MASTER OF SCIENCE IN GEOLOGY DEGREE RESEARCH PROJECT

Tectonic Evolution of Mui Basin and the Depositional Sequence of the Basin Sediments

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Registration Number: I56/65053/2010

A research project submitted to the Department of Geology in the Faculty of Science for the award of the degree of Masters of Science in Geology of University of Nairobi.

07th July, 2014

Declaration and Approval

Declaration by candidate

I certify that although I may have conferred with colleagues, and drawn upon some sources cited in this work, the content on this research project is my original work and has not been presented for a degree in any other institution for any award:

Sign…………………………………………..	Date……………….…………..….
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This research project has been submitted for examination with my approval as the official University Supervisor:

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Acknowledgement

I wish to express my deep regards to the teaching staff of the department of Geology, University of Nairobi. I also record my sincere to the Principal Secretary, Ministry of Energy and Petroleum of the Republic of Kenya, who availed the funds and the opportunity to me to undertake this study.

I gratefully acknowledge with profound thanks, thoughtful help, support, encouragement, supervision and guidance provided by Dr. E. W. Dindi and Mr. A. K. Waswa. Their close supervision throughout the period of writing this project report remains the practical experience of this project writing.

I owe my sincere gratitude and overwhelming appreciation to my family members for their perseverance, support and benevolence throughout the study period.

Finally, I sincere acknowledge the Almighty God.

Dedication

This project report is dedicated to my family – Kerubo, Ariri and Kemunto, professional colleagues and friends.

ABSTRACT

This study was conducted over the Mui Basin which is located in the south eastern parts of Kenya. It focuses on the tectonic evolution and depositional history of the basin. One of the motivating factors for the choice of this basin is the recently discovery of coal deposits reserves of well into millions of metric tons within the basin. In order to maximize on the costs of exploration, exploitation and development of such resources ones' understanding of the same is crucial.

In order to undertake the study of establishing the causes or events that are associated with Mui Basin the author analyzed the orientation trends of both veins and joints measured on the outcrops in the basement rocks of the periphery or/within the basin to establish the deformation forces that operated during their formation. A study to establish the depositional sequence of the Sediments into the basin was also conducted.

The geology of Mui Basin can be divided into metamorphosed sediments (meta-sediments) of the Precambrian Mozambique Belt, their intrusive rocks and the sediments of the Mui Basin. Meta-sediments include: biotite gneisses, migmatites, granitoid gneisses and marble, whereas intrusive are either quartzites or pegmatites. The Mui Basin sediments are varied and include: alluvial soils, mudstones, sandstone, clays, shale and or coal or lignite.

The study found that Mui Basin was formed as a result of tectonic movements. The Neoproterozoic rocks at the periphery exhibit a general regional structural of north – south trend. The main deformational stress that caused the formation of the basin was that of tensile stress; although both shear and composite stresses played a significant role. The Mui basin sediments are mainly those of autocyclic type which exhibit repetitive patterns of sandstones and mud rocks. Deposition of sediments into the basin appears to have taken place in two different environments since sandstones and mud rocks are known to be deposited in different environments. In its early stages the basin had shallow and seasonal marine/lake waters which lead to the deposition of calcareous sediments found throughout the basin. Evidence of the shallow marine environment is the presence of gypsum and limestone sediments.

It is recommended from the study of Mui sediments – that since there exists large deposits of economic sediments within the basin a comprehensive study should be carried out to ascertain their quantities and quality to allow for private investments. Some of these economic sediments are the lignite/coal deposits, clays, gypsum and limestone/lime clays and marble.

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CHAPTER 1 INTRODUCTION

1.1 Background of the study

The Mui Basin is bound by UTM coordinates (eastings of) 0406000 & 0418000 and (northings of) 9900000 & 9800000 respectively; partly covering the four map sheets of Migwani 151/1, Nuu 151/2, Kitui 151/3 and Mwitika 151/4. The metamorphic structures of Mui Basin are associated with the tectonic events of the Pre-Cambrian Era. The Mutito faults trends North-South and are known to have been formed during the Precambrian and reactivated during the Tertiary Period which is considered to have caused deposition of the Mui Sediments. According to Sanders (1954) the Mui Basin Sediments are evidently deposited from waters of a lake which owed its origin to tectonic movements. The area runs from Kyamatu in the south through Makongo hills to the southern parts of the Nuu hills. The western boundary runs from Kyengomo in the south through Inyuu Bridge, Miambani to slightly beyond Mikuyuni market in the north. Mui Basin lies within the Mozambique Belt on the eastern parts of Kenya – east of the Rift Valley.

1.2 Location and description of the Study Area

1.2.1 Location

The study area (Figure 1.1) is located in the eastern region of Kenya. The Mui basin covers an estimated area of about 600 square kilometres, sediment thickness ranges from about 50 metres to over 500 metres. The altitude of Mui Basin is between 600 and 900 metres above sea-level; the highest area is the periphery of Mutito Hills rising to over 1000 metres. The Mui Basin is in Kitui County of Kenya. Kitui County extends for roughly 200 kilometres from north to south and about 120 kilometres from east to west.

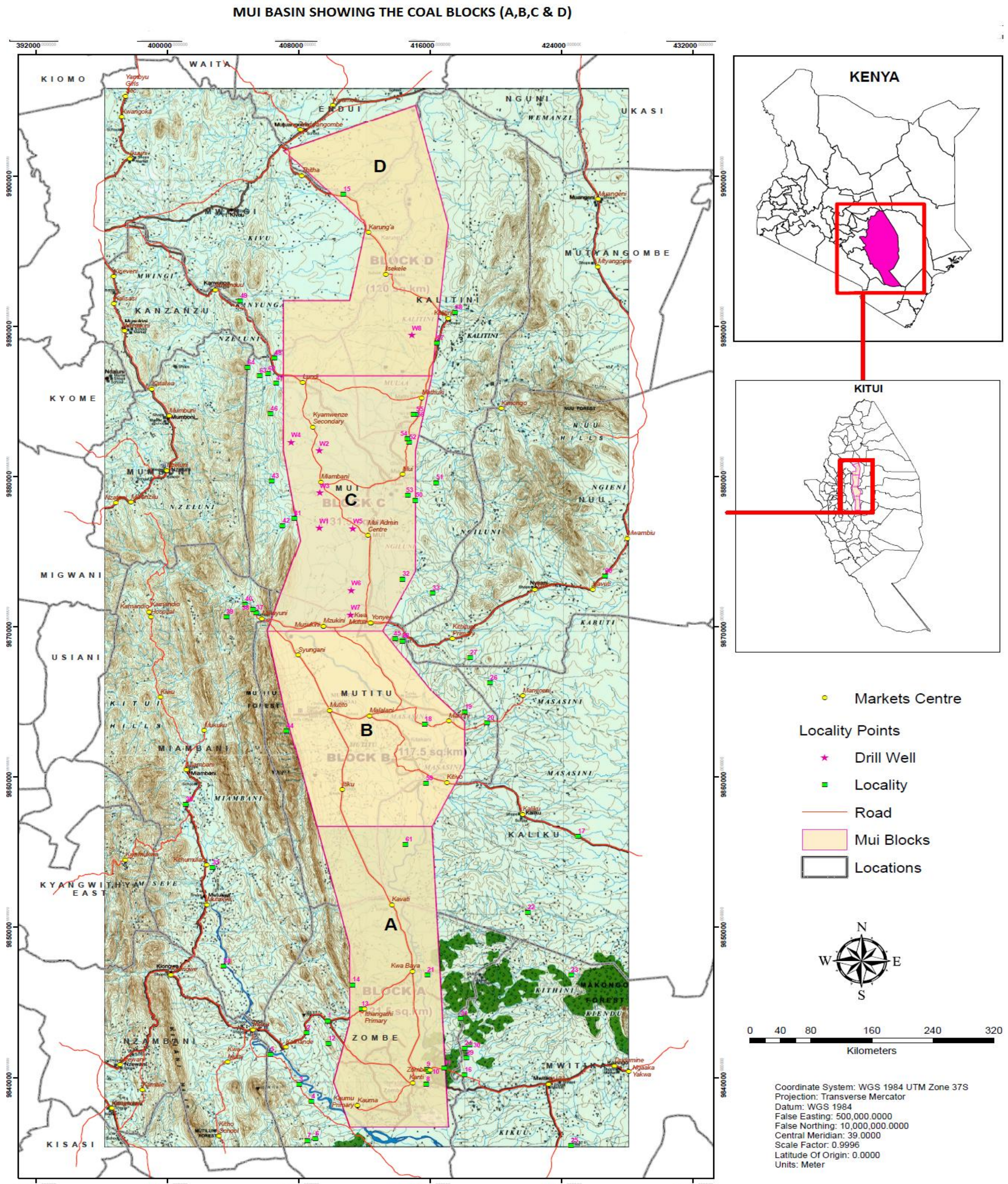


Figure 1.1 Map showing the study area

1.2.2 Climate and Rainfall

Mui Basin climate is semi-arid; it receives roughly between 710 mm and 760 mm of rainfall annually. It has two rainy seasons (one long around March-May and one short November-February). The average rainfall for high areas around Mutito Ranges is between 760 mm and 1200 mm annually. The short rains are more reliable while long rains are usually unreliable. Mui Basin experiences high temperatures throughout the year, ranging from 16°C to 34°C. The hottest months are between June-September and January-February; with the mean annual temperature of about 28°C. Due to limited rainfall received, surface water sources are very scarce. The major sources of surface water are seasonal rivers that form during the rainy seasons and dry up immediately after the rains. The area is therefore characterized by hot and dry climate making agriculture rather expensive. The climate in the area is influenced by the topography – cooler climate near hills and along rivers whereas hotter climate is found in fairly flat areas. Rainfall appears to be influenced by Mutito Ranges.

1.2.3 Vegetation (flora) and Fauna

Except for the forested ranges, the natural vegetation for most of the area is that of dry bush and thickets composed mainly of acacia to trees shrubs similar to those found in similar semi-arid areas of Kenya. These bushes, however, are almost impassible during the rainy season. The indigenous vegetation is characterized by trees that are drought resistant whose distribution is influenced by rainfall amounts, geology and soils, and topography (which in turn control the availability of water during the dry seasons).

1.2.4 Accessibility, Communication and Infrastructure

The Mui Basin can be accessed from Nairobi through the Nairobi – Mwingi – Garissa Highway which is all bitumen road and therefore all-weather. On reaching Mwingi town (which is about 160 kilometres northeast of Nairobi) one can access the study area either through Lundi-Miambani road which is about 3 Kilometres off the Highway from the township or Karunga-Kalitini road a further 10 Kilometres off the Highway (both roads to the left from Mwingi Town). The roads are generally good in dry weather but become impassible in rainy seasons. The other alternative route from Nairobi is through Kitui town (about 170 kilometres southeast of Nairobi) through the Nairobi-Kitui road which is also all bitumen roads and hence all-weather. From Kitui town, one accesses Mui Basin through Kitui-Zombe road which is murramed and is generally good during dry weather, but becomes impassible in rainy season. The study area is well served with electric power, mobile services providers for example Safaricom, Airtel and Yu services.

1.2.5 Population, land use and economic activities

The study area is sparsely populated and the distribution depends mainly on the climatic and economic conditions of a particular area and tends to be denser in trading Centre and near major rivers. The main land use activities in the area are in agriculture or livestock keeping; the local people practice rural subsistence farming on their small land holdings. They cultivate maize, millet, cassava, and cowpeas as stable food and pawpaw, bananas, beans, pigeon, kales, cabbages as either fruits or vegetables. Livestock is mainly cattle and goats which is the main source of in-come for families educating their children. Earth bricks making by the youth is also a source of in-come and are used for construction of permanent houses by the locals. The local population use crop/livestock system as a way to spread the risk and ensure survival. Traditional land use system is well adapted to the difficult climate and physical environment. Local County administration is headquartered at Kitui town whereas District Commissioners are in Mathuki and Zombe District headquarters respectively. The local people are the Akamba and the language and culture are those of the Akamba people.

1.2.6 Economic rock deposits in the area

The Mui Basin is endowed with many construction materials and economic minerals deposits, construction materials include: sands used in building and construction industry, quartzites also used in the same industry as ballast, gneisses used in road construction as in-fills, clays for brick making and a good source of raw material in ceramic industry, economic minerals include lateritic soils which can be a good source of bauxites (for Aluminum) and magnetite, hematite or limonite (for iron) or lateritic soils (for road construction), some marble and gypsum (for cement or ceramic industries).

1.2.7 Drainage

Most rivers in the study area are semi-permanent or seasonal and become flooded during heavy rainfall but turn into dry sand courses for most parts of the year when there is no rains. The rivers contain water sandy beds during the dry seasons. The major rivers are: the Mui, Enziu, and Ikoo.

1.3 Statement of the Problem

There are two (2) main problems that require solutions in this research project. They are stated as follows:

i) The Mui Basin was formed due to the tectonic movements. It was formed during the Paleozoic Era. Determination of the deformation stresses that caused them is therefore of paramount importance in understanding the underlying tectonic forces that caused the formation of the basin.

ii) The depositional sequence of the basin sediments is at the moment lacking for the strata/sediments of the basin. A detailed examination of the cores recovered from the drilled appraisal/exploratory wells is sought to help understand and solve the deposition history/sequence of the basin sediments (including economic sediments e.g. coal bearing beds and others found throughout the basin).

1.4 Objectives of the study

i) To determine the orientation trends of both veins and joints measured from outcrops in the Neoproterozoic Mozambique Belt rocks of the periphery of the Mui Basin in order to establish the deformation forces that were operational during their formation

ii) To develop the tectonic history of Mui Basin and establish the depositional sequence of the sediments including the coal bearing beds.

1.5 Significance of the study

The analysis of the veins and joints orientation trends will determine the deformation stresses and strains that lead to the evolution of the Mui Basin. Determination of the deformation forces and strains that lead to the formation of the Mui Basin will greatly increase to insight knowledge to similar basins. By analyzing the orientation trends of both veins and joints measured from outcrops within or at the periphery of the basin using modern geological software will enable the author formulate the evolution history of the basin.

Establishing the sequence of deposition of the sediments in the basin will enable the correlation of the various strata include the coal bearing beds. The correlation of the strata will establish whether the coal bearing beds are extensive or just limited. The information on the lateral extent of the strata will be of use during the mining of coal.

CHAPTER 2 LITERATURE REVIEW AND GEOLOGICAL SETTING

2.1 Literature Review

A reasonable geological work has been done on the Area trying to explain the complexity of the structural geology and history on this part of Mozambique Belt. Among the earliest documented work was that of Sanders who stated that the earliest geological reference of Kitui County were those of Dr. Rev J.L. Kraph who entered the area in 1949 and again in 1951. In this work he mentions the abundance of iron ore deposits of high quality in the area. During the reconnaissance survey and mapping by Schoeman (1951) in his report – "A geological reconnaissance of the area west of Kitui Township" he describes the rocks in the area as having undergone high-grade metamorphism. He did petrology and petrography of the Basement System in the area where he describes them as composed of the high grade metamorphic rocks such as psammitic, pelitic or semi-pelitic sediments, gneisses and granulites. Schoeman also noted that migmatites and granitoid gneisses occupy a wide area where they grade into unaffected metamorphic rocks.

Thompson (1948) carried out resistivity tests around Mui market in an attempt to choose a well site for coal exploration. Hamilton (1950), accompanied by Thompson investigated lignite prospect at the Mui Basin. In 1963, Baker did the geology of Endau area which is to the south eastern side of Mui Basin and noted the folding in almost North-South trend. He however, could not interpret them as most of the area lack Neoproterozoic Mozambique Belt rocks exposures; the same folding trend was commonly encountered in the study area.

Sanders (1954) in his report of the Geology of the Kitui area also reported of exposed rocks as those consisting of almost entirely folded Basement System gneisses and migmatites of Archean Age (between 4000-2500 million years ago) that is before the Proterozoic Eons, which include metamorphosed sedimentary rocks comprising crystalline limestone, garnet and sillimanite gneisses. Sanders took considerable amount of the time mapping the prospect and examining of drill cores of lignite discovered by a prospector in a well at Mui; which is now abundant in the area. Sanders describe Mui Basin sediments as evidently deposited from waters of a lake which owed its origin to tectonic movements. He also describes Kankar limestone in the Mui Basin as produced by alterations of powerful leaching during periods of seasonal rainfall, with desiccation and upward capillary migration of solutions during the dry season, which is attended by the deposition of colloidal hydroxides of Aluminum and Iron, and also Carbonates of Calcium, Magnesium and Iron. Kunkur limestone is formed due to the brining to the surfaces of the impure limestone (Opiyo, 1981).

Dodson (1955) in his report on the Geology of the North Kitui area describes the Basement System as consisting of a vast succession of heterogeneous Para-gneisses, quartzites, crystalline limestone, psammitic and pelitic rocks. He noted that the Basement System in the area included gneisses of semi-pelitic and pelitic composition which could have undergone metasomatism which he considered as magmatitic.

Crowther (1957) in his report on the Geology of Mwingi area, north of Kitui noted that the area is mainly made up of very highly metamorphosed and granitized sedimentary rocks of the Basement System of East Africa; which he categorized as calcareous, semi calcareous, pelitic, semi pelitic and psammitic rocks. He however, did not mention or infer in his report the coal deposits of the Mui Basin.

Saggerson (1957) when he mapped the geology of South Kitui area did note the continuation of migmatites and granitoid gneisses along the axis of the Kitui anticline. He considered the granitization as being in situ and as being contributed by magmatic fluids. Saggerson attributed the high microcline content in the area as being an indication of high degree of alkali metasomatic exchange.

Granitoid gneisses mainly outcrop at the raised Ranges and small hills of the area. These preferential occurrences at the hilltops have been attributed by many authors (Mathu, 1980; Mutunguti, 2001) due to their exceptional high resistance to weathering processes. Mathu (1980) in his thesis – “Polymetarmorphic Textures and Structures of the Migwani area of Kitui did deduce that the migmatites and granitoid gneisses commonly found in the area as representing portions of highly granitized core. He described the multiple foliation, cataclasis of distinctive textures as a result of events of regional metamorphism which explains the polymetamorphosed rocks and structures found in the area.

Opiyo (1981) in his thesis- "The Geology of Ishiara area" described that all rocks of the Mozambique Belt have undergone some form of deformation and cataclasis (a process of progressive fracturing and comminution of the existing rock to form a cataclastic metamorphic rock); however the cataclasis textures are rarely visible in the hand specimens.

Nyamai (1995) did a more comprehensive study of the petrography and geochemistry of the Mozambique Belt rocks of the Matuu area, not very far from the study area, where he described the main rocks as consisting of plagioclase, clinopyroxene, orthopyroxene, biotite and hornblende with secondary apatite, sphene and epidote. Further geological work by Nyamai (1999) in the Matuu – Masinga area revealed that the rocks in the area vary from medium to high grade gneisses and granulites, diorites and gabbro. He noted that the rocks have suffered a complexity of structural deformation which includes several shear zones formed in high grade metamorphism and at various foliation surfaces. In 2003 Nyamai *et al,* while working on the eastern segment of the Mozambique Belt noted that the metamorphic rocks in the area contains mainly mafic and ultra-mafic rocks whose ophiolitic (a metamorphic rock texture thought to be formed by uplift of oceanic crust and mantle into the continental crust) texture has survived a high grade metamorphism and great deformation.

2.2 Geological setting

2.2.1 Introduction

The Mui Basin lies within the Mozambique Belt of the Kenya-Tanganyika Province of the Precambrian rocks with a general North-South trending geological structures. The periphery of Mui Basin is largely covered by Precambrian (540 Ma before present and older) crystalline rocks, which mainly consists of gneisses, migmatites, with minor Intrusives. These Precambrian rocks are generally referred to as "Neoproterozoic Mozambique Belt rocks" and generally show a regional structural North-South trend of foliation. Originally this Neoproterozoic Mozambique Belt consisted of sedimentary rocks. These rocks are metamorphosed. Hills at the periphery are mostly formed by granitoid gneisses, which are more resistant to erosion. This regional setting is in agreement with the geology of the Mozambique belt. More recently aged Quaternary and Tertiary deposits overlay this basement system, for example on hill slopes and in the riverbed.

2.2.2 Meta-sediments

The meta-sediments of Mui Basin and its periphery include: granitoid gneisses, biotite gneisses and migmatites, and these rocks in many places occur in association with some marbles and intrusive rocks (mainly quartzites and pegmatites) as is shown in the map showing the spatial distribution of the lithology of the basin and the periphery in figure 2.1 below.

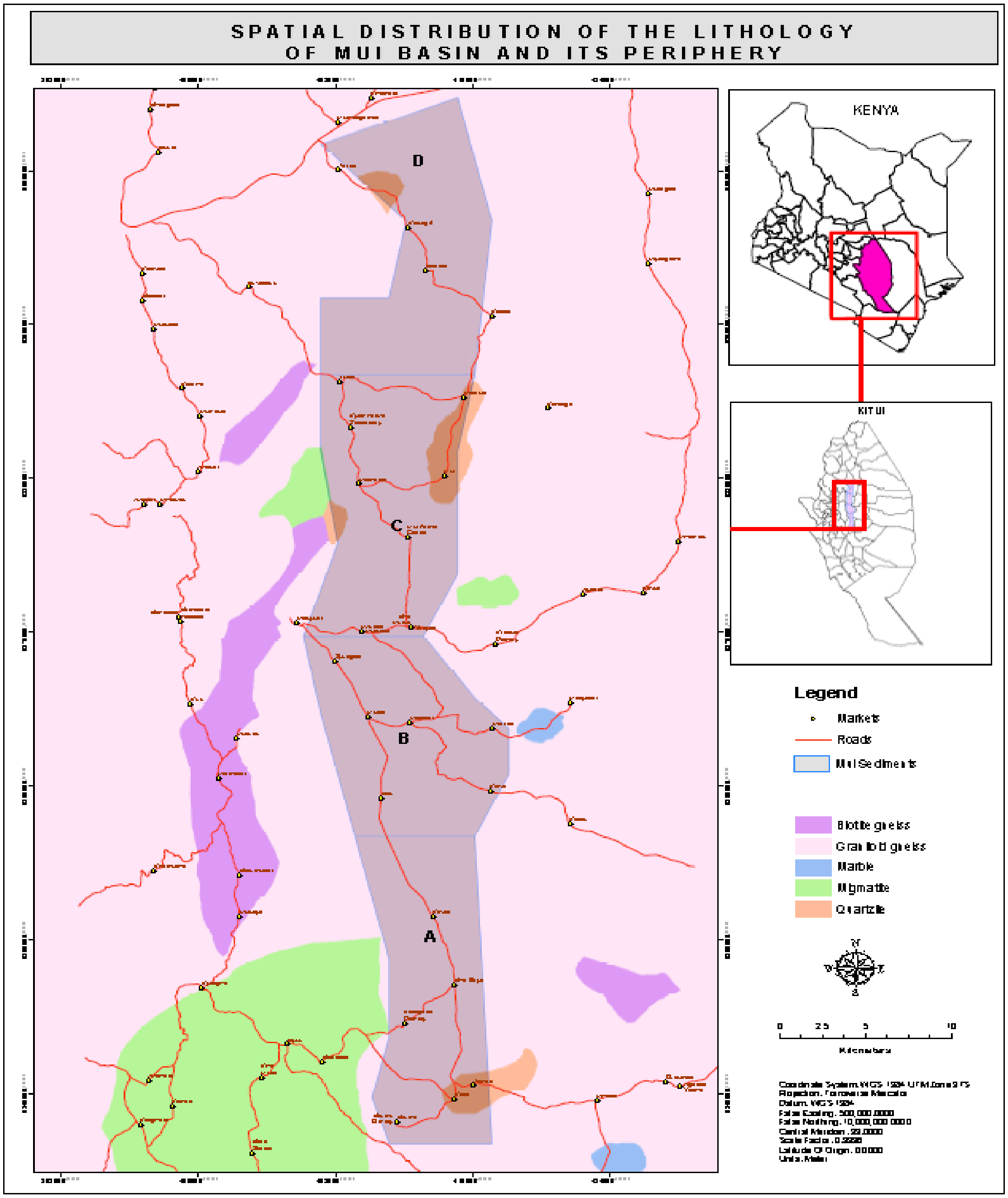


Figure 2.1 The spatial distribution of the lithological units of the Mui Basin and its periphery

2.2.2.1 Biotite gneisses

Biotite gneiss is granitic gneiss in which the dominant mafic mineral is biotite. They consists mainly of alternating layers of foliated and granoblastic textured materials of alternating light and dark coloured bands that shows that foliations were mainly restricted to the darker bands. This is thought to be the product of high-grade metamorphism by Coch and Ludman (1991) who considers these layering to be as a result of metamorphic ion migration rather than relic sedimentary bedding. The general trend of these outcrops is in north-south whose variation ranges from about -20º to +20º in the north direction. The physical characteristics of the biotite gneisses in the area range from coarsely crystalline with some veinlets of pegmatite whose colour also ranges from yellowish grey to pinkish grey. Biotite gneisses may also be found interbedded with coarse to fine crystalline marble or it grades into migmatites or granitoid gneisses in some localities.

2.2.2.2 Migmatites

These are high-grade metamorphic rocks that form under extreme temperatures conditions during prograde metamorphism, where partial melting occurs in pre-existing rocks. Migmatites are not crystallized from a totally molten material and are composed of new material crystallized from incipient melting (leucosome) and old material that resisted melting (mesosome). Migmatites in the study area are found as composite, heterogeous rock consisting of mafic rocks mingled with felsic rocks that form crisscross veins and irregular pods. Mehnert (1968) defines migmatites as mega-scopically composite rocks consisting of two or more petro graphically different rocks; one being the country rock in a more or less metamorphic stage, the other being the pegmatite, aplitic, granitic or generally plutonic in appearance. Migmatites in Mui area occur within extremely deformed rocks. According to McGeary and Plummer (1992) if temperatures are raised high enough, partial melting of rocks may take place and magma is sweated out into layers within the foliation planes of a solid rock. The light coloured magma being more mobile is thus more favoured as sweats within the pre-existing rocks. After solidification of the injected magma, the rock becomes migmatites. Migmatites often display obliterated foliations due to the fused edges of the partial melt layers. Migmatites formations (e.g. at locality 12 – Kathande area, west of Block A) are lighter than biotite gneisses or the biotite rich zones showing some foliation tendencies yet in some parts tend to exhibit schistose structures (not bands or stripes but more like flakes e.g. in mica or other platy minerals).

2.2.2.3 Granitoid gneiss (granitic gneiss)

Granitoid gneiss is a high-grade regional metamorphic rock formed from pre-existing formations that were originally igneous or sedimentary rocks. Granitoid gneiss mainly outcrops at the raised Ranges and small hills of the area. These preferential occurrences at the hilltops have been attributed by many authors (Mathu, 1980; Mutunguti, 2001) due to their exceptional high resistance to weathering processes. The granitization process is thought to have resulted from a combined effect of subsurface melting of deeply buried meta-sediments. The high temperatures and pressure attained in the subsurface, makes the rock to become plastic and buoyant (as a result of decrease in density due to addition of volatile gases and depletion of the denser minerals) and gets intruded into the overlying rocks and finally into the surface via existing joints parallel to the foliation. Once on the surface or near surface, granitoid crystallize in a massive range of hills and/or mountains, forming rocks that are relatively harder and more resistant to weathering and erosion.

2.2.2.4 Marble

Marble consists of re-crystallized calcite (from limestone) or dolomite (from dolomite rock). Marble can also be defined as granular limestone or dolomite that has been re-crystallized under the influence of heat, pressure, and aqueous solutions. Marble often occur interbedded with such metamorphic rocks as mica schists, phyllite, gneisses, and granites. The marble ranges from white to black in colour, depending on the other mineral impurities. Like other metamorphic rocks, marble has no fossil, and any layering that appears in it probably does not correspond to the original bedding of the precursor limestone. Marble has a uniform texture (non-foliated). Marble outcrops are prominently observed at two areas namely: south of Mwitika shopping centre (locality 25) and south-west of Manyaoeni shopping centre (locality 20 – fig 3.1). The marble found at the study area occurred either as a vein fills or as crystalline calcite that appear to be fused with biotite gneiss or granitoid gneiss. At these contacts the marble is fine grained and is tainted pinkish or brownish in colour.

The marble outcrops in the area occur forming long strips that are generally trending north or 7^0 to 15^0 to the northwest. This apparent north trend is similar or parallel to the general strike of granitic meta-sediments. The similarity implies that the re-crystallizing fluids were probably injected into the weaker upper subsurface foliations of the biotite gneisses. Although the exact place of origin of these fluids cannot be accurately be ascertained, they are thought to originate from the high-pressured zone below, where a combined effect of subsurface melting of deeply buried limestone that formed part of the sediments that were metamorphosed from the effect of high temperatures and pressures. Where marble outcrops it occurs fused with the biotite gneiss which implies that the re-crystallizing fluids were simultaneously precipitated and crystallized after metamorphism. The crystallizing fluids appear to have been injected into the weaker zones of the banded biotite gneiss where the calcite fluids circulated within the bands and at intervals pushing the foliations far apart and creating pure marble outcrops. The pinkish colouration in marbles closer to the biotite gneiss is considered to be due to the introduction into their lattice (crystalline) structure of higher percentage of iron ions from biotite through adsorption.

2.2.2.5 Quartzites

A quartzite is a hard, non-foliated metamorphic rock which was originally sandstone. Sandstone is converted into quartzite through heating and pressure usually related to tectonic compression within orogenic belts. When sandstone is metamorphosed to quartzite, individual quartz grains re-crystallize along with former cementing material to form interlocking mosaic quartz crystals erasing all or most of sedimentary structures. Myron (2003) describes quartzite as forming by re-crystallization of relatively pure quartz sandstone. Quartzites in the study area occur as intrusive veins of various sizes in biotite gneisses, granitoid gneisses, or migmatites. They occur as pure white, pinkish brown or reddish when it occurs in the vicinity of lateritic formations probably due to addition of iron oxides from the laterites. In granitoid gneisses, quartzites are confined in areas that show intermediate degree of granitization for example closer to migmatites. Quartzites also occur as basal sediments in the Mui Basin as is exhibited at locality 52 (between Mui market and Mathuki shopping centre – figure 3.1) where huge boulders of quartzitic conglomerates or cobbles some measuring about 130 cm in diameter were found; other areas where these basal sediments were around the Masasini Area. These quartzitic conglomerates or cobbles are of specific orientation which is generally conformable to that of the main outcrop.

Two types of quartzite veins were observed that is those that are conformable type and the discordant ones. The conformable veins appear to have been injected within the foliations of former rocks and are therefore conformable with the general strike and dip of the former rocks. The discordant type cut across the strike of former rocks and in some places cutting across the conformable veins. The discordant veins are therefore considered to be as result of later fluid re-injection or rejuvenation. The discordant veins are of various sizes and were rare (only encountered south of Kaumu Primary School – locality 7 (fig 3.1) of Kathande area) where the whole ridge is composed of white crystalline quartzite – almost covering an area of 1Km^2). Although limited in occurrence, the locals use the quartzite for building and construction industry as ballast.

2.2.2.6 Pegmatites

Pegmatites are very crystalline, intrusive igneous rocks or almost wholly crystalline igneous rock of interlocking crystals of various sizes. Pegmatites are composed mostly of quartz, feldspar and mica (in granite) or rarely composed of intermediate or mafic minerals (like amphibole, Ca-plagioclase or pyroxene). Most bodies of pegmatites are tabular, cigar-shaped, or irregular. Pegmatites in the study area are confined to highly granitized meta-sediments and are generally very coarse grained.

Pegmatites invade almost all rocks of the Basement System although they are best seen in zones of granitization and migmatization at the periphery of the study area, forming boudins in the conformable pegmatites. Pegmatites are very crystalline rocks composed of interlocking crystals composed mainly of quartz, feldspar and mica. Some of the pegmatites are concordant to the general foliation; however, the majority of them are discordant and are observed to cut across the country rock. Myron (2003) describes pegmatites as unusually coarse grained rocks mainly of magmatic origin. The pegmatites have been formed as a result of late magmatism into the country rock filling pre-existing joints. Morrison (1984) also describes pegmatites as representing the last portion of magma crystallization that have been formed from igneous solutions, that is, from solutions which remained after a large part of the parent magma has crystallized. On solidification this fluid became the pegmatite veins and masses that are found mostly in the marginal regions of many deep – seated igneous bodies. The pegmatite veins of various types found at the periphery of the Mui Basin implies that the area has been subjected to intense tectonic history where the rocks underwent various compression and extensional stresses under intense heating periods. These veins either conform to the biotite gneiss strike or cut across it indicating that several forces have been in play over the geological time.

2.2.3 Characteristics and types of joints and veins as they have been described by various authors

Joints are fractures in a solid rock where displacement associated with the opening of the said fracture is greater than the displacement due to lateral movement in the plane of the fracture be it up, down or sideways. Joints are fractures in rocks along which no appreciable displacement has occurred relative to the fracture surface. Joints occur generally having a regular spacing that is related to either the mechanical properties of the individual rock or the thickness of the layer involved. Joints occur in sets within which, individual joints are either parallel or sub-parallel to each other. Twiss and Moores (1992), defines joints as surfaces along which rocks or minerals have broken; they are therefore surfaces across which the material has lost cohesion. Pollard and Aydin (1988) describe joints as two parallel surfaces that meet at the joint front, these surfaces are approximately planar and the relative displacement of originally adjacent points across the fractures is small compared to the fracture length. According to Hamblin (1994), joints form in response to compression, tension and shearing forces. Joints are fractures along which there has been no appreciable displacement parallel to the fracture and only slightly movement normal to the fracture plane.

Joints form in solid, hard rock that is stretched such that its brittle strength is exceeded (the point at which it breaks). When this happens the rock fractures in a plane that is *parallel* to the *maximum principal stress* and *perpendicular* to the minimum principal stress (the direction in which the rock is being stretched). Joints are broadly classified or grouped into two categories, namely those that result from tectonic movement (tectonic joints) which are either tensional or shear joints or those which are not as result of tectonic movement (non-tectonic joints). This study was mainly concern with the former. Tectonic joints are formed during deformation episodes whenever the differential stress is high enough to induce failure in the rock, irrespective of the tectonic regime. Their orientation usually shows a direct relationship to folding and thrusting caused by tectonic movements. Tectonic joints are expressions of residual stress remaining in the rock long after the deformation has ceased. Tensional tectonic joints have a rough irregular surface, whereas the shear joints tend to be smooth. Studies have shown that some joints are formed in response to stresses that are regional in nature. Regional mapping has also revealed that joints or joints sets are also related to other geological structures such as major faults or broad upwarps of the crust. Joints orientations therefore are closely related to the direction of maximum stress that led to their formation. Field geologists map joints or joint sets because their orientations are often used to re-construct the orientation of the direction of stress that was operating on the bedrock at the time they were forming. Laing (1991) considers rocks that exhibit considerable plastic deformation to form very few joints whereas those that is brittle to be prone to jointing.

By analysing the orientation of joints one is able to relate them to the direction of maximum stress acting on the rocks that forms them. For field geologist joints and joint sets are mapped because their orientation can be used to re-construct the orientation of the directed stress that was operating on the country rock at the time these joints were forming. Tectonic joints analysis gives the tectonic history of an area because they give information on stress orientation at the time of formation; ii) unloading joints (release joints) – formed either due to uplift or erosion thus reducing compressive load; iii) cooling joints – formed via cooling of hot rock masses, particularly lava. The joints in Mui Basin and it periphery are predominantly those due to tectonic movements.According to Renton (1994), single joint set is caused by tensional forces hence are called tensional joints. He explained that these forces normally produce joint set that is perpendicular to the direction of stress. He further points out that those joints occurring as two equally well-developed joint sets, intersect at an angle of 80^0 are shear joints, they occur in migmatites where they occur cutting across the older ones in an oblique angles. The third group, the composite joint sets, consists of a combination of the two.

Veins are tabular rock body of material within a country rock that results from cooling and crystallization of a molten rock (e.g. magma) filling joint fractures or fault planes. Veins are filled joints or shear fractures and the filling material range from quartz and feldspars, to calcite and/or dolomite. The other definition of a vein being a distinct sheet like body of crystallized minerals within a rock, which forms when mineral constituents carried by an aqueous solution within the rock mass are deposited through precipitation. Veins are masses of rock which occupy fissures in rocks and originate in different ways either in igneous rocks, in sedimentary rocks or of minerals deposited by water or gases. Veins are essentially irregular, discontinuous and largely of limited extent in distance.

