THE GEOLOGY OF THE KAVIRONDIAN GROUP OF SEDIMENTS

BY

WILSON MWANIKI NGECU

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

Signed Wilson Mwaniki
W. M. NGECU

This thesis has been submitted for examination with my approval as a University supervisor

Signed S.J. Gaciri
DR. S. J. GACIRI

ABSTRACT

The Kavirondian sediments form the Kavirondian Group and are exposed both in Kakamega and South Nyanza Districts in western Kenya. This lithological Group forms one of the three stratigraphical Groups which constitute the Nyanzian Shield. The other two Groups are the Nyanzian Group and the Dodoman Group. The latter Group has not been identified in western Kenya and therefore the Kenyan part of the Shield is composed only of the Nyanzian and the Kavirondian Groups. The Nyanzian Group is composed of the tholeiitic and calc-alkaline volcanic rocks and it is unconformably overlain by clastic sediments of the Kavirondian Group.

In this work, the stratigraphy, provenance and environments of deposition of the Kavirondian sediments have been investigated. An area of about 2,360 square kilometres which is covered by the greenstone rocks of the Nyanzian Shield was geologically mapped using base maps, aerial photographs and spot images. The base maps were at a scale of 1:50,000 but the geological maps compiled were at a scale of 1:25,000. Rock samples were also collected for petrographical, geochemical and geochronological analysis.

Petrographic investigations of the Kavirondian sediments were carried out through the preparation and microscopic study of thin sections of samples from the study area. Samples for the geochemical work were crushed, milled and pulverised. The powders were then converted into pellets by pressing in collapsible aluminium cups. Analyses were made using a combination of techniques including X-ray fluorescence (XRF) spectrometry, atomic absorption spectrometry (AAS) and induced couple plasma (ICP). One set of rock samples was crushed and milled for isotope studies. Rubidium-strontium whole rock analysis was carried out in

order to provide radiometric ages.

The result of petrographical and chemical analyses of the sediments show that the Kavirondian sediments were derived from a multiple of sources which include older granite rocks, volcanic rocks and recycled sedimentary rocks. The radiometric dating indicates that the Kavirondian sediments are about 2,500 Ma old. The age of the granite intrusions which occur at the margins of the sedimentary formations is about 2,400 Ma. These radiometric ages indicate that in the Nyanzian Shield of western Kenya, the Nyanzian Group rock suites which form an angular unconformity with the Kavirondian Group sediments are the oldest rocks in the Shield. The Kavirondian sediments are younger than the Nyanzian Group volcanic rocks and finally the granite intrusives which occur on the margins of the sedimentary formations are the youngest. All the three rock suites were formed between middle Archaean and early Proterozoic.

Field studies of the lithological relationships and the primary structures indicate that the Kavirondian Group can be divided into four formations. These include the Shivakala Formation which is stratigraphically lowest in the succession, the Igukhu Formation, the Mroda Formation and the Mudaa Formation which is stratigraphically uppermost in the succession. Lithological relationships and primary structures also revealed that the basal conglomerates were deposited in a sedimentary basin as alluvial fan deposits while the resedimented conglomerates, greywackes and mudstones were deposited by turbidity currents in relatively deep water on the upper, middle and lower fans. It was similarly noted that there exists a sedimentological gap between the terrestrial sedimentation of basal conglomerates and the marine sedimentation of the turbidites. The gap is indicated by lack of transitional sediments between the terrestrial and marine sediments.

Lithological correlation of the sediments was attempted. However, due to the sudden changes of lithofacies and the diachronous nature of the lithological boundaries, lithostratigraphical correlation at regional scale was not possible. Therefore, lithostratigraphic correlation was quite local in nature. Geochronological results were, however, used to infer the stratigraphic position of the Kavirondian sediments in relation to the Nyanzian rock suites and the surrounding granite intrusions. The results were also used to propose chrono-correlations between the Kavirondian sediments and Archaean sediments found in other Archaean terraines in the world.

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First and foremost, I would like to thank the Board of Postgraduate Studies of the University of Nairobi for awarding me a scholarship for three academic years between 1986 and 1989 during which time I managed to carry out a research which preceded the writing of this thesis for a degree of Doctor of Philosophy. I am also particularly indebted to Dr. S. J. Gaciri for his supervision and guidance during the study.

It is with much indebtedness that I wish to thank the National Council of Science and Technology (NCST) for funding most aspects of this research. I humbly note that without the funding, it would have been impossible to carry out the research.

I would also like to very sincerely thank the DAAD for its financial assistance during the field session of the project and for facilitating a short study visit to the Technical University of Berlin where I carried out chemical analyses related to this work. On the same note, I wish to thank Professor Klitzsch, Dr. Matheis and colleagues in the Geological Institute, University of Berlin, for their guidance and assistance when I was carrying out the chemical analyses.

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Chapter 1

INTRODUCTION

1.1 The Study Areas

The areas covered by this study lie both in Kakamega and South Nyanza Districts of Kenya (Fig. 1). The two districts are administered from Kakamega and Homa Bay municipalities, respectively. The total area covered during this study is about 2,360 square kilometres.The Nyanzian volcanic rocks and the granite intrusives which are found on the margins of Kavirondian sediments were not studied in detail because the purpose of this study was limited to the geology of the Kavirondian Group.

The stratigraphic terminology used by the previous workers in the study area has been revised in this work. This was necessary because of the recent changes and updating (Hedberg, 1975) of the lithostratigraphic terminology and nomenclature by the International Sub-Commission on Stratigraphy. The term 'Nyanzian Shield' (see Sanders, 1965) was used to describe three lithostratigraphic units which include, the Nyanzian System, the Dodoman System and the Kavirondian System. In this work, the term 'System' has been dropped in favour of the term 'Group'. In consequence, the previous Nyanzian System changes to Nyanzian

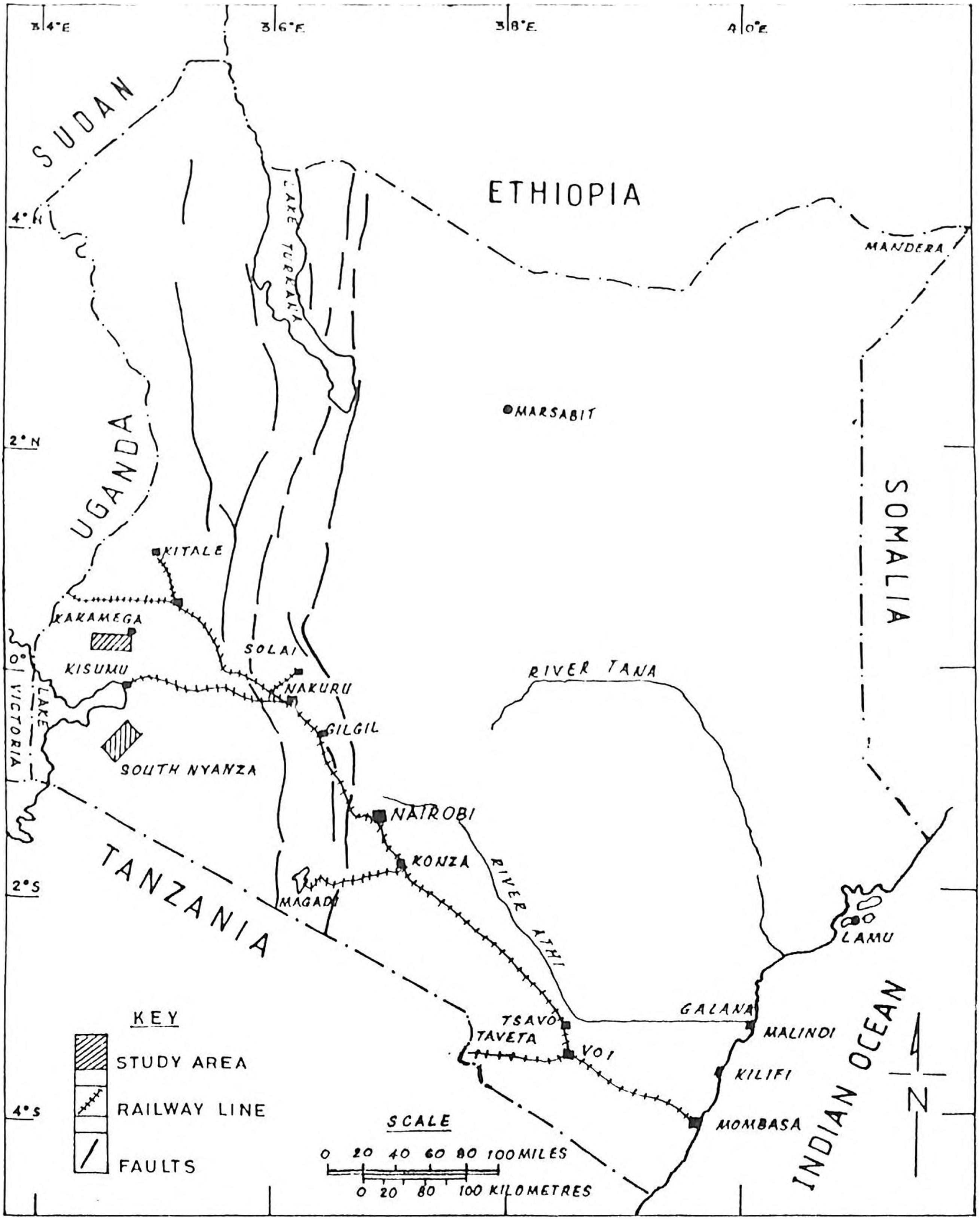


FIG. 1. MAP OF KENYA SHOWING LOCATION OF THE STUDY AREA

Group, the Dodoman System changes to Dodoman Group and the Kavirondian System changes to the Kavirondian Group.

The Nyanzian Group refers to all volcanic rocks which extruded in the Nyanzian Shield during the Archaean. The Kavirondian Group, on the other hand, refers to all the sediments which were deposited in the Nyanzian Shield during the Archaean.

In order to describe the location, communication and land use of the studied area, the area has been divided into two parts, i.e., the Kakamega and the South Nyanza areas.

1.1.1 The Kakamega Area

In the Kakamega area, the sections mapped cover about 1,120 square kilometres, of which 196 square kilometres lie in the Bunyala topographical sheet 102/1, 784 square kilometres within the Yala topographical sheet 102/3, and about 140 square kilometres is within the Kaimosi topographical sheet 102/4.

The study area is bounded by longitudes $34^0\ 26'$ E and $34^0\ 48'$ E and latitudes $0^0\ 00'$ and $0^0\ 14'$ N. On the local grid, the area is bounded on the west by the Easting 660(0) and on the east by the Easting 700(0). In the south and north, the area is bounded by Northings 000(0) and 027(5.0), respectively. The Kakamega area which is generally thickly populated has an average population density of about 294 persons per square kilometre (National Atlas of Kenya, 1970). Communication is generally good and the area is served by a railway line, several all weather roads, many dry weather roads and motorable tracks.

Sugarcane which for a long time has been the only cash crop of the area, is grown both in plantations and small holdings. Recently, coffee and tea farming have been introduced in the area, especially in Maragoli and Kakamega Nyayo tea zone in the hope of diversifying cash crop production. The main subsistence crops of the area include maize, beans, millet, sorghum, potatoes and vegetables. The subsistence crops are usually grown in small holdings.

Generally, the soils in the Kakamega area are very thick and therefore rocks of the Kavirondian Group, with the exception of conglomerate outcrops, are poorly exposed. The argillaceous members of the Kavirondian Group are found exposed in the valleys of minor streams and major rivers, eroded footpaths, road cuts and in the excavations made by the local gold prospectors. On the divides (uplands between river valleys) where almost no outcrops are available, soil type changes were observed in order to assist in inferring the geological boundaries. The Nyanzian volcanic rocks, granite intrusions and basic dykes are, however, well exposed.

1.1.2 The South Nyanza Area

In South Nyanza, the area mapped was 700 square kilometres within the Oyugis topographical sheet 130/1 and about 540 square kilometres within the Awendo topographical sheet 130/3.

The area mapped within the Oyugis sheet is bounded by longitudes 34^0 $30'$ E and 34^0 $45'$ E and latitudes 0^0 $45'$ S and 0^0 $30'$ S. On the local grid, the area is bounded by Easting 667(0) on the western side, Easting 694(5.0) on the eastern side and Northings 017(0) and 044(5.0) on the southern and northern sides, respectively.

South Nyanza is moderately populated and its average population density is about 147 persons per square kilometre (National Atlas of Kenya, 1970). In communication, the area is served by several all weather roads, tracks and footpaths.

The area is also moderately cultivated. Sugarcane, cotton and coffee are the main cash crops grown in the area. Sugarcane is grown in large plantations by Sony Sugar Company while the local population grows the crop in small holdings. Coffee is exclusively grown on the Kisii highlands by small scale farmers. Maize is the main subsistence crop. Other crops include cassava, millet, sorghum, bananas and beans.

In South Nyanza, the Kavirondian outcrops are few, scattered and occur as minor lithological traps and lenses within the older Nyanzian Group. Except for the conglomerate, other Kavirondian formations are covered by thick soils and therefore they are found only in stream beds and on the eroded footpaths. Several areas had therefore to be mapped using soil changes. The Nyanzian volcanic rocks, granite intrusions and dolerite dykes are well exposed.

1.2 Physiography

1.2.1 The Kakamega area

The physiography of the Kakamega area may be divided into three units. The first unit is represented by the area south of the Edzawa river. This unit is characterised by a peneplain which is lower in the west and higher in the east. It rises from 1,250 metres above sea level in the west to 1,650 metres above sea level in the east. The terrain also rises southwards from the Edzawa river to reach its maximum altitude of 1,740 metres above sea level south of Kima mission.

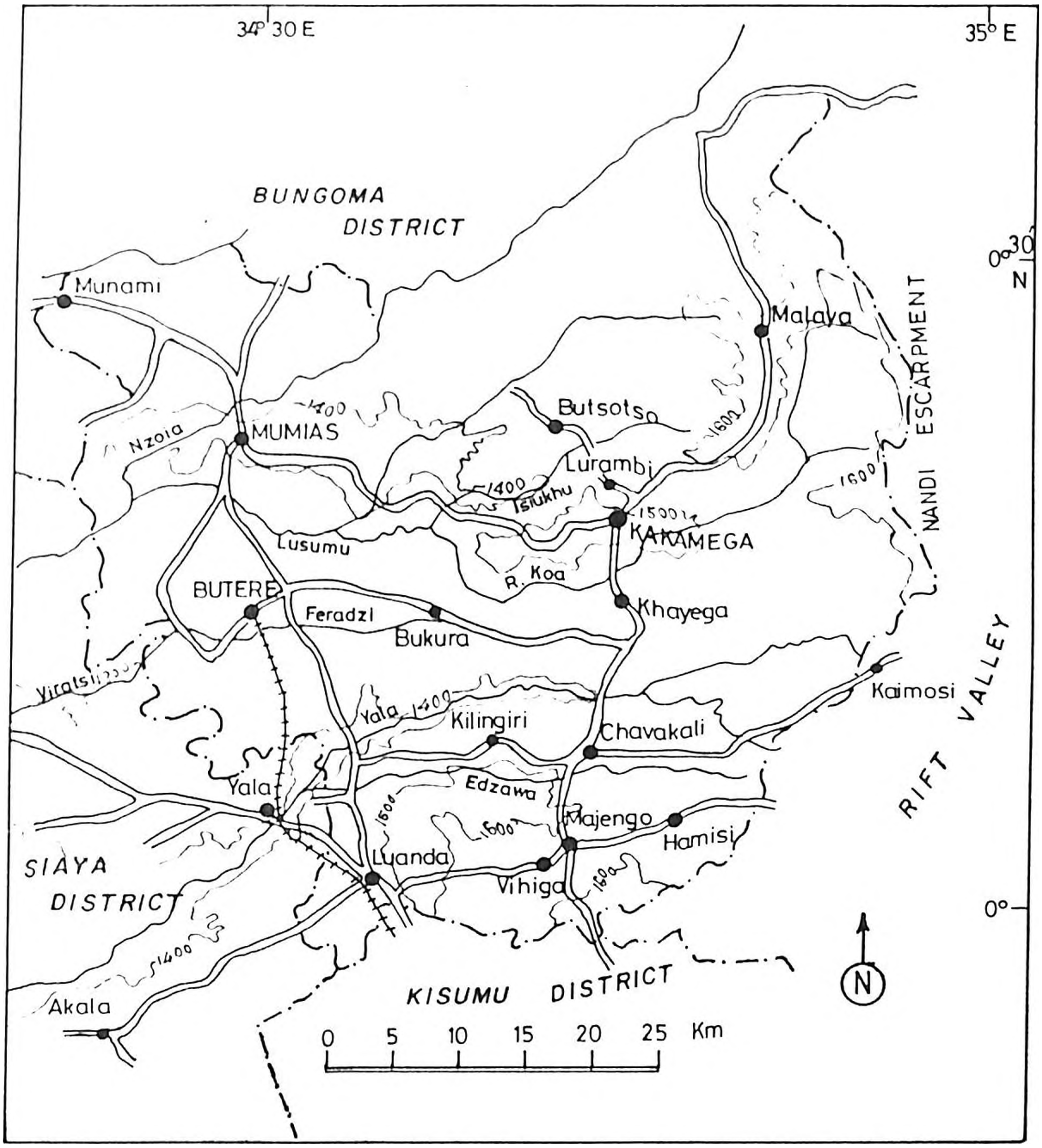
The second unit is represented by the region which lies between the Edzawa and the Yala rivers. This area is characterised by conspicuous isolated hog back shaped ridges which are called 'Giant Quartz Veins'. The trend of the ridges is approximately east-west and, from the crests of the ridges, the land drops precipitously on both sides.

The third unit is the area which lies to the north of the Yala river. This area is an undulating plain which rises from approximately 1,250 metres above sea level in the west to about 1,540 metres above sea level in the east.

Five major rivers found in the area from south to north are the Edzawa, the Yala, the Feradzi, the Koa and the Isukhu. The drainage pattern of the area is dendritic. It is characterised by many small streams which drain from the higher grounds into the main rivers. The courses of these rivers are sometimes controlled by tectonic structures. Indeed, a section of the Isukhu river which lies to the east of Mbesa, is controlled by a fault for a distance of about 2 kilometres. The fault appears to run in a south-west to north-east direction. A section of the Edzawa river which lies to the south of Zururo market is also controlled by a fault which runs in an east-west direction for a distance of 2.5 kilometres. The Yala river is also controlled by a fault for a distance of 0.5 kilometres, 2 kilometres west of Igukhu dispensary. The bedrocks, however, appear to have no major control over the river valleys. The physiography of the Kakamega area is illustrated in Figure 2.

1.2.2 The South Nyanza area

The South Nyanza area can be divided into four physiographic units. The first one is the divide which lies on the northern side of the Riana river and south of the Mogusi river. This is an extensive divide which gently slopes from the Kisii highlands on the eastern side to the Lake Victoria basin on the western side. The area generally rises from about 1,310 metres above sea level near the Otaro School in the west to about 1,616 metres above sea level at Ruga in the east. The land



KEY
District boundaries
Roads
Rivers
Towns
Railways
Contour

Fig. 2 :- A Sketch map showing the Physiography of Kakamega District.

also drops at a higher gradient towards north-west. The divide is patronised by small residual hills which break the monotomy of the gently rolling land.

The second unit is represented by the divide between the Riana and the Kuja rivers. The divide is gently rolling from east to west. On the northern side, the relief drops gently towards the valley of the Riana river and on the southern side of the region, the land drops steeply to the Kuja river valley. The eastern edge of this region is marked by the conspicuous Marongo hill whose maximum height is about 1,920 metres above sea level. The Marongo hill forms the main watershed of the area.

The third unit is the region between the Kuja and the Sare rivers. The region is gently rolling from south-east to north-west and the ridge falls steeply from Ibencho market which is about 1,920 metres above sea level to Omware school which is about 1,462 metres above sea level. The ridge also falls gently towards north-west. On the north-western corner of the ridge, Nyakuru school is 1,310 metres above sea level. Generally, the land appears to decrease in gradient from south to north. Most of the Sare river valley is about 1,341 metres above sea level while the valley of the Kuja river is about 1,310 metres above sea level.

The fourth unit is the region between the Oyani and the Sare rivers. The land is characterised by an undulating surface which rises from about 1,463 metres above sea level in the west to about 1,554 metres above sea level in the east. The four main rivers of the area are the Oyani, the Sare, the Kuja and the Riana. Unlike in the Kakamega area, rivers in this region are characterised by trellis drainage patterns which are basically controlled by the bed-rock. The tendency of the rivers is to flow along the beds of lower resistance rocks or fractured rocks.

River Kuja appears to have undergone several phases of rejuvenation and

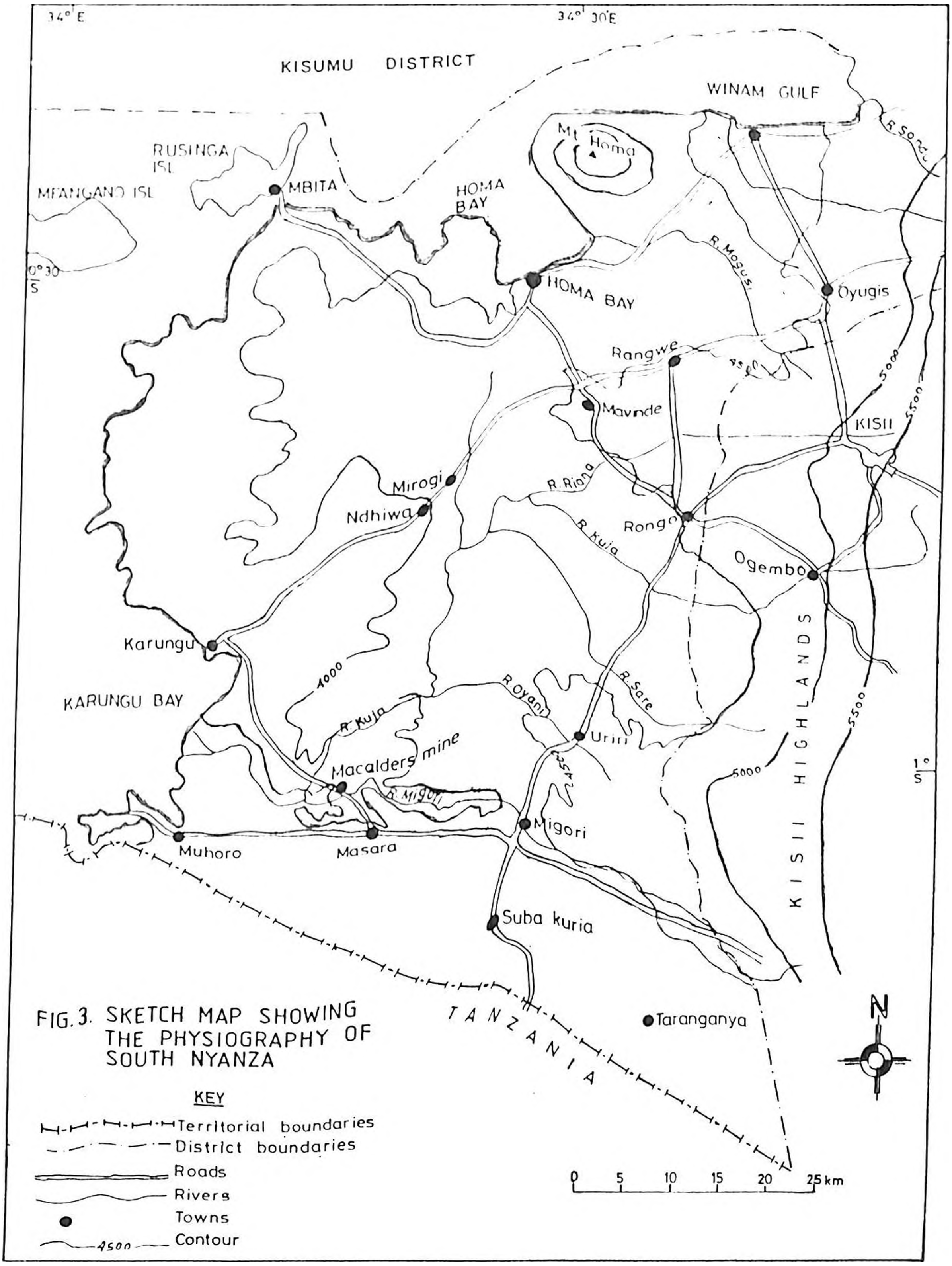


FIG. 3. SKETCH MAP SHOWING THE PHYSIOGRAPHY OF SOUTH NYANZA

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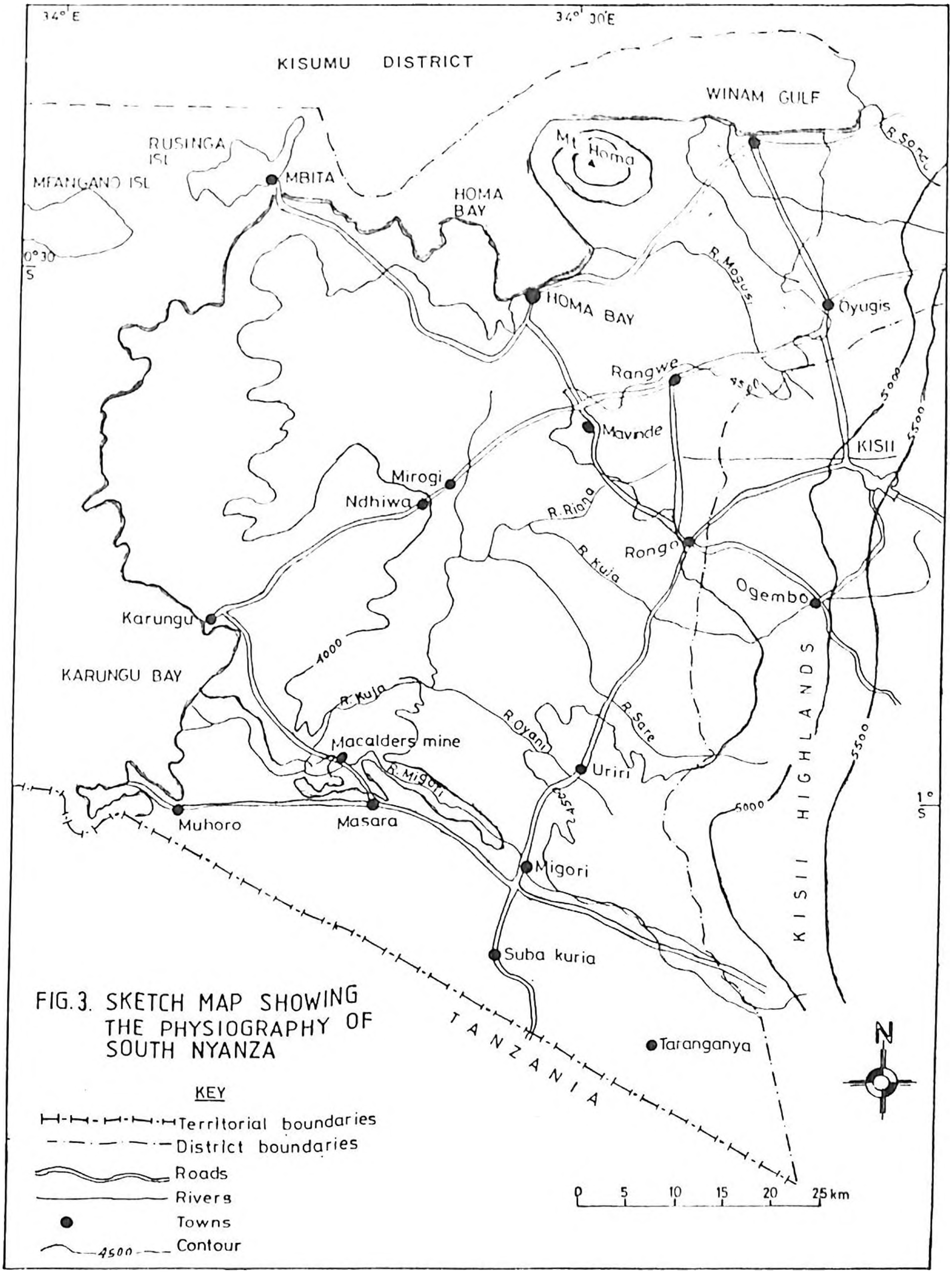

FIG. 3. SKETCH MAP SHOWING THE PHYSIOGRAPHY OF SOUTH NYANZA

presently the river is deeply incised. At least three river terraces were recognised on its valley in the area north-west of Ranen market. For the physiography of the mapped area in South Nyanza see Figure 3.

