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## The Geology of a small part of the Dodoma Sheet, south of Dodoma, Tanzania

International Programme

Open Report OR\10\058



BRITISH GEOLOGICAL SURVEY

INTERNATIONAL PROGRAMME

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## The Geology of a small part of the Dodoma Sheet, south of Dodoma, Tanzania

Robert J Thomas

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### **BGS Central Enquiries Desk**

Tel 0115 936 3143 Fax 0115 936 3276  
email [enquiries@bgs.ac.uk](mailto:enquiries@bgs.ac.uk)

### **Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG**

Tel 0115 936 3241 Fax 0115 936 3488  
email [sales@bgs.ac.uk](mailto:sales@bgs.ac.uk)

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Tel 0131 667 1000 Fax 0131 668 2683  
email [scotsales@bgs.ac.uk](mailto: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 [bgs\\_london@bgs.ac.uk](mailto:bgs_london@bgs.ac.uk)

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

Tel 029 2052 1962 Fax 029 2052 1963

### **Macleans 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

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### *Parent Body*

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

Tel 01793 411500 Fax 01793 411501  
[www.nerc.ac.uk](http://www.nerc.ac.uk)

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## Introduction

This geological report is based on a small amount of half-daily fieldwork carried out between 6 and 13 August 2010, during a teaching exercise of between 18 and 30 new recruits at the Geological Survey of Tanzania. It was concentrated along the gravel road that runs south of Dodoma, and is based on only 12 outcrops, but these were studied in some detail (Figure 1). The rocks form part of the Neoproterozoic Tanzanian Craton, and a fairly complex geological history was revealed for the first time and 9 new lithostratigraphic units identified (the published geological map of the Dodoma Sheet only shows two pre-Quaternary units: Chadha, 1967). The data were recorded and the geological map created in the BGS SIGMAMobile digital geological mapping system as an ARC-GIS (version 9.2) project.

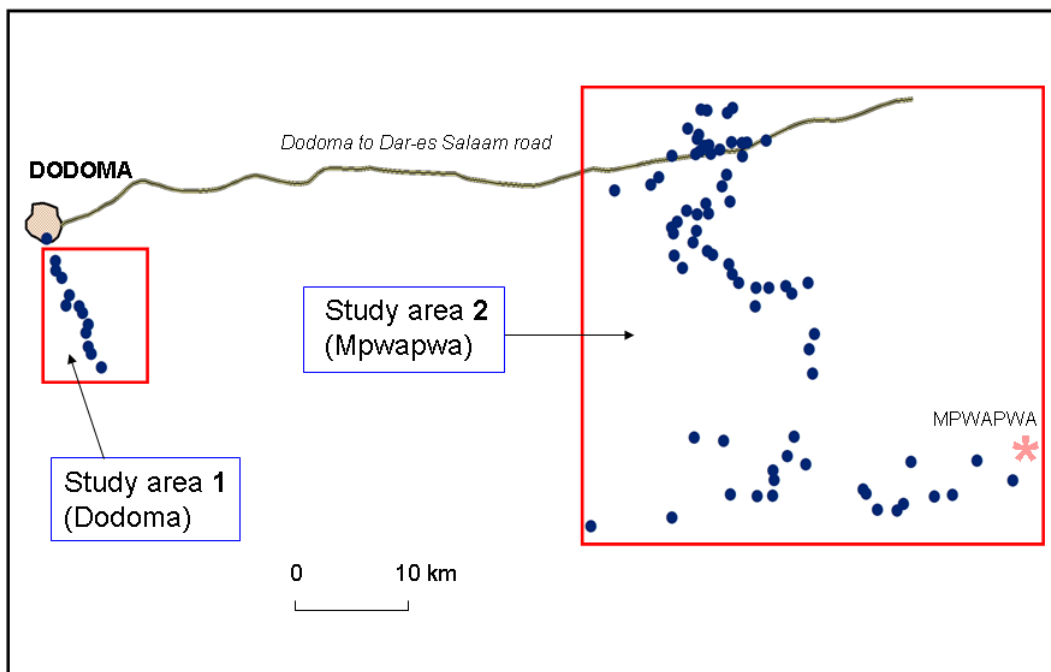
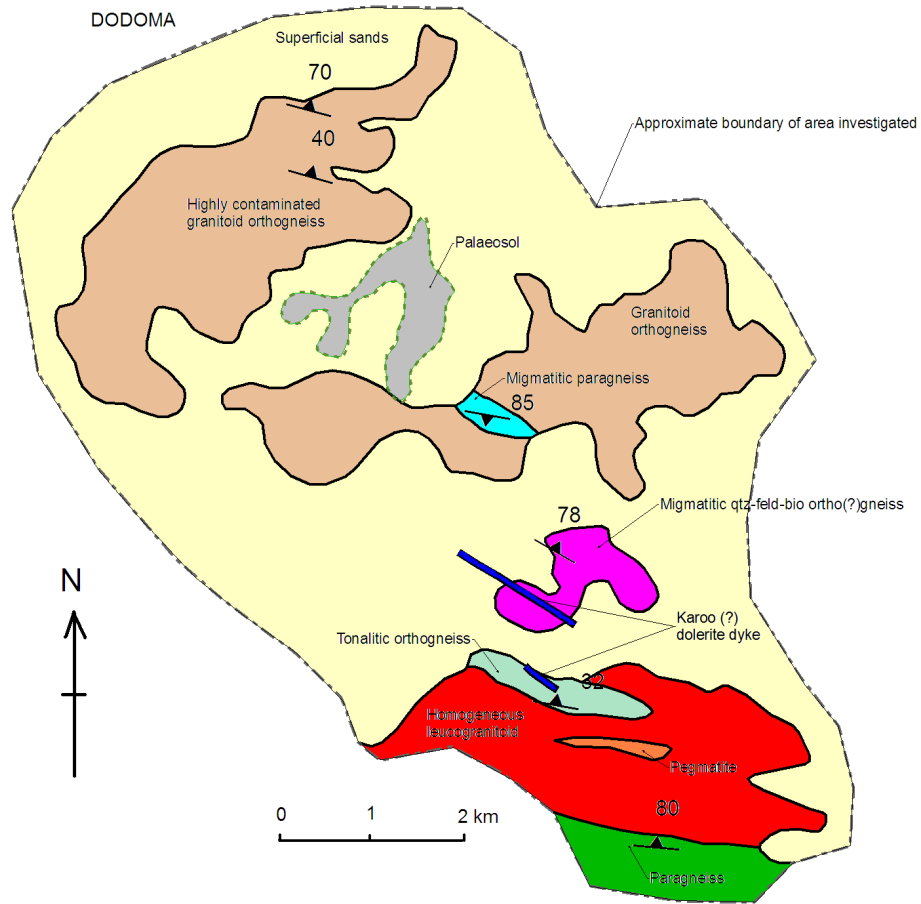


Figure 1. The two study areas of the 2010 field season. The Dodoma craton study area (1) is immediately south of Dodoma.

## Lithostratigraphy

The lithostratigraphy of the area is shown in the legend to the geological map produced (Figure 2). 11 different units were mapped ranging from two sequences of (presumably) Archaean supracrustal paragneisses, five granitoid units, two suites of mafic dykes (Archaean? and Jurassic?) and two Quaternary units. Major structural and metamorphic events were distinguished, but the precise ages of these events remains unknown. Each unit is described below, in turn, oldest to youngest (as far as is known).



LEGEND

	Supracrustal rocks	Intrusive igneous rocks	Structural/metamorphic events
Quaternary	<ul style="list-style-type: none"> <li>Sand</li> <li>Palaeosol</li> </ul>		
Jurassic?		<ul style="list-style-type: none"> <li>Dolerite dykes, gabbro</li> </ul>	<ul style="list-style-type: none"> <li>Epidotised fractures</li> </ul>
Probably Neo-Archaeon		<ul style="list-style-type: none"> <li>Altered meta-dolerite dykes</li> <li>Pegmatite</li> <li>Weakly- to unfoliated leucogranodiorite</li> <li>Contaminated, schleiric leucogranitoid orthogneiss</li> <li>Migmatitic tonalitic orthogneiss</li> <li>Banded migmatitic granitic ortho(?)gneiss</li> </ul>	<ul style="list-style-type: none"> <li>Retrogression, thrusting at low grade?</li> <li>Amphibolite metamorphism, migmatitisation, fabric formation</li> </ul>
		<ul style="list-style-type: none"> <li>Paragneiss: medium- to fine-grained, laminated grey biotite gneiss with interlayered quartzite</li> <li>Banded quartz-feldspar-biotite gneiss/migmatite, with amphibolite boudins</li> </ul>	<ul style="list-style-type: none"> <li>High- to medium-grade shearing?</li> </ul>

Figure 2. Geological map of the area immediately south of Dodoma generated from the ARC-GIS project.

Archaean supracrustal rocks

1) Banded quartz-feldspar-biotite gneiss/migmatite with amphibolite boudins

Locality BTHOMAS\_508 (806953/9310329) is an artisanal quarry excavated into a sequence of sub-vertical, WNW-striking, semi-pelitic banded paragneisses which are, for the most part, stromatic migmatites. The gneisses comprise quartz-feldspar-biotite banded on a mm-, cm- and 10 cm-scale with abundant foliation-parallel leucosomes up to a few centimetres thick. Some finer-grained "greenstone" chloritic lenses also occur. The layering is locally often tightly folded, with measured fold axes typically plunging steeply west (Figure 3a). The sequence contains



abundant trains of dismembered pods and boudins of coarse-grained amphibolite ( $\pm$  actinolite) and hornblende gneiss, strung out parallel to the pervasive foliation (Figure 3b). These probably represent meta-basic igneous rocks, of volcanic, pyroclastic or intrusive origin, within the original sedimentary sequence. The western side of the outcrop is cut by swarms of numerous sheets of coarse-grained, pale grey to almost white, foliated leucogranite orthogneiss up to about 1 m in thickness, intruded, and foliated, parallel to the layering in the gneisses. These may represent intrusive apophyses of a phase of the leucogranitoids which envelop the gneisses. It is probable that the paragneisses occur as a large enclave within the adjacent orthogneisses. The gneisses are intruded by an altered metadolerite dyke and cut by a prominent phyllonitic thrust zone (see below in intrusive rocks and structural sections respectively).

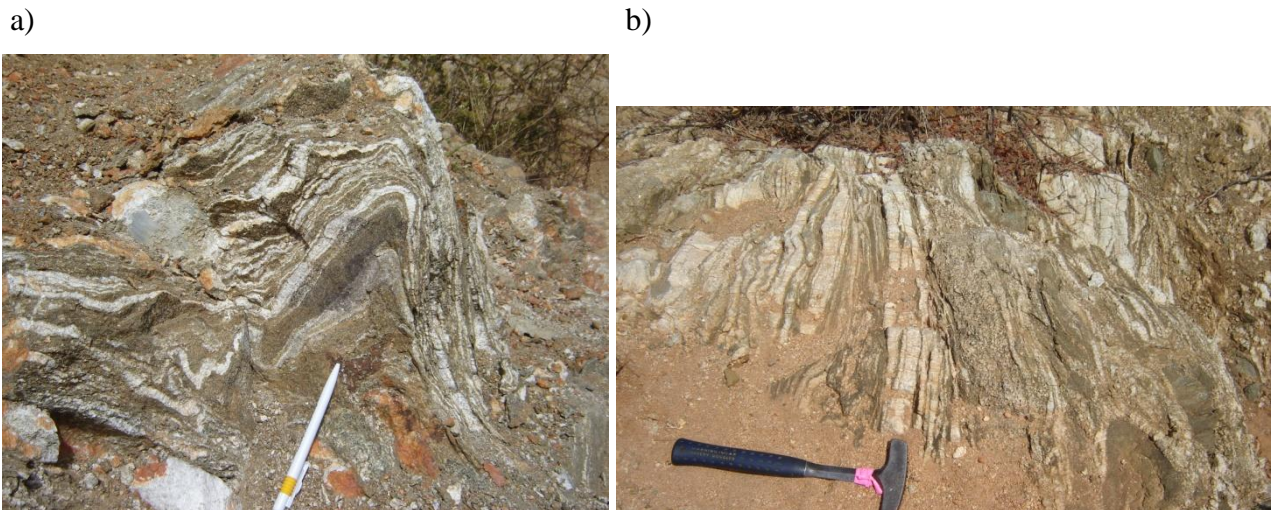


Figure 3. *Archaean banded gneiss and migmatite. a) West-plunging tight minor M-fold in semi-pelitic paragneiss; b) Paragneiss sequence, with stromatic migmatite (left) and amphibolitic boudins (right).*

**2) Paragneiss: medium- to fine-grained, laminated grey biotite gneiss with interlayered quartzite**

In the furthest south point on the traverse (locality BTHOMAS\_512: 808838/9305642), a dry river bed (east of road bridge) contains good outcrops of sub-vertical to steeply N-dipping, highly foliated to protomylonitic, fine- to medium-grained, laminated biotite gneiss/schist, composed of quartz, feldspar and biotite. Lamination occurs on mm-scale due to compositional variation between the three constituent mineral phases. The rocks are essentially non-migmatitic. The fine compositional layering suggests they represent a metasedimentary package of semi-pelitic composition, such as a metamorphosed turbidite sequence. The western part of outcrop especially, contains foliation-parallel layers and boudins up to 30 cm thick of prominent white, medium- to coarse-grained rocks which look like leucogranite sheets at first glance, but on closer inspection appear to be made up almost entirely of highly foliated, rather inequigranular quartz, with very little identifiable feldspar (Figure 4a). Small grains of a black mineral also occur (pyroxene, spinel?). These rocks thus may represent quartzite layers in the paragneiss sequence. Similar layers to the west also include black siliceous quartzites and white, pyroxene/spinel (?)-bearing quartzite (Figure 4b). Towards the east, the foliation intensifies to a 10 m wide zone of protomylonites that appear to form the core of a ductile shear zone, as described below in the structural geology section.

a)



b)

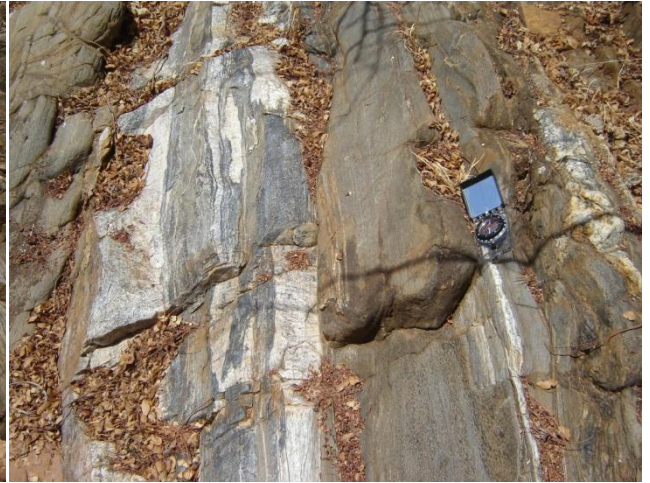


Figure 4. *Archaean paragneiss. a) Medium- to fine-grained laminated grey biotite gneiss with interlayered foliated coarse-grained white quartzite layers; b) Interlayered white and dark-grey quartzite layers within the grey biotite gneiss.*

## Archaean granitoids

### 3) *Migmatitic tonalitic orthogneiss*

Near the southern part of the area examined, good outcrops occur on the northern flank of a prominent range of hills, for example at locality BTHOMAS\_501 (807735/9307227). The rocks are fresh, very fresh where worked by local people for stone aggregate. Close to the main gravel road the rocks exposed are locally migmatitic, medium- to dark grey tonalitic orthogneiss, with a strong foliation dipping at moderate angles to the north. The tonalite is coarse-grained (average grain size 2-4 mm), very strongly foliated orthogneiss, with ca 10-15% quartz, plagioclase (no definite K-feldspar identified), biotite and hornblende. It is generally quite equigranular and homogeneous, but some facies are slightly inequigranular and have plagioclase grains up to 5 mm in size. In one locality two phases of tonalite are seen - "normal" orthogneiss intruded by coarser-grained, light grey leucotonalite veins. The tonalite rarely contains some biotite-feldspar gneisses and schlieren, drawn out parallel to the foliation, which may be supracrustal gneiss enclaves. In one place, ENE-plunging stretching lineations were observed.

Most outcrops are complexly veined, with the orthogneiss cut by a deformed, anastomosing network of felsic veins, some of which are clearly leucosomes, bordered by thin (mm-scale) biotite melanosome selvages with sharp contacts to the tonalite. Some areas show stromatic migmatite, with sub-parallel leucosome veins in the foliation. However, other felsic veins are more pegmatitic, irregular and diffuse. A few simple pegmatite veins intrude orthogneiss, up to 30 cm thick

### 4) *Contaminated, schlieric leucogranitoid orthogneiss*

The first outcrops in the range of rocky hills south of Dodoma, are bouldery granitoid outcrops (e.g. locality BTHOMAS\_503: 804971/9313842). The outcrops are composed of light grey, leucocratic (CI<10), sub-equigranular coarse-grained granitoid (grain size 2-5 mm average). The feldspar ratio is hard to ascertain in the field; plagioclase is certainly the dominant phase present and the rocks probably classify as granodiorite, with biotite as the main mafic phase. The outcrops are generally highly contaminated with biotite ± hornblende-bearing banded gneiss enclaves and biotite schlieren. Enclaves range in size from minute wisps up to the metre-scale. They are heterogeneous, with some quite mafic biotite and hornblende-rich, while others are made up of biotite-quartz-feldspar gneiss in variable modal proportions. They tend to be

chaotically oriented, but a vague alignment sub-parallel to edge of outcrop ridge (edge of pluton?) is apparent (Figure 5a). The granitoid itself is not strongly foliated, but in some zones has a weak parallel fabric to enclaves. The granitoid contains a few leucocratic patches with diffuse margins which may be leucosomes. It is cut by thin (mm-scale) epidote-filled straight fractures with bleached alteration haloes up to 1 cm thick at the margins.

Some 800 m to the south, at locality BTHOMAS\_504 (805002/9313102) a large pavement lies adjacent to the roadside. It is composed of the same coarse-grained contaminated leucogranitoid, with a fairly consistent north-dipping swirling foliation. It is slightly more migmatitic, with swirling schlieren fabric and deformed gneiss enclaves in various stages of assimilation. Many enclaves show tight folding of an earlier metamorphic fabric (Figure 5b). Some zones are fairly strongly migmatitic, with anastomosing networks of thin, diffuse leucosome veins and patches forming rather nebulitic masses. It also contains some additional plagioclase-porphyroblastic, medium-grained, granoblastic, microdioritic autoliths, up to 30 cm in length, ovoid in shape, or elongated parallel to foliation (Figure 5c).

On a regional scale, contamination of the granitoid orthogneiss occurs in diffuse zones. For example at locality BTHOMAS\_507 (805866/931040), in quite extensive outcrops, the orthogneiss is highly contaminated in several zones with dark biotite and hornblende-rich enclaves and schlieren, showing all stages of assimilation (Figure 5d). In this locality, away from the margins of the granitoid massif, the foliation is quite strong throughout, but irregular, swirling, reticulate and chaotic, with no overall trend and thus not measurable. It is cut by some late leucocratic pegmatoid patches rich in magnetite as crystals up to 1 cm in size and cut by epidote-filled straight sided thin fractures.



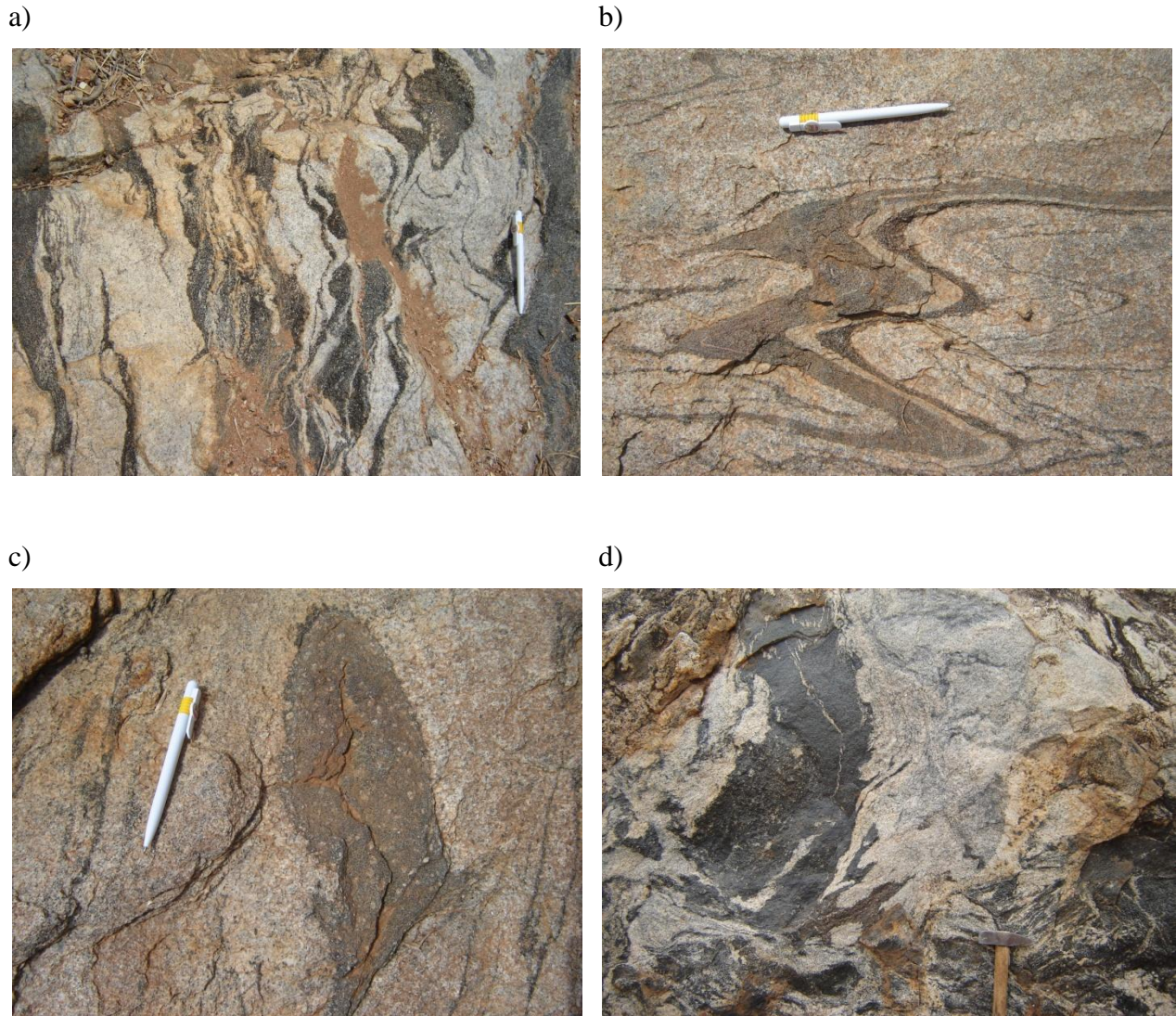


Figure 5. Archaean leucogranitoid orthogneiss. a) Strongly contaminated zone showing mafic gneissose enclaves and schlieren in sub-parallel alignment; b) Tightly folded gneissic schlieren enclaves. Left hand prominent layer is hornblende-rich; the right hand layer is biotite-rich; c) Ovoid porphyroblastic microdiorite autolith in the granitoids; d) Large irregular, hornblende-rich, deformed enclaves in contaminated zone. The diffuse brownish pegmatoid vein above the hammer handle is rich in magnetite (black spots).

##### 5) **Banded migmatitic granitic orthogneiss (?)**

South of the leucogranite orthogneiss, across an obscured contact, a prominent range of bouldery koppies is made up of grey, coarse-grained, heterogeneous, migmatitic to banded, quartz-feldspar-biotite gneiss of overall granitic/granodioritic composition (e.g. locality BTHOMAS\_510: 807742/9308935). The rocks are most likely orthogneisses, but this is not certain due to the locally well-developed banding and compositional variation (Figure 6a). The rocks are heterogeneous in single outcrop, but several hundred metres of the same rock-types are exposed, imparting larger-scale homogeneity. The strong, though swirling, ductile, foliation dips fairly consistently NNE and localised ductile folding of the layering/ foliation is common (Figure 6b.). The gneiss is cut by a ca. 4 m wide sheet of coarse-grained, yellowish-weathering, equigranular, massive and largely unfoliated leucogranitoid, probably related to the latest granitoid phase in the area (see below).



a)



b)



Figure 6. *Archaean banded migmatitic granitic orthogneiss (?)*. a) *Strong compositional layering and foliation*; b) *Ductile folding of layering, in part defined by thin stromatic leucosomes*.

#### 6) *Weakly- to unfoliated leucogranodiorite*

South of the tonalitic orthogneiss (contact unseen: see above) a prominent range of rounded, bouldery hills is composed of light grey, slightly yellowish-weathering, fairly equigranular, massive to very weakly foliated and homogeneous leucocratic granitoid. At locality BTHOMAS\_501 (807735/9307227), the granitoid is composed of quartz (ca 35%), feldspar (ca 60%) and only ca 5% biotite. All feldspars are white/pale grey and K-feldspar is not readily identified in the field and again, a granodioritic mineralogy is probable. It is relatively free of enclaves and later veins, but a few diffuse aplitic patches were observed. A finer-grained phase of the granite was observed in a few places (see below). A few irregular thin pegmatites (up to 30 cm) cut the granitoids in this locality. Rarely, thin zones a few metres wide contain trains of medium-grained, granoblastic but equigranular and foliated, grey quartz-feldspar- biotite schist/gneiss enclaves measuring up to 2 m x 20 cm. These are flattened and aligned parallel to the weak foliation in the granitoid, which dips north, parallel to that of the tonalitic orthogneiss to the north. Some almost totally assimilated diffuse enclaves were also seen. The granitoid is cut by thin (mm scale) straight fractures infilled with secondary green epidote.

#### 7) *Pegmatite*

Insignificant pegmatite veins are intrusive into most lithologies, but a few larger bodies, found in the south of the area, appear to be spatially and genetically linked to the unfoliated leucogranodiorite (Unit 6 above). For example at locality BTHOMAS\_502 (807989/9306691), a large, steeply south-dipping pegmatite sheet intrudes the leucogranodiorite. It is at least 50 m wide in places and can be traced for several hundreds of metres along strike, where it forms the crest of an E-W trending ridge. The body is a coarse- to very coarse-grained, white, pegmatite, with a simple quartz-feldspar  $\pm$  magnetite mineralogy, but with very little mica. The pegmatite has a prominent (largely igneous?) foliation parallel to its margins. Rare thin (few cm wide) foliation-parallel white quartz veins in the pegmatite suggest it may be a rather distal pegmatite. It is extremely inequigranular, ranging almost from medium-grained aplite to foliation-parallel patches with feldspars up to >5 cm. The northern boundary is exposed where it intrudes with a sharp, steeply S-dipping contact into fairly fine-grained yellowish-weathering, homogeneous, essentially unfoliated biotite leucogranodiorite, which probably represents a fine-grained facies of unit 6, above (2 to 5 mm average grain size).

Pegmatites are generally uncontaminated by enclaves, but in places a few gneissose xenoliths of layered biotite gneiss and grey hornblende-biotite-feldspar orthogneiss of tonalitic composition

were seen (Figure 7a). These lithologies are comparable to those seen in the adjacent country rocks. To the west of BTHOMAS\_512, in the stream (west of the road bridge) there are outcrops of a large schorl pegmatite- garnet aplite body.

There is evidence to suggest that the large pegmatites are a late phase of the massive leucogranodiorite. At locality BTHOMAS\_501 (see above) the banded migmatitic granitic orthogneiss (?) is cut by a 4 m wide sheet of coarse-grained, yellowish-weathering equigranular massive and largely unfoliated leucogranitoid, presumably an apophysis from the main pluton to the south. This sheet is associated, as a late phase, with a large irregular pegmatite mass. Granite-pegmatite contacts are diffuse and complex, never sharp, suggesting that pegmatite is a late-stage volatile-rich phase of the granite (Figure 7b). This pegmatite has local development of graphic quartz-feldspar intergrowth suggesting crystallisation under eutectic conditions.

a)



b)



Figure 7. Archaean pegmatite. a) Layered biotite gneiss enclave in large pegmatite body. b) Diffuse pegmatite phase of the granite (left) in gradational contact with the leucogranodiorite sheet (right), suggesting that the pegmatite is a late, volatile-rich phase of the leucogranodiorite).

### 8) Altered metadolerite dykes

The gneisses of the study area are cut by two altered metadolerite dykes. It is not known if they are of the same age/swarm. At BTHOMAS\_508 (see above), the banded quartz-feldspar-biotite gneiss/migmatite is intruded by a 2 to 3 m wide, altered, sinuous, highly altered, deformed, foliation sub-parallel, sub-vertical, dark green metadolerite dyke (Figure 8). The dyke is strongly deformed, exhibiting pinch and swell features along its length (trend 130°) and has retrogressed, highly foliated margins which are converted to dark green chlorite-epidote-actinolite schist. The core of the dyke is less altered, but has the same retrogressed mineralogy. The second dyke is about some 300 m east of locality BTHOMAS\_502, where the large pegmatite sheet is intruded by an altered dolerite dyke up to 10 m wide, trending ca. 150 degrees. It is cut by thin, epidote-filled fractures.





Figure 8. *Altered metadolerite of unknown age cutting migmatitic gneisses in artisanal quarry. Archaean pegmatite. The dyke dips steeply SW (left) and shows pinch-and-swell features (figure for scale).*

#### 9) *Jurassic mafic dykes*

Two prominent (Karoo-age?) unaltered dolerite dykes were observed. Both form small outcrops composed of rounded black boulders which are aligned across the veld, giving trends of about  $160^\circ$ . The dolerite at BTHOMAS\_511 (807544/9308301) is coarse-grained and strictly classifies as gabbro. It is highly magnetic (ilmenite?). No contacts are exposed, but both dolerites must be 10 to 20 m wide.

### Quaternary deposits

#### 10) *Palaeosols*

Some drainage basins between the rocky outcrops are occupied by quite thick palaeosol deposits of unknown age. For example, at locality BTHOMAS\_505 (806147/9311188), the river valley is filled with buff- to orange-weathered, horizontally (pseudo)-bedded palaeosol (Figure 9a). The deposit is at least 3 or 4 m thick, and the base is not exposed. The soil is quite well consolidated and made up mainly of sandy and silty material. Most of the outcrops contain rusty-mottled horizons (Figure 9b), with some irregular secondary calcareous concretionary growth. The deposits contain a number of horizons with conglomeratic and gritty layers and lenses, indicative of fluvial transport (Figure 9c). The observed pseudo-bedding is presumably due to past water-table fluctuations.

a)



b)



c)



Figure 9. *Palaeosol deposits of unknown age. a) Horizontally pseudo-bedded orange and buff weathering, quite well-consolidated sols. The figure's feet are resting on a fluvial grit layer; b) Typical rusty brown mottling of some sol horizons; c) Small conglomerate/gritty lens showing that some of the material has been fluvially transported.*

### 11) **Sand**

Between the hilly outcropping areas, and overlying the palaeosols, there are large flat areas with a cover of loose to poorly-consolidated reddish Quaternary sand. Such deposits appear to cover the city of Dodoma and surrounds.

## **Structural geology and metamorphism**

The structural history of the area is dominated by (presumably) Archaean tectonic events, which imposed the ductile foliations on the two supracrustal paragneiss sequences and the older granitoid orthogneisses. This tectonism was accompanied by amphibolite grade metamorphism and local migmatitisation. It is inferred that these events were largely finished, or waning by the



time of emplacement of the leucogranodiorite, which is essentially undeformed. The older orthogneisses contain amphibolite grade gneissose enclaves with pre-existing ductile (folded) foliations; it is unclear if these fabrics represent an older, separate tectonic event, or if the deformation in the older orthogneisses is due to later phases of the same (protracted) event.

Two subsequent ductile tectonic events are recognised, but the age relations between them are not known. The most likely first event (due to its medium- to high-grade character), is seen as a shear zone which affects the biotite and quartzitic paragneisses of locality BTHOMAS\_512 (see above). Towards the eastern part of the exposure, the deformation intensifies to a 10 m wide zone of protomylonites that appear to form the core of a ductile shear zone (Figure 10a). The outcrops show rare development of moderately ( $20\text{--}35^\circ$ ) west-plunging stretching lineations. Lination-parallel kinematic indicators of the shear zone indicate an oblique sinistral strike-slip sense of movement from rarely-developed sigma quartzite boudins and asymmetrical tight to isoclinal minor folds (Figure 10b and c respectively). A tiny ptigmatic felsic vein (mm-scale thickness) was seen in a more homogeneous biotite-rich layer (Figure 10d).

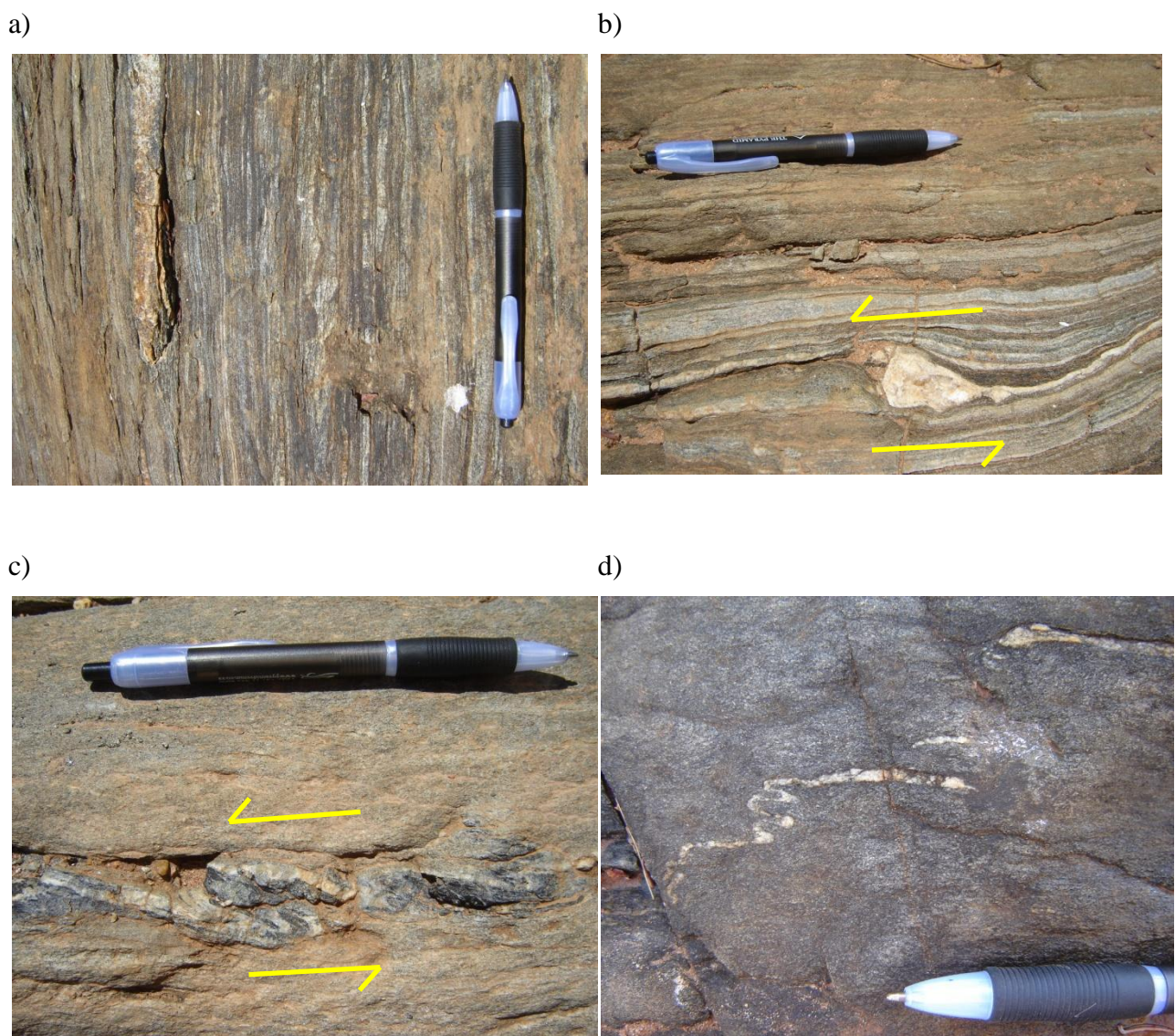
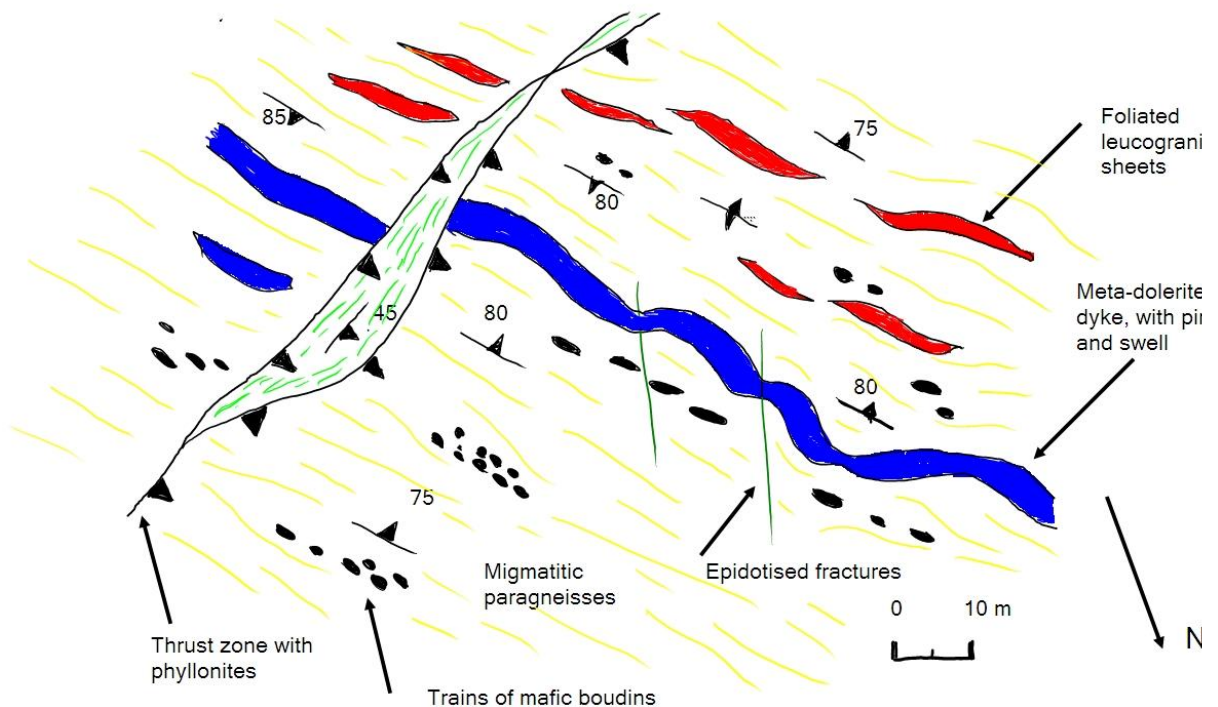


Figure 10. *Oblique strike-slip sinistral shear zone in biotite and quartzitic paragneisses. a) Strong protomylonitic planar fabric in fine-grained, grey, semi-pelitic biotite gneisses; b) Small quartzite sigma clast showing sinistral sense of shear; c) Minor asymmetrical isoclinal S folds indicating sinistral sense of shear; d) Small felsic ptigmatic vein in homogeneous grey biotite paragneiss.*

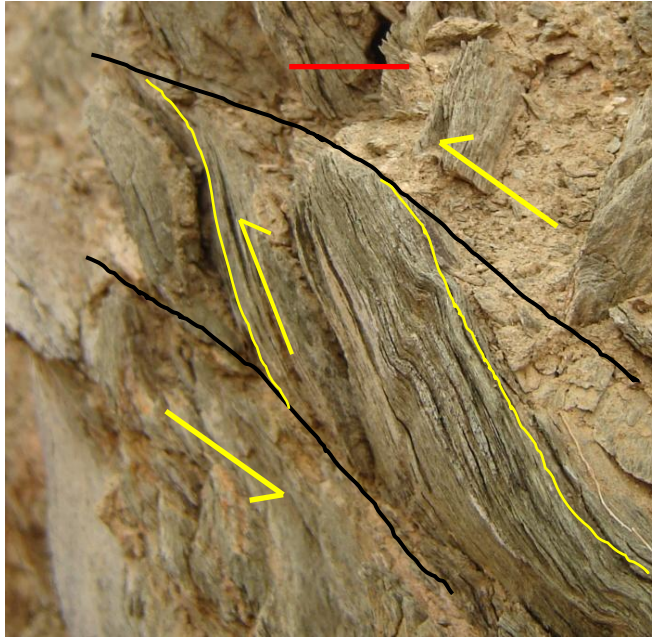
At locality BTHOMAS\_508 (see above) the migmatitic paragneisses and metadolerite dyke are cut by a north-dipping thrust zone in southern part of outcrop (Figure 11). Thrust zone, which dips at about  $45^\circ$  NE is made up of an anastomosing array of thrust planes and slices, forming a zone which widens and narrows from about 2 to 12 metres in width and is occupied by greenish-grey phyllonite, with strong, fine, NE-dipping layering. Examination of the phyllonites shows the development of top-to-the-south S-C fabrics (Figure 11b), overprinted by a late extensional (top-to-the-north) crenulational cleavage (Figure 11c). No lineations were seen to further constrain the movement vectors, but the large, sub-vertical metadolerite dyke appears to show (if it is the same dyke on either side of the thrust plane) left-lateral displacement across the thrust, implying it has a sinistral oblique movement. The precise geometry of the late extensional features is also not determined. The thrusting clearly took place under greenschist facies conditions (as shown by the chlorite phyllonites) and this event may also be responsible for the pervasive retrograde metamorphism observed in the metadolerite dyke.

a)





b)



c)



Figure 11. a) Field sketch of phyllonitic thrust zone in migmatitic paragneisses, exposed in artisanal quarry at Locality BTHOMAS\_508; b) Phyllonites showing sigmoidal S-C fabric and top-to-the-south (left) – thrust- sense of movement (yellow arrows). Red bar is 1 cm; c) Late extensional crenulation folds and cleavage in phyllonites showing top-to-the-north (right) - normal- sense of movement.

### Economic geology

No indications of possible showings of economic minerals were seen. However, local artisanal workers were active in a number of places, manually quarrying rocks for aggregate. Lithologies used were both granitoids and the migmatitic gneisses.

### Reference

Chadha, D.S. (based on original work by Eades, Reeve, Stockley and Williams) (1967). Geological Map of Sheet 162 (Dodoma) 1: 100 000 scale, Geological Survey of Tanzania. (Digital version 2001)