2.2.4 Geological Structures of the Mui Basin and its periphery

This section on structural geology attempts to describe geological structures encountered in the study area. George (1996) describes geological structures as consisting of: - geometric arrangement of planes, lines, surfaces, rock bodies in their form and the orientation of this arrangement reflect the interaction between the deforming forces and the pre-existing rock body. Park (1997) further elaborates that structural geology signifies that something has been produced by deformation; that is by action of forces on and within the earth's crust. The geological structures found in the area include: - those found in the metamorphic rocks of the area, those in the volcanic intrusions of the area, and those in the sedimentary deposits of the basin which results from geological processes that occur either within the ground or on the surface of the earth. Most of the structures occurring on the surface of the rocks in the study area were caused by physical interaction between the rocks and the environmental agents such as heat variations or water movements. The structures occurring within (like joints or veins) the rocks have been caused by the tectonic movements which appear to be occurring frequently in the area resulting to the numerous joints and veins of various ages. The joints at peripheral Neoproterozoic Mozambique belt rocks of Mui basin varies in number from one rock type to the other. The joints numbers increase from migmatites through pegmatites to quartzites, biotite gneisses to the granitoid gneisses. The veins found in the Mui area are mostly comprised of quartz and/or pegmatite, sometimes found occurring together with joints on some outcrops. Since veins represent molten rock that was injected into former joints their measurements do represent the orientation of former joints prior to them being filled. The variation of veins orientation shows the variation of the orientation of the deformation stresses over time.

Faults are also some of the structures which were observed in the study area. The main faults are those found in the Mutito Ranges, details of the nature and characteristics of faults in the study area is found in chapter 4 subs – title 4.1.1. The metamorphic structures of Mui Basin are associated with the tectonic events of the Pre-Cambrian Era.

The Mui Sediments within the study area exhibited graded bedding which is characterized by systematic change in grain size from the base of the bed to the top, with coarser sediments at the base grading upwards progressively into finer grains. Ngecu (1991) described graded bedding as resulting from successive increment of material of which coarser sediments precedes the finer ones.

2.2.5 The Mui Basin Sediments

Sanders (1954) describe Mui Basin sediments as having been deposited from waters of a lake which owed its origin to tectonic movements. The Mui Basin sediments include: i) Sandstones, ii) basal Conglomerates, iii) Mudstones and Shales, iv) Limestone and Gypsum, v) Peat, lignite and Coal, vi) Clays, vii) Recent Sediments and lateritic soils.

2.2.5.1 Sandstones

Sandstones (arenites) are clastic sedimentary rocks composed mainly of sand-sized minerals or rock grains of quartz and /or feldspar. Sandstones usually allow percolation of water and other fluids.

The sandstones of Mui Basin are the most predominant sediments of the study area and are associated with shales, conglomerates or siltstones with variable colour. The Mui Basin sandstones were formed in various environments and are characterized by grains between 0.1mm to 2.0mm. When the grain size is less than 0.1mm then we have either shales or siltstone and for very large grains then we have conglomerates. The individual grains of the Mui Basin sandstones are cemented together by calcite, silica (quartz), clays or gypsum.

The mineral cementing the sandstones influences their durability, colour, porosity or even their usefulness. The sandstone formations in Mui Basin ranges from fairly consolidated to highly consolidated and compact. Likewise the grain sizes range from coarse to fine grained and well sorted to poorly sorted.

2.2.5.2 Conglomerates

Conglomerates rocks are clastic sedimentary rocks with the largest grain size. Conglomerates in Mui Basin are found mainly along rivers or at the base of the sediments of the basin as rounded or sub-rounded pieces of rocks. These sediments are characterized by poor bedding. The Mui conglomerates are well sorted pebbles that were derived from the basic intrusive rocks and/or Precambrian rocks.

2.2.5.3 Limestone and Gypsum

Kankar limestone occurs in the open field in the Mui Basin as deposits along rivers or where it was deposited in former water pods (inland basins) when they dried. They also form as veins in a few outcrops and occur at the surface of the weathered granitized sediments. This is attributed to the lime rich feldspars constituting the mineral composition of country rock.

Gypsum at the Mui Basin, although not as abundant and well developed as that found elsewhere such as that from Isinya area or that from Garissa, gypsum is found in small quantities at the Basin. Gypsum occurs as an evaporite deposited either from lake or sea water, as well as in hot springs from volcanic vapours, and sulphate solutions in veins. The uses of gypsum are many and varied but that of Mui (which is small scale) is in cement manufacturing.

2.2.5.4 Mudstones and shale

Shale is a fine-grained, clastic sedimentary rock composed of mud mixed with flakes of clay minerals and is characterized by breaks along thin laminae or parallel layering or bedding called fissility. Shales are the most common sedimentary rocks. Shales are composed of variable amount of clay minerals and quartz grains and it’s predominate colour is grey. The Mui Basin shales ranges in colour from reddish brown to green to even yellowish brown depending on content of ferric oxides or micaceous minerals it contains.

2.2.5.5 Lateritic soils

Laterites are soils rich in Iron and Aluminium, formed in hot and wet tropical areas, and are rusting-red because of iron oxides. They are reddish to blackish brown superficial deposits formed by leaching of silica enriched with Aluminium and Iron oxides which develops under intense and long periods of weathering of the underlying country rock. In Mui Basin the stable sites for leaching and slow water infiltration and accumulation include the flat plains and along erosion gullies. Laterites are associated with iron ore, bauxite (Aluminium ore) and lateritic nickel ore. Laterites from the area can be used as building blocks, road building, water supply (because of the permeability of the laterites layer) and as water treatment (for removal of phosphorus and heavy metals at sewerage facilities. Laterites from the Mui Basin can therefore use for the foresaid uses especially road building to improve on infrastructure of the area.

2.2.5.6 Clays

Clay minerals are generally formed over long periods of time by the gradual chemical weathering of rocks, usually silicate bearing, by low concentrations of carbonic acid and other diluted solvents. Clay's deposits may be formed in place as residual deposits in soil, but thick deposits usually are formed as a result of a secondary sedimentary deposition process after they have been eroded and transported from their original location of formation. Clay deposits are associated with very low energy depositional environments such as large lake and marine basins. There are thick layers of clays which are widespread in the Mui Basin implying that the Mui Basin sediments were deposited from waters that were fairly still as deposition took place. The Mui Basin clays are a mixture of kaolinite (from weathered biotite or granitoid gneisses) and montmorillonite (smectite group of clays). Kaolinite clay is part of the group of industrial minerals formed from chemical weathering of rocks in hot, moist climates e.g. in tropical rainforest areas. Weathering of silica rich rocks such as gneisses or granite are the origins of clay (the periphery of the basin comprises mainly of gneisses). The feldspar weather to form clays.

The uses of clays include: i) agriculture and as medicine for both animals (clay licks) and humans for stomach upset etc., ii) as building material (as bricks, or even raw clay) and in ceramic industry. Because of the abundance of clays in the Mui Basin, the locals may consider developing it into a vibrant economic activity both in the ceramic industry and in building materials such as roofing tiles and bricks etc.

2.2.6 Peat, Lignite and Coal (bituminous and sub-bituminous)

2.2.6.1 Peat

Peat is an accumulation of partially decayed vegetation, formed in wetland condition where oxygen is insufficient thus reducing or inhibited rates of decomposition due to the acidic or anaerobic conditions, composed mainly of wetland vegetation. Peat, under certain circumstances could be considered an early component in the formation coal. Due its softness, peat is easily compressed and under pressure water in the peat is forced out and upon drying; peat can be used as industrial fuel (in Scotland it is used in Scotch whisky distilleries). Peat is known to be burned to produce heat and electricity like in Finland, Russia and Ireland. In Kenya, the Mui peat can be used as a source of heat in tea factories which relies on wood fuel as their main heat source and in so doing mitigate on the problem of deforestation which is a major concern in Kenya. Apart from the use in energy peat can be used in: i) agriculture, mixed with soil to improve its structure and to increase acidity thus retaining moisture in the soil when dry and preventing the excess water from killing roots when it is wet; ii) in water aquaria because of its soft texture for bottom-dwelling species and soften water by acting as an ion exchange and also contain substances that are beneficial for plants and for the reproductive health of fishes; iii) water filtration such as for the treatment of septic tank effluent, as well as for urban runoff; and as a filter for septic tanks; iv) as a balneotherpy (the use of bathing to treat treeing); many traditional spa treatments include peat as part of peloids; v) in wetlands, peat can be used as a habitat for distinctive fauna and flora. The peat of Mui if harnessed properly it can increase tourism to the area when the health spas are developed or boost water supply or treatment in an area which has a perennial water problems. When all this is done the economic wellbeing of the local people will dramatically improve.

2.2.6.2 Lignite

The definition of lignite according to The Free Dictionary is: i) a soft, brownish-black coal in which vegetation has proceeded further than in peat but not as far as in bituminous coal; ii) lignite is a brown carbonaceous sedimentary rock with woody texture consisting of accumulated layers of partially decomposed vegetation that can be used as fuel also known as brown coal; iii) a soft, brownish-black form of coal having more carbon than that of peat but less than bituminous coal; and does not burn as well as other forms of coal. Lignite is generally yellow to dark brown or rarely black coal that formed from peat at shallow depths and temperatures lower than 100^0C. Lignite is the intermediate product between peat and sub bituminous coal in the coalification process.

Due to its high value of sulphur content it pollutes more than bituminous coal, it has a carbon content of around 25-35% with inherent moisture of about 50% and ash content ranging from 6% to 19% (according to *en.wikipedia.org/wiki/*lignite) compared with 6% to 12% for bituminous coal. Due to the high moisture content of lignite and therefore low energy value, it is burned in power stations constructed very close to the mines, however, the main concern being the high emissions of carbon dioxide to the atmosphere therefore causing environmental issues.

Lignite is estimated to be of Tertiary Period of the Cenozoic Era (making them younger geologically than higher-grade coals). Lignite beds lie close to the surface and are of great thickness, they are easily worked and its cost of production is therefore low. As we have seen earlier due to its low energy value and bulkiness, lignite is used as a fuel primarily by local utilities and industries and by domestic consumers close to the mine sites. Mui Basin has more lignite than probably the other forms of coals combined thus making the use in local industries and domestic consumption very attractive

2.2.6.3 Bituminous and sub-bituminous coal

By definition coal is a fossil fuel consisting of carbonized vegetable matter deposited in the Carboniferous Period. The other definition being that coal is a fossil fuel that forms when dead plant matter is converted into peat; which in turn is converted into lignite, then sub-bituminous coal, after that bituminous coal, and lastly anthracite. This involves biological and geological processes that take place over a long period. Coal is the largest source of energy for the generation of electricity worldwide, and the largest worldwide anthropogenic (human impact on the environment) sources of carbon dioxide releases.

Coal can be extracted from the ground either by underground mining (shaft mining) or at ground level (by open pit mining).

The uses of coal include: i) coal as a fuel - solid fuel to produce electricity and heat through combustion; ii) coking coal and use of coke – baking of low-ash and low-sulphur without oxygen to temperatures of about 1000^0C to remove volatiles and fuse together the fixed carbon and residual ash to form coke. Metallurgical coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace; iii) gasification – coal gasification can be used to produce syngas (a mixture of carbon monoxide and hydrogen gas which is then converted into transportation fuels, such as gasoline and diesel, through the Fischer-Tropsh process; iv) liquefaction – coal can also be converted into synthetic fuels equivalent to gasoline or diesel by several different processes; v) refined coal – coal up-grading to remove moisture and certain pollutants from low-rank coals such as sub-bituminous and lignite coal.

2.2.7 Work yet to be done in the Mui Basin

Comprehensive chronological sequence or evolution of the Mui Basin is yet to be documented hence need for a detailed study and analysis of the orientations of veins and joints within and at the periphery of the basin. Upon this analysis – the tectonic history of the basin will be deduced and hence the deposition sequence of its sediments. The results from the study of Mui Basin tectonic evolution or history and depositional sequence will be used in the correlation (if any) in similar coal-bearing basins throughout the country

CHAPTER 3 METHODOLOGY

3.1 Research Design

The first step in the study involved a review the previous geological reports of the Mui Basin and its periphery. This was followed by a careful analysis of the orientation of measured joints and veins from various localities spread throughout the Neoproterozoic Mozambique Belt rocks in the periphery or within the Mui Basin. The orientation trends of joints and veins were measured in degrees, using a simple dry magnetic portable compass (a Standard Brunton Geo) whose accuracy is to the nearest 1°, and has no major limitations since the study was conducted close to the equator where compasses are very stable. The UTM coordinates of the different locations are defined using a handheld GPS receiver-Garmin and are found in appendix 1; whereas the orientations of veins and joints in degrees are in appendix 2. Since the study area is vast, the selected sites were deliberately sparsely distributed in order to get a general overview for the purpose of this project. The basin is mainly comprised of the Mui Sediments where joints or veins are known to be almost none existence. In order to get the structural features of the area it was necessary to collect data from Intra-basinal highs (the Intrusives – mainly the Quartzites) or from the Neoproterozoic Mozambique Belt rocks at the periphery.

The second step of the research involved the geological logging of the cores recovered while under taking the exploratory and appraisal drilling for coal reserve estimation of the basin. The results from the logs of the cores recovered permitted the drawing of stratigraphical columns for each well in order to determine the depositional sequence of the basin. The stratigraphical columns of the wells are then correlated in order to determine if there are any similarities in the deposition of the sediments into the basin throughout the basin.

The third step involved the modeling of the evolution history of the basin. This followed from the analysis of the stress deformation responsible for the formation of the joints and veins in the area. The analysis of the stresses of deformation led to the formulation of the tectonic history of the basin.

3.2 Data Collection Techniques

During the field study a total of 2072 joints and 843 veins were measured. The measurement was made possible by the use of a simple portable hand bearing compass which was able to measure pure direction of the orientation of the observed joints/veins. For the purpose of this project the analysis of both the joints and veins orientation are used to determine the deformation stresses which have been in operation in the area. 64 localities spread throughout the study area (figure 2.1) were visited during data acquisition. However, in 18 localities of the 64 neither joints nor veins were observed. The rock type where neither joints nor veins were observed was mainly that of intrusive quartzite (in 9 out of the 18 sites) and to a lesser extent migmatites or granitoid gneisses and the Mui Sediments. In all the remaining 46 localities, joints or veins were observed either occurring together or alone and also in varying numbers (appendix 2). Joints were observed in all the 46 localities except for two (at localities 2 & 6) both of which were in migmatites rock outcrops. Twelve localities had only joints (4, 16, 17, 20, 21, 22, 23, 25, 28, 29, 32 & 37); whereas at six localities (2, 6, 14, 19, 26 & 33) less than five (5) veins were observed. At locality 43 only four (4) joints were noted. Data measurements less than five (5) falls short of the threshold for plotting of a reasonable rose diagram.

Depositional sequence of the basin was established upon a careful analysis of the cores recovered from the continuous diamond core drilling that was undertaken while doing the reserve estimation. The core that was logged for the geological stratigraphy was recovered from the continuous diamond drilling therefore giving a precise lithology of the deposited sediments. The only major challenge of using this method of stratigraphical study occurs when there is no core recovery/ when a large percentage of the core is lost. As a mitigation measure to this challenge, one either analyzes the slurry from the drill water or evenly apportions proportionately the core recovered thus compensating for the loss. Once the geological logs of the cores were completed for a few selected wells, stratigraphical columns were drawn to help in correlation of the depositional sequence of the basin. Depositional history of the basin was established by correlating the stratigraphical columns or sequences from selected core logs of about ten wells spread throughout the basin which were drilled to various depths ranging from 192 metres to slightly over 450 metres.

3.3 Data quality, quantity and distribution

Joints in the study area were observed on both sides of the basin in almost equal proportions as is illustrated in Table 3.1: West of Block A from the southernmost point – Kaumu Primary School through the Kathande area to near Miambani (see figure 3.1) a total of about **248** joints were measured. They were at localities **1, 4, 5, 12,13,14,34 & 35.** East of Block A from the southernmost point – the Mwitika area to Kaliku area – a total of **531** joints were measured at localities **16,17,21,22,23,24,25,29 & 31.** The joints observed west of Block B, from Kithumulani area in the south to Mikuyuni market in the north were **84** at localities **36 & 44.** Joints observed and measured east of Block B, from Kaliku area in the south to Kithituni Primary School in the north were **381** at localities **19,20,26,27 & 28.** West of Blocks C & D – north of Miambani administrative location and Mumbuni location extending to Mutwangombe-Thitha area – a total of **590** joints were measured in thirteen localities - **15,37,39,40,41,42,43,46,47,48,49,62 & 63.** The observed joints east of Blocks C & D, from Kithituni Primary School in the south to Kalitini market in the north had a total of **238** at localities **32, 33,50,51,57 & 58.**

Table 3.1 Showing the number of joints and veins on either side of the basin

Area	Number of joints	Number of veins
West of:-		
Block A	248	180
Block B	84	44
Blocks C & D	590	477
Total	**922**	**701**
East of:-		
Block A	531	19
Block B	381	48
Blocks C & D	238	75
Total	**1150**	**142**

Veins west of Block A are **180** at localities **1, 5,6,12,13,14,34 & 35.** The veins observed east of Block A were only **19**. The veins west of Block B were **44**, while those to the east were **48.** Veins west of Blocks C & D were **477,** while those observed in the east were **75.**

Veins distribution in the study area was rather uneven with majority (701) found at the western side of the basin, while the eastern side (142 veins) representing less than 20% of the observed and measured. The joints however, showed a more evenly distribution pattern of almost on a 50:50 basis on either side (western – 922 and eastern – 1150) of the basin. The data of the joints/veins acquired from the field visit although not very large for the study area is thought to be representative because of the distribution of the sites visited. The rose diagrams derived from these data are deemed sufficient for the analysis of the tectonic history of the area since majority of them had enough data input for such analysis.

The continuous diamond core drilling enables one to determine the exact lithology continuously as depth increases. The lithology change with depth change, help in determining the correlation (if any) of different lithologies from different sites of the basin. From this correlation of the lithology the depositional sequence of the sediments is determined. Depth ranges of the stratigraphical columns derived from the wells logged (from 192m – 450m) is representative since in some sites the thickness of the basin's sediments is less than these depths.

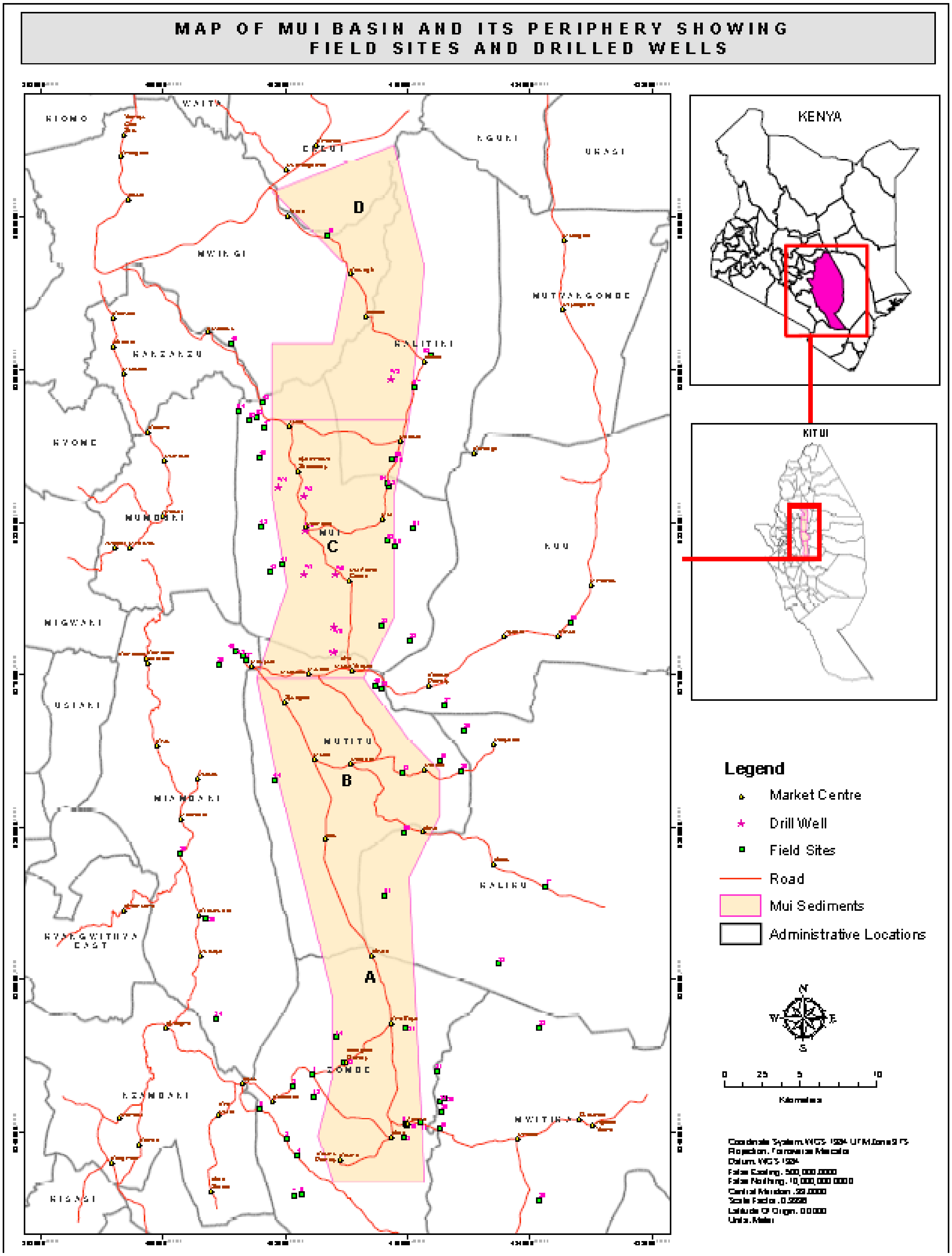


Figure 3.1 Map of the study area showing field locations (sites) and wells drilled - see over leaf.

3.4 Data Analysis

The analysis of the orientation of the joints and veins was done using Fabric8. Fabric8 is geological software (developed by Prof Eckart Wallbrecher and was last updated in May 2013). It allows plotting of Rose Diagrams (among its many programs) with graphic presentation of circularly distributed data. Circularly distributed orientation data (strike lines) may be of pure direction without a defined length or they may have defined length (i.e. lineation on satellite images). For this reason you have to choose the type of data in the menu “data”. In the menu “Fill the Diagram” you decide whether the rose diagram shall be filled with a colour or not. Also in the menu “Number of data” is the orientation of either joints or veins from a given location in three digits (i.e. from 001º to 360º). In the menu “Input” you decide whether the data will be entered manually or by a computer program. In the menu “Range” for a full circle you choose 1º - 360º and half circle 1º - 180º. The three different rose types are:-

1) Block rose: The diagram is plotted with sectors
2) Star rose: The diagram is plotted with the centres of the sectors
3) Floating intervals: The sectors are calculated in a “floating way (meaning the sectors overlap).

The width of the sectors is chosen, with which the diagram shall be plotted, in the field “interval” and increment which should be divisor of the interval. The program is used for presentation and statistical evaluation of orientation data which has “azimuth of dip/angle of dip”. An azimuth is defined as an angular measurement in a spherical coordinate system or an angle measured clockwise in the horizontal plane between a reference direction and any other line. The resultant rose diagram generated from the data input gives the preferred orientation in percentage at the top right side, whereas that of the entries (data number) is shown at the top left side.

The lithology of the core analyzed was determined upon critical examination of the grain size, texture, colour of the minerals comprising each rock type (strata). From the analysis of these characteristics one is able to classify the Mui Sediments into three broad rock types namely: - Recent Sediments (alluvial soils and lateritic soils), Mud rocks (comprising of mudstones, shales, claystones, clays, lime, limestone and gypsum) and sandstones (and/or conglomerates). Recent Sediments are the unconsolidated top layers of the Mui Sediments and varies both in composition, colour and even grain size. The alluvial soils and lateritic soils are mainly fine grained but are also found in medium grained aggregates especially the lateritic soils.

Mud rocks are fine to medium grained and vary in colour. Mud rocks of the basin are very fine grained – composed mainly of either silt or clay size grained particles. Claystones are fine to very fine grained (between 0.002 – 0.063 mm). Clays fine to very fine grained (≤0.002 mm) showing crumby or sticky properties. Mudstones fine to very fine grained (silt size grains – 0.002 to 0.063 mm). Shales same grains as those of mudstones but shows fissility and have either dull or vitreous lustre. Lime/limestone or gypsum is fine to medium grained (0.063 to 0.20 mm).

The sandstones or conglomerates are generally medium to coarse or even very coarse grained sedimentary rocks, those of Mui Basin exhibits a variety of colour. Clay sandstones are fine to very fine grained (0.063 to 0.20 mm). Sandstones of Mui basin are either medium grained (0.20 to 0.63 mm) or coarse grained (0.63 to 2.00 mm). The conglomerates are very coarse grained to pebbly (≥2.00 mm), and are held together by finer grained matrix.

CHAPTER 4 RESULTS OF DATA ANALYSIS

4.1 Geological Structures of the Mui Basin and its periphery

The structures of Mui Basin are those of metamorphic and sedimentary. Those of metamorphic are associated with the tectonic events of the Pre-Cambrian Era they include faults, folds and/or upwarps, veins and joints. Tectonic structures originate as a result of the distortion of the earth's crust due to the forces within it. These forces occurring within the earth's crust cause structural deformation thus forming tectonic structures of the earth (on the existing rocks of the earth's crust). The sedimentary structures of the basin include graded bedding and Bioturbations. The other structures which are of interest are those found within the basin which resulted from intrusions into the sediments (here referred as the Intrabasinal highs). Mui Basin geological structures can be divided mainly into three types namely: - a) metamorphic structures, b) sedimentary structures and, c) Intrabasinal highs. Figure 4.1 below shows the directions of the strike of the rock foliation, fault line down throw, inferred fault line and anticline structure of the ridges (Intrabasinal highs)

4.1.1 Metamorphic Structures

The metamorphic structures of the study area include: faults, folds/upwarps, veins and joints. Faults in the area occur as planar fractures or discontinuities in a volume of rock, across which there has been significant displacement along the fractures as a result of the earth movement. Folds/upwarps in the area are dislocations in rocks bodies without fracture; they are the common manifestation of ductile deformation where temperature, confining pressure and presence of fluids play an important role. Joints in the area are expressed as fractures on rock structures showing no appreciable displacement occurring. Veins in the area occur as distinct sheet like bodies of crystallized minerals within a rock as a result of formation of mineral constituents carried by aqueous solutions within the rock mass are deposited through precipitation. A brief account of each is given in the subsequent sub-titles.

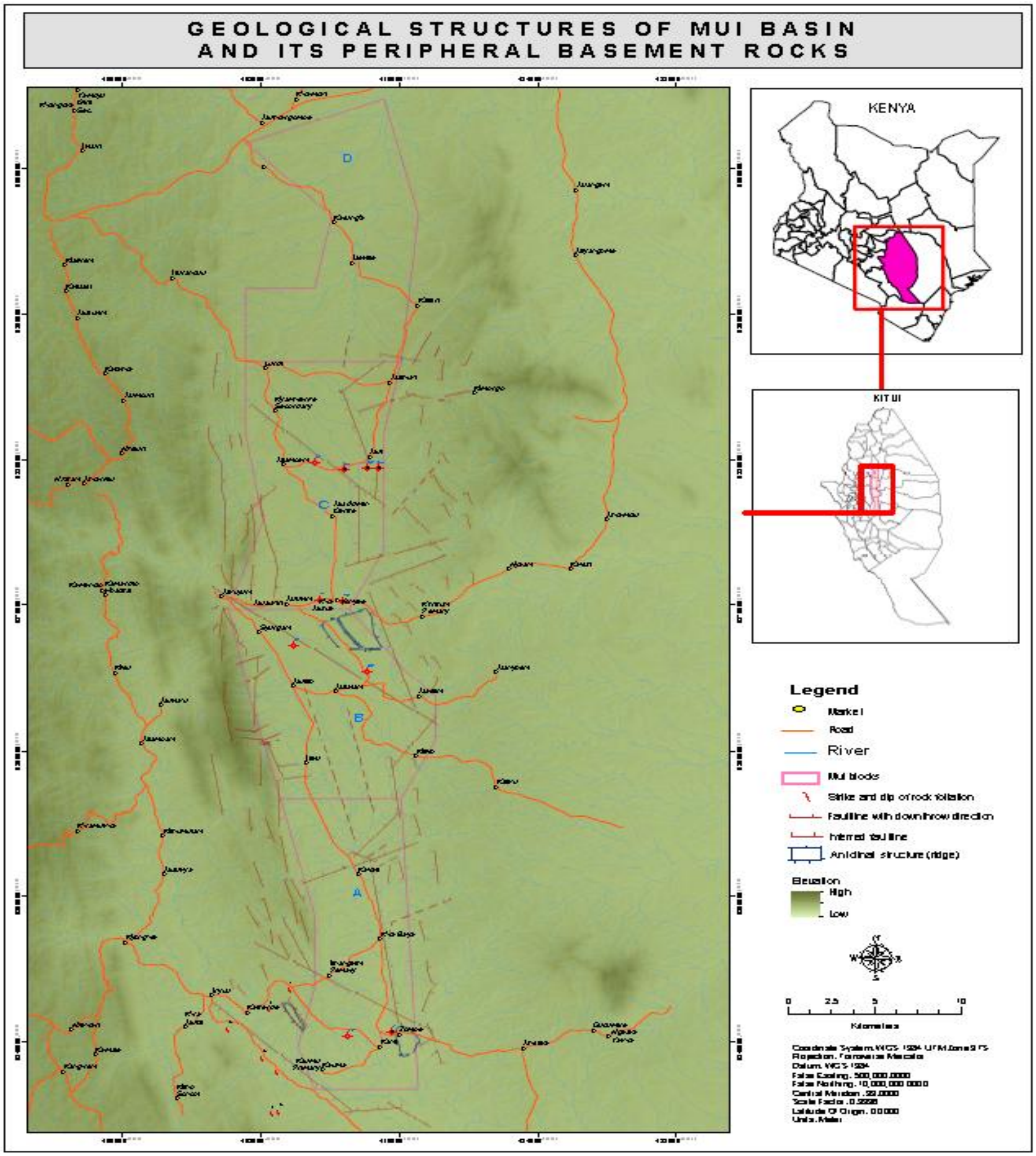


Figure 4.1 Map showing geological structures of Mui Basin and its peripheral basement rocks

4.1.2 Faults and their orientations

Majority of the faults are to the west of the Mui Basin and are largely confined within the Mutito Ranges although a few are found east of Mui River. Mutito faults are characterized by the linear vegetation pattern, abrupt change in altitudes and the linear trend in drainage found in the area. The faults at the Mutito Ranges are largely those classified as normal faults which have undergone vertical movements of rock materials forming the hanging wall (moved down relative to the footwall). The faults are deeply inclined and the angle ranges between 65º and 90º and dip to the east; the vertical movement is tens or sometimes hundreds of metres of down throw to produce cliffs or scarp features as seen in plate 4.1. The Mutito faults, about 130 Km long trends N-S and forms a 5-7 Km wide fault zone on the western side of the basin are known to have been formed during Proterozoic Period and reactivated during Tertiary -Pleistocene Period which is considered to have caused deposition of the Mui Sediments. Complex Mozambique Belt structures east of the Mutito fault scarps are considered to have been formed as a result of Mozambique migmatites between faults and powerful shearing movement along Mutito fault zone.

In the eastern side of the basin on the other hand has fewer faults which are not as prominent as those in the west, however , some conspicuous ones are found between Ngiluni Ridges and Mui River plains from where they form an apparent drop of step faults of a few metres in height. Other faults on this side of the basin are those directly opposite Kabati, in Makongo Hills (plate 4.2 below). Except for the Makongo faults scarp, the vertical drop of the faults in the eastern side of Mui Basin (e.g. plate 4.3) is not as high as those found in the Mutito Ranges. Measurements on the outcrops (in the eastern side of the basin) show they dip to the west and therefore they are also normal faults. The other main faults in the study area are those found near Ithangathi primary school, Zombe/Mwitika Bridge and at the Ikoo River near Mikuyuni Market.

Plate 4.1 Faults of the Mutito Ranges from Mutito Township. Down-throw facing the cameraman is to the east.

Plate 4.2 The eastern escarpment on Makongo Hill. Down-throw is to the west from the cameraman. Note the step faulting and magnitude of the down-throw.

Plate 4.3 Gentle step faults drop to the Mui Basin in the foreground from the eastern side, near Kathumu Primary School

4.1.3 Folds/upwarps

Localised subsurface intrusions into the basin sediments resulted in the formation of 'basin' ridges (ridges found within the basin). These intrusions formed the anticline structures; examples of these structures are that of the Zombe ridge in the southern parts of the basin and the Mwalano ridge in the middle near Yoonye market (figure 4.1). These ridges are as a result of the rocks that are intruded into the subsurface like the quartzites, granitic and marble resisting weathering due to their hardness or rather weather-resistant properties. The quartzite ridges are found near Zombe market, and Mathuki market. Both granitic and quartzite are found at the Yoonye (Mwalano) ridge. Marble ridges are restricted the Kaliku ridge and the Masasini Rise.

4.2 Characteristics of tensional, shear and composite joints or veins both in the field and on Rose Diagrams

The Mui Basin joints are predominantly those formed due to tectonic movement. Joints or veins on the rocks at the periphery of the Mui Basin vary both in number and size from one rock type to the other, their numbers increasing from migmatites to pegmatites, followed by quartzites, then biotite gneisses and finally granitoid gneisses. Joints of the study area are considered relatively younger compared to the veins because most of them cut across the veins. The orientations of joints from various rock outcrops (localities) are shown in appendix 2.

Veins in the Mui Basin are predominantly filled with either quartz or feldspar and are found occurring together with joints on most outcrops. The Mui Basin veins can be classified as either those that are conformable or those that are discordant to the general strike of the country rock. A classic example of these two types is found at locality 01 (Kathande area near Ithangathi Primary School – see fig 3.1 above) - the migmatites outcrop with pegmatitic veins (Plate 4.4). The veins have two observable sets – the first which is older and conformable to the general orientation/foliation of the formation (330º), whereas second set is younger and discordant which generally cut across the formation and are partially deformed due to miniature faulting. Another characteristic of the Mui Basin veins is that those in granitoid gneisses are generally filled by quartz crystals, whereas those in migmatites are filled by very large quartz-feldspar crystals. Veins represent molten rock injected into former joints; therefore the measurements of their orientation will indicate relative movement if any to the present orientation of joint. Variations in veins orientation from the present set of joints represent variations over time of the direction of the deforming forces. Deformational stresses have operated throughout the geological history of the area as seen in some veins which display some faulting along present joints or some rejuvenated joints.

A typical example of tensional stressed veins in the field are found at locality 1 (Kathande area near Ithangathi Primary School) on a magmatitic outcrop that strikes at 330º and exhibits four (4) sets of veins filled with pegmatites (of quartzites and feldspars). The first set which is partially sheared and is conformable to the former lineation of biotite crystals; and appears to be the oldest. The second set cuts through the first set and is larger and shows some boudinage structures, some measuring about 5-20 cm and are discordant with the former lineation. The third set which is also discordant – shows some boudinage structures and is pegmatitic cutting across the entire outcrop with some measuring about 1.5-2.5 metres in width. The fourth and last set is almost perpendicular to the previous lineation and exhibits some distortion probably due to some lateral movements (the zig zag movements caused by partial melting of the underlying rocks). These set of veins is discordant with first and second sets and measured about 25-40 cm in width and comprises of pegmatites.

Plate 4.4 Pegmatitic veins on migmatitic outcrop at locality 1: Scale – the GPS on the major vein in the plate at locality 1 (the Kathande area near Ithangathi Primary School).

The Rose Diagram for the veins at locality 1 exhibiting tensional deformational stress is as shown in fig 4.2, with a trend of 330°.

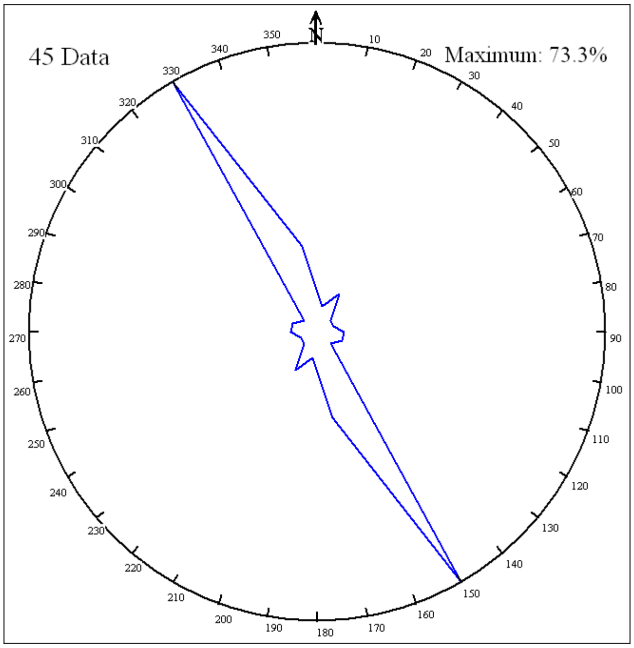


Figure 4.2 Showing tensional deformational stress at locality 1 – Kathande area near Ithangathi Primary School

The percentage in the rose diagram (e.g. 73.3% in the figure above) is the preffered orientation and is normally at the top right hand side. The number of entries (i.e. the number of either joints or veins used as the input) that is the data number is that which is at the top left hand side. Deformational stress that results into a predominantly single joint set as that in figure 4.2 is caused by tensional forces and are called tensional joints. At locality 44 (on top of Mutito Ranges directly west of Mutito Township) which are at an altitude of 1046 metres and on an outcrop of granitoid gneiss exhibit a perfect example of what a characteristic of shear joints are in the field (plates 4.5, 4.6 & 4.7). The joints seen in the said plates are parallel to the fault line of the Mutito Ranges. However, the veins at the same locality exhibit tensional stress that trend in an N-S direction. The veins are mainly filled by either large quartz crystals or pegmatitic (well developed) crystals of K-feldspars. The well development of crystals in the veins is an indication that the granite intrusion into the country rock crystallized quite slowly to enable the development of large crystals; erosion has since left the columnar granitoid gneisses of the Mutito Ranges.