1.3 Climate

1.3.1 Introduction

The area covered by this study lies within the proximity of Lake Victoria and therefore experiences equatorial climate. The rainfall is continuous throughout the year with little distinction between the long and the short rain seasons. This is due to the fact that daily westerly winds from Lake Victoria converges with the south-east trade winds, causing the combined airmass to rise. The clouds formed as a result of the convergence of air masses produce heavy showers, especially in the afternoons. It has been observed that although the whole area experiences equatorial climate, the area to the north of Winam Gulf experiences more rainfall. The climate of the area is discussed in two parts, the Kakamega District and the South Nyanza District.

1.3.2 The Kakamega District

Although there are some modifications in rainfall and temperatures due to the differences in altitude within different parts of the district, generally the climate is uniform with well distributed rainfall. Rainfall is generally high with no marked dry season. Rainfall ranges between 1,120 millimetres in the drier parts to about 2,000 millimetres in the wettest parts. There is usually a markedly high rainfall during the months of March and September and a period of less rainfall between December and February. Rainfall expectation is high. At least 500-1,100 millime-

STATION	ALTITUDE (mm)	RAINFALL in (mm) 1982	1983	1984	1985	No. of rainy days in 1985	Average rainfall(mm)	No. of years Recorded
Eregi Teachers College	1524.0	2367.1	2070.5	1804.2	1732.8	155	1942.0	25
Kaimosi Farmers Training Centre	1706.9	1866.7	1891.6	1238.8	1197.2	127	1803.0	32
Butere Health centre	1432.6	2237.7	2042.3	1247.3	2043.3	224	1883.4	47
Kakamega Met.	1584.9	2244.8	1919.5	1638.5	2068.5	193	1820.2	68
Bukura Farmers Training Centre	1463.0	2034.4	1862.3	1647.0	1927.4	172	1810.7	55
St. Mary School. Yala	1463.04	1742.7	1742.7	1892.6	1892.6	194	1975.5	22

TABLE 1 ANNUAL RAINFALL AVERAGES RECORDED AT SIX STATIONS IN KAKAMEGA DISTRICT. SOURCE: METEOROLOGICAL DEPARTMENT, NAIROBI.

ALTI-TUDE (m)	NAME OF THE STATION	KINDS OF RECORDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total for Years	No. of Years Recorded
	Kakamega	Mean max.	27.1	27.2	27.5	26.0	25.8	25.2	24.4	23.8	20.0	25.7	25.9	25.9	25.8	
	Forest	Mean Temp.	19.0	18.0	19.7	19.3	19.0	18.3	18.0	17.5	17.8	18.4	18.9	18.7	18.6	
1676	Station	Mean min.	10.8	10.4	11.7	12.6	12.2	11.3	11.6	11.1	10.6	11.5	12.0	11.4	11.4	
		Abso. min	5.0	4.4	5.0	9.0	8.0	8.0	8.0	8.0	5.0	8.0	7.8	6.0	4.4	8. 0
	Kaimosi	Mean max.	26.8	27.4	27.1	26.7	26.0	25.3	23.8	24.9	25.9	25.7	25.4	26.2	25.9	
	Mission	Mean Temp.	21.0	21.6	21.4	21.1	20.5	20.1	19.3	19.8	20.4	20.4	20.6	20.8	20.6	
1615		Mean min.	15.3	15.7	15.7	15.6	14.9	14.8	14.7	14.9	15.0	15.8	15.4	15.4	15.2	
		Abso. min.	10.0	9.4	10.0	10.0	8.3	8.9	8.9	8.9	10.6	10.6	11.1	8.9	8.3	8.0
	Kazimoto	Mean max.	28.9	27.6	27.4	25.8	25.3	23.9	24.3	25.2	26.6	27.3	27.3	27.3	26.4	
	Estate	Mean Temp.	20.2	19.9	20.4	20.3	19.4	18.2	17.5	17.6	19.1	19.9	18.9	18.9	19.1	
1885		Mean min.	11.4	12.0	13.3	13.3	12.9	11.0	11.1	10.6	10.0	11.6	12.4	10.4	11.7	
		Abso. min.	3.9	5.6	7.8	8.9	8.3	4.4	5.6	5.6	6.7	7.8	8.3	3.3	3.3	11.0

TABLE 2 ALL TEMPERATURES RECORDED IN THIS TABLE WERE OBTAINED BETWEEN 1970 AND 1985. TEMPERATURES ARE IN DEGREES CENTIGRADE. SOURCE: METEOROLOGICAL DEPARTMENT, NAIROBI.

tres are expected during the wetter season and 450-850 millimetres during the drier season. Due to the wet climate, evaporation is not high. Evaporation is normally between 1,600-1,800 millimetres per year for nearly the whole district. Rainfall records of some selected stations in the Kakamega area are given in Table 1.

Temperatures are generally high and uniform. The annual mean temperature in the eastern part of the district is about 18^0 C while in other parts of the district the annual mean temperature is higher than 20.5^0 C. The annual temperature range is about 5^0 C and the diurnal range is usually over 12^0 C. In Kakamega District, the humidity is about 70% throughout the year. The humidity, however, decreases with the increase of the altitude. Temperature records of some selected stations in the Kakamega area are given in Table 2.

1.3.3 The South Nyanza District

Some parts of South Nyanza are very close to Lake Victoria and consequently experience equatorial climate. This type of climate is charaterised by convectional rainfall which usually occurs in the form of thunderstorms and showers from nimbus clouds during the afternoons. Rainfall is normally discontinuous and is interspersed by spells of sunshine. Further inland from the lake shores, the land is drier because moisture charged winds pass over the low lying areas like Rongo and Asumbi and eventually form relief rainfall on the slopes of the higher Kisii highlands. The contrasts in rainfall due to local air circulation are tremendous. Annual averages are between 700 and 1,800 millimetres. Long rains which are in the range of 250 to 1,000 millimetres start in the beginning of March and end during the month of May. There is a dry spell until the second rainy season starts around November. This second rainy season is feeble and registers between 0 and

STATION	ALTITUDE (m)	RAINFALL IN (mm) 1982	1983	1984	1985	No. of rainy days (1985)	Average rainfall (mm)	No. of Years Recorded
Sony Sugar Factory	1463.0	2036.4	1863.9	731.5	1674.8	132	1904.3	13
Rongo Chief's Camp	1402.1	1402.1	877.8	1484.0	1859.6	102	1463.6	25
Wanjare Chief's Camp	1676.4	1659.5	1888.5	719.8	1816.6	184	1792.0	32
Asumbi Teachers College	1423.4	1752.4	1588.8	1171.6	1368.0	97	1527.9	21
Kamagambo Training College	1524.0	1565.5	1648.3	1467.4	2092.5	143	1847.6	14
Oyugis Agric. Station	1463.0	1743.0	1622.1	761.7	1061.5	177	1598.8	17

TABLE 3 ANNUAL RAINFALL AVERAGES RECORDED AT SIX STATIONS IN SOUTH NYANZA. SOURCE: METEOROLOGICAL DEPARTMENT, NAIROBI.

ALTITUDE (m)	NAME OF THE STATION	KIND O RECORDS	JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL FOR YEARS	NO.OF YEARS RECORDED
1218	Malcader mine	Mean max	30.0	30.3	30.2	29.4	29.1	29.1	20.0	29.1	29.7	30.0	30.0	29.3	29.3	15.0
		Mean Tem	23.5	24.0	23.9	23.4	23.2	23.1	22.1	22.7	23.0	23.2	22.2	22.9	23.2	
		Mean min	16.9	17.6	17.6	17.3	17.2	16.8	16.1	16.2	16.3	16.4	16.4	16.5	16.8	
		Absol. min.	11.7	12.8	13.9	13.9	12.2	12.8	12.2	11.1	13.3	9.4	12.8	12.8	9.4	
1218	Homa Bay D.C. Office.	Mean max	34.7	34.8	34.6	33.1	33.2	33.8	33.4	33.4	33.7	32.9	33.9	33.9	33.6	4.0
		Mean Tem	26.3	26.4	26.4	25.5	25.2	25.2	25.1	26.0	25.7	26.0	25.7	25.7	25.8	
		Mean min	17.9	18.0	18.2	17.6	17.1	17.5	17.8	18.6	17.6	19.1	17.6	17.5	17.9	
		Absol. min.	10.0	13.9	12.2	15.6	11.1	15.6	15.6	13.9	14.4	15.6	11.1	15.5	10.0	

TABLE 4 THE TEMPERATURES SHOWN ON THE TABLE WERE RECORDED BETWEEN 1961 AND 1983 ALL TEMPERATURES ARE IN DEGREE CENTIGRADE. SOURCE: METEOROLOGICAL DEPARTMENT, NAIROBI.

700 millimetres of rain. During the months of January and February, another dry spell is experienced. Considering the rainfall regimes, the climate of the area can be classified as modified type of tropical climate. Generally, there are wide variations in the local climate although the general patterns in rainfall are roughly the same. Long rains occur around March and April but the amount received depend on the position of a particular station in relation to relief. Rainfall records of some selected stations in South Nyanza are given in Table 3.

It will be noticed from Table 4 that temperatures for Homa Bay which is on the shores of Lake Victoria are generally high throughout the year. However, as one moves away from Lake Victoria, the temperatures become lower. At Macalder mine, which is much further from Lake Victoria, temperatures are clearly defined into a very hot season between January and March. In April, temperatures start falling until October when they start rising again. Relative humidity is generally high near the lake but it decreases as one moves further from the shores of the lake. Evaporation is about 2,000 to 2,200 millimetres per year. This high evaporation rate is promoted by local winds.

1.4 Objectives of the Research

The first objective of this study is to establish the stratigraphy and the possible correlation of the different lithostratigraphical units which are found within the Kavirondian Group. The stratigraphical knowledge gained will be a guide to future mineral exploration work within the Group, in that the stratigraphy of the various lithostratigraphical units will now be better understood and therefore any promising litho-units can be compared and correlated with others which lie within the same stratigraphic horizons elsewhere.

The second objective is to determine the provenance of the Kavirondian sediments. The knowledge of the provenance provides the basis for predicting the sources of minerals which have immigrated from one lithofacies to another. An understanding of the provenance also assists in determining which minerals have formed in situ.

The third objective is to study the environments of deposition of the sediments. The knowledge gained from the study of environments of deposition will be useful in determining the mineralogical associations of the minerals formed in similar lithofacies.

Chapter 2

GEOLOGY OF THE STUDY AREAS

2.1 Introduction

In this chapter, the literature review of the geological work carried out by previous workers and a description of the rock types found in the study area are presented.

The Archaean greenstone belt of western Kenya is a part of the greater Nyanzian Shield which forms a major structural unit of which the limits were defined by MacConnel (1951) and Cahen and Snelling (1984). Accordingly, the Shield is bounded by the Mozambiquian belt on the eastern side. On the southern and south-eastern sides, it is bounded by the Ubendian belt. In south-eastern Uganda, the structural boundary of the Shield is placed at its unconformity with the Buganda-Toro series and on the western side, the boundary is marked by the unconformity between the Shield and Karagwe-Ankolean rock suites.

Three lithological groups have been recognised in the Nyanzian Shield. The groups include the Dodoman, the Nyanzian and the Kavirondian. In the area covered by the present study, only the Nyanzian and Kavirondian Groups have been recognised. The Nyanzian Group forms the lower succession in the Nyanzian

Shield. It is composed of steeply dipping basic, intermediate and acid volcanic rocks which are usually accompanied by minor pyroclastic developments. The upper succession of the western Kenya Archaean greenstone belt is predominantly composed of sedimentary formations which make up the Kavirondian Group.

The major intrusives are younger than the Kavirondian Group sediments and they are represented by Mumias, Maragoli Wanjare and Kitere granites. Other rock suites mapped are minor intrusives which include adamellites, syenites, syenodiorites, diorites, epidiorites, quartz porphyry, granite porphyry, diorite porphyry, dolerites and lamprophyres as the minor intrusives in the vicinity of Kakamega town. Although the primary purpose of this study is to investigate the geology of the Kavirondian Group, it is felt that a general grasp of the other rock types found in the study area is necessary because petrographical and geochemical data indicate that the Kavirondian sediments were partly derived from them.

2.2 Literature review

2.2.1 The Kakamega Area

According to Huddleston (1954), the earliest references to the geology of western Kenya are attributed to Gregory and Scott Elliot in 1895 who made references to the existence of Archaean rocks near Mumias and mentioned the occurrence of sediments in the western side of the Nandi hills although no precise locality was mentioned. Gregory (1921) recorded that the geology of the country lying between the Nandi hills and Lake Victoria was composed of sedimentary rocks of the Karagwe series.

Combe (1927-1930) made geological traverses in a large portion of west Maragoli. He recorded the presence of a broad belt which he likened to the Karagwe-Ankolean sediments and suggested that the sediments form a broad synclinal structure. The conglomerates within the synclinal structure were observed to contain large boulders which were identified as having been derived from the nearby "green-grey rock" suites which were composed of ancient lavas which had been much altered and decomposed. The lavas were considered to be mostly phonolites, andesites, dolerites and rhyolites. It is, however, unlikely that phonolites formed part of the boulders in the conglomerates because it is now evident from this work that phonolites are Tertiary extrusions and are unlikely to have contributed to the Kavirondian sedimentation. Combe (1930) suggested that the lavas were comparable to the Ventersdorp System of South Africa and that the sediments which he considered to be of the Karagwe-Ankole series might be equivalent to the Nama-Transvaal system.

Odman (1929) made a rapid reconnaissance of large parts of Western Province where he termed the sediments he came across as the "Kavirondian series". These rocks were composed of volcanic rocks and sediments. Therefore, he concluded that the rocks were equivalent to the Karagwe-Ankolean System of Uganda. It is now understood that "Kavirondian series" included what is currently known as the Nyanzian and the Kavirondian Groups. The basic lavas were considered to be the older members of the series while the pyroclastic rocks associated with rhyolite and rhyodacites were considered to be indicative of subsiding volcanic activity in the area. The volcanic pebbles in the conglomerates of the sedimentary part of the "Kavirondian series" were taken to indicate the stratigraphical boundary of the two divisions of the series both of which were clearly intruded by granites. Odman (1929) observed that the rocks of the "Kavirondian series" were isoclinally folded and only locally did he observe these rocks dipping toward the north. During this study ,however, several rocks which dip to the north, especially within the fault zones, were observed.

Kitson (1932) observed that the strike of the "Karagwe-Ankolean" rocks in Kakamega area was east-west but that the basin of the Koa and the Lugadsi rivers had a pronounced northward swing. It is evident from this work that the northward swing is due to the presence of normal faults which have similar trends. Kitson (1932) also noted that the general structure of the "Karagwe-Ankolean" rocks included at least two synclines and two anticlines. He also differentiated four different kinds of granite of different ages both north and south of the Karagwe-Ankolean rock suites. Murray-Hughes (1933) confirmed that the volcanic rocks of the Kakamega region were older than the Kavirondian sediments which he had previously equated with the Muva-Ankolean series.

Davies (1933) suggested that the Kavirondian shales at Bukura might correspond to the "Karagwe-Ankolean" sediments of eastern Uganda. As an after thought, he stated that the rocks he had previously described as belonging to the "Karagwe-Ankolean" were actually equivalent to the "Samia series" in age. He regarded the "Samia series" as younger than both the granite intrusions and the Kavirondian Group. Davies further suggested that the "Samia series" was partly formed under normal sedimentary conditions and partly under volcanic extrusion.

Pulfrey (1936) geologically mapped the area then known as the "Eldoret Mining Syndicate Concession" which was about 90 square kilometres. The area was located on the Edzawa-Yala divide. He noted that the area was a part of the dissected peneplain of northern Nyanza (now Western Province) and the "Muva-Ankolean" sediments in the peneplain were part of large roof pendant which rested on an extensive granite batholith. He observed that the sediments formed a simple geological structure which consisted of two folds which were separated by a "flat intermediate limb". These folds were subsidiary to the major folds of Kakamega District which were generally isoclinal. The folds were steeply dipping to the north and only rarely were the rocks found to be dipping to the south.

Pulfrey (1945) mapped east Marama and the adjoining areas. The northern part of the area he mapped was occupied by the porphyritic Mumias granite. He considered the Mumias granite as an eastward extension of the more extensive Kitosh granite which extended to eastern Uganda. South of the Mumias granite, around Sabatia-Isaiah, he noted a narrow belt of sheared volcanic rocks. Further east, about 3.5 kilometres north of Shingulu, he noted volcanic rocks of the Kakamega inlier. South of the Kakamega inlier towards the Edzawa river valley, he found both arenaceous and argillaceous sediments of the Kavirondian Group. In the area south of the Edzawa river, volcanic suites once again appeared in large inliers which stretched from Ishibuye to the Mwaia river. Other minor inliers of volcanic rocks were recognised near Yala town, along the Mwiengi river and west of the Ibuvi hill. The western side of the volcanic inliers was found to be occupied by the Maseno granite. Pulfrey (1945) further observed that the volcanic rock suites and the sedimentary rocks were cut by dolerite dykes and quartz veins. The dolerite dykes were particularly common in a broad belt which run from north-west near Matioli to south-west in Lusumu valley. "Giant Quartz veins" were observed to form conspicuous humps at New Kisa and Kimingini.

Pulfrey (1945) suggested that a period of folding followed the extrusion of the volcanic rocks and that during a later orogeny, sedimentation of the Kavirondian Group sediments took place. During a later epoch, the already folded Nyanzian volcanic rocks were again refolded along with the Kavirondian sediments. Pulfrey

(1945) suggested the following geological succession for east Marama.

Pleistocene and Recent

7) Superficial deposits, alluvial deposits, gravel of fluvial deposits and high level pluvial sediments.

Unconformity

Upper Precambrian to Early Proterozoic.

6) Intrusion of dykes, small igneous bodies and dolerites.

5) Emplacement of Quartz veins.

4) Major plutonic phase - intrusion of Mumias granite, Ibuvi adamellite and the Edzawa syenite.

Igneous Contact

3) Intrusion of dolerite dykes.

2) Deposition of the Kavirondian Group.

Unconformity

1) Deposition of the Nyanzian Group.

Pulfrey (1946) reported that most of the Maragoli region was occupied by the Kavirondian sediments. He also reported widespread development of the Nyanzian volcanics on the southern margin of the Kavirondian sediments. He then suggested the following revised rock succession for the area.

Pleistocene and Recent

12) Superficial deposits, alluvials, gravel of the pluvial periods. Formation

and commencement and erosion of Ironstone capping.

11) Faulting and warping.

10) Extrusion of phonolites in the south.

9) Completion of formation of the Kavirondian Peneplain.

Upper Precambrian

8) Intrusion of dykes and small igneous masses mainly dolerite, lamprophyres, porphyrites, granophyres and granite porphyry.

Emplacement of Quartz Veins

7) Late veining and invasion of granite masses by syenite, granite and monzonite.

6) Major plutonic phase

(b) Maragoli granite intruded.

(a) Ibuvi and Siadiga adamellite intruded.

Igneous Contact

5) Introduction of dolerite dykes now epidioritized.

4) Folding and Faulting.

3) Deposition of sediments of the Kavirondian Group.

Unconformity

2) Folding.

1) Extrusion of volcanic rocks of the Nyanzian Group which include rhyolite, andesites, basalts and tuffs.

Generally, the lithological sequences in the Maragoli area and the Kakamega area are in agreement. However, the following differences are noted:-

a) Conglomerates are exclusively absent in the Kavirondian Group of the Maragoli area.

b) Early phase of the major intrusions in the Maragoli area are represented by syenites whereas in Kakamega area, the early phase of intrusions are represented by diorites.

c) Major granitic plutons in the Maragoli area can be divided into earlier soda-rich phases and later potash-rich phases.

d) Tertiary volcanic rocks which are present in the Maragoli area are conspicuously absent in the Kakamega area.

In an attempt to correlate the tectonic events between the Maragoli area and the neighbouring areas, Pulfrey (1946) observed that in all areas there was a period of folding and denudation which followed Nyanzian volcanism during which sediments were deposited. Kavirondian sedimentation was followed by a period of folding and faulting. The last phase of faulting gave rise to Maragoli "scarp" on the southern side of the Maragoli hills. He then correlated this last faulting phase with the post-Miocene rift valley faulting. The Maragoli fracture was therefore taken to form the northern fault boundary of the Kavirondian (now Winam) Gulf transverse fault.

Huddleston (1954) geologically mapped the Kakamega District and noted several similarities between the Nyanzian volcanic rocks in the area and those described by Saggerson (1952) in South Nyanza. He described the Kavirondian series as sedimentary successions which were composed of conglomerates, grits and siltstones. He noted that the sediments overlie the Nyanzian volcanic rocks with a strong angular unconformity on the upturned edges of the steeply folded Nyanzian rocks. Opiyo (1988) failed to locate any such unconformities and concluded that the Nyanzian volcanic rocks and the Kavirondian sediments were contemporaneous. In the present study, however, it has been observed that unconformities in the area are indicated by sudden changes of dips. Similarly, dips on the Nyanzian volcanic rocks are at high angles while those of the Kavirondian sediments are generally much lower. However, it is true that due to isoclinal folding direct observation of unconformities is clearly hampered.

Huddleston (1954) mapped the following rock suites in the Kakamega area.

a) Highly granitised gneisses of the Mozambiquian Belt at the Nandi hills.

b) Acid and basic volcanic rocks which steeply dip due north. The volcanic rocks are associated with minor pyroclastic developments and they make up the Nyanzian Group.

c) Conglomerates, grits and mudstones of the Kavirondian Group.

d) Maragoli and Mumias granites, altered diorites of different ages and a variety of minor dolerite dykes which intruded both the Nyanzian and the Kavirondian Groups.

e) Tertiary phonolites resting on a generally uneven surface in the south central portion of the area near Boyani market.

f) Pleistocene and recent soils, gravel and lateritic ironstone.

The geological succession of Kakamega District according to Huddleston (1954) is as follows:-

Pleistocene and Recent

Superficial deposit - Black clay, sandy soils laterite and valley alluvium.

Tertiary

Phonolites in the south central portion of the area.

Unconformity

Upper Precambrian

Dyke intrusions mainly dolerite, some lamprophyres and quartz porphyries.

Major plutonic phase - intrusion of Maragoli and Mumias and slightly earlier intrusion of the Kakamega diorites.

Precambrian

Folding and faulting.

Deposition of the Kavirondian conglomerates, grits and mudstones.

Unconformity

Granitoids, gneisses, migmatities and hornblende schists.

Sander's (1965) noted that the petrology, structural and tectonic setting of igneous and metamorphic rocks in the Webuye area show the order of evolution similar to that of the major Precambrian groups. The granite foreland in Webuye shows progressive eastward deformation in moving from west to east. The Nyanzian and the Kavirondian rocks were progressively metamorphosed from west to east. Sanders (1965) also noted that the rock suites of the Nyanzian Shield are older than those of the Mozambiquian belt, an observation which was first made by Holmes in 1951.

To justify his conclusions, Sanders used geological evidence derived from isotope age determinations obtained after analysis of three rock suites.

1. Ages of 410 to 635 million years were obtained from feldspars and micas from the Mozambiquian belt.

2. Apparent ages of 710 to 1,060 million years were obtained from the deformed

granites and granodiorites of the Nyanzian Shield situated within the western orogenic belt from the Mozambiquian belt.

3. Ages of 2,510 and 3,150 million years were obtained for the Kavirondian and the Nyanzian rocks, respectively.

Yanagi and Suwa (1981) described the Nyanzian volcanic rocks as having tholeiitic affinity, on the basis of their having up to 70% silica content. Rocks with silica content less than 60% have a calc-alkaline affinity. During this study, samples collected and studied from several outcrops show that most of the acid volcanic rocks were mainly calc-alkaline but basic rocks, especially basalts, have tholeiitic affinity. Opiyo (1988) also observed that rocks from the Nyanzian Shield around Maseno contained a silica content lower than 70% and hence they are of calc-alkaline affinity.

Suwa et al. (1983), in his study of the geological structures of the Archaean greenstone belt north-west of Kisumu, concluded that within the Nyanzian Group, basalts occupied the lowest stratigraphic position, andesites occupied the middle level and rhyolites and tuffs occupied the uppermost stratigraphic level.

Ichangi (1983) noted that pyrite mineralisation in the Bukura-Mbesa area occurs mainly within the steeply dipping thermally metamorphosed mudstones and grits are mineralised to a lesser extent along the contacts with the Mumias granite.

UNESCO/Rosta (1987) sponsored an integrated geological investigation exercise in the area between Maseno and Kakamega. The purpose of the project was to update the available data of the geology of the area through detailed geological mapping and economic mineral exploration. The findings of this investigation are still in the process of preparation.

2.2.2 The South Nyanza Area

According to Huddleston (1951), the earliest known geological work in South Nyanza was carried out by in Toll in 1907. Several rock samples attributed to Toll show that he visited the area between the Giri river and Kisii municipality. No records were however left behind of his observations and analyses.

According to Huddleston (1951), Coates in 1909 spent two months studying the geology of the area between Oyugis town and the Kuja river. He considered the rocks of the Wire hill and similar rocks south of Oyugis to be of sedimentary origin. Through this study, this observation is found to be unlikely because the Wire hill is basically composed of andesite and rhyolite rock suites while the area south of Oyugis is composed of early Proterozoic basalts and sediments of the Kisii series.

According to Huddleston (1951), Onsward in 1914 made geological traverses from Kisii to Homa Bay through Kendu Bay. He recognised augite-andesite rocks associated with agglomerate in the Oyani river. However, observations made during the present study show that the rocks Onsward described as agglomerate are actually Kavirondian conglomerate. Onsward further considered Nyagongo, Kitere and Wanjare granites as granite gneisses but according to the observations made during the present study, there is neither petrographical nor chemical evidence to show that these granites are granite gneisses.

Wayland (1931) made a rapid reconnaissance of parts of the Nyanzian Shield in South Nyanza, after which he proposed a provisional rock succession in which he suggested that the lowest succession was composed of crystalline complex, the middle succession was composed of Gori conglomerate and the upper succession was composed of conglomerate which belonged to Karagwe-Ankolean series. He further proposed that the Kitere phyllites and conglomerates which occur between Kisii and Oyugis are part of the Karagwe-Ankolean series.

Murray-Hughes (1933), without making any specific mention of the rock types he found in South Nyanza, compiled a map in which he indicated that there were sediments in the area which he ascribed to the upper division of the basement complex. According to Holmes (1951) and Sanders (1965), Nyanzian Group rock suites in western Kenya greenstone belt are the oldest and therefore the proposition of older basement complex in the region is outdated.

Between the years 1934 and 1937, Kenya Consolidated Goldfields Limited was given an exclusive prospecting licence to prospect an area of about 2,108 square kilometres in South Nyanza. During this period, Hallam et al., 1934-1937 (cit. Huddleston, 1951) mapped 1,800 square kilometres of the licenced area and in 1937 a progress report on the geology of the mapped area was presented to the government by the company. In the progress report, the following stratigraphic succession was adopted:-

Pliocene

Homa and Ruri volcanics

Miocene

Gwasi volcanics

Post Karoo

Dolerites

Unconformity

Bukoban (Precambrian)

Kisii series

3. Andesite

2. Quartzite, soapstone and chert

1. Basalt

Unconformity

Precambrian

Kavirondian series - Conglomerate and diorite-porphyry

Unconformity

Kitere granite, Wanjare granite and diorite, quartz-porphyries and felsite of the Wanjare series and amphibolites facies.

Greenstone Series

Acid to basic lavas with tuffs and agglomerates.

In the report the Wanjare granite was considered to be older than the Kitere granite and to be of the same age as the Wire hill series. Kavirondian Group was considered to be younger than the diorite porphyry and its thickness was estimated to be about 61 metres. Kisii series was estimated to be 457 metres thick.

