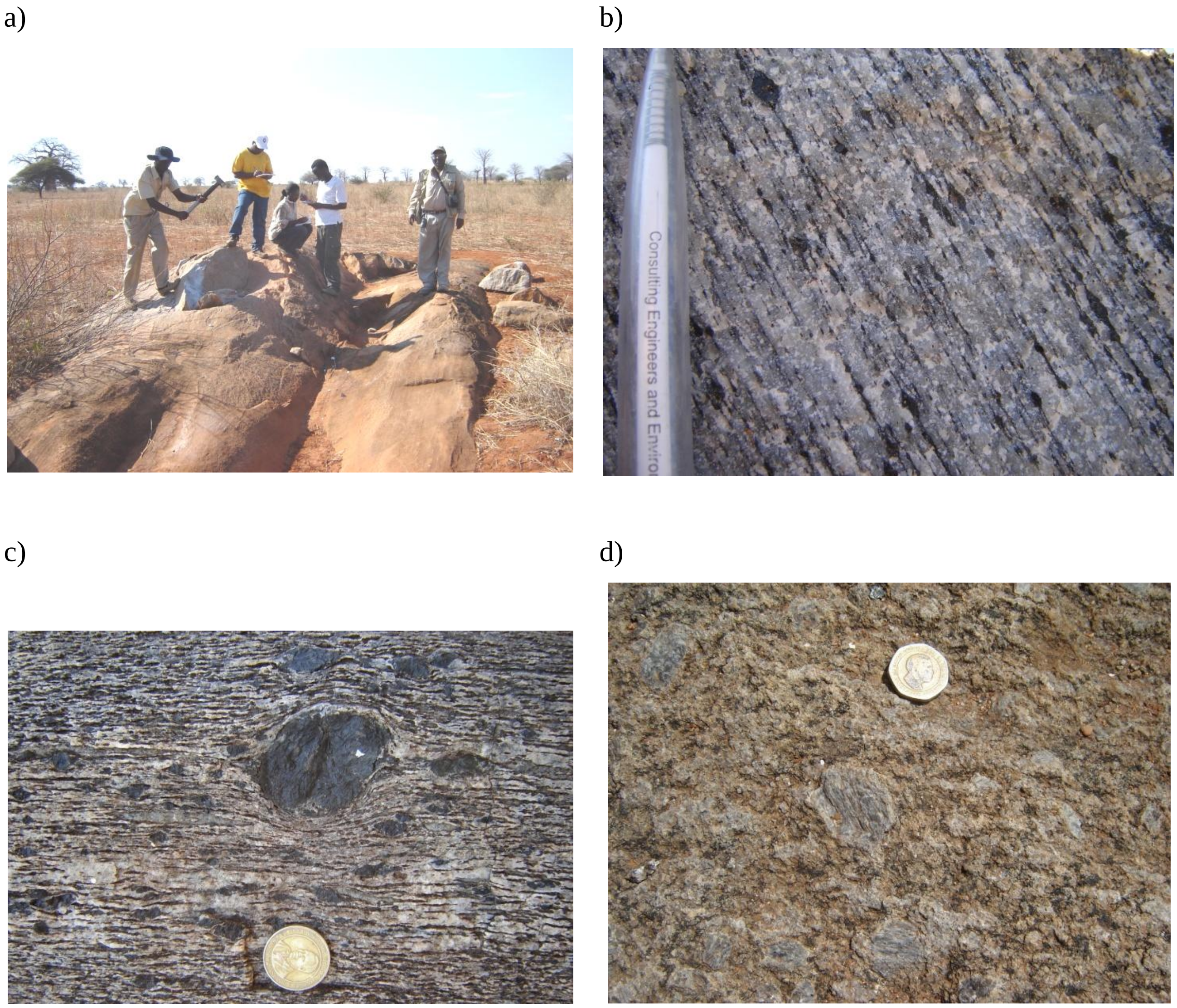


Figure 13. *Post-Mpwapwa Group (?) granitoids. a) Low pavements of homogeneous biotite granite (Locality BTHOMAS_532: 866451/9311900); b) Sheared hornblende tonalite; c) Large hornblende porphyroclast in sheared tonalite (b, c Locality BTHOMAS_532: 859995/9322749; d) Porphyritic charnockite, with large grey K-feldspar phenocrysts in coarse groundmass of dark greenish grey groundmass (Locality BTHOMAS_601: 866149/9294387).*

Pegmatite

The Mpwapwa Group are intruded by relatively few simple pegmatite bodies. A few of these have been pitted for minerals (mainly garnet), but with little apparent success. They contain only quartz, feldspar and minor muscovite, though highly tectonised tourmaline pegmatites were found in the boundary shear zone in the north of the area (see structural section, below).

Structure and metamorphism

The study area contains part of the eastern boundary of the Tanzanian Craton. The structural history can be described in terms of several tectono-metamorphic events occurring adjacent to and within the boundary zone.

1) *Archaean Tanzanian Craton*

The Tanzanian Craton occupies the western part of the area. The geology of the craton is much simpler than that described from the area south of Dodoma (see Dodoma geology geological report). Some 12 outcrops of the craton were examined. Each was composed of migmatised granodioritic orthogneiss. As described above, the foliation, where present, in these rocks away from the craton is poorly-developed, irregular and swirling with no regional pervasive trend. The rocks are quite strongly migmatised, with irregular coarse leucosomes throughout. Locally a second phase of migmatisation is associated with small, closely-spaced ductile shear zones (see Figure 3d). In summary, then Archaean deformation appears to be restricted to a weak, irregular gneissosity, with local small-scale shearing. Metamorphism took place under hydrous amphibolite grade, leading to extensive migmatisation.

2) *Mpwapwa Group*

Detailed structural analysis of the Mpwapwa Group is beyond the scope of this study, and the structure of the rocks is only documented where they occur in the craton-marginal tectonic zone. However, it is clear from the geological map of Temperley et al. (1953) that in the main massif of the group, north of Mpwapwa, the rocks underwent polyphase deformational events, with roughly E-W trending large-scale isoclinal folds refolded along N-S axes, giving rise to Type 3 interference structures (see Figure 2). These structures are not apparent in the marginal shear zone, presumably because they were pervasively overprinted by the shearing. The metamorphic grade of the Mpwapwa Group is exemplified by the assemblages garnet + kyanite in metapelites and garnet + clinopyroxene in some metabasites. These parageneses represent metamorphism at moderate- to high-P, upper amphibolite facies conditions. Localised, but not widespread, migmatisation in certain lithotypes suggests metamorphism took place at least under partially hydrous conditions.

3) *Boundary zone*

Coming from the west, the boundary zone is taken as the first appearance of highly foliated to protomylonitic fabrics in the cratonic granitoids. This is nowhere a sharp boundary, but occurs over a transitional, NNE-trending zone of up to over 1 km wide. The eastern boundary, being within the heterogeneous gneisses of the Mpwapwa Group is also poorly-defined, but is taken as the position where shear fabrics are replaced with non-shear related foliations and layering of the Mpwapwa Group. The zone, thus defined is from less than 1 km to over 2 km in width. The bounding thrust and shear zones mapped are shown on Figure 14. The main north-south thrust is positioned at the mapped tectonic contact between the craton and the Mpwapwa Group, but of course the mylonitised zone is wider than this, with diffuse margins. In the narrower zones it is made up of almost totally mylonitic rocks, whereas in wider zones, the strain is heterogeneously partitioned into an anastomosing array of high strain zones alternating with low strain zones characterised by simply foliated rocks.

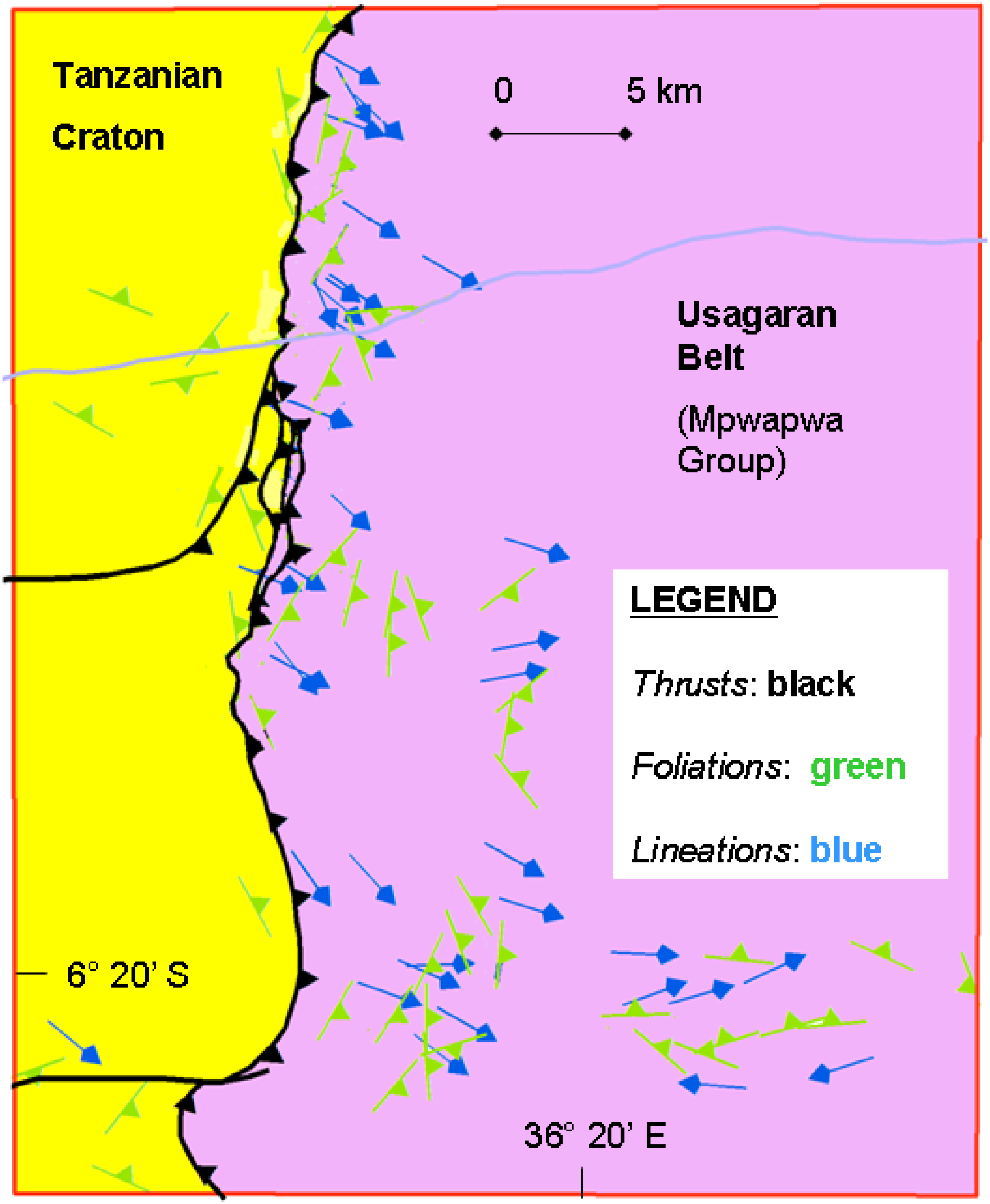


Figure 14. *Structural map of the area, showing main craton boundary thrust zones and foliations (green) and lineations (blue).Note consistency of lineations. Dashed line is main Dodoma to Dar-es-Salaam road.*

In the central part of the area, along the gravel road to Mpwapwa from the main Dodoma-Dar highway, the boundary zone is about 2 km wide and made up of a number of high strain zones, which locally make up a number of imbricate sheets with some interleaving of craton and Mpwapwa Group domains (Figure 15). These take the form of moderately SE-dipping protomylonitic fabrics in the cratonic rocks and parallel-foliated Mpwapwa Group rocks. The contact between the two groups is relatively usually sharp (<100 m), and was observed to within a few metres in the foot traverse between Localities BTHOMAS_609 and 610 (859828/9328304;

861269/9328649 respectively). A detailed 1.5 km long foot traverse was completed between these two localities and described in Part 3 of the Appendix. The Mpwapwa Group rocks in this traverse are highly foliated and lineated, but only mylonitised in localised domains. The bulk of observed mylonitic zones are partitioned into the cratonic granitoids, although the more homogeneous massive original nature of these rocks doubtless makes the high-strain zones more visible within them. The granitoid protomylonites are high-grade, porphyroclastic rocks and these sometimes form sigma clasts with a consistent top-to-the-NW sense of tectonic transport (i.e. towards the craton). The rocks are composed of fine- to medium-grained quartz, often with ribbon texture, plagioclase, as rounded mm-scale porphyroclasts and in the foliated groundmass, secondary small biotite flakes in foliae wrapping round porphyroclasts and secondary epidote (see Appendix). Stretching lineations are towards the SE, slightly oblique to the shear foliations, but essentially near-orthogonal in this zone.

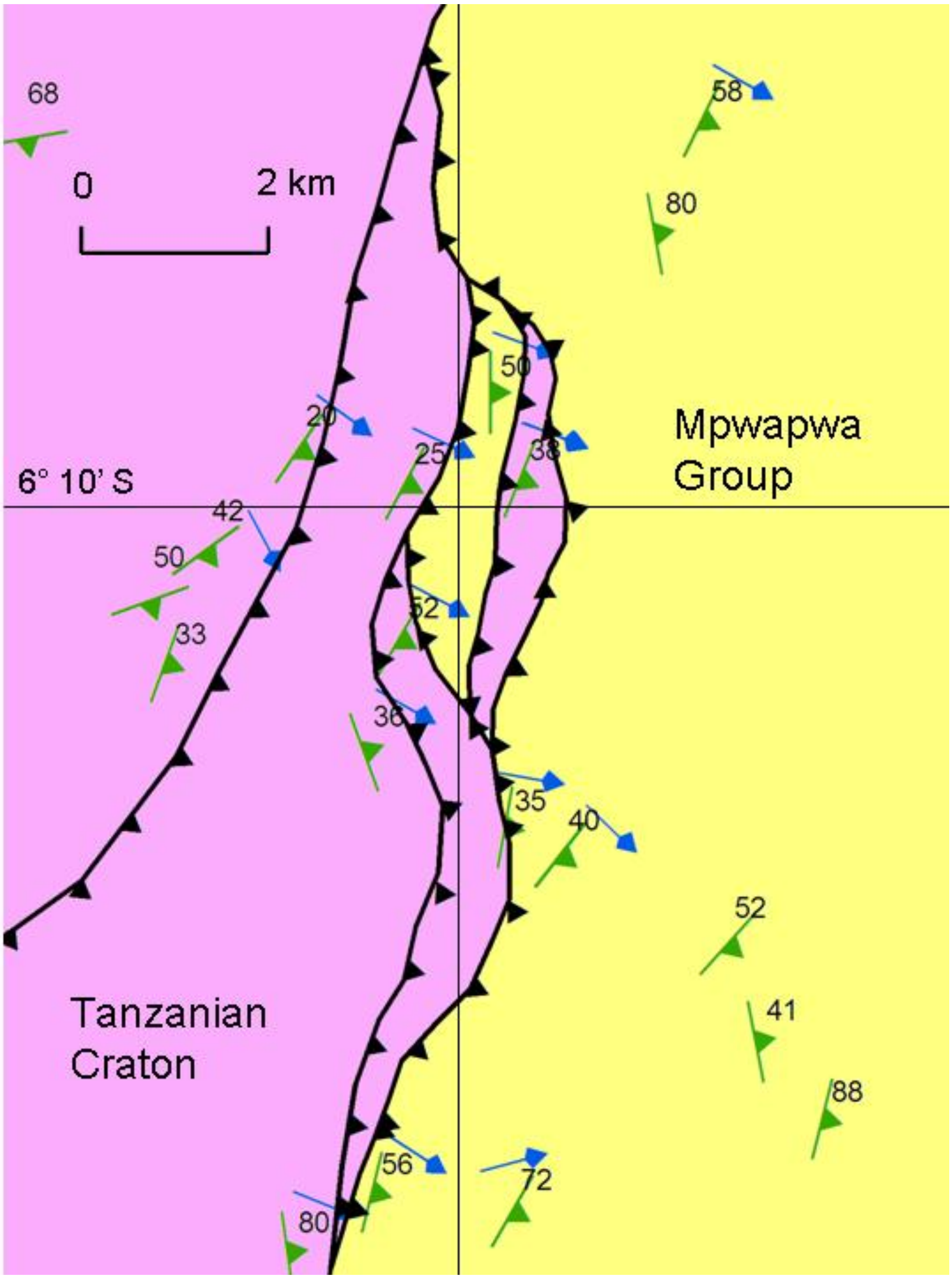


Figure 15. *Sketch geological map of the central part of the mapped thrust zone, showing tectonic imbricate slivers between cratonic and Mpwapwa Group.*

The narrow sections of the thrust belt are best exemplified by the road section up the mountain with aerials on top near kilometre 56 on the Dodoma to Dar-es-Salaam road. At the base, porphyroclastic mylonites representing highly deformed cratonic granitoid show massive grain size reduction. A four-stage progression in the deformation in cratonic granitoid is shown in Figure 16. The final stage of the mylonitisation process seen is the pale green very fine-grained siliceous mylonites seen below Locality BTHOMAS_539 (859995/9322749). These rocks are tectonites composed of a bimineralic assemblage of elongate recrystallised quartz aggregates and secondary epidote/clinozoisite (see Appendix). Note that unsheared granitoids are shown in Figure 3 for comparison.

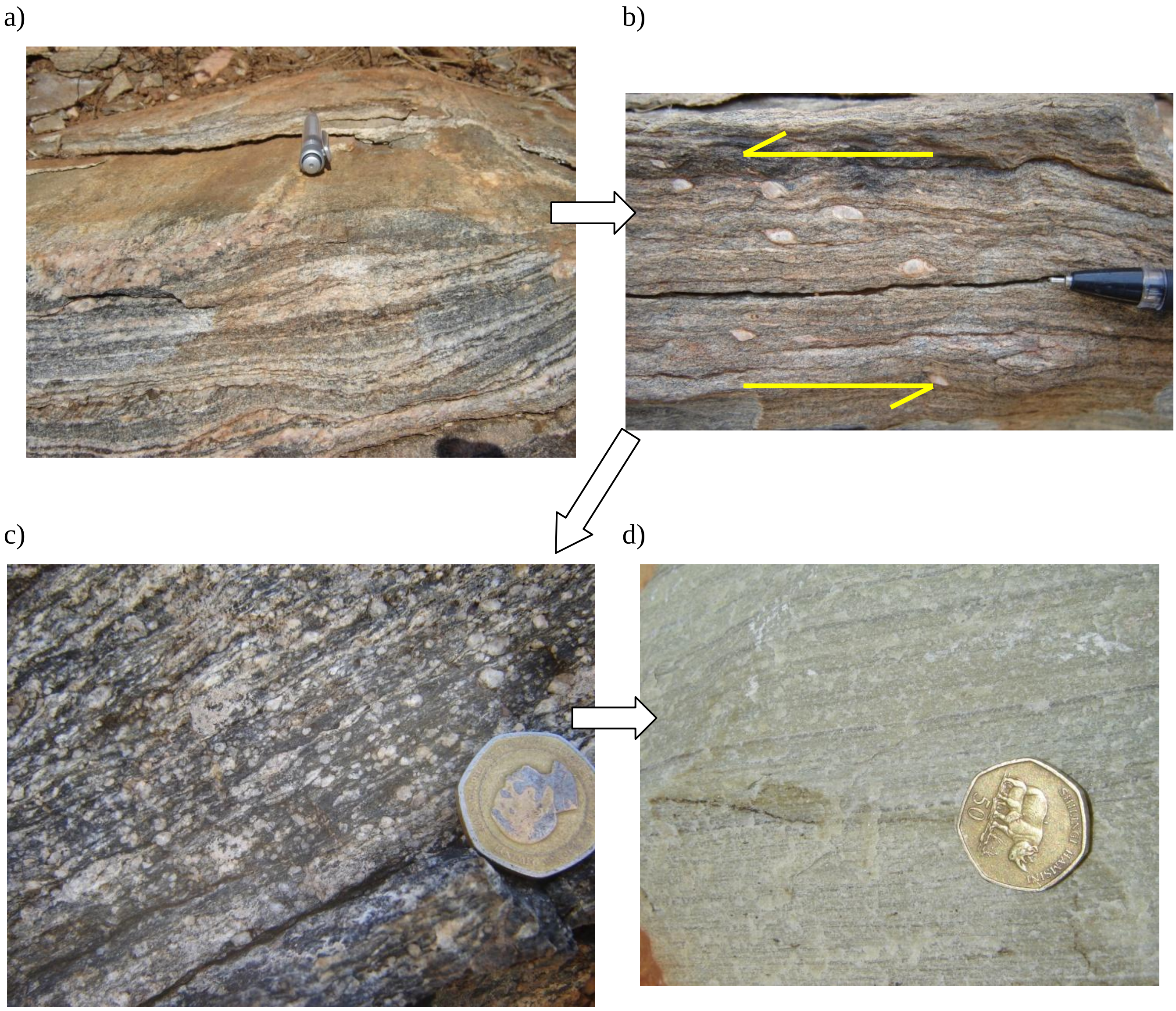


Figure 16. *Progressive shearing of cratonic granitoid. a) Strongly planar foliated granitoid, with lineation (parallel to pen) (Locality BTHOMAS_597: 859316/9325480); b) protomylonitic fabric in granitoid, with high degree of grain size diminution and small feldspar sigma clasts showing top-to-the NW (left) senses of movement (Locality BTHOMAS_610: 861269/9328649); c) porphyroclastic texture in sheared granitoid (Locality BTHOMAS_555: 860300/9330834); Note originally ca. 8 mm sized feldspar grains are now ca 3 mm in size (Locality BTHOMAS_536: 859011.9323223); d) Fine-grained quartz-epidote recrystallised mylonite (Locality BTHOMAS_532: 859995/9322749).*

In most sections of the thrust belt, the strain is manifest in string S-fabrics, with well-developed stretching lineations. In some zones, however, these S-dominated domains alternate with less extensive zones of L-dominated constructional strain fabrics, resulting in L-tectonites with in rodding and mullion structures. These L-domains are typically formed where the S-fabric is tightly and complexly deformed by minor folds with axes plunging parallel to the lineation direction (Figure 4).

Due to the already banded and foliated nature of the regional fabric in the Mpwapwa Group, deformation in these rocks in the shear zone is less obvious, as much of the strain will have been partitioned along pre-formed foliation planes. All the rocks are extremely strongly foliated and locally mylonitic fabrics are seen, especially in more massive units. For example, a pegmatite intruded into strongly lineated, equigranular, fine-grained quartz-feldspathic gneiss (L-tectonite) appears far more mylonitised that the host gneisses (Figure 17a), which show well-developed fold mullion structures (Figure 17b). However, some Mpwapwa Group gneisses do locally exhibit mylonitic fabrics; for example the quartzo-feldspathic gneisses, with attenuated ribbon quartz (see Figure 9b) and porphyroclastic textures (Figure 17c), the intrusive tonalite (Figure 13c, d), and the gneisses of uncertain origin (Figure 17d).

a)

b)

c)

d)

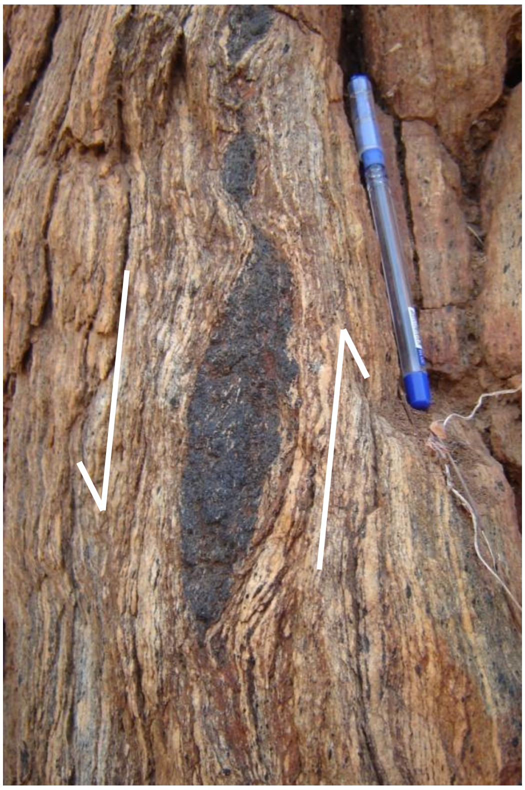


Figure 17. *Boundary shear zone deformation in the Mpwapwa Group. a) Mylonitised L-tectonite in deformed pegmatite (Locality BTHOMAS_581: 861219/9299980); b) Fold mullions developed in quartzo-feldspathic gneisses (Locality BTHOMAS_545: 859316/9325480); c) Mylonitised porphyroclastic quartzo-feldspathic gneiss (Locality BTHOMAS_545: 859316/9325480); d) High strain shear fabric in Mpwapwa Group tonalitic gneisses with oblique sinistral (top (right) to the NW (left) sense of movement (Locality BTHOMAS_580: 865382/9297691).*

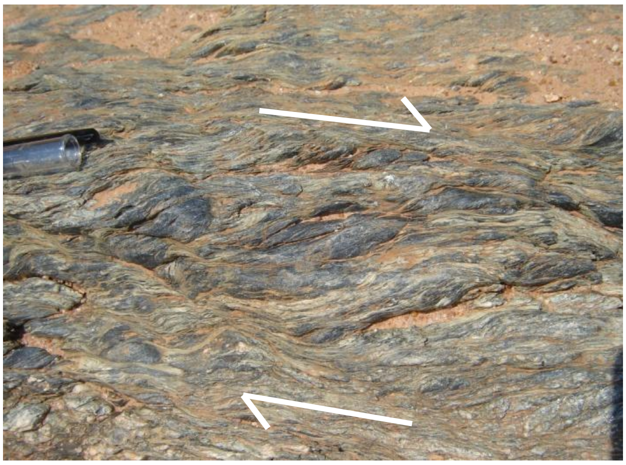
In one high strain locality, with intensely strong lineations, curious "scallop" structures have been developed on foliation planes in mylonitic grey quartzites. The origin of these structures is unclear, but they are perhaps the products of progressively increasing strain in the very competent quartzite lithology, whereby early-formed lineations have been tightly folded in certain domains (Figure 18)

a) b)

Figure 18. *Curious "scallop" structures developed on foliation planes in mylonitic grey quartzites. In both pictures the foliation plane is in the plane of the picture. The origin of these structures is unclear, but they perhaps represent re-folded lineations in a high-strain progressive shear regime (Locality BTHOMAS_588: 860412/9327587).*

In some zones north and south of the central, frontal parts of the thrust zone, the shear zone becomes rotated into a steeper (locally sub-vertical) attitude and the movements become more oblique (moderate- to shallow-plunging oblique lineations). Thus, north of the main Dodoma to Dar-es-Salaam road, the shear belt dips at some 75° to the east with an oblique SE-plunging lineation. In these zones, sigma porphyroclasts give an oblique **sinistral** sense of movement. Microstructural petrographic analysis on oriented samples support this kinematic shear sense (see Appendix). To the south of the frontal zone, west of Msagale, the boundary shear zone bends from an approximately N-S orientation to almost E-W. In this area the craton-bounding structure is represented by sub-vertical shear zones with oblique, moderately plunging lineations. These shear zones are retrogressed and are at upper greenschist to epidote amphibolite facies. In these lower-grade shears, lineations are weak, but senses of movement are determined as **dextral** from clear C-S shear fabrics and asymmetrical crenulation folds, features not seen in the higher grade shear zones further north (Figure 19).

a)



b)

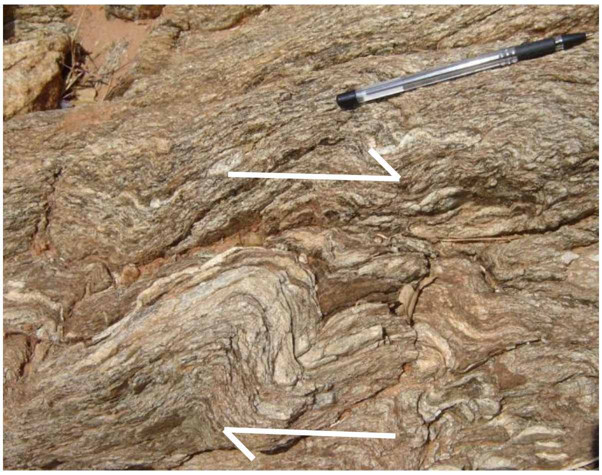


Figure 19. *Lower grade high strain mylonitised cratonic granitoids in the boundary zone (Locality BTHOMAS_560: 850060/9293415). a) Dextral C-S shear fabric; b) Dextral asymmetrical crenulation folds of the shear fabric.*

From the field evidence, it is clear that at least the latest deformation is late with respect to the youngest lithological units present in the area. All rock unit are affected, if not pervasively, then at least along intensely mylonitic ductile shear zones. For example, the youngest of the post-Mpwapwa Group intrusive rocks, such as the porphyritic charnockite and large, late pegmatite bodies are locally intensely deformed in the same style as the older rock units, with the development of strong shear fabrics in localised domains (Figure 20).

a)

b)

Figure 20. *Late ductile mylonitisation in post-Mpwapwa Group intrusive units. a) Porphyroclastic texture in porphyritic charnockite, with augened grey K-feldspars in mylonitic matrix groundmass (Locality BTHOMAS_601: 866149/9294387); b) Mylonitised pegmatite, with quartz-ribbon texture and fragmented, competent black tourmaline porphyroclasts (Locality BTHOMAS_610: 861269/9328304).*

The structural broad geology and structure of the area is given in Figure 21.

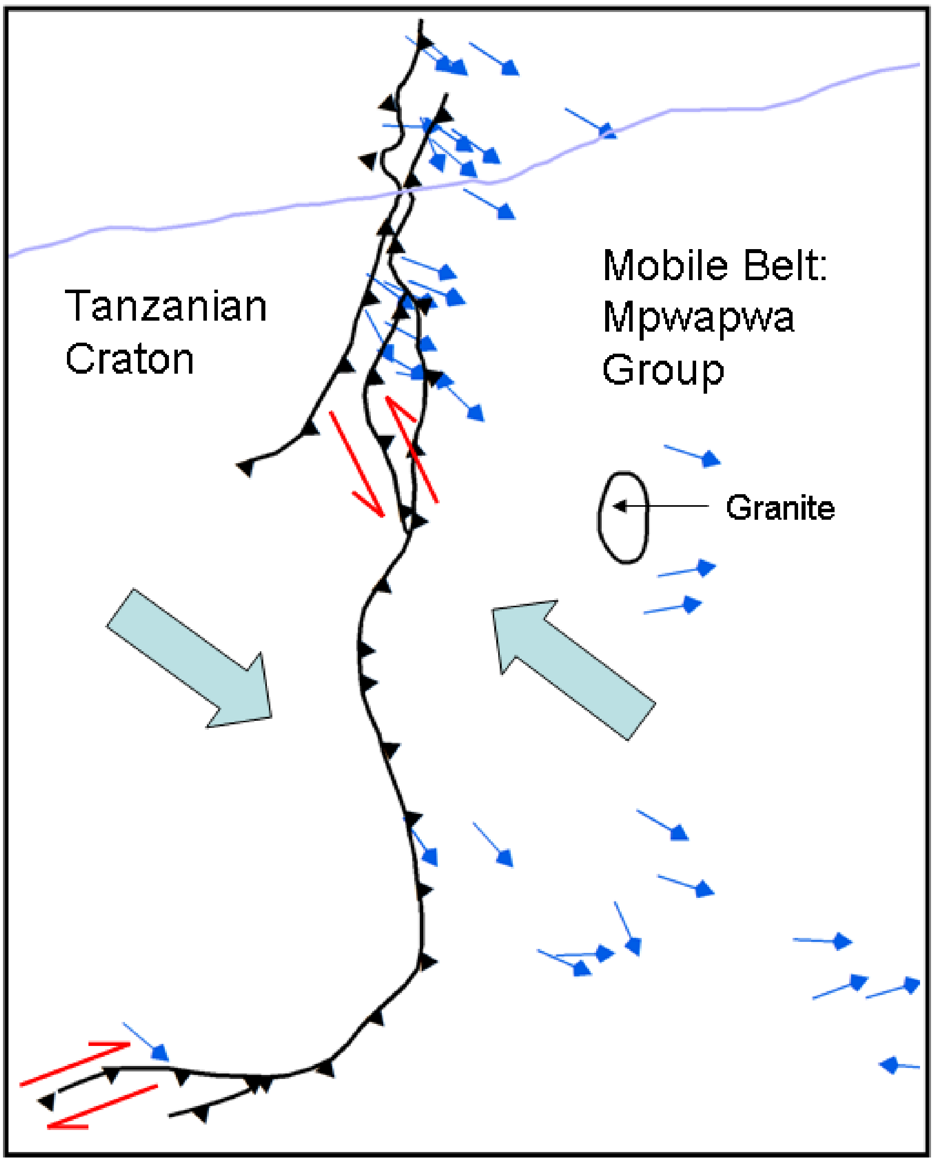


Figure 21. *Structural synopsis, showing main craton boundary thrust zones and lineations (blue). The red half-arrows show the change from oblique sinistral senses of movement in the north to oblique dextral in the south. This arrangement suggests that, in broad terms this part of the craton acted as an indenter with respect to the eastern mobile belt (Mpwapwa Group, which escaped towards the NW and SW. Large Blue block arrows show relative movement vectors. Note consistency of lineations. Blue line is the main Dodoma to Dar-es-Salaam road.*

Economic geology

The area has no important economic deposits. Mining activity is restricted to a few small artisanal quarry workings for road and building stone. The alluvial gypsum mine at Msagali closed in 2004. Some pitting was seen in small pegmatite bodies, but these do not appear to have yielded anything of significance. In one place, garnets were reputedly recovered from an ophicalcite marble (Locality BTHOMAS_556). There are a number of shallow pits on the hillside at the kyanite-clinopyroxene rock locality (see above), but it is not clear what was being searched for. A series of recent shafts has been sunk into the sub-vertical high-strain schists of detailed section Locality BTHOMAS_610. It is not clear what commodity is being prospected, but the spoil consists of scaly greenish-gray chlorite schist which may represent low-grade late shear movements in the craton boundary shear zone.

Discussion: a working hypothesis for the evolution of the area

The craton margin in the study area has been identified as a major single 1 to 2 km wide shear zone. In the central part of the area, the zone is mildly imbricate and has the kinematics of a SE-facing, ductile ramp zone, with dips around 45° E to SE, and a top-to-the-NW (towards the craton) sense of movement. The Mpwapwa Group lies to the east of the thrust belt and no cratonic rocks were identified east of the contact zone (c.f. Temperley, 1938). The thrust belt affects both cratonic rocks and the Mpwapwa Group to the east; both are pervasively sheared and locally mylonitised. The thrust belt is somewhat curved in detail, and swings almost E-W in the south along a late shear zone. Within this curved geometry, stretching lineations plunge consistently to the SE (to ca 130°). The shear belt tends to steepen in some domains in the north and south, giving rise to oblique sinistral and dextral shear senses respectively. This suggests that in its SE movement relative to the Mpwapwa Group, this part of the Tanzanian craton has locally acted as an indenter, with the Mpwapwa Group rocks having escaped to the NW and SW along oblique shear zones with opposing senses of movement, in localised steeply-dipping shear domains. The craton margin in regional terms is thus a fairly simple single structural belt-like domain, with little complex craton-mobile belt tectonic interslicing seen, except over a short section in the central part of the area, crossed by the main road to Mpwapwa (Figure 14 and Figure 15).

The question of how major a structure the thrust belt is, in a regional sense and in terms of amount of displacement has not been fully resolved. However, the metamorphic grade of the Mpwapwa Group and the disposition of its various constituent lithotypes may provide clues. Metamorphism, as evidenced by kyanite in pelitic rocks, garnet-clinopyroxene in some metabasites and localised migmatisation occurred under moderate to high pressure amphibolite facies, as might be expected at the base of a thrust stack and resulting crustal thickening. From about 20 km east of the boundary thrust zone, the Mpwapwa Group are affected by polyphase folding which is presumably pre-thrusting in age, as illustrated on the schematic cross section through the boundary zone as shown in Figure 22.

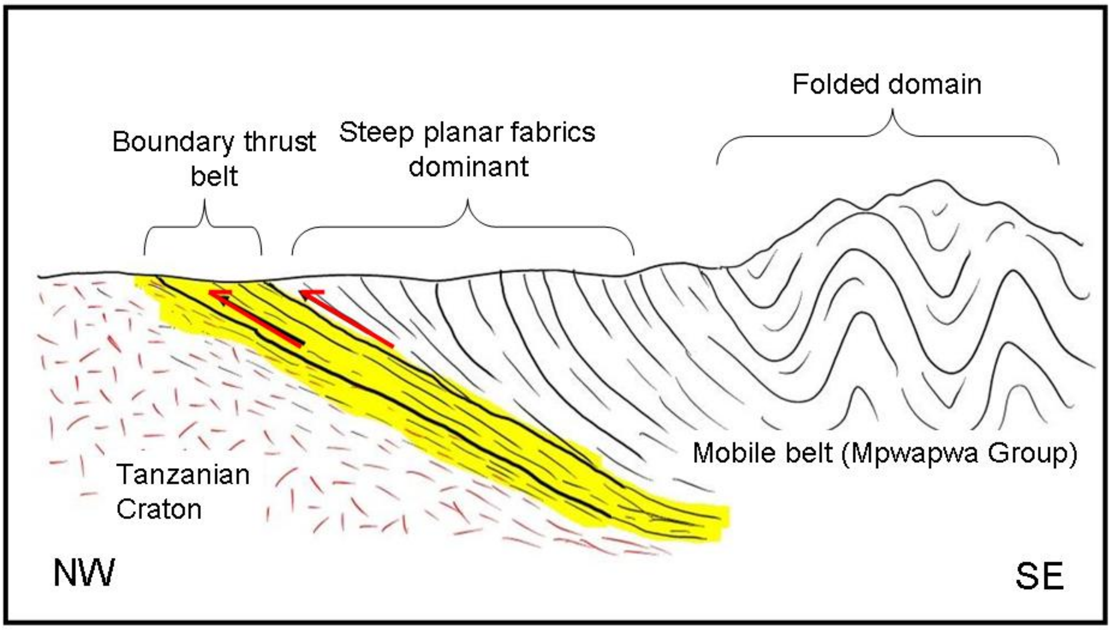


Figure 22. *Schematic NW-SE cross-section across the eastern margin of the Tanzanian Craton in the study area, showing the top-to-the-NW sense of movement of the bounding thrust zone.*

In addition, there appears to be an E-W zonation of Mpwapwa Group lithological units. Most of the quartzite, marble + calc-silicate rocks and pelitic schists/gneisses tend to occur close to the craton margin, with semi-pelitic gneiss/migmatite to the east, along with interlayered repetitions of bimodal acid, quartzo-feldspathic gneisses and mafic gneisses (amphibolite, mafic garnet amphibolite). This zonation suggests that the quartzites, calcareous and meta-pelitic rocks, clearly of metasedimentary origin might represent a primary sedimentary package of continental-margin shelf rocks deposited at the edge of the craton under shallow marine conditions.

To the east, the semi-pelitic gneisses might represent more distal (greywacke-type?) deposits. The felsic-mafic gneiss alternations seen in the western part of the main mountainous massif of the Mpwapwa Group in the eastern part of the area (and shown constituting the massif on the map of Temperley et al., 1953), suggests that they might represent bimodal volcanic protoliths. The garnet-free layered, and the garnet-bearing massive, amphibolites are quite different rocks in terms of composition, mineralogy and fabric. They may represent different types of mafic rocks, with the former perhaps representing mafic tuffs, and the latter, massive mafic sills, for example as evidenced by the local inclusion of gneissose xenoliths. This predominantly volcanic protolith interpretation is probably more realistic than proposing an exclusively sedimentary origin (e.g. alternating highly feldspathic sandstone and marl-type sediment) or mixed volcano-sedimentary (e.g. alternating feldspathic sandstone and mafic igneous rocks), though these cannot be entirely discounted. However, if the bimodal volcanic model pertains, such rocks are typical in a rift tectonic environment.

It is thus speculated that the Mpwapwa Group were deposited in a rifted passive-margin setting at the edge of the Tanzanian Craton, with marine environments at the immediate continental margin, where limestones, quartzites and pelites were deposited, with minor mafic igneous intercalations (tuffs?), and bimodal volcanic rocks more distally. The thrust event which subsequently took place at this rifted margin inverted the Mpwapwa Group basin and transported the Mpwapwa Group NW over the craton margin. This event telescoped, but did not obliterate the original depositional zonation. The Mpwapwa Group can thus be viewed as a parauthochthonus succession rather than being truly allochthonous. The absence of any tectonised ophiolitic material at the boundary suggests it is not a suture and that no oceanic crust was consumed. Nevertheless, the thrusting produced sufficient crustal thickening to result in kyanite-garnet assemblages in metapelitic rocks and garnet-clinopyroxene assemblages in some metabasites.

The timing of these events is unknown. The Tanzanian Craton is Neoarchaean, but there are no other constraints on the age of the Mpwapwa Group (other than it is intruded by Jurassic (?) dolerite dykes). If they are related to the Usagaran-Ubendian supracrustal units, they are Palaeoproterozoic in age, but they could be much younger. The age of the thrusting is also unconstrained. If the Mpwapwa Group is Palaeoproterozoic, then the thrusting could also be Palaeoproterozoic or the result of any younger orogenic event. For example, tectonism could be a far-field effect of the Neoproterozoic East African Orogeny which lies to the east, or the thrusting could have been older and re-worked at a later stage, such as during the Neoproterozoic orogeny: the boundary thrust could represent the western orogenic front of the East African Orogen: all options are currently open.

The above account represents a working hypothesis for the tectono-metamorphic evolution of the Tanzanian Craton margin-Mpwapwa Group in the Mpwapwa area that would need to be tested by extending the area under study and by selected analytical follow-up work.

Sampling strategy to test the model

With the above hypothesis and uncertainties in mind, the geochronological questions could be answered by the set of samples that were taken for U-Pb zircon dating.

1) One sample of unsheared, relatively undeformed granodioritic orthogneiss was taken to ascertain the age of the Tanzania Craton rocks in the area;
2) Two samples of quartzites of the Mpwapwa Group, with heavy mineral layers were taken in order to examine their detrital zircon age spectra and provide the maximum age of deposition;
3) One sample of a pink quartzo-feldspathic gneiss from the bimodal gneisses, which may be a meta-rhyolite, were taken to try and directly date the Mpwapwa Group;
4) One sample each (two samples) was taken from the post-Mpwapwa group plutonic rocks (granite, charnockite,) to give a minimum age of the Mpwapwa Group.
5) One sheared post-Mpwapwa Group tonalite sample was taken in order to confirm the minimum age of the group and to ascertain the age of shearing (metamorphic zircon overgrowths, if present).

A sampling strategy to test the rifted margin hypothesis would focus on the major and trace element geochemistry of the mafic rocks of the Mpwapwa Group (Amphibolites ± garnet-cpx) and the felsic meta-rhyolitic (?) rocks, but that was not undertaken during the current fieldwork.

References

Temperley, B.N. (1938). The geology of the country around Mpwapwa. Department of Lands and Mines, Geological Division, Short Paper 19, Government Printer, Dar-es-Salaam, 61 pp.

Temperley, B.N., Reeve, W.H. and King, A.J. (1953). Mpwapwa-South (B37/M1), 1: 125 000 series geological map, Tanganyika Series. Geological Survey Department, Dodoma.

Pinna, P., Muhongo, S., Mcharo, B.A., Le Goff, E., Deschamps, Y., Ralay, F. and Milesi, J.P. (2004). Geology and Mineral map of Tanzania. Bureau de Reserches Geologique et Minieres-University of Dar-es-Salaam-Geological Survey of Tanzania. 1: 2 000 000 scale.

APPENDICES

1 SAMPLES

26 representative samples were taken from the study area. 18 samples were submitted for thin sections at the GST laboratories. 7 Samples were taken for U-Pb zircon geochronology and sent to BGS, Keyworth (Table 1).

Sample	Locality	Description (Mpwapwa Group unless stated)	Purpose	Thin section
DOD1	BTHOMAS_517	Quartzite	U-Pb detrital zircon geochronology	Yes
DOD2	BTHOMAS_517	Quartzite	GST collection	Yes
DOD3	BTHOMAS_517	Calc-silicate rock	GST collection	
DOD4	BTHOMAS_517	Quartzite	U-Pb detrital zircon geochronology	Yes
DOD5	BTHOMAS_524	Mafic garnet-cpx amphibolite	GST collection	
DOD6	BTHOMAS_531	Granite (post-Mpwapwa Group)	GST collection	
DOD7	BTHOMAS_532	Granite (post-Mpwapwa Group)	U-Pb zircon geochronology	Yes
DOD8	BTHOMAS_536	Granodioritic orthogneiss (Cratonic)	U-Pb zircon geochronology	Yes
DOD9	BTHOMAS_536	Granodioritic mylonite (Cratonic)	Oriented thin section	Yes
DOD10	BTHOMAS_538	Ulramylonite	GST collection	Yes
DOD11	BTHOMAS_539	Sheared tonalite (post-Mpwapwa?)	U-Pb zircon geochronology	Yes
DOD12	BTHOMAS_547	Kyanite metapelite	GST collection	Yes
DOD13	BTHOMAS_548	Mafic garnet-cpx amphibolite	GST collection	Yes
DOD14	BTHOMAS_555	Kyanite quartzite	GST collection	Yes
DOD15	BTHOMAS_557	Mylonite	GST collection	
DOD16	BTHOMAS_555	Pink felsic (metarhyolitic?) Q-F gneiss	U-Pb zircon geochronology	Yes
DOD17	BTHOMAS_517	Quartzite	GST collection	Yes
DOD18	BTHOMAS_562	Calc-silicate gneiss	GST collection	
DOD19	BTHOMAS_563	Charnockite (post-Mpwapwa Group)	U-Pb zircon geochronology	Yes
DOD20	BTHOMAS_564	Mafic garnet-cpx amphibolite	GST collection	Yes
DOD21A	BTHOMAS_569	Kyanite rock	GST collection	Yes
DOD21B	BTHOMAS_569	Kyanite-cpx (?) rock	GST collection	Yes
DOD21C	BTHOMAS_569	Kyanite rock	GST collection	Yes
DOD22	BTHOMAS_580	Gneiss with bulk tonalitic composition	GST collection	
DOD23	BTHOMAS_581	Mylonitised pegmatite	GST collection	
DOD24	BTHOMAS_517	Specular haematite	GST collection	

Table 1. Samples collected, location (relates to ARC-GIS Project), description and purpose.

2 PETROGRAPHY

All modal percentages are approximate estimates. Figure numbers in text refer to Mpwapwa area report. Figs "DOD- x" etc. refer to sample number. ppl = plane polarized light; xn = crossed polars.

DOD-1 *Mpwapwa Group Quartzite*

Sugary white quartzite, with diffuse heavy mineral layers. Composed of **quartz** (>95%): Strained granoblastic, inequigranular 0.5 to 1.5 mm averages grain size, parallel orientation of larger grains in particular defined fabric. Wavy to undulose grain boundaries. No feldspar seen. **Muscovite** (2%) as strongly oriented flakes up to 0.5 mm long and thin aggregated foliae of a few flakes. **Opaque mineral** in grains up to 0.5 mm, also aligned. Trace quantities of **apatite** and **zircon**.

Sample **DOD-2** is almost identical to DOD-1, but the slide was of very poor quality.

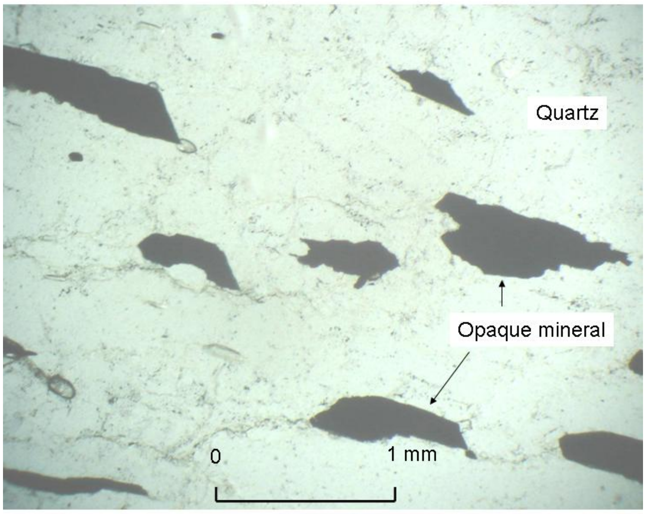
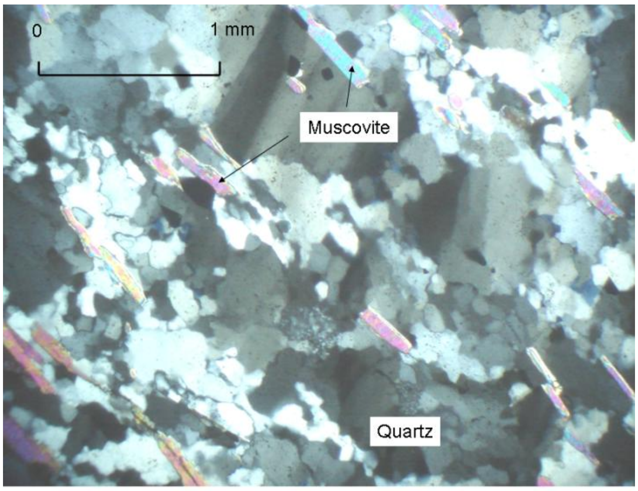


Figure DOD-1*. Quartzite, aligned opaque minerals in part defining the foliation (ppl).*

DOD-4 *Mpwapwa Group Quartzite*

Strongly layered, pale grey quartzite with darker rich layers (Figs 5a, b). Composed of **quartz** (>95%), very strongly oriented, up to 2 mm, with crenulate grain boundaries, strained extinction and ca. 5:1 elongation ratios. No feldspar seen. **Muscovite** (3%), very strongly oriented flakes up to 1 mm long and thin aggregated foliae of several flakes. **Opaque mineral** aligned grains up to 0.8 mm. Trace quantities of **zircon**. Crude layering is defined by grain size variations in quartz and parallel alignment of other minerals.

a)



b)

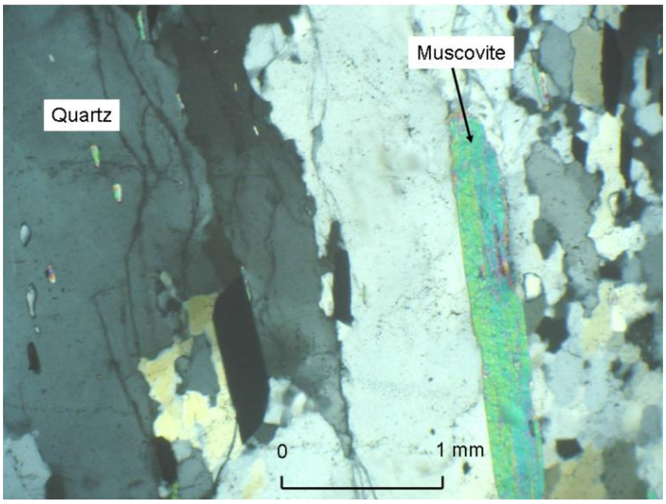


Figure DOD-4 *Quartzite. a)inequigranular, highly foliated, strained quartz with crenulate inter-grain boundaries and strongly aligned flakes of muscovite (xn); b) Aligned muscovite flake, opaque grain (centre-left) and strained quartz (xn).*

DOD-6 *Post-Mpwapwa Group potassic granite*

Coarse-grained, equigranular unfoliated pinkish-grey, leucocratic biotite granite. Composed of **quartz** (35%), grains up to 3 mm, interlocking texture, slightly strained, curved grain boundaries. **Microcline** (45%), unaltered, grains up to 1 to 2 mm in size. **Plagioclase** (15%), unaltered, 1 to 2 mm across. Some myrmekitic reaction between feldspars. **Biotite** (5%), very dark brown, unaltered, flakes up to 1 mm long with rare zircon-cored pleochroic haloes. Accessory **zircon** and **apatite** and rare **allanite**. Only alteration is a few small secondary **opaque mineral-muscovite** aggregates.

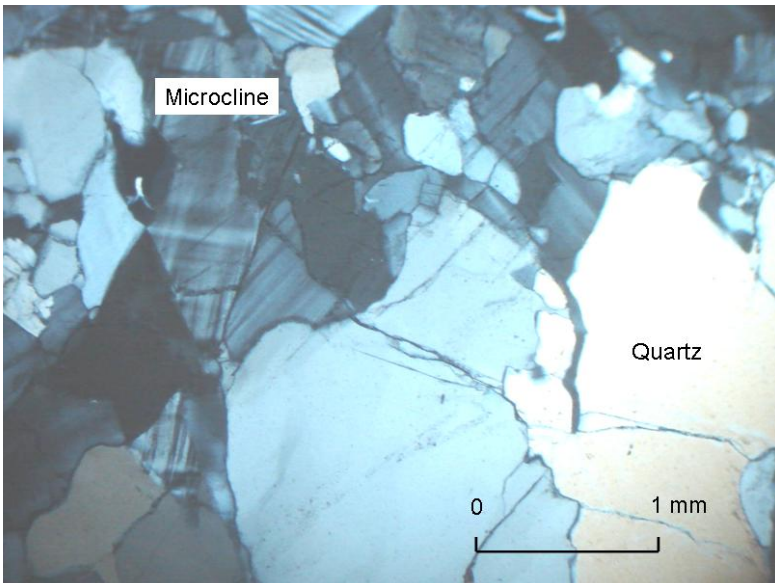
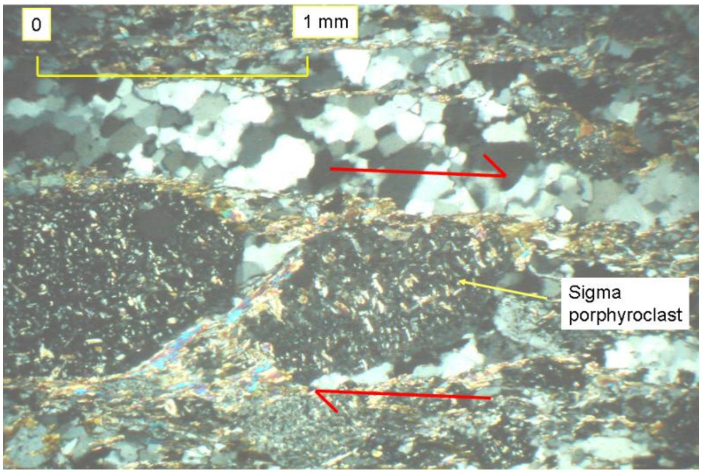


Figure DOD-7. *Leucocratic biotite granite, showing large quartz grains and microcline.*

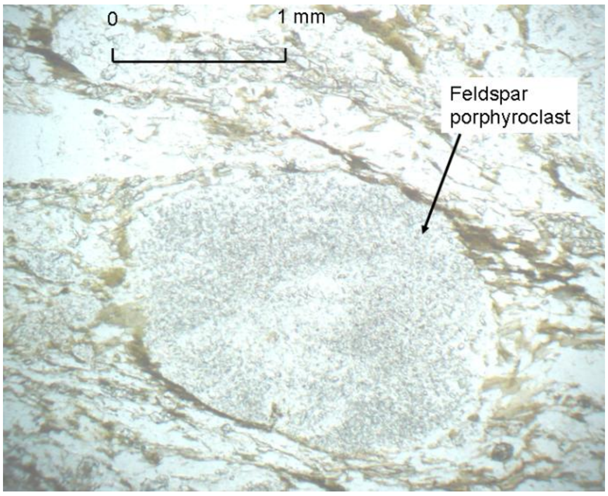
DOD-9 *Protomylonitic Archaean (Tanzania Craton) granitoid*

Strongly deformed, protomylonitic feldspar porphyroclastic granitoid orthogneiss, with very strong foliation and oblique lineation (see Fig. 14c). Much grain size reduction with mm-sized feldspar porphyroclasts. Oriented sample cut parallel to lineation. Composed of **quartz**, **plagioclase**, **biotite** and **epidote** with extremely variable grain size from microgranular to plagioclase porphyroclasts up to about 1 mm in size. Very strong foliation defined by grain size variations of constituents, stretched recrystallised quartz ribbons up to 1.5 mm in length and foliae of fine-grained brown biotite wrapping round coarser grains and porphyroclasts. The biotite is secondary; having replaced the coarse, original phase in the granodiorite. Plagioclase is sericitised and saussuritised (sericite and clinozoisite respectively), on a coarse scale, so that the twinning is still clearly visible. Some porphyroclasts are asymmetrical sigma shapes with sinistral senses of movement, confirming the field observations (Fig. 14c). Subtle C-S fabrics defined by new biotite flakes aligned at an acute angle to the main foliation give the same shear-sense.

a)



b)



c)

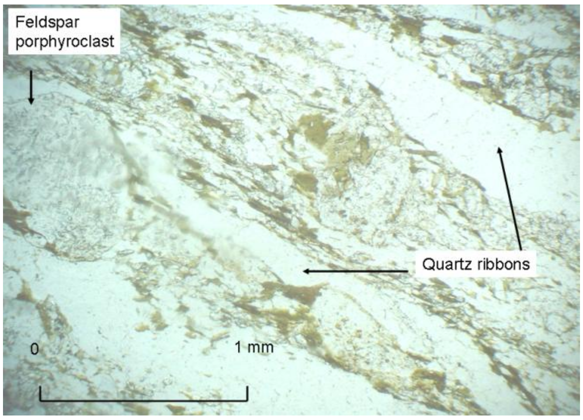
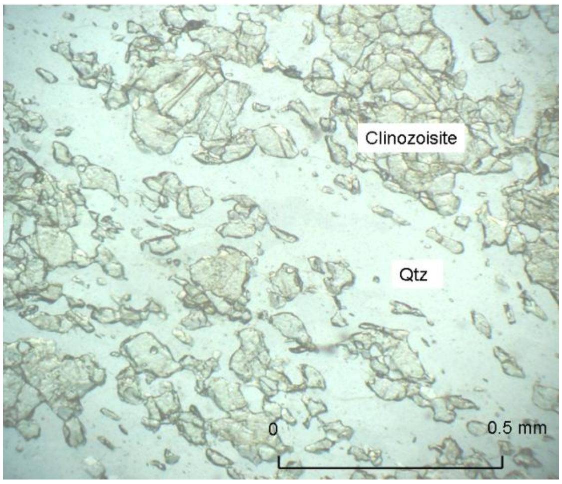


Figure DOD-9. *Protomylonitic granodiorite. a) Sigma plagioclase porphyroclasts with sinistral shear-sense; b) Rounded feldspar porphyroclast; c) quartz ribbon fabric*

DOD-10 *Recrystallised mylonitic Archaean (Tanzania Craton) granitoid?*

Fine-grained, pale greenish recrystallised homogeneous mylonite with quartz-ribbon texture (Fig. 14d). Probably ultramylonitic cratonic granodiorite orthogneiss. Composed of a bimineralic assemblage of elongate recrystallised **quartz** aggregates and secondary **epidote/clinozoisite**. Individual grains no longer strongly oriented, but banding produced by grain size variations and modal differences in the two minerals. Relict small plagioclase porphyroclastic are rarely preserved.

a)



b)

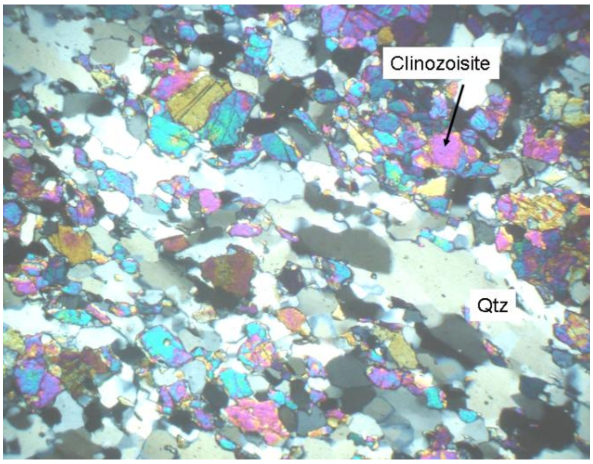
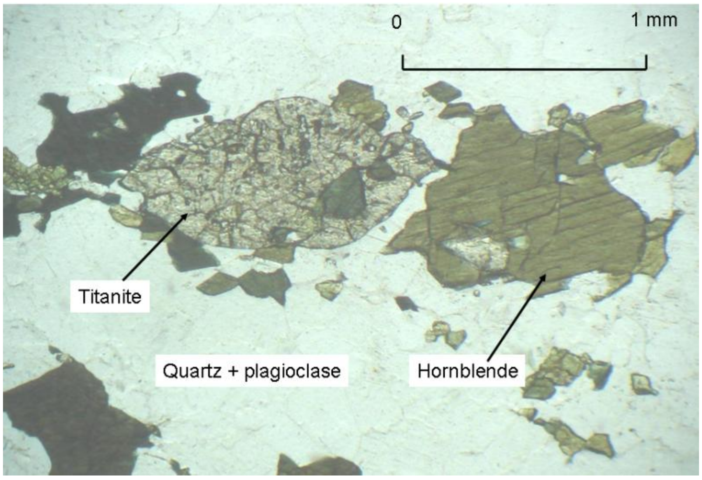


Figure DOD-10. *Recrystallised ultramylonitic granodiorite, with aggregates of secondary clinozoisite and quartz ribbons a) ppl; b) xn.*

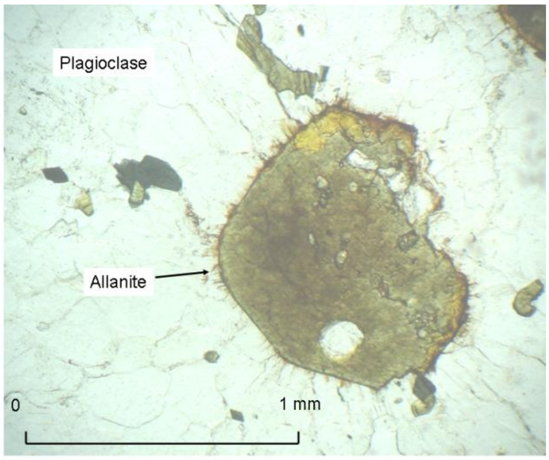
DOD-11 *Post-Mpwapwa Group sheared tonalite*

Coarse-grained foliated grey hornblende-bearing granitoid (not apparent in thin section: see Fig. 13b, c, d). Composed of **quartz** (15%), **plagioclase** (65%, with periclinal twinning), and very dark green **hornblende** (12%), no biotite, with quite high quantities (total 3%) of accessory **allanite** (euhedral grains up to 0.8 mm, metamict, with by narrow halo of expansion cracks), **titanite** (subhedral grains up to 0.5 mm in length, aggregated with hornblende), with traces of **zircon** (up to 500 µ) and secondary **carbonate**.

a)



b)



c)

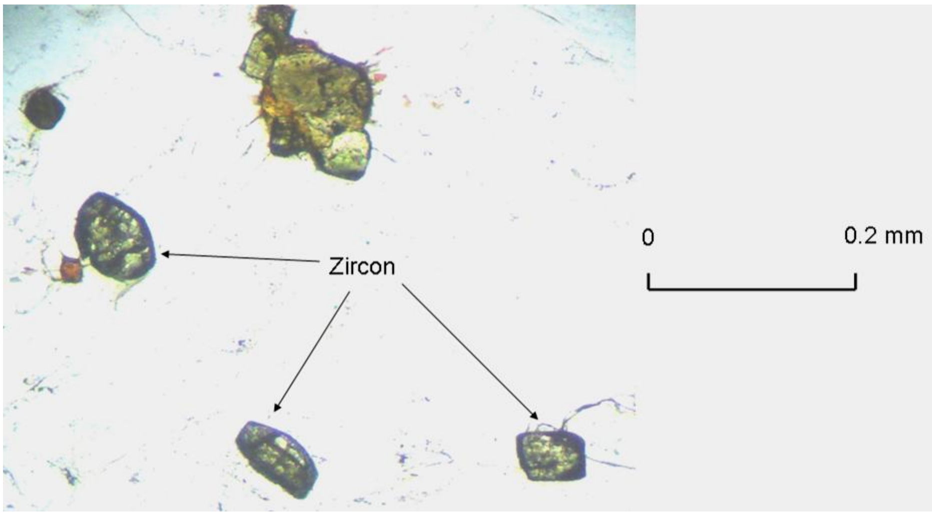


Figure DOD-11. *Oriented mafic aggregate with dark green hornblende large titanite grain separating quartz-plagioclase domains; b) large, metamict allanite (orthite) grain with thin halo of expansion cracks; c) prominent euhedral zircon grains.*

DOD-12 *Mpwapwa Group two mica-kyanite metapelite*

Coarse-grained, foliated and layered schist/gneiss. Composed of **quartz**, with very little feldspar and layers rich in unaltered brown **biotite**, **muscovite** and **kyanite,** crystals up to 5 mm in size, all strongly aligned and forming the foliation. Minor amounts of **opaque mineral, zircon** and **apatite**.

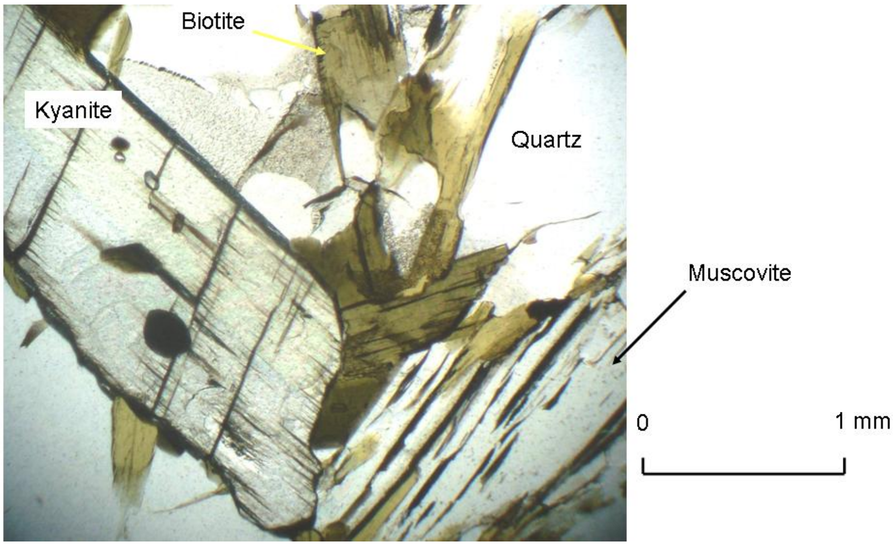


Figure DOD-12. *Quartz-biotite-muscovite-kyanite metapelite (ppl).*

DOD-13 *Mpwapwa Group garnet-clinopyroxene amphibolite*

Poorly-foliated, dark grey mafic metabasites with garnet porphyroblasts and macroscopic plagioclase-hornblende and clinopyroxene (see Fig. 11). Composed of about 40% clear **plagioclase**, with abundant green **hornblende** (ca 40%), anhedral clear pale green **clinopyroxene** (diopside?) and anhedral embayed and inclusion-filled **garnet** up to 3 mm in size. Quite large amounts (1-2%) of rounded, subhedral **titanite**, often in trains aligned parallel to the foliation which is defined mainly by alternating plagioclase-rich and –poor layers and grain size differences. Some large ragged **opaque mineral** grains present.

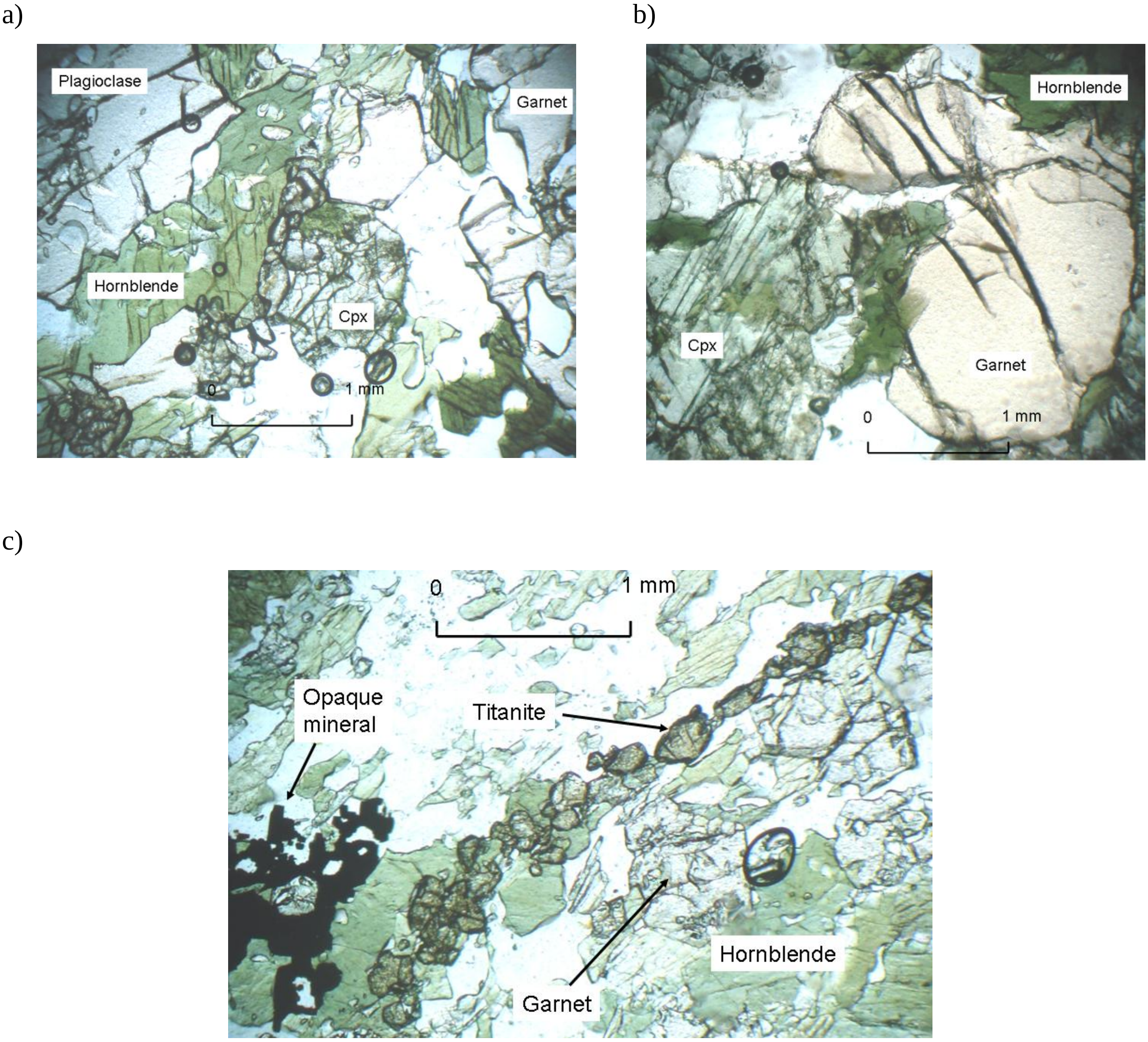


Figure DOD-13.*Garnet-cpx amphibolite, showing typical petrographic features: a) hornblende-cpx aggregates with plagioclase; b) garnet grain with cpx; c) trains of small titanite grains.*

DOD-16 *Mpwapwa Group quartzo-feldspathic gneiss.*

Medium- to coarse-grained, very leucocratic (CI ca. 5), saccharoidal, pink quartzo-feldspathic gneiss with very strong layering, foliation and lineation, with ribbon-quartz fabric. Composed of strongly parallel oriented **quartz** (35%), **K-feldspar** (40%); **Plagioclase** (20%), with sub-equal **biotite** and **muscovite** (together 5%) in thin foliae and very small amounts of **zircon**. Extremely inequigranular, with K-feldspar grains up to about 2 mm in size. Foliation defined by parallel alignment of minerals (especially micas, quartz aggregated, and grain size variations in the mineralogy.

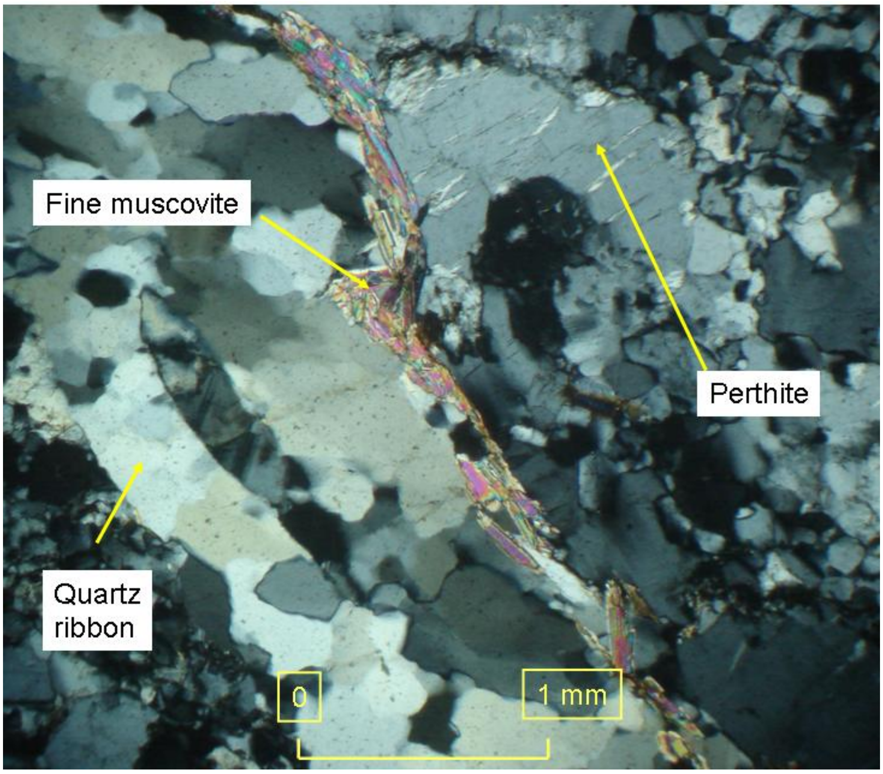
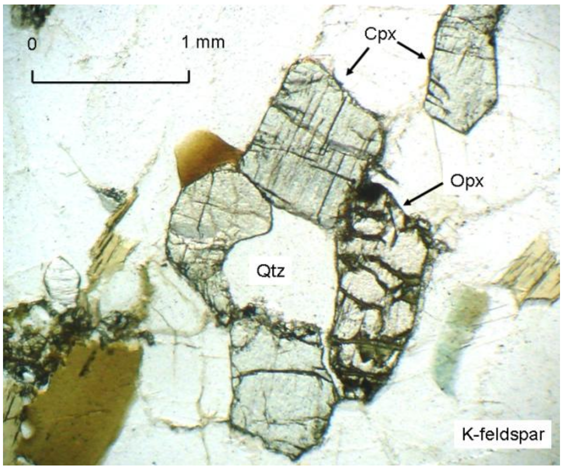


Figure DOD-16. *Leucocratic quartzo-feldspathic gneiss, with quartz ribbon fabric and thin foliae of fine muscovite flakes.*

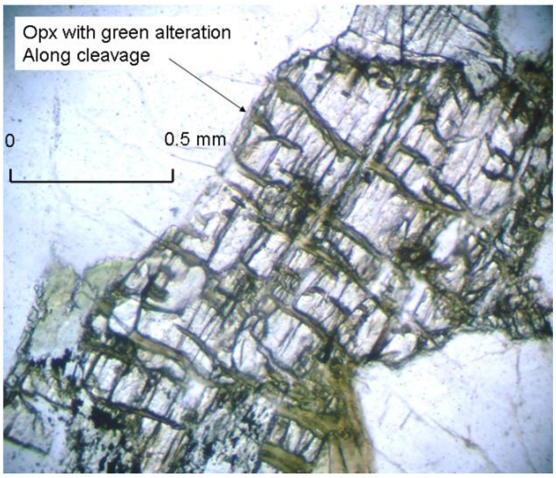
DOD-19 *Post-Mpwapwa Group two-pyroxene charnockite*

Massive to poorly-foliated, coarse-grained, very dark grey to grayish-green charnockite with prominent blue, opalescent quartz, very dark feldspar and black mafic minerals. Rock has characteristic resinous lustre. Composed of **quartz** (30%), grains up to 3 mm, **orthoclase** (32%: locally micro- string perthitic, unaltered), **Plagioclase** (25%, locally micro- patch antiperthitic, subhedral; some reaction with K-feldspar to myrmekite), **orthopyroxene** (4%: grains up to 2 mm, altered along cleavage and prism-perpendicular cracks to greenish serpentine), anhedral **clinopyroxene** (4%: pale green, locally showing exsolution lamellae), dark brown **biotite** (4%), in slightly oriented mafic aggregates with pyroxenes, along with trace amounts of accessory **apatite**, **zircon** and **opaque mineral**.

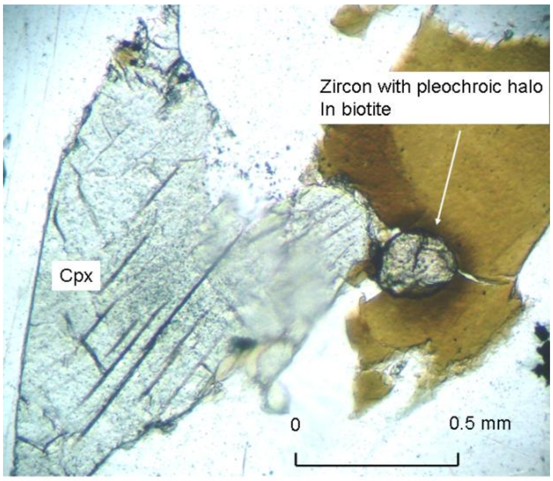
a)



b)



c)



d)

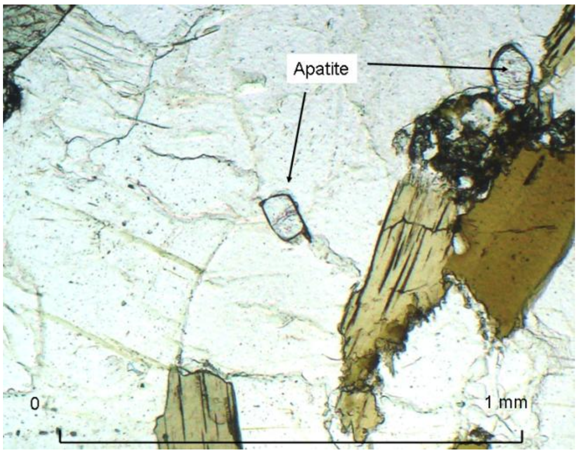
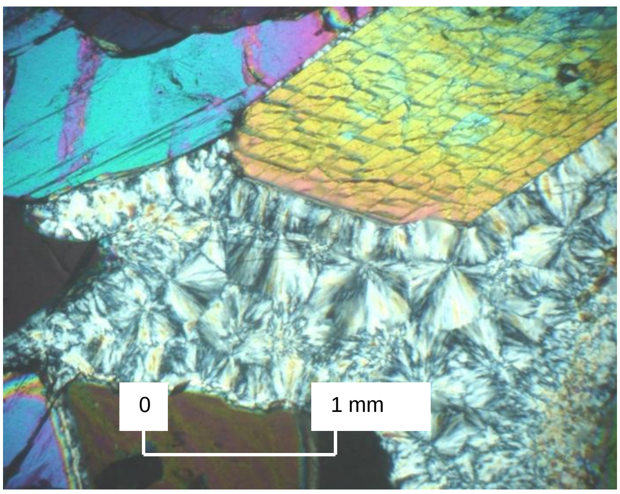


Figure DOD-19. *Two-pyroxene charnockite, showing typical petrographic features: a) opx-cpx-biotite aggregate with quartz and feldspars; b) large subhedral orthopyroxene (opx) grain with greenish serpentine alteration along cleavage and cracks; c) clinopyroxene (cpx)-biotite with zircon-cored pleochroic haloes in latter; d) stumpy prisms of accessory apatite.*

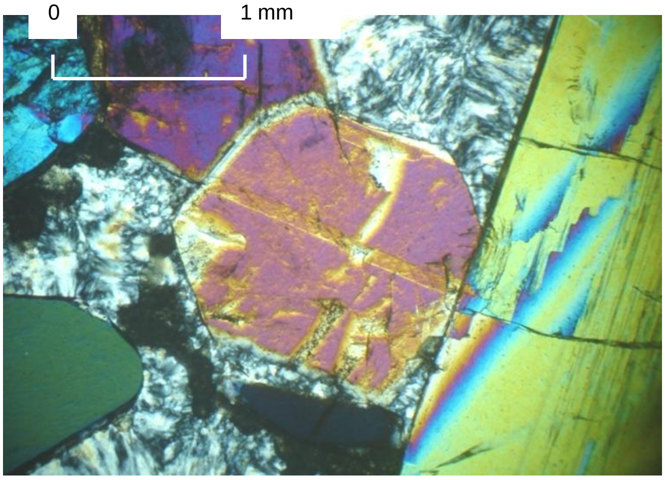
DOD-21B *Mpwapwa Group kyanite rock*

Massive blue-green fibrous to platy rock made up chiefly of kyanite blades up to 2 cm in greenish groundmass. Composed of large euhedral blades of **kyanite** (50%), euhedral pale green **clino-amphibole** (probably **actinolite**), grains up to about 1 to 2 mm, pale green euhedral **diopside** grains < 1 mm across, set in a fibrous and radiating interstitial groundmass of **chalcedonic quartz** (20%). Rock must have very unusual protolith – maybe an aluminous, ashy siliceous tuff?

a)



b)



c)

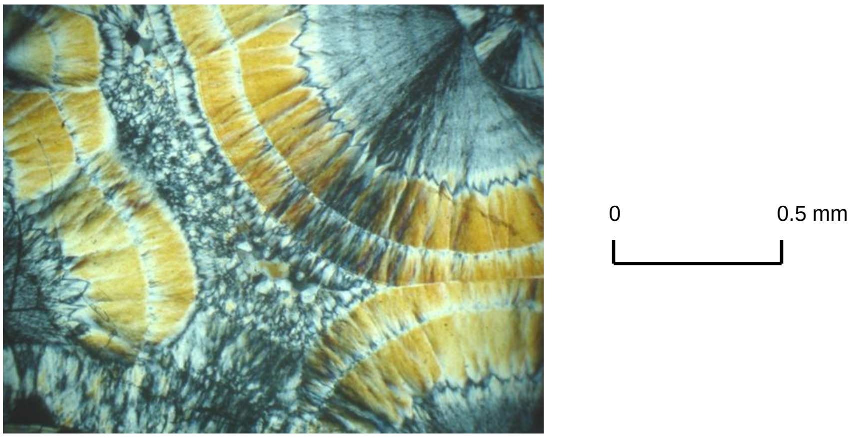


Figure DOD-19. *Kyanite rock: a) euhedral clino-amphibole (top right) + kyanite (top left) and chalcedonic groundmass; b) euhedral clinopyroxene (centre) and kyanite grains with chalcedonic groundmass; c) detail of radiating rosettes of chalcedony, with slightly coarser quartz in triple junction between rosettes*

3 DETAILED WEST-EAST TRAVERSE ACROSS THE BOUNDARY SHEAR ZONE IN THE NORTH PART OF THE AREA

An approximately 1.5 km long detailed foot traverse was undertaken across the Tanzanian Craton-Mpwapwa Group boundary shear zone in the northern part of the area, between Localities BTHOMAS_509 (859828/9328304) and 510 (861269/9328649). In this traverse, the shear zone is a relatively simple, singular structure, with much of the visible strain concentrated at the craton boundary itself.

Western part of section, Cratonic granitoid to the boundary

The western most outcrops in the section are almost totally unstrained grey, coarse-grained, cratonic granodioritic orthogneiss (quartz-plagioclase-biotite-hornblende, minor K-feldspar). Exposures are migmatitic with coarse-grained irregular leucosome veins with anhedral dark hornblende blebs up to 1.5 cm (Figure a-iv). The foliation is variably developed and largely chaotic, with no regional orientation measurable. Traversing eastwards, the fabric gradually intensifies, such that 300 m east of the traverse start, the granitoid has a strong, regular, steeply east-dipping foliation with strong ESE-plunging lineation (S=55/102; L=50/110). About 200 m to the west, near the top of the first traverse hill, the granitoid is strongly mylonitised in the core of the boundary shear zone. The exposures are mainly S-dominated mylonites, but with a very strong lineation and development of some S-L tectonite domains with sub-vertical foliation and moderately SE-plunging stretching lineations (S=90/074; L=22/164: Figure a-iii). Small feldspar sigma porphyroclasts give an oblique sinistral strike-slip sense of movement, which at lower shear zone dips translate to top-to-the-NW (thrust) shear sense (see Fig. 16b). Minor tight folds also plunge parallel to the lineation direction. The most strongly mylonitic zone within the cratonic granodiorite is over 200 m wide and must have accommodated considerable movement. To the east are ultramylonites of uncertain protolith, but some deformed amphibolite layers, probably of the Mpwapwa Group suggests that the craton margin has been crossed, or that it is a tectonic mélange of both craton and envelope. However, to the east are exposures of more identifiably granitoid mylonites (ca 5m wide), suggesting a minor degree of Craton-Mpwapwa interslicing over an approx 200 m wide zone.

Eastern part of section, Mpwapwa Group

West of the craton boundary, thin amphibolite layers at the structural base of the Mpwapwa Group are overlain by grey, heterogeneous quartz-feldspar-two mica-garnet schists and gneisses (biotite-dominated), typically with large, but variably-sized garnet porphyroblasts up to 1.5 cm across. The entire Mpwapwa Group sequence from here to the eastern end of the traverse dips steeply to the east (at ca. 70°). While the degree of strain and mylonitisation within the regionally homogeneous cratonic granitoids is easy to detect, strain variations within the layered Mpwapwa Group is harder to ascertain, and alternating zones of high and low strain are seen throughout the section. Within the basal sequence is at least one, approximately 5 m thick, layer of dark bluish-grey “dirty”, heterogeneous garnet-bearing schist with sparse rounded, apparently exotic, clasts of coarse-grained granitic material up to 5 cm in size (Figure a-ii). These appear to be worked clasts within the paragneiss and the layer is possibly a metamorphosed diamictite or matrix-supported meta-conglomerate within the paragneiss sequence.

Structurally above the diamictite-bearing schists is a thick package, approximately 450 m thick, of mixed micaceous schist/paragneiss (± garnet throughout), of mainly pelitic to semi-pelitic composition with thin layers of amphibolite and hornblende gneiss. Near the top of this sequence are fine satiny muscovite schists with flaggy biotite-quartz-feldspar banded gneiss, and fine-grained, pale grayish-green actinolite-muscovite-rich schist. Some deep artisanal pits and shafts have been sunk into a hillside into these schists. The spoil from the shafts is dominated by greenish-grey, soapy chlorite-rich schist, but the commodity being sought is unclear. The package also includes some greenish actinolite-bearing mica schists with more mafic composition.

Structurally above the schist package are several layers of white to pale grey, rather massive, recrystallised, coarse-grained quartzite, separated by sections with poor schist outcrop. The quartzites are about 5 to 10m thick. They are locally layered (pale grey and dark-grey alternations) and the layering is sometimes tightly folded. In one locality the layering was disrupted by small-scale, annealed normal faults, which might be of syn-sedimentary (growth fault) origin (Figure a-i). At this point, the topography flattens and outcrop stops. However, it continues along strike on the hillsides to the north, on the other side of a NW-SE oriented dry valley. The quartzites do not crop out along strike on the other (north) side of the valley, in which there is consequently most likely a late fault.

The section to the north of the valley-fault commences with dark biotite-garnet-dominated schists, some 200 m thick, with rare thin (2 to 3 m) quartzite and felsic quartzo-feldspathic gneiss layers. It contains one prominent light green, medium-grained actinolite amphibolite layer some 5 m thick with a strong, SE-plunging mineral stretching lineation defined by prismatic hornblende grains up to ca 1 cm long (Figure b-iii). Some of the semi-pelites have large knobbly weathered garnet porphyroblasts up to 1 cm in size, which in many outcrops is altered to a greyish retrogression product.

The pelitic schist package is overlain by a ca 300 m thick sequence of white- to pale-pink, very leucocratic, coarse-grained saccharoidal muscovite-bearing quartzo-feldspathic gneisses with CI<5. The gneisses are associated with highly tectonised pegmatites, with ductile quartz ribbon fabrics and brittly-crushed black tourmaline crystals (Figure b-iii). The felsic sequence is overlain by thin white to pale grey coarse-grained quartzite, and the top of the exposed sequence in the east is marked by Ca-rich banded epidote amphibolite with epidote-rich layers up to 30 cm thick and cm- to 10 cm-scale mafic-felsic interlayered gneiss (Figure b-i).

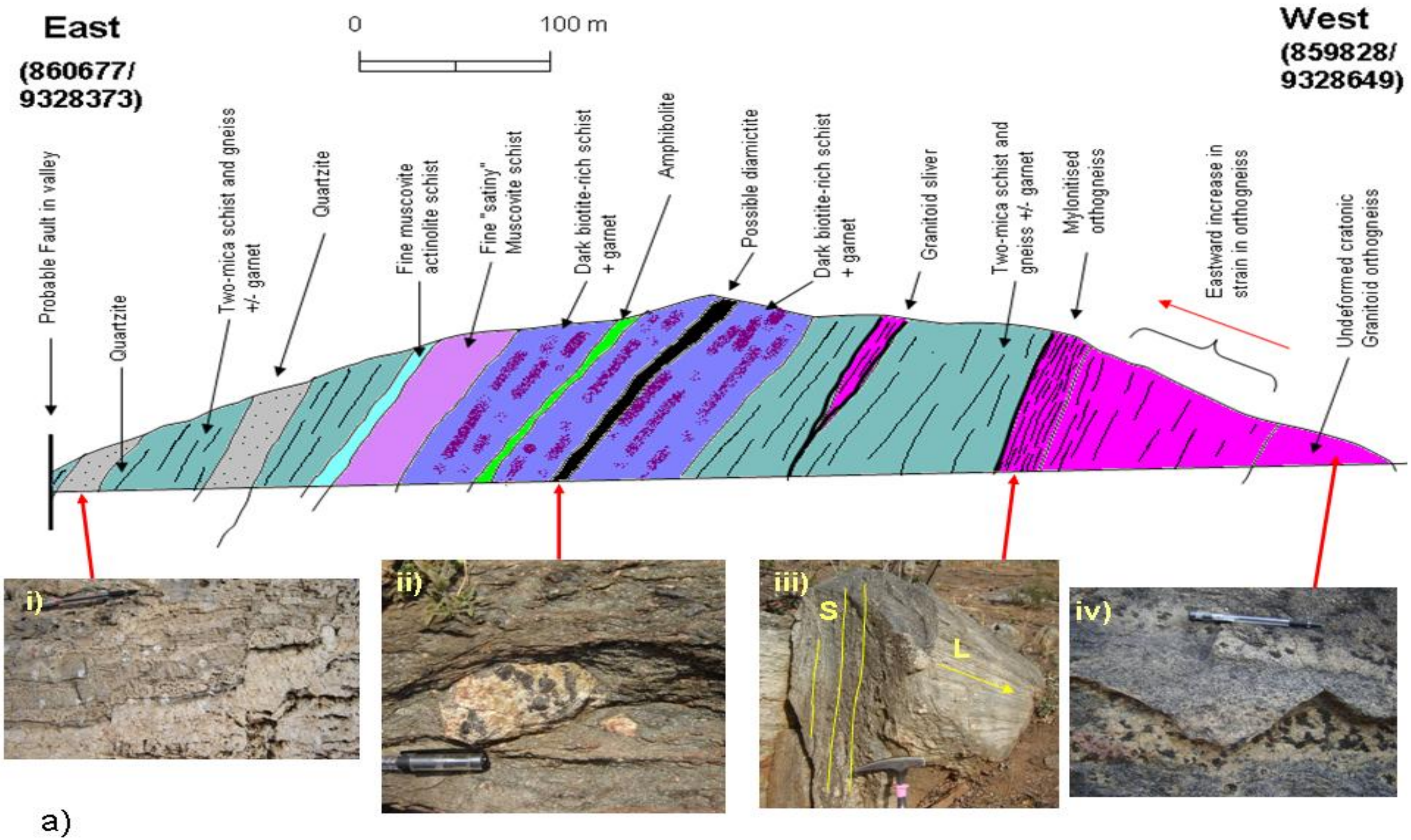


Figure a) *Western half of the traverse. i) Minor annealed normal (growth?) faults displacing layering in dark and pale grey layered quartzite; ii) Possible diamictite schist, with coarse=grained granitic clast (pebble?) in grey, heterogeneous mica schist matrix; iii) S-L mylonitic domain in the core of the shear zone – deformed cratonic granitoid; iv) Coarse-grained, grey, weakly deformed granodioritic cratonic orthogneiss with coarse plagioclase-hornblende leucosomes*

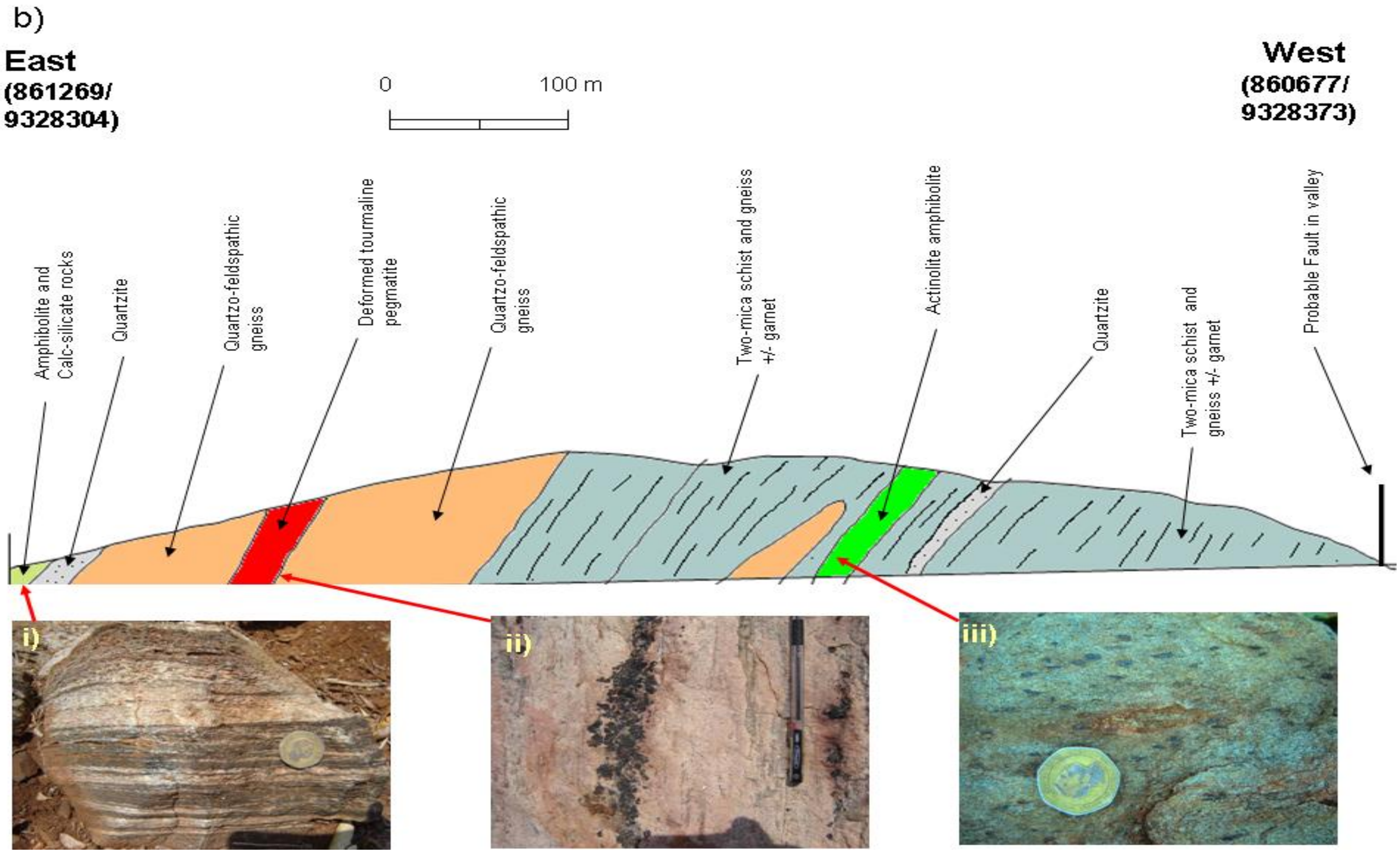


***Figure b)** Eastern half of the traverse. i) Well-banded mafic amphibolitic gneiss and felsic calc-silicate gneiss; ii) Mylonitised tourmaline pegmatite with quartz-ribbon fabric and crushed schorl; iii) Green medium-grained actinolite amphibolite with dark hornblende porphyroblasts defining a SE-plunging mineral stretching lineation.*