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Geological Mapping, Structural Setting and Petrographic Description of the Archean Volcanic Rocks of Mnanka Area, North Mara

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ABSTRACT

The Mnanka area is situated within the Musoma Mara Greenstone Belt, the area is near to Nyabigena, Gokona and Nyabirama gold mines. Mnanka area comprises of the sequence of predominant rhyolitic volcanic rocks, chert and metasediments. Gold mineralizations in Mnanka area is structure controlled and occur mainly as hydrothermal disseminated intrusion related deposits. Hence the predominant observed structures are joints and flow banding. Measurements from flow banding plotted on stereonets using win-TENSOR software has provided an estimate for the general strike of the area lying 070° to 100° dipping at an average range angle of 70° to 85° while data from joints plotted on stereonets suggest multiple deformation events one of which conforms to the East Africa Rift System (striking WSW-ENE, NNE-SSW and N-S).

1. INTRODUCTION

This paper focuses on performing a systematic geological mapping and description of structures and rocks of the Mnanka area. The Mnanka area is located in the Mara region, Tarime district within the Musoma Mara Greenstone Belt. The gold at Mnanka is hosted by volcanic rocks that belong to the Musoma Mara Greenstone Belt (Figure 1). The Mnanka volcanics are found within the Kemambo group that comprises of the sequence of predominant rhyolitic volcanic rocks, chert and metasediments south of the Nyarwana fault.

Figure 1: Map showing Gold mines in Archean Greenstone Belt

Archaean rocks in the North Mara region form two geologically distinct domains separated by the Nyarwana Fault. South of the Nyarwana Fault the geology is dominated by granitoids and gabbroic rocks with lesser amounts of rhyolitic volcanics, ferruginous chert and siltstone, and minor amphibolites facies metasediment (Mason, 1999). Early mapping and interpretation suggests that the basement geology of northern domain (an area north of Nyarwana fault) comprises sedimentary and volcanogenic packages. The basement geology of the area immediately between the Nyarwana Fault and the Utimbaru (Escarpment) is largely obscured by Tertiary phonolite cover somewhat limiting geological knowledge of this area.

However, exposures at Nyabigena, indicate that the basement in this area includes altered, but massive, andesitic volcanics, greenschist facies andesitic volcanic sandstone and semi-schist, finely laminated unfoliated greywacke and massive grey siltstone. The andesitic volcanic rocks in this area have no obvious correlatives elsewhere in the North Mara region (Allibone et al., 2003).

However, the similarity of the unfoliated greywacke rocks to the north of the Utimbaru Fault, and possible presence of gabbroic plutons like those south of the Nyarwana Fault implies that the fault-bounded block in between is not part of an exotic terrain.

North of the Utimbaru (Escarpment) Fault the geology is dominated by a distinct sequence of sedimentary rocks that includes a basal conglomerate, overlying basaltic volcanics, sandstone, greywacke, and ferruginous shales. Subordinate cross cutting intrusions include dacitic porphyries, syenite, granite and minor gabbro/dolerite dikes. Many of these intrusive rocks are texturally and petrologically distinct from those south of the Nyarwana Fault. Petrological work was restricted to 9 samples taken from drill cuttings obtained from the Mnanka prospect area and were restricted principally to lithological and alteration identification. Rocks identified included rhyolitic tuffs, granophyre, and micrographic granitoid. All rocks suffered low to medium intensity hydrothermal alteration to phyllic and prophylitic assembages (Mason, 1999). The company now continues to focus on extending mineralisation on the northern, western and eastern domains of the Gokona deposit. Following the successful drill programme to date in Nyakunguru village, next is to expand the step-out drilling to allow accelerated follow-up of identified positive intersections.

2. MATERIALS AND METHODS

Field work during this study involved geological mapping with careful observations of individual outcrops. Right hand rule was used over orientations measurements taken by Suunto compass. Lithologies were documented in detail. If present, mineralization and alterations were recorded and any structural feature was measured. Mapping was done by traversing perpendicular to the NE general regional strike of the Mnanka area, the Open Loop traverses were carried out during our mapping. All of this information was recorded in a geological field book and plotted on satellite map images.

Different geological structures including joints, and flow banding which encountered during mapping were described and measured. Field equipment included hand lens, Suunto compass, Global Positioning System (GPS) device, geological hammer, magnetic pencil, scale ruler (1:5000), back packs, mapping folder (hard board), field notebook, sample bags, marker pens, protractor, colored pencils, satellite images and personal protective equipment (PPE).

3. RESULTS AND DISCUSSION

3.1 Geological map and rock distribution

The geological map at a scale of 1:1000 was produced covering an area of 25 square kilometers as shown in geological map (Figure 2). Lithological units encountered in the study area are predominantly rhyolite, diorite, phonolite, and andesite. The large part of the area is covered by Mbuga soil.

3.1.1 Phonolite

The outcrop is highly weathered, massive, and pale to dark in color and also has phenocryst containing good cleavage ranges between 2mm to 1cm width. The phonolite rock is silica undersaturated, it is free of quartz or other silica crystals, and is dominated by low-silica feldspathoid minerals more than feldspar minerals, hence the phenocrysts contain feldspathoids (nepheline, leucite and analcite). Phonolite is a rare extrusive volcanic rock of intermediate chemical composition between felsic and mafic, with texture ranging from aphanitic (fine-grain) to porphyritic (mixed fine- and coarse-grain).

3.1.2 Rhyolite

The outcrop is moderate weathered, it may have any texture from glassy to aphanitic to porphyritic and the rocks are massive. Rhyolite is an igneous, volcanic rock, of felsic (silica-rich) composition. The mineral assemblage is usually quartz, alkali feldspar and plagioclase. Minerals like biotite and hornblende are common accessory minerals.

3.1.3 Diorite

The outcrop is a grey to dark grey intermediate intrusive igneous rock composed principally of plagioclase feldspar (typically andesine), biotite, hornblende, and/or pyroxene. It may contain small amounts of quartz, microcline and olivine. Zircon, apatite, magnetite, ilmenite and sulfides occur as accessory minerals. It can also be black or bluish-grey, and frequently has a greenish cast.

When olivine and more iron-rich augite are present, the rock grades into ferrodiorite, which is transitional to gabbro. The presence of significant quartz makes the rock type quartz-diorite or tonalite, and if orthoclase (potassium feldspar) is present at greater than ten percent the rock type grades into monzodiorite or granodiorite. Diorite has a medium grain size texture, occasionally with porphyry. Diorite results from partial melting of a mafic rock above a subduction zone.

3.1.4 Andesite

Andesite is an extrusive igneous, volcanic rock, of intermediate composition, with aphanitic to porphyritic texture. In a general sense, it is the intermediate type between basalt and dacite, and ranges from 57% to 63% silicon dioxide (SiO_2). The mineral assemblage is typically dominated by plagioclase plus pyroxene and/or hornblende. Magnetite, zircon, apatite, ilmenite, biotite, and garnet are common accessory minerals. Akali feldspar may be present in minor amounts. Classification of andesites may be refined according to the most abundant phenocryst. Example: hornblende-phyric andesite, if hornblende is the principal accessory mineral. Andesite can be considered as the extrusive equivalent of plutonic diorite. Characteristic of subduction zones, andesite represents the dominant rock type in island arcs. The average composition of the continental crust is andesitic.

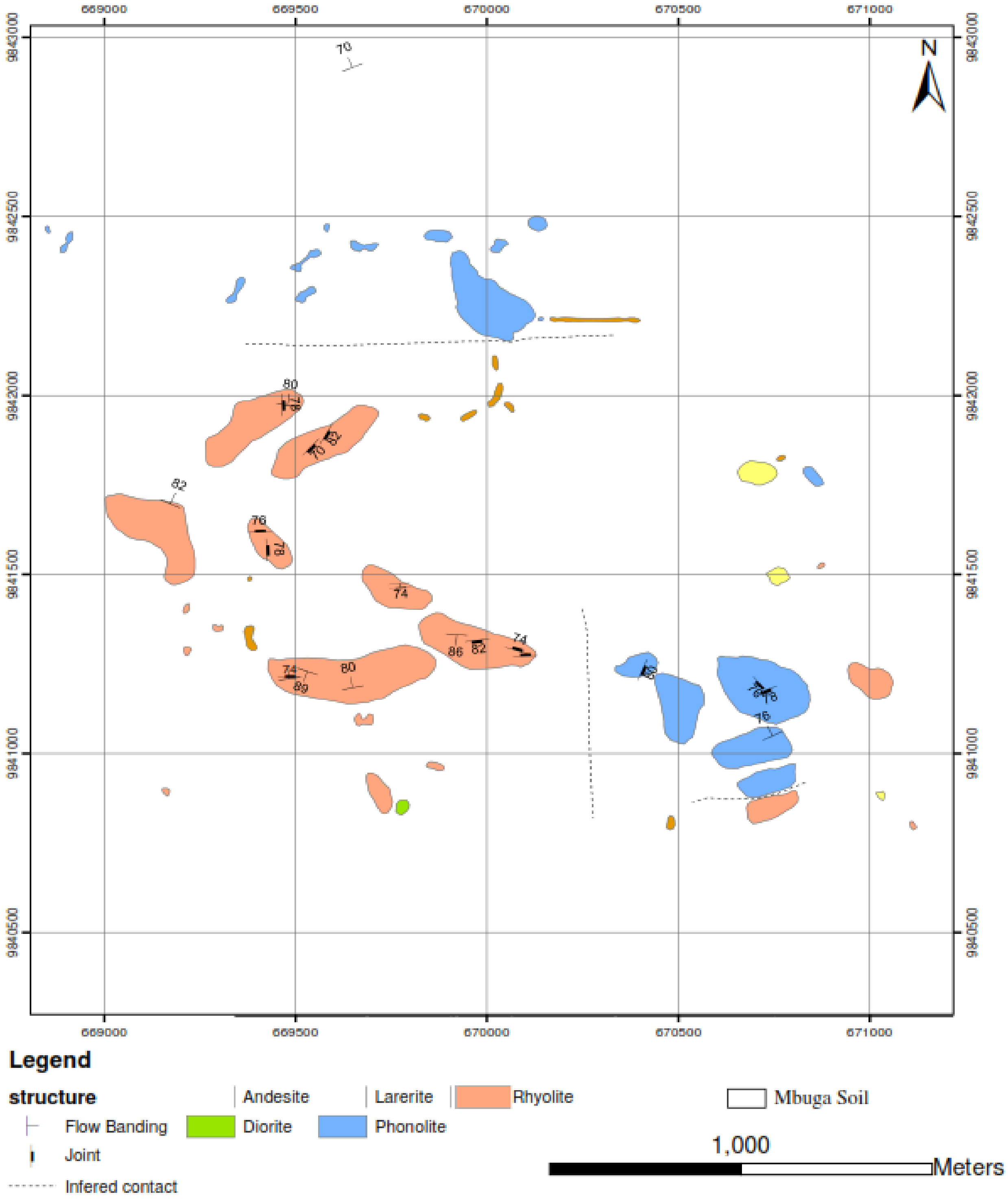


Figure 2: The Geological map of Mnanka area.

3.2 Structural analysis

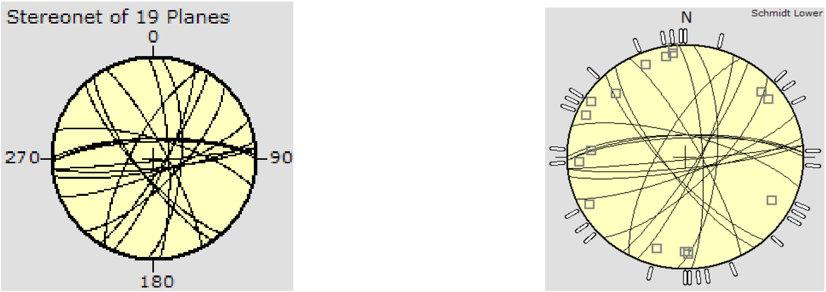
The structures measured were predominantly Joints and flow banding. Most of the lithology in the mapped area of Mnanka Prospect is dominantly comprising of acid volcanogenic rocks, micrographic granite, and porphyritic andesite when traversing perpendicular to the NE general regional strike of the Mnanka area. The mapped area has been subjected to deformations producing minor joints and flow bandings that have resulted into changing orientation of the lithologies.

3.2.1 Joints

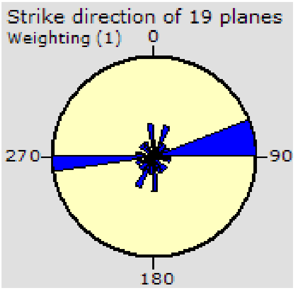
The outcrops in the area have been deformed producing several sets of joints some of which have been filled with minerals like sulfides, Quartz, K- feldspars, plagioclase, Hornblende and ilmenite.

Kavana

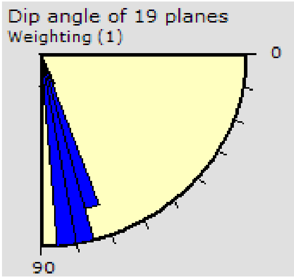
A. Stereonets



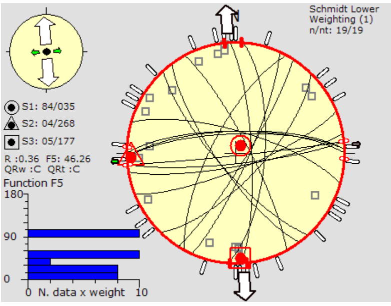
B. Strike of joint planes



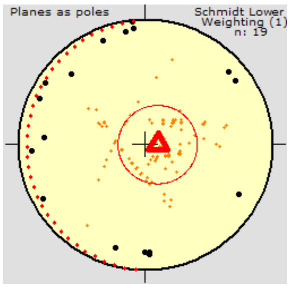
C. Dip angle of joint planes



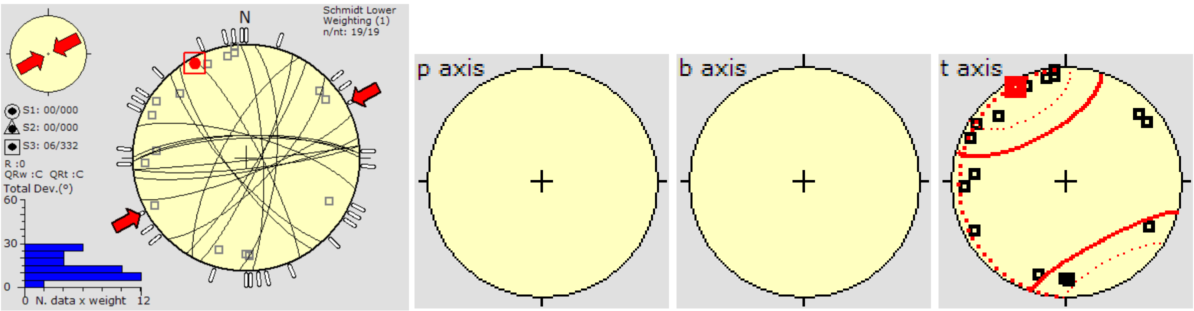
D. Rotation optimization of stress tensor.



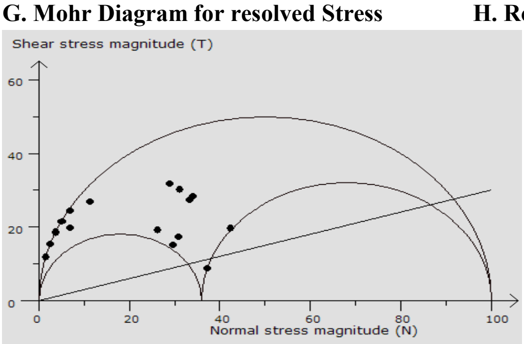
E. Orientation statistics of poles of joint planes



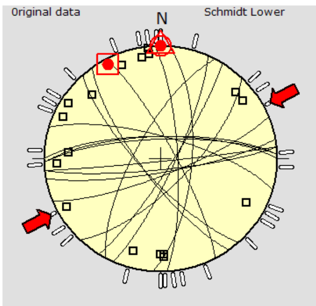
F. Stress Tensor from PBT Kinematic Axes



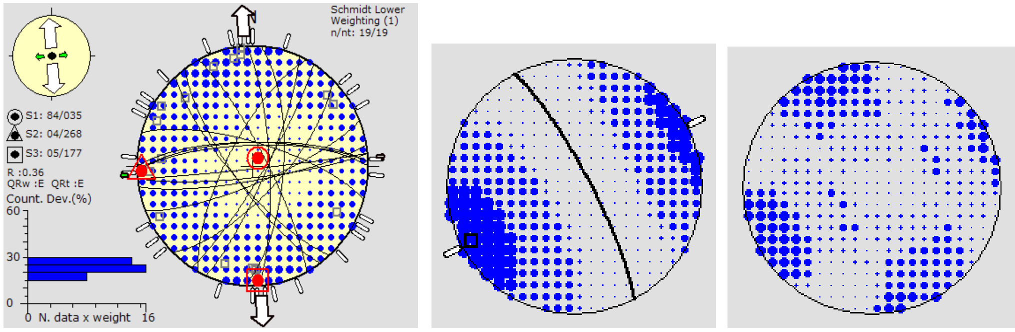
G. Mohr Diagram for resolved Stress



H. Rotational Diagram showing the Original data



I. Stress tensor from right dihedron method



J. Diagram showing Regression/Stability curves

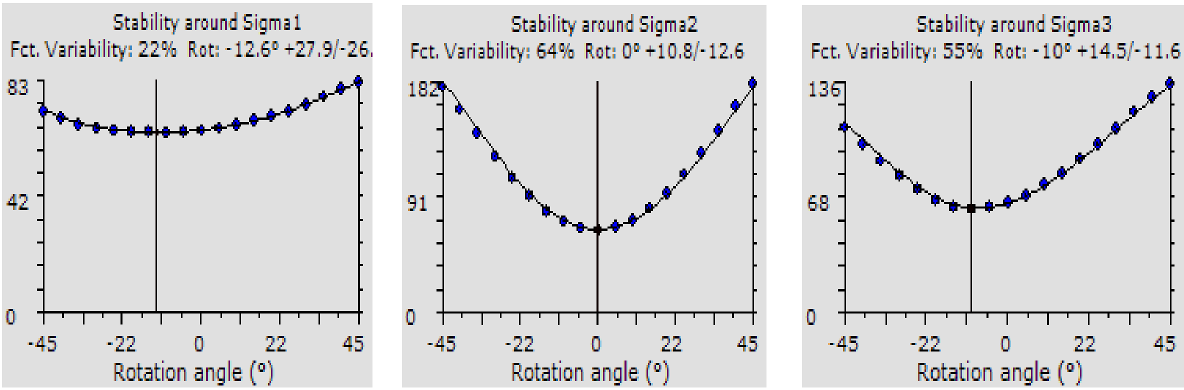


Figure 3: Structural analysis of joints

The joint measurement analysis presented (Figure 3) illustrates several orientations of the joints indicative of different, multiple deformation events that have occurred in the area. The most common deformation strikes WSW-ENE, followed by that in the NNE-SSW and the nearly N-S striking deformations that approximates the general deformation characteristics of the Great East African Rift Systems (EARS). There are also other deformations that have affected the area oriented randomly in the area. Most deformations dip between 70º to 85º Also the orientation statistics of poles of joint planes 84˚/152˚ (Figure 3). The orientation statistics of kinematics axes (PBT axes) are p-axis 00˚/000˚, b-axes 00˚/000˚ and t-axis 06˚/332˚ (Figure 3). Both the stress tensor from Right Dihedron (R. Dieder) method (Figure 3) and rotational optimization of stress tensor (Fig. 4) both resulted $^{\delta}$1=84˚/035˚, $^{\delta}$2=04˚/268˚ and $^{\delta}$3=05˚/177˚.

3.2.2 Flow banding

This structures were observed in outcrops of igneous, volcanic rock of felsic composition such as Rhyolite its mineral assemblage is usually Quartz, alkali feldspar and plagioclase. The stereographic distribution of poles of flow banding (Figure 4) shows that most of the flow banding have dip attitude ranging between 70˚-85˚and striking in W-E followed by WNW-ESE , WSW-ENE, SSW-NNE in rose diagram (Figure 4) with orientation statistics of poles of flow banding 89˚/350˚ (Figure 4). The rotational optimization of stress tensor (Figure 4) both resulted $^{\delta}$1=90˚/000˚, $^{\delta}$2=00˚/090˚ and $^{\delta}$3=00˚/000˚.

3.3 Petrography

11 thin sections from representative rock samples from within the mapped area were prepared for petrographic study. The study involved the description of the physical properties such as texture, crystallinity, crystal habit, colour and mineral composition.

3.3.1 Rhyolite

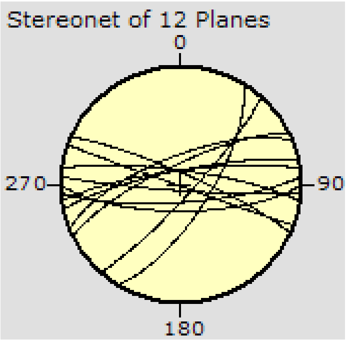
Acid volcanogenic rocks are observed in some samples, and most may have been rhyolitic in composition. Some are interpreted a quartz-phyric rhyolite, and others formed as fragmental rocks of rhyolite breccia containing flow-banded rhyolite fragments.

3.3.1.1 Sample: DY2ST2

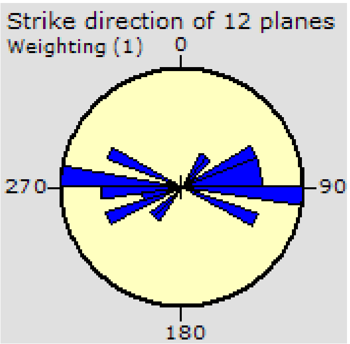
Rock name of this sample is *Quartz-K-feldspar-sericite altered meta-rhyolite breccia.* The sawn rock slice represents a fine-grained massive white to grey rock with indistinct coarse fragmental texture defined by small to large angular fragments up to ~2 cm in size. Some of the fragments display a structure (flow structure of igneous origin), which varies in orientation from fragment to fragment. In thin section, this sample displays a partly preserved coarse clast-supported fragmental texture, severely modified by metamorphic alteration effects.

Small to large lithic fragments are abundant. They range in size from ~0.4 mm up to ~1-2 cm. Larger fragments contain minor equant quartz crystals (phenocrysts) and prismatic K-feldspar crystals (phenocrysts), sparsely distributed through a very fine-grained mosaic of tiny K-feldspar grains and indistinct thin trails of small quartz grains.Together, alignment of the quartz trails and K-feldspar crystals defines a primary fluidal structure (flow banding) in acid lava. The orientation of the structure varies from fragment to fragment.

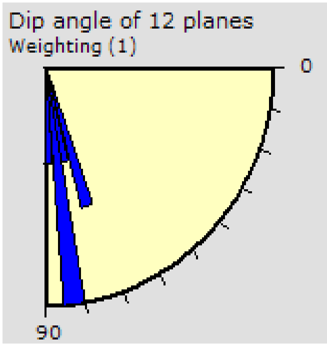
A. Stereonets



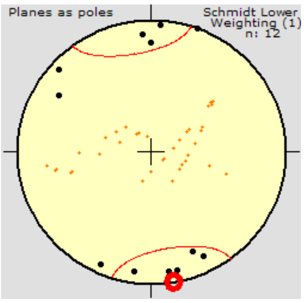
B. Strike of Flow banding



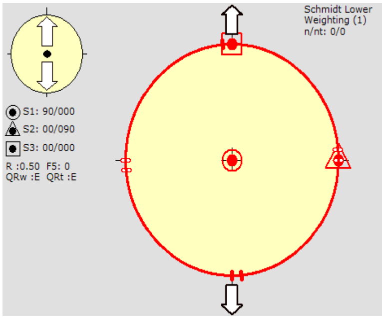
C. Dip of Flow Banding



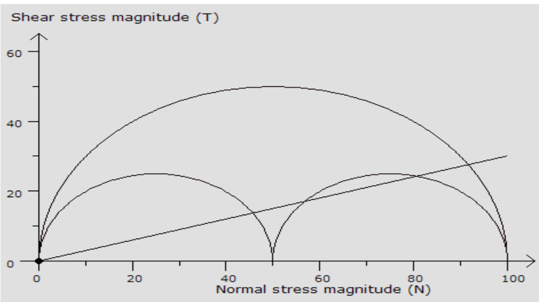
D. Orientation statistics of poles of joint planes



E. Rotation optimization of stress tensor.



F. Mohr Diagram for resolved Stress



G. Rotational Diagram showing the Original data

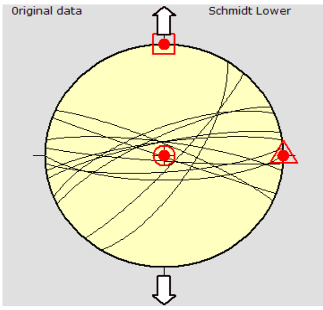


Figure 4: Structural analysis of Flow Banding

Tiny sericite flecks lightly pervade the feldspar-quartz mosaic, and in places they are confined to ovoid fractures which appear to reflect precursor conchoidal fractures developed in primary glass.Fine-grained matrix is composed mostly of small anhedral quartz grains which build a uniformly fine-grained matrix enclosing the altered fragments. Tiny sericite flecks lightly pervade the quartz mosaic. This sample is considered to have initially formed as an acid volcanogenic breccia.

It was composed of rhyolitic lava fragments composed of minor quartz and K-feldspar phenocrysts in abundant quenched flow-banded glassy groundmass. It remains uncertain whether the breccia formed as a lava breccia (i.e. in-situ fragmentation of viscous rhyolitic lava) or whether it formed by limited transport of lava clasts. The rock formed in an acid igneous volcanic terrain. The inferred glassy groundmass may have devitrified shortly after formation of the rock body, or possibly at a later time. At a later time, the rock suffered replacement by a fine-grained assemblage of quartz + K-feldspar + minor sericite. The clasts were replaced by K-feldspar + quartz + minor sericite, and the matrix was replaced mainly by quartz + minor sericite (Photo 1).

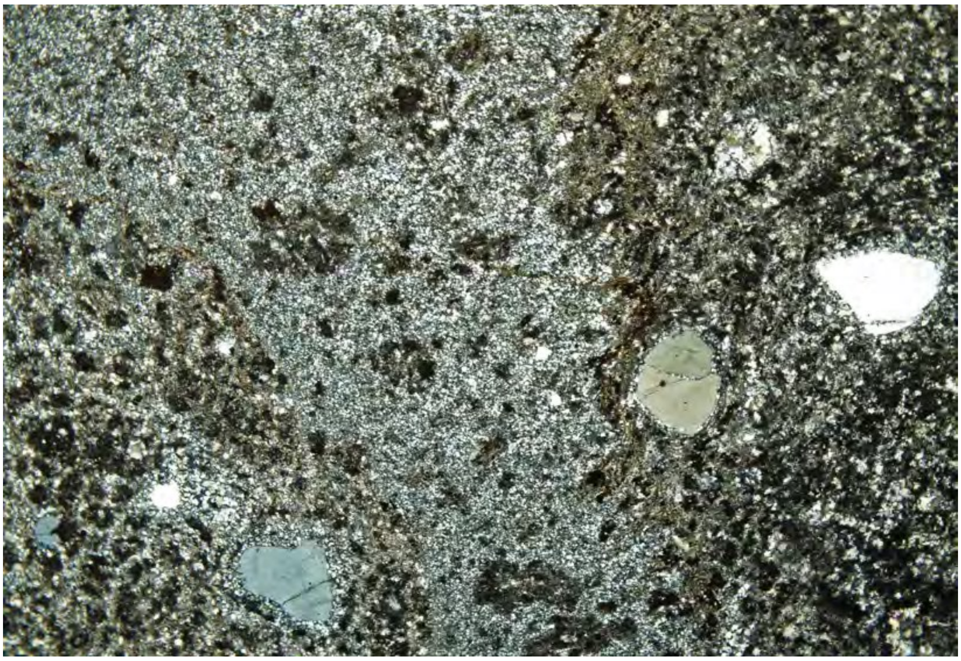


Photo 2: SAMPLE DY2ST2 (Transmitted light, crossed polarisers, Obj. x2.5, Image PC202564).

3.3.1.2 Sample: DY2ST3

Rock name of this sample is *weakly weathered, K-feldspar-quartz-sulfide-carbonate altered meta-rhyolite breccia.* The sawn rock slice represents a massive fine-grained grey rock with small disseminated lustrous sulfide grains (pyrite). Weathering has generated irregularly shaped large cream patches with small orange-brown oxidation spots after pyrite. The section mostly captures the pale grey sulfide-bearing area, with only minor cream oxidised part of the rock.

The section offcut effervesces in reaction with dilute HCl, indicating minor calcite occurs in irregularly scattered small white patches. In polished thin section, this sample displays a partly preserved coarse-grained, clast-supported fragmental texture, severely modified by alteration effects. K-feldspar is abundant, it forms a very fine-grained massive replacement mat which occupies small to large angular lithic fragments ranging from millimetre to centimetre size.

Pyrite occurs in minor amount as small subhedral cubic crystals ~0.1-0.4 mm in size, and small aggregates of crystals.

Most of the pyrite occurs in the matrix areas, not the lithic fragment sites. At one margin of the section, pyrite has suffered complete replacement by fine-grained dense dark red-brown goethite, and goethite also forms a diffuse stain in enclosing host rock. Mostly goethite is absent from the section. Carbonate (calcite) occurs in minor amount as rhombic grains in small aggregates scattered sparsely through the rock. Most occur in the matrix, but some also occurs in the fragment sites. Chlorite occurs in trace amount as small pleochroic pale green flakes which are locally intergrown with some of the carbonate aggregates. Mostly chlorite is absent. This sample is considered to have initially formed as a felsic volcanogenic breccia. It was composed of acid lava fragments, some with strong flow banding and containing minor quartz phenocrysts, in a fine-grained matrix derived from the same acid igneous source.

The rock was infiltrated by CO2-S-bearing hydrothermal fluid. This caused strong pervasive replacement, producing the fine-grained alteration assemblage of K-feldspar + quartz + carbonate + pyrite. The lava clasts were replaced mostly by a fine-grained mat of K-feldspar, accompanied by minor carbonate. The matrix was replaced mostly by quartz, accompanied by minor pyrite and carbonate (Photo 2).

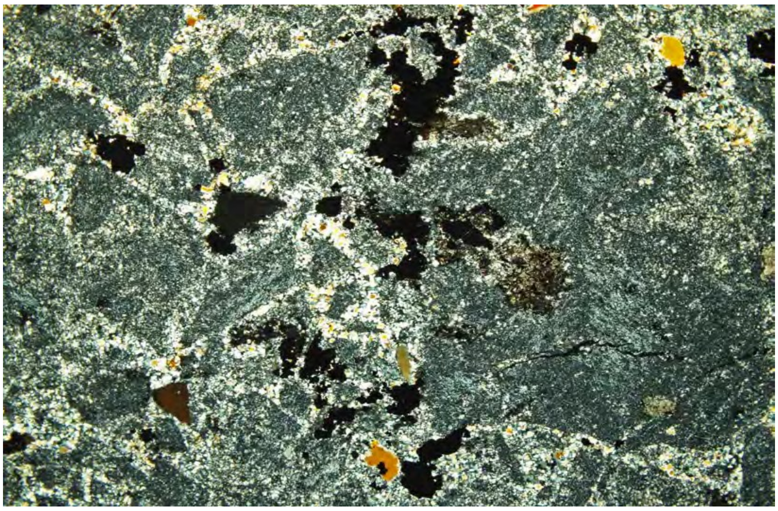


Photo 3: SAMPLE DY2ST3 (Transmitted light, crossed polarisers, Obj. x2.5, Image PC202565).

3.3.1.3 Sample: DY4ST3

Rock name of this sample is *weakly weathered, high-intensity sericite-quartz altered meta-rhyolite.* The sawn rock slice represents a fine-grained felsic rock with minor uniformly distributed equant euhedral translucent grey quartz crystals (phenocrysts). The rock has a pale pinkish cream rock, with concentration of dark pink to red ferruginous material along thin fractures, indicating weak oxidation has affected the rock.

In thin section, this sample displays a partly preserved massive porphyritic igneous texture, severely modified by strong pervasive alteration, and weak later oxidation overprint. Quartz crystals ~0.4-2.0 mm in size are distributed sparsely but uniformly through the rock. All display a euhedral equant crystal form, but some are weakly rounded by magmatic corrosion. These quartz crystals are readily interpreted as igneous phenocrysts. Most of the rock is composed of a fine-grained massive replacement assemblage of sericite and quartz.

The sericite forms tiny randomly oriented flakes that are concentrated in a massive mat. Quartz forms tiny anhedral grains in a massive mosaic. The sericite and quartz vary in abundance over large areas. Rutile is present in trace amount a tiny granules and small aggregates sprinkled through the rock.Minor ferruginous stain (goethite) occurs in minor amount as orange-red stains concentrated along thin discontinuous trails or microfractures spaced irregularly through the-rock.This sample is considered to have initially crystallised as an acid igneous rock possibly of rhyolitic composition. It contained a minor proportion of quartz phenocrysts in fine-grained groundmass.

Many primary minerals and textures were destroyed by infiltration by hydrothermal fluid, which produced the fine- grained alteration assemblage of sericite + quartz + trace rutile. Quartz phenocrysts survived. After uplift and erosion had elevated the rock body into the near-surface environment, circulation of a small amount of meteoric water produced minor goethite as a faint pervasive stain and as concentrations along minor thin fractures (Photo 3).

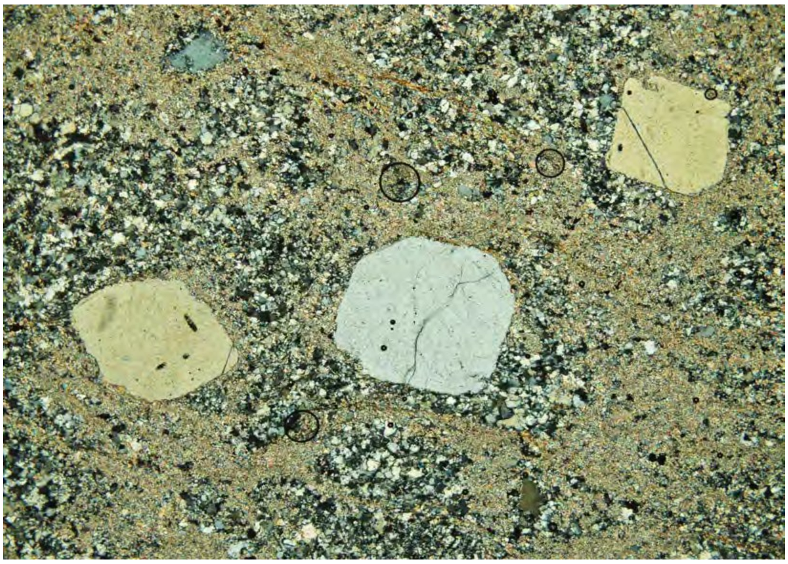


Photo 4: SAMPLE DY4ST3 (Transmitted light, crossed polarisers, Obj. x4, Image PC202574).

3.3.2 Micrographic granite

Micrographic granite sample is crystallised with larger crystals (quartz, plagioclase, K-feldspar) in micrographic groundmass (quartz, K-feldspar). Ferromagnesian minerals with zircon inclusions formed in minor amount, but have been obscured by alteration effects.

3.3.2.1 Sample: DY6ST1

Rock name of this sample is *Biotite-chlorite meta-micrographic granite.* In thin section, this sample displays a massive micrographic granitoid texture, modified by selective metamorphic recrystallisation. A significant proportion of the rock is composed of large crystals of felsic minerals. Quartz forms large equant euhedral crystals ~2-4 mm in size. Plagioclase occurs as randomly oriented prismatic crystals of similar size to quartz, but displaying the combined simple and multiple twinning of this mineral. K-feldspar forms subhedral grains of similar size which display the combined albite and pericline twinning of microcline, accompanied by ragged trails of exsolved albite (ie these are microcline microperthite alkali feldspar grains). Much of the rock is composed of large ragged grains ~1-2 mm in size which are composed of micrographic intergrowths of clear quartz and K-feldspar.

Biotite occurs in significant amount as tiny randomly oriented flakes, mostly pleochroic from drab green to almost colourless. Although pleochroic in greens superficially similar to chlorite, all of these flakes display the moderately high birefringence of biotite. Most of the biotite is concentrated in ragged patches, which are interpreted as primary ferromagnesian grain sites but none is preserved for confirmation nor are primary grain shapes preserved. Some of the biotite projects as small trails into nearby feldspar grains.

Chlorite is present in trace amount as small pleochroic green flakes which occur in some of the feldspar grain sites. Zircon occurs as euhedral prisms ~100-200 µm in size. They occur in the biotite aggregates, and display the characteristic prismatic crystal form, high relief, lack of cleavage, and high birefringence of this mineral. This sample crystallised as a massive micrographic granitoid, composed of quartz, K-feldspar, plagioclase, minor ferromagnesian minerals, and trace zircon.

Early crystallization produced euhedral crystals of plagioclase, quartz and K-feldspar, and rapid crystallization of residual silicate liquid produced abundant micrographic intergrowths of quartz and K-feldspar. Ferromagnesian crystals with small zircon inclusions formed in the primary igneous assemblage, but their timing has been obscured by later effects.

The rock was modified in response to low-grade regional metamorphism in the green schist facies. This generated new fine-grained biotite + chlorite. The biotite formed mostly in dense aggregates after primary ferromagnesian grains, and also formed in lesser amount as replacement trails which project into nearby feldspar grains. Primary zircon crystals survived in the biotite aggregates. Chlorite formed in minor amount as small replacement flakes in some of the feldspar grains.

This view of meta-micrographic granite captures euhedral quartz phenocrysts (clear, white at top, grey at bottom left) and plagioclase phenocrysts (twinned, grey, right) in abundant micrographic groundmass (intergrown white quartz and grey K-feldspar). Note the presence of fine-grained aggregates and trails of metamorphic biotite (dull brown), which results in a turbid dark appearance throughout the hand sample (Photo 4).

Photo 5: SAMPLE DY6ST1 (Transmitted light, crossed polarisers, Obj. x4, Image PC202569)

3.3.2.2 Sample: DY4ST7

Rock name of this sample is *high-intensity sericite-quartz altered meta-acid igneous rock.* The sawn rock slice represents a fine-grained massive pale grey rock in which indistinct larger patches up to centimetre size are faintly distinguishable. In thin section, this sample displays a weakly preserved porphyritic acid igneous texture, severely modified by strong pervasive alteration effects. Quartz crystals occur in minor amount, scattered sparsely through the rock.

They form euhedral equant crystals ~0.4-1.5 mm in size, with some modification of the crystal forms by magmatic rounding. Most of the rock is composed of a very fine-grained massive mat of tiny colourless sericite flakes. Distributed through the sericite mat are small to larger ragged patches of fine-grained quartz. Possible phlogopite (Mg-biotite) occurs in minor amount as small flakes similar in size and shape to sericite, but displaying very pale orange-colourless pleochroism. It is concentrated in small ragged patches scattered irregularly through the sericite mat.

Rutile is present in minor amount as small granules with typical deep yellow-brown to red colour and extreme birefringence. They are sparsely sprinkled through the sericite mat. This sample is considered to have initially crystallised as an acid igneous rock, possibly a rhyolite of Lava origin. It contained minor quartz phenocrysts in groundmass which may have been glassy. Subsequent infiltration by fluid during low-grade regional metamorphism caused strong pervasive replacement by fine-grained sericite + quartz + minor phlogopite + rutile.

Most of the rock was completely replaced by the fine-grained new assemblage, but the primary quartz crystals survived This view of altered meta-acid igneous rock (porphyritic rhyolite) captures preserved small phenocrysts of quartz (clear, euhedral, pale yellow, white, grey) in fine-grained altered groundmass composed of quartz (tiny white to grey grains) and sericite (dense patches of tiny brightly coloured yellowish flakes) (Photo 5).

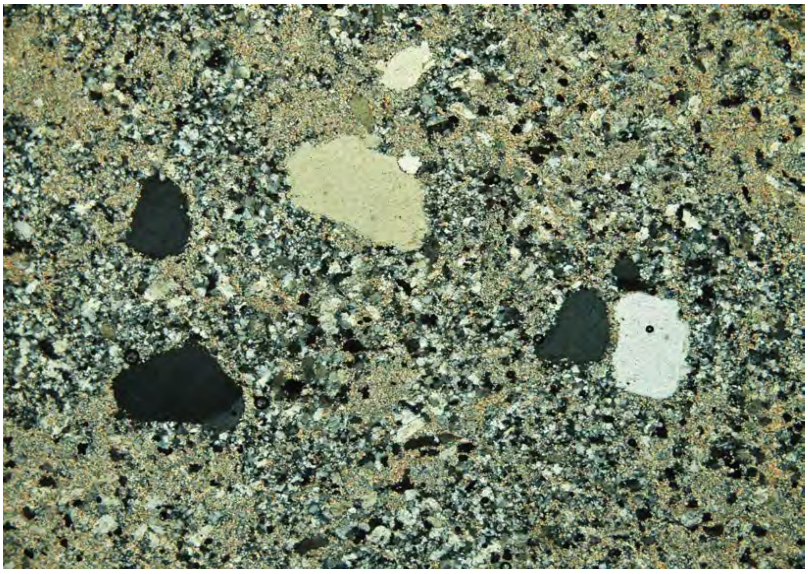


Photo 6: SAMPLE ST7DY4 (Transmitted light, crossed polarisers, Obj. x4)

3.3.3 Andesite

Porphyritic andesite is identified in 1 sample. Minor early-formed phenocrysts (plagioclase > clinopyroxene) lie in a fine-grained holocrystalline groundmass (plagioclase > hornblende >ilmenite).

3.3.3.1 Sample: DY5ST2

Rock name of this sample is *weakly weathered, plagioclase-pyroxene porphyritic andesite.*

The sawn rock slice represents a fine-grained massive dark greenish grey rock, containing minor scattered large blocky translucent grey to white feldspar crystals (phenocrysts). The sample fails to respond to the hand magnet, suggesting magnetite is absent. Fine-grained groundmass dominates the rock. Plagioclase occurs as randomly oriented acicular laths up to ~0.4 mm long, and smaller anhedral interstitial grains.

Hornblende forms small subhedral grains which display a pleochroic reddish brown colour. Opaques occur in minor amount as small equant crystals, ilmenite as suggested by lack of magnetic response of the hand sample. Goethite occurs in minor amount as dense dark red-brown concentrations along irregularly oriented thin fractures, and as diffuse stainings in host rock marginal to the fractures. This sample crystallised as a sparsely porphyritic andesite. It contains minor phenocrysts (plagioclase > clinopyroxene) in fine-grained holocrystalline groundmass (plagioclase > hornblende >> ilmenite).

It remains uncertain whether it formed as a lava flow or a shallow intrusive body (eg dyke). This view of porphyritic andesite captures a plagioclase phenocryst (grey, twinned, oriented E-W) and a euhedral blocky clinopyroxene phenocryst (centre, pale yellow with simple twin lamella), in fine-grained groundmass containing small plagioclase laths (grey) and tiny hornblende grains (reddish brown) (Photo 6).

Photo 6: SAMPLE DY5ST2 (Transmitted light, crossed polarisers, Obj. x10, Image PC202576).

3.3.4 Clastic sediments

Therefore we observe some different samples which have minor sedimentary rock composition:

Clastic sediments are identified in a number of samples. Arkose was deposited as a partly sorted, clast-supported, non-layered sediment composed of closely-packed angular crystal fragments (quartz = plagioclase = K-feldspar >> zircon) and minor lithic fragments (granitoid), accompanied by minor detrital clays. Sandstone contained abundant sub rounded to rounded clastic grains (quartz) and other obscured clasts in fine-grained matrix.

3.3.4.1 Sample: DY5ST1

Rock name of this sample is *Biotite-chlorite-sericite meta-arkose.* The sawn rock sample represents a grey rock with readily distinguished paler grey to white fragments of varied size up to ~2 mm.

In thin section, this sample displays a well-preserved clast-supported clastic sedimentary texture without layering, modified by metamorphic effects. Lithic fragments are present in minor amount. They range ~2-6 mm in size, and are composed of anhedral plagioclase, K-feldspar and quartz grains in massive crystalline texture of granitoid texture. Biotite occurs in significant amount as small but well-shaped flakes, concentrated in matrix between the crystal and lithic fragments.

Some of the biotite is concentrated around margins of crystal fragments, and has partly replaced some of the feldspar clastic grains. The biotite flakes display the typical optical properties of this mineral: tan brown to straw yellow pleochroism, moderately high birefringence, and parallel extinction to its single perfect cleavage. This sample initially formed as a partly sorted, non-layered, clast-supported sandy sediment.

It was composed of abundant crystal fragments (quartz = plagioclase = K-feldspar) and minor lithic fragments (granitoid) in minor fine clay matrix. All of the crystal and lithic fragments are interpreted to have been derived from a felsic crystalline (granitoid) terrain.

The coarse grain size, lack of layering, and angular shapes of the clasts suggests that the clastic materials were transported only a short distance from their source. Arkose is an appropriate name for such a sediment.

After burial, the rock body suffered low-grade regional metamorphism in the greenschist facies. This generated the new fine-grained assemblage of biotite + chlorite + calcite + sericite. Most of the new minerals formed by recrystallisation of the minor primary clay matrix, but some formed as replacement flakes and patches in the feldspar crystal fragments. The presence of biotite in the metamorphic assemblage confirms that P-T conditions reached the middle greenschist facies (ie biotite grade) (Photo 7).

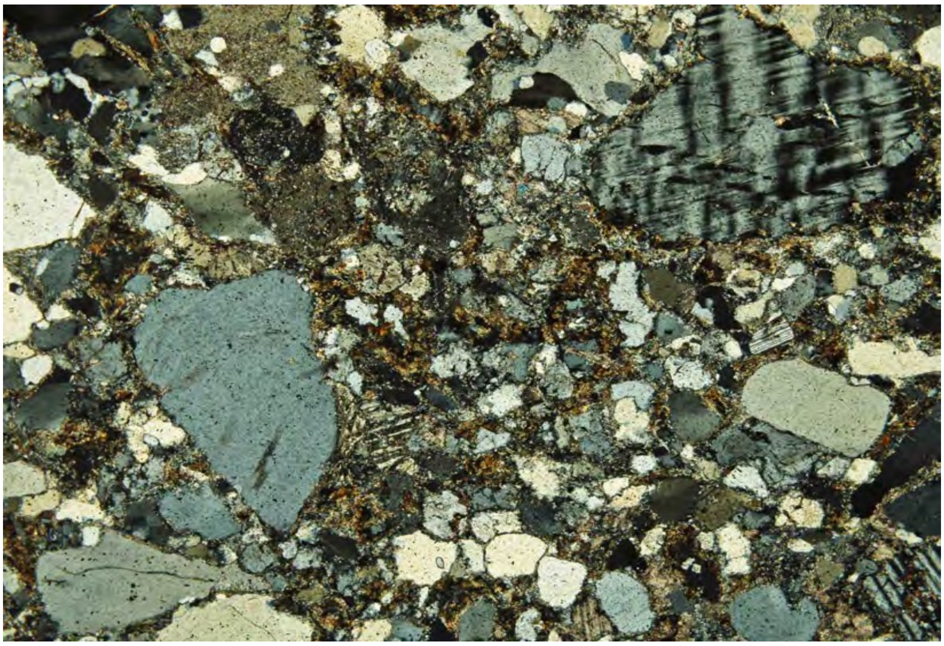


Photo 7: SAMPLE DY5ST1 (Transmitted light, crossed polarisers, Obj. x4, Image PC202562)

3.3.4.2 Sample: DY5ST3

Rock name of this sample is weakly *weathered, biotite-chlorite-sericite meta-arkose.* The sawn rock slice represents a coarse-grained sandy sediment composed of closely packed grey to white grains. A faint yellow-brown pervasive stain of weathering origin has affected the matrix, and becomes darker orange-brown closer to the active weathering surface of the sample. In thin section, this sample displays a well-preserved clastic sedimentary texture which was clast-supported and non-layered, modified by metamorphic recrystallisation and weak overprinting oxidation effects.

Clastic grains are abundant. Quartz forms angular crystal fragments ~0.2-1.5 mm in size, with average size ~0.8 mm, and displaying the characteristic lack of cleavage and low birefringence of this mineral. Plagioclase forms angular crystal fragments of similar size, but displaying the characteristic combined simple and multiple twinning of this mineral, with birefringence somewhat lower than for quartz. K-feldspar occurs in similar size, shape and abundance to plagioclase, but is distinguished by its combined albite and pericline twinning ('tartan' twinning) typical of microcline.

Muscovite occurs in trace amount as a single large platy crystal ~6 mm long, within a platy lithic fragment also containing microgranular plagioclase: this appears to represent a metamorphic shear seal derived from a felsic crystalline metamorphic source. Biotite occurs in significant amount as small, randomly oriented flakes ~20-100 µm long, forming fine-grained concentrations around and between the crystal fragments, in the matrix areas of the rock.The biotite displays a drab orange-brown staining of incipient weathering origin. In places, pleochroic drab green chlorite flakes are distinguished with difficulty because of the same weak oxidation overprint. Small colourless sericite flakes are intergrown with the biotite and chlorite flakes.

This sample was initially deposited as a partly-sorted, non-layered sandy sediment composed of abundant crystal fragments (plagioclase = K-feldspar = quartz >> muscovite) accompanied by minor fine-grained clay matrix. The angular shapes of the crystal fragments and preservation of the feldspars indicates that the clastic materials were transported only a short to moderate distance from the felsic crystalline source terrain. After burial, the sediment suffered low-grade regional metamorphism in the middle greenschist facies (biotite grade).

This generated new metamorphic biotite + minor chlorite + sericite. All of these minerals formed by recrystallisation of the groundmass clays. The primary clastic grains suffered little or no modification. Over a long period of time, uplift and erosion of the region elevated the rock body into a near-surface environment. Circulation of a small amount of meteoric water caused weak oxidation of the Fe-Mg-bearing phyllosilicate minerals, causing weak staining of the biotite and chlorite flakes. This is observed as a pervasive yellow-brown discolouration of the rock in hand-sample (Photo 8).

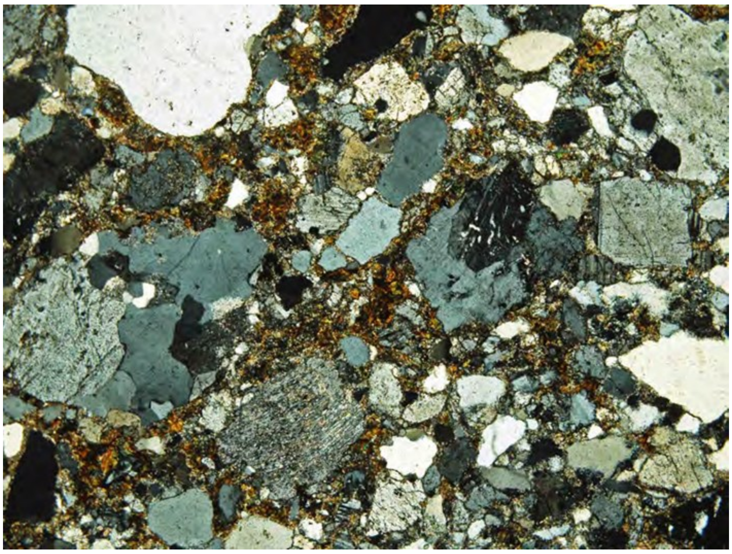


Photo 8: SAMPLE DY5ST3 (Transmitted light, crossed polarisers, Obj. x4, Image PC202566)

3.3.4.3 Sample: DY5ST1.1

Rock name of this sample is *weakly weathered, biotite-sericite-chlorite meta-arkose.* The sawn rock slab represents a fine-grained grey rock with faint yellow-brown discolouration from weak oxidation (weathering) effects. Minor larger pale grey to white grains up to ~5 mm in size are sparsely and irregularly scattered through the rock.

Biotite is present in significant amount. It forms small randomly oriented flakes that are pleochroic from tan brown to pale yellow, but most flakes have suffered dull yellow-brown oxidation staining which partly obscures the pleochroism. Minor small colourless sericite flakes are intergrown with the biotite, and chlorite forms uncommon pleochroic drab green flakes. All of the biotite, sericite and chlorite occur mostly in the matrix, concentrated between the clastic fragments. A trace amount of sericite has partly replaced some of the feldspar clasts, and biotite flakes from the matrix tend to project into the margins of the clastic grains. Rutile occurs in trace amount as small turbid granules which are concentrated in uncommon small aggregates ~0.2-0.4 mm in size. These are considered to be completely altered primary Fe-Ti oxide clastic grains (eg. ilmenite).

This sample was initially deposited as a clast-supported, non-layered sandy clastic sediment composed of abundant crystal fragments (K-feldspar = plagioclase > quartz >> Fe-Ti oxide) and minor lithic fragments (meta-granitoid), accompanied by minor fine-grained clay matrix. Arkose is an appropriate name for this type of sandy sediment. In response to low-grade regional metamorphism in the greenschist facies, the fine-grained matrix recrystallised to form new biotite + minor sericite + chlorite. The trace Fe-Ti oxide clastic grains were replaced by fine-grained dense rutile aggregates.

The clastic felsic grains mostly survived, although they suffered incipient replacement by biotite and sericite around their margins and locally within some fragments. The presence of biotite in the metamorphic assemblage confirms that P-T conditions reached into the middle greenschist facies. Good preservation of the primary clastic grain shapes suggests that a higher metamorphic grade (eg upper greenschist to amphibolite facies) was not reached. At a much later time, circulation of near-surface meteoric waters caused weak ferruginous oxidation staining of the biotite flakes (Photo 9).

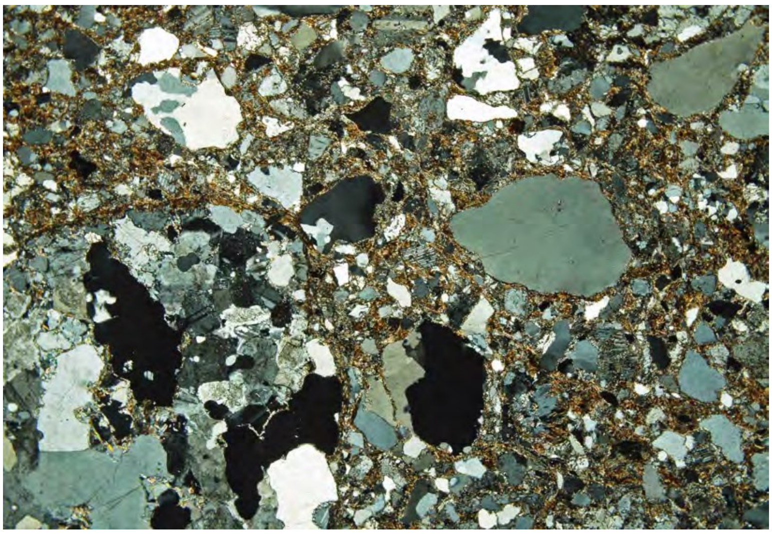


Photo 9: SAMPLE ST1.1DY5 (Transmitted light, crossed polarisers, Obj. x2.5, Image PC202567

3.3.4.4 Sample: DY6ST1

The sawn rock slice represents a massive crystalline rock in which large equant felsic grains (clear translucent grey quartz, white to grey feldspar) are locally distinguishable. Fine-grained dull greenish grey mineral (biotite) forms ragged small patches and trails distributed through the rock.

3.3.4.5 Sample: DY1ST5

Rock name of this sample is *high-intensity sericite altered meta-quartz sandstone.* The sawn rock slice represents a fine-grained massive pale pinkish cream rock, which contains abundant small translucent grey grains (quartz clasts). In thin section, this sample displays a partly preserved clastic sedimentary texture, modified by strong pervasive selective alteration effects. Quartz is moderately abundant.

It occurs as subrounded grains mostly ~0.4-2.0 mm in size, distributed uniformly through the rock. All are readily identified as relict primary clastic grains. Sericite is the other principal mineral. It forms tiny randomly oriented colourless flecks which form a dense massive mat enclosing the quartz grains. The sericite appears to have partly replaced margins of the quartz grains.

Rutile occurs in trace amount as tiny granules which are concentrated in small aggregates ~0.2-0.4 mm in size sparsely scattered through the rock. These are interpreted as completely altered primary Fe-Ti oxide clastic grains. This sample is considered to have initially formed as a clastic sediment broadly of sandstone type, composed of abundant subrounded quartz grains and trace Fe-Ti oxide grains.

Other primary components have been obscured by subsequent alteration effects. During a low-grade metamorphic event, the rock was infiltrated by a large volume of hydrothermal fluid, which caused severe replacement by sericite + trace rutile. The sericite formed by replacement of all components other than primary quartz, and rutile formed as replacements of accessory small Fe-Ti oxide clastic grains. (Photo 10)

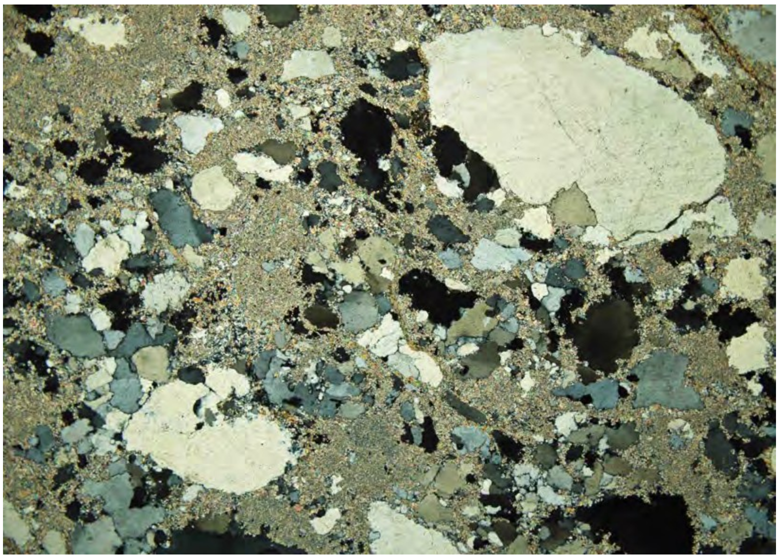


Photo 10: SAMPLE DY1ST5 (Transmitted light, crossed polarisers, Obj. x2.5, Image PC202571)

3.3.4.6 Sample: DY1ST4

Rock name of this sample is *weakly weathered, weakly foliated and high-intensity sericite altered meta- sandstone.* The sawn rock slice represents a fine-grained pale pinkish cream rock, in which diffuse cream patches are scattered through a pinkish matrix. Translucent grey quartz grains are distributed throughout the rock in significant amount. In thin section, this sample displays a partly preserved clastic sedimentary texture, modified by strong pervasive metamorphic alteration effects. Quartz is abundant. Most occurs as subrounded grains ~0.4-2.0 mm in size.

They are distributed throughout the rock, but in places were concentrated in particular subparallel bands (layers). In these bands, the quartz grains display suturing of their grain contacts. Sericite is the other principal mineral. It mostly occurs as small randomly oriented flakes ~20-100 μ m long. They form a dense mat which encloses the abundant quartz grains described above. Within the fine-grained sericite mat, some larger plates display a moderate preferred orientation, and therefore define a weak foliation through the rock. These larger flakes have suffered preferential yellow-brown ferruginous staining. Rutile occurs in trace amount as tiny deep yellow-brown granules which are concentrated in small aggregates sparsely scattered through the sericite mat. These possibly represent completely altered Fe-Ti oxide grains. This sample is considered to have been deposited initially as a clastic sediment of sandstone type. It contained abundant clastic quartz grains and trace Fe-Ti oxide grains, but other primary components have been obscured by later alteration. During a low-grade regional metamorphic event, the rock was infiltrated by hydrothermal fluid. This caused strong replacement by fine-grained dense mat of sericite and trace rutile. Development of a weak foliation as larger aligned flakes in the sericite mat indicates that the rock accepted mild strain during this event. Over a long period of time, uplift and erosion elevated the rock body into the near-surface environment. Circulation of a small amount of meteoric water through the rock generated minor goethite as staining of the larger foliated sericite flakes (Photo 11).

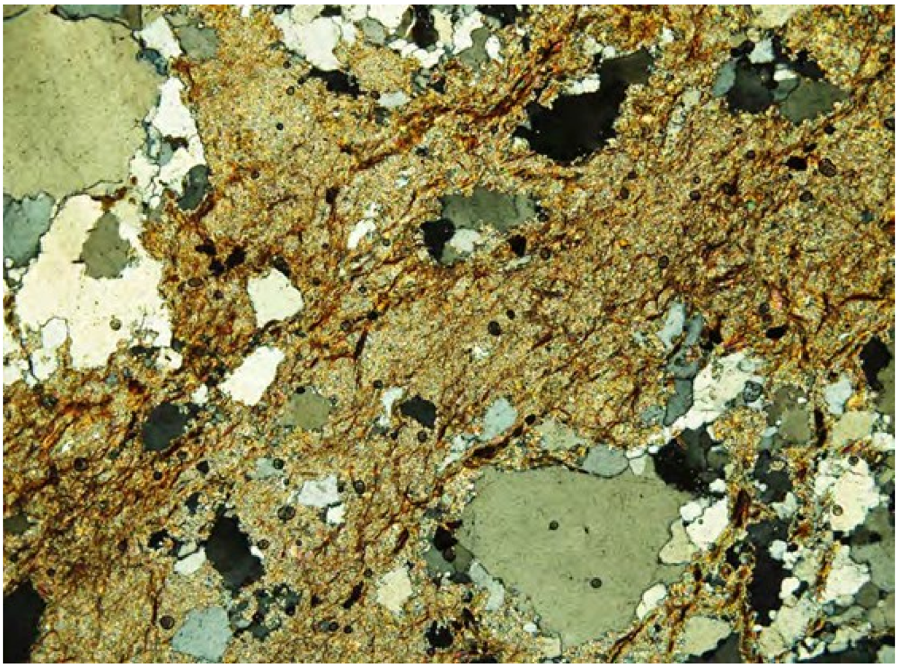


Photo 11: SAMPLE DY1ST5 (Transmitted light, crossed polarisers, Obj. x2.5, Image PC202571)

4. CONCLUSION

The Mnanka area comprises of the sequence of predominant rhyolitic volcanic rocks, chert and metasediments. These lithologies include plagioclase-quartz porphyritic, spherulitic, breccia textured and flow banded rhyolitic rocks interlayered with minor amounts of proximal volcanogenic and epiclastic sediments. All rocks suffered low to medium intensity hydrothermal alteration to phyllic and prophylitic assemblages. The average strike of the lithologies is between (070^o-090^o) dipping at an average angle between (70°-85°).

The mineralization is structural controlled due to hydrothermal intrusion and hosted in porphyritic andesite and rhyolite and occurs as gold nuggets and fine disseminations in quartz veins and sulphides. The region has suffered several cycles of deformation, which lead to the development of the East African Rift system (EARS) in Tertiary to Recent time. The latter is responsible for much of the present day geomorphology of the region. The rift-related extensional tectonics was accompanied by phonolitic lava flows which blanket much of the area.

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