Huddleston (1951) studied an area of 1,250 square kilometres in South Nyanza which is bounded by latitudes 0^0 $30'$ S and 1^0 $00'$ S and Longitudes 34^0 $30'$ E and 35^0 $00'$ E. After his studies, Huddleston (1951) devised the following succession for the studied area.

Pleistocene and Recent

Superficial deposits, black clay, sandy clay, laterite and valley alluvium.

Tertiary

Homa Lavas, Agglomerate and Tuffs.

Unconformity

Bukoban (Kisii series) Late Precambrian

Rhyolites, felsites, andesite with the associated tuff, feldspathic sandstone, conglomerate, Quartzite and cherts.

Basalts with soapstone locally Porphyritic Basalts

Unconformity

Kavirondian series - Precambrian

Conglomerate, grit and sandstone with minor mudstones.

Unconformity

Nyanzian series - Precambrian

Huddleston (1951) observed that the Nyanzian rocks formed the oldest rock suites in South Nyanza. The Nyanzian rocks were largely basic to acid lavas which were associated with tuffs and agglomerates and, although the age relationships of the lavas were not clear, overfolding, dip and strike directions suggested an order of succession which from the base was composed of basic lavas through intermediate rock types to acid lavas on the top. Huddleston noted that the successions already described could not be observed along the Sare river because the rock outcrops included andesites, tuffs and feldspathic sandstones. He also noted that the Kavirondian series which was composed of boulder conglomerate, grit, sandstone and mudstone formed an angular unconformity with the underlying Nyanzian Group.

On the thickness of the Kavirondian sediments, Huddleston (1951) commented that the sediments were approximately 1,520 metres thick but in places where the sediments occurred as minor lenses within the Nyanzian Group, the thickness did not usually exceed 1,070 metres. These proposed thicknesses appear to be an under estimation when compared with those of other Archaean terraines in the world. Ramakrishna et al. (1976) observed that the Dharwar Supergroup of India is 8,200 metres thick. The older cycle (Bababudan Group) is 1,200 metres thick while the younger cycle (Chitradurga Group) is 7,000 metres thick.

In Australia, the Kalgoorlie-Norsemena succession is 9 kilometres thick but the upper part of the succession which is mainly composed of felsic volcanic rocks is about 1.2 kilometres thick. In the Superior Province of Canada, Baragar (1968) noted that the stratigraphic thickness of the Archaean greenstone pile ranges from 7 to 17 kilometres. Anhaeusser et al. (1969) observed that in most Archaean greenstone belts, the stratigraphic sections usually range from 10 to 25 kilometres thick. It is, however, noted that there are usually variations in thickness between the lower volcanic successions and the upper sedimentary successions in different Archaean terraines in the world.

Onuonga (1983), discussing the geology of the Macalder mines area, showed that the volcanic rocks around Macalder mines are bimodal and belong to at least two distinct fractionating sequences. He further observed that in the vicinity of the mine, there was widespread metamorphism which he attributed to migration of alkalis and iron. This migration had altered the composition of the surrounding rocks such that the rocks could not be clearly classified as those of tholeiitic affinity or calc-alkaline affinity.

Since 1951 when Huddleston mapped several parts of South Nyanza, the Mines and Geological Department of the Ministry of Environment and Natural Resources, has done a lot of work in the area in conjunction with various international organisations. Between 1984 and 1986, a major project whose purpose was to review the geology of the area south of Oyugis, with special emphasis to exprolation of economic mineral deposits, was carried out by the United Nations Development Programme (U.N.D.P.) in conjunction with the the Mines and Geological Department. The findings of this project are still in the "classified information" Archives of the Mines and Geological Department.

2.3 A description of the rock types found in the study area

2.3.1 Basalts

In the Kakamega area, basalts occur as a restricted large outcrop in the Shikamala area about 1 kilometre north west of Butere township (see Appendix C1). Other minor outcrops of basalts occur as intercalations within the andesite rock suites around Shihuli market.

In the South Nyanza area, basalts appear as long narrow zones in the areas south of the Sare river, around Kamagambo and in the area south east of Imbo market.

In the field, basalts occur as highly weathered rocks which, due to some tectonic movements have undergone shearing. The strike of the shear zones is east-west. Shearing is much more pronounced near the contacts between basalts and granite intrusives. The sheared basalts show no original igneous structures and textures and therefore it is impossible to determine whether they represent mere volcanic piles or pillow lavas sequences. One well exposed, fresh outcrop at Shinamwenyuli, appears as a massive steeply inclined rock in which the only structures are columnar joints. The length of the joints vary from 4 to 15 centimetres. Columnar joints appear to reflect contraction during the cooling process of the solidifying lava. At another outcrop near Awendo, basalt is surrounded by andesite rock suites. The basalt shows irregular and flattened pillow structures which are closely packed. The contact between the basalt and the other rock suites is not clear because the margins of the basalt outcrop are extensively weathered. When weathered, basalts form deep red clay soils.

In hand specimen, basalts are dark green, fine grained rocks. The rocks yield almost no information because they are both extensively altered and often very fine grained.

In thin section, most of the original mineral assemblages have been replaced by amphiboles and chlorite. However, tiny crystals of quartz and plagioclase were observed. Some of the plagioclase and amphiboles were observed as having formed intergrowths which form a loose mass in highly chloritic and epidotised groundmass. In all specimens studied, there was a total absence of olivines. According to Hatch et al. (1983), presence of quartz and lack of olivines in a basalt implies that it is tholeiitic. Tholeiitic basalts are closely associated with calc-alkaline magma differentiates such as andesites, dacites and rhyolites. Epidote and iron oxide are the common accessory minerals. Thin sections of the samples collected from the margins of basalt outcrops, also show feldspars which surround brown coloured hornblende. Some of the hornblende has been replaced by brown-greenish biotite while some feldspars have altered into sericite.

2.3.2 Andesites

In the Kakamega area, andesite outcrops are found in the vicinity of Khayega, around Sabatia and north of Butere.

In the South Nyanza area, andesite outcrops covers a large area of the Sony Sugar belt which lies to the south-east of Awendo market. The andesite outcrops in this area are sandwiched between basalts and basal Conglomerates. Andesite outcrops at Buari and Ranjira are found intercalated with andesitic tuffs.

Two types of andesites have been recognised in the study area. The first type is light medium green in colour. The rock is non-porphyritic, vesicular and contains whitish feldspar phenocrysts which measure up to 4 millimetres long. In some samples, the feldspar phenocrysts, show micro-brecciation around their margins, which give the rock a streaky, lenticular dark coloured flow banding. The second type of andesite is porphyritic, fine grained and more silicic than the first one. It is also distinguished from the non-porphyric type by its blue-greenish colour. Augite and hornblende phenocrysts are set in a microcrystalline green epidote and chlorite mass.

In thin section, the andesites appear as highly weathered rocks in which feldspars have undergone extensive saussuritisation and sericitisation. Oligoclase and andesine appear as minor scattered crystals. Augite, which appears colourless, is the main mafic mineral. It is considerably altered into chlorite. Some chlorite pseudomorphs appear to have been formed from hornblende. Other minerals include sphene, quartz and calcite. Some quarz and calcite crystals fill the fractured vesicles between the larger phenocrysts.

2.3.3 Andesite Tuffs

Although the andesitic tuffs were studied as a unit, in the geological map they were put together with andesites. This was found necessary because although the andesite tuffs outcrops are many, they are not volumetrically extensive to warrant separate divisions on the map.

A well exposed outcrop of andesitic tuffs occurs at Maloba where it appear in form of elongated bands which are intercalated within the andesitic lavas.

In hand-specimen, the tuffs show feldspar phenocrysts within the fragments. Quartz and mafic minerals occur as fine grains on a glassy groundmass. The sizes of the fragments ranges from 0.3 to 10 centimetres long. The fragments are generally angular.

In thin section, andesitic tuffs show broken mineral crystals and rock fragments which occur in fine grained chlorite and calcite groundmass. The tuffs are highly sericitised but a few crystals of andesine and oligoclase are still noticeable. Augite and hornblende occur as anhedral crystals which are partly altered into chlorite. Minute rock fragments are seen to be both angular or sub-rounded. Accessory minerals recognised include ilmenite, sphene, apatite and magnetite.

2.3.4 Dacites

Well exposed outcrop of dacites were observed near Sawagongo. Dacites show a petrographic compositional gradation with andesites. These are porphyritic rocks which contain phenocrysts of quartz, orthoclase, oligoclase, andesine and few crystals of hornblende and pyroxene. These phenocrysts are set in a groundmass of glassy material.

Dacite is not easy to differentiate from porphyritic andesite but it is readily differentitaed from non-porphyritic andesite because the latter usually has more plagioclase phenocrysts than dacite.

In the valley of the Edzawa river, about 5 kilometres west of Maragoli, dacites were observed to be very similar in outlook to rhyolites and the only differences between the two rocks is the lower proportion of quartz in dacites. Feldspars in the dacites assume prismatic shapes.

In thin section, the dacite were found to contain quartz and plagioclase phenocrysts which were set in the groundmass of granular very fine grained crystals of quartz and feldspar. Augite appeares as short, prismatic and sometimes tabular dark green crystals. The margins of some crystals were observed to have altered to chlorite and uralite.

Ilmenite, sphene and apatite are the common accessory minerals. Pyrite occurs as disseminated grains within some feldspar and augite crystals.

2.3.5 Rhyolites

In the Kakamega area, rhyolites occur as long narrow wedges which are infolded into the Mozambiquan belt on the western margin of the Nandi escarpment. Rhyolites also occur as an extensive outcrop which extend from Irumbi market through Luanda Market to Sawagongo school. At Shiatsala, north-west of Yala town, rhyolites occur as minor isolated outcrops. A triangular shaped outcrop of rhyolites occurs at Runyereri on the Kakamega-Kisumu highway between Maragoli and Mbale markets.

In the South Nyanza area, rhyolites occur extensively but as isolated outcrops.

The outcrops are particularly well exposed in the area between the southern margin of the Kitere granite and the northern margin of Awendo andesites. Other rhyolite outcrops occur immediately north-west and south of the Wanjare granite.

Rhyolites are hard, dense, silicious, chert like rocks, which contain grey feldspar phenocrysts which measure up to 3 millimetres long. Quartz generally occur as fragmented angular crystals but in some samples it occurs as round phenocrysts. Fresh rhyolite samples are light grey to green-grey in colour. When weathered, the rocks become reddish yellow. In most of the samples, feldspar phenocrysts are considerably sericitised. The phenocrysts are set in a groundmass of very fine quartz, sericite and chlorite grains. Near the granite intrusions, the rhyolites appear slightly darker than normal. The darkness is possibly a result of thermal metamorphism.

Two types of rhyolites have been noted in the South Nyanza area. The first one contains small crystals of quartz which are set in the background of a very fine grained matrix. The rock is very silicious and when fresh, it is dark grey to almost black in colour. This type of rhyolite has parallel bands of light and dark minerals which occur alternately, thus forming flow banding. On the weathered surfaces, the rocks commonly have patches of iron oxide staining. When completely weathered, the rocks form dull creamy soils. The second type of rhyolite contains larger quartz phenocrysts which measure up to 8 millimetres long. This type of rhyolite does not show any sign of flow banding. The quartz and feldspar phenocrysts are close packed in a fine grained groudmass. The rock is generally pink but a pale grey variety has also been noted.

In thin sections, all the varieties of rhyolites show similar mineralogy. Phenocrysts of feldspar are normally sericitised although in some thin sections orthoclase and plagioclase are still identifiable. Most of the hornblende has also altered into chlorite. Individual quartz crystals are anhedral. The matrix is composed of microcrystalline intergrowths of quartz and feldspar. Chlorite in the matrix appears as tiny pseudomorphs. It is observed that only a small fraction of feldspars which make up the matrix are identifiable as most of it have altered into sericite. In one thin section of a rock sample collected in the Kuja river, the matrix was found to be extremely cryptocrystalline and most of the minerals could not be recognised except for tiny quartz crystals.

Rhyolites which occur near the contact with the Kitere granite shows large irregular clots of pyrite. The common mafic mineral constituents of the rhyolites are amphiboles and pyroxenes. In the matrix, however, acicular aegirine and patchy aggregates of riebeckite which has been partly altered into chlorite were observed.

2.3.6 Rhyolitic Tuffs

The rhyolitic tuffs and rhyolites have been put together in the geological map because the tuffs occur only as minor intercalations within the rhyolites.

The greatest developments of rhyolitic tuffs in the Kakamega area are around the Ebulonga and the Wemitabi areas. Other minor outcrops are found in the area between Ramula and Agero schools. On the banks of the Yala river near Lihanda, tuff fragments have been compressed and flattened. The fragments were compressed by a tectonic movement directed from north or south because the fragments are elongated east-west.

In the South Nyanza area, the rocks are well exposed in the areas north-west and south-east of Ranen. The outcrops are especially well developed in the valley of the Kuja river where they occur as small lenticular bodies within the rhyolites.

In hand specimen, rhyolitic tuffs are hard, granular rocks which bear whitish feldspar crystals and black clear quartz crystals. The rocks also contain angular fragments which measure up to 3.5 centimetres long. Traces of crude stratification have been observed on some outcrops. Generally, tuffs occur as mauve coloured slaggy rocks, which are easily weathered. In some localities, for instance around Rongo market, the rocks have formed localised laterite caps.

In thin section, the tuffs and agglomerates are characterised by tiny rock fragments which are oriented in different directions and measure more than one millimetre long. The fragments contain orthoclase and oligoclase crystals which generally have undergone extensive sericitisation. Quartz crystals are found in a re-crystallised granular quartzo-felspathic matrix. Hornblende crystals appear in small amounts scattered all over the thin section. Generally, the edges of the hornblende have been altered into chlorite. Accessory minerals include sphene, epidote, magnetite and apatite. Pyrite occurred as a circular grains impregnated within other minerals crystal margins.

2.4 Tertiary Volcanic Rocks

The only rocks of Tertiary age found in the area covered by this project are the phonolites. These rocks occur in a small area around Gambogi market about 2.5 kilometres south west of Boyani market. The rocks are dark grey and sometimes grey-green in colour. They are both dense and compact. In texture, the rocks are fine grained, non-porphyritic and tend to break into slabby blocks.

In thin section, the most distinctive feature of phonolites is the presence of alkaline feldspars. These are usually micro-phenocrysts of sanidine. Orthoclase crystals which are also common in the rock, appear as long needle-like crystals which measure up to one millimetre long. The most common feldspathoid is nepheline whose crystals measure up to 1.3 millimetres long. It has been observed that the feldspar micro-phenocrysts occur in lathy prisms which often criss-cross with the nepheline. Nepheline usually appears as euhedral crystals. Other common minerals in the rock include augite and aegerine. The most common accessory minerals include apatite and iron oxide.

2.5 Pleistocene and Recent Deposits

This group includes all superficial deposits which are found in the study area. These deposits usually attain only a small thickness. The deposits are composed of terrace gravels, lateritic iron caps, semi-consolidated alluvial deposits and soils. The terrace gravels are normally less than 1 metre thick. Laterite iron cappings are found overlying rocks of different ages and types. In some localities like Kwisero, well rounded pebbles which measure up to about 5 centimentres in diameter, are embedded in the laterite capping even though the underlying rock is mudstone. Around Kamagambo, lateritic gossanous capping which contains grains of pyrite, overlie a rhyolitic rock suite which is rich in sulphide minerals. The gossan represents oxidation of the exposed surfaces of the weathered sulphide-rich rhyolite zones.

Alluvial and swamp deposits are found along the courses of most streams where they are covered by luxurious vegetation growth. In the valleys of the large rivers and streams, recent alluvium and semi-consolidated deposits are worked for gold by the local population.

Variations in soil types depends on the underlying rocks. Nyanzian rocks generally form black cotton soils after they are completely weathered. The Kavirondian greywackes form sandy light brown soils while mudstone yield clayey yellowish brown soils. On weathering, granites form light yellow to brown soils. Granites which contain large xenoliths of mafic rocks produce dark reddish brown soils. It is therefore observed that the colour of the soils, often represent the underlying rock type.

2.6 Major Intrusives

2.6.1 Mumias Granite

The Mumias and the Kakamega granites are stocks of a large batholith called the "Kitoshi batholith". The Mumias granite is found in the northern side of the study area and it extends westwards from about 4 kilometres south of Kakamega town to eastern Uganda, where it is called "Buteba Granite". Two types of granites have been observed within the Mumias and the Kakamega stocks.

The first one is a massive porphyritic, non foliated variety whose petrographic compositional range is from granite to granodiorite. This granite varies from cream white or greenish white, where appreciable amounts of hornblende is present to pink where pink feldspars predominate. This granite is generally characterised by rough tors and large towering blocks which are apparently produced by large vertical joints.

The second type of granite is a light coloured coarse to medium grained granite. The coarser parts of the granite contain large feldspar phenocrysts which measure up to 3 centimetres long. Xenoliths are commonly encountered in both types of granites. They are composed of hornblende and dark brown biotite. The hornblende in the xenoliths, like those found within the larger feldspar phenocrysts form prisms which measure up to 10 millimetres long. Hornblende and biotite account from about 30 to 40% of the total minerals which make up the xenoliths. The origin of the xenoliths appear to be the country rocks which were broken up by the highly charged invading magma with which they become incorporated. The country rocks did not have enough time to melt and therefore, they were incorporated whole in the cooling magma.

The contact between the Mumias granite and the country rocks are in many cases sharp and irregular. It has been observed that the main country rocks which have contacts with the granite are greywackes and mudstone. On the contact zones, these country rocks have altered into phyllites as a result of thermal metamorphism.

The Mumias granites are also invaded by numerous felsic aplitic and pegmatitic veins. The presence of such veins in the granite bodies is attributed to the concentration of residual solutions of magmas which contained exclusively one mineral into the fractures and joints in the granite body. These veins most of which are pegmatitic originate as a result of metasomatism. Their variation in colours is attributed to mineralogical impurities.

The pegmatitic veins normally form four major zone sequences (Fig. 4).

1. Border zone - this is a fine grained zone which is commonly granitic in texture and is normally located at the contact with the country rock.

2. Wall zone - this zone is coarser and much thicker than the border zone.

3. Intermediate zone - this is one or several zones which are usually incomplete before one reaches the core.

4. Core - it is usually very coarse grained and often contains rare earth minerals.

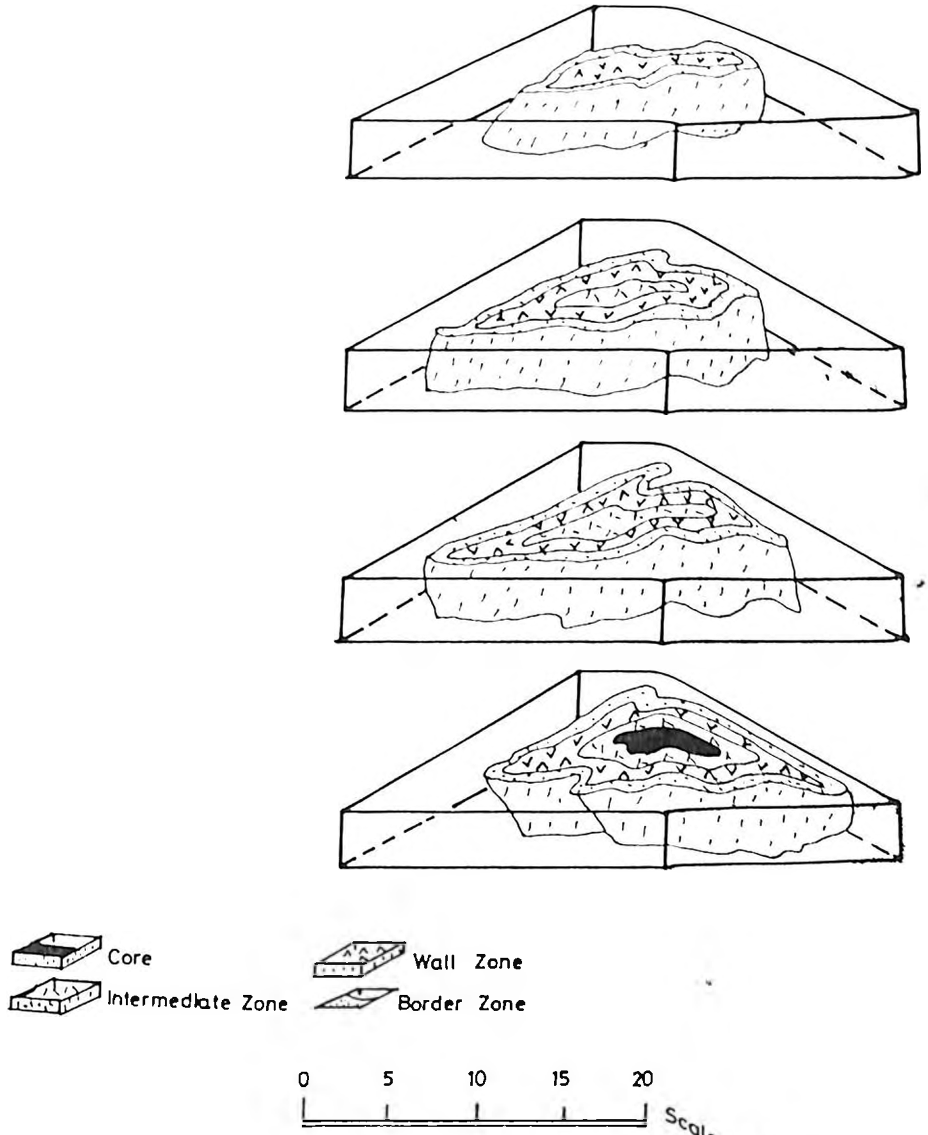

Fig 4 Block diagram showing four stages of pegmatite development as observed in Mumias Granite near Bukura.

In thin section, the Mumias granite show large feldspar phenocrysts which are set in a groundmass of minute hypidiomorphic quartz and feldspar crystals. The feldspar phenocryst are composed of orthoclase and microcline. Some of the orthoclase has altered into kaolionite and sericite. Hornblende and biotite occur within the larger phenocrysts of feldspar. In some samples, hornblende can hardly be recognised because most of it has altered into chlorite. The commonest accessory mineral is sphene.

2.6.2 Kakamega Diorites

Diorites occur about 7 kilometres south of Kakamega town where they are found as marginal suite of the Kakamega granite. The origin of the diorite is probably through the contamination of silicic magma by incorporation and digestion of more mafic rocks or through the assimilation of sialic materials by mafic magma. In hand specimen the rock is mottled black and sometimes grey in colour. Near the contact with the Kakamega granite, the rock is coarse grained but further away, it becomes fine grained. The rock contains feldspar phenocrysts which measure up to 5 millimetres long. The phenocrysts are set in a fine grained groundmass which is composed of mafic minerals. In some samples mafic minerals which are elongated and aligned in one direction were observed in the xenolith.

In thin section, the rock essentially consists of sodic plagioclase. The main plagioclase is andesine and it forms prisms with microcline and orthoclase. Quartz appears as small angular grains which occur interstitially between the plagioclase crystals. The most characteristic mafic mineral observed was green hornblende and some of the hornblende was found to be partially altered to biotite. Some of the biotite was found to have pleochroic round rings which were probably caused by alpha particle bombardment from tiny zircon grains. In some specimens, both hornblende and biotite were found to have been altered into chlorite. Accessory minerals recognised included sphene, apatite and iron oxide.

2.6.3 Maragoli Granite

This granite body occurs in the southern part of the study area around Boyani Market. Broadly, the body extends from Girigoi school through Vihiga to Kima mission. The granite body forms contacts with the Nyanzian volcanic rocks around Epanga in the east and Esaba school on the western side. The granite body then extends uninterrupted through Marengo dispensary to the Nyawara area.

In the field, the granite is massive and often gives rise to characteristic tors. When the tors undergo exfoliation, angular to sub-angular huge granitic boulders are formed.

In hand-specimen, the whole granite body looks petrographically similar but after chemical analysis, the granite body is found to be composed of rock types which range from granodiorite through tonalite and adamellite to granite sensu stricto.

Generally, the granite grades from fine grained to coarse grained type. The fine grained type is usually found near the contacts between the granite body and the Nyanzian volcanic rocks or the Kavirondian sediments while the coarse grained type is found in the central part of the intrusion. The coarse grained type contains close packed pink feldspars phenocrysts which measure up to 5 centimetres long. The Maragoli granite also contains large mafic xenoliths. The petrographic composition of the xenoliths is similar to the country rock intruded by the granite and on several outcrops around Vihiga, xenoliths have reacted with granite, thus forming large bodies of hybrid rock around the xenolith.

In thin section, the feldspar phenocrysts are cloudy orthoclase and microcline. The cloudy orthoclase is usually surrounded on its edges by clear oligoclase. Feldspar phenoctysts are set in a granular groundmass of allotriomorphic granular matrix of quartz and feldspar. The mafic minerals are hornblende and biotite. The biotite are pleochroic and show an interplay of colours from dark brown to pale yellow. In several samples the mafic minerals have undergone chloritisation and in the fractured edges of the crystals, tiny cubes of magnetite are observed. Epidote occurs as a bright green granular mineral. Apatite, sphene and zircon are the main accessory minerals.

2.6.4 Kitere Granite

The Kitere granite extends from Nyarombo in the west through Ranen to Nyamiamu in the east. On the western side, the intrusion joins Nyarombo and Magena markets. On the northern side, it joins Magena and Kamagambo through Disi. On the eastern side, it joins Kamagambo and Nyamiamu. The intrusion therefore forms an irregular circular shape.

The Kitere granite is a pale grey or pinkish grey rock which is both prophyritic and fairly fine grained. It contains pale pink and sometimes greenish feldspars phenocrysts which measure up to about 2 millimetres long. Sometimes hornblende also forms phenocrysts of almost the same size as the feldspars. Most of the hornblende has altered into chlorite. Xenoliths are generally not common within the Kitere granite body. On the margins, however, a few xenoliths which do not exceed 7 centimetres in length have been observed.

In thin section, the feldspars which were originally orthoclase have been highly sericitised and kaolinised. Microcline forms micrographic intergrowths within interstitial quartz. Green hornblende which occurs as small phenocrysts is the main mafic mineral and it encloses small crystals of clear quartz. When altered, hornblende is replaced by pale green epidote and chlorite. Biotite is another common mineral but most of it has altered into chlorite. Apatite, zircon and sphene are the major accessory minerals.

A thin section of a sample collected from the granite margin shows that the granite grades into granodiorite. The main plagioclase feldspar in the granodiorite is oligoclase. It is usually zoned around the cloudy core of the initial orthoclase Quartz whose proportion of the whole rock is about 13% forms fine intergrowths with the feldspars. Hornblende is the main mafic mineral and its proportion of the whole rock is more than in the normal granite. In some cases hornblende has been extensively altered into chlorite and epidote. Small amounts of biotites were also observed.

2.6.5 Wanjare Granite

The granite occurs in a triangular area whose corners can be approximately demarcated by Itierio in the south, Mosocho in the north and Nyawita school in the west. On the western and southern sides the granite invades both the Nyanzian and Kavirondian rocks. In the east, the Wanjare granite disappears below the late Proterozoic Kisii series.

The Wanjare granite is a coarse grained leucocratic granite whose colour ranges from pink to pale grey. On the periphery where the granite forms contacts with country rocks, the granite is fine grained and more mafic.

In thin section, microcline which forms large phenocrysts is the main feldspar.

Orthoclase and albite occur in lesser amounts and they form small anhedral crystals which occur between the larger microcline phenocrysts. In several samples albite was observed to have replaced the outer margins of the orthoclase. In such cases orthoclase appears cloudy in the centre of the surrounding albite. The mafic minerals include hornblende and brown biotite. Both minerals have been considerably altered into chlorite. Accessory minerals identified in the samples include sphene, tourmaline and ilmenite.

2.6.6 Oyugis Granite

This small granite body outcrops between Oyugis township in the east and Luora school in the west. It covers an area of about 27 square kilometres. The granite is pale grey in colour and contains pale pink to greenish feldspar phenocrysts. The phenocrysts measure about 2 centimetres long. On the margins of the intrusion the granite is fine grained. The granite is intruded by several dolerite dykes whose general strike is east-west. On the contact zones between the granite and the dolerite dykes, a coarse grained hybrid rock has been formed.