The Rose Diagram for the joints is shown in fig 4.3: at locality 44 – west of Mutito Township (typical examples of Rose Diagram exhibiting shear jointing).

Plate 4.5 Rejuvenated joint in granitoid gneiss. This was at locality 44 forming part of the Mutito Ranges. Scale – geological hammer

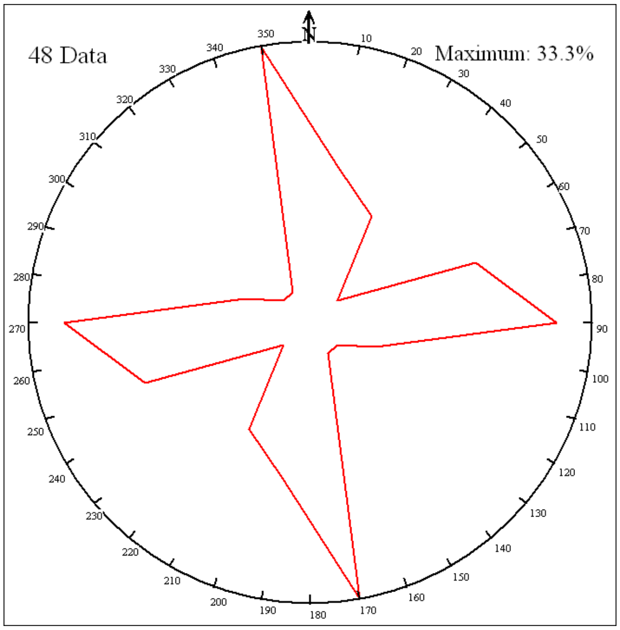


Figure 4.3: A typical example of a Rose Diagram exhibiting shear jointing from locality 44

Those joints that exhibit two sets which are well-developed almost in equal proportions as that in figure 4.3 do intersect at an angle of 80º. These set of joints are known as shear joints that is, they are caused by two sets of deformational forces.

Plate 4.6 **Developing joints in granitoid gneiss at locality 44 forming part of the Mutito Ranges. Scale - GPS**

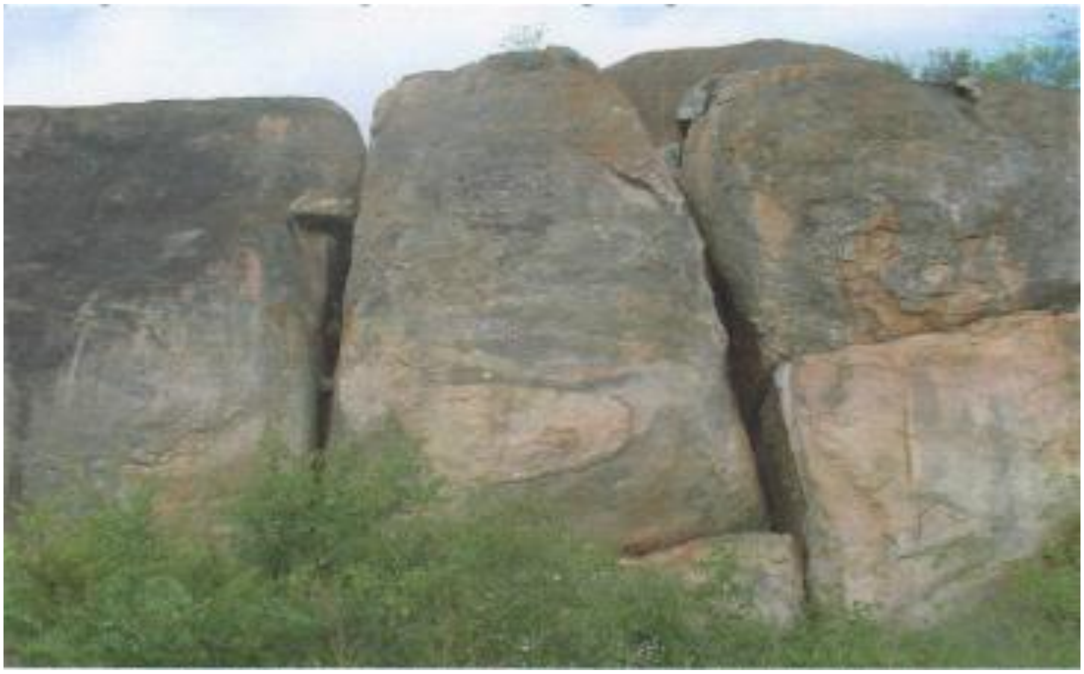


Plate 4.7 Typical joint set of the Mutito Ranges forming transverse joints.

Rose Diagrams best illustrating tensional joints are given fig 4.4; these were at localities 5, 12,14,35,47 & 63.

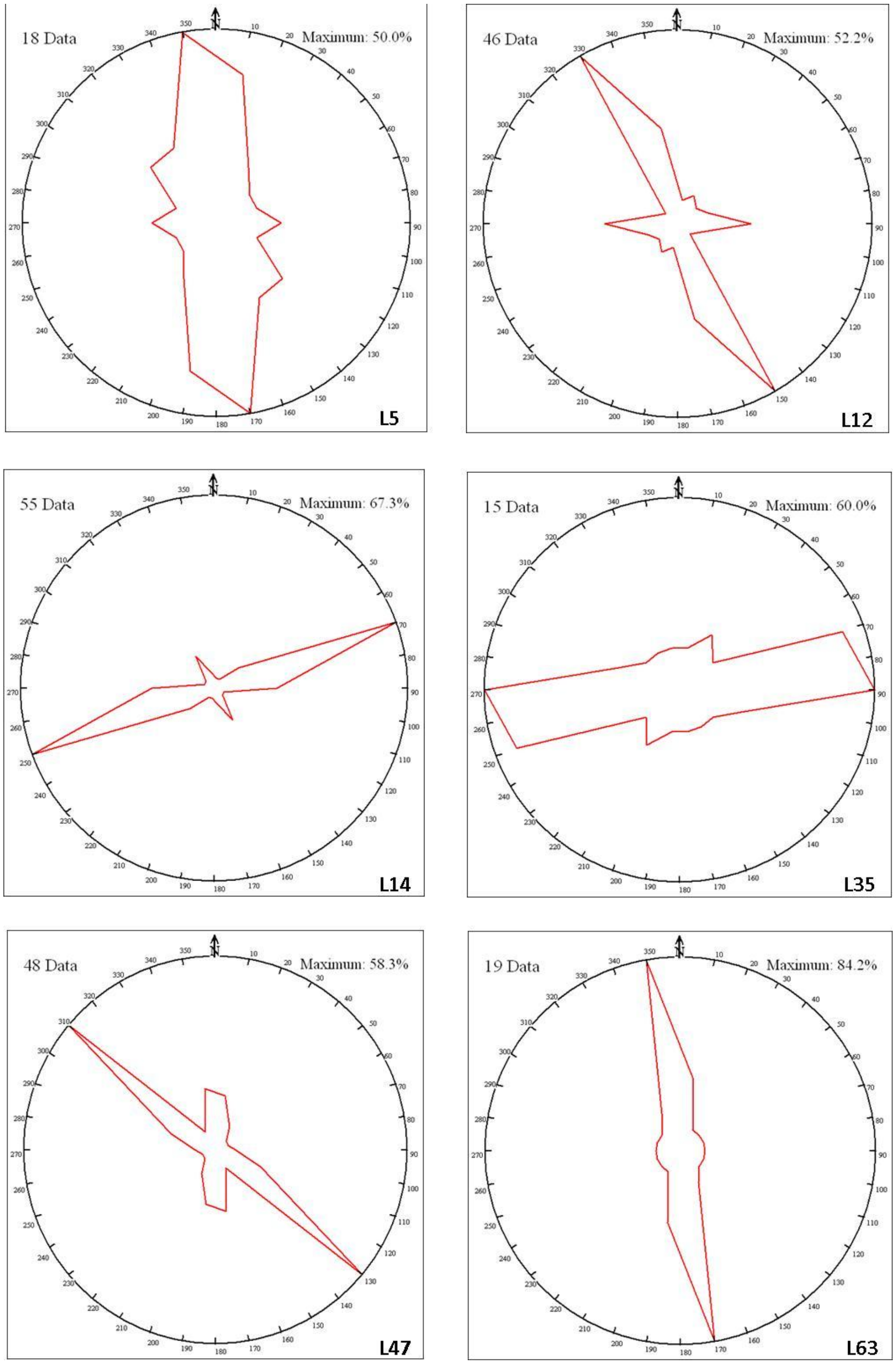


Figure 4.4 Showing tensional joints from various localities

At localities L5 (Kathande area near Inyuu market) and L35 (Kithumulani Shopping Centre) the resulting rose diagrams were broad with a not well developed smaller set; this is partly due to the number of data entry (the joints measured at the sites) and the fact that under natural conditions – deformational forces are not entirely monolithic. The preferred orientation at both localities is between 50% and 60% indicating that not very strong tensional stress occurred at these localities.

Localities L12 (Kathande area south of locality 1), L14 (north of Ithangathi Primary) and L47 (west of Lundi market), show well developed set of joints but with a non – pronounced set; this is due to the fact tensional stress was more prominent and the large data entry. The preferred orientation (between 50 and 70%) indicates moderate tensional stress at these localities.

At locality L63 (west of Lundi market) – although the number of joints measured is not large - the preferred orientation (84.2%) of the joints analyzed indicates that the dominant deformational force was that of tensional stress.

Rose Diagrams best illustrating tensional veins (figure 4.5) which were measured at localities 1, 5, 12, 35, 36,41,42,47 & 63.

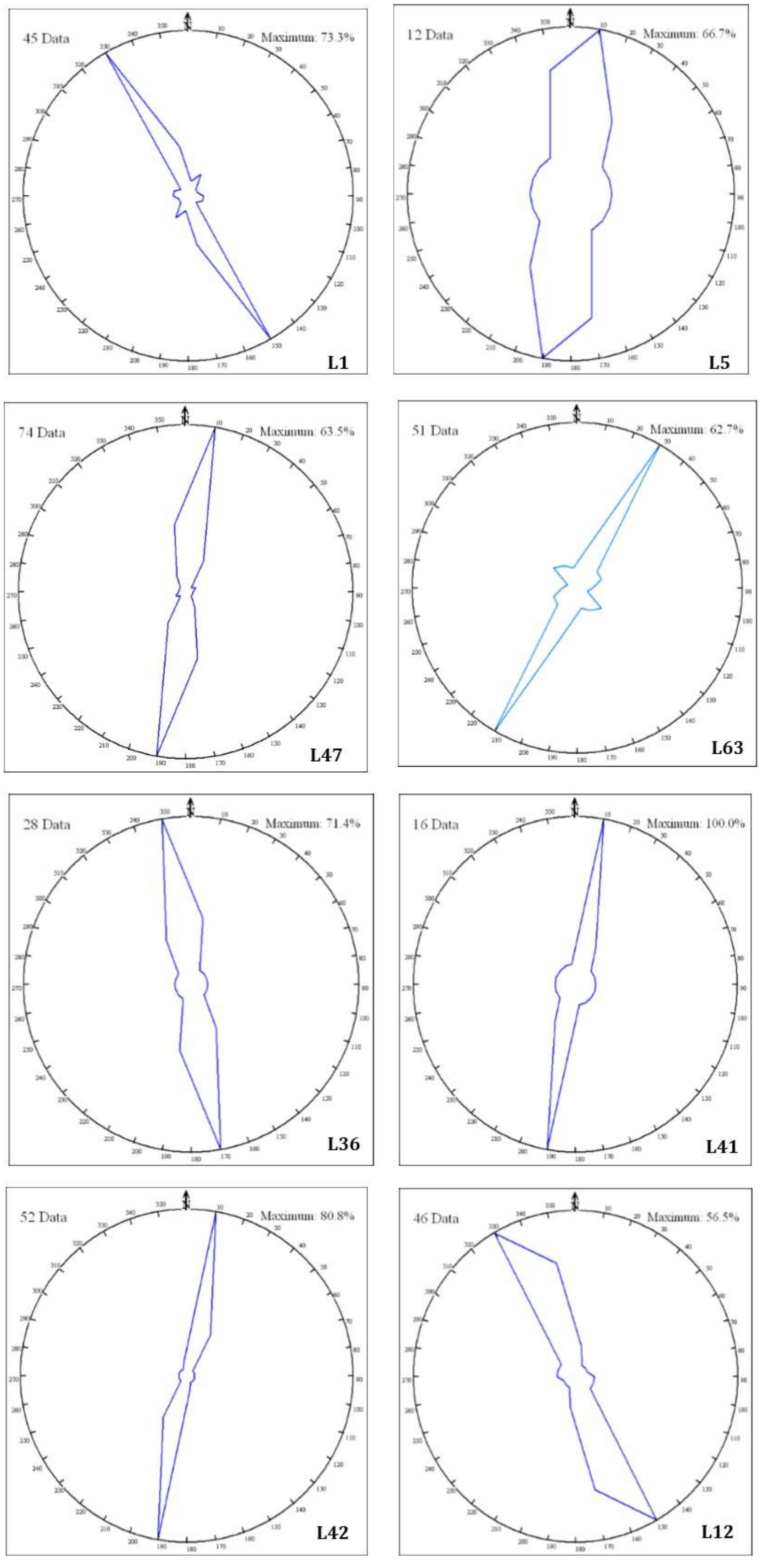


Figure 4.5 Showing tensional veins from various localities

The rose diagrams derived from localities L5 (Kathande area near Inyuu market) and L12 (Kathande area south of locality 1) are broad partly due to the data entry numbers and the preferred orientation of the veins measured (between 56 & 66%). However, compared to rose diagrams of the joints from the same localities – those of the veins have higher preferred orientation thus less broad.

Localities L35 (Kithumulani Shopping Centre) and L63 (west of Lundi market) where the preferred orientation and data entry number is medium they exhibit well developed set of veins with the other which is not pronounced. This implies that tensional stress was more prominent compared to the forms of stresses.

The rose diagrams for veins at localities L1, L36, L41, L42 & L47 all showed strong preferred orientations (between 73 and 100%) indicating therefore that tensional stress was the dominant form of deformational force at these localities. At locality L6 (southwest of Kaumu Primary School) however, although the data entry is small, the preferred orientation was at 100% implying that at this locality tensional stress was very strong.

Rose Diagrams illustrating shear jointing (figure 4.6) drawn from joints at localities 19, 33,41,44,45 & 49.

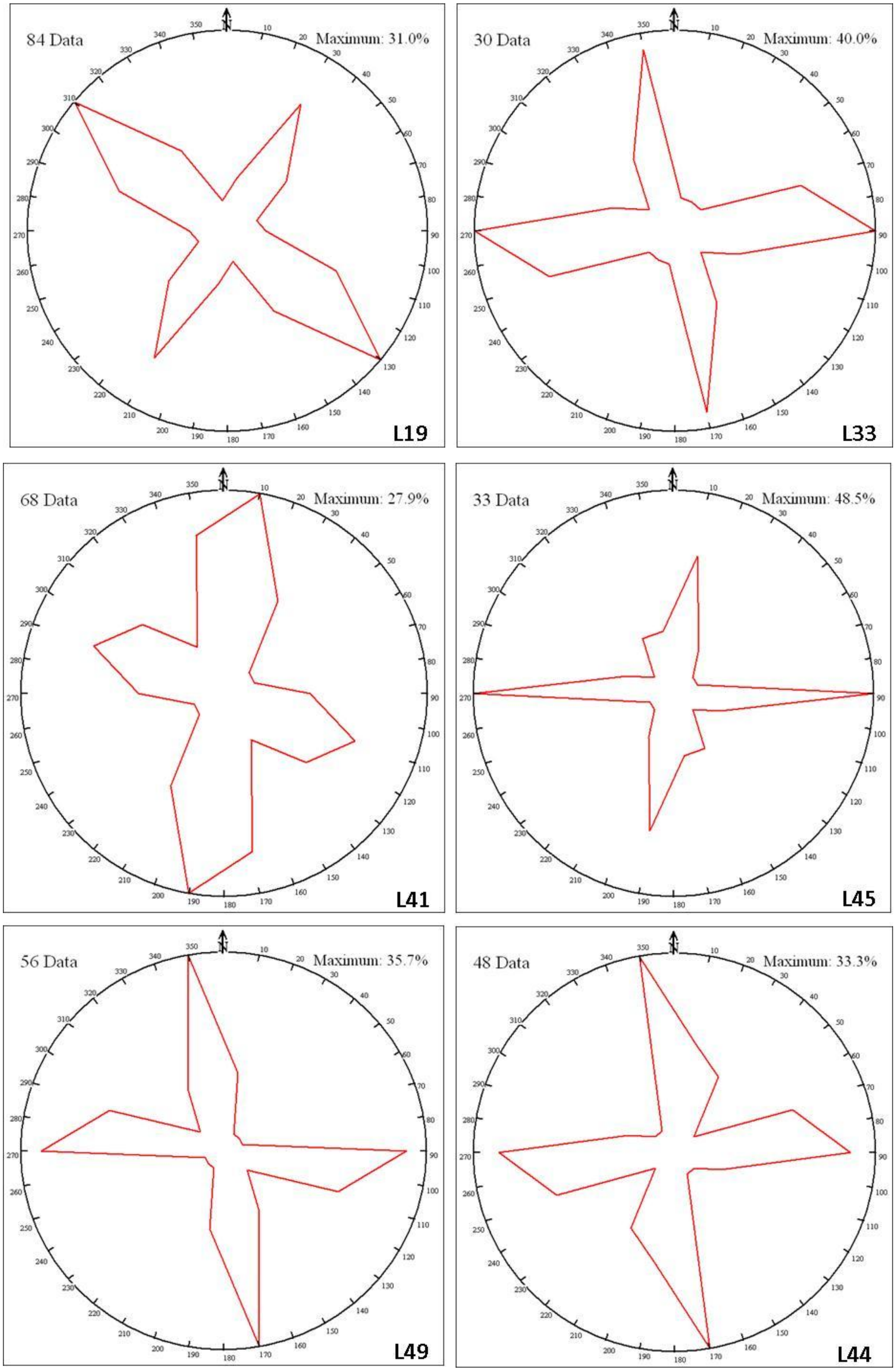


Figure 4.6 Showing shear joints from various localities 19, 33,41,44,45 & 49

It is important to note that in shear stresses since there are two sets of deformational forces involved the range of preferred orientations is much less than those attained in tensional stresses due to the two forces involved.

Localities L19 (Maritini Shopping Centre near Manyoeni), L41 (west of Kathonzweni market), L44 (west of Mutito Township) and L49 (west of Block D near Ituvandu Shopping Centre) where the preferred orientations ranges between 25% to 35%, the two sets of joints are almost equally developed implying that the shear stress at these localities were of equal measure. The intersection angle of 80º is also well pronounced. When the preferred orientation is less than 30% the rose diagram is much broad (locality L41) indicating that the other set of joints although pronounced was a bit weaker compared to the other.

At locality L33 (north of Kithituni Primary School) where the preferred orientation was 40% the sets are much more developed as is shown by the type of rose diagram derived. At this locality the shear stress was almost of the same magnitude in the two sets. Locality L45 although the preferred orientation of 48.5% is high the shear stress show that there was a possibility of being influenced by a third force.

Rose Diagrams that illustrates shear veins (fig 4.7) which were at localities 15 (west of Block D near Thitha market),19 (Maritini Shopping Centre),27 (south of Kithituni Primary School),31 (east of Block A) & 48 (west of Lundi market).

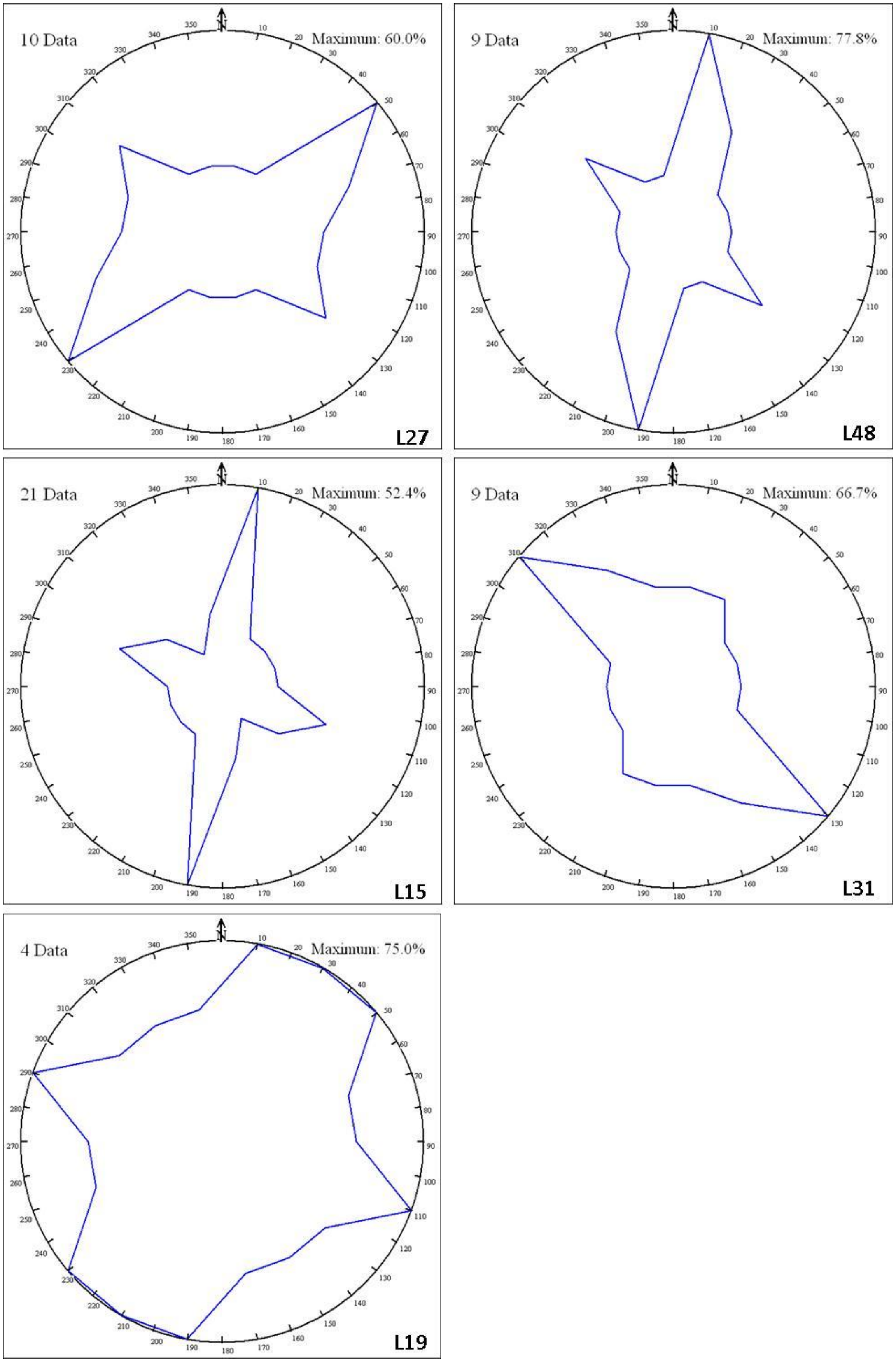
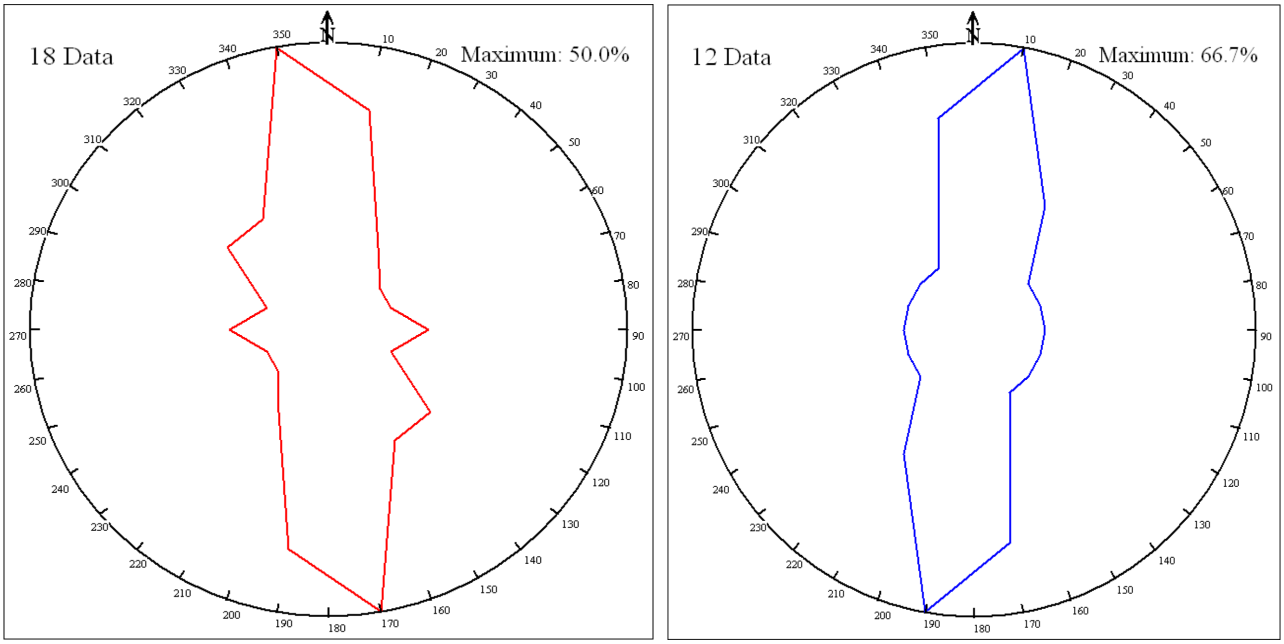


Figure 4.7 Showing shear veins from localities 15,19,27,31 & 48

The rose diagrams for the shear veins were not well developed due the limited number of data entry at all the localities except at locality L21. The number of measured veins in some localities poised the main limitation to the analysis of the orientations of the veins in the study area.

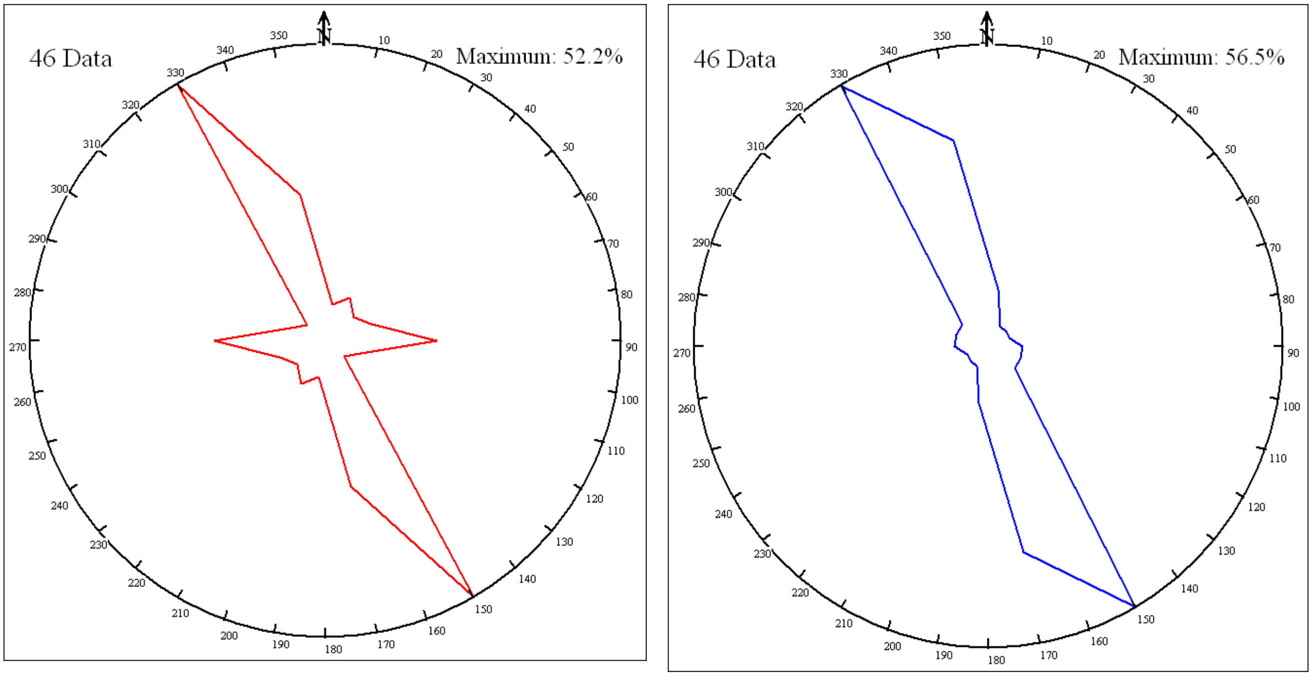
At locality L5 (Kathande area near Inyuu market) figure 4.8; rose diagrams for both the veins and joints are broad partly due to the number of data entry and the preferred orientation (between 50 & 70%). The trend of veins is 010º and that of joints is 350º implying that has been a rotation of deformational stress of 020º to the west over time.



L5 Tensional joints **L5 Tensional veins**

Figure 4.8 Rose Diagrams illustrating both tensional joints and veins at locality 5

Locality L12 (Kathande area south of locality 1) figure 4.9; also exhibit broad rose diagrams due to the low percentage of the preferred orientation. The veins and joints trend at 330º meaning that this locality has not experienced any deformational stress rotation.

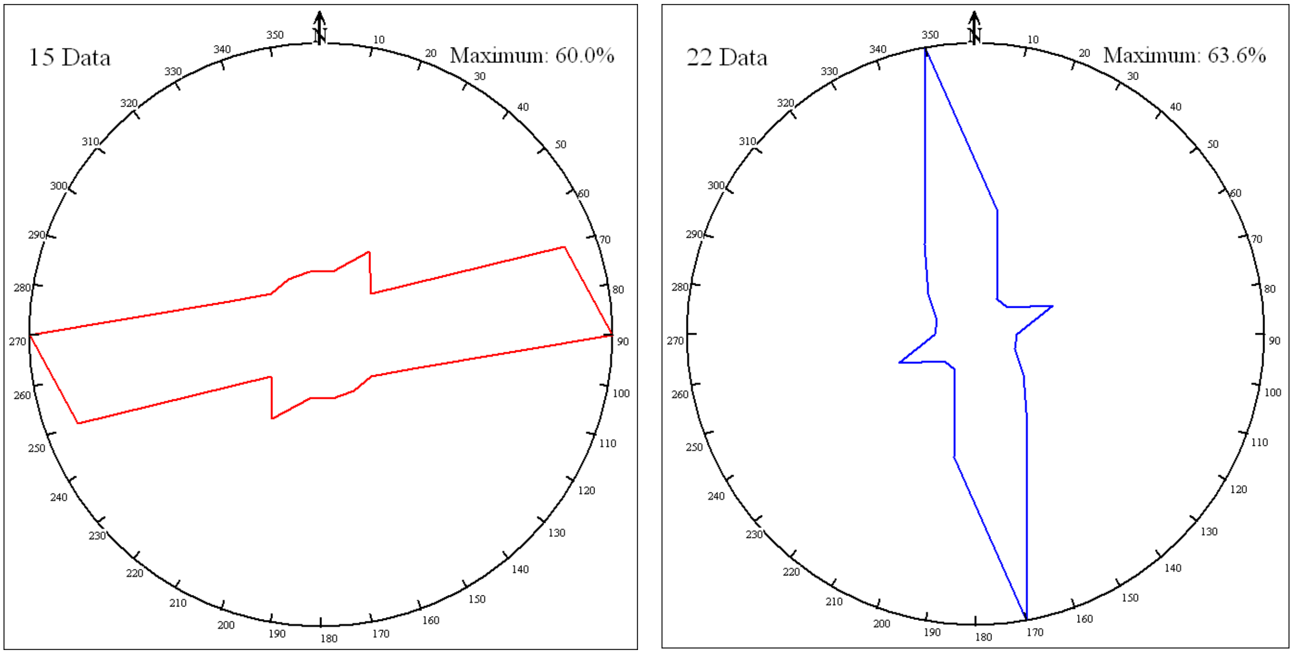


L12 Tensional joints

L12 Tensional veins

Figure 4.9 Rose diagrams for both the veins and joints at locality 12

At locality L35 – (Kithumulani Shopping Centre) figure 4.10; veins trend at 350º and joints at 090º a rotation of about 100º to the east. The broad rose diagram for the joints is partly due to the low number of data entry and that of preferred orientation.



L35 Tensional joints

L35 Tensional veins

Figure 4.10 Rose diagrams for both the veins and joints at locality 35

At locality L47 (west of Lundi market) figure 4.11, although the preferred orientation is low the number of data entry is high resulting into a less broad rose diagrams. The veins trend at 010º, while the joints trend at 310º; a rotation of 060º to the west

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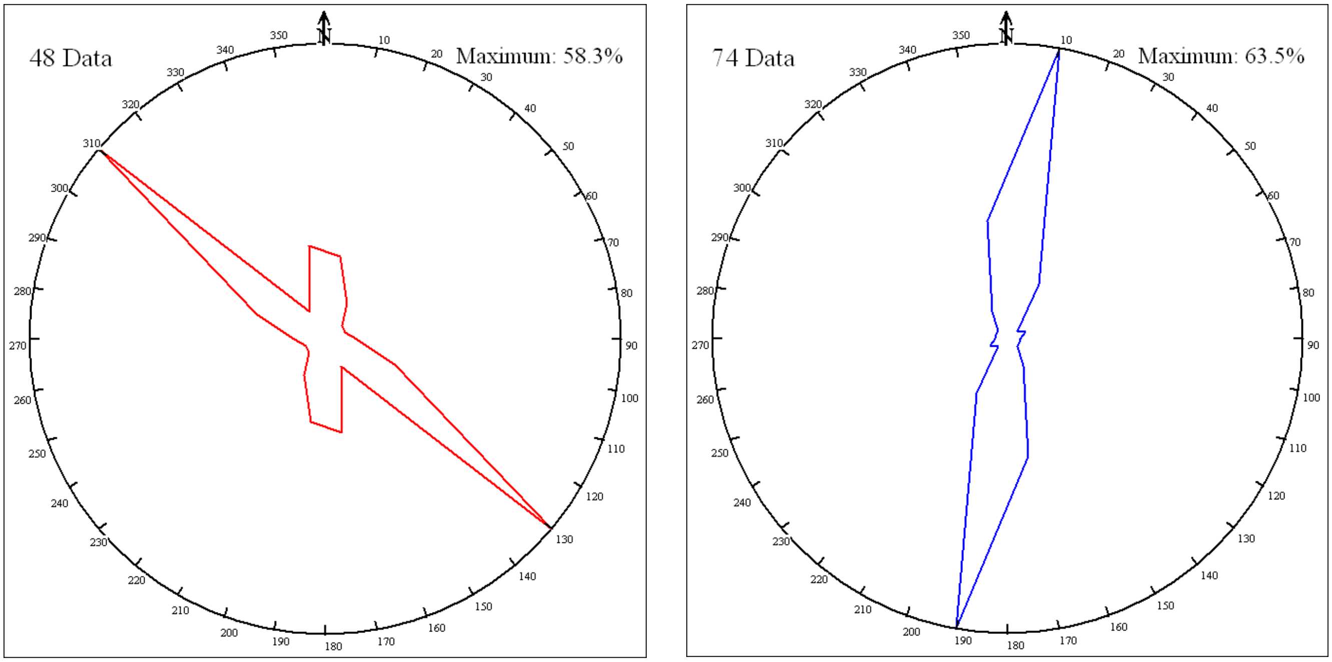
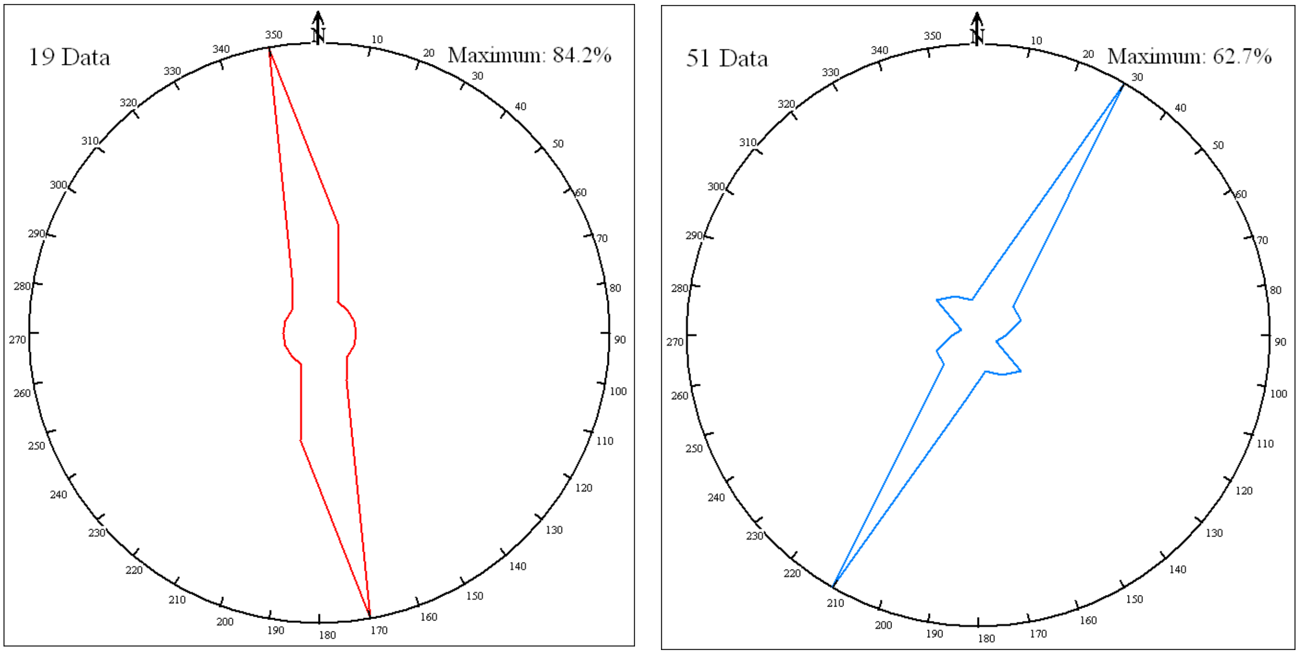


L47 Tensional joints

L47 Tensional veins

Figure 4.11 Rose diagrams for both the veins and joints at locality 47

Locality L63, (west of Lundi market) figure 4.12; the preferred orientation of 84.2% is quite high resulting to a well-developed single set of joints although the data entry is moderate. The veins trend at 030º whereas that of joints is 350º, a rotation of 040º to the west.



L63 Tensional joints

L63 Tensional veins

Figure 4.12 Rose diagrams for both the veins and joints at locality 63

Joints found west of Block A show strong characteristics of both stresses; tensional stresses observed at localities **4, 5, 12, 14 &35** trending either between 070º to 090º or 330º to 350ºand shear stresses at localities **1, 13 & 34**. Joints east of the same Block are predominantly shear joints (localities **16,17,21,22 & 25**) although some were tensional (localities **23 & 31**) trending between 290º to 330º. The joints west of Block B showed both characteristics - shear (locality **44**) and tensional (locality **36**) trending west-east. However, east of Block B (localities **19, 27, 28 & 45**) showed strong shear characteristics (although tensional joints were observed at localities **20 & 26**) trending 310º to 010º. West of Blocks C & D shear jointing was observed at localities **37, 39, 40, 41, 46, 48, 49 & 62;** whereas tensional joints were encountered at localities **15, 42, 47, & 63** trending between 310º to 090º. Joints east of Blocks C & D showed both characteristics of composite stress (localities **50 & 58**) and shear stress (localities **32, 33 & 51**) although locality **57** exhibited tensional stress trending at 070º.

The veins west of Block A (localities **1, 5,12,13,34 & 35**) all showed strong characteristics of tensional stresses trending between 330º and 010º. Veins east of Block A were only at locality **31** and they showed shearing stresses. West of Block B the two localities (**36 & 44**) both had tensional veins trending in N-S (locality 44) and 350º (locality 36). East of Block B at localities **19 &27** both had shear veins; whereas tensional veins were observed at locality **45**. Majority of the veins measured were west of Blocks C & D (localities **39, 40,41,42,43,47,49,62 & 63**) were predominantly tensional trending between 350º to 030º. However, composite veins were observed at locality **46** (showing both characteristics of shearing and tensional stresses) and shear veins were observed at localities **15 & 48**. All veins (localities **50, 51 & 58**) east of Blocks C & D showed strong characteristics of tensional stress trending between 350º to 050º. Table 4.1 below is a summary of the number of either joints or veins and their characteristics at various localities.

Table 4.1 Showing the numbers of either joints or veins and their characteristics at various localities

Area	Number showing tensional characteristics	Number showing shear characteristics	Number showing composite characteristics	Total	Total data from the field	Rock type
West of Block A						Migmatites & Granitoid gneisses
Joints	**156**	**92**	**-**	248	248	
Veins	**171**	**-**	**-**	171	180	
East of Block A						Quartzites, Biotite gneisses, Granitoid gneisses & Marble
Joints	**126**	**357**	**48**	531	531	
Veins		**9**	**10**		19	
West of Block B						Granitoid gneisses & Biotite gneisses
Joints	**36**	**48**	**-**	84	84	
Veins	**44**	**-**	**-**	44	44	
East of Block B						Granitoid gneisses & Marble
Joints	**80**	**281**		361	381	
Veins	**32**	**14**		46	48	
West of Blocks C & D						Granitoid gneisses, Migmatites, Biotite gneisses & Quartzites
Joints	**119**	**467**	**-**	586	590	
Veins	**422**	**30**	**25**	477	477	
East of Blocks C & D						Granitoid gneisses, Migmatites & Quartzites
Joints	**34**	**133**	**71**	238	238	
Veins	**74**	**-**	**-**	74	75	

Remarks: Totals do not tally with that of the field data where either joints or veins are less than four (4) in a locality hence not sufficient for the drawing of rose diagrams.

Veins represent molten rock that was injected into former fractures. If the exposed rock unto which the vein is found not to have undergone any transformational change such as either rotational or folding, then their current orientation is the same as that of original fracture or joint unto which lava was injected. Occurrence of veins and joints on the same outcrop with the later crossing the former implies that the veins are therefore older than the joints at that area. Cross cutting relationship and material filling the fracture help in resolving the chronological order of deformation. However, variations of veins' orientation from that of joints can be interpreted to mean that the direction of the principal stress that caused the formation of the two sets is not the same. This can only be explained if we consider variation with time in the direction of the deforming forces. Sources of these deforming forces are speculative. Two of such possible forces are diapiric and sediment overburden. Diapiric forces are due to intruding magma from subsurface whereas that of sediment overburden are as a result of sediment deposition, loading and down warping within the basinal area. As there is no rejuvenation of volcanism in the area, the most probable deforming source is the sediment loading. Varying sediment depositional centres within the basin can lead to varying sediment loading within the basin with time. The study of the joints in the area gave information on the sequence and timing of deformation and provided information on the timing and geometry of the brittle deformation of the crust. The study of the orientation of systematic joints and veins provided information about the orientation of one or more principal stress directions involved in the brittle. Data from joints or veins was plotted in Rose Diagram since their strike had been determined in the field.

Localities where both veins and joints show characteristics of the same deformational stresses over geologic history of the basin include localities **5, 12 & 35** which shows tensional stresses west of Block A and at locality **36** west of Block B which has also exhibited tensional stress over time. Other sets of tensional deformational stress were found at localities **40, 42, 47 & 63** also west of Blocks C & D and at localities **19 & 27** shear stress has been operating over the geologic time east of Block B; whereas the same stress has operated at locality **48,** west of Blocks C & D, west of Lundi market. Table 4.2 below shows localities where both joints and veins exhibited tensional stress.

Table 4.2 Showing localities where both joints and veins exhibited tensional stress

Area	Trending direction of stress	Rotation of the trending direction over time
West of Block A		
Locality 5	Joints' trending 350º; Veins' trending 010º	Rotation of 020º west
Locality 12	Joints' trending 330º, Veins' trending 330º	Rotation of 000º
Locality 35	Joints' trending 090º, Veins' trending 340º	Rotation of 110º east
West of Block B		
Locality 36	Joints' trending 090º, Veins trending 350º	Rotation of 100º east
West of Blocks C & D		
Locality 40	Joints' trending 050º, Veins' trending 350º	Rotation of 060º east
Locality 42	Joints' trending 010º, Veins' trending 010º	Rotation of 000º
Locality 47	Joints' trending 310º, Veins' trending 010º	Rotation of 060º west
Locality 63	Joints' trending 350º, Veins' trending 030º	Rotation of 040º west

Rose diagrams derived from the orientations of joints and veins are divided into three groups; namely single set, double set and triple (or composite) set as shown in appendices 3 & 4. Tensional joints in the study area occur as a single joint set and are caused by tensional forces. The forces that produce these joint set is normally perpendicular to the direction of stress. Shear joints occur as two well-developed joint sets intersecting at an angle of 80º. Majority of the shear joints were encountered in migmatites where they cut across the older ones in oblique angles and appear larger. The third group, the composite joint sets, consists of a combination of the two. Most single joint set are concentrated in the Mutito Ranges. From their orientation, perpendicular maximum stresses that caused their formation are directed southeast-northwest. However, the one from the eastern side appear to be oriented in a northeast- southwest direction. If these forces emanated from sedimentation then the loci (a Centre or source) of thick sedimentation (depocentre – maximum deposition within a sedimentary basin) is centered southeast from locality 14 & 15, and southwest from locality 31.

4.3 Sedimentary Structures

4.3.1 Graded bedding

Graded bedding of the Mui Sediments is characterized by systematic change in grain or clastic size from the base of the bed to the top, with coarser sediments at the base, which grades upwards progressively into finer grains. The graded bedding structures of the basin sediments are observed prominently on the walls of river channels and on the cores of the wells drilled. In the Mui Basin sediments the most common rock consists of pebbles comprising the base layer and includes granites or gneiss boulders cemented by a matrix of either sand or silica; whereas the top layers are composed of fine-grained clays or soils.

4.3.2 Bioturbations

Bioturbations is the reworking of soils and sediments by animals or plants thus changing the texture of sediments. Bioturbations in the area are caused by burrowing into the soft sediments by biological stirring of the sediments. The burrowing occurs commonly along the river banks and on the cores of drilled wells. The Mui Basin sediments are mainly bioturbated by burrowing animals and occur mainly in sandstones and to a lesser extent in mudstone.

4.4 Stratigraphical controls and Intrabasinal Highs (Quartzite and Granitic Intrusions)

Four Intrabasinal highs were noted in the study area, they include: - the Zombe and adjacent ridges, the southern Kathande granitic ridge, the Mwalano granitic ridge and the Mathuki and adjacent quartzite ridges. All the ridges except for that of Kathande protrude as extensions into the basin from east, thus temporarily blocking the normal flow channels of rivers. These blockages of the rivers channels resulted in periodic flooding and resultant deposition of large volumes of silts and clays into the floodplains occurred.

The Mui Basin floodplains which are believed to be responsible for the sediment deposition that forms the coal beds in the area appear to have been controlled by isolated intra-basinal highs e.g. the Mwalano ridge at the middle of the basin and Zombe ridge in the south. The stratigraphical columns from the drill logs of the appraisal drilling for coal reserve estimation; it appears that there were several complete episodes of depositional cycle, that is, the deposition of coarse grained sediments through to medium grained to fine to even very fine grained. Within these episodes, there were suitable environmental conditions for the deposition and formation of coal hence the different coal seams in a given stratigraphical column as is evident from the logs of different wells (figures 4.13, 4.14, 4.15 and 4.16).

4.4.1 Zombe Ridge

The Zombe ridge is at locality 11 (east of Zombe Township) found in the southernmost part of the study area, rising to about 645 metres above sea level and is about 30 metres above the surrounding areas. The trend/strike of the Zombe ridge which also acts as a fault scarp is 300^0; whose down throw is to the north. The Zombe ridge is regarded as the southernmost barrier ridge – which prevented water from flowing south thus forming a swamp which was ideal for the formation of coal found in the area north of Zombe. The ridge is comprised mainly of quartzite though some biotite gneisses are also found within it but has since been eroded because of its susceptibility to weathering.

Zombe ridge has an oval shape and trends north-south. The cores from Zombe I well suggests of a possibility of a fault and downthrown to the west by the Mui fault line. In the western side of this extension of the downthrown quartzite there are large deposits of lime and kankar limestone. The effects of the Zombe ridge forced the Mui River to change its flow channel, creating floodplains in the south and west of its course causing periodic flooding. These floodplains extend probably as far as the Zombe Chief's Camp in the south and also to the confluence of Ithangathi and Mui Rivers in the north. The presence of shallow quartzites caused thin water masses which are considered to have accelerated evaporation because of high temperatures. This evaporation caused preferential deposition of lime and the percolation of these lime rich fluids into adjacent sediments, which either on evaporation or evapotranspiration led to localised lime and/or kankar limestone deposition.

4.4.2 Mwalano Ridge (Yoonye Ridge)

The Mwalano ridge (also known as Yoonye hill) is at locality 45 (fig 3.1). The Mwalano or Yoonye hill (the most extensive Intrabasinal ridge of Maui Basin) is aligned with all other ridges, all trend approximately N-S. Mwalano ridge is considered to have played a significant role in the Mui River flood plains due to its location in the middle of the basin. The ridge is considered to have hindered the down flow of the Mui River thus initiating periodic channel overbank flows into the low-lying floodplains. This repetitive overflows or flooding into the floodplains is what accelerated and promoted the accumulation of floodplain deposits which were mostly carried as fine grained sediments in suspension. The source of sediments in the Yoonye-Mui floodplain is from the flooded Mui River but the exact locations where the river burst is indistinguishable and varies from Mui Market all the way downstream to Yoonye area. The deposition of sediments in the floodplains is closely associated to the formation of coal seams found in the area. The formation of the coal seams and deposition of the sediments in the floodplains occurred repetitively (in a cyclic manner) because the coal seams occur at different depths. The Yoonye-Mui floodplains Sediments, have fine deposits of widespread lime at distinct localities throughout the sub-basin e.g. near Mui Dispensary. The occurrence of these lime deposits in certain locations indicates that the area experienced extensive evaporations that lead to preferential deposition of lime. Lime deposition due to evaporation is only possible where water columns is small leading to temperature rise similar to that of the lakeshores or on the basined islands.

Characteristics of the ridge: - it appears that granitoid gneiss was overlain by biotite gneiss which has since been weathered and eroded as is evident at the foot of the ridge where the K-feldspars and plagioclases have weathered out leaving biotite crystals. The ridge also appears to have been a barrier to the Mui River thus forming the floodplains of Yoonye and the eventual Yoonye-Kateiko coalfields. Sediments of the Yoonye area are mainly fine grained sands implying that their source was far away (conglomerates, coarse grained sands are deposited in that order before the finer sands and finally silts and clays). This then means that the sediments from the nearby Nzia Hills never reached the Yoonye area or the Nzia Hills are much younger compared to the Yoonye Sediments.

Locality 55 south of Mathuki market exhibits the best bottommost (basal) sediments of the Mui Basin where huge boulders of quartzite conglomerates whose colour ranges from whitish grey to brownish white, through clear crystals of quartz are found. The quartzites have been affected by later jointing. Other areas where basal sediments were found are at the Masasini area.

4.4.3 The Kathande Rise

Kathande Rise forms a ridge in the southwest of the Mui Basin where it borders the Thua River basin and rises to about 764 metres above sea level. Kathande Rise is a granitic ridge which is believed to have formed by localized infusion of pegmatite fluids in jointed biotite gneisses. During the process of infusion of these fluids, the injection of weathering-resistant minerals (mainly quartz) strengthened the resultant granitic rock that withstood erosional processes over the period to stand above the erosion prone surrounding biotite gneisses. Outcrops at this ridge have several veins perhaps an indication that the granitic rocks here have undergone several deformations despite having resisted erosion. A closer look at rocky outcrops of the Kathande ridge shows that migmatization is more preferable in light coloured (felsic) rocks than in the biotite rich zones an indication that up warping was more prevalent in the light coloured rocks than the darker ones (biotite rich). The felsic rocks, since they are comprised of low-temperature minerals e.g. feldspars and quartz melted easily and was infused into a homogeneous granitic rock compared to those of the biotite rich zones. For this reason, veins in the biotite rich rocks are distinctly straight unlike those in felsic zones which are highly migmatized.

The southern edge of the Kathande ridge prevented the Mui Basin sediments from "wandering" into the Thua River basin and instead re-directed those southwards into the Zombe sub-basin. The high altitude of the ridge increased the depositional gradient of the Zombe sub-basin, thus depositing coarse grained, poorly sorted and angular sediments encountered while drilling the Zombe II well.

4.4.4 Mathuki and Adjacent Quartzite Ridge

The Mathuki ridge comprises purely of quartzite which is pure white crystalline quartz and rises to about 811 metres above sea level. Mathuki ridge forms part of the eastern basement rocks that partially project into the Mui Basin between Mathuki and Mui Markets which obstructs the down flow of Kathi and Mwanziu Rivers leading to overbank flooding. The Mathuki and adjacent ridges are considered to have caused the Isekele floodplain accumulations northwest of Kalitini market.

4.4.5 Upwarping and granitization mechanism in Mutito Ranges

Mutito Ranges and the adjacent hills of Baikanziu display granitoid gneisses of variable texture. Mutito granitoid display conspicuously coarse grained and well developed K-feldspars and quartz crystals whereas those of Baikanziu show aphanitic (fine grained homogenous rock – not seen by the naked eye) texture. The coarse grained crystals of Mutito Ranges meant that the crystallization process occurred slowly whereas that of the Baikanziu hills crystals was fast. Slow crystallization is only possible in the sub-surface or underground, based on this explanation therefore, the Mutito granitoid gneisses were initially covered by country rock (either of biotite gneisses or migmatites) that the granitoid gneisses intruded into. This explanation is supported by the presence of biotite gneiss on top of Mutito Range e.g. at localities 40 and 44. The biotite gneisses or the migmatites that covered the Mutito Range granitoid gneiss have been eroded over time due to their susceptibility to weathering leaving columnar granitoid gneisses. On the other hand, Baikanziu hills consist of fine-grained biotite gneisses comprising of a locally uplifted granitoid gneiss hill which incorporated unmelted lumps of biotite rocks. Evidence of granitization involving uplifting and quartzification processes has locally been well illustrated. In this granitization process, the pegmatizing/ quartzifying fluids as they pushed the overlying layers up apparently did not totally melt the biotite rich gneisses but rather increased their elasticity. However, at some contact boundary zones partial melting is displayed and is common where the biotite gneisses were thin leading into total homogeneity resulting to the formation of granitoid gneiss. The temperatures of the quartzitic fluids is considered either equal or slightly lower than that of the melting temperature of the biotite gneiss thus the inability to completely melt thick biotite gneiss, hence the sharp boundaries between the biotite gneiss and the quartzites. The aphanitic texture displayed by the granitoid gneisses of Baikanziu implies rapid cooling as found in near surface intrusion with thin overlying layer. Baikanziu granitoid gneisses are characterized by white colours possibly due to excessive diffusion of silica –rich fluids into the biotite gneisses and they display hollow depressions or voids which indicates a later dissolution of easily weathered rocks. These rocks are likely to have been lumps of biotite fragments in a silica-rich magma melt that brought about assimilation where a melt reacts with a pre-existing rock as demonstrated by the presence of several incomplete melted pieces of biotite rock within a granitoid rock.

4.5 Depositional sequence of Mui Basin Sediments

The deposition sequence of the Mui Basin is characterized by cyclic or rhymic sediments as in Table 4.1. They are sequences of sedimentary rocks characterized by repetitive patterns of different rock types (strata) within the sequence. Cyclic sediments occur where there is a repetition of a specific series of connected events that effects the environment the sediments are deposited in. Changes in the environment of deposition change the type and amount of sediments that are deposited, resulting in different sedimentary rock types. According to *en.wikipedia.org/wiki/cyclic_sediments, (2012)* cyclic sediments can be identified as either autocyclic or allocyclic.

Table 4.3 Showing lithology and depths where the cyclic marine environment appears to have ended

Name of well	Location of well in UTM coordinates	Depth in metres where the episode appears to end	Lithology (rock type) and descriptions
FPL 10	0407426E, 9888905N	89.65 – 99.00	Mottled Mudstone
FPL 06	0409234E, 9876587N	42.65 – 55.50 **117.70 – 121.25** **179.80 – 202.05**	Mottled sandstone **Mottled sandstone** **Mottled sandstone**
Kathonzweni III	0411284E, 9876566N	12.07 – 14.35 **31.43 – 51.55**	Mottled lime-rich-sandy mudstone **Mottled sandstone**
TOME 6	0411180E, 9872424N	80.17 – 99.48 **132.00 – 133.35** **141.00 – 148.46**	Mottled mudstone **Mottled mudstone** **Mottled claystones**
Yoonye 12	0411148E, 9870814N	72.75 – 78.00 **91.00 – 101.20** **141.10 – 144.00** **156.70 – 167.50**	Mottled sandy mudstone **Mottled mudstone** **Mottled mudstone** **Mottled mudstone**
FPL 09	0409263E, 9878926N	105.75 – 110.55 **162.00 – 167.65** **167.55 – 195.40**	Mottled mudstone **Mottled clayey sandstone** **Mottled sandy mudstone**

Autocycles are cyclic sediments that are created by processes that only take place within the basin that the sediments are deposited in. The Mui sediments are largely of the autocyclic type. Alloycycles are cycles of sediments caused by processes that also occur outside the depositional basin. Sea level fluctuations, climate changes and tectonic activity are examples of these kinds of processes.

The Mui Basin sediments can broadly be divided into three categories namely: - Recent Sediments (alluvial soils and lateritic soils), Mud rocks (comprising of mudstones, shales, claystones, lime clays, limestones and gypsum) and sandstones (and/or conglomerates). In most parts the mud rocks found in the basin are calcareous supporting the theory that some sediments of Mui were as a result of lithification of the skeletons of the small organisms containing carbonates dwelling in the shallow lake waters of the basin in the early stages of its formation. Calcareous mudstone and sandstone which are widespread in Mui Basin could have been formed through this process.

The Mui Sediments depositional environments appear to be from two different types namely: shallow marine environment (for the basal conglomerates and some sandstones found in the area) and either fluvial or alluvial (for mud rocks or the sandstones in the area). Conglomerates are present at the base of sequence laid down during marine transgression above an unconformity, and are known as basal conglomerates.

Figures 4.13, 4.14, 4.15 and 4.16 - show stratigraphic columns of selected drill wells from the basin. The general strata sequence of the Mui Sediments being sandstones/conglomerates as basal sediments then mud rocks (mainly mudstone and shale or lime clays) and finally alluvial soils. These sequence is repetitive an indication that the depositional environment kept on changing from high-energy or high flow-rate events to quieter, normal conditions.

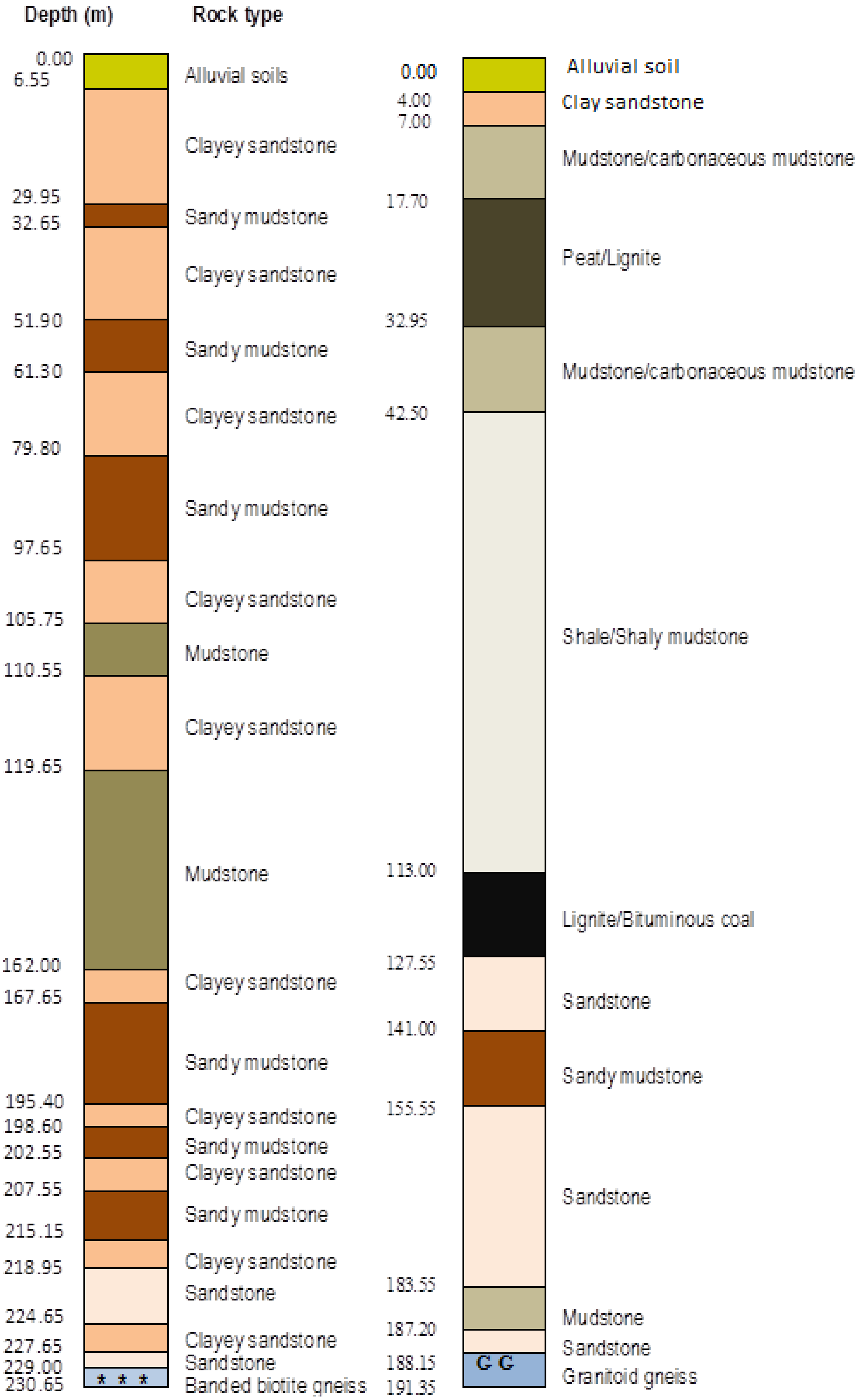


Figure 4.13 The stratigraphical columns of Foundation Piling Wells no 09 and 08 respectively

Foundation Piling wells number 09 and 08 are near Miambani Shopping Centre and near Kyamwenze Secondary School respectively; both are towards the western side of the basin (Block C). Although the wells are about 2 Km from each other FPL 09 did not encounter any coal bearing sediments (carbonaceous mudstone). The stratigraphical column of FPL 09 shows that from depths 0.00m to 6.55m comprises of Recent Sediments. From 6.55m to 32.65m deep it comprises of mud rock whereas from 32.65m to 51.90m comprises of sandstones; the sequence repeats itself from mud rock to sandstones till the basement rocks (Neoproterozoic Mozambique rocks). Stratigraphical column of FPL 08 indicate that the Recent Sediments are up to a depth of 4.00m. Sandstones follow and are between 4.00m to 7.00m; mud rocks are between 7.00m and 127.55m. The sequence repeats between sandstones and mud rocks till the basement rocks. In both wells as is the case in the sequence of Mui Sediments the basal sediments are the sandstones.

The thickness of each sequence varies from one unit to the other depending on the depositional environment. Mud rocks are deposited in low – energy to normal conditions whereas deposition of sandstones occurs during the high – energy /high flow – rate environments. Prolonged conditions of either depositional environment result to large thickness of a particular lithological unit in the sequence or vice versa as is evident from figure 4.13 above. FPL 08 comprises of a massive thickness of about 128m, (Recent Sediment from 0.00m to 4.00m and mud rocks from 4m to 127.55m); mainly due its proximity to the Mui River.

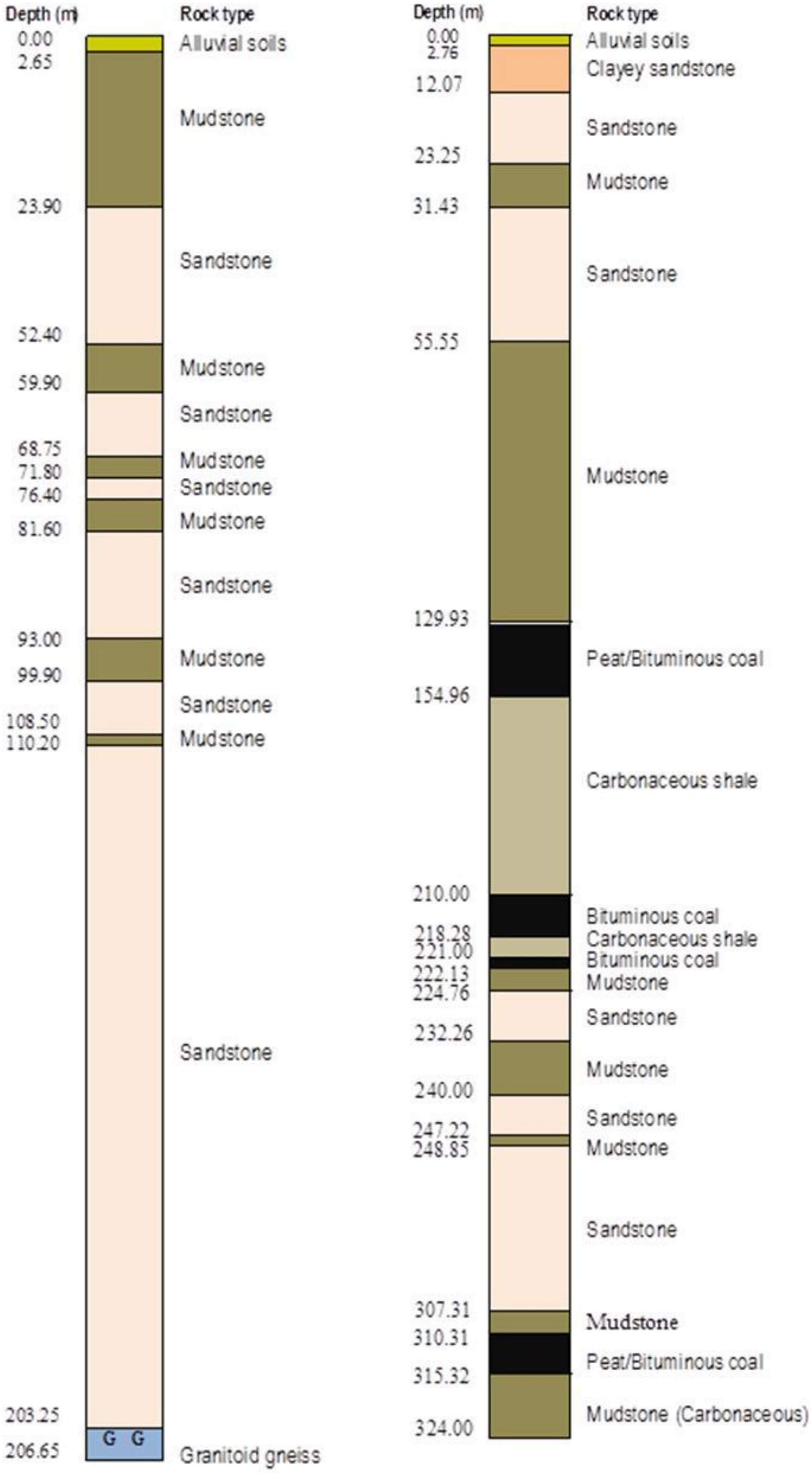


Figure 4.14 The stratigraphical columns of Foundation Piling 10 and Kathonzweni III Wells respectively

Foundation Piling well number 10 (fig 4.14) is near Kyamwenze Secondary School towards the western side of Block C. Kathonzweni III well is near Mui Administrative Centre (Kathonzweni Shopping Centre) at the middle of the basin (Block C). The two wells exhibit the repetitive deposition sequence which is typical of the sediments in the basin, but their thicknesses are remarkably different although they are relatively close to each other. The first 24.00m in FPL 10 well comprises of almost entirely of Recent Sediments (2.65m) and mud rocks (from 2.65 to 23.90m); whereas the sediments in the first 25.00m of Kathonzweni III well is basically that of sandstones (alluvial soils up to 2.76m then sandstone from 2.76 to 23.25m).

The sandstone thicknesses in FPL 10 are largely greater than those of the mud rocks (mainly the mudstone). However, the stratigraphical column of Kathonzweni III indicate that it mud rocks (mudstone, peat & coal or carbonaceous shales) represent the largest portions of its sediments. The variations in the thicknesses of the sediments suggest that the depositional environments were slightly different at the two wells. The deposition of sediments around the Kathonzweni Shopping Centre suggest a depositional environment which was much quieter and low – energy than that found around the Kyamwenze area which was characterized by high – energy as evidenced by the deposits of sandstone sediments. The factors influencing these environments include: - the proximity of the Mui River (which is believed to control the type and size of sediments deposited in the basin) and the distance of deposition of the sediments from their source. The other factor that may have influenced the thicknesses and type of sediments is the intra basinal highs: - Kathonzweni III well sediments' deposition was controlled also by the Mwalano (Yoonye) ridge which acted as a barrier to the flow of the Mui River.

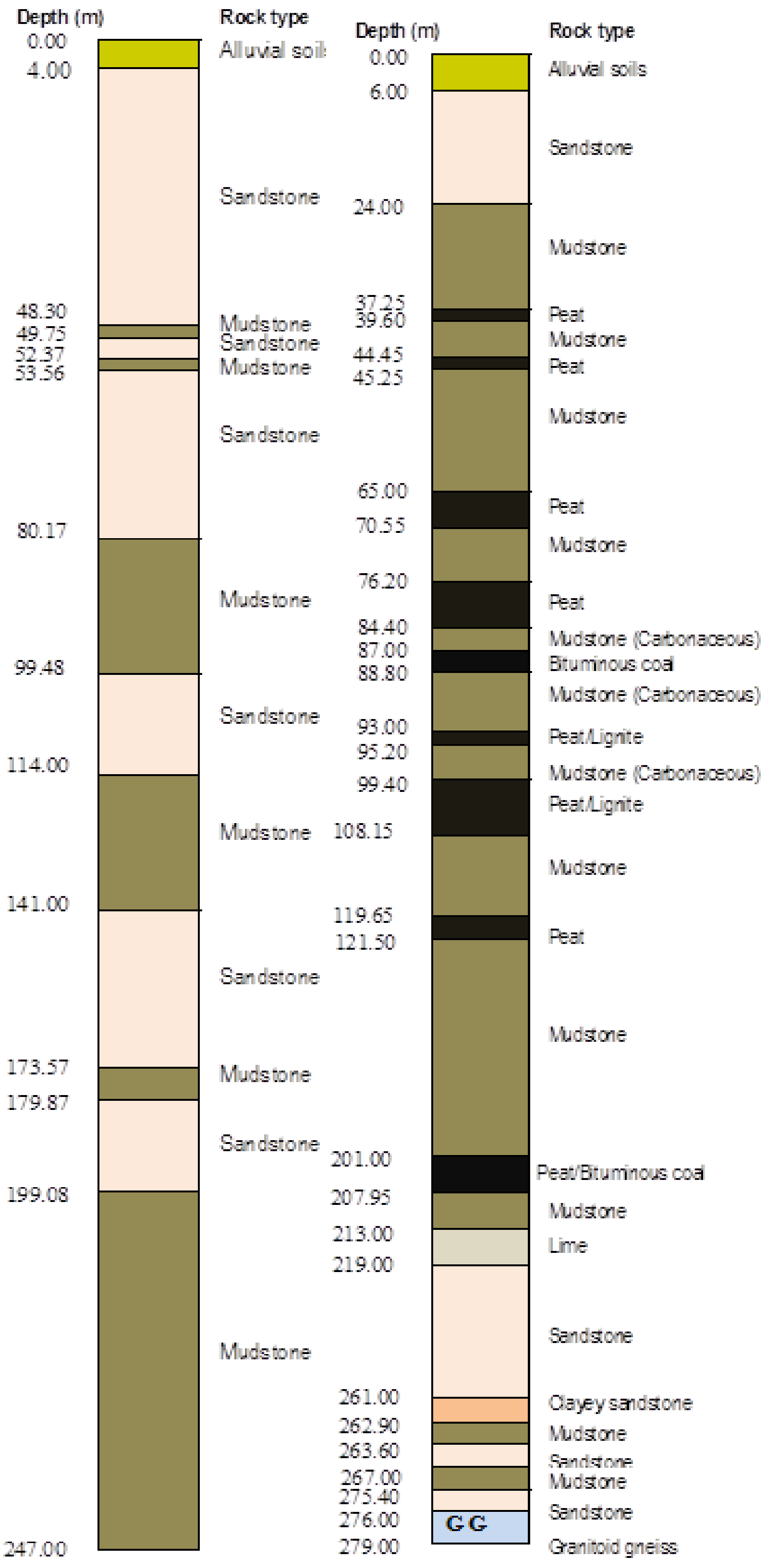


Figure 4.15 The stratigraphical columns of Tome VI and Kalitini II Wells respectively

Tome VI well is located almost south of Kathonzweni III well. Sandstones were the main sediments encountered in the first 50.00m in the stratigraphical column of Tome VI. Mud rocks sediments were much deeper comparing favourably to that found at FPL 9.

Kalitini II well is near Kalitini Shopping Centre to the east of Block D. Although Kalitini II exhibits the repetitive nature of the sediments in the basin – mud rocks represent the single largest thickness sequence of about 185m from 24.00m to 219.00m. Large thicknesses of mud rocks were found in most of the stratigraphical columns where coal bearing sediments were encountered (see the stratigraphical columns of other wells).

Yoonye 12 is to the south of Tome VI near Kwa Muta Shopping Centre. The top 70m of its stratigraphy comprises mainly of sandstones. From 70m to where the column ends (300m), the main sediments are those of mud rocks (mudstones, coal/peat or shale). The explanation for the type sediment deposited here is partly the proximity of Mui River and the distance of source of the sediments.

FPL 06 the deepest of the drilled wells is about 2.5km west of Kathonzweni III. Evidence of former river channel sediments in the stratigraphy of the well were encountered (the large rounded pebbles of sand grains tending to conglomerates and ‘fresh’ sand beds similar to those found in riverbeds). This explains the large sandstones/sands beds found in the stratigraphical column of FPL 06.

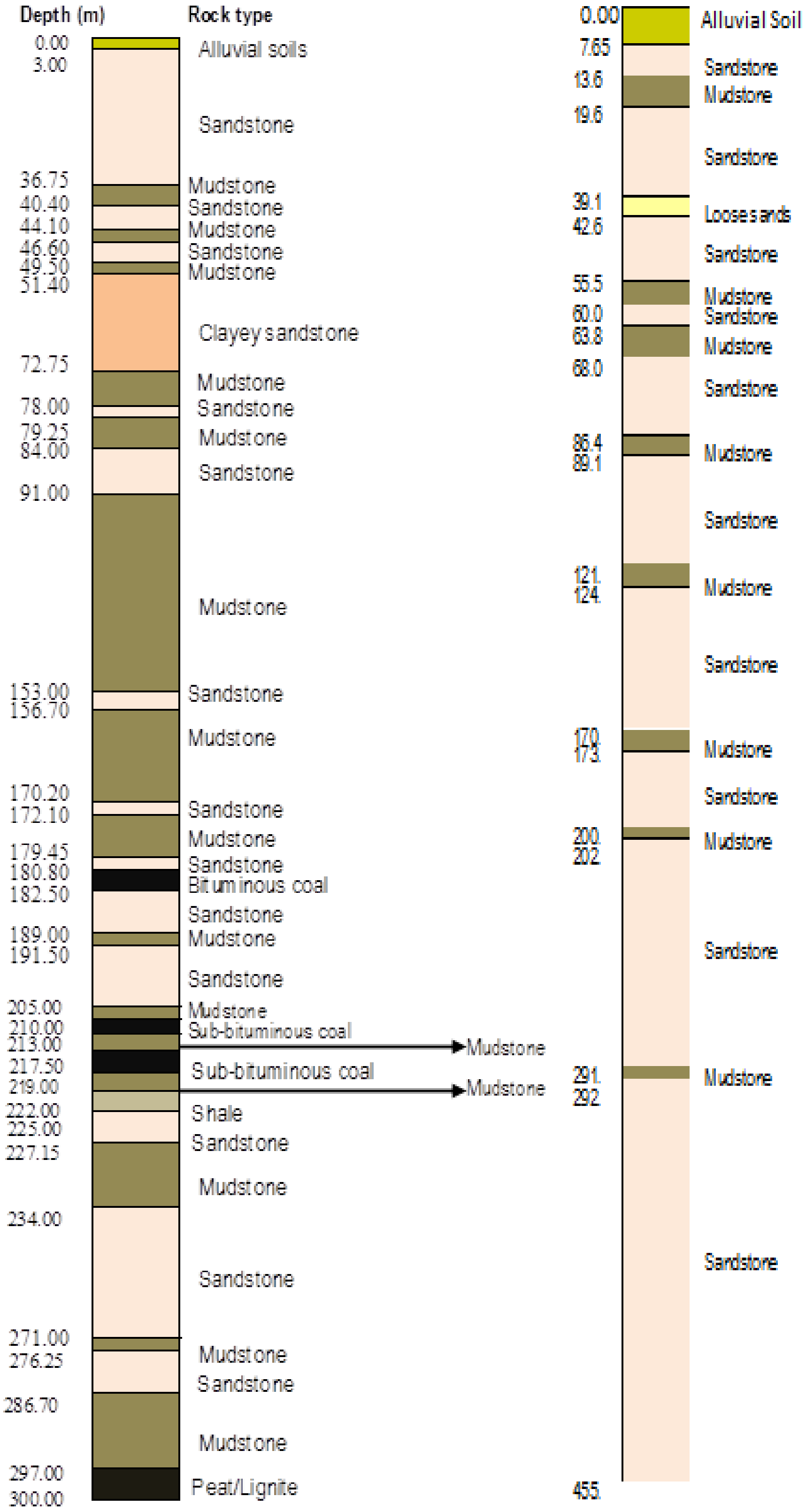


Figure 4.16 The stratigraphical columns of Yoonye 12 and Foundation Piling 06 respectively

4.5.1 Alluvial/Fluvial Soils

Alluvial/Fluvial Soils of the Mui Basin Sediments range in colour from black, dark brownish grey, brownish/whitish grey or reddish brown depending on the source of the sediments. Mui fluvial sediments were carried as bed load at the time of high flow-rate; whereas the alluvial sediments in the basin were deposited in areas of high relief and are coarse-grained. The source of Mui Sediments is from the weathered metamorphic rocks at the periphery of the basin and Intrabasinal high. The colour of these alluvial/fluvial sediments varies depending on the parent rock. Alluvial/fluvial sediments were deposited either along former river channels or at former alluvial valleys. Due to tectonic movements and the fairly gentle topography within the basin; river channels have been migrating over geological time as is evident from the logs of the cores recovered from the drill wells spread throughout the basin. Lateritic soils and Recent Sediments are found either occurring together with these sediments or associated with them.

4.5.2 Sandstones and Clayey Sandstones

Clayey sandstones in the Mui Basin are fine to medium grained and well sorted and sometimes grades to lime rich sandstone. Colour ranges from whitish/yellowish grey, mottled red (when calcareous) to greenish/brownish grey. Whereas sandstones colour ranges from greenish/whitish/yellowish grey, dark grey, brownish grey/mottled red to bluish grey (when calcareous). Grain size – medium to coarse but can be found from fine through very coarse grained and is friable to massive – at some localities sandstone grades to lime rich sandstone. The lime comes from the leaching of Kankar limestone or weathered crystalline marble at the periphery. Sandstones are deposited in high-energy environments.

4.5.3 Mudstone/Shale

The Mui mudstones or shales are fine grained clastic sedimentary rocks and are found to be closely associated with other mud rocks such as clays, claystones, lime, limestones and even gypsum. The coal bearing formations were found between these beds, although in very rear occasion coal beds were found between sandstones e.g. at Yoonye 12 well where coal seam is between sandstone beds between 180.80 to 182.50 metres (see figure 4.16). Mudstones/shales of the Mui basin range in colour from greenish/whitish/brownish grey, dark grey (tending to black), mottled red to grey. Mudstone/shale sediments were deposited as interbedded formations in a quieter, normal environment compared to that of sandstone deposition.

4.6 Evidence of cyclic sediments deposition and changes in environmental conditions of deposition

The stratigraphical columns in figures 4.13, 4.14, 4.15 and 4.16; shows that the sediments in the Mui Basin are autocycles that is sediments created by processes that take place within the basin. These sediments are mainly composed of either sandstones (and/or conglomerates) or mud rocks (mudstones or shales, clays or claystones, lime or the coal bearing formations) and alluvial soils. As indicated above depositional environments for the two types are different, namely high energy environments and low energy (quiet) environmental conditions. The limestone and calcareous mudstone or calcareous sandstones which form a greater part of the Mui Sediments support the theory that the Mui Basin sediments were deposited from water of a lake. A careful analysis of the logs from the cores recovered from the drill wells suggests that these shallow marine environment was also seasonal as is evident from the mottled formations found interbedded between non-mottled ones. Mottled formations form as a result of oxidation due to exposure and baking from the heat of the sun.

The occurrence of gypsum in the basin, although in small quantities is further evidence of shallow marine environment since gypsum as an evaporite is deposited from lake or sea. The seasonality of this lacustrine environment has been exhibited in various core logs from wells drilled for coal appraisal drilling and below is a few examples of end of an episode of the lacustrine event. The table below shows the location of the well where the core log were taken, the depth at which they were taken and last lithology formation before the next episode started.

CHAPTER 5: DISCUSSIONS, CONCLUSION AND RECOMMENDATIONS

5.1 Discussions

This research entailed a critical review of the previous geological and structural work and/or reports of the Mozambiquean Belt on the eastern parts of Kenya and Tanzania. The review enabled the author a much more insight into the general geological structures and structural trends found in the study area and its periphery. In order to develop a model of the evolution history and depositional sequence of the Mui Basin the following analysis was necessary:

1. The analysis of the orientations measured joints and veins.
2. The correlation of the cores recovered from the study area.

5.1.1 Deformation forces responsible for the formation of Mui Basin

From the analysis of the rose diagrams for both joints and veins the main stresses that were in operation the Mui Basin are two namely the tensional stress forces and the shear stress forces although in some few localities both forces (composite) were in operation. For the purposes of discussions under this section joints or veins are divided as those occurring either in the east or west of the basin (fig 3.1).

5.1.2 Characteristics of veins and joints on either side of Block A

Veins west of Block A are predominantly (171 out of 180 measured in the field) those of tensional stress deformation – indicating that initially the deformation forces acting in the west of Block A was that of tensile stress. The average trending of this tensile stress is 330º. Although veins east of this block were limited (only 19 were measured) they exhibited both shear and composite stress almost in equal measure. Initially therefore the deformation forces acting at the southernmost of eastern part of the basin was that of more than one stress.

Joints west of Block A were characterized by both tensional stresses (about 63% of those observed) and shear stress – an indication that recent deformational stress has been caused by both tensile and shear stresses. East of Block A – all the three types of stress were exhibited; but shear jointing being dominant (with about 67% of the measured).

5.1.3 Characteristics of veins and joints on either side of Block B

The veins west of Block B exhibited tensional stress and were trending almost N-S direction. East of this block the number of veins encountered was limited but they exhibited both shear (localities 19 &27) and tensional (locality 45) stress.

Joints west of Block B exhibited both shear (locality 44) and tensional (locality 36) stresses. East of Block B the predominant jointing is that of shear stress (about 93% of observed veins) except for locality 26 which exhibited tensional jointing.

5.1.4 Characteristics of veins and joints on either side of Blocks C & D

West of Blocks C & D tensional veins were dominant (89%) although some shear stress (localities 15 & 48) and composite stress (locality 46) were encountered. East of Blocks C & D all the veins encountered showed strong tensional stress.

Joints west of Blocks C & D, showed strong characteristics of shear jointing (79%) except for localities 15, 47 &63 (which exhibited tensional stress). East of these blocks the joints exhibited either shear stress (localities 32, 33, 51 &57) or composite stress (localities 50 & 58).

5.2 Conclusion

5.2.1 Deformation forces acting in the area resulting to the formation of the Mui Basin

5.2.1.1 West of Block A

The veins are predominantly those of tensional stress implying that the initial deformation was that of tensile – elongation. Areas which experienced this forces included the southernmost parts of the around the Kathande area (localities 5 & 12) and the Miambani – Kithumulani area (localities 35 & 36). The joints exhibited both tensile and shear characteristics (average trend for tensile stress is either 070º or 330º) implying that both deformation forces have been in operation in the near Recent almost in equal measure.

5.2.1.2 East of Block A

The number of veins observed east of this Block was limited (only 19), but they exhibited both shear and composite characteristics. The deformation force that operated east of Block A during the early stages of the basin formation was therefore a combination of both shear and tensional stresses. About 67% of the joints measured east of Block A showed shear stress implying that the predominant deformational forces over the recent geological history are that of shear stress.

5.2.1.3 West of Block B

Only 44 veins were measured west of Block B. All the veins west of this block exhibited tensional stress implying that initial deformation force was that of tensile in N-S direction. Joints west of Block B showed both tensional (43%) and shear (57%) almost in equal proportion. The Recent forces in this area (Mutito Ranges) is therefore both tensile and shear.

5.2.1.4 East of Block B

East of Block B no veins were observed. The joints on this side of the block showed predominantly shear stress except for locality 26 west of Manyoeni market (which exhibited tensional stress). Recent deformation force therefore is that of shear stress.

5.2.1.5 West of Blocks C & D

Veins west of blocks (C & D) all (except for localities 15 & 48 - exhibiting shear stress and locality 46 with composite stress) exhibited strong tensile stress. Except for these it can also be concluded that tensile stress was the initial predominant force that operated west of blocks C & D. On the other hand joints exhibited both tensional and shear stresses although shear is predominant (about 79% of them).

5.2.1.6 East of Blocks C & D

The veins east of blocks C & D all exhibited tensional stress implying the area also experienced tensile stress during the early stages of the basin formation. The joints however, indicate that the force has since changed over time to either shear stress (70%) or composite stress (30%).

5.2.1.7 Summary

West of the basin the initial force that was experienced was that of tensile stress; in other words tensile stress was primarily the dominant force when the was being formed. The only exception to this general observation being at locality 46 – west of Kyamwenze Secondary School; locality 48 – near Lundi market and locality 15 – the extreme north near Thitha market. In the south the Kathande – Kithumulani areas later stages however, experienced both tensile and shear stresses almost in equal magnitudes. Further north, the Mutito Range area later stages of the development of the basin both tensile and shear stresses were responsible for the basin's formation. However, in the second half north of Mutito Range all through to near Mutwangombe although both tensile and shear stresses are exhibited in the Recent past, shear stress is dominant.

East of the basin although limited veins were analyzed due the numbers available, the few analyzed shows that the initial predominant forces during the formation of the basin was also tensile stress; the exception being at locality 27 (west of Kithituni Primary School) which showed shear stress. However, later as the basin developed both tensile and shear stresses were in operation in the southernmost parts east of the basin although shear stress is predominant. Further north experienced shear stress in later stages of the basin formation except at locality 26 – west of Manyoeni market which experienced tensional stress. The remaining half north of Kithituni Primary School all the way to Kalitini area did experience in the later stages of the basin's formation both shear and composite stresses although shear stress was dominant in that region.

5.2.2 Depositional sequence of Mui Basin sediments

The Mui Basin sediments exhibit repetitive patterns of mud rocks and sandstones implying that the Mui Basin has been experiencing mainly two sets of depositional environments namely: - the high – energy and the low – energy (normal) conditions. The high – energy deposition environments resulted to the deposition of sandstones and/or conglomerates. The low – energy depositional environment in Mui Basin resulted to sediments deposits of mainly the mudstones, shales, and lime clays and in some places peat/coal, limestone and gypsum. Mui Basin sediments are of the autocyclic type (deposited from processes that occur within the basin) since there is no evidence that they were deposited as a result of either sea level fluctuations or tectonic activities. The widespread calcareous sediments found in the area are as a result of lithification of skeletons of the small organisms containing carbonates that are known to dwell in shallow lake waters of the basin in the early stages of its formation.

The mottled sediments commonly found throughout the Mui Basin were caused by the seasonal shallow marine environment. Mottled sediments are as a result of oxidation due to the sediments' exposure and baking from the sun's heat. The presence of gypsum further confirms the theory of seasonal shallow marine environment.

From the stratigraphy of the drilled wells the first to be deposited into the floor of the basin were the sandstones and/or conglomerates (for those wells that were drilled to the basement – to the Neoproterozoic Mozambique Belt rocks). These sediments are characterized by high – energy environments having very coarse (sometimes pebbly) to coarse grain sizes. Coal bearing sediments were generally found within the mud rocks beds – the only exception was found in the Yoonye 12 sequence at depths between 180.80m to 182.50m where coal was found between sandstones. Where coal was encountered mud rocks formed the single largest sediments deposits.

River channels within the basin seem to have migrated over geologic time; the evidence for this was found in the sediments recovered from FPL 06. The evidence for this is found in the large well rounded pebbles of sand grains (some tending to conglomerates) over large beds of sandstones/sands and the 'fresh' sands beds encountered during drilling. Source of the Mui sediments is mainly from the weathered metamorphic rocks at the periphery of the basin and to a lesser extent from weathered Intrabasinal highs within the basin.

5.3 Recommendations

During the study of the sequence of deposition of the Mui sediments; huge deposits of clays and lateritic soils were found to occur over the expansive basin. A detailed study of these clays should be undertaken in order to establish its suitability in its use in ceramic industry thus providing employment opportunities for the local people. The lateritic soils are known for the use in the construction industry for road building and can be very useful in the area which has rather poor road network. The other economic sediments found in the basin are fairly large deposits of lignite and coal beds, gypsum, limestone and/or lime clays. The coal deposits in the area has been Concessioned (two Blocks to a Chinese firm, the other two are underway). Limestone and/or lime clays are being mined in small scale by a ceramic factory located in Nairobi, but its development and exploitation can be improve if sufficient information and its reserve is available. Gypsum in the area has not been developed partly because of lack of information of its availability and its reserve potential. Quartzite which is found mainly on the Intrabasinal highs within the basin – especially that around Mathuki area are of very high quality and be used in construction industry for building of commercial and residential houses. More research work is therefore recommended to establish the reserve (quantities) of these economic sediments in order to develop them to improve the standards and living conditions of the local population.

Due to the scarcity of clean drinking water in the study area – drilled wells with water can be developed into water-points once the water has been tested and found to be good for human or livestock consumption.

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APPENDIX 1 UTM COORDINATES FOR THE LOCALITIES WHERE JOINTS/VEINS MEASUREMENTS WERE DONE AND THOSE OF DRILL WELL WHERE THE STRATIGRAPHICAL COLUMNS WERE DONE

LOCALITY COORDINATES IN UTM

Locality	Northing	Easting	Altitude (metres)	Locality's outcrop strike
01	0409750	9843784	724	330º
02	0408465	9842992	707	340º
03	0408018	9839537	643	353º
04	0408757	9838410	645	337º
05	0406258	9841529	653	315º
06	0408987	9835923	694	330º
07	0408514	9835812	739	350º
08	0415752	9839580	720	330º
09	0415789	9840546	680	320º
10	0415898	9840430	635	305º
11	0416847	9840629	645	300º
12	0409782	9842270	764	350º
13	0411800	9844581	654	330º
14	0411257	9846177	705-819	342º
15	0410692	9898804	967	358º
16	0418078	9840177	618	277º
17	0424997	9856044	693	015º
18	0415648	9863521	655	N/A
19	0418096	9864347	712	045º
20 `	0419458	9863627	719	330º

21	0415814	9846831	720	338º
22	0421930	9851000	724	340º
23	0424571	9846831	665	005º
24	0418101	9841948	595	310º
25	0424571	9835487	702	355º
26	0419638	9866267	728	353º
27	0418418	9867963	749	045º
28	0414288	9869074	730	350º
29	0418200	9841329	607	330º
30	0418393	9842191	689	000º
31	0417841	9843922		331º
32	0414299	9873184	697	335º
33	0416133	9872239	734	345º
34	0403393	9847414	676	330º
35	0402724	9853982	693	350º
36	0401100	9858201		342º
37	0405388	9870955	729	005º
38	0405182	9871174	741	312º
39	0403576	9870664	900	358º
40	0404707	9871507	755	343º
41	0407696	9877239	801	350º
42	0406993	9876715	760	008º
43	0406345	9879705	804	353º
44	0407225	9863092	1046	347º
45	0413869	9869212	772	348º

46	0406266	9884185	889	355º
47	0406616	9886217	801	004º
48	0406506	9887882	848	021º
49	0404413	9891704	911	350º
50	0415093	9878429	742	000º
51	0416350	9879605	766	357º
52	0414702	9882286	723	
53	0414626	9878755	705	
54	0414604	9882528	755	
55	0415142	9884137	808	350º
56	0414985	9884128	811	
57	0416391	9888878	790	022º
58	0417499	9890911	780	353º
59	0415728	9859592	645	
60	0426644	9873377		320º
61	0414483	9855515		
62	0406117	9886867	809	009º
63	0405590	9886718	822	350º
64	0404863	9887258	930	

COORDINATES OF WELLS WHERE STRATIGRAPHICAL COLUMNS WERE TAKEN

W1	0409234	9876587	W1	Fpl VI
W2	0409232	9881733	W2	Fpl VIII
W3	0409263	9878926	W3	Fpl IX
W4	0407516	9882294	W4	Fpl X
W5	0411284	9876566	W5	Kathonzweni III
W6	0411180	9872424	W6	TOME VI
W7	0411148	9870814	W7	Yoonye XII
W8	0414874	9889413	W8	Kalitini II

Note Fpl denotes Foundation Piling Limited, a company that was contracted to do appraisal drilling for coal reserve estimations and TOME denotes Turn O Metal Engineering Limited another company that was drilling for coal in the basin.

APPENDIX 2 VEINS AND JOINTS ORIENTATION IN DEGREES

Locality 01

Joints orientations:

335º,300º,315º,048º,325º,336º,335º,080º,045º,333º,325º,040º,003º,046º,334º & 295º

n=16.

Veins orientation:

330º,326º,336º,322º,340º,348º,333º,332º,324º,325º,320º,322º,333º,331º,335º,325º,329º,328º ,332º,333º,004º, 328º,335º,333º,324º,323º,325º,030º,275º,035º,353º,285º,030º,354º,330º,348º,358º,338º,332º, 340º,333º,322º, 334º,335º & 345º

n=45

Locality 02

Veins orientation:

340º, 332º & 336º

n=3

Locality 04

Joints orientation:

290º,280º,293º,313º,324º,334º,308º,070º,310º,080º,075º,080º,070º,082º,050º,055º,075º,058º, 065º,085º,063º & 070º

n=22

Locality 05

Joints orientation:

355°,342°,300°,320º,340°,000°,305°,015°,000°,345°,342°,023°,334°,352°,012°,356°,080° & 010°

n=18

Veins orientation:

355°,015°,010°,353°,015°,007°,010°,004°,025°,347°,349° & 026°

n=12

Locality 06

Veins orientation:

016°, 025° & 015°

n=3

Locality 12

Joints orientation:

000°,344°,357°,350°,343°,345°,333°,338°,337°,334°,323°,320°,333°,345°,334°,336°,328°,330°, 336°,339°,275°, 275°,070°,080°,085°,275°,285°,334°,338°,337°,082°,085°,333°,342°,343°,342°,345°,335°,336°, 333°,334°,336°, 075°,042°, 032° & 038°.

n=46

Veins orientation:

327º,335º,330º,331º,352º,331º,338º,336º,338º,287º,334º,350º,278º,347º,345º,338º,323º,330º,352º,352º,004º,005º,356º,356º,336º,340º,333º,320º,330º,355º,332º,333º,315º,335º,332º,323º,345º,326º,332º,354º,342º,340º,337º,345º, 340º & 000º

n=46

Locality 13

Joints orientation:

065º,075º,034º,327º,057º,070º,330º,330º,3330º,334º,334º,327º,334º,335º,334º,324º,074º,045º,072º,075º,015º,070º,015º,025º,337º,337º,007º,080º,085º,334º,345º,062º,342º,345º,341º,340º,346º & 085º

n=38

Veins orientation:

342º,325º,333º,330º,334º,340º,006º,003º,334º,320º,340º,344º,340º,337º & 332º

n=15

Locality 14

Joints orientation:

072º,069º,057º,064º,066º,070º,071º,077º,336º,070º,075º,072º,071º,068º,065º,062º,073º,342º,328º,326º,334º,069º,070º,068º,336º,059º,056º,073º,060º,065º,074º,073º,074º,079º,070º,070º,080º,080º,079º,080º,080º,072º, 086º,085º,064º,056º, 080º,090º,083º,074º,071º,082º,060º,075º & 065º

n=55

Veins orientation:

343º, 331º & 300º

n=3

Locality 15

Joints orientation:

358º,085º,355º,285º,282º,342º,285º,287º,075º,283º,286º,293º,015º,070º,082º,283º,272º,086º,
090º,293º,292º,
074º,085º,079º,082º,284º,280º,284º,287º,080º,082º,084º,082º,085º,080º,087º,277º,284º,275º,
278º,090º,085º, 082º,080º,273º,358º, 348º,293º,064º,035º,087º & 075º.

n=52

Veins orientation:

058º,295º,357º,007º,015º,020º,355º,005º,307º,293º,013º,005º,315º,009º,012º,007º,072º,004º,
286º,086º & 282º

n=21

Locality 16

Joints orientation:

300º,310º,300º,312º,011º,347º,016º,352º,345º,055º,310º,045º,025º,295º,045º,042º,288º,044º,
048º,000º,048º,
007º,018º,067º,296º,020º,019º,020º,026º,004º,010º,040º,039º,298º,014º,060º,065º,045º,353º,
002º,022º,024º, 027º,004º, 013º,011º,
062º,050º,043º,310º,043º,018º,065º,050º,055º,055º,045º,042º,048º,045º,046º & 052º.

n=62

Locality 17

Joints orientation:

354º, 016º, 280º, 015º, 310º & 297º

n=6

Locality 19

Joints orientation:

300º,325º,310º,041º,047º,032º,014º,018º,018º,028º,314º,344º,037º,308º,319º,286º,313º,298º,
316º,308º,288º,
085º,063º,025º,318º,294º,306º,297º,295º,023º,022º,028º,304º,033º,043º,333º,012º,317º,305º,
316º,047º,301º,
293º,036º,311º,052º,028º,296º,299º,294º,018º,312º,332º,282º,023º,327º,025º,045º,023º,335º,
327º,075º,333º, 319º,334º,325º,293º,344º,028º,
315º,278º,030º,310º,043º,302º,306º,330º,292º,306º,037º,050º,275º,315º & 033º

n=84

Veins orientation:

013º, 295º, 023º & 054º

n=4

Locality 20

Joints orientation:

344º,308º,310º,002º,000º,282º,317º,340º,322º,005º,045º,002º,015º,010º,007º,008º,005º,006º,
004º,006º,007º,
002º,088º,280º,322º,005º,009º,010º,335º,084º,347º,325º,084º,333º,300º,277º,275º,016º,020º,
335º,022º,043º, 315º,046º,055º,355º, 288º,335º,054º,040º,337º,052º,314º,345º,012º,018º &
357º

n=55

Locality 21

Joints orientation:

270º,278º,282º,000º,283º,275º,285º,070º,345º,320º,085º,072º,075º,276º,270º,304º,270º,277º, 028º,317º,066º,

330º,000º,273º,085º,085º,080º,340º,347º,346º,347º,285º,078º,273º,085º,085º,274º,276º,353º, 085º,076º,272º,

025º,024º,296º,298º,304º,294º,025º,028º,032º,055º,355º,034º,080º,278º,080º,270º,070º,062º, 355º,350º,347º,

070º,065º,276º,085º,358º,000º,293º,285º,043º,065º,303º,065º,083º,085º,320º,070º,060º,073º, 075º,357º,355º,

007º,073º,065º,276º,277º,270º,081º,275º,026º,282º,270º,281º,286º,350º,353º,355º,018º,022º, 074º,028º,272º, 081º,088º,338º,074º,086º,277º,272º,038º,050º,079º, 078º,270º,086º,085º,293º,082º,085º,286º,356º,057º,352º,355º,082º,278º,318º,028º,326º,325º, 000º,061º,064º, 058º,351º, 000º,356º,008º,006º,320º,310º & 310º.

n=144

Locality 22

Joints orientation:

018º,027º,017º,357º,330º,328º,308º,342º,290º,356º,350º,348º,010º,012º,063º,358º,325º,002º, 002º,280º,355º,

333º,330º,345º,315º,325º,080º,014º,026º,085º,073º,323º,325º,333º,318º,070º,075º,355º,352º, 063º,059º,062º,

068º,025º,050º,000º,080º,340º,315º,325º,326º,300º,005º,300º,002º,014º,055º,282º,294º,300º, 343º,000º,355º, 291º,070º,270º,270º,065º,074º& 075º

n=70

Locality 23

Joints orientation:

305º,300º,025º,288º,303º,305º,000º,000º,049º,048º,080º,282º,280º,064º,085º,303º,305º,270º, 070º,327º,052º, 055º,300º,082º,296º,084º,065º,270º,076º,086º,072º,273º,078º,297º,302º,078º,289º,286º,277º, 296º,280º,279º, 270º,286º,065º,291º,292º,290º,084º,062º,295º,060º,085º,057º,065º,306º,315º,296º,296º,025º, 300º,275º,065º, 030º,046º,285º,270º,082º,065º, 353º,063º,307º,335º,292º,333º,334º,285º,343º,018º & 020º

n=80

Locality 24

Joints orientation:

018º,062º,050º,051º,010º,330º,042º,333º,010º,333º,342º,055º,296º,058º,045º,052º,047º,016º, 062º,293º,270º, 340º,305º,021º,303º,300º,298º,030º,307º,315º,315º,010º,025º,018º,303º,036º,303º,305º,333º, 065º,055º,047º, 309º,304º,009º,006º, 005º,355º & 046º

n=48

Veins orientation:

345º, 333º, 333º, 320º, 308º, 318º, 315º, 325º, 012º & 011º

n=10

Locality 25

Joints orientation:

326º,335º,270º,003º,021º,010º,012º,295º,310º,276º,274º,085º,009º,038º,015º,013º,276º,005º, 028º,000º,080º, 300º,310º, 277º,285º,286º,312º,006º,088º & 330º

n=30

Locality 26

Joints orientation:

320º,079º,273º,078º,047º,296º,280º,275º,337º,276º,025º,300º,315º,313º,283º,318º,342º,285º, 312º,019º,355º, 300º,015º, 315º & 300º

n=25

Veins orientation:

353º & 340º

n=2

Locality 27

000º,080º,058º,305º,300º,312º,322º,000º,024º,078º,277º,048º,080º,010º,333º,325º,335º,335º, 352º,270º,060º, 025º,345º,000º,016º,000º,350º,345º,335º,020º,027º,008º,000º,000º,077º,030º,000º,025º,080º, 052º,045º,315º, 315º,311º,309º,310º, 312º,309º,310º,307º,311º,045º,055º,060º,060º,015º,007º,310º,025º & 022º

n=61

Veins orientation:

290º, 315º, 065º, 045º, 060º, 040º, 052º, 085º, 305º & 040º

n=10

Locality 28

Joints orientation:

075º,315º,298º,000º,282º,086º,081º,044º,062º,087º,279º,081º,078º,300º,073º,348º,064º,075º, 300º,073º,075º, 078º,076º,300º,285º,293º,340º,335º,339º,324º,325º,320º,062º,065º,078º,010º,078º,082º,306º, 085º,075º,071º, 353º,075º,073º,069º,062º,326º,302º,276º,063º,085º,078º,082º,075º,076º,074º,075º,077º,298º, 333º,012º,014º, 065º,064º,072º,022º,070º,019º,354º,322º,011º,076º,063º,324º,276º,034º,274º,355º,041º,002º, 016º,015º,064º, 067º,065º,060º,085º,084º,083º,320º,004º,358º,009º,311º,075º,316º,341º,080º,281º,316º,007º, 284º,066º,045º, 350º,326º,348º,318º,008º,310º,276º,284º,274º,275º, 285º,041º,042º,085º,314º,313º,334º & 275º.

n=123

Locality 29

Joints orientation:

083º,061º,332º,358º,021º,327º,007º,072º,046º,027º,336º,030º,056º,332º,294º,322º,060º,022º, 003º,021º,354º, 011º,294º,346º,353º,327º,314º,276º,292º,062º,055º,333º,044º,072º,050º,325º,320º,323º,043º, 314º,316º,332º, 002º,323º & 003º

n=45

Locality 31

Joints orientation:

326º,318º,008º,320º,286º,005º,340º,065º,066º,330º,337º,323º,320º,338º,318º,339º,352º,016º, 325º,326º,328º, 317º,322º,028º,333º,335º,335º,024º,323º,310º,021º,334º,085º,003º,001º,014º,276º,315º,075º, 054º,314º,308º, 335º,322º,078º&306º

n=46

Veins orientation:

315º, 310º, 310º, 350º, 324º, 339º, 000º, 027º & 302º

n=9

Locality 32

Joints orientation:

302º,275º,333º,279º,294º,028º,011º,015º,001º,007º,012º,326º,013º,324º,315º,300º,006º,026º, 082º,018º,033º,
349º,033º,270º,028º,338º,310º,308º,305º,313º,055º,066º,069º,327º,327º,008º,324º,319º,016º, 003º,315º,316º, 322º,298º,030º,060º, 076º,302º,292º,352º,346º & 047º

n=52

Locality 33

Joints orientation:

347º,352º,290º,357º,077º,278º,276º,276º,275º,355º,075º,274º,330º,336º,345º,072º,077º,075º, 076º,081º,082º, 346º,283º, 069º,352º,083º,088º,351º,340º,339º & 084º

n=31

Veins orientation:

009º

n=1

Locality 34

Joints orientation;

345º,348º,076º,059º,055º,043º,330º,044º,331º,074º,068º,052º,061º,333º,325º,330º,340º,074º, 072º,321º,332º, 358º,352º, 002º,008º,051º,066º,065º,045º,049º,026º,053º,044º,066º,085º,071º,035º & 270º.

n=38

Veins orientation:

332º,335º,323º,333º,325º,000º,352º,354º,320º,324º,323º,313º,316º,333º,325º,345º,346º,330º, 336º,320º,315º, 313º,331º, 314º,308º,286º,333º,335º,332º,062º & 338º.

n=31

Locality 35

Joints orientation:

070º,075º,063º,035º,060º,085º,081º,084º,063º,061º,085º,083º,088º,086º & 282º

n=15

Veins orientation:

343º,340º,338º,342º,304º,015º,075º,331º,353º,075º,348º,321º,355º,353º,358º,011º,009º,347º, 358º,355º,347º & 019º

n=22

Locality 36

Joints orientation:

280º,066º,087º,275º,010º,081º,042º,088º,270º,079º,270º,080º,058º,278º,077º,058º,060º,074º, 059º,053º,060º, 278º,277º, 061º,068º,081º,075º,070º,072º,352º,358º,000º,083º,357º,066º & 055º

n=36

Veins orientation:

355º,003º,347º,348º,345º,352º,349º,342º,332º,333º,346º,342º,005º,343º,340º,338º,323º,355º,
000º,002º,356º, 350º,348º, 355º,004º,006º,357º & 350º

n=28

Locality 37

Joints orientation:

310º,306º,307º,305º,304º,310º,305º,309º,304º,317º,322º,316º,303º,307º,302º,301º,322º,315º,
316º,342º,045º,
049º,044º,032º,038º,030º,032º,029º,029º,036º,028º,026º,025º,030º,023º,029º,008º,018º,016º,
025º,030º,024º,
023º,085º,073º,074º,079º,073º,074º,081º,077º,275º,325º,330º,034º,281º,315º,305º,025º,280º,
287º,033º,032º,
345º,035º,355º,018º,070º,076º,343º,348º,318º,306º,314º,000º,000º,075º,081º,291º,002º,325º,
032º,016º,035º,
318º,026º,032º,352º,320º,052º,322º,285º,070º,055º,275º,285º,273º,282º,320º,293º,285º,285º,
002º,005º,065º, 085º,009º,355º,353º,088º,345º,353º,060º,354º,342º,
322º,290º,295º,294º,308º,305º,310,302º & 308º

n=124

Locality 39

Joints orientation:

020º,004º,013º,300º,000º,282º,293º,290º,000º,293º,018º,018º,010º,075º,008º,004º,015º,012º,
012º,022º,027º, 275º,017º, 016º,025º,010º,300º,298º,027º,020º,015º,010º,075º,072º,298º,297º
& 346º

n=37

Veins orientation:

010º,012º,010º,068º,015º,025º,040º,008º,072º,015º,000º,005º,004º,002º,002º,352º,004º,014º, 008º,014º,009º,
358º,002º,003º,012º,000º,011º,004º,003º,002º,348º,003º,358º,357º,000º,359º,355º,354º,006º, 022º,006º,010º,
001º,003º,004º,007º,000º,002º,357º,358º,354º,342º,351º,347º,345º,346º,345º,356º,354º,000º, 338º,020º,343º, 350º,000º,342º,350º & 347º

n=68

Locality 40

Joints orientation:

050º,060º,074º,058º,070º,045º,040º,342º,338º,289º,357º,055º,050º & 063º

n=14

Veins orientation:

345º,349º,346º,344º,350º,344º,340º,347º,350º,348º,338º,002º,010º,340º,328º,327º,332º,333º, 342º,353º,354º, 358º,340º, 346º,344º,337º,354º,022º,341º,015º,330º,332º & 356º

n=33

Locality 41

Joints orientation:

344º,285º,275º,348º,345º,353º,287º,073º,342º,347º,273º,336º,327º,345º,290º,025º,319º,027º, 017º,289º,022º,
002º,014º,035º,000º,329º,325º,353º,019º,355º,357º,358º,285º,356º,023º,010º,090º,274º,272º, 085º,343º,015º,
313º,300º,305º,008º,015º,295º,313º,010º,023º,025º,316º,285º,295º,011º,011º,013º,305º,310º, 015º,280º,013º, 012º,019º,287º,025º & 292º

n=68

Veins orientation:

008º,010º,020º,018º,014º,015º,013º,016º,015º,015º,016º,017º,010º,011º,004º & 020º

n=16

Locality 42

Joints orientation:

013º,085º,011º,004º,004º,015º,359º,090º,015º,295º,007º,011º,002º,065º,065º,285º,075º,282º,
080º,060º,009º, 357º,003º, 006º,075º,070º,026º,022º,305º,285º,083º,011º,009º & 010º

n=34

Veins orientation:

020º,011º,014º,011º,016º,012º,024º,356º,014º,010º,012º,010º,014º,013º,003º,015º,017º,010º,
012º,011º,020º,
008º,013º,012º,008º,014º,020º,021º,025º,026º,025º,020º,018º,019º,015º,016º,014º,014º,017º,
015º,015º,017º, 026º,005º,357º,005º, 010º,013º,009º,007º,011º & 006º

n=52

Locality 43

Joints orientation:

084º, 075º, 050º & 085º

n=4

Veins orientation:

008º,017º,021º,342º,351º,343º,354º,022º,359º,358º,018º,015º,353º,354º,004º,352º,357º,013º,
352º,290º,350º,
346º,030º,001º,355º,020º,355º,356º,350º,313º,350º,350º,002º,012º,320º,317º,330º,340º,017º,

355º,357º,003º,
347º,358º,025º,037º,010º,358º,355º,000º,004º,003º,359º,355º,000º,012º,007º,010º,002º,356º,
353º,004º,015º, 007º,353º,352º,357º,348º,356º, 358º,000º & 007º

n=72

Locality 44

Joints orientation:

348º,355º,008º,344º,355º,073º,352º,345º,090º,024º,064º,014º,073º,062º,075º,274º,344º,084º,
004º,350º,082º,
078º,359º,002º,076º,353º,084º,086º,276º,085º,086º,010º,034º,348º,350º,355º,359º,026º,005º,
295º,072º,080º, 085º,284º,039º,035º, 003º & 084º

n=48

Veins orientation:

351º,352º,011º,046º,013º,003º,333º,330º,334º,004º,346º,021º,318º,007º,344º & 357º

n=16

Locality 45

Joints orientation:

080º,320º,276º,279º,016º,359º,083º,278º,019º,017º,020º,355º,013º,019º,023º,002º,001º,000º,
014º,352º,280º, 280º,276º, 090º,086º,085º,083º,083º,086º,328º,320º,080º & 084º

n=33

Veins orientation:

355º,352º,353º,354º,357º,350º,353º,357º,354º,346º,353º,356º,355º,349º,348º,354º,070º,354º,
358º,358º,000º, 022º,022º, 004º,003º,357º,020º,020º, 017º,014º,020º & 346º

n=32

Locality 46

Joints orientation:

298º,290º,293º,290º,282º,300º,082º,078º,305º,290º,279º,282º,278º,087º,349º,318º,008º,281º,273º,275º,276º,
320º,078º,280º,287º,347º,067º,072º,275º,343º,342º,077º,083º,076º,284º,282º,008º,349º,353º,007º,347º,077º,
302º,303º,290º,304º,306º,298º,296º,302º,067º,289º,300º,067º,009º,014º,003º,285º,070º,294º,290º,353º,275º,
287º,385º,288º,350º,323º,354º,350º,345º,000º,354º,349º,343º,345º,350º,349º,340º,346º,343º,344º,356º,347º, 347º,352º & 345º

n=87

Veins orientation:

046º,052º,317º,280º,294º,284º,351º,046º,340º,088º,080º,005º,337º,338º,003º,036º,019º,290º,290º,030º,013º, 075º,069º, 049º & 050º

n=25

Locality 47

Joints orientation:

300º,000º,002º,021º,020º,315º,313º,317º,357º,007º,357º,284º,004º,345º,343º,012º,308º,304º,305º,317º,344º,
312º,292º,295º,307º,313º,283º,357º,312º,308º,309º,307º,276º,006º,342º,303º,322º,302º,309º,299º,307º,306º, 304º,304º,306º,305º, 312º & 307º

n=48

Veins orientation:

003º,000º,002º,011º,034º,030º,020º,027º,358º,025º,022º,345º,337º,016º,001º,354º,340º,327º,014º,328º,353º

,344º,342º,347º,346º,347º,000º,001º,011º,001º,012º,004º,005º,032º,355º,353º,356º,358º,357º, 354º,004º,002º, 003º,001º,009º,000º,010º,003º,002º,358º,000º,005º,008º,002º,359º,004º,006º,010º,012º,010º, 005º,007º,006º, 005º,013º,008º,006º,008º,012º, 008º,013º,023º,014º & 010º

n=74

Locality 48

Joints orientation:

272º,015º,003º,304º,290º,305º,300º,305º,016º,318º,313º,293º,307º,310º,348º,022º,025º,311º, 346º,311º,302º, 295º,310º, 285º,007º,008º,013º,005º,011º,008º,357º,320º & 273º

n=33

Veins orientation:

018º, 026º, 008º, 020º, 018º, 315º, 009º, 315º & 013º

n=9

Locality 49

Joints orientation:

354º,353º,280º,003º,357º,350º,004º,006º,275º,273º,274º,345º,356º,272º,359º,353º,357º,273º, 271º,350º,353º, 002º,000º,280º,352º,087º,291º,297º,298º,296º,299º,296º,354º,343º,340º,271º,276º,358º,357º, 322º,274º,321º, 274º,294º,321º,323º, 325º,271º,086º,344º,010º,275º,278º,318º,279º & 274º

n=56

036º,042º,044º,043º,054º,059º,057º,060º,063º,046º,052º,028º,046º,051º,354º,072º,053º,052º, 051º,025º,081º, 064º,065º, 033º,006º,285º,323º,357º,002º,332º,042º,018º & 336º

n=33

Locality 50

Joints orientation:

336º,032º,306º,017º,006º,344º,059º,050º,307º,067º,004º,015º,079º,055º,297º,005º,340º,288º, 025º,335º,063º, 070º,003º, 005º,025º,060º,354º,359º,035º,346º,322º,338º,005º,004º,347º,298º,062º,042º,028º,324º & 045º

n=41

Veins orientation:

356º,358º,006º,303º,356º,050º,018º,351º,024º,010º,008º,012º,330º & 357º

n=14

Locality 51

Joints orientation:

351º,280º,285º,282º,338º,357º,286º,282º,353º,357º,285º,339º,344º,350º,064º,280º,358º,064º, 355º,356º,283º, 276º,000º,040º,075º,055º,284º,002º,281º,288º,274º,272º,278º,348º,347º,281º,088º,350º,330º, 341º,276º,280º, 350º,348º,350º,046º, 040º,304º,322º & 014º

n=50

Veins orientation:

000º,000º,350º,355º,000º,341º,344º,334º,333º,342º,280º,350º,348º,345º,339º & 000º

n=16

Locality 57

Joints orientation:

074º,080º,285º,063º,070º,065º,063º,065º,064º,312º,070º,020º,075º,075º,072º,070º,075º,017º, 088º,068º,353º, 355º,350º, 273º,275º,087º,080º,270º,328º,022º,037º,032º,030º & 035º

n=34

Locality 58

Joints orientation:

002º,000º,344º,345º,346º,050º,354º,056º,004º,010º,055º,025º,325º,324º,039º,303º,296º,304º, 016º,346º,340º, 010º,293º, 300º,038º,042º,036º,038º,320º & 036º

n=30

Veins orientation:

025º,070º,039º,048º,040º,040º,045º,045º,354º,045º,042º,041º,053º,069º,057º,012º,050º,046º, 045º,046º,035º, 046º,042º, 042º,351º & 045º

n=26

Locality 62

Joints orientation:

310º,285º,075º,015º,080º,003º,308º,306º,020º,305º,020º,305º,305º & 018º

n=14

Veins orientation:

014º,000º,014º,010º,010º,012º,005º,017º,005º,005º,020º,020º,008º,023º,007º,012º,015º,016º, 010º,027º,014º, 014º & 012º

n=23

Locality 63

Joints orientation:

320º,351º,347º,340º,358º,003º,355º,353º,359º,359º,002º,353º,353^0,000º,357º,357º,355º,357º & 000º

n=19

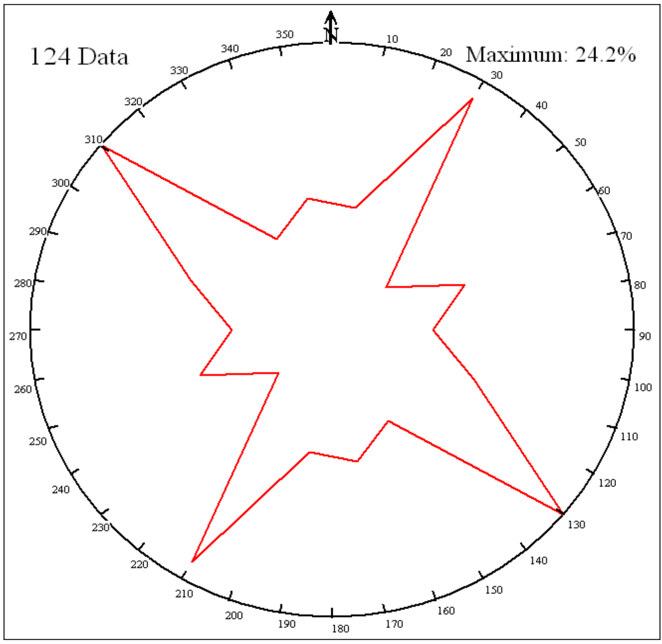
Veins orientation:

315º,010º,022º,000º,020º,313º,005º,330º,358º,302º,320º,300º,273º,325º,069º,050º,075º,075º, 355º,045º,018º,
026º,035º,036º,037º,014º,035º,037º,032º,030º,036º,027º,030º,035º,032º,025º,027º,028º,030º, 030º,023º,024º, 037º,032º,021º,037º, 032º,046º,028º,032º & 026º

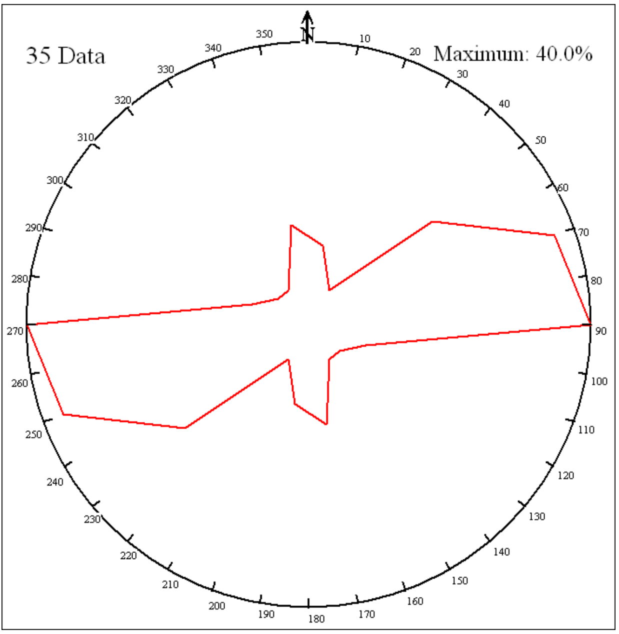
n=51

APPENDIX 3 ROSE DIAGRAMS OF THE JOINTS MEASURED IN THE FIELD

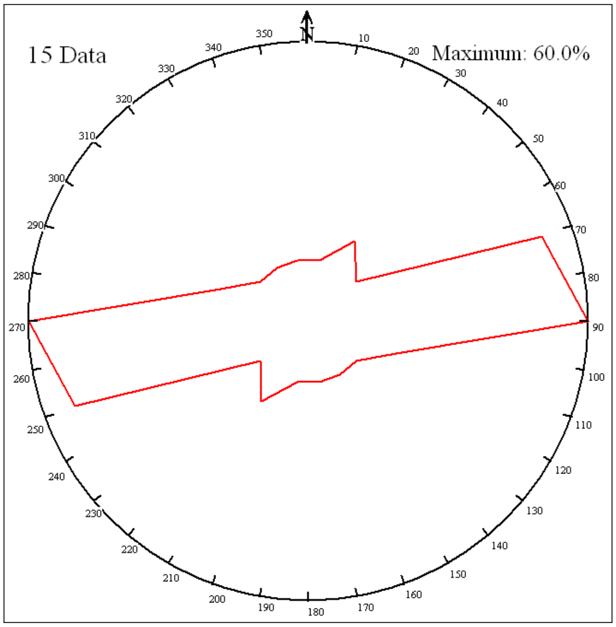
Rose Diagrams for the joint measured in the field at localities indicated below



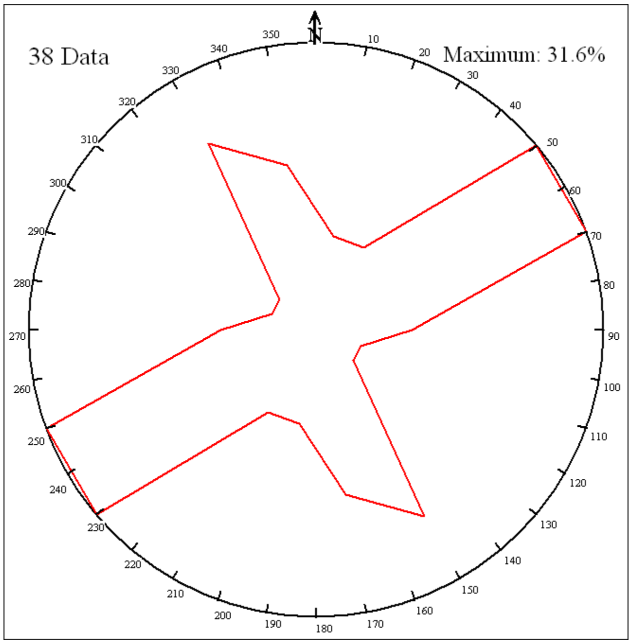
L37 Shear joints



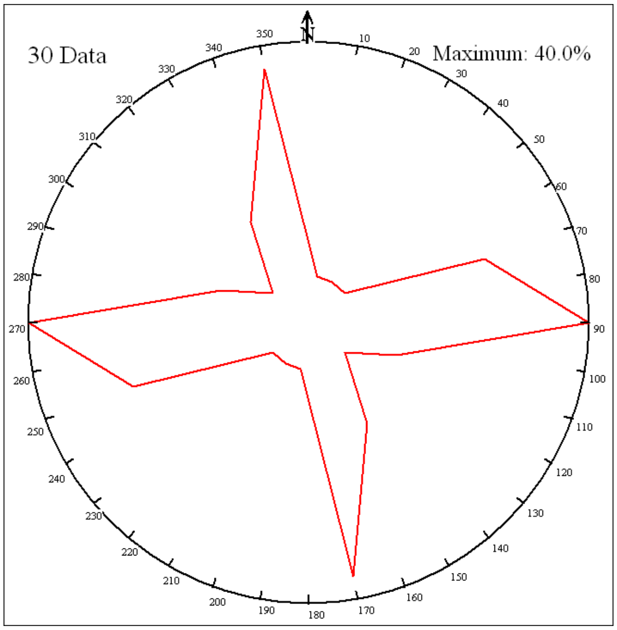
L36 Tensional joints



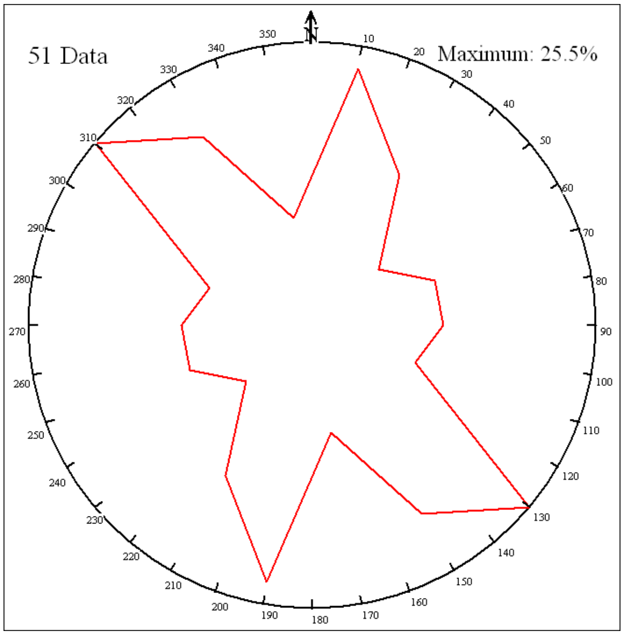
L35 Tensional joints



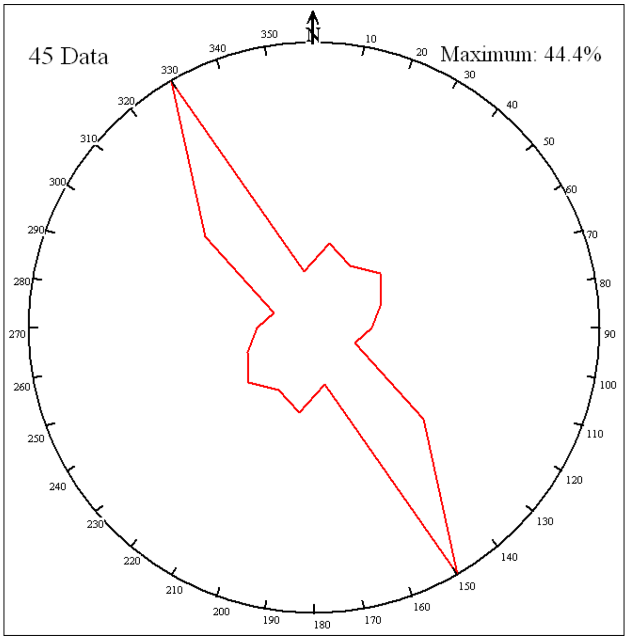
L34 Shear joints



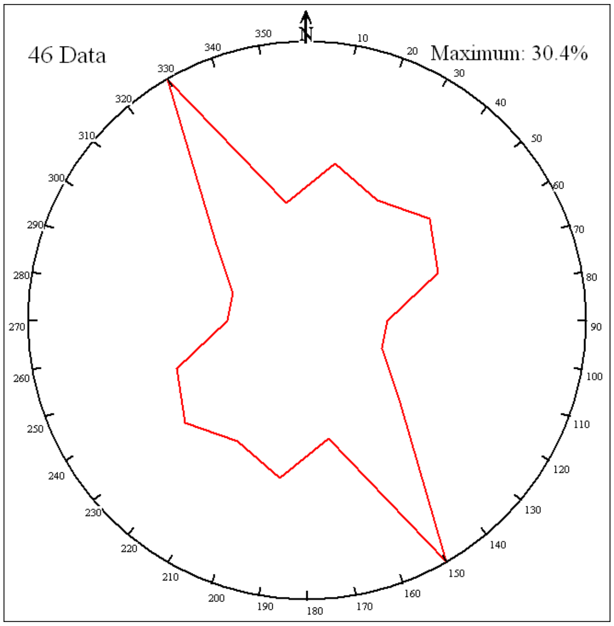
L33 Shear Joints



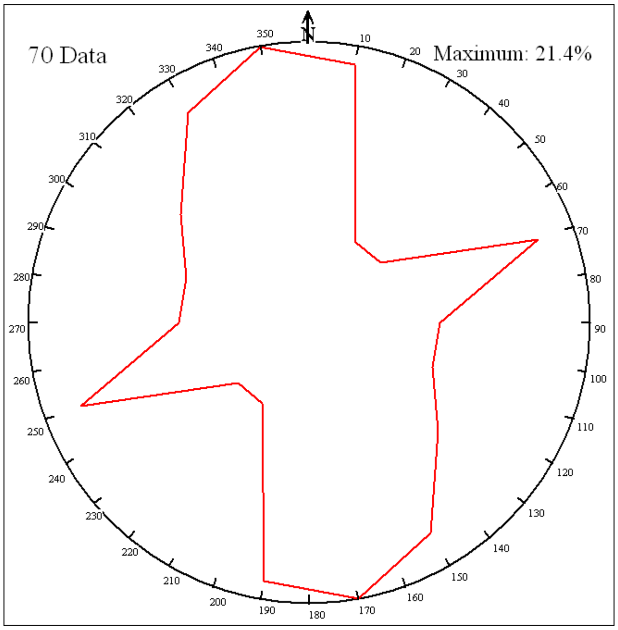
L32 Shear joints



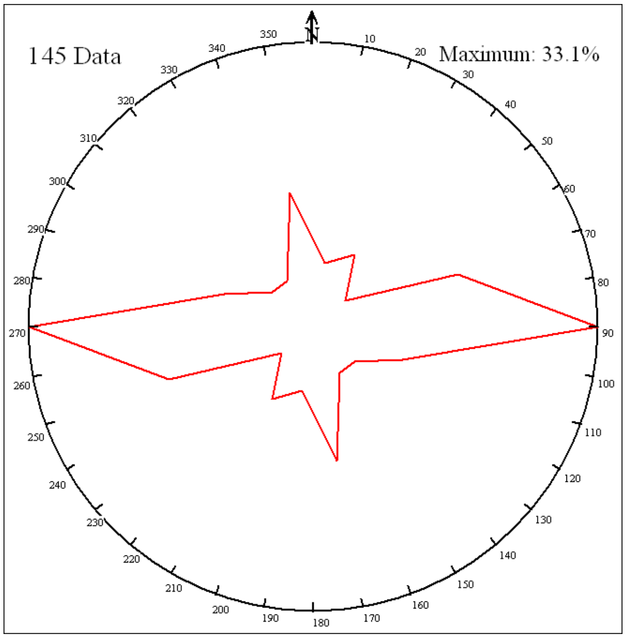
L31 Tensional joints



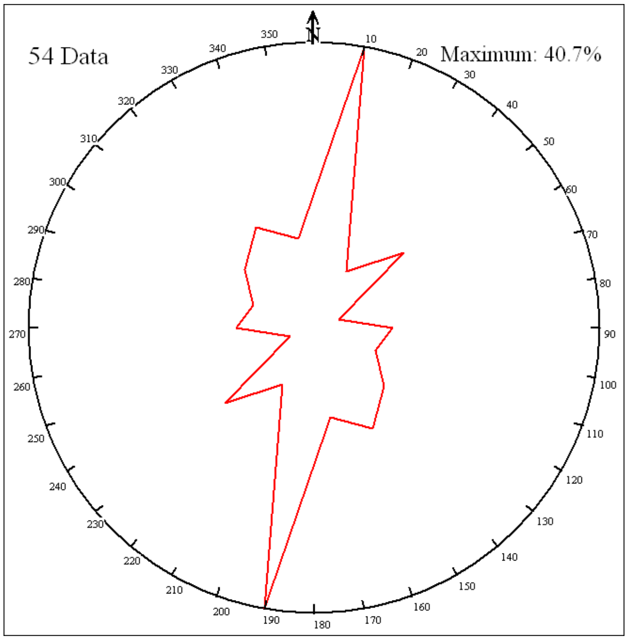
L29 Shear joints



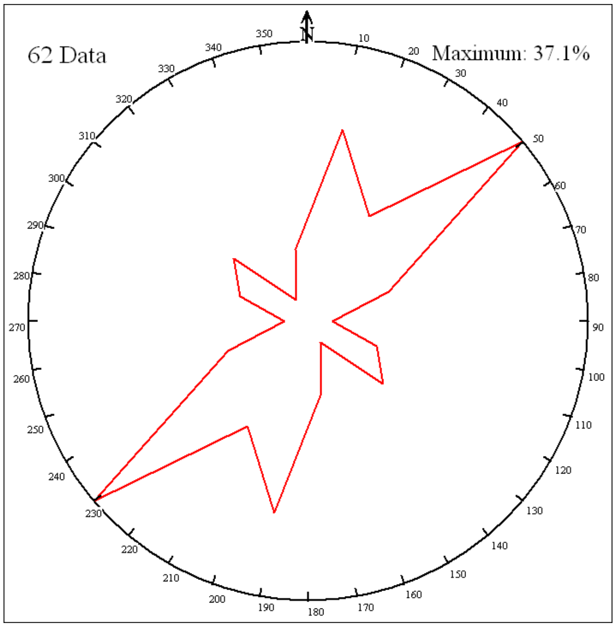
L22 shear joints



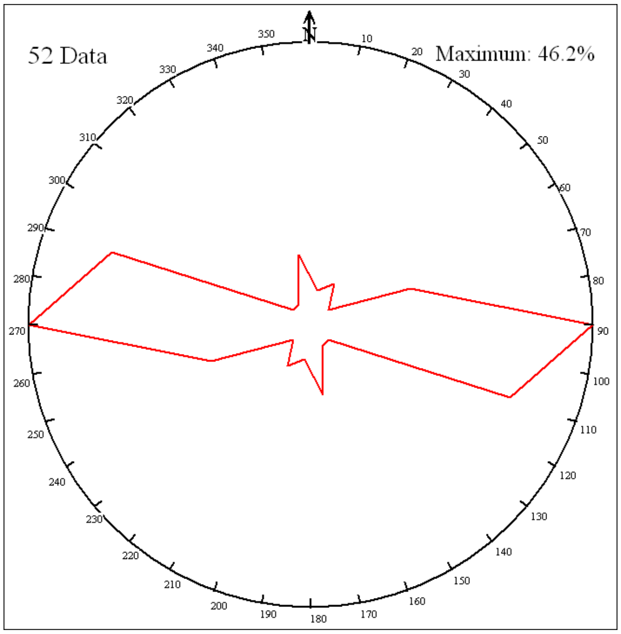
L21 Shear joints



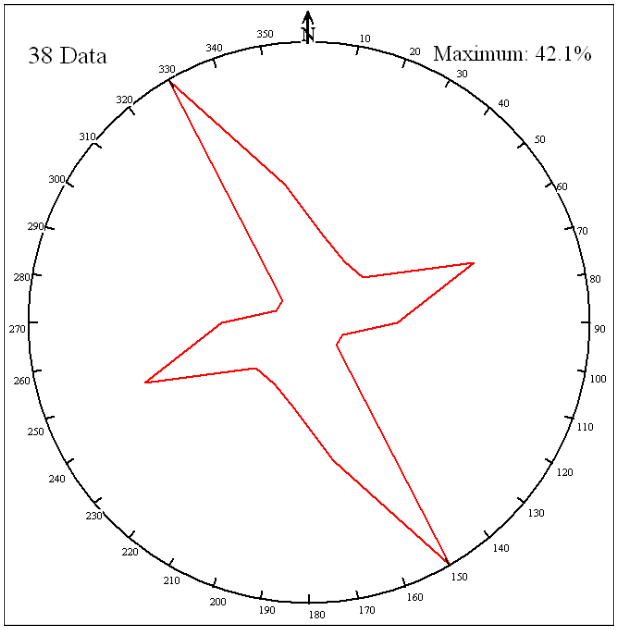
L20 Tensional joints



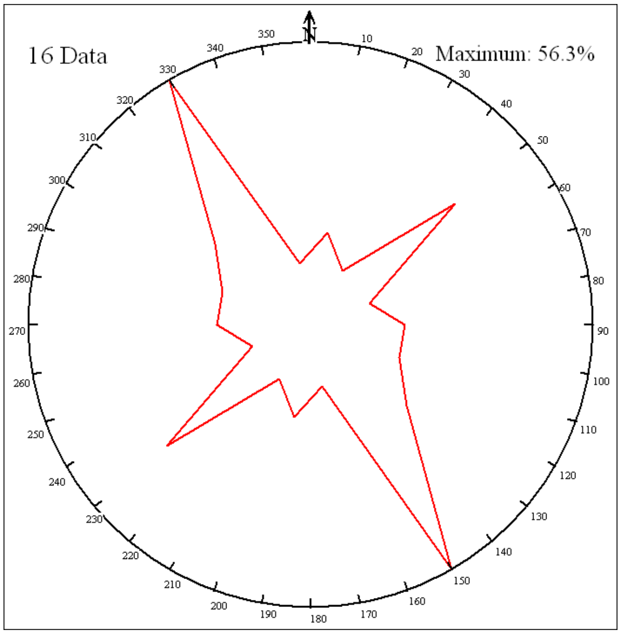
L16 Shear joints



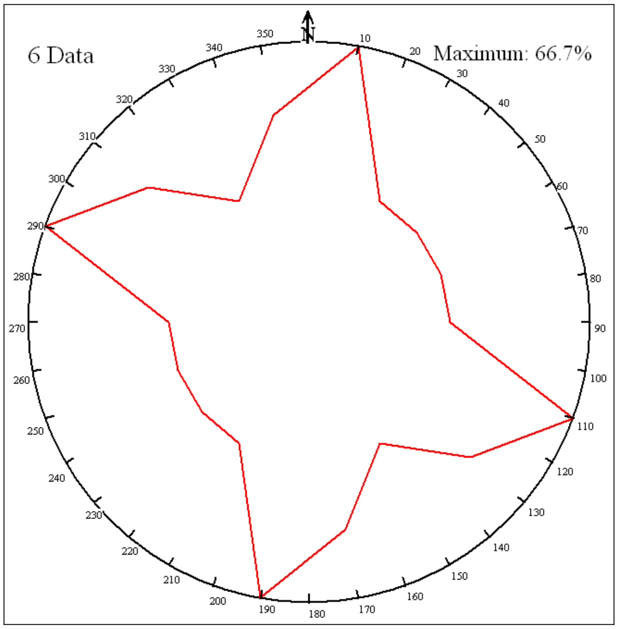
L15 Tensional joints



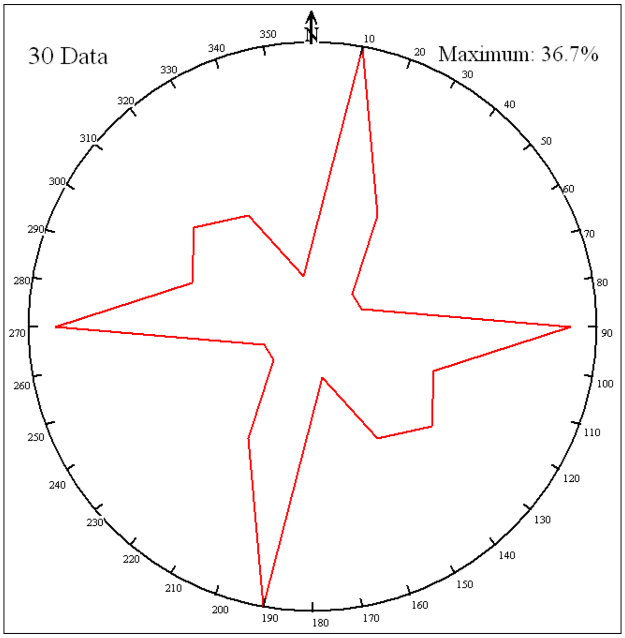
L13 Shear joints



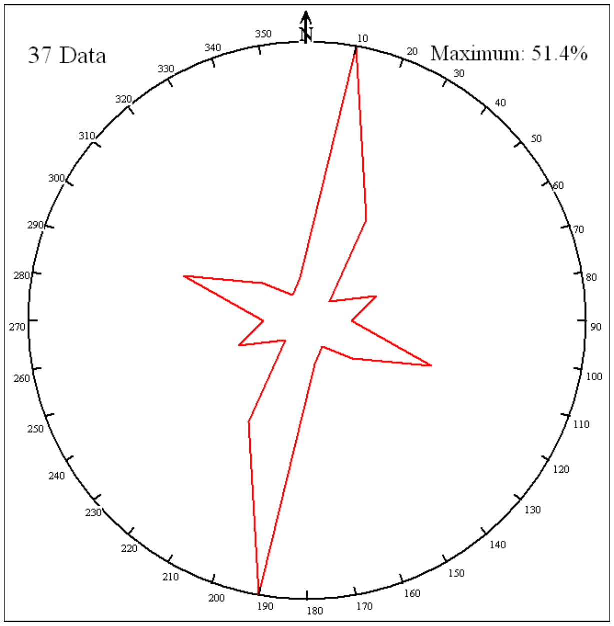
L1 Shear joints



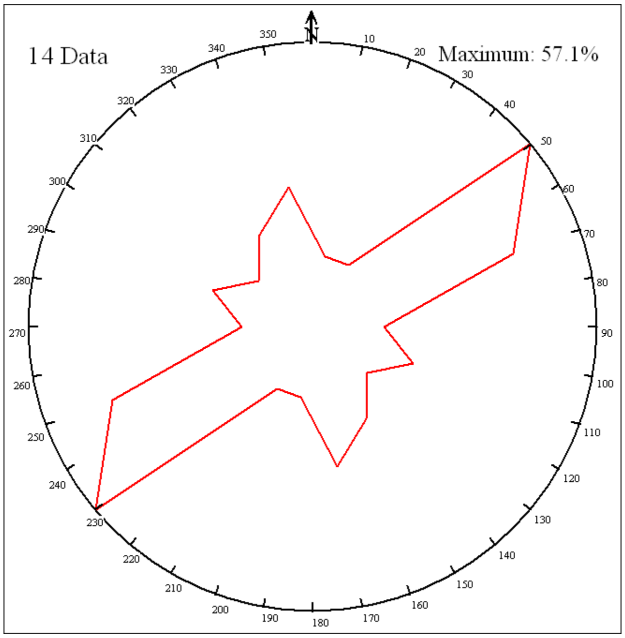
L17 Shear joints



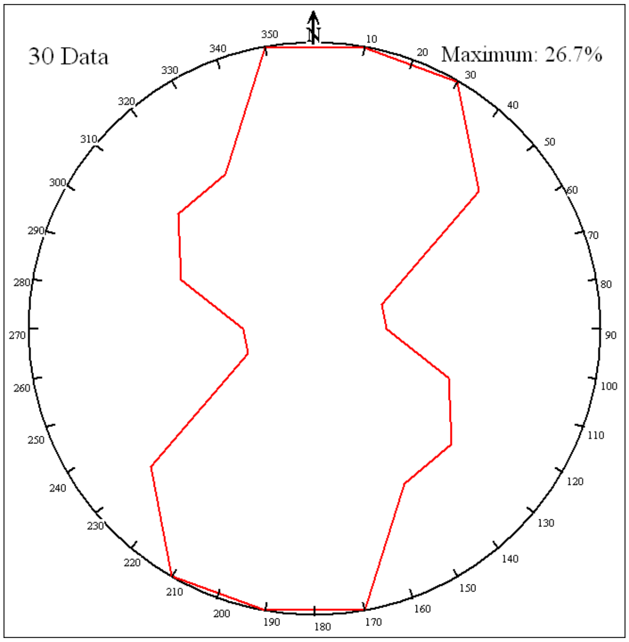
L25 Shear joints



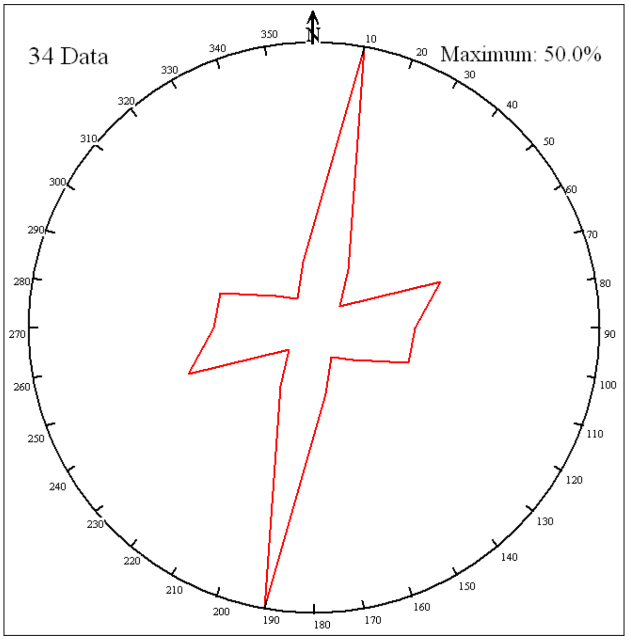
L39 Shear joints



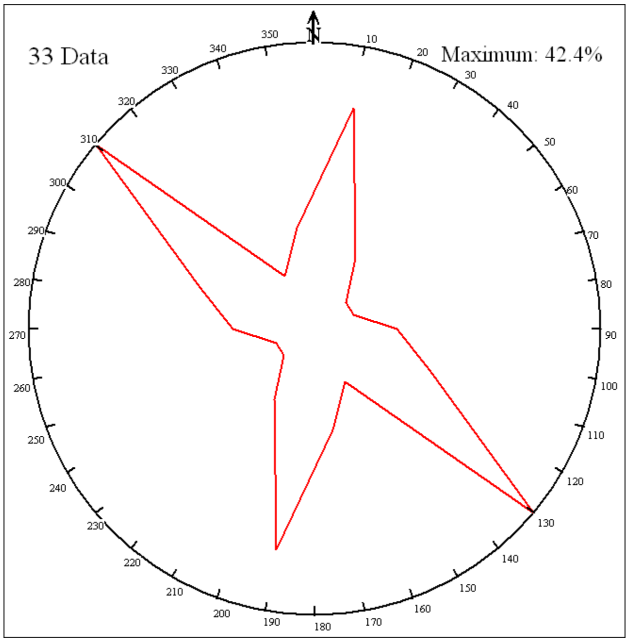
L40 Tensional joints



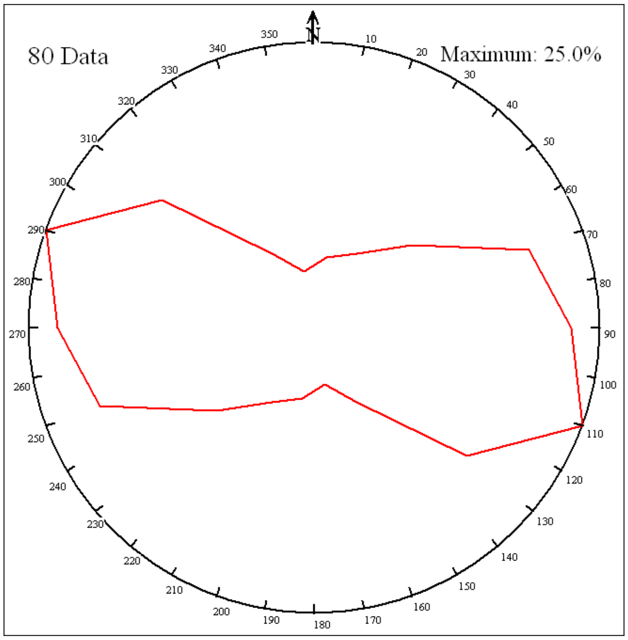
L58 Composite joints



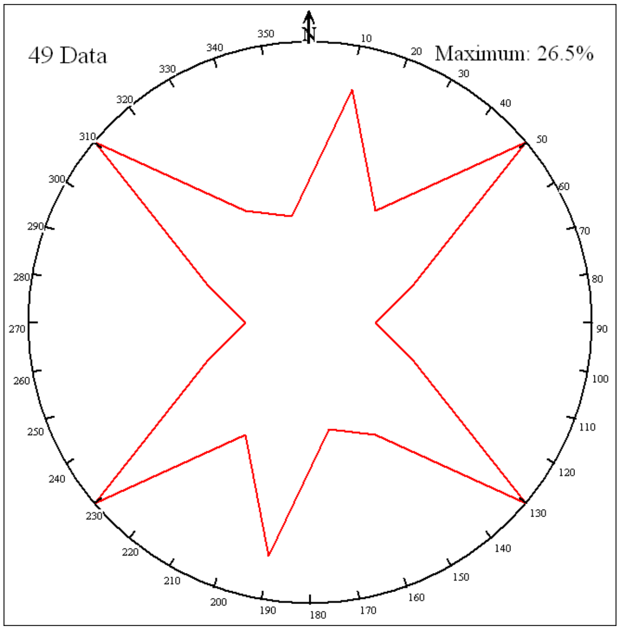
L42 Tensional joints



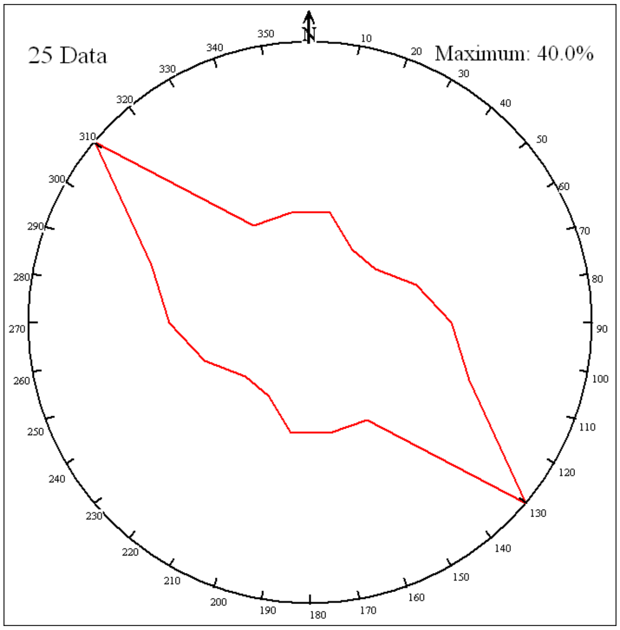
L48 Shear joints



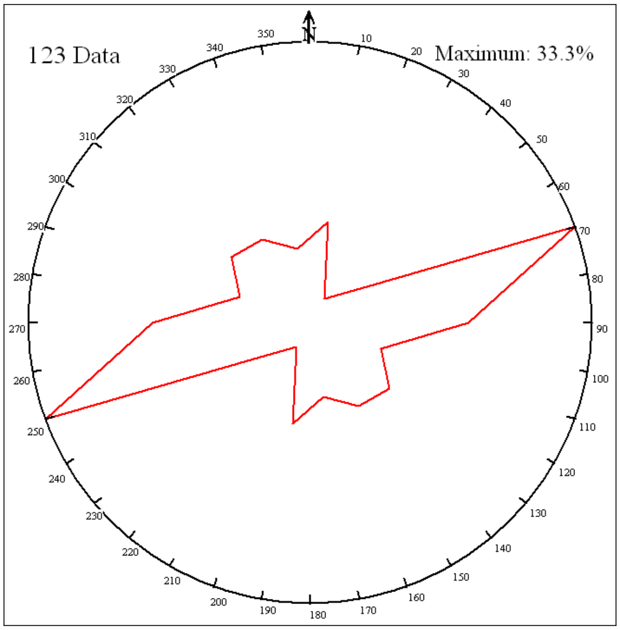
L23 Tensional joints



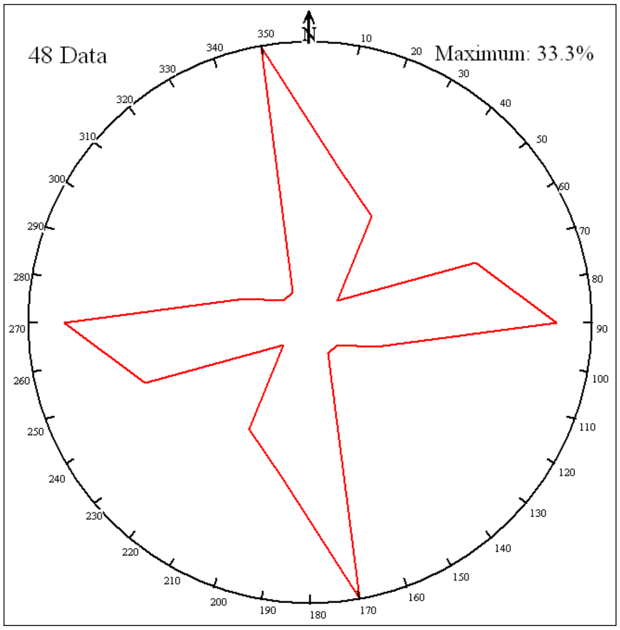
L24 Composite joints



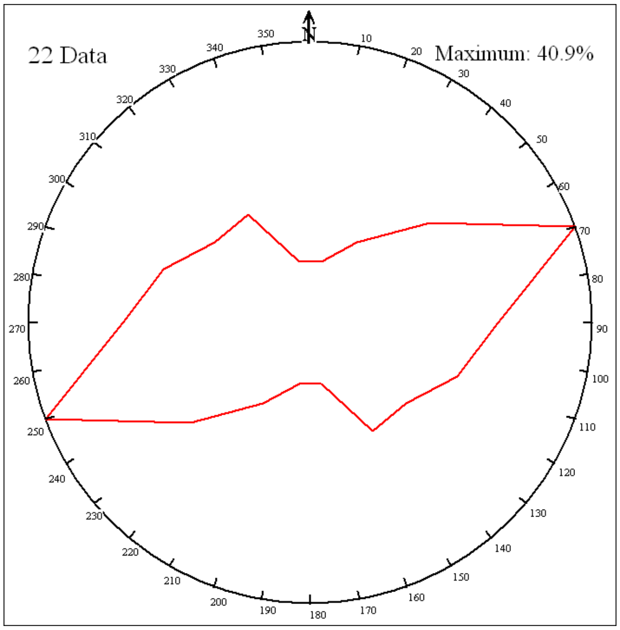
L26 Tensional joints



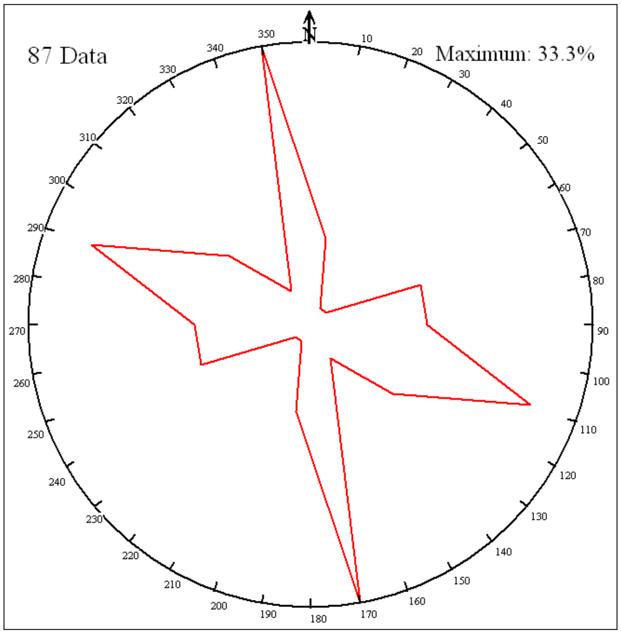
L28 Shear joints



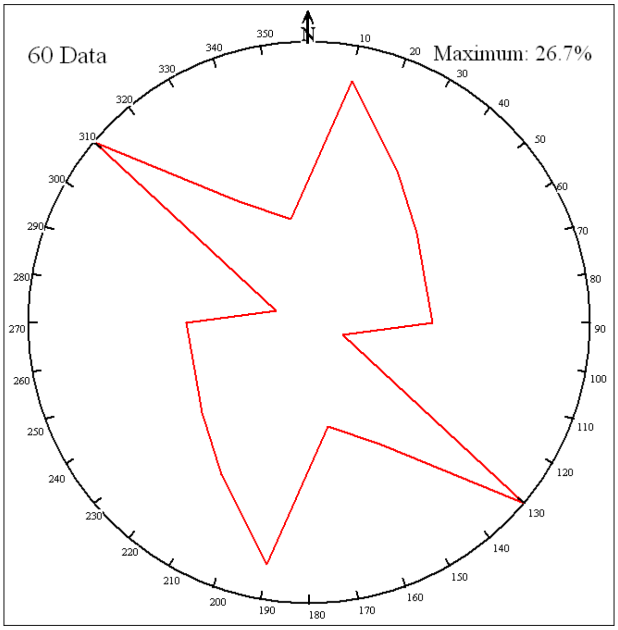
L44 Shear joints



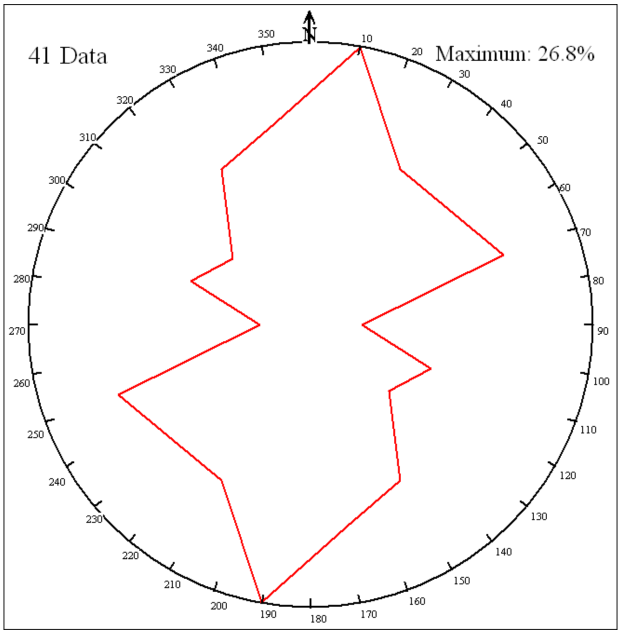
L4 Tensional joints



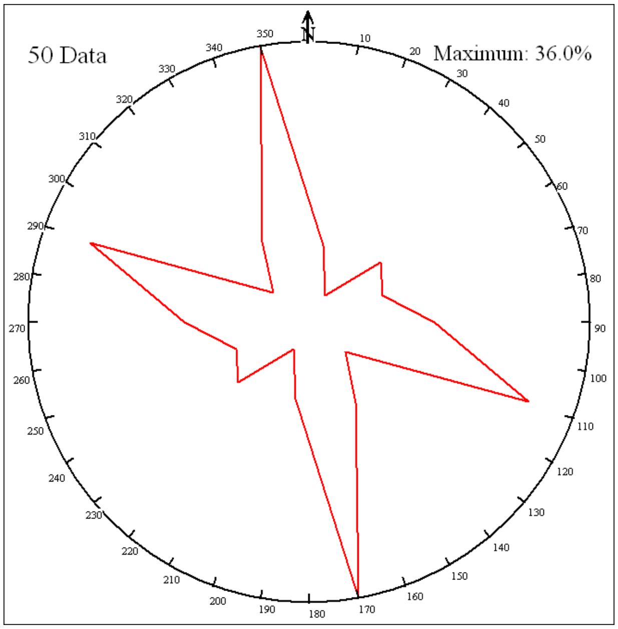
L46 Shear joints



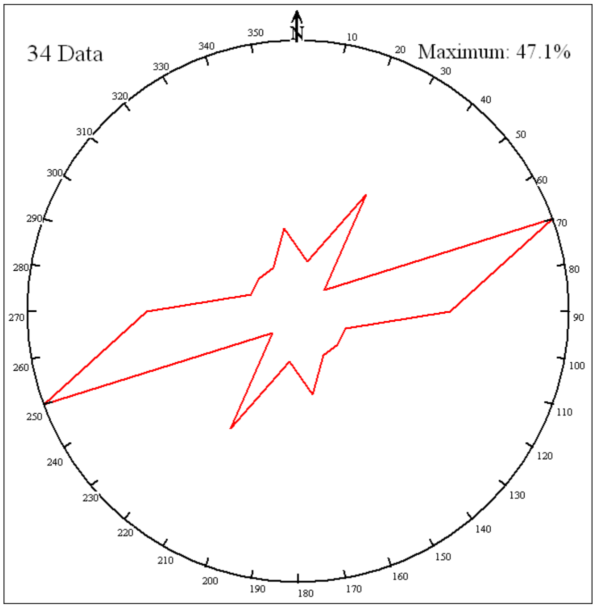
L27 Shear joints



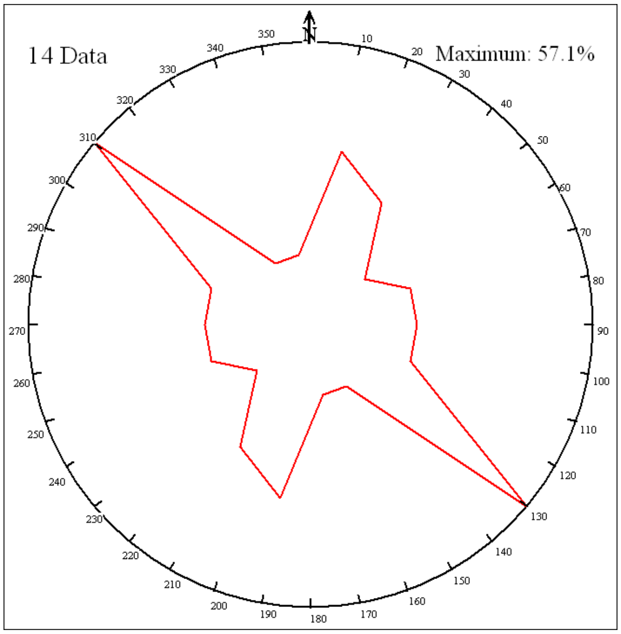
L50 Composite joints



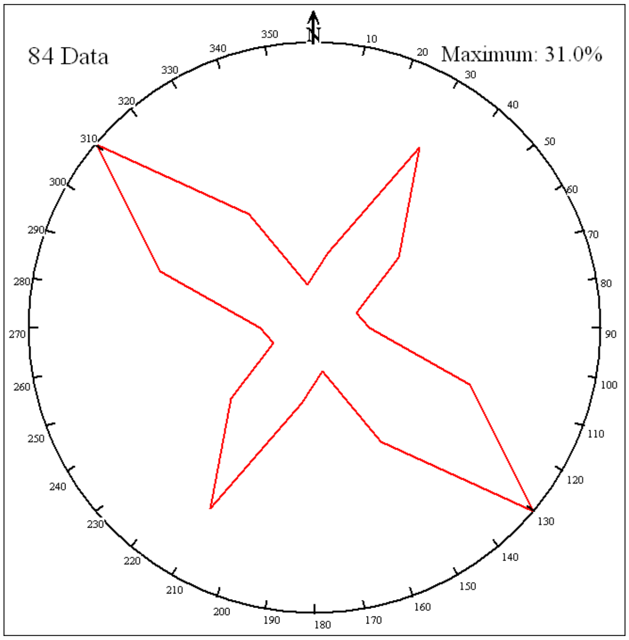
L51 Shear joints



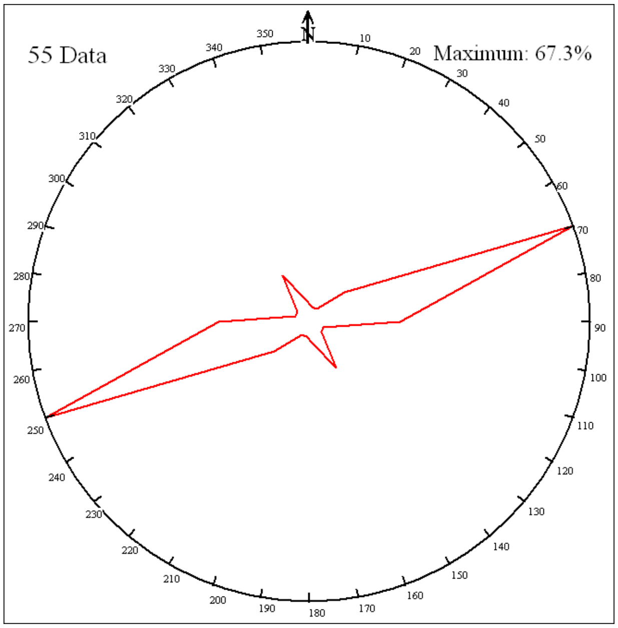
L57 Tensional joints



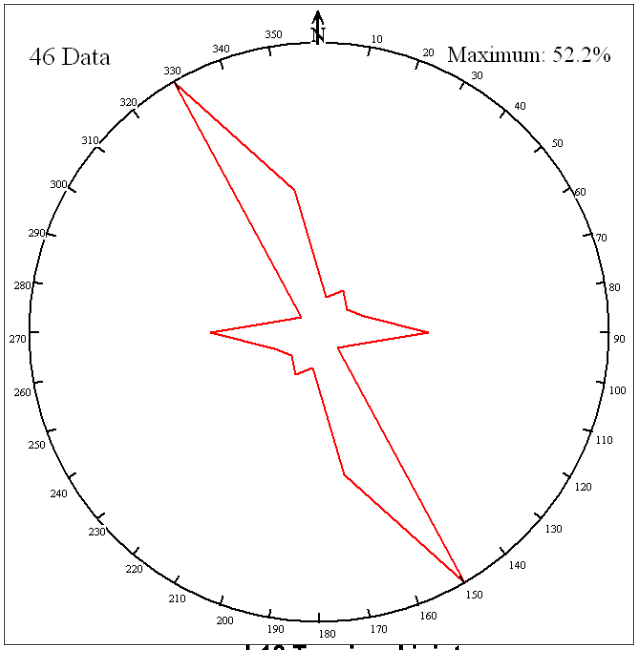
L62 Shear joints



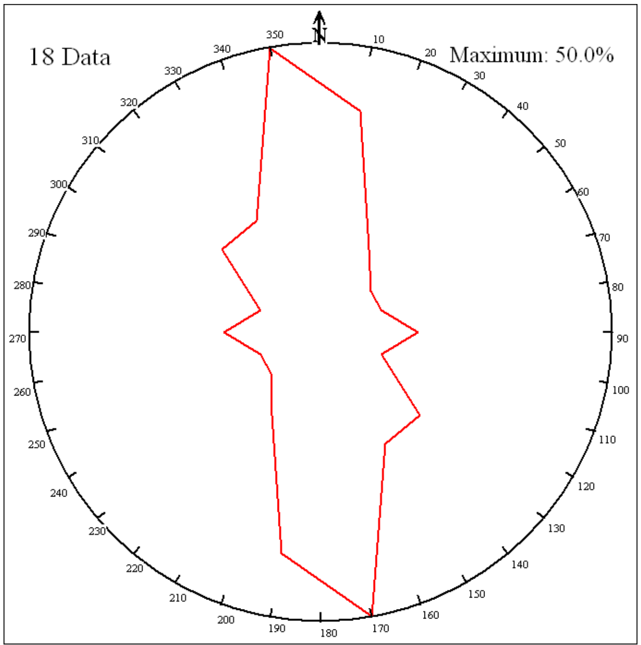
L19 Shear joints



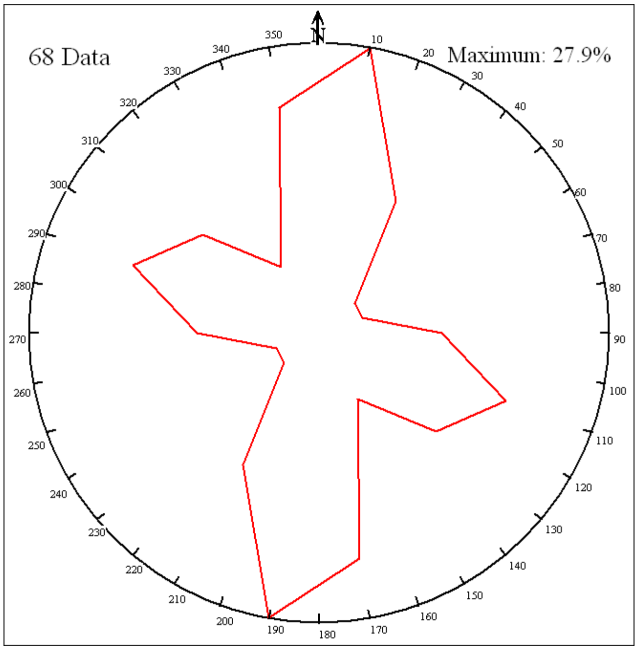
L14 Tensional joints



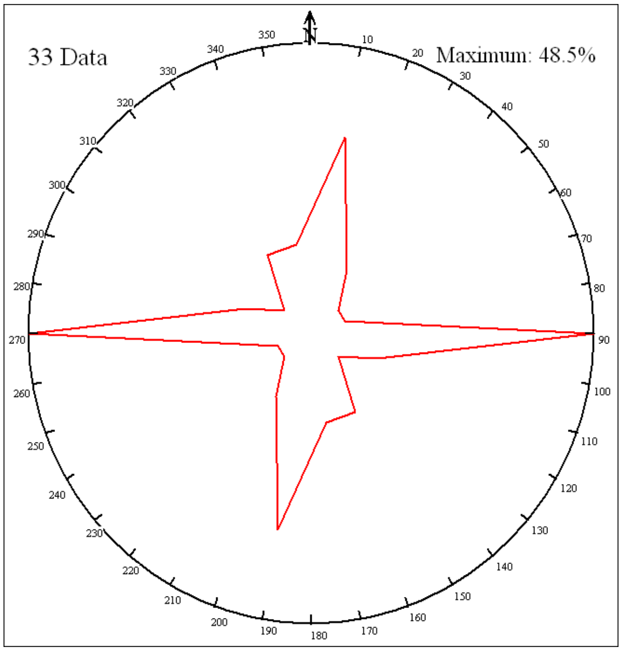
L12 Tensional joints



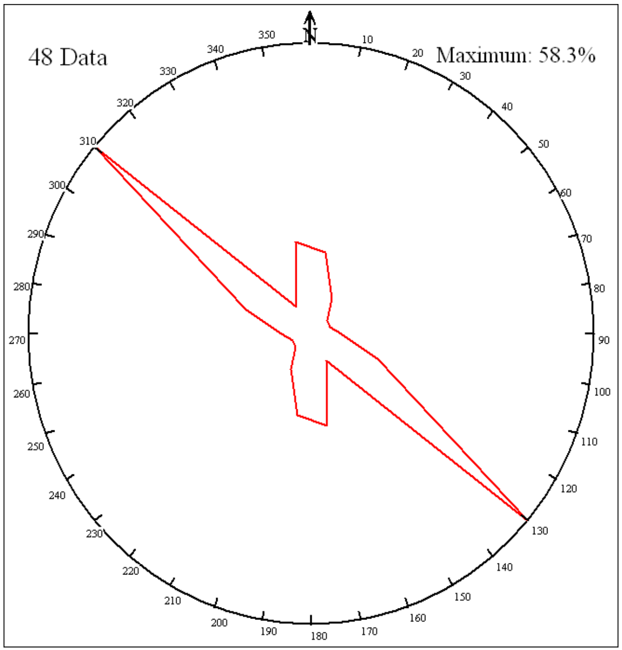
L5 Tensional joints



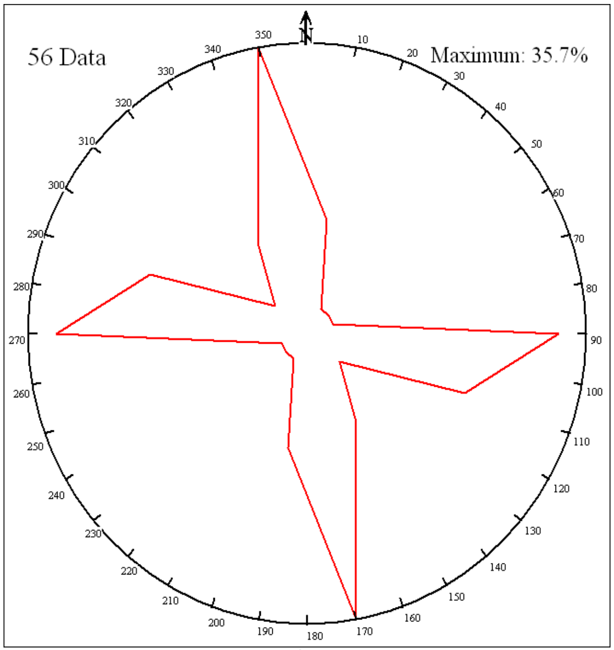
L41 Shear joints



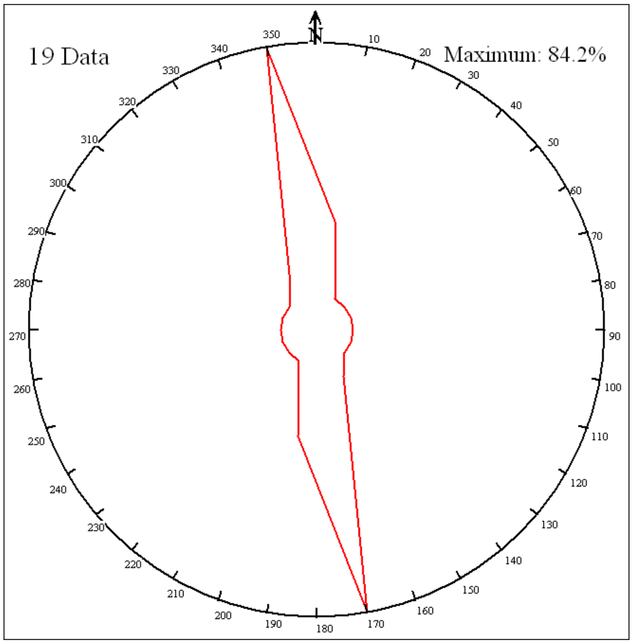
L45 Shear joints



L47 Tensional joints



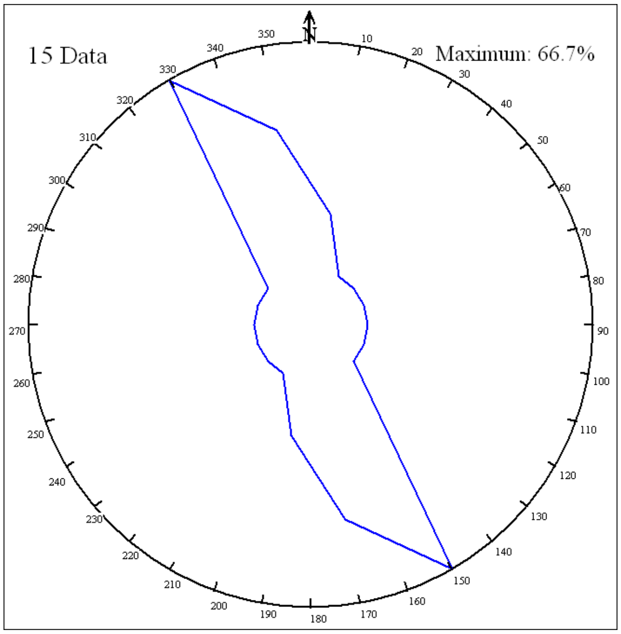
L49 Shear joints



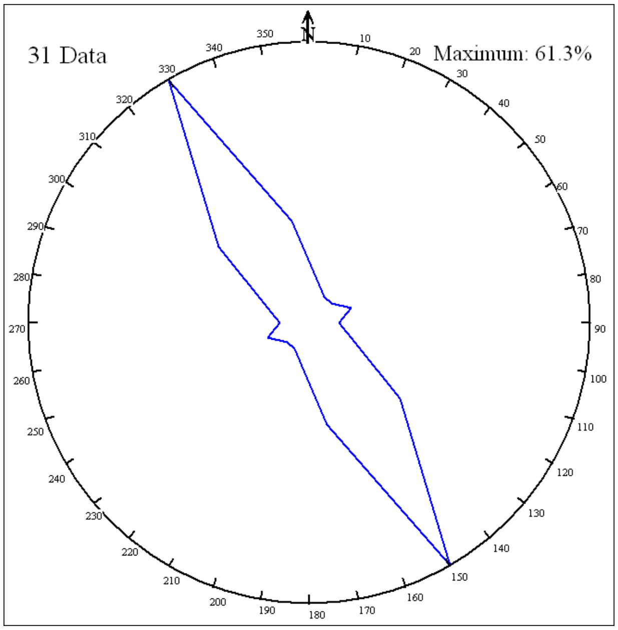
L63 Tensional joints

APPENDIX 4 ROSE DIAGRAMS OF THE VEINS MEASURED IN THE FIELD

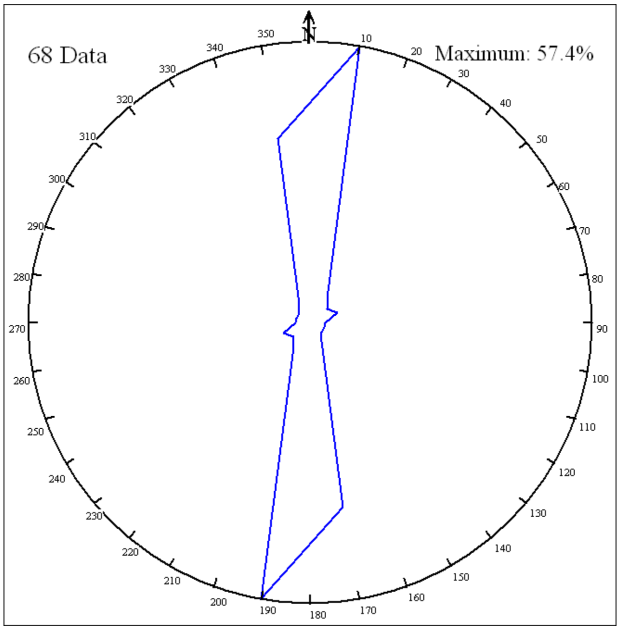
Rose Diagrams for veins measured from localities indicated below them



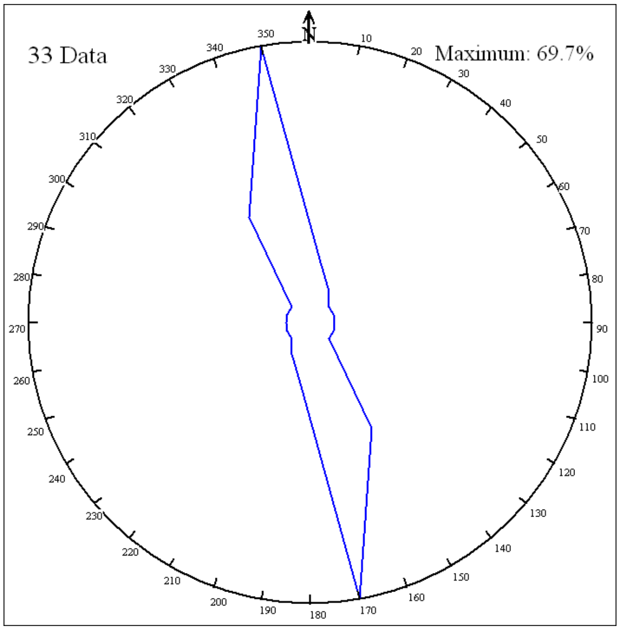
L13 Tensional veins



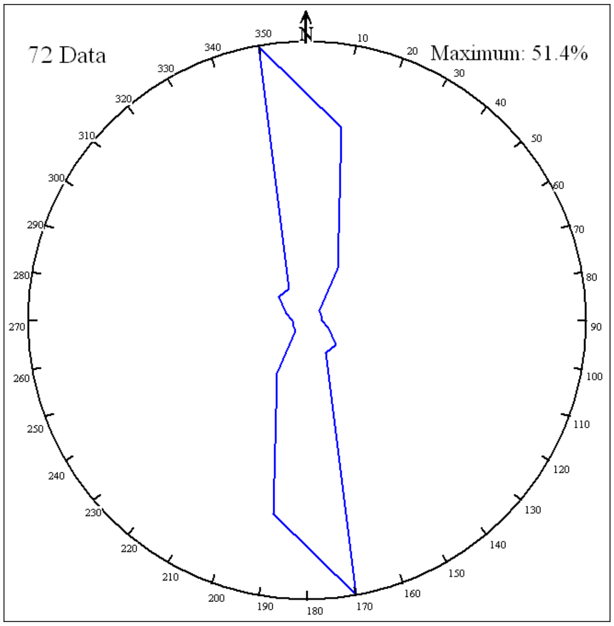
L34Tensional stress



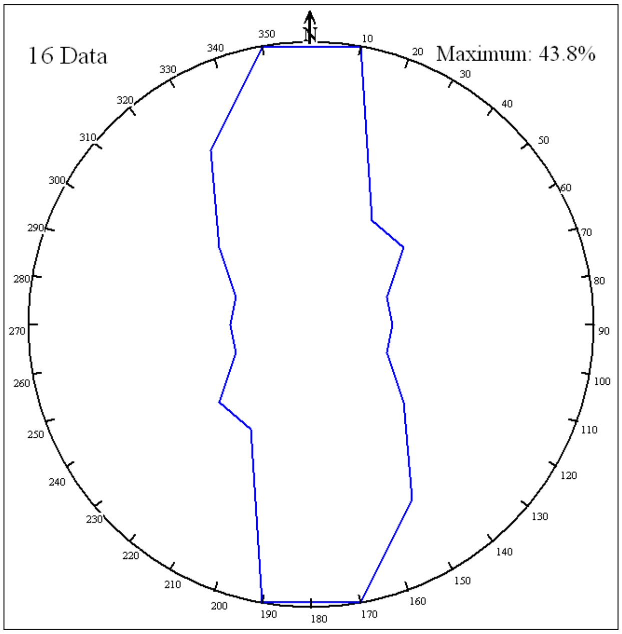
L39 Tensional veins



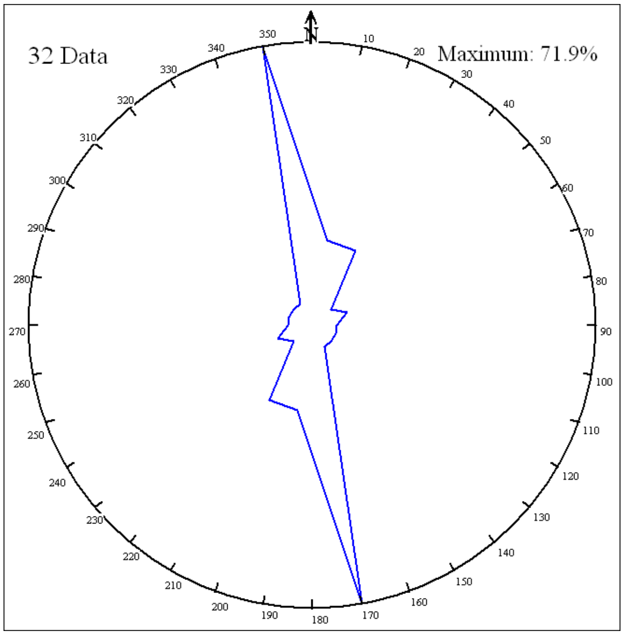
L40 Tensional veins



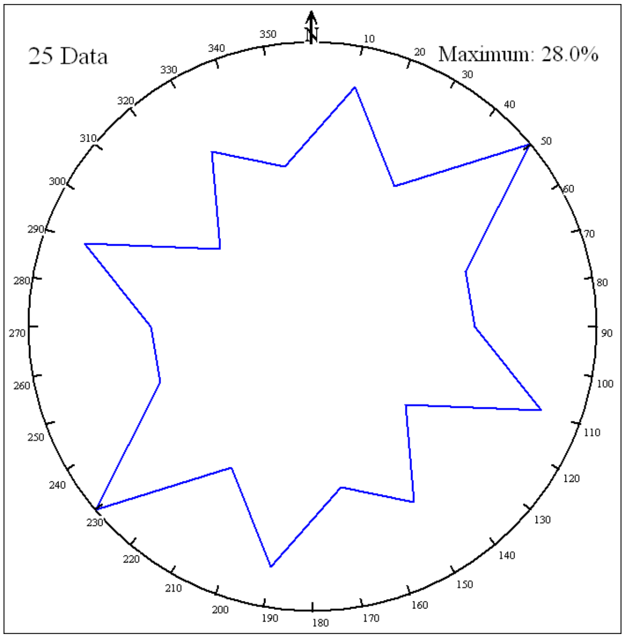
L43 Tensional veins



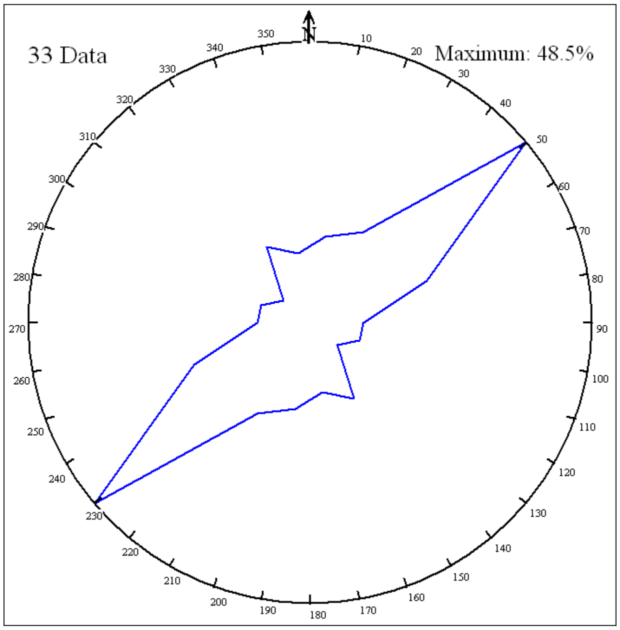
L44 Tensional veins



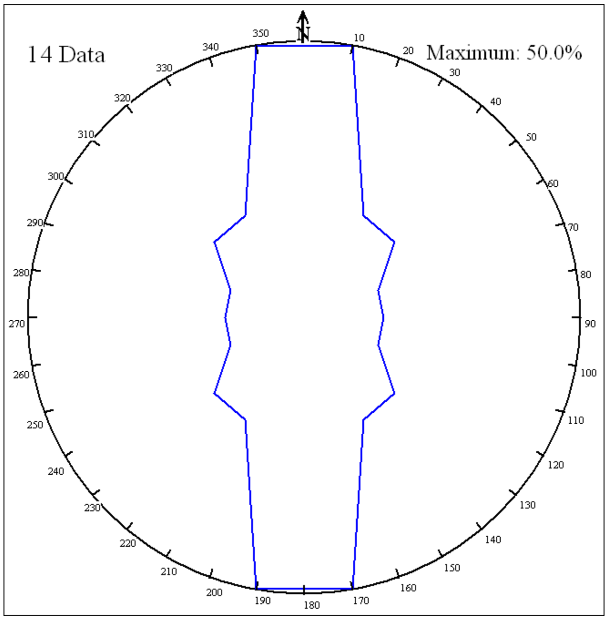
L45 Tensional veins



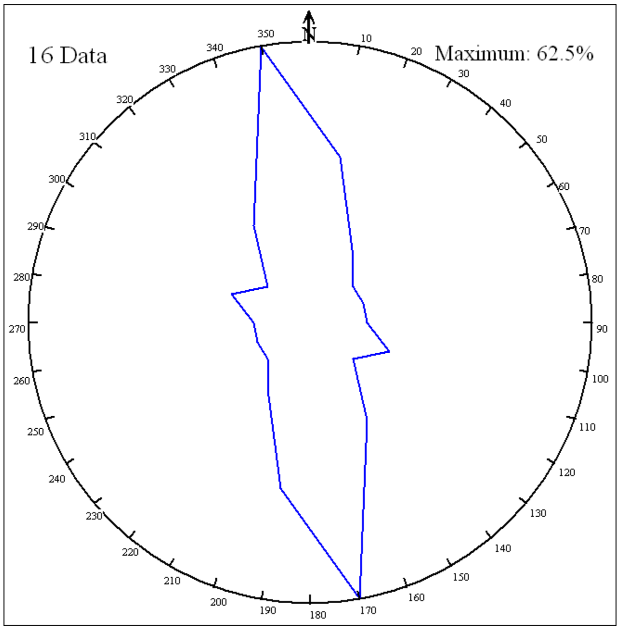
L46 Composite veins



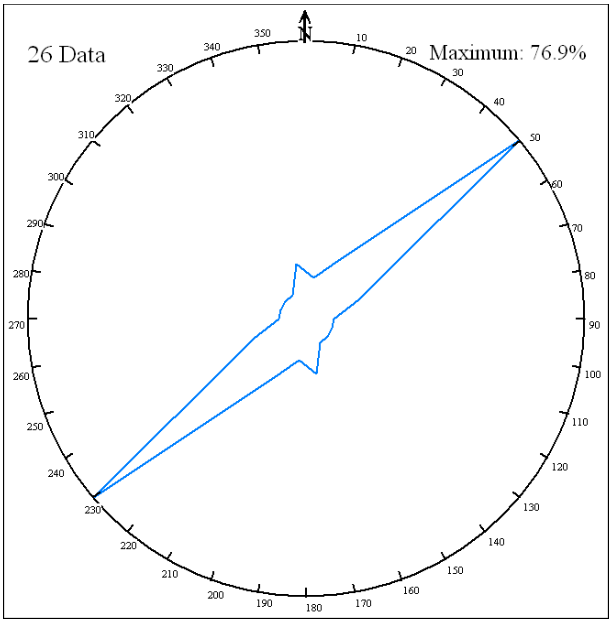
L49 Tensional veins



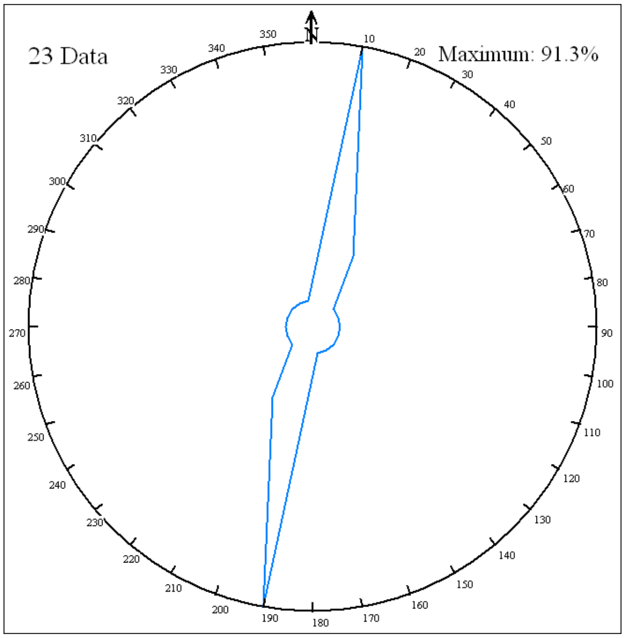
L50 Tensional veins



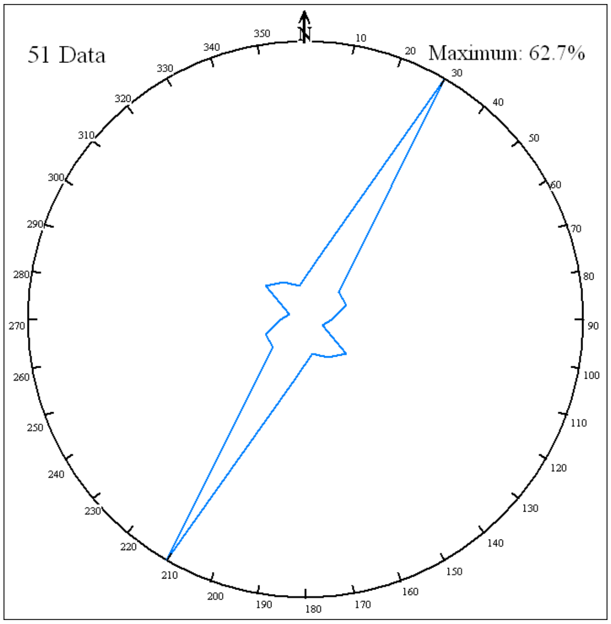
L51 Tensional veins



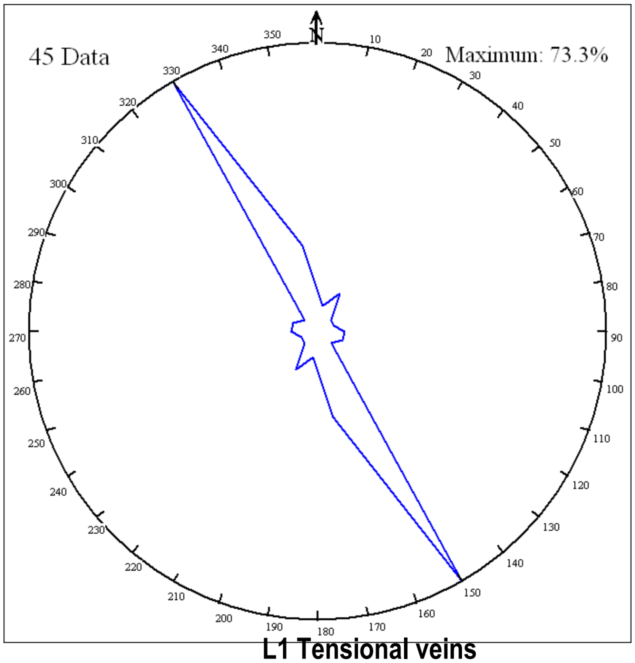
L58 Tensional veins



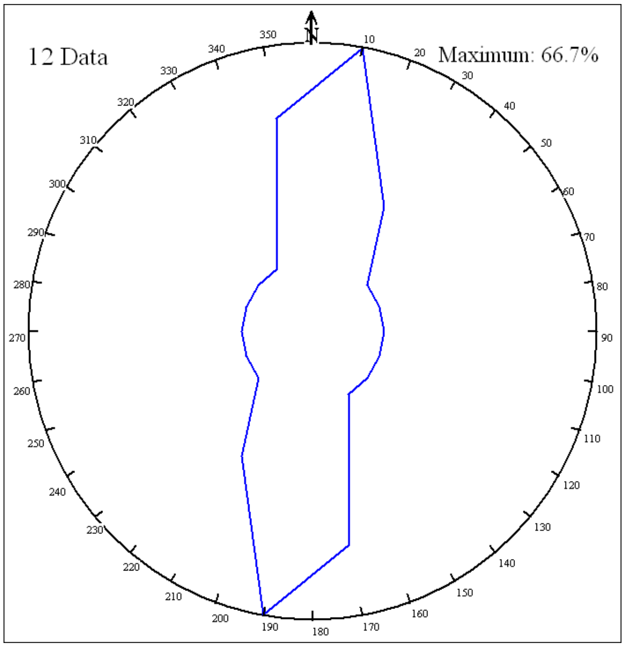
L62 Tensional veins



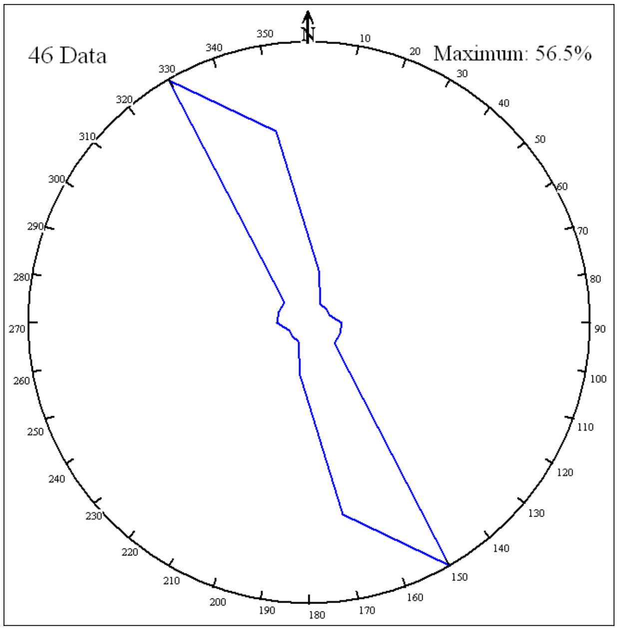
L63 Tensional veins



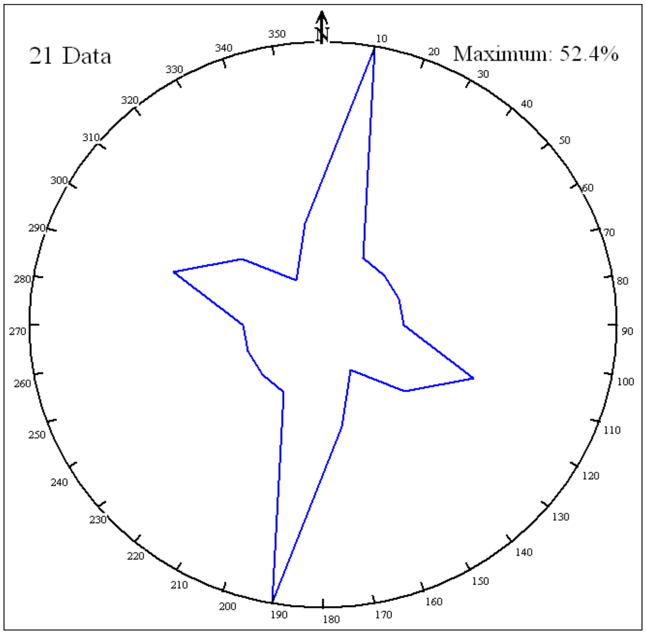
L1 Tensional veins



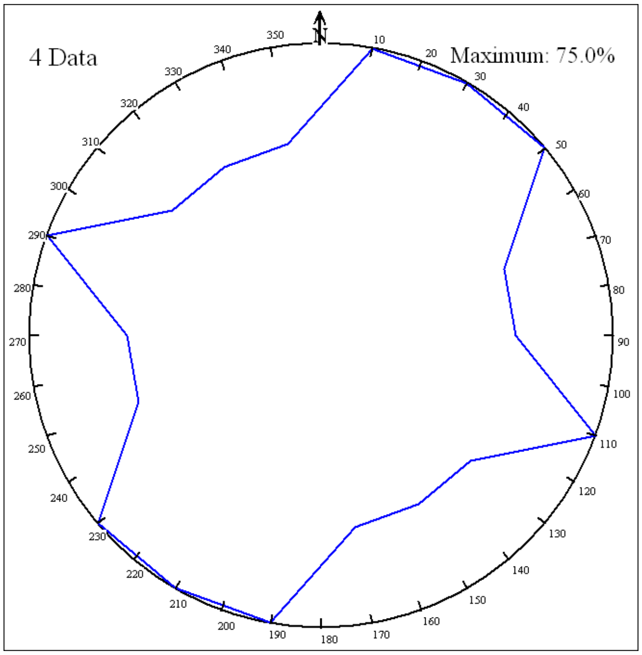
L5 Tensional veins



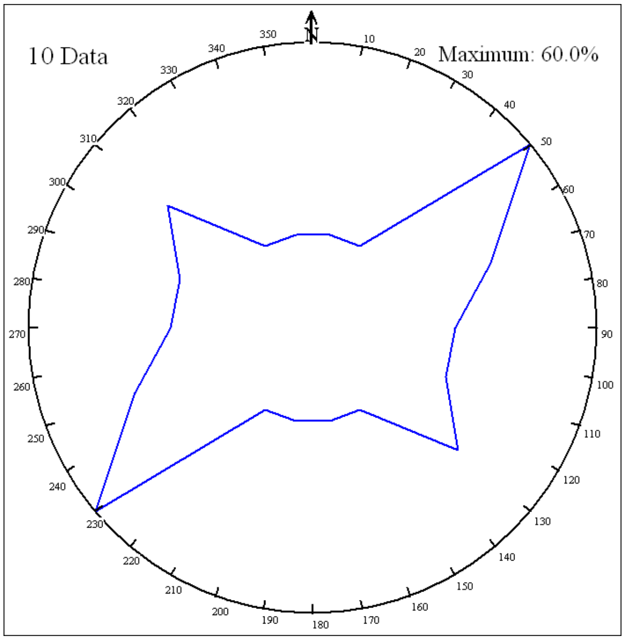
L 12 Tensional veins



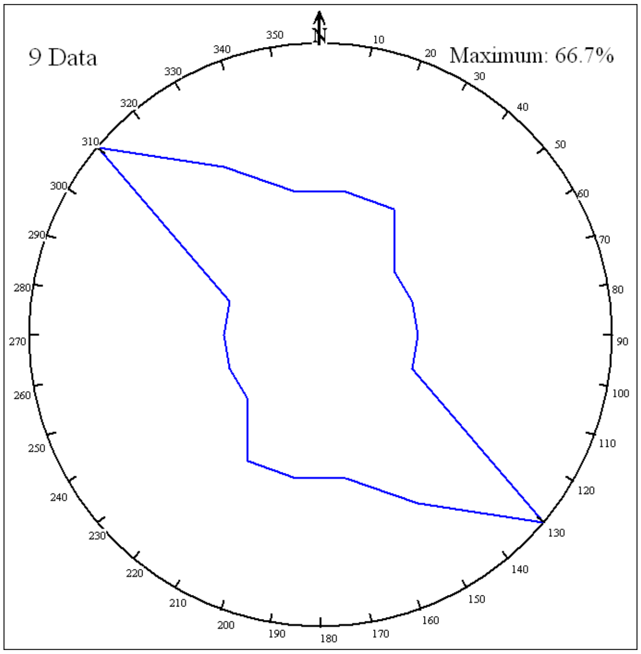
L15 Shear veins



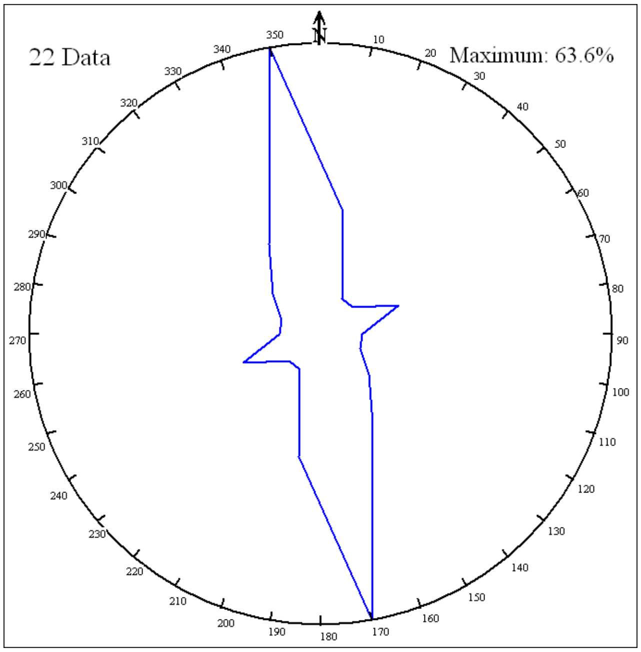
L19 Shear veins



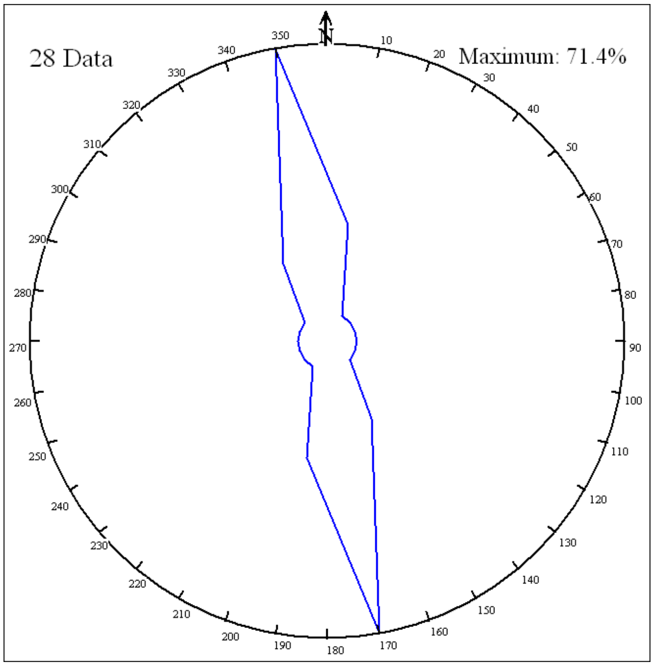
L27 Shear veins



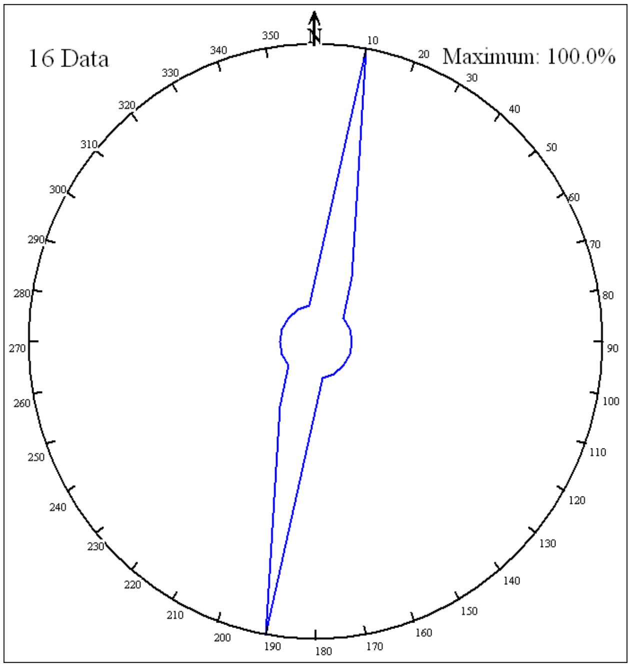
L31 Shear veins



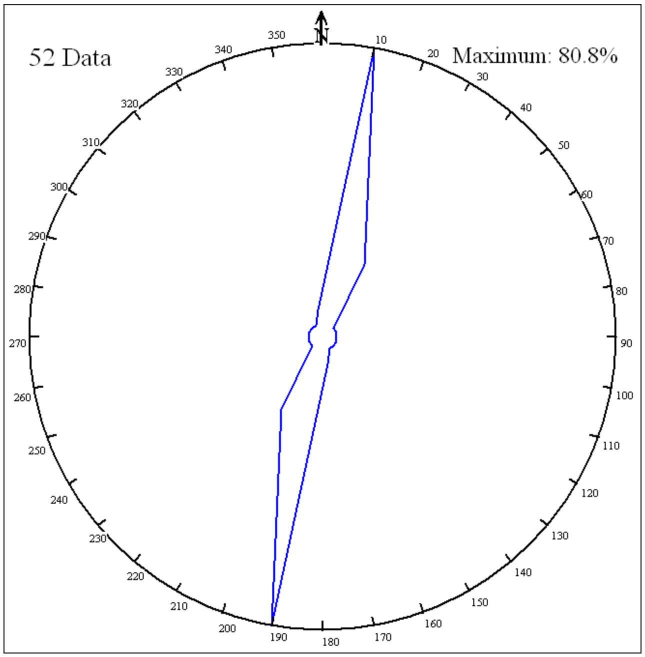
L35 Tensional veins



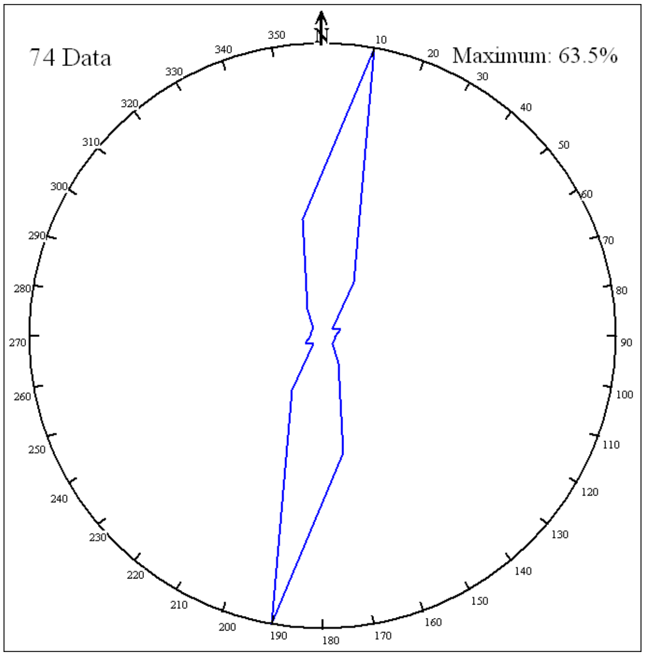
L36 Tensional veins



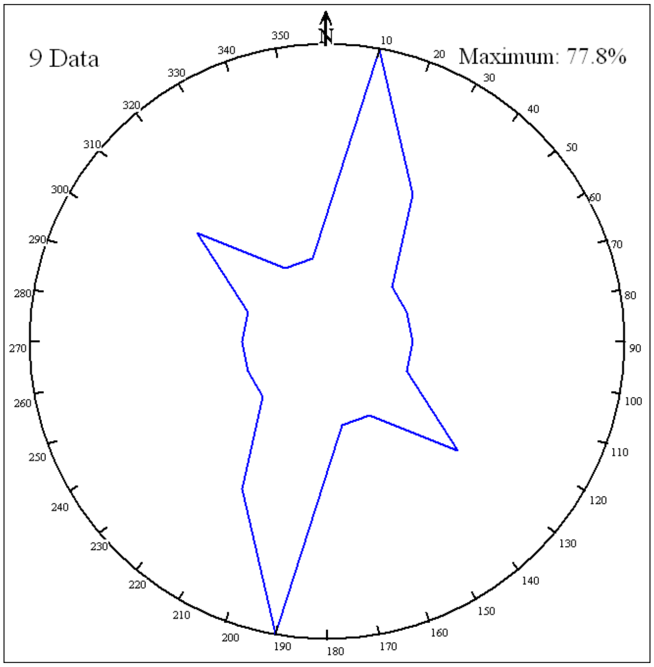
L41 Tensional veins



L42 Tensional veins



L47 Tensional veins



L48 Shear veins

APPENDIX 5 Core logs of Kalitini II well – Record sheet

Depth in metres	Thickness	CR	CR%	Rock type	Remarks
0.00 – 3.00	3.00	0.33	11	Kankar limestone	Whitish grey
3.00 – 6.00	3.00	1.00	33	Claystones	Mottled red/grey
6.00 – 13.33	7.33	0.86	12	Claystones	Mottled red/grey
13.33 – 15.00	1.67	0.50	30	Claystones	Whitish grey
15.00 – 23.40	8.40	1.50	18	Claystones	Mottled red/grey
23.40 – 24.00	0.60	0.50	83	Claystones	Yellowish grey
24.00 – 27.00	3.00	1.32	44	Mudstone	Grey/dark grey
27.00 – 27.45	0.45	0.30	67	Carb. Mudstone	Dark grey/black
27.45 – 30.00	2.55	1.62	64	Mudstone	Grey
30.00 – 31.80	1.80	1.80	100	Mudstone	Greenish grey
31.80 – 37.25	5.45	5.45	100	Mudstone	Dark grey/grey
37.25 – 38.25	1.00	1.00	100	Carb. Mudstone	Dark grey/black
38.25 – 39.60	1.35	1.20	89	Carb. Mudstone	Brownish black
39.60 – 40.20	0.60	0.45	75	Mudstone	Brownish grey
40.20 – 40.45	0.25	0.20	80	Calcareous Sst	Whitish grey
40.45 – 41.80	1.35	1.10	80	Mudstone	Grey/dark grey
41.80 – 41.90	0.10	0.08	80	Sandstone	Brownish grey
41.90 – 44.45	2.55	1.40	55	Calcareous Sst	Whitish grey

44.45 – 45.25	0.80	0.60	75	Peat	Black/dark grey
45.25 – 46.05	0.80	0.80	100	Mudstone	Dark grey
46.05 – 54.00	7.95	7.95	100	Mudstone	Greenish grey
54.00 – 63.50	9.50	7.60	80	Mudstone	Greenish grey
63.50 – 65.00	1.50	1.00	67	Carb. Mudstone	Dark grey/black
65.00 – 65.95	0.95	0.65	68	Peat	Brownish grey
65.95 – 66.30	0.35	0.25	71	Carb. Mudstone	Dark grey/grey
66.30 – 67.40	1.10	0.85	77	Peat	Brownish black
67.40 – 68.60	1.20	1.00	83	Carb. Mudstone	Dark grey/black
68.60 -70.55	1.95	1.85	95	Peat	Black
70.55 – 71.25	0.70	0.70	100	Carb. Mudstone	Dark grey
71.25 -74.70	3.45	2.00	58	Sandy Mudstone	Greenish grey
74.70 – 75.00	0.30	0.15	50	Calcareous Sst	Whitish grey
75.00 – 75.80	0.80	0.80	100	Mudstone	Greenish grey
75.80 – 76.20	0.40	0.40	100	Carb. Mudstone	Dark grey
76.20 – 77.35	1.15	1.15	100	Peat/Lignite	Black
77.35 – 80.00	2.65	2.65	100	Carb. Mudstone	Dark grey/black
80.00 – 80.80	0.80	0.80	100	Peat/Lignite	Brownish black
80.80 – 81.00	0.20	0.20	100	Shaly Mudstone	Brownish grey
81.00 – 83.85	2.85	2.85	100	Peat	Black

83.85 – 84.00	0.15	0.15	100	Mudstone	Brownish grey
84.00 – 84.20	0.20	0.20	100	Carb. Mudstone	Dark grey/black
84.20 – 84.55	0.35	0.35	100	Peat	Black
84.55 – 85.25	0.70	0.70	100	Carb. Mudstone	Black/dark grey
85.25 – 90.10	4.85	4.85	100	Peat	Black/dark grey
90.10 – 90.70	0.60	0.60	100	Carb. Mudstone	Brownish grey
90.70 – 93.00	2.30	2.30	100	Shaly Mudstone	Brownish grey
93.00 – 93.40	0.40	0.40	100	Carb. Mudstone	Black/dark grey
93.40 – 96.00	2.60	2.60	100	Peat/Lignite	Brownish black
96.00 – 96.65	0.65	0.65	100	Carb. Mudstone	Black/dark grey
96.65 – 97.00	0.35	0.35	100	Coal	Black
97.00 – 97.40	0.40	0.40	100	Carb. Mudstone	Dark grey/black
97.40 – 97.70	0.30	0.30	100	Peat/lignite	Black
97.70 – 99.45	1.75	1.60	91	Carb. Mudstone	Brownish grey
99.45 – 100.55	1.10	0.95	86	Peat	Brownish black
100.55 – 101.00	0.45	0.40	89	Lignite/coal	Black
101.00 – 101.35	0.35	0.30	89	Carb. Mudstone	Brownish black
101.35 – 101.70	0.35	0.30	89	Peat	Black
101.70 – 102.20	0.50	0.45	90	Carb. Mudstone	Brownish black
102.20 – 103.20	1.00	0.90	90	Lignite/Coal	Black

103.20 – 103.40	0.20	0.16	90	Carb. Mudstone	Brownish black
103.40 – 104.40	1.00	0.90	90	Lignite/Peat	Black
104.40 – 105.05	0.65	0.60	90	Carb. Mudstone	Brownish black
105.05 – 106.05	1.00	0.90	90	Peat	Black
106.05 – 107.65	1.60	1.50	92	Carb. Mudstone	Brownish grey
107.65 – 108.15	0.50	0.46	92	Peat/Lignite	Black
108.15 – 110.20	2.05	2.05	100	Carb. Mudstone	Brownish grey
110.20 – 112.65	2.45	1.90	78	Carb. Mudstone	Brownish grey
112.65 – 117.00	4.35	3.70	85	Shaly Mudstone	Greenish grey
117.00 – 119.75	2.75	2.75	100	Shaly Mudstone	Brownish grey
119.75 – 120.00	0.25	0.25	100	Lignite/Peat	Black
120.00 – 120.60	0.60	0.60	100	Shaly Mudstone	Brownish grey
120.60 – 121.50	0.90	0.90	100	Carb. Mudstone	Brownish grey
121.50 – 123.60	2.10	1.70	82	Mudstone	Brownish grey
123.60 – 124.35	0.75	0.30	42	Carb. Mudstone	Brownish grey
124.35 – 126.35	2.00	1.60	80	Mudstone	Brownish grey
126.35 – 126.65	0.30	0.30	100	Carb. Mudstone	Brownish grey
126.65 – 132.00	5.35	5.35	100	Mudstone	Greenish grey
132.00 – 141.00	9.00	9.00	100	Mudstone	Greenish grey/grey

141.00 – 156.00	15.00	15.00	100	Shaly Mudstone	Grey
156.00 – 162.00	6.00	6.00	100	Shaly Mudstone	Greenish grey
162.00 – 168.00	6.00	6.00	100	Shaly Mudstone	Brownish grey
168.00 – 171.00	3.00	0.05	1.7	Mudstone	Brownish grey
171.00 – 172.30	1.30	1.10	84	Mudstone	Brownish grey
172.30 – 174.00	1.70	1.45	84	Mudstone	Greenish grey
174.00 – 177.00	3.00	1.48	49	Mudstone	Whitish grey
177.00 – 189.00	12.00	12.00	100	Mudstone	Greenish grey
189.00 – 192.55	3.55	3.55	100	Mudstone	Whitish grey
192.55 – 201.00	8.45	8.45	100	Mudstone	Dark grey
201.00 – 201.95	0.95	0.95	100	Peat	Black/dark grey
201.95 – 202.35	0.40	0.40	100	Carb. Mudstone	Dark grey
202.35 – 202.90	0.55	0.55	100	Coal	Black
202.90 – 203.50	0.60	0.60	100	Carb. Mudstone	Dark grey
203.50 – 204.90	1.40	1.40	100	Lignite	Black
204.90 – 205.40	0.50	0.50	100	Carb. Mudstone	Dark grey/grey
205.40 – 205.65	0.25	025	100	Coal	Black
205.65 – 206.05	0.40	0.40	100	Carb. Mudstone	Dark grey
206.05 – 207.05	1.00	1.00	100	Coal	Black
207.05 – 207.25	0.20	0.20	100	Sandstone	Whitish grey

207.25 – 207.95	0.70	0.70	100	Coal	Black
207.95 – 213.00	5.05	4.25	84	Mudstone/lime	Whitish grey
213.00 – 219.00	6.00	6.00	100	Sandy lime	Whitish grey
219.00 – 222.00	3.00	2.10	70	Clayey Sandstone	Whitish grey
222.00 – 225.00	3.00	3.00	100	Sandstone(clayey)	Whitish grey
225.00 – 228.00	3.00	3.00	100	Sandstone	Greenish grey
228.00 – 231.00	3.00	1.95	65	Sandstone	Greenish grey
231.00 – 234.00	3.00	2.48	83	Sandstone	Greenish grey
234.00 – 243.00	9.00	6.80	76	Sandstone/Mudstone	Whitish grey
243.00 – 252.00	9.00	8.87	99	Sandstone	Brownish grey
252.00 – 261.00	9.00	4.88	54	Sandstone	Brownish grey
261.00 – 262.90	1.90	1.75	93	Clayey Sandstone	Whitish grey
262.90 – 263.60	1.50	1.40	93	Mudstone	Whitish grey
263.60 – 264.00	0.40	0.40	100	Sandstone	Brownish grey
264.00 – 264.85	0.85	0.70	83	Sandy Mudstone	Whitish grey
264.85 – 267.00	2.15	1.80	83	Clayey Sandstone	Brownish grey
267.00 – 275.40	8.40	4.40	52	Sandy Mudstone	Whitish grey
275.40 – 276.00	0.60	0.31	52	Pyritic Sandstone	Shiny yellowish grey
276.00 – 279.00	3.00	0.60	20	Weathered granitoid gneiss	Whitish grey with shiny pyrite

				with large pyrite crystals	crystals

Note: Carb. Mudstone is short for carbonaceous mudstone whereas calcareous sst is calcareous sandstone.