In thin section, the Oyugis granite resembles the Kitere granite. Most of the feldspars which were originally orthoclase have undergone both sericitisation and kaolinisation and therefore sericite and kaolinite are the main secondary minerals. The groundmass on which the feldspar phenocrysts are set is composed of minute quartz and feldspar crystals. Green hornblende which is extensively altered into chlorite is the main mafic mineral.

2.7 Minor Intrusives

2.7.1 Minor Quartz Dykes

These are minor dykes which are almost exclusively found in greywacke outcrops. The dykes are composed of smoky quartz although white-cream types have also been observed. The dykes are about 4 metres long and about 5 centimetres wide. On most of the outcrops where the dykes were observed, they normally divide into small branches of minor veinlets at the ends. At one outcrop about 200 metres west of Igukhu dispensary, the dykes were found to be associated with the nearby Kimingini "Giant Quartz Vein". The quartz from "The Giant Quartz Veins" appear to have migrated and penetrated through the cracks and joints into the greywackes where they form a north-south trend.

Another major greywacke outcrop which is invaded by similar minor dykes is found under the Yala river bridge about 2 kilometres south of Konjero market. These minor quartz dykes also have a north-south trend and appear to be associated with the "Giant Quartz Vein" found at the nearby Kisa hill.

In hand specimen, the rocks contain large quartz phenocrysts which measure up to 4 millimetres. The phenocrysts are set in a fine groundmass of small quartz crystals. A few feldspar phenocrysts are feebly recognized although most of them have altered into sericite.

In thin section, the large quartz crystals were observed to have formed euhedral crystals whose rims are surrounded by brownish iron oxide. The fine grained quartz and feldspars which form the groundmass have extensively altered into sericite and kaolinite.

2.7.2 Aplites and Pegmatites

These occur as thin veinlets which cut across the granite outcrops. They sometimes appear at the contacts between the granite intrusions and the country rock. White quartz is the dominant mineral. The mineral occurs as large subhedral to euhedral crystals on whose margins, dark-brown mica was observed. Pink feldspar which commonly appear on the granite intrusions were not observed within the aplites and pegmatites.

2.7.3 Dolerite Dykes

Dolerite dykes intrude almost every rock type found in the study area. The dykes often form prominent craggy outcrops which sometimes give rise to low hills. The smaller dykes are only a few metres long while the more extensive ones are more than 4 kilometres long. In width, the dykes vary from about 5 metres to as much as 23 metres.

On the margins with the country rock, the dykes are fine grained but towards the centre, the rocks become coarse grained. Within the coarser grained types, mottled dark green hornblende and prismatic feldspar crystals were observed. The dykes generally have three strike directions. Most of them have a north-east to south-west strike direction, some have an approximately east-west strike direction and the rest north-west to south-east direction.

Dolerite dykes found in the study area are divided into two groups. The first group is composed of the older dykes which have been observed to cut across the Nyanzian and the Kavirondian rocks. The second group is composed of those dykes which have been observed to cut across the granite intrusions and other younger rock types.

The first group of dykes are composed of fine grained to coarse grained rock whose colour ranges from dark green to grey. These rocks show an ophitic texture in which the original irregular shaped clinopyroxenes have altered into hornblende and actinolite. Plagioclase feldspars which were originally euhedral and randomly arranged, have undergone partial alteration and albite has been formed. On weathering, the rocks which form the dykes turn light yellow to brown in colour.

The younger dykes are also fine to coarse grained. They are greenish-grey to grey in colour. Some of the rocks are aphyric while others are phyric. These rocks are considerably less altered. The phyric types show white plagioclase feldspar which penetrate into the pyroxene crystals which are usually more than 10 millimetres long. Textures in which plagioclase phenocrysts penetrate into pyroxenes are known as subophitic. Subophitic texture is attributed to simultaneous crystallization which occurs because of the inherent tendency of plagioclase to nucleate more readily than pyroxene. In effect then, many plagioclase centres of crystallization were set up as compared with few, more widely spaced centres of pyroxene crystallization. When weathered, the phyric dolerites produce soils which have nodular appearance in which the nodules are the weathered feldspar phenocrysts.

In thin section, the mineralogy of the two types of dolerites is similar. The plagioclase feldspars though intensely altered in the older dolerites, show a holocrystalline granular texture in which lath shaped plagioclase crystals partly penetrate into pyroxene crystals. The rest of the feldspars have altered into sericite and kaolinite. The original augite, has also altered to pale green or brown hornblende. Quartz occurs as minute interstitial grains.

In the younger dolerites, the feldspars are mostly andesine. In the phyric type, however, oligoclase is also observed. In most of the thin sections studied, quartz and feldspar occur as micrographic intergrowths. Due to the presence of quartz, dolerites in the study area are classified as quartz dolerites. The main mafic minerals found in the rocks are augite and hornblende. Hornblende is generally an alteration product of the original augite and it occurs as subhedral to euhedral grains which show typical amphibole cleavage. Augite and hornblende have also altered into chlorite. The chlorite appears blue in colour. It is probable that the bluish colour is a result of the green colour of chlorite being superimposed on the dark-yellow to greenish-brown colour of hornblende.

Biotite which shows dark brown to yellow pleochroism is widely distributed in the samples studied. Epidote occurs together with clinozoisite in considerable amounts. Ilmenite, magnetite, sphene and apatite are the common accessory minerals.

2.8 Minor Intrusives in the South Nyanza area

2.8.1 Quartz-Diorite Porphyries

These are irregular rock masses which intrude the Nyanzian volcanic. The most outstanding outcrops of quartz diorite porphyries occur about 2 kilometres south of Oyugis town. On the northern margin of the Kitere granites the porphyries intrude Nyanza rhyolites and basalts.

In hand specimen, the rocks are dark grey to green in colour. The rocks contain greenish feldspar phenocrysts which in some samples measure up to 1 millimetre long.

In thin section, feldspar phenocrysts are set in a fine grained groundmass of minute quartz and feldspar crystals. The feldspar phenocrysts are generally highly sericitized. The phenocrysts also contain fine granular epidote crystals. The most common phenocrysts are oligoclase and andesine although a few orthoclase crystals were observed. Hornblende which had been considerably altered into chlorite is the main mafic mineral. Few crystals of colourless augite which had been partially altered into chlorite were also observed.

2.8.2 Granite Porphyries

These rocks were encountered as minor isolated outcrops on granite margins where they intrude into the Nyanzian volcanic rocks. In the southern margin of Wanjare granite, granite porphyry was observed to intrude into the Nyanzian rhyolite. Under the Obeche bridge near Nyamu school, an outcrop of granite porphyry which cross-cut Nyanzian rhyolite was observed. On the northern margin, the granite porphyry borders the Nyanzian rhyolites while on the southern margin the porphyry is bounded by Kavirondian Conglomerates. Other minor outcrops occur at Ligisa Omoyo and Ndiru markets. Due to the small sizes of these outcrops, they were mapped together with the granite intrusives.

When fresh, these rocks range from pink to faint green in colour. On weathering the rocks become pale yellow. Orthoclase is the dominant feldspar. It occurs as long pink feldspar phenocrysts which measure up to 6 millimetres long. Other feldspars include microcline and oligoclase. Quartz occurs as large euhedral phenocrysts which measure up to 1 millimetre long.

In thin section, the feldspar phenocrysts were recognised as orthoclase and albite. These minerals have been considerably altered into sericite and kaolinite. A few quartz crystals have been corroded. Fresh quartz occurs as elongated, prismatic crystals which form intergrowths with shorter prismatic bipyramidal crystals of feldspars. The two minerals also form the groundmass. The main mafic mineral observed on the slides is hornblende. It occurs as minute, extensively chloritised crystals. Leucoxenised ilmenite, magnetite, sphene and apatite are the common accessory minerals.

2.8.3 Augite-hornblende Porphyries

The porphyries are medium grained greenish-grey rocks which occur as small dykes and sills close to the contacts of granite and country rocks. Outcrops of these porphyries occur both at Kamagambo and Nyangao schools. The rock contain glistening dark green hornblende phenocrysts whose length is about 0.5 centimetres long.

In thin section, the hornblende phenocrysts show ragged outlines which surround the inner core of colourless augite. Augite probably formed the original phenocrysts and with passage of time, most of it has altered into hornblende. Feldspars are extensively altered into sericite. Plagioclase twinning can still be observed although the original nature of the crystals is not determinable. The plagioclase also shows narrow rims of fresh oligoclase which is sometimes zoned.

Another rock which occurs in the form of small dykes along the margins of the major granite intrusions, is a hornblende porphyry which contains closely interlocking prismatic crystals. The hornblende crystals are usually more than 3 millimetres long. The phenocrysts are set in a very fine grained grey groundmass which is composed of minute grains of feldspars and hornblende. Under the microscope, the hornblende shows faint pleochroism which changes from yellow-green to pale green. The hornblende has undergone mild chloritization. The groundmass is composed of fine grained aggregate of orthoclase. Some of the minute feldspars have altered into epidote. On the broken edges, epidote is surrounded by minute quartz crystals. Apatite, magnetite and calcite are the main accessory minerals.

2.8.4 Dolerite Dykes

Two types of dolerite dykes have been identified in the South Nyanza area. The first type is emplaced in the Nyanzian volcanic rocks but does not cut across the Kavirondian sediments. These older dolerites have been metamorphosed to form amphibolites. Their strike is usually north-west to south-east and only rarely does the strike change to approximately east-west.

In hand specimen, these are fine grained to coarse grained rocks which are dark green in colour. The rocks are considerably altered and when thermally metamorphosed along the contacts with the major granitic intrusives, the rock become coarse grained with large hornblende phenocrysts. Near the contacts with the granites, the dykes are cut across by minor aplitic veinlets of quartz and calcite.

In thin section, the feldspars, though rarely determinable, are considerably altered into sericite and kaolinite aggregates. Augite and hornblende are the main mafic minerals in the rock. Hornblende occurs as fibrous, acicular and sometime radially arranged crystals. Hornblende is probably an alteration product of augite. The groundmass, which is largely composed of augite and hornblende is extensively chloritised. Accessory minerals in this rock include ilmenite, epidote and calcite.

The younger dolerites are those which intrude both the Kavirondian sediments and the granite intrusions. Their general strike is north-west to south-east. The larger dykes have been traced for about 4 kilometres.

In hand specimen, the younger dykes are dark green to grey in colour. They are medium to coarse grained and generally show no signs of shearing. The rocks contain glistening dark augite phenocrysts which are set in a very fine grained grey mineral groundmass.

In thin section, hornblende and augite phenocrysts have to some extent been uralised and chloritised. The main plagioclase feldspar is andesine but it has undergone extensive sericitisation. Biotites which shows dark brown to pale yellow or dark green to pale yellow pleochroism are common. The groundmass is composed of minute andesine crystals which have largely altered to sericite. Quartz grains which occur as small interstitial crystals form fine micrographic intergrowths with feldspars. Sphene, calcite and apatite are the common accessory minerals.

2.9 Giant Quartz Veins

2.9.1 Introduction

Due to their geological setting, the quartz veins will in this work be divided into those found in the Kakamega area and those found in the South Nyanza area.

2.9.2 Giant Quartz Veins in the Kakamega Area

The "Giant Quartz Veins" have wide distribution in the Kakamega area where they have been observed to cut across all other rock types except the Tertiary rock suites. The most prominent vein outcrops have an approximately east-west strike. The veins stretch for a distance of about 12 kilometres from New Kisa through Eregi to Kimingini with only minor breaks between the quartz ridges. The thickness of the veins ranges from a few metres to about 2 kilometres. These steep, conspicuous "hog back" shaped ridges are mainly emplaced in Mudstones Formation.

Another co-linear emplacement of similar veins occurs between Kibiriri and Bukura ridges. The veins have a north-east to south-west trend and their lateral extent is about 3 kilometres with only small breaks between individual hills.

The rocks are composed of fractured and coarse grained crystalline quartz. The veins are cut-across by smaller veinlets which are dark grey to blue in colour. The veinlets form a close network thoughout the "Giant Quartz Veins" and the surrounding country rocks. These small veinlets are auriferous unlike the "Giant Quartz Veins". The genesis of these small auriferous veinlets is not clearly understood but they are probably products of secondary crystallization. Other minor veinlets which appear to have branched from the "Giant Quartz Veins" have been observed in surrounding country rocks. Like the main veins, these veinlets are barren of gold mineralisation.

In thin section, the "Giant Quartz Veins" are entirely composed of quartz. The texture of the quartz varies from microcrystalline to coarse subhedral and euhedral crystals on whose margins, a few shreds of sericite appear to represent original feldspar. Under crossed nicols, the coarse grained quartz shows wandering extinction which is due to crystal distortion caused by mechanical deformation of the host rock. In the fractured margins of the quartz crystals, reddish brown iron oxide has been formed.

2.9.3 Quartz Veins in the South Nyanza area

In the South Nyanza area, the most conspicuous quartz veins are extensive lenticular bodies which give Marongo hill a "hog back" shape. The ridge is exclusively composed of quartz and can be traced for about 4 kilometres. The width of the Got Nyingo outcrop is over 0.5 kilometres.

Another conspicuous ridge of the "Giant White Quartz Veins" extends from Uriri to Akoko and its trend is north-west to south-east. This ridge is about 3 extent is about 3 kilometres with only small breaks between individual hills.

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Another conspicuous ridge of the "Giant White Quartz Veins" extends from Uriri to Akoko and its trend is north-west to south-east. This ridge is about 3 kilometres long and its minimum width is about 30 metres. At Uriri the quartz vein forms the Uriri hill which is about 1,690 metres above sea level.

Other minor outcrops of quartz veins occur on the road between Oyugis and Rangwe. These small veins appear to have brached from the major Uriri-Akoko quartz ridge in the east.

Unlike in the Kakamega area, the quartz veins in the South Nyanza area were emplaced in the Nyanzian and Bukoban volcanic rocks, otherwise the petrography of quartz in both areas is similar.

2.10 Summary

The Nyanzian Group volcanic rocks are the oldest rocks found in the study area. The rocks are unconformably overlain by the sediments of the Kavirondian Group. The rocks of both Nyanzian and Kavirondian Groups are intruded by early to late Proterozoic granite intrusions such as Mumias, Maragoli, Wanjare and Kitere granites. The Nyanzian Group, the Kavirondian Group and the Proterozoic granites have, on the other hand, been intruded by minor mafic and felsic intrusives which include dolerite dykes an d quartz veins. All the above mentioned rocks were deposited during Archaean and Proterozoic and they are overlain by recent deposits which include laterites, unconsolidated gravels and alluvial deposits.

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Chapter 3

MATERIALS AND METHODS

3.1 Introduction

Although the Archaean sedimentary belts throughout the world bear some striking similarities, it has recently become evident that each of the belts has some unique specific characteristics in their mode of deposition, structural setting and economic mineral potential. It is therefore necessary to study in detail the western Kenya Archaean sedimentary rocks in order to establish some stratigraphical and sedimentological models of the area. Such models will facilitate comparisons of our Archaean sedimentary belt with those found in other parts of the world which are generally better understood like the Australian Coolgardie-Kurrawang Group, Swaziland Supergroup, the Zimbabwean Bulawayan-Shamvian Groups, and the Canadian Michipcoten and Yellow Knife Groups among others.

The methods used in the study of the Kavirondian sediments are described below.

3.2 Field Methods

3.2.1 Introduction

During this study, an area of about 520 square kilometres of Kavirondian rock outcrops was geologically mapped in detail. Mapping and sample collection was carried out between September 1987 and April 1988. Topographical maps published by the Survey of Kenya (1970) at a scale of 1:50,000 were used as the base maps. Aerial photographs at a scale of 1:25,000 were studied in the present study to determine the main structural trends although their importance in lithological determination was minimal. This is due to thick vegetation cover, deep soils and extensive laterite cover. Satellite imagery was, however, useful in delineating the major structures and in the extrapolation of the major lithological units.

The field methods included geological mapping along the streams, river valleys, road cuts, footpaths and the natural outcrops. In such places, it was possible to find fairly good outcrops but generally outcrops of the sedimentary formations in the area are poorly exposed because of the thick soils. In the field, rocks were studied macroscopically in order to determine their lithological boundaries, sedimentological and paleogeographical aspects. This was done through the study of textures, structures and mineralogy. Similarly, outcrops were macroscopically studied at some distance away from tectonic features such as faults which can sometimes be recognised by vegetation or rock type variations. Later, the outcrops were investigated on site in order to study finer attributes of the rocks. In order to study the rock textures, grain sizes, their degree of sorting and shapes were observed and measured using a ruler where possible. The measurements of the direction of the anisotropic grain fabrics were also taken.

The nature and the amount of matrix and rock fragments were determined and used in rock classification. Bed thicknesses, shapes and their lateral and vertical extents were measured using a tape measure. Other structural parameters studied in the field included grading, channelling, slumps and laminations. Other parameters which were observed included colour changes within the individual bed, between different beds and the degree of rock alteration. The contacts between beds and formations were studied through outcrop observations in light of their sharpness and gradation within the Kavirondian Group. The contacts with the underlying Nyanzian volcanic rocks and the surrounding intrusives were also studied through field observations in order to find out how these rocks relate to the Kavirondian sediments.

Since conglomerates are generally well indurated, they are not amenable to the methods appropriate for study of unconsolidated sediments. During the field work, therefore, the relative numbers of different types of pebbles and boulders within the conglomerate sub-facies were counted and recorded. These counts provided the basis for qualitative evaluation of provenance.

3.2.2 Field Sampling

Field sampling in the study area was carried out for the following two main purposes: (a) petrographic studies and chemical analysis, (b) radiometric dating. The various sampling techniques are described below.

(a) In sampling for petrographic and chemical analyses, the main consideration was that the rock samples were truly representative of the units studied. Consequently, samples were as far as possible broken directly from the outcrops to ensure that they were in situ. Where several outcrops were involved, suites of small samples which represented several outcrops with the similar lithologies were collected in order to obtain average results. The sizes of the samples collected depended on the grain size but in most cases, samples of fist size, about 20 cm in diameter, were adequate, for both petrographical and chemical analyses.

Within the massive beds which showed colour changes, several samples were collected from different points either vertically or horizontally depending on the direction of colour change. This facilitated the understanding of changes in the chemistry of rocks within the same bed.

(b) The samples for radiometric dating were especially collected to suit the Rb/Sr whole rock age determinations. Age determinations are made through correlating $^{87}Sr/^{86}Sr$ isotope ratios with the chemical Rb/Sr of the suites of the whole rock samples, therefore, great care had to be taken during sampling. The factors likely to affect the Rb/Sr age determinations include weathering, thermal and hydrothermal alterations. The disturbances during metamorphism sometimes may cause complete Sr isotopic homogenisation with the effect that the age resets to zero. Weathering thermal and hydrothermal alterations usually give deceptive age determinations because of secondary mineralisation. Samples for geochronology were therefore obtained from very fresh outcrops. Where possible, the samples were collected from recently detonated rock boulders. Representative samples for whole rock radiometric dating weighed between three and four kilograms and about 33 cm in diameter each. For every one age determination, at least seven rock samples were collected. This was the average number of samples required in order to construct an isochron. The samples were generally collected from relatively short distances of about 200 $\times$ 200 metres so that minimal chemical changes could be detected within individual rock suites. The outcrops were first observed to identify the points which showed among themselves petrographical variations. The rocks were required to show minimal variations especially in minerals like feldspars and biotites. Such variations indicated that the samples exhibit a small range in chemical Rb/Sr ratios which is needed to determine an age for the rock suite.

Finally, for whole rock age determination, samples were collected well away from contacts and xenoliths. Contacts and xenoliths are usually obvious sources of rock alterations.

3.3 Laboratory Methods

3.3.1 Introduction

Thin sections were made for a total of 215 rock samples collected from the project area for petrographic studies. The rock samples represented mudstones, greywackes and conglomerate pebbles. The modal compositions analysis of 35 samples in volume percent was carried out using point counter. In order to reduce the error margin, at least 200 points per thin section were counted. The problem of distinguishing fresh untwinned feldspar from quartz during petrographic identification was eliminated by staining slides for both potash feldspars and plagioclase. HF etch and sodium cobaltnitrate were used as staining media.

3.3.2 Sample Preparation and Geochronological Analysis

Rock samples of about 3 kilograms were crushed using a jaw crusher. The finer rock chips so obtained were milled to the fineness of 120 mesh.

In order to extract rubidium and strontium from the powdered samples the ion exchange separation method described by Aldrich et al. (1956) was employed.

In the method, about 200 milligrams of the fine powder was weighed and put in white teflon beakers. A spike solution of rubidium and strontium of 200 millilitres was added to the sample in the teflon beakers. The beakers were then placed on a hot plate to dry over a period of 12 hours. For each test seven samples were used.

Once dry, 2 millilitres of concentrated hydrofluoric acid was added to the sample in each of the seven beakers and the beakers were then covered with cork lids. The beakers were left on the hot plate for a period of 12 hours. The purpose of the hydrofluoric acid was to digest the sample thereby breaking the silicate chains. After twelve hours, the cork lids were removed and the samples evaporated to dryness. Afterwards, 2 millilitres of concentrated nitric acid were added into each beaker and the samples were once again evaporated to dryness. The purpose of the nitric acid was to reduce hydrofluoric acid through ion exchange.

In order to form chloride salts, 2 millilitres of 6 molar hydrochloric acid was added to the samples. The beakers containing the samples were placed on the hot plate for about two hours during which time, the samples evaporated to dryness.

To dissolve the already formed salts, 2 millilitres of 2.5 molar hydrochloric acid were added to the samples. The samples were then put in a centrifuge for five minutes so that the suspended salts could be separated from the dissolved salts.

Once the dissolved salts had been obtained, 2 millilitres of each samples were put into ion exchange columns. The samples were washed through the columns by adding 2 millilitres of 2.5 molar hydrochloric acid. After about 15 minutes, another 30 millilitres of 2.5 molar hydrochloric acid were added to the samples in the ion exchange columns. This was to clean the columns of any previous ions and to remove any undissolved salts. It took about one hour to collect all the impure solution from the columns. The collected solution was discarded.

In order to collect rubidium solution, 20 millilitres of 2.5 molar hydrochloric acid was added into the ion exchange columns. Glass-beakers were used to collect Rubidium rich solution. Once the rubidium was collected, 15 millilitres of 2.5 molar hydrochloric acid were added into the column in order to clean them up of any remaining rubidium. The solutions which were collected from the columns were discarded.

In order to collect strontium solution, 15 millilitres of 2.5 molar hydrochloric acid were added into the columns. The strontium rich solution was collected into the teflon beakers. Later, four drops of concentrated nitric acid were added to each sample in order to oxidise any organic matter which might have got into the samples within the columns resin. The samples were now ready for the isotope mass spectrometer spike runs.

In order to determine rubidium-strontium ratios, stable isotope dilution of rubidium and strontium concentrations and $^{87}Sr/^{86}Sr$ determinations were carried out using a single mass-spectrometer of 280 millimetres radius, 60 degrees curvature instrument with on-line data reduction computer. Single tantalum filament for strontium and triple tantalum filaments for rubidium were employed as surface ionization sources.

Strontium and rubidium ratios were normalised to 8.3750. Repeated measurements on mass spectrometer gave a value of 0.71031, with a standard deviation of 0.00035. The reproduction of rubidium/strontium ratios for most of the samples was better than 2%.

A rubidium decay constant of $1.42 \times 10^{-11}\ y^{-1}$ was used to calculate ages. Regressions were carried out by using the method published by York (1966), using the program published by MacIntyre et al. (1966). When few samples are analysed, significantly large error estimates for Isochrons result from the MacIntyre program.

When the mean square of weighted deviates (MSWD) was less than or equal to 1.0, the regression fitted within the assigned limits for experimental errors, and the programme stopped at model one. The error limit for model one has no meaning if the MSWD exceeded 1.0 except to indicate what the uncertainties would have been if all the samples had fitted within the experimental error.

Greater points scatter indicate departure from the geological assumptions of homogeneous initial $^{87}Sr/^{86}Sr$ and subsequent chemical closure of all samples to rubidium and strontium. It therefore becomes necessary to turn to error regression program in models two and three which test alternative methods of distributing the excess residual variance.

Model two tested the assumption that the geological variance of $^{87}Sr/^{86}Sr$ which was beyond experimental limits was proportional to $^{87}Sr/^{86}Sr$ for each sample and therefore gave stronger weighting to samples of low $^{87}Sr/^{86}Sr$.

In model three, the assumption was that the excess geological variance of $^{87}Sr/^{86}Sr$ was independent of $^{87}Rb/^{86}Sr$ and therefore added the same additional variances to all samples. This model was found to be useful when the samples had the same age but different initial $^{87}Sr/^{86}Sr$ ratios.

The uncertainties of the slope and the initial $^{87}Sr/^{86}Sr$ intercepts were at 95% confidence limit.

3.3.3 Geochemical Analysis

3.3.3.1 Introduction

During chemical analyses, the samples were analysed by use of three different analytical devices. The three devices were, (a) atomic absorption spectrophotometry, (b) induced couple plasma (ICP), (c) X-ray fluorescence (XRF).

The atomic absorption spectrophotometry (AAS) was used to analyse Na, K, Rb, Li and Zn. These elements occurred in traces and therefore the AAS device was suitable in their analyses because of its higher detection limit. The major disadvantage of this analytical device is that only one sample can be analysed on it at a time.

In order to analyse Sr, Fe, Mg, Mn, Ca, Ti, Cr, Pb, Ba and P, induced couple plasma (ICP) device was used. This device has a lower detection limit than the AAS but its main advantage is that, on it many samples can be analysed at the same time and therefore saving a lot of time.

The X-ray fluorescence (XRF) was used to analyse Si and Zr which could not be analysed using the other two devices because during the preparation of the samples for AAS and ICP analyses, these elements had been digested.

3.3.3.2 Procedures for Preparing Samples for Both AAS and I.C.P.

The samples were crushed using a jaw crusher. The smaller rock chips so obtained were milled to rock powder of about 125 mesh. About 0.5 grams was weighed from the powdered samples and put in glass-graphite vessels. The samples were moistened by adding a few drops of distilled water into the glass-graphite vessels making sure that samples covered the base of the vessel. Later 15 millilitres of hydrofluoric acid and 5 millilitres of perchloric acid were added to the sample. The samples were gently hand shaken. The glass-graphite vessels were then placed on an aluminium block where the sample was heated to dryness at 110^0-130^0C. Heating continued until a yellow-white precipitate was obtained. Care was, however, taken to stop the sample from becoming brown because this would mean formation of oxides instead of radicals. The vessels were then removed and allowed to cool for about two hours.

Once the samples had cooled, 5 millilitres of perchloric acid was added to the sample. The vessels were again placed on the aluminium block and heated at 150^0 C. Heating continued until a white precipitate was obtained. The vessels were removed from the block and the sample allowed to cool for one hour. Finally, 5 millilitres of perchloric acid was added to the sample. The vessels were placed on the block and heated at 150^0 C until the sample solutions started producing fumes. The vessels were then removed from the block and allowed to cool for 30 minutes. The solutions in the vessels were diluted by adding 20 millilitres of distilled water. The vessels were again placed on the aluminium block whose temperature was between 50^0-60^0 C, for a period of four hours. During this time all the salts were dissolved and a clear solution was obtained. The clear solution was left to cool for about 2 hours after which it was diluted with 100 millilitres of distilled water. The sample solutions were then put in plastic bottles ready for analyses.

Since both the I.C.P. and AAS devices compare the reference standard samples with samples of unknown values, two reference standard samples from United States Geological Survey and four samples from Japanese Geological Survey were used as reference samples to standardise and control the values of the samples from this project.

In order to carry out the analyses, a Perkin Elmer I.C.P. device Model 5500 with an on-line laboratory computer model 7500 was used. The other samples were analysed by using Philips P4 Atomic Absorption Spectrophotometer which had an on-line Epson computer FX 800.

3.3.3.3 Procedures for X-ray Fluorescence Analyses

Sample pellets for X-ray fluorescence analysis were prepared by pressing 5 grams of the rock powder in collapsible aluminum cups with a backing of boric acid, at a pressure of 30 tons using a hydraulic press to obtain pellets which were 40 millimetres in diameter.

The pellets were analysed using Philips PW 1404 Model sequential X-ray spectrometer system. The device is a microprocessor controlled by a 60 KVA X-ray generator. A Philips Model P 851 on-line computer was used to prepare calibration curves and to standardise values of the samples from this project with reference standard rock samples from United States Geological Survey, Centre de Recherches Petrographique et Geochimiques, Paris and Japanese Geological Survey.

Chapter 4

THE KAVIRONDIAN GROUP

4.1 Introduction

In the Kakamega area, the rocks of the Kavirondian Group are intruded by the Mumias and Kakamega granites on the northern side. In the southern side, they are intruded by the Maragoli granite. In the south west, the Kavirondian sediments unconformably overlie the Nyanzian volcanic rocks. Generally, the Kavirondian sediments have an east-west strike except where the strike has been slightly changed by faults.

In the South Nyanza area, the Kavirondian sediments occur (see Appendices C2 and C3) as minor lenses which are sandwiched between the older Nyanzian rock suites and granite intrusives. The most extensive Kavirondian sediments occur to the south-west of Ranen where several lenses of conglomerate outcrops were mapped. The strike of the lenses over most of the area is north-west to south-east. The lenses too lie unconformably over the Nyanzian volcanic rocks. Another Kavirondian conglomerate outcrop was mapped at Randung and it extends to Rodi Kopany. A conglomerate outcrop which extends from Kagor to Nyawita, which previously had been considered to be a part of the Archaean craton, has been found during this study to belong to early Proterozoic after radiometric dating was carried out on the granitic boulders collected from this outcrop.

The Kavirondian Group belongs to the upper succession of the western Kenya greenstone belt. The sedimentary sequences are composed of terrigenous clastic rocks which consist of conglomerate, greywacke, sandstone and mudstone. The group was previously named "Kavirondian series" by Hitchen (1936). However, Stockley (1943) renamed the rocks as the "Kavirondian system". The sediments lie at an angular unconformity on the upturned edges of the folded Nyanzian rocks. The unconformity is depicted by the high dip angles within the Nyanzian rocks where dip angles are in the order of 65^0 to vertical and vary in direction from both east to north west. Steep isoclinal folds are generally found over the greater part of the area and shearing is locally intense and variable.

The Kavirondian rocks dip to the north and south and the dip angles are in the order of 45^0 to about 65^0. The dips are not as steep as those of the underlying Nyanzian rocks, thus indicating that the Kavirondian rocks were deposited on the eroded edges of the Nyanzian folds. The Kavirondian sediments were later infolded along with the Nyanzian rocks during an orogeny which occurred around 2500 Ma into a series of tight folds that strike east-west during a period of fairly intense deformation. Considerable movement and deformation therefore must have taken place before the sedimentation of the Kavirondian sediments. Later, both the Nyanzian and the Kavirondian Groups were folded together and possibly infolded into the surrounding granitoids.

The coarser sediments are composed of boulders of flattened and sheared granite, basalt, andesite and rhyolite pebbles. The finer sediments have quartz, feldspars and rock fragments among other minerals. The rocks of the Kavirondian sequence are invaded by numerous intrusions of dolerite dykes and giant quartz veins. The intrusions have contributed to thermal and hydrothermal alterations within their contacts with the sediments. On tectonic evolution of the Archaean belts, Anhaeusser et al. (1969) observed that though the stratigraphic sections of the belts are largely obscured, they range from 10 to 20 kilometres in thickness. Condie (1981) was, however, sceptical about the thickness of Archaean sediments and pointed out that such a great thickness was an overestimation because in most sections of the greenstone belts, neither the base nor the top is well exposed for direct observation. The thickness can be overestimated due to migration of volcanic centres and migration of sedimentary basins with passage of time. Isoclinal folding which is characteristic in the greenstone belts may also cause thinning and thickening of the lithological units. This is likely to have happened in the Nyanzian shield where, in several places, lithological units occur as mere lenses probably as a result of prolonged denudation and tectonic deformation.

Unlike some Archaean belts in the world, where trace fossils have been reported and sometimes used as marker beds, no such fossils have been observed in the western Kenya greenstone belt. In describing the stratigraphic units of this area therefore, lithostratigraphy has been exclusively used. Hedberg (1975) defined a lithostratigraphic unit as a body of rock strata that is unified by consisting dominantly of:-

(i) a certain lithologic type,

(ii) a combination of lithologic types,

(iii) and other impressive unifying lithological features.

According to the above definition, chronostratigraphic terms like "system" and "series" which have been commonly used by previous workers in the area are dropped in this work. This is necessary because the units were defined using lithological characteristics and then described using geochronological terminology. A chronostratigraphic unit (Hedberg, 1975) is a body of rock strata that is unified by being formed during a specific interval of geological time. Such a unit represents all rocks formed during a certain time span of the earth's history and only those rocks formed during that time span. Chronostratigraphic units are bounded by isochronous boundaries. The rank and the relative magnitude of the units in the chronostratigraphical hierarchy are a function of the length of the time interval that their rocks subtend rather than of their physical thickness. The turbidite and alluvial deposits in the study area show depositional environments which suggest that their deposition took place at different times. The lithological boundaries of the formations are also diachronous, thus indicating that the sediments were deposited at different times.

When rocks are observed to have diachronous boundaries, they are lithostratigraphically divisible and similarly lithostratigraphical terminology should prevail. At this stage, chronostratigraphic terminology is rendered obsolete. Hedberg (1975) observed that certain stratigraphic units in some parts of the World are locally called "Systems" although they do not coincide with the "Standard Systems" and are somewhat larger in scope. The "Karroo System" of Africa and the "Hokoni System" of New Zealand are examples of rocks which are locally accepted as "Systems" while they are indeed purely lithostratigraphic units.

Kavirondian sediments are divisible into groups, formations, members and even beds and therefore the need of using informal chronostratigraphic terminology does not arise. The proposition of the "Kavirondian Group" as a formal name of the Archaean sediments found in western Kenya is conventionally necessary and will therefore be used in this work.

Well preserved outcrops of the sediments of the Kavirondian Group have been identified both in Kakamega and South Nyanza Districts. In order to define this Group, formation stratotypes have been compounded together to form composite stratotypes. Therefore, within the Kavirondian Group, four formations are proposed based on lithological changes. The four formations include:-

(i) The Shivakala Formation which is characterised by conglomerates.

(ii) The Igukhu Formation which is characterised by greywacke.

(iii) Mroda Formation which is characterised by sandstones.

(iv) Mudaa Formation which is characterised by mudstones.

In this work, the author also wishes to suggest usage of the term "Greywacke" instead of the term "Grit" which has been extensively used by the previous workers in the area. The rocks made up of medium sized clastic sediments whose diameter is between 0.063 and 2 mm are regarded as greywackes and not grits. A good discussion of differences between the two types of sediments is provided by Pettijohn (1957) and Boswell (1960).

Donaldson and Jackson (1965) pointed out that "Most Archaean sandstones of the North Spirit area in Canada may be classed as greywacke on the basis of the now widely accepted criterion of matrix content". Bailey (1930) and Packham (1954) divided sedimentary rocks into two major classes :-

(a) sandstone suites,

(b) greywacke suites.

The classification was based on the primary structures association and the interstratification nature of the rocks. According to this classification, most of the greywacke rock suites are characterised by sedimentary structure which largely

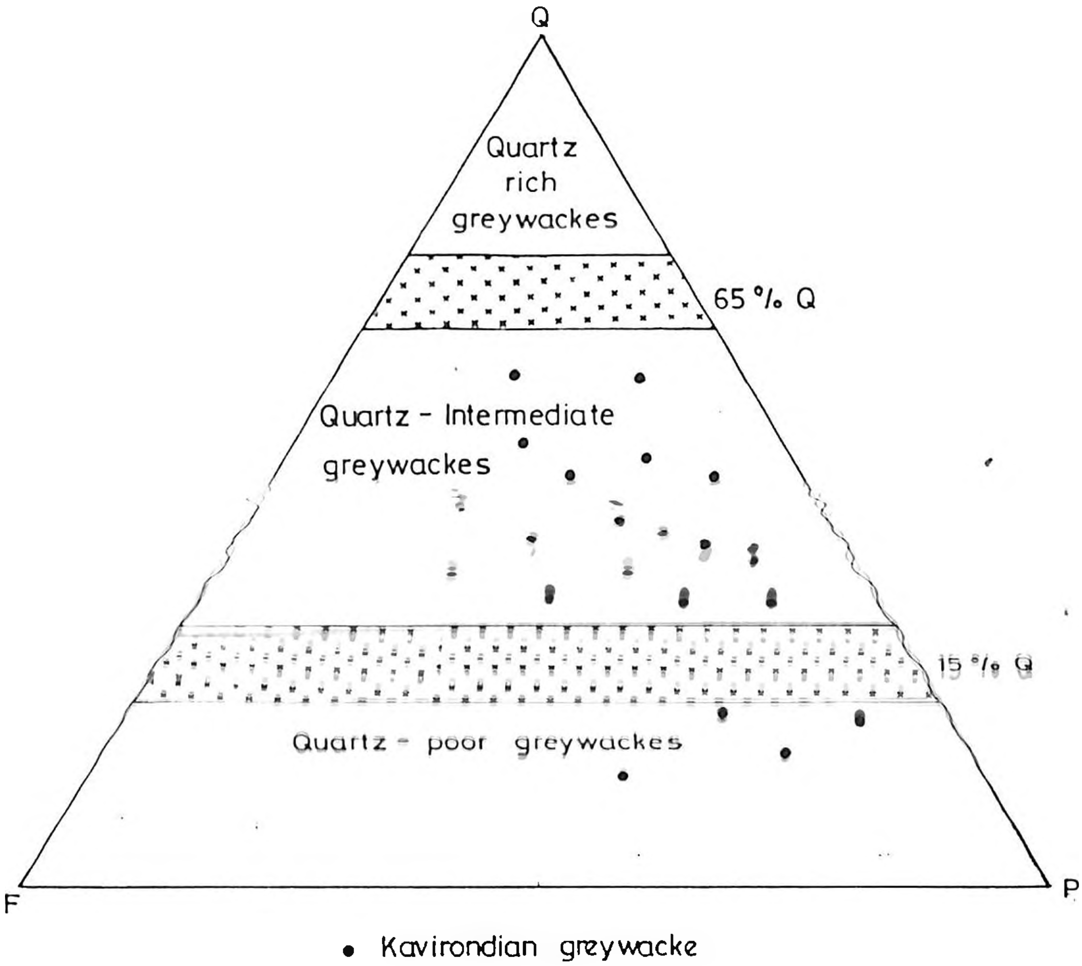

Fig. 5 APPROXIMATE LIMITS OF FLAMEWORK COMPOSITION FOR THE THREE MAJOR TYPES OF GREYWACKE. (AFTER CROOK 1974). NOTE THE CONCENTRATION OF KAVIRONDIAN GREYWACKE IN THE QUARTZ-INTERMEDIAT SECTOR.

obey the classical flysch divisions of Bouma (1962). Greywacke arenites of Packham (1954) have sufficient matrix to fit the definition of greywacke as proposed by Gilbert (1954) and Petijohn (1957), whose greywacke and other sandstone definitions are today accepted as a sedimentary petrology blue print by sedimentary petrologists.

In this work, the terminology of Crook (1974) which encompasses most of the previous terminologies has been adopted. Greywackes are aggregates of sharp angular fragments of every size between sand or fine gravel and clayey material. The greywacke matrix consist chiefly of clay minerals, iron oxide, chlorite and micas. These clastic rocks have been divided (Crook, 1974) into three categories (see Figure 5).

4.2 Stratigraphy

4.2.1 Introduction

The Kavirondian Group is divided into four formations. From the stratigraphically lowermost to the stratigraphically uppermost (Fig. 6), they include the Shivakala Formation, the Igukhu Formation, Mroda Formation and Mudaa Formation.

The Kavirondian rock succession (Fig. 6) is a composite succession which is based on the holostratotypes of the proposed four formations within the Kavirondian Group. The Kavirondian Group succession proposed in this work, cannot be compared with the previously suggested successions (Pulfrey, 1945 and Huddleston, 1954) because those previous successions were generalised successions for all the rocks of the Nyanzian Shield. Prior to this study, no other author had proposed a rock succession for the Kavirondian Group as a lithostratigraphical unit. In consequence, comparisons of the successions proposed in this work and

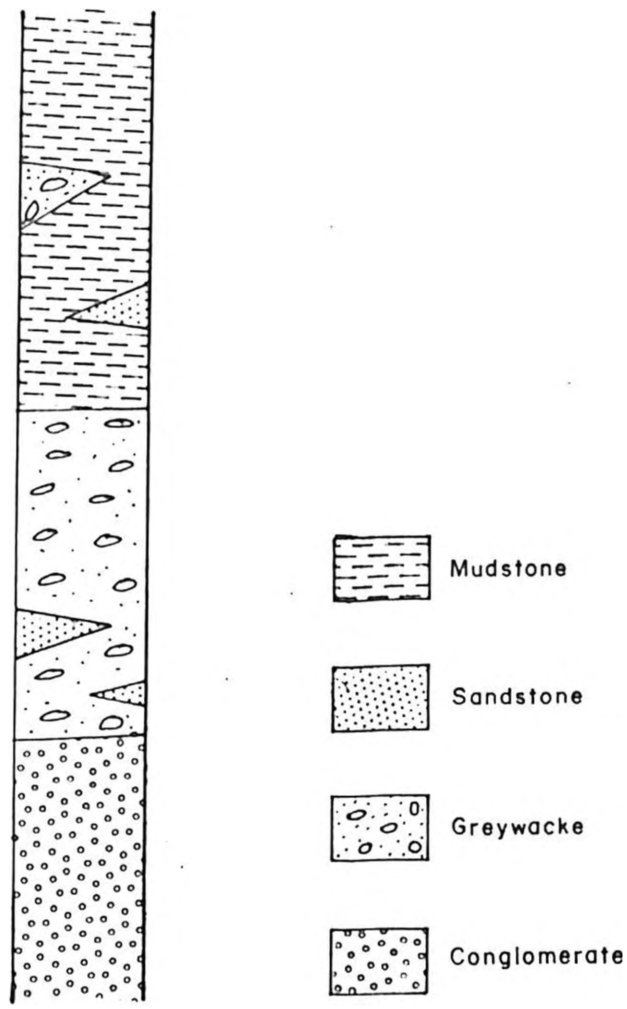

Fig. 6 :- The Kavirondian group rock succession in western Kenya.

successions proposed by other workers in the study area is impossible.

4.2.2 The Shivakala Formation

4.2.2.1 Introduction

This formation covers an area of about 15 square kilometres west of Mukumu Hospital. The most westerly point of the formation is the Aisere Shopping Centre. From Mukumu Hospital to Aisere Shopping Centre is about 6.5 kilometres. Bukusi School is the most northerly point while Shigokho School is the most southerly point. The distance between the two schools is about 3.5 kilometres. The type section is at Shivakala school and its location in local grid is 909227.

This formation is here designated as the unit stratotype and is about 260 metres thick. The formation is composed of polymictic conglomerates which are intruded on the north-eastern side by both the Kakamega granite and diorite. On the northern side, the conglomerate is intruded by Mumias granite while in the southern side, they form a sharp contact with sandstone and greywacke formations. The conglomerates are basal, marginal accumulations which were shed in a wedge-shaped basin from a sharply elevated highland. These rocks are made up of unsorted pebbles and boulders which measure up to 0.5 metres in diameter. Some pebbles are derived from the underlying Nyanzian volcanic rocks. Other pebbles like the quartzites, cherts and granites were derived from earlier phases of sedimentation and intrusions. The pebbles are held together by matrix which was also derived from the previously elevated parts of the underlying Nyanzian volcanic rocks and earlier intrusions of granites (see Plates 1 and 2).

The bases of the beds are usually sharp and planar, especially where unconformities with the underlying Nyanzian Group are observable across the width of outcrops (see Plates 3 and 4).

Some crude stratification is observed within the massive beds through the apparent changes in clast sizes and rough clast alignment with the long axes parallel to the bedding plane. On most of the outcrops, the minerals which make up the matrix are not aligned along the bedding plane like the pebbles. This implies that the pebbles were imbricated before deposition. On the sediments-granite contacts, however, the matrix has been sheared along with the conglomerate pebbles.

The conglomerates do not show obvious sedimentary structures (see Plates 5 and 6). A minor scour structure which measured about 10 centimetres deep and 2 metres wide was observed near Biuru Shopping Centre. Crude graded bedding was also observed at Shiduhu where it was restricted to the uppermost part of a bed. The matrix which support the conglomerate pebbles is composed of fine to medium grained sandy cement. The matrix is greenish grey to dark grey in colour and contains about 30% quartz. The rest of the minerals which make up the matrix have undergone metamorphism and only sericite and chlorite are recognisable.

4.2.2.2 Petrography of Granite Boulders and Pebbles

The boulders and pebbles are coarse grained. This is especially true to the boulder derived from earlier granitoids. However, boulders and pebbles derived from recycled sedimentary rock and the underlying Nyanzian volcanic rocks are medium and fine grained. The larger boulders are about 10 centimetres in diameter while the smaller ones are only about 2 centimetres. Most of granitic pebbles examined were composed of about 50% plagioclase feldspar, 35% quartz, 10% biotite and 5% accessory minerals. The platy minerals show no preferred orientation and the samples generally show hypidiomorphic granular textures. Plagioclase crystals are

PLATE 1. A photograph of matrix supported, porphyritic granite boulder at Got Regea. This is an oligomictic conglomerate outcrop whose top is generally weathered. The well-rounded granite boulders are up to 20 cm in diameter.

PLATE 2. A photograph of oligomictic conglomerate at Mukumu. The clasts are dispersed, ungraded and show crude imbrication.

PLATE 3. The photograph shows a band of Proterozoic granite intrusion which cross-cuts an oligomictic conglomerate formation near Yala town. At the top right hand corner of the outcrop, the granite (Maragoli granite) overlies the Kavirondian conglomerate.

PLATE 4. The photograph shows an outcrop near Yala town where sharp contact boundary was observed between Kavirondian conglomerate at the base, greywacke in the middle and Maragoli granite at the top.

PLATE 5. The photograph shows clast supported polymictic conglomerate at Got Regea. This conglomerate outcrop is composed of basaltic and andesitic pebbles derived from the underlying Nyanzian volcanic rocks.

PLATE 6. The photograph shows a polymictic conglomerate outcrop at Ramula in which the pebbles are flattened and imbricated. The pebbles were apparently derived from the underlying Nyanzian volcanic rocks.

slightly altered. They show fine inclusions of sericite and are twinned according to the albite and pericline laws. A few crystals exhibit carlsbad twinning and a faint normal zoning. Quartz occurs as crystals which are about 5 millimetres in diameter. They show planes of tiny bubbles and distinct strain shadows.

Biotite occurs as subhedral crystals which are about 3 millimetres long. Most of the biotite appears to have been formed as a result of hornblende alteration. The mineral is strongly pleochroic and changes its colours from brown, deep brown to pale yellow. Epidotes are fairly fresh and colourless, however, some of them have cores which are deep yellow or brown. This characteristic suggests formation of allenite. Chlorite is normally pale yellow with low birefringence. It mainly occurs on the margins of biotite where it forms small isolated flakes. Muscovite is scattered throughout the margins of plagioclase crystals where it occurs as very fine flakes.

Among the opaque minerals, sphene occurs in form of fine granular clusters which are partly altered into zircon. Zircon also occurs as small crystals within biotite where it forms pleochroic haloes. Other opaque minerals include pyrite, ilmenite, hematite and magnetite.

4.2.2.3 Andesite Pebbles

Andesite pebbles are not many in the conglomerate formation in the Kakamega area. The pebbles, however, form one side of the Got Regea hill. The rocks are fine-grained and show plagioclase composition which ranges from albite to andesine. These rocks are widely saussuritized. Quartz takes only about 6% of the total rock mass and its grains are usually not more than 0.4 millimetres in diameter. Sphene and zircon are the mafic minerals recognised in the pebbles.

Most of the andesite pebbles are flattened and show faint foliation.

4.2.2.4 Rhyo-dacite Pebbles

These pebbles are remarkably uniform in size. They contain sanidine phenocrysts which are enveloped by sodic plagioclase phenocrysts which are usually about 2 millimetres in diameter and contribute about 35% of the total rock mass. Some plagioclase phenocrysts have been altered into sericite. Quartz occurs as rounded and fragmented crystals which measure to about 2.5 millimetres in diameter. Their compositional contribution in the rock is about 20% of the total rock mass. The matrix of the pebbles is composed of very fine grained quartz, feldspar, mica and chlorite grains.

4.2.2.5 Rhyolite Pebbles

These are usually light to dark grey chert looking rocks which carry small quartz and feldspar phenocrysts which occur in the ground mass of much finer quartz and feldspars. Some feldspar phenocrysts are slightly altered to sericite, otherwise most of them are clear and glassy. The phenocrysts are identified to be sanidine because of their small axial angle. In some samples, small amounts of microcline and sodic oligoclase were observed. The pebbles do not show clear flow banding. Mafic minerals are rare but fine biotite crystals are scattered throughout the rock.

4.2.2.6 Basalt Pebbles

The basalt pebbles are dense fine grained dark green rocks in which minute feldspar laths and shreddy hornblende form tight felt-like mass in sparse isotropic brown groundmass composed of iron oxide. The feldspars have been interpreted as calcic

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4.2.2.7 Quartz Pebbles

Chert pebbles have colour ranging from white, black grey to cream white. Some pebbles show crude flow banding while others show none. Jasper occurs in considerable amounts in the conglomerates both as clasts and in the matrix. Most of the jasper pebbles are well rounded and sometimes show strain cracks which possibly imply long distance transport from the source area. Quartzite pebbles are also common in the basal conglomerates. The quartzite pebbles are well rounded and are rarely fragmented. Well rounded and rarely fragmented quartzite are a result of abrasion during cycles of peneplanation during tectonic cycles.

4.2.3 Igukhu Formation

4.2.3.1 Introduction

The formation is named after a locality which is about 40 metres from the Yala river bridge between Khayega and Chavakali markets. In local grid, the Igukhu outcrop is located at 945185. In this locality, a large outcrop of greywacke was studied and it has been chosen as the unit stratotype. The outcrop is about one square kilometre and several hundreds of metres thick. The greywackes are mineralogically and texturally immature. This is shown by the chemically and mechanically unstable rock fragments and the relative low alumina to soda ratio. Generally, alumina-soda ratios are an index of chemical immaturity. Textural immaturity is also indicated by the angular nature of the coarser fraction minerals and the abun-

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dance of fine matrix. Although most of the greywacke workers consider the matrix as the most important characteristic of the rock, the amount of quartz contained in greywacke has also been used to divide the rocks into three groups (see Fig. 5). Greywacke which contained less than 15% quartz as frame work grains were called the "poor quartz greywackes" and are basically derived from basic and ultrabasic rocks. Those which contain between 15% and 65% quartz as framework grains are called "quartz intermediate greywacke". The third type contains more than 55% quartz as framework grains and are called "quartz rich greywacke". This type of greywacke is mainly derived from sedimentary sources although it is sometimes accompanied by minor granitic and low grade metamorphic admixtures (Middleton and Hampton, 1973).

Greywacke encountered in the study area falls into the first two classes. The first type of greywacke in the study area is coarse grained with quartz and feldspar grains visible with the naked eyes (see Plate 7). This type of greywacke occurs on the outcrops where there are no mudstone intercalations, especially at Igukhu. This type of greywacke is thick bedded and passes upwards into thin beds of brown mudstone. The greywacke is greenish grey or dark grey rock. On a small outcrop at Matioli school, the dark grey greywacke can be mistaken for basic igneous rocks. When mildly weathered, this type of greywacke becomes buff coloured. When completely weathered, the rock yields light brownish-yellow soils. The bases of the thick bedded greywacke are usually sharp and planar (see Plate 8). Limited load cast and flame structures have been formed on these sharp bases. The grains are generally coarse at the bases of the beds and measure up to 1.5 millimetres in diameter. The grains decrease in size upwards until they acquire matrix size at the top of the bed.

PLATE 7. The photograph shows unstratified grade greywacke at Igukhu Health Centre. The greywacke formation is invaded by post-sedimentation quartz-veins. The quartz veins are cross-cut by minor faults.

PLATE 8. The photograph shows a deformed and folded layer of greywacke (on the upper part of the photograph) which has a sharp and planar boundary with the underlying blocky mudstone. The outcrop is near Bukura market.

PLATE 9. The photograph shows parallel laminated beds of greywacke at the base (light in colour) followed by mudstone beds (dark in colour) at Lidhabidha. The beds show normal grading from left to right. Note the syn-sedimentary fault on the left edge of the ruler.

The second type of greywacke is normally fine grained and muddy. It occurs within the gradational zones between classical greywacke and mudstone formations. This type of greywacke is found on minor outcrops at Bushiangala school and under the Yala river bridge between Eshibakala and Malaba schools. The beds are, on average, three centimetres thick and display graded bedding. Parallel laminated beds which often occur on the upper beds of this formation are sometimes contorted and convolute (see Plate 9). This type of greywacke apparently represent distal turbidity deposits.

The petrography of greywacke is described in detail below.

4.2.3.2 Feldspars

Although diagenetic changes have affected the clastic particles to some degree, it is evident from the more fresh samples that plagioclase feldspars are dominant in the greywacke. The plagioclase feldspars are composed of albite, andesine and limited amount of oligoclase. Potassium feldspars which are much less are composed of orthoclase and microcline. The margins of the feldspars are often altered and have been replaced by sericite and chlorite. The feldspar minerals are aligned in parallel zones. According to Reimer (1971), such secondary zones in plagioclase feldspars are post-depositional in origin and are attributed to slight incipient albitisation during the diagenesis of the enclosing sediments. Huckenholz (1963), Dickison and Hatherton (1967) and Ojakangas (1968), also attributed irregular secondary zoning in plagioclase to albitisation.

According to Folk (1968), sandstones which contain abundant plagioclase feldspars in excess of potassium feldspars are of volcanic origin. However, Baker and Arth (1976), Baker et al. (1981) and Anhaeusser (1981) noted that during the early stages of Archaean development, the Na-rich granites (tonalites and trondhjemites) were the dominant granites and were characterised by Na-rich plagioclase feldspars.

It is now understood that the Na-rich granites and the felsic volcanic rocks (rhyolites and dacites) formed one end of the well documented Archaean bimodal rock suites and it is believed that these rocks were the main source of plagioclase feldspars. The other end consisted of tholeiitic basalts and andesites which contributed minimally as a source of plagioclase feldspars. During the course of the greenstone development (Condie, 1981 and Anhaeusser, 1981) the K-rich granitic varieties intruded into the greenstone belts as a result of upper crust partial melting.

4.2.3.3 Quartz

Quartz in greywacke occurs as angular to subangular grains which are set in a groundmass of fine grained quartz, feldspar and sericite. Most of the quartz grains are clear and of uniform extinction. Some quartz grains are polycrystalline and appear as mosaic of smaller grains which superficially resemble quartzite. The polycrystalline quartz consists of several polygonal grains which are recognisable as individual separate grains (under closed nicols) and deviate slightly from a common orientation. Their boundaries are simple, unsutured and meet at 120^0 angle. Polygonal quartz is a product of static annealing of strongly deformed quartz and this type of quartz is characteristically found in granitic plutons.

4.2.3.4 Rock Fragments

On most of the greywacke outcrops, rock fragments form about 20% of the total rock mass. Rock fragments of sedimentary origin consist mainly of mudstone and fine grained siltstone. They are recognised by their dark colour, abundant muscovite and generally flattened outlines. The fragments are of intraformational origin derived from erosion of earlier mudstone beds as is indicated by their similarity with the preserved mudstone. Volcanic rock fragments constitute a minor part of the identified lithic component. These fragments are composed of felsic material which contain fine clasts which are tightly interlocked and form a mosaic of quartzo-feldspathic material. The clasts are recognised by the diffuse outlines of the grains and the presence of fine, widely scattered crystals of chlorite, quartz and feldspar phenocrysts.

Mafic rock fragments are rare but a few were observed on several small outcrops near Wamage School. They are characterised by the presence of fine plagioclase laths that are uncommon in the more felsic fragments. The fragments are generally much darker and contain more chlorite than the felsic fragments.

4.2.3.5 Matrix

The matrix contained in the greywacke of the study area make up about 40% of the total rock. The matrix completely surround the larger detrital grains. The matrix size of the sediments is taken at about 30 microns (0.02 millimetres) in diameter. According to Spencer (1963), this diameter is the most ideal for separating two fundamentally different size populations which include sand and matrix. Folk (1968) also suggested the 30 microns diameter as the upper limit of matrix constitution. The matrix is generally composed of dense, very fine grained tightly meshed intergrowths of chlorite. The matrix appears to have been derived from the mechanically and chemically unstable fragments of both sedimentary and igneous rock suites. The matrix formed after the breakdown of sedimentary rocks is characterised by chlorite-muscovite association whose formation apparently preceded greywacke deposition. The matrix formed as a result of the breakdown of the silicic rocks is usually quartzo-feldspathic. The micrographs on Plates 10 and 11 show textural features of the greywackes.

4.2.4 Mroda Formation

Sandstone appears in the study area as thin bands which are intercalated within the greywacke and mudstone. These are grey fine grained rocks which, after weathering, produce buff coloured soils. The best sandstone outcrop occurs at Mroda school, whose local grid is 745139, and has been designated as the stratotype. The outcrop is about 100 square metres and about 17 metres thick. The sandstone forms beds which are about half a metre thick. The bases of the beds are sometimes sharp although most often the boundaries between the beds are gradational. At Mroda, sandstones also display many white mica flakes on the bedding planes.

The most important sedimentary structure in the bedded sandstone is the graded bedding. Internal structures in the sandstone beds include groove marks, load casts and flame structures. On the blocky sandstones, grains are not graded and the sandstone normally shows cross-lamination and ripple drifts (see Plates 12 and 13). Petrographically the sandstone contains fine well rounded quartz grains and limited amout of feldspars. Most of the feldspars have altered into sericite. Quartz grains attain a diameter of about 0.3 millimetres. The matrix is composed of very fine grains of quartz and feldspars and chlorite is widespread. Mica flakes,

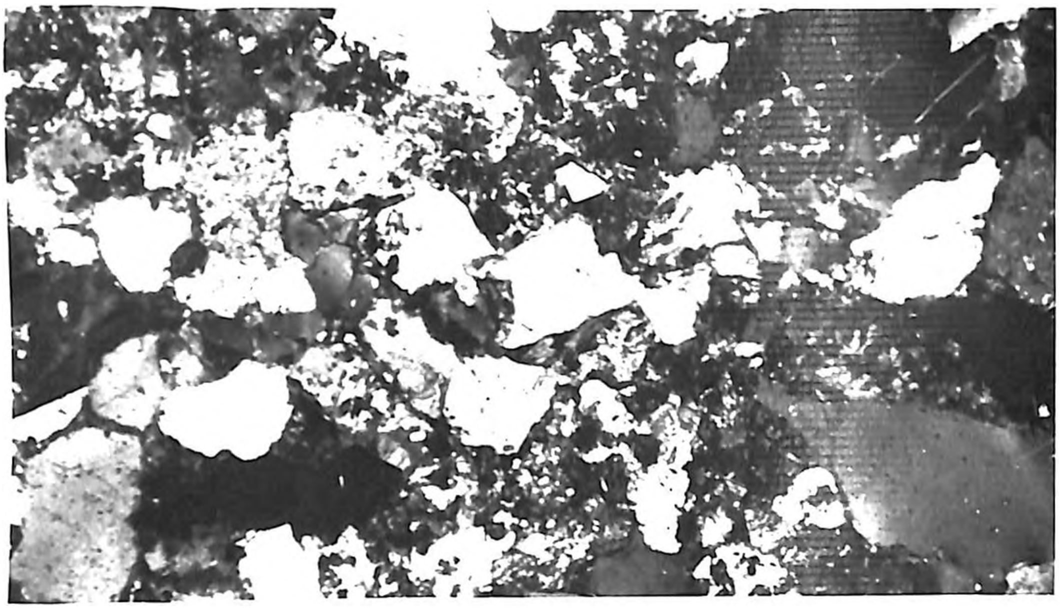


PLATE 10. Micrograph of coarse grained greywacke showing typical greywacke texture. Note the irregular shaped quartz crystals (white) and feldspars (grey). The dark clasts are mudstone fragments of intraformational origin.

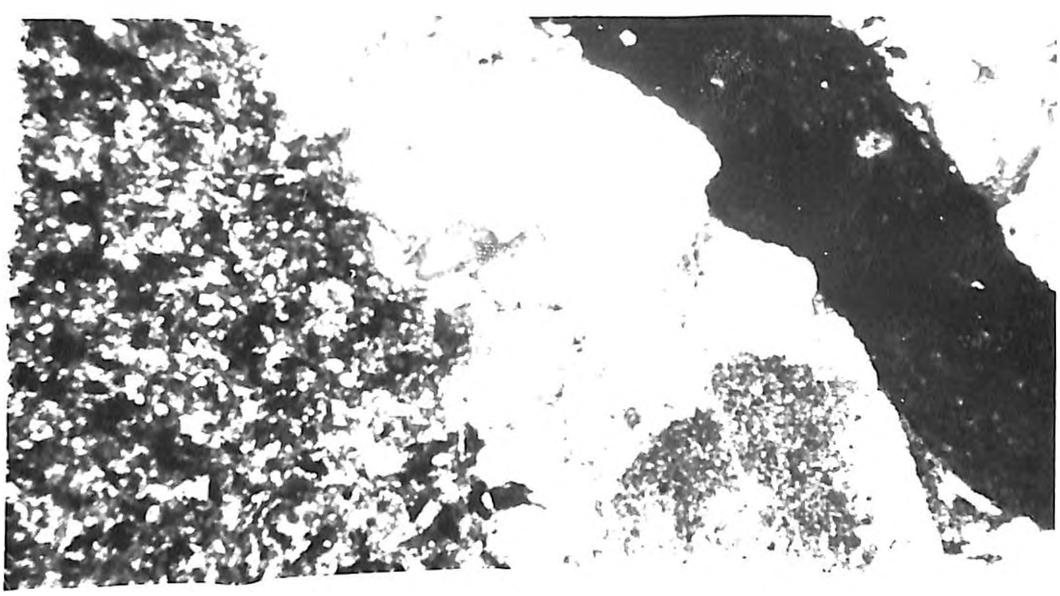


PLATE 11. Micrograph showing the sharp contact between the mudstone on the right and greywacke on the left. Note the rock fragments within the greywacke.

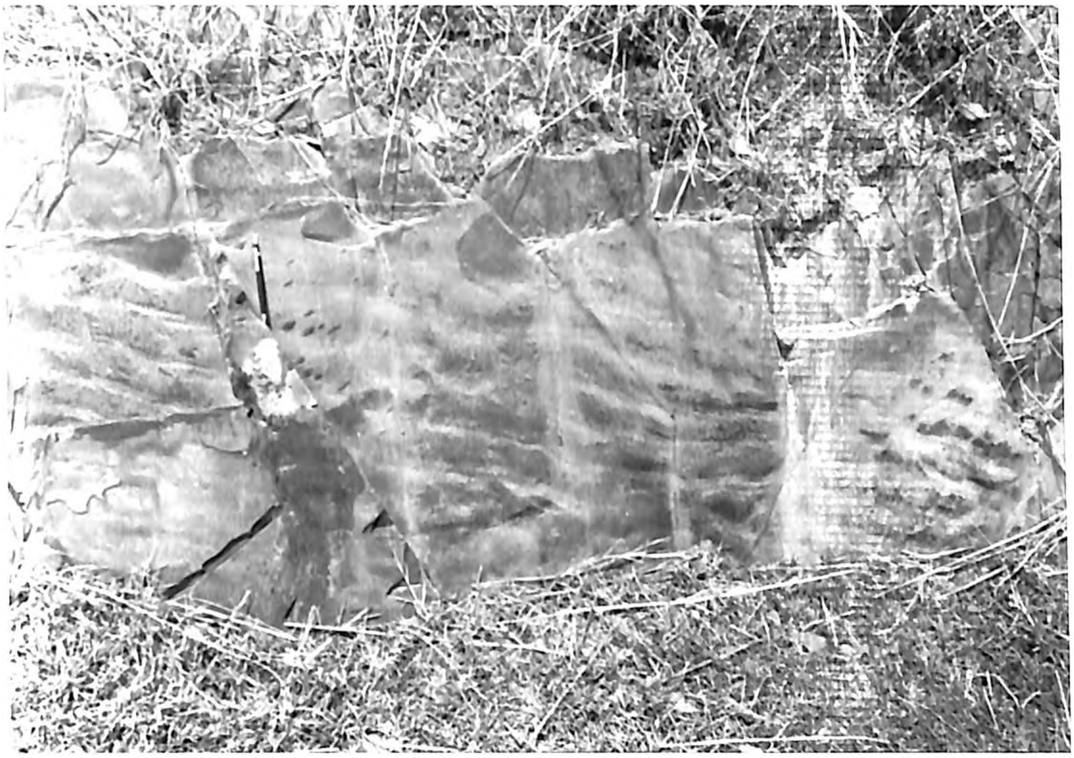


PLATE 12. The photograph shows assymetrical wave ripples which have been traversed by aclastic dyke on the right hand side next to the pencil. The direction of the sediments transport is from top to bottom. The outcrop is near Luanda market.

PLATE 13. The photograph shows a sharp contact boundary between the greywacke (below the compass) and the mudstone (above the compass) near Sawagongo. Note the straight crested wave ripples.

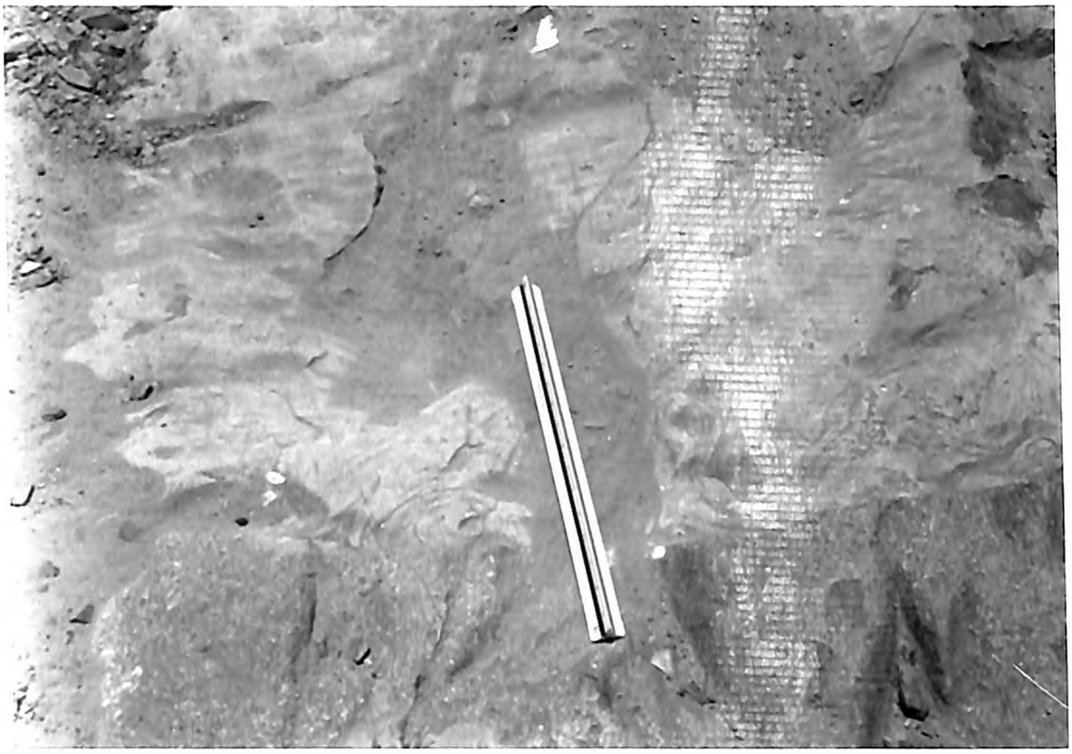


PLATE 14. The photograph shows a well graded greywacke bed in the lower part of the photo which forms a sharp contact with mudstone bed on the upper part of the photo. The mudstone bed has convolute structures. The central part of the photograph (along the ruler) shows an area of sediment mixing, probably a fluxo-turbidite. The photo was taken on the banks of the Yala river near Kojero.

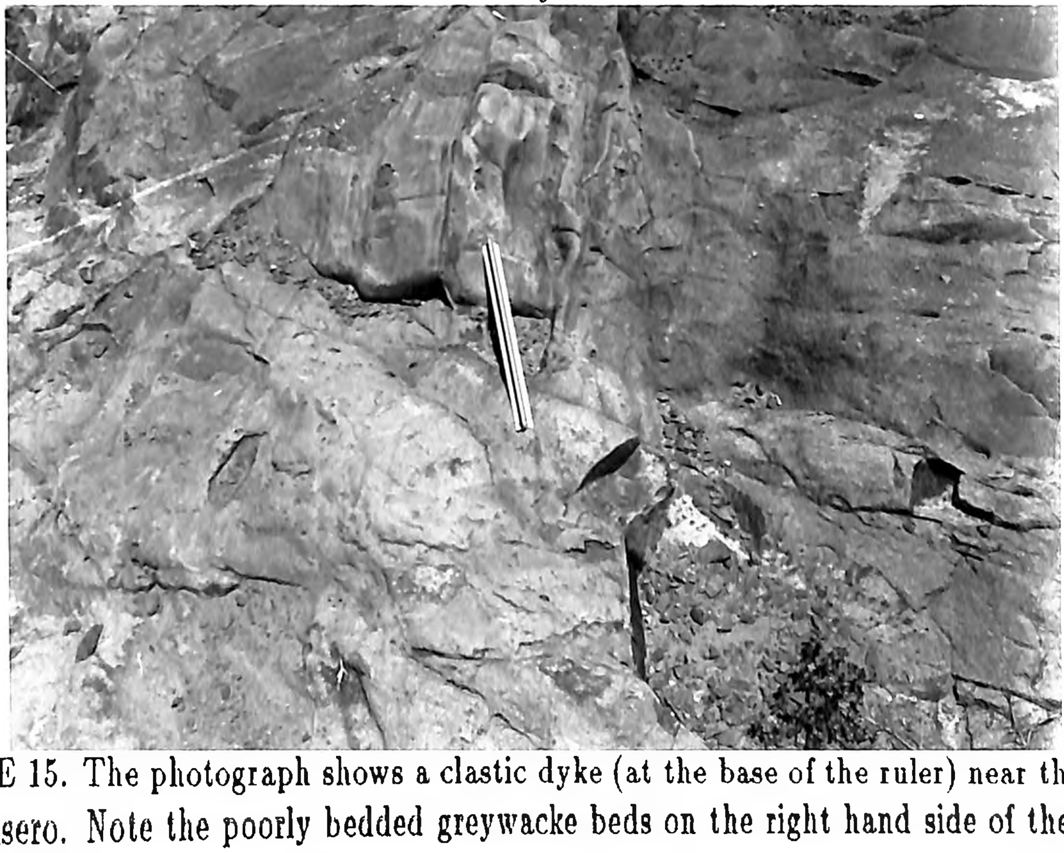


PLATE 15. The photograph shows a clastic dyke (at the base of the ruler) near the town of Kwisero. Note the poorly bedded greywacke beds on the right hand side of the photo and the blocky mudstone beds on the left hand side of the photo.

PLATE 16. The micrograph shows porphyblasts of chiastolite formed as a result of contact metamorphism with the mudstones near the granite-mudstone boundaries.

commonly muscovite, are often found on the bedding planes. Some mica was found to be associated with a variety of manganiferous minerals which are pale pink in colour. Biotite is the main ferromagnesian mineral in the sandstone and it appears to have been formed through the hornblende alteration.

4.2.5 Mudaa Formation

A well preserved outcrop of mudstone was observed at Mudaa school. The local grid of Mudaa outcrop is 825152. The outcrop is about four square kilometres. The thickness of the outcrop could not be precisely determined but it is within the range of 150 metres. This outcrop is used as the stratotype. The mudstone beds are invaded by thin bands of greywacke and sandstone which have east-west strike (see Plate 14).

On the southern side of the outcrop, the mudstones lie unconformably over the Nyanzian volcanic rocks while on the northern side the rocks are intruded by the giant quartz vein.

When fresh, mudstones are dark-grey, grey or purple soft rocks which are mostly blocky (see Plate 15). On some outcrops especially around Viyalo market, banded graphitic mudstone were encountered. Most of the graphitic mudstones also contain tiny grains of pyrite.

On the contacts with granite intrusions, mudstones show the greatest effect of metamorphism. Due to thermal metamorphism, mudstones near the contacts are highly micaceous. The mudstones also contain elongated white crystals of chiastolite and black crystals of biotite.

Petrographically, mudstone are composed of minute grains of quartz and feldspar. In most cases, however, the original minerals have altered to chlorite, sericite, muscovite and clusters of iron oxide. Chlorite normally shows an anomolous "Berlin Blue" interference colour. Chlorite which shows such colour interference is usually penninite. Tourmaline in mudstone occurs as long slender crystals which are about one millimetre long. When mudstones have undergone secondary alteration especially near the major granite intrusions, they develop white spots which, in thin section, form clear square shaped outlines of shreddy fine grained sericite aggregate. This sericite represents the chiastolite which has been altered (see Plate 16).

4.3 Correlation

The lithostratigraphic correlation of the Kavirondian sediments poses considerable difficulties. Correlation through "walking out" the units is hampered by thick soil cover which causes lack of well exposed surface outcrops on which to extend the hypostratotype.

The sediments are also characterised by lithological variations both laterally and vertically. These lithological variations are caused by lateral gradations, inter-tonguing and pinching out. In lateral gradation rock beds are normally terminated by gradual replacement of their lithologic characters by those of other types. In most cases gradation is observed between greywacke and mudstone. Intertonguing is mainly observed when sandstone and greywacke beds disappear into the laterally adjacent rock beds. Sandstone and greywacke normally split into many thin units each of which reaches an independent pinch-out position. The resulting intertonguing zones have many vertical intercalations of thin beds which represent the two rock types. Sometimes, rock beds pinch-out through progressive thinning to extinction. Pinch-out of one type of bed is often accompanied by an increase in thickness of the adjacent bed.

Lithological correlation of six diamond drill holes in the study area is shown in Figure 7. Greywacke band within the mudstone has been used as the marker bed. The diagram illustrates the impact of the lateral facies variations on correlation.

In Figure 8, surface correlation of conglomerate formations in the study area is shown. It is again observed from the diagram that variations in lithofacies within the fine grained members of the Kavirondian Group, generally hinders regional correlation.

Lithostratigraphy cannot independently resolve the regional correlation of the Kavirondian sediments with similar sediments found in other Archaean shields and consequently a tentative geochronostratigraphical correlation is proposed.

In Zimbabwe, the Shamvaian System which is largely sedimentary, dates about 2650 Ma (Vail and Dodson, 1970) and it unconformably overlies the Bulawayan System.

The Bulawayan system which is composed of volcanic rock suites resembles the Nyanzian Group lithologically and its older age limit is given by the Rhodesdale granite which intrudes it. The Rhodesdale granite yields K:Ar age of 2970 m.y. The Rhodesdale granite can be compared with the older granite of the Nyanzian shield while the Bulawayan system is comparable to the Nyanzian Group. The Shamvaian System sediments can be compared with the Kavirondian sediments.

In the Canadian shield, the greenstone belt features mafic to felsic volcanic rock cycles of mixed tholeiitic and calc-alkaline compositions. These volcanic rock suites are overlain by sedimentary rocks which include basal conglomerate, greywacke and shale. The sequences are commonly synclinally deformed and are typically in contact with younger pegmatitic granitic intrusives. The granitic rocks

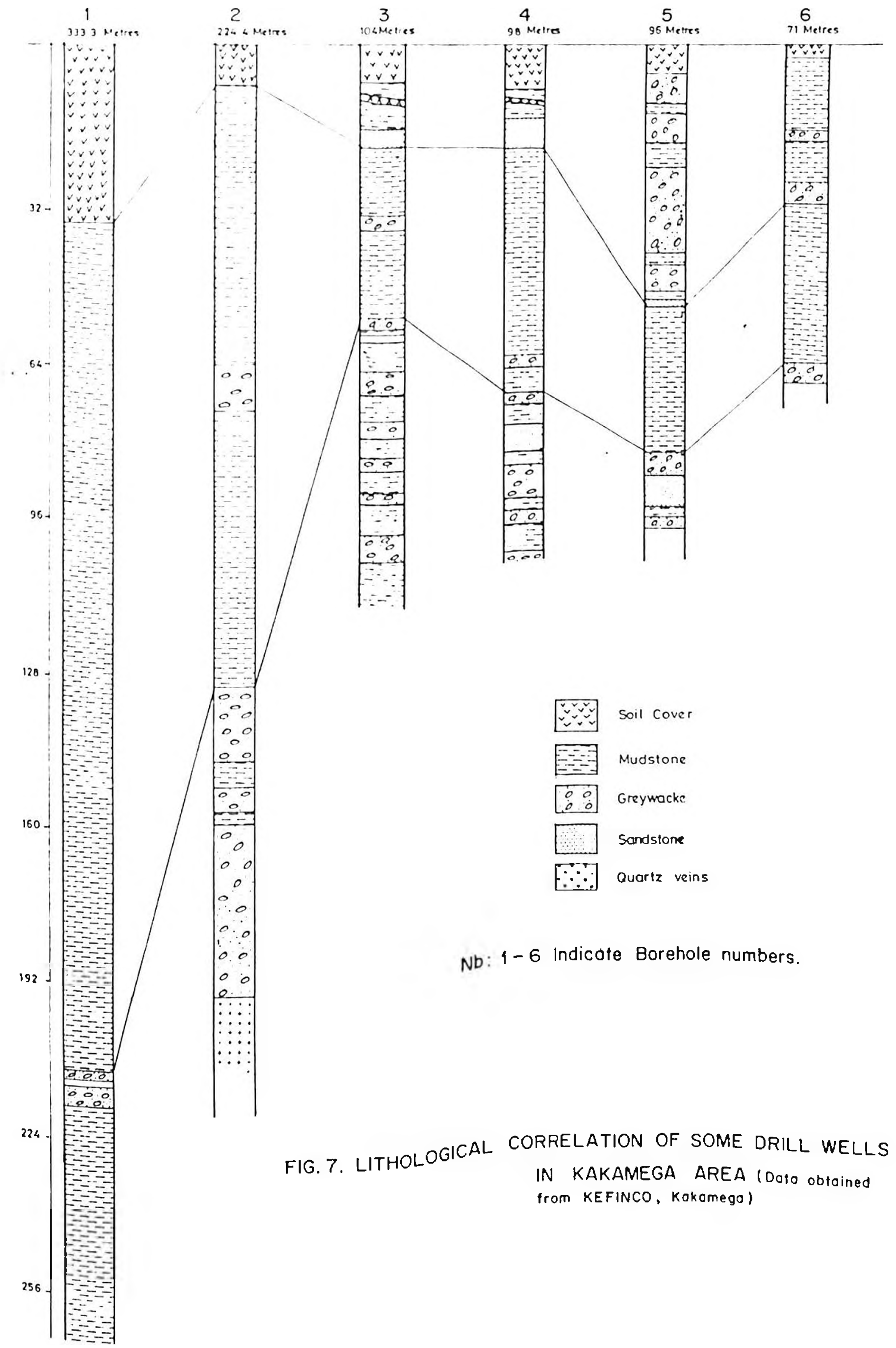


FIG. 7. LITHOLOGICAL CORRELATION OF SOME DRILL WELLS IN KAKAMEGA AREA (Data obtained from KEFINCO, Kakamega)

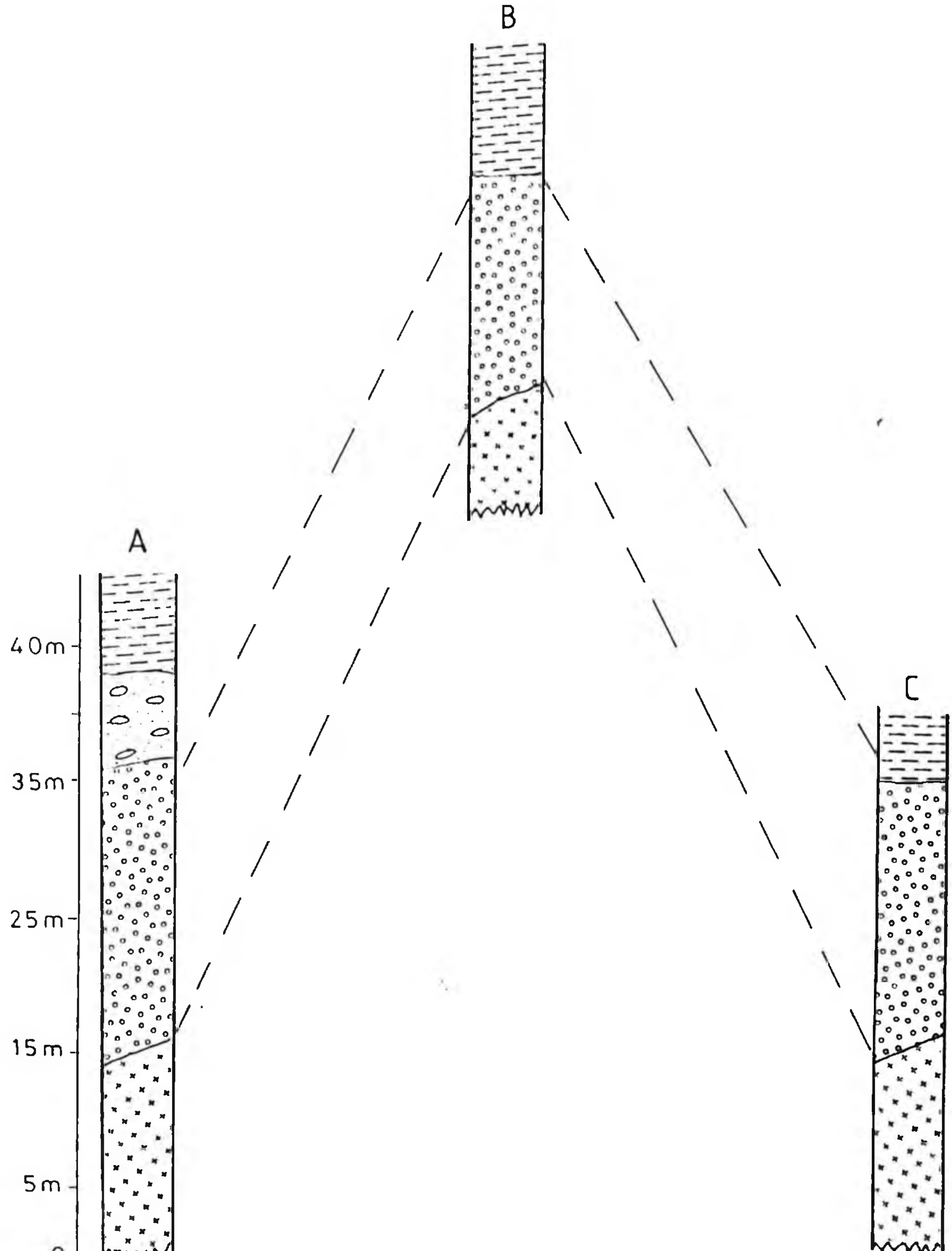


Fig. 8 Lithologic correlation of Kavirondian sediments

A — Mukumu conglomerate facies
B — Ramula conglomerate facies
C — Got Regea conglomerate formation.
— Volcanic rocks
— Conglomerate
— Greywacke
— Mudstone.

The scale is contant.

include a wide variety of older tonalitic, trondhjemitic and granodioritic gneisses and younger more potassic batholithic suites. The trondhjemite-tonalite suite of Duxbury Massif, Eastmain District, Unguva, have been dated at 2915 ±180 Ma (Verpealst et al., 1980). The main period of volcanism which gave rise to the greenstone belt has been dated at 2760 Ma (Turek and Peterson, 1970 and Krogh and Davis, 1972) and the post-tectonic pegmatitic granite has been dated at 2560 Ma (Krogh et al., 1976).

Lithologically, the Canadian shield compares best with the Nyanzian shield among all the Archaean shields. In both the Canadian shield and the Nyanzian shield no ultramafic rock of the Komatite type have been reported and their lithological successions start with the lower tholeiitic mafic rocks through the middle calc alkaline felsic volcanic rocks to the upper sedimentary successions. Geochronostratigraphically, the trondhjemite-tonalite rock suites of Duxbury Massif is comparable to the older granite of the Nyanzian shield. The main period of volcanism in both areas appears to have been around 2700 Ma and the deposition of the sediments in both areas took place between 2650 and 2550 Ma. The post-tectonic granite batholith suites in both areas compare well because in the Canadian shield, the batholitic intrusion took place around 2560 Ma while in the Nyanzian shield the intrusion took place around 2450 Ma.

In South Africa, the Barberton Belt which is the best studied Archaean greenstone belt is composed of the Swaziland Supergroup. The Supergroup is divided into three groups which from the stratigraphically lowermost to the stratigraphically uppermost include the Onverwacht, the Fig Tree and the Moodies.

The Onverwacht Group comprises chiefly of ultramafic to the mafic volcanic rocks (Anhaeusser, 1991) with minor felsic volcanic rocks and cherts. The lowest formation of the Onverwacht Group is the Sandspruit Formation. This formation consists of 60-70% ultramafic rocks and 30% mafic rocks. The Komati Formation which overlies the Sandspruit Formation is composed of 70% mafic rocks and 30% ultramafic rocks. The Hooggenoeg and Kromberg Formations which overlie the Komati Formation, respectively, consist of mafic to felsic volcanic cycles and the respective pyroclastic rocks. The Swartkoppie Formation which is the uppermost in the succession, is composed of mafic to felsic volcanic rocks. Conformably overlying the Onverwacht Group is the Fig Tree Group. The Fig Tree Group is composed of three formations which include from the base to the top, the Sheba Formation mainly composed of greywacke and the associated shales with minor chert horizons. The middle Belvue Formation begins with massive chert unit which is followed by greywacke siltstone, shales and locally, felsic tuffs. The uppermost Schoongezicht Formation is composed of felsic tuffs, breccias and agglomerates.

The oldest reliable age reported in the Onverwacht Group is 3426 ±200 Ma (Anhaeusser, 1981). This age was obtained from basaltic komatiite from the Tjakastad Subgroup. A zircon U-Pb age of 3282 ±100 Ma (Van Niekerk and Burger, 1969) was obtained from Hooggenoen lavas and tonalitic diapirs which have deformed both the Fig Tree and Moodies sediments, were emplaced 3240 ±40 Ma ago (Oosthuyzen, 1970).

Although Van Eeden et al. (1956) suggested that the Nyanzian rocks are comparable to the Fig Tree series, it is generally impossible to correlate geochronostratigraphically the rocks of the Onverwacht Group with the rocks of the Nyanzian Shield. The radiometric data available show that the ages of the various formations which make up the Onverwacht Group are much higher than those obtained from the various formations within the Nyanzian Shield. Consequently it is not possible to extend the chronozone boundaries from one geological unit to another.

In Australia, the Yilgarn Subprovince is subdivided into three zones (Rutland,1976) which include the Wheat Belt zone, Murchison zone and the Eastern Goldfield zone.

The Wheat Belt zone is characterised by high grade metamorphic rocks which include argillaceous, calcareous and arenaceous sediments. The Murchison zone is mainly composed of volcano-sedimentary rocks. Eastern Goldfield zone is distinguished by the relative abundance of greenstone rocks.

According to Rutland (1976), the Wheat Belt zone forms an older basement of the Eastern Goldfield greenstone belt. In the Wheat Belt zone, radiometric age of 2900 Ma has been obtained from high grade gneisses but no radiometric data is available for the Murchison zone. The greenstone belt of the Eastern Goldfield zone provide radiometric ages of about 2700 Ma and the associated granitic intrusives yield an age of 2600 Ma. Some minor granitic intrusions within the Eastern Goldfield zone yield an age of 2474 Ma.

Although no hard and fast line correlation can be carried out between the Yilgarn Subprovince and the Nyanzian Shield due to lack of enough data, the Wheat Belt Zone is apparently comparable to the older granitoids of the Nyanzian Shield. The Eastern Goldfield belt is comparable to the Nyanzian Group and the minor granitic intrusions within the Eastern Goldfield zone are comparable to the early Proterozoic granite intrusives like the Mumias and Maragoli granites.

All sedimentary rocks which were deposited between 2700 Ma and 2474 Ma within the Yilgarn Subprovince can be compared and correlated with the Kavirondian sediments.

4.4 Structural Geology

4.4.1 Introduction

In this study the structural geology of the study area has been divided into two groups. The two groups include the primary structures and secondary structures.

The primary structures are those structures which were formed soon after deposition of the sediments before total compaction took place. The structures were caused by the instability of the sedimentary basin which apparently occurred periodically due to water wave movements. The waves were generated by the planetary wind movements and mild earthquake shocks. These structures include those bodies of sediments which show effect of in situ internal, physical, non-biogenic soft sediment mixing and reconstitution but which have not flowed relative to the surrounding undisturbed sediments. Other structures included in the group are of local nature and they result from contemporaneous deformation. These structures are normally confined to one or two beds which lie within relatively undeformed beds.

Secondary structures formed after total lithification of the sediments. They were triggered by internal processes as faulting, rifting, uplift and folding. Secondary structures, unlike the primary structures, are not restricted to one or two beds. They traverse through members, formations and sometimes even a whole group.

4.4.2 Primary Structures

4.4.2.1 Soft Sediment Intrusions

Soft sediment intrusions are allochthonous sediment structures which are formed when unlithified muds, clays and sand rendered quick by rapid seepage, liquefaction or fluidization, flow when subjected to shearing.

Several authors have used different terminology to describe these structures. Sutton and Watson (1960) used the terms sand injections, dykes and sills to describe them. Selley (1969) described them as streamer and cusp structures while Daley (1971) described the structures as diapiric. During this study, the terms dykes, sills and sand volcanoes will be used to describe the structures because they are more informative and well entrenched in literature. These structures are found about one kilometre east of Lidambidza market on the banks of the Yala river. The structures are also well preserved near Wamage School in the Edzawa river valley. The structures are best preserved on outcrops whose general lithology is mudstone which is interbedded with minor sandstone bands. Sedimentary dykes in the study area are crumped discordant bodies whose size ranges from a few centimetres to a maximum of 15 centimetres high (see Plate 15). Most of the dykes were deformed by pressure release during their early stages of formation. The central hollow part of the dykes were filled with silt and mud grains which later lithified within the dykes. Sometimes dykes were filled with volcanic and granitic fragments which were derived from the older rock suites. Grains and pebbles within the dyke are concentrated in the centre leaving a hollow space between them and the inner side of the dyke wall. On lithification, the grains and pebbles form vertical pillars within the dyke. A large clastic dyke in a greywacke unit at Shikunga market illustrated in Figure 9.

Sedimentary sills are tabular structures which have similar characteristics as the dykes but they usually form parallel to the bedding plane of the host rocks. Sills generally lack internal stratification, grading or sole marks. In some sills near Kwisero market, some ptygmatic folds and compactional wrinkles were observed. The folds and the wrinkles suggest that the sills internal injections took place when they were still soft and uncompacted and external pressure from the new incoming sediments made them contorted.

The sand volcanoes are formed when liquefied sediments undergo slumping or very rapid sedimentation and in the process water contained in the sediments is expelled. During dewatering, renewed packing takes place and sediments in the rising columns of water become mobile thus acting as quicksand. The quicksand then moves to the surface of the bed and forms small cones. When the sediments forming the cones finally undergo compaction, sand volcanoes are formed. These structures were found on an outcrop which is about one kilometre south west of Igukhu hospital. Most of the volcanoes observed were about five centimetres high and about three centimetres in diameter.

On the opening of one of the volcanoes, it was noted that it was filled with rock fragments and sand of different sizes. The rock fragments were generally derived from the surrounding mudstone formation.

4.4.2.2 Soft Sediment Mixing

The most common sediment mixing structures in the study area are the fluidization channels. These are flow paths along which escaping pore fluids have partially or fully fluidized the sediment. The structures were described as pillars by Wentworth (1966).

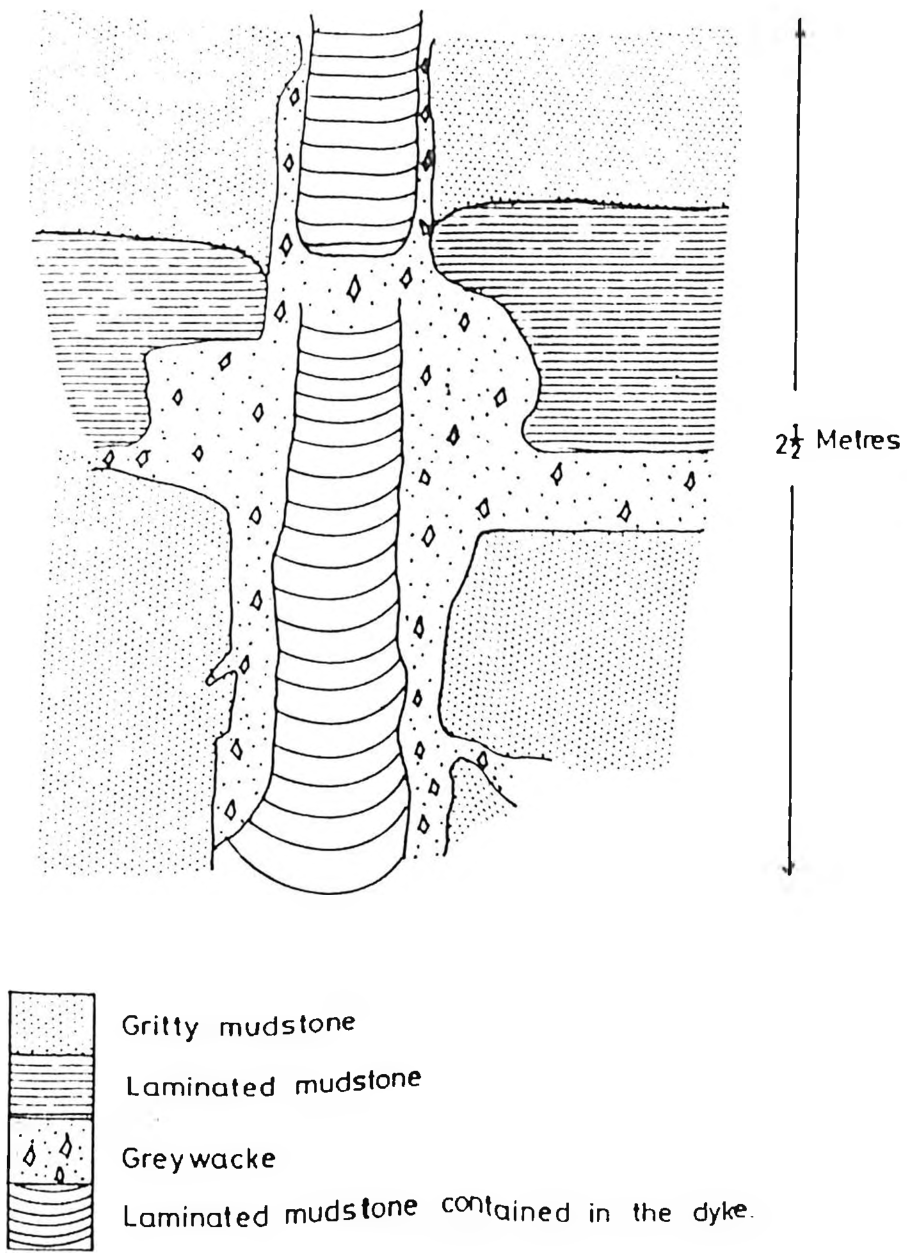


FIG. 9. A SCHEMATIC SECTION OF A LARGE CLASTIC DYKE IN GREYWACKE UNIT AT SHIKUNGA MARKET.

The term pillars has been adopted in this work because it is non-genetic and geometrically describes the vertical structures. Three types of pillars were recognised in the area.

1. Some pillar structures are formed as a result of partial or complete fluidization along the flow paths which develop within sediments undergoing hydroplastic shear. The structures occur as narrow, often irregular light coloured ridges of fine sediments which are about four centimetres high. Each ridge is separated from the next one by a concave shaped farrow which is about six centimetres wide. These structures are best preserved in Feradzi river valley near Butere railway station.

2. The pillars of the second type are formed between upward-curving margins of dish structures. The structures represent fluidization channels which develop around semi-permeable lamination. The structures are generally about three centimetres high and are more frequent where sediment consolidation has involved complete sediment liquefaction. According to Wentworth (1966), in the beds where dewatering has occurred rather slowly, pillars are infrequent and irregularly distributed but when consolidation has involved complete sediment liquefication, the pillars tend to be common and regularly spaced. These pillar structures are well preserved about five hundred metres south of Rosterman Mines.

3. The third type of pillar structures are formed where local fluid escape velocities exceed those required for minimum sediment fluidization. The individual pillars are unrelated to dish structures and occur as steeply inclined zones of homogeneous sand which are concordant to the bedding of the surrounding sediment. Most of these pillars originate at the base of sand units which overlie mud layers. On average, these structures are about two centimetres high although some which are ten centimetres high have been recognised. The structures were observed on

a massive sandstone-mudstone outcrop which lies one kilometre west of Got Kokwiri. Similarly, well preserved pillar structures were observed in the Yala river valley near Sianga.

4.4.2.3 Pre-consolidation Folds

These are structures which occur due to the deformation of the primary lamination without obliterating them. This type of deformation is usually caused by hydroplastic flow.

Convolute bedding falls in this group of structures. The structures occur in mudstones interbedded with silt outcrops which are found three kilometres south of Konjero market under the Yala river bridge (see Plates 17 and 18).

The structures are composed of sharp crested anticlines and rounded synclines and are best observed on slightly weathered surfaces where there is good contrast of colour and relief.

Convolute bedding is produced by differential liquefaction of sedimentary units. The lateral intrastratal flow of the liquefied layers produces contortions. The convolute bedding may also be produced by irregular distribution of pressure within a bed. Due to the irregular pressure distribution, anticlinal convolute folds are drawn up and the spaces between the folds are depressed. Other methods of producing convolute bedding have been proposed by different authors but as (Dott and Howland, 1962; Dzulynski and Smith, 1963; and Pettijohn, 1963) observed, convolute beddings are complex, polygenetic structures and irrespective of differences in interpretation and the differences exhibited by the structures, the structures arise in response to vertical patterns of pressure acting upon easily deformed plastic and laminated sediments.

Load cast structures are also formed as a result of soft sediment folding. The structures are found on the banks of a small stream which is found about one and half kilometres east of Shikunga Shopping Centre. Another large outcrop of mudstone interlayered with siltstone which contains load structures was also observed half a kilometre west of Mudaa School. The structures found near Mudaa School are sole markings which are preserved on the lower side of a sandstone layer which overlies a mudstone layer. The structures range from three centimetres to nine centimetres in diameter. They occur as swellings which vary in shape from minute burges to large well rounded and sometimes irregular knobby structures (see Plates 19 and 20).

Load cast structures in the study area were apparently formed due to downward sinking of the heavier fluidized sand sediments over the underlying more plastic mud layers. Once a critical thickness of sand had been deposited, mud started sliding upwards plastically within the sand and formed irregular minor moulds. Structures initiated this way continued in development until they were stopped by continued deposition of sand. The continued deposition of sand reduced the differential pressure on the mud layers to the minimum and plastic flow came to an end. Sometimes, overlying of sand on the mud layers apparently led mud to adjust itself mainly through vertical movements while sand layers sunk in form of lobes as load structures.

Slump structures also form soft sediment folds. The structures are widespread in the Archaean fine sediments of western Kenya. Well preserved slump structures are found about one and half kilometres west of Lidambizda market. Other remarkably well preserved slump structures are found under the river Yala Bridge about two kilometres south of Emwiru School (see Plate 21).

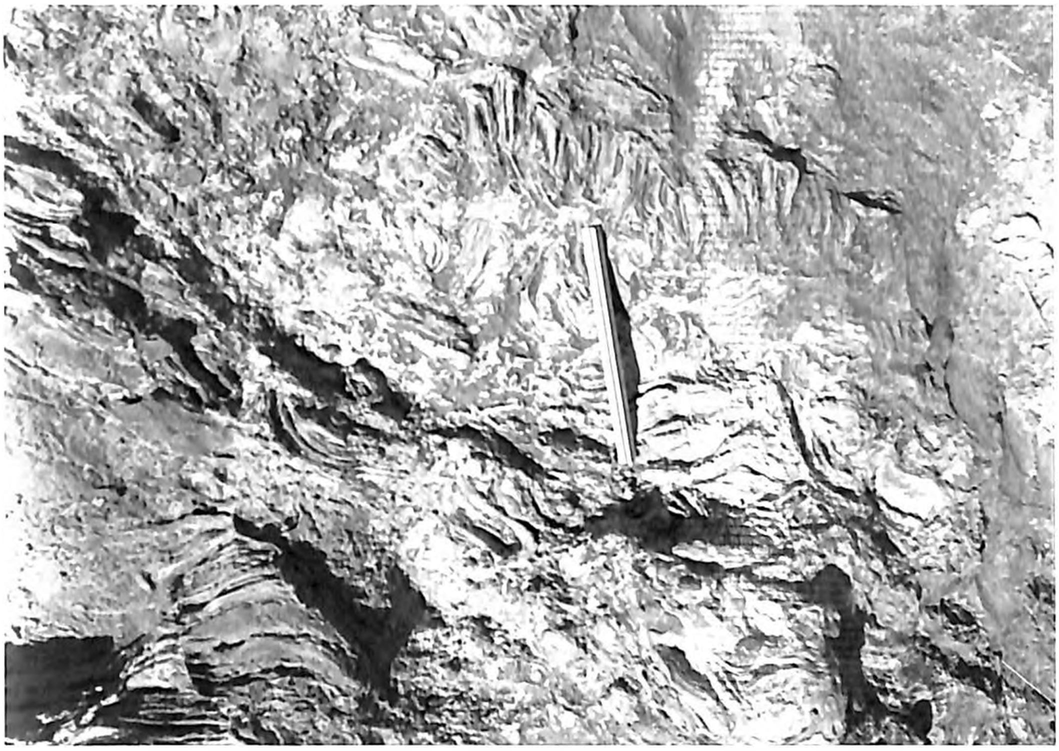


PLATE 17. The photograph shows convolute bedding in siltstone near Rosterman mine near Kakamega town. Note the faulted zone near the lower tip of the ruler.

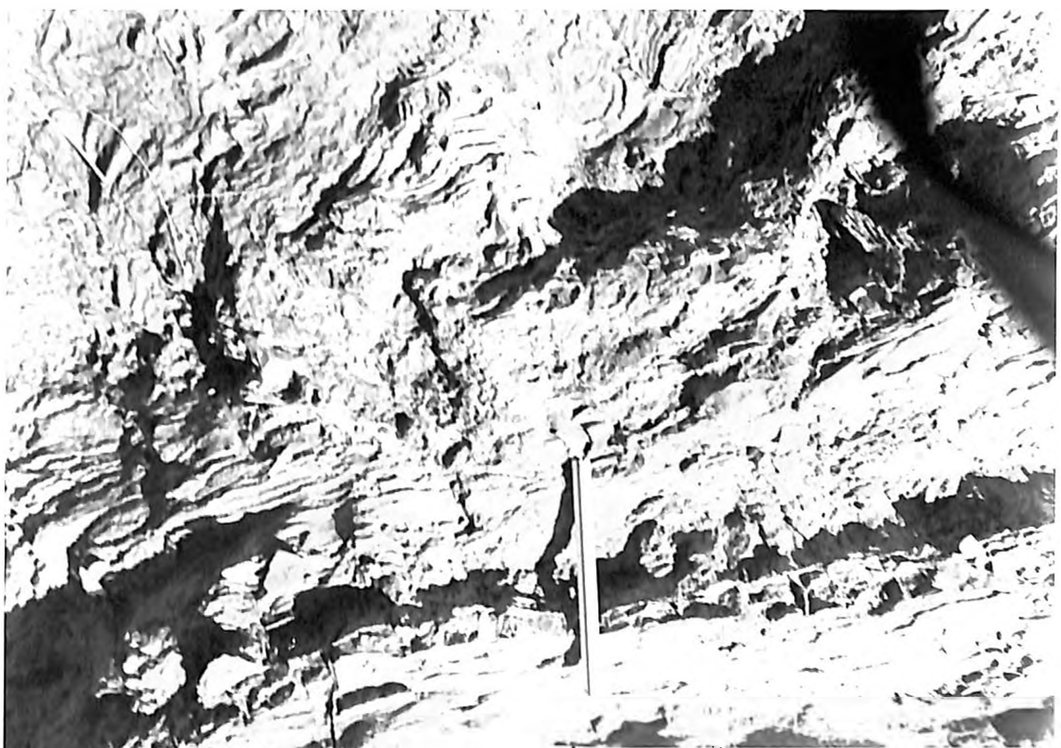


PLATE 18. The photograph shows extensive syn-sedimentary distortions of the beds which were probably caused by slumping within the thin-bedded mudstones at Mudaa school. Note the slump structures along the middle part of the ruler.

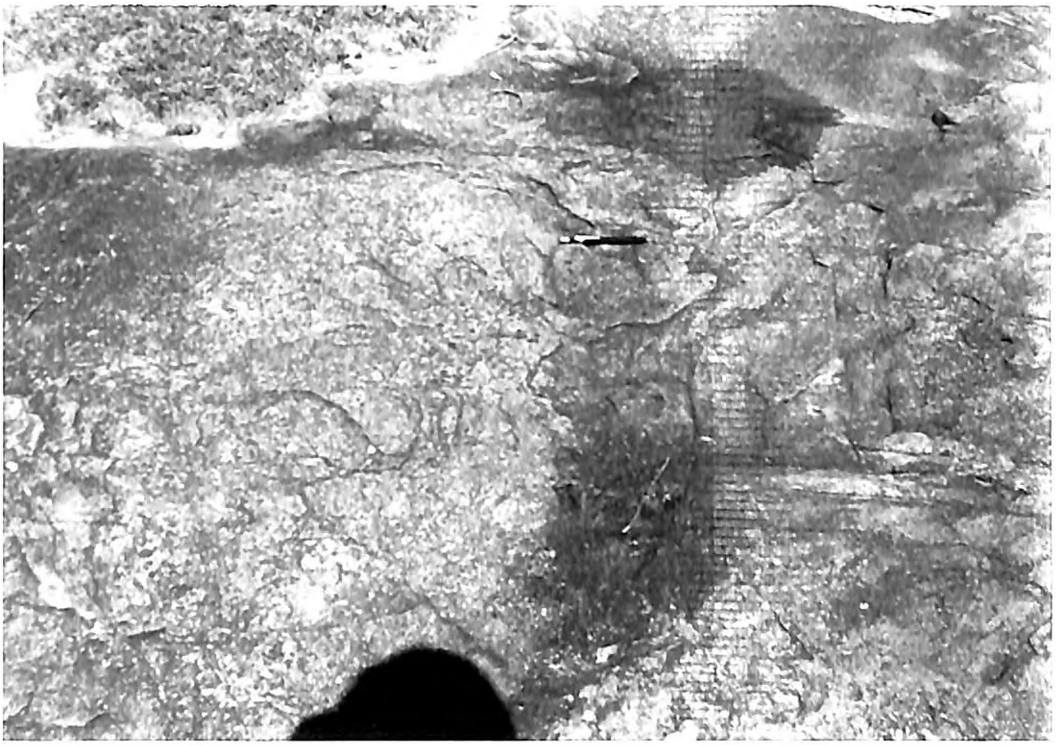


PLATE 19. The photograph shows elongated flute moulds on the greywacke beds near Muruada school. The flute moulds show the direction of sediment transport to be from left to right.

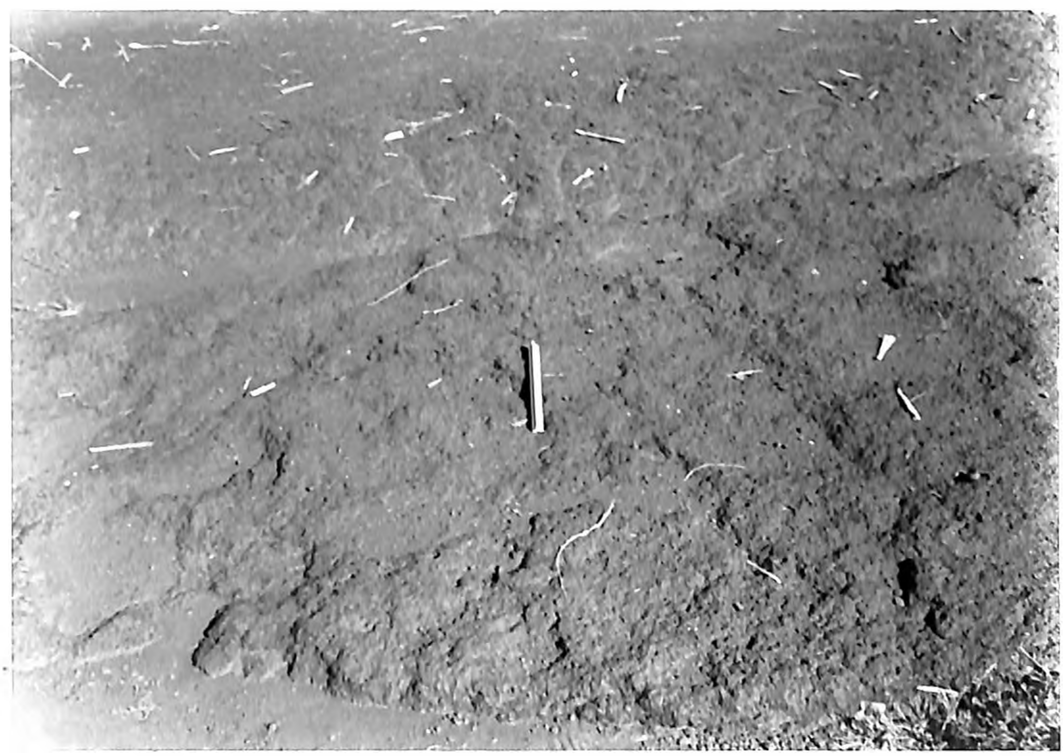


PLATE 20. The photograph shows load crested ripple marks with prod moulds found near Lidhabidha market. The sediment transport is from left to right.

PLATE 21. The micrograph shows a slump structure which after formation was filled by quartz (white). Such structures are common within the siltstones.

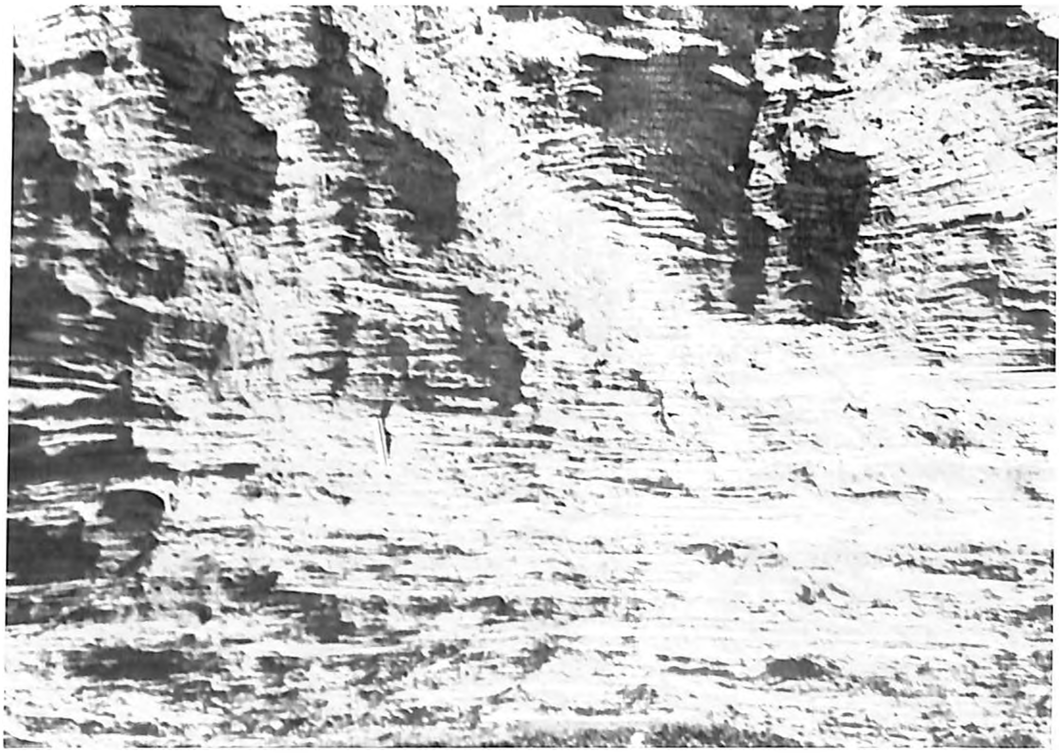


PLATE 22. The photograph shows laminated graded mudstone beds of turbidity origin. The bed shows assymetrical folding on the upper part. The outcrop was noted on the banks of the Edzawa river near Musalaba market.

PLATE 23. The photograph shows cyclic sedimentation of siltstone (light in colour) and mudstone (darker) at Yala river bank near Kwisero. Thse are probably deposits of dilute turbidity currents.

The term "slump structures" has been widely uncritically used (Potter and Mast, 1963) to describe structures, some of which are completely dissimilar and certainly not due to slumping. The term, however, includes all the penecontemporaneous deformation structures which are caused by the movement and displacement of already deposited sediment layers under the action of gravity.

Slump structures may also be attributed to rapid sedimentation which occurs in unstable sedimentary basin due to slope gradient and the nature of sediments being deposited in the basin. During the slumping, beds are broken and transported into a new environment, where they form disordered mixtures of lithologically different types of fine sediments. In the process, sediments become contorted and syn-sedimentary faults and fractures are formed (see Plates 9, 17 and 18). The structures are commonly formed within the sand-mud admixtures during the early stages of sedimentation. According to Dzulynski and Walton (1965), syn-sedimentary faults are formed shortly after deposition when the sediments are still fluidized due to the dilatant behaviour of sand. In western Kenya, however, slump structures especially open tensional fissures and syn-sedimentary faults were apparently produced through plastic deformation. The deformation was due to shearing effect of tools pushing over and prodding into the already deposited, cohesive, closely packed sandy layers (see Plate 26).

4.4.2.4 Graded Bedding

Graded bedding is the most common feature in the study area. Reineck and Singh (1973) defined graded bedding as the boundaries of sedimentation units which are characterised by gradation in grain size from coarse at the base to fine at the top of the unit. This type of bedding is common on outcrops along the Yala river especially on greywacke formations.

On most outcrops, graded bedding is cyclic. One bed may display B, C and E Bouma divisions and then the next bed may display A, C and D divisions. On the massive outcrops, grading occurs only once (see Plates 22 and 23).

Graded bedding may result from successive increment of material each of which is finer than the preceding one. Sometimes when there were no fine sediments at the base of the bed, sedimentation may have resulted from rapid decrease in velocity and competence of the transporting fluid.

In the study area, graded bedding apparently has been formed as a result of suspension deposition during which different sizes of grains were carried in fluid and deposited slowly by gravity action. During the process, the mean grain size of the sediments decreased upwards and the sorting improved.

4.4.2.5 Flaser Bedding

These are sand cross-beds which contain numerous intercalations of mud flasers. The structures are best observed one kilometre east of Shikunga market. The origin of the structures is related to the alteration of current action and slack water movements. During the periods of high current activity, sand and silt were transported and deposited as ripples while mud was held in suspension. When the current paused, the mud in suspension was segregated due to hydraulic difference and deposited in the ripple troughs (see Plate 24). During the next sedimentation episode, ripple crests were eroded away and the new sand was deposited in form of ripples which covered the previously formed ripple beds which contained flasers in the troughs. The structures which resulted from this kind of sedimentation are concave upwards when they occupy the ripple troughs and concave downwards when they overlie the ripple crests.

4.4.2.6 Longitudinal Furrows and Ridges

Longitudinal furrows and ridges are found three kilometres east of Yala bridge on Kakamega-Kisumu highway. The structures are composed of closely continuous ridges which alternate with furrows. The wavelengths of the ridges do not usually exceed eight centimetres. According to Dzulynski and Walton (1965), parallel ridges are caused by the flow of sediment suspension in stringers which are arranged longitudinally to the moving fluid. Each stringer moves in form of two helical spirals. In the course of fluid motion, scouring occurs along the stringers and the eroded material is piled up on the sides in form of longitudinal ridges. While some of the ridges and furrow structures have been formed through the above process, most of the ridges and furrow structures in western Kenya have been formed during the current flow. The intensity and the velocity of the current flow combine to initiate bifurcation of the ridges. Higher current velocities produce straight parallel ridges while lower velocity currents produce coelescent ridges which converge at high angles. When the current is very slow, the ridges formed often curve around minor irregularities (see Plates 24 and 25).

4.4.3 Secondary Structures

4.4.3.1 Introduction

The Kavirondian Group is composed of a series of isoclinal folds which are steeply folded into the surrounding younger granitoid plutons and the Nyanzian volcanic rocks. The Kavirondian sediments whose strike planes (Fig. 10) are approximately east-west have been folded from north to south and the axial surfaces of the folds

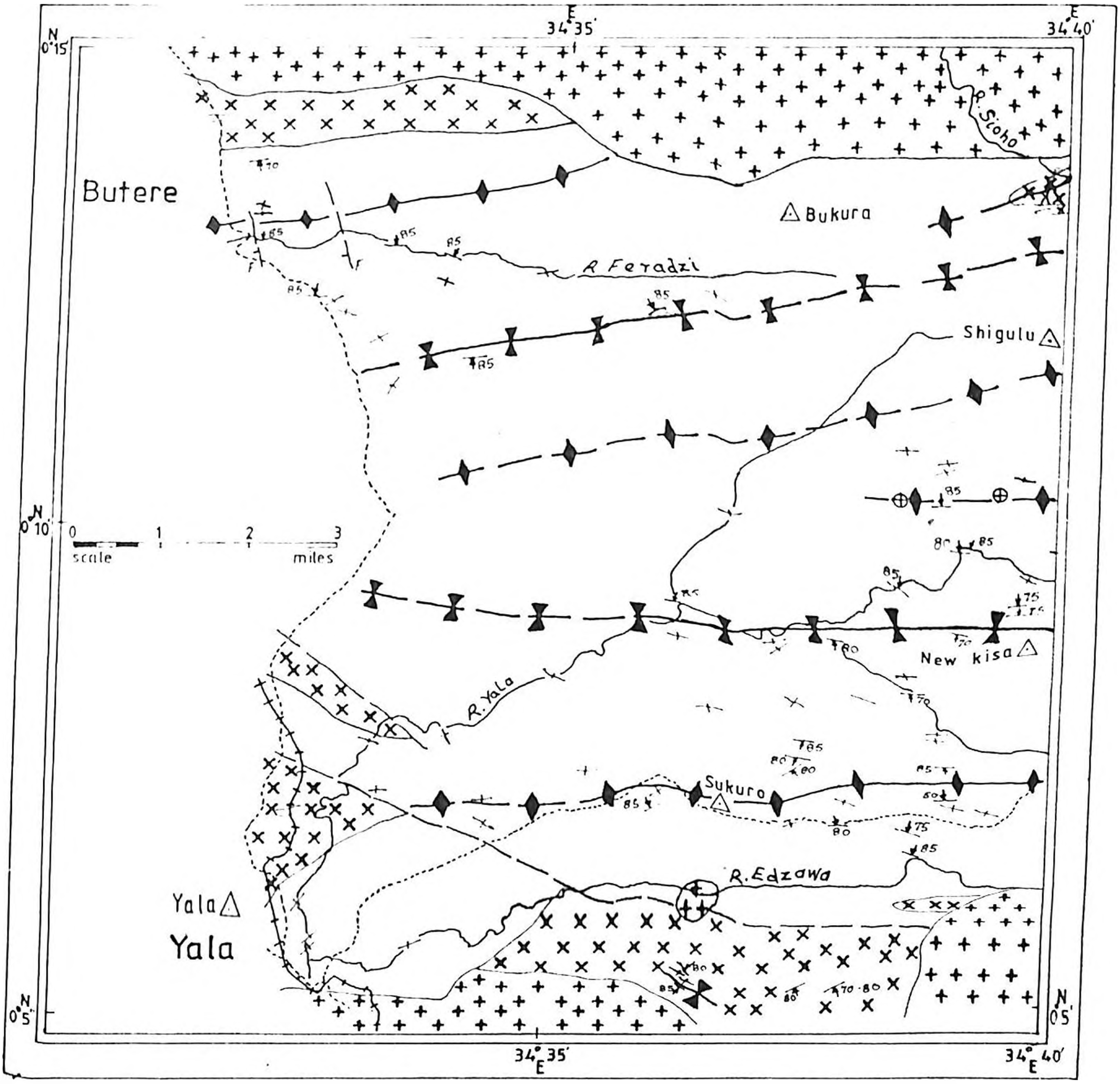


Fig 10 Sketch map showing tectonic features in Eastern Marama and adjoining areas (After Pulfrey, 1945)

Major Intrusives

Nyanzian Volcanics

Anticlinal axes

Synclinal axes

Inferred faults, tick on downthrow side

Strike & Dip (degrees)

Strike of vertical beds

Horizontal beds

Major road

Railway

PLATE 24. The photograph shows assymetrical ripple marks in siltstone at New Kisa. The direction of sediment transport was from right to left.

PLATE 25. The photograph shows oblique ripple waves and obstacle scour marks (dark brown) on mudstone outcrop near the town of Luanda. The scour marks are especially concentrated behind the pencil.

are from east to west. The angles of dip range from about 45^0 to 65^0. Most of the isoclinal folds generally dip to the north.

Huddleston (1954) observed that there have been two episodes of deformation within the Nyanzian shield which preceded and succeeded the Kavirondian sedimentation. During the earlier episode, Nyanzian volcanic rocks were faulted and folded alone while during the second episode, the Nyanzian volcanic rocks and the Kavirondian sediments were folded together. This observation agrees with the radiometric data by Cahen and Snelling (1984) who gave the age of 2,800 Ma for the post Nyanzian Masaba granite. The age represents the upper age limit of the post Nyanzian orogeny during which Nyanzian rocks were extensively deformed and folded. The second episode occurred around 2400 Ma and probably marks the upper age limit of the post Kavirondian Orogeny.

During the earlier episode, the Nyanzian rorks were folded prior to the deposition of the Kavirondian sediments. Data obtained during this study indicate that the denudation of the Nyanzian volcanic rocks and the Na-rich granites largely contributed to the availability of coarse and fine grained members of the Kavirondian sequences. During the second episode, the Kavirondian sediments which had by now been deposited, were folded along with the underlying Nyanzian volcanic rocks and thrown into a series of steep isoclinal folds whose axial surface followed an east-west direction. In the Butere area, however, sediments were overfolded thereby swinging the strike from east-west direction to north-west-south-east direction.

In the South Nyanza area, structures of the Kavirondian sediments are difficult to elucidate because of the poor exposures. Huddleston (1951), however, observed that south of Kitere granite where few Kavirondian sediments are exposed, almost all the formations dip to the east or north-east and the dips are of 45^0 to 50^0 magnitude. The dips of the underlying Nyanzian volcanic rocks are usually about 70^0 to vertical and invariably dip to the north-east. The general strike of the Kavirondian sediments in the South Nyanza area is south-east - north-west (see Appendix C3).

4.4.3.2 Faults

Faults mapped in the study area are mainly normal faults although Pulfrey (1945) and Huddleston (1951) reported a few upthrust faults in the Kakamega area. The most important characteristic of the faults in the study area is how they control the drainage system and the topography of the area. It has been noted (Odera and Winani, 1978) that in the Archaean terrane of western Kenya, there are numerous faults and most of the streams especially those underlain by the Kavirondian sediments are controlled by them. River Yala, for example, is fault controlled throughout most of its length. Based on their orientation,, the faults found in the study area can be broadly divided into three groups. There are those with an almost east-west orientation. There are others with a north-west - south-east trend and those with north-east - south-west trend.

The first group of almost east-west trending faults is represented by a major fault which extends for a distance of about six kilometres between Rihada and Kagiro Schools. The fault is inferred to be a strike slip oblique type whose slip is about two kilometres. The fault controls the valley of river Yala for a distance of four kilometres between Sianga shopping centre and the area around Lihanda at the confluence of the Mala and Yala rivers.

Another east-west trending fault extends for a distance of about fifteen kilometres from Mudaa School to Kimingini through Eregi College. This normal fault marks the zone through which the giant quartz vein is emplaced. The fault has its downthrow towards the south. Throughout the fault zone, extensive shearing and brecciation of mudstones and greywacke has been observed. The giant quartz vein is also extensively brecciated and this may imply reactivation of the fault after the emplacement of the vein. The fault also apparently controls the long profile of river Yala between Sabane and Lidambidha, a distance of about three kilometres. On this stretch, the river changes its course from north-east to east-west and then to north-east again.

The second group is represented by a major fault which has north-west to south-east orientation between Ulumbi and Shiatsala Schools, a distance of about ten kilometres. Throughout its length, the fault is indicated by brecciation, shearing and anomalous dips. This fault was also recognised by Pulfrey (1945). It is, however, difficult to tell whether this is a normal or a reversed fault although its effect on topography of the area suggests that the fault has its downthrow on the north-eastern side. Another fault in this group extends from Shitoli to Shinaboga School. The fault is about five kilometres long and for a distance of about two kilometres the fault controls the valley of a small stream which drains into Isiukhu river. On the northern side, this fault also controls the valley of Isiukhu river for a distance of about one kilometre. This is a normal fault which has its downthrow to the south west. Pulfrey (unpublished report, 1941) referred to this fault as Yaanamakour fault.

Another fault extends about four kilometres between Eshikumu and Bukura. This is a normal fault which forms a boundary between mudstone formation on the eastern side and conglomerate formation on the western side. The fault has its downthrow to the south-west. Finally, another minor fault extends for about two kilometres between Denesi and Ematsuri Schools. This strike slip fault is a post granite emplacement fault along which sediments have undergone a south eastward slip of about seventy metres. The fault controls the valley of river Edzawa for a distance of about one kilometre.

The third group of faults are those which have a north east-south west orientation. A major fault in this group is a thrust fault which lies along a section of Isiukhu river. The fault extends about two kilometres east of Mbesa market to a point which is about one kilometre north east of Shikulu market. The fault controls the valley of river Isiukhu for a distance of one and half kilometres.

4.4.3.3 Cleavage and Shearing

Kavirondian sediments often show mild fracture cleavage. This type of cleavage was mainly observed along the margins where granites and giant quartz veins intrude into the mudstone. Cleavage was also observed along the fault zones which pass through the mudstone formations. The strike of the cleavage is usually parallel to bedding planes. According to Pulfrey (1945), sometimes the cleavage strike changed in relation to bedding plane due to shufling of the finer grained sediments when folding was in progress. Fractional cleavage is well developed on a mudstone outcrop along the Yala river about five hundred metres west of the Yala bridge on the Kakamega-Kisumu highway. Mudstones in this area have turned into slates whose cleavage strike is east-west. Further west, near Shibunane, cleavage changes its strike to north-west - south-east. The change of the cleavage strike is attributed to existence of a mid-river valley fault whose trend is the same as the cleavage strike.

Shearing was also observed in the Kavirondian conglomerate formations at Shiduha, Sishehe, Matundu and Shitoli. In all these places sheared Kavirondian conglomerate pebbles occur along the fault zones. On these zones, shearing affects both the pebbles and the surrounding matrix. During the shear, pebbles were flattened and elongated along the direction of the shear strike. It is noted that in the Shivakala area, the westward direction of the shear strike approximately conforms with the trend of a thrust fault which occurs along the Koa river. The shear strike also conforms with the fold axes of the Kavirondian sediments.

In the South Nyanza area, only three post Kavirondian faults were recognised. The faults have no control over the drainage patterns of the area. The faults, however, largely control topography and it was observed that most of the feeder roads especially around Sony Sugar belt are constructed parallel to the faults. The first major fault recognised in the area is a normal fault which has a north west to south east trend. The fault extends from Kuroko School to Kanyimach School, a distance of about six kilometres. The fault separates the Nyanzian rhyolites and the Kavirondian conglomerate. The fault's down-throw is on the north-eastern side. The other major fault extends from Kanyamkago School to Karathing Church, a distance of about ten kilometres. This is a normal fault which separates the Kavirondian conglomerates on the south-western side and the Nyanzian andesites on the north-eastern side. The fault has its downthrow to the north east.

Another minor fault which is only about three kilometres long is found in the Kawere area. This is also a normal fault whose downthrow is to the north east. The fault also separates the Nyanzian andesites from Kavirondian conglomerates.

Shearing was not noted within the Kavirondian sediments of this area but

Huddleston (1951) reported shearing and dislocation in both the Nyanzian rhyolites and Kavirondian conglomerates along the valley of the Sare river.

4.5 Metamorphism

4.5.1 Introduction

In the central part of the sedimentary basin covered by this study in Kakamega area, there is a general retention of sedimentary structures. The nature of the metamorphic mineral assemblages suggests that metamorphism in this area does not exceed the lower greenschist level. It has, however, been observed that near the major intrusions, the degree of metamorphism is much higher. The commonest metamorphic minerals in the central zone which is away from the major intrusions include muscovite, chlorite, epidote and to a lesser extent, prehnite and actinolite. Graphite occurs sporadically with the mudstone facies. The occurrence of this type of graphite indicates that the mudstones belong to the greenschist metamorphic facies.

Three types of metamorphism have been recognised in the study area. They include thermal, hydrothermal and dynamic metamorphism.

4.5.2 Thermal Metamorphism

This kind of metamorphism is apparent near the major granite intrusions such as Mumias, Maragoli, Kitere and Wanjare granites. The metamorphism is therefore responsible for the metamorphic alterations exhibited by the Kavirondian sediments and the Nyanzian volcanic rocks which occur within short distances of the intrusions.

The most conspicuous thermal metamorphic effects were observed on the Kavirondian mudstones adjacent to Mumias and Maragoli granites. The mudstones have been thermally metamorphosed to form fine grained phyllite rock which occasionally shows incipient segregation banding of light and darker minerals. The schistosity planes which show satiny luster have developed as a result of abundant muscovite and chlorite. Epidotization has occurred in the areas of intensely compressed isoclinal folds. The metamorphic grade decreases as one moves further from the intrusion. Petrographic studies show that the sediments which occur on the granite-sediment contact are characterised by high temperature minerals while the sediments further away from the intrusion are characterised by low temperature mineral assemblages.

In the southern part of the Kakamega District, on the sandstone - Maragoli granite contact, hornfels have been observed close to Ibuvi intrusion. These are light in colour, fine-grained, massive rocks which are mainly composed of quartz, feldspars, biotite, muscovite and garnet. Andalusite, cordierite, garnet and vesuvianite occur as large porphyroblasts which are crowded by small inclusions.

Further away from the intrusion, occurs a spotted slate in which the textures of the parent rock are retained. The spots are largely chiastolite (see Plate 16) although some of them were found to be composed of clots of minute graphite flakes and clusters of minute magnetite grains. The rock also contains coarse mica flakes which show no regular orientation.

Pulfrey (1945) identified four metamorphic zones (Fig. 11) within the Kavirondian sediments. These zones are basically based on mineralogical changes within the sedimentary basin. Although most of the zones are continuous, some are indistinct and uncontinuous. The zones include the hornblende zone, biotite zone, spotted zone and chiastolite zone. Chiastolite zone mainly occurs within the phyl-

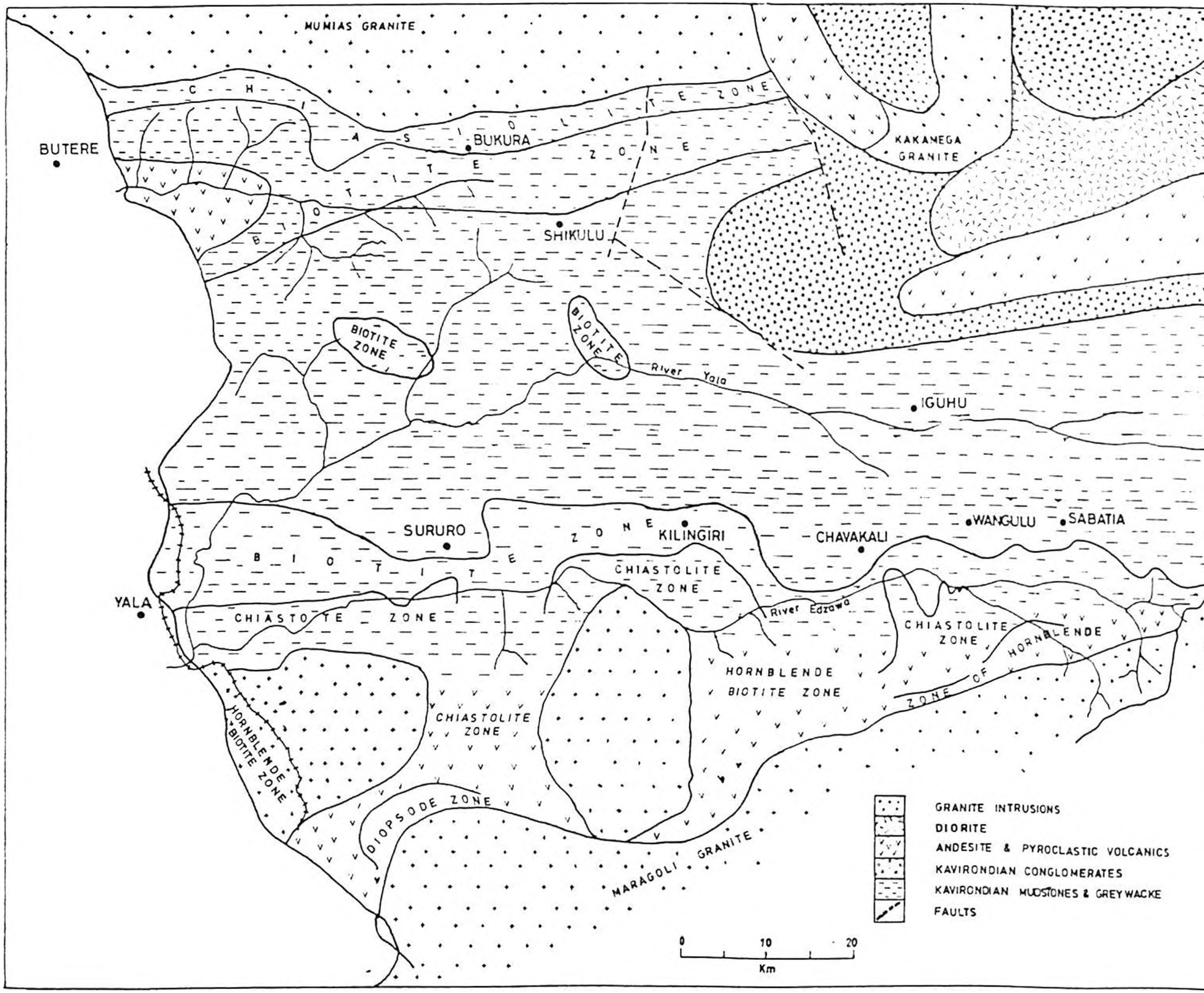


Fig 11 A SKETCH MAP SHOWING THE RELATIONSHIP BETWEEN THE MAJOR INTRUSIVES AND THE ZONES OF THERMAL METAMORPHISM
(After Pulfrey, 1945)

PLATE 26. The photograph shows slump structures some of which have been deformed by a gravity fault on the right hand side of the photograph. The structures are found in a mixed bed near Kisa market.

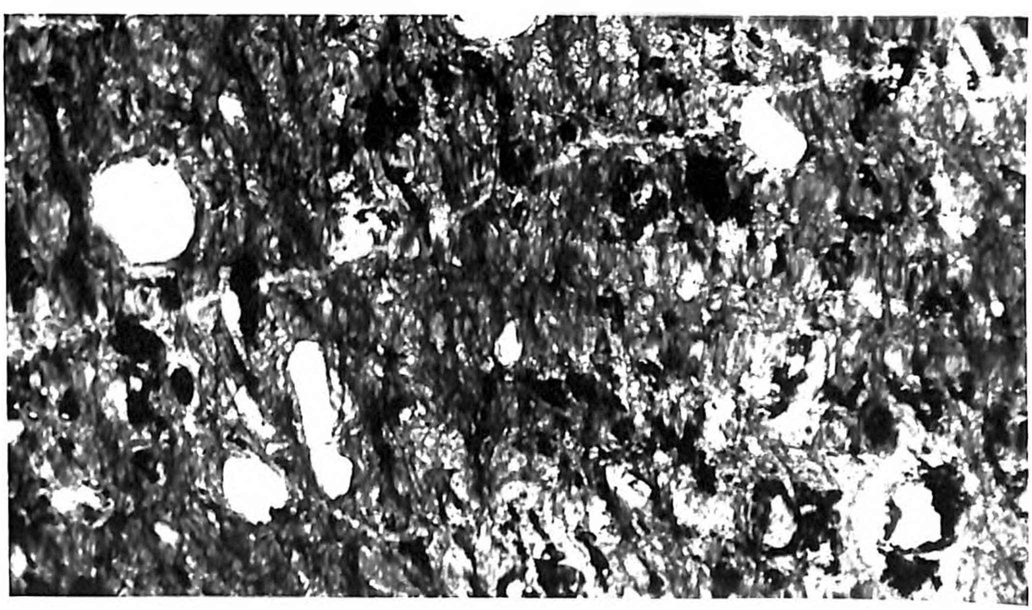


PLATE 27. The micrograph shows a sheared greywacke near the greywacke-granite contact. The slightly sheared quartz (white) are enclosed by sheared feldspars (dull white) and mafic minerals (dark) which form the groundmass.

litic mudstones. The phyllite contains small prisms of chiastolite which sometimes attains the size of two millimetres.

4.5.3 Hydrothermal Metamorphism

Although this kind of metamorphism has been observed on the contact between granite and the sediments, its main effect was observed on the contact between giant quartz veins and mudstones at New Kisa.

The mudstones were apparently affected by hydrothermal solutions which had been separated from the silica rich magma. The mudstones affected by this kind of metamorphism are fine grained micaceous rocks which occasionally show segregation layering. Minerals such as mica and chlorite are noticeable and they impart a satiny luster to the surface of schistosity. The rocks have a light brown colour which make them look like they are baked. The mudstones near the intrusion are also intensively jointed. Further away from the giant quartz vein, the rocks are dark brown, massive and fine grained and their characteristic minerals include andalusite and cordierite.

The thin sections of sample wmn/102, wmn/103 and wmn/107 which were collected from the mudstone facies close to the giant quartz vein at New Kisa, show that cordierite occurs in the form of porphyroblasts which have irregular boundaries. Sometimes the mineral shows large inclusions of other minerals which appear like an irregular sponge. Cordierite crystals show a bluish tint and sector twinning. In some samples, most of the cordierite has altered into chlorite and sericite. Andalusite also appears as porphyroblasts which contain inclusions of quartz, biotite, graphite and chiastolite. Chiastolite appears as rhombic cross-sections with dark cruciform patterns which result from the concentration of included graphitic dusts which are symmetrically concentrated along the edges, centres and axial directions of the growing porphyroblasts (see Plate 27). As a result of metamorphic alterations, andalusite has changed to sericite. On sample wmn/103 which was collected very close to the vein, scattered subhedral crystals of sillimanite were observed. Mica, feldspars and quartz appear as tiny anhedral minerals which form the matrix. Feldspars are sometimes partially altered and their margins contain zones of kaolin and sericite. A few crystals of biotite and garnet appear as porphyloblasts. Some biotite crystals have been altered and show halos of magnetite and chlorite.

4.5.4 Dynamic Metamorphism

4.5.4.1 Introduction

Some metamorphic rocks have been formed by extreme milling and pulverising along a fault zone which runs along a small stream which is found four kilometres west of Mbale town. The greywacke rocks were affected by this type of metamorphism have resulted into mylonites and phyllonites.

4.5.4.2 Mylonites

The rocks were formed by extreme milling and pulverization along a fault zone. The fault traverses across the greywacke formation and passes into the Maragoli granite. These rocks are generally fine grained but in some places they contain some scattered lenses of uncrushed parent rock. The lenses form "cat eye structures" which are elongated parallel to the flow structures. Mylonites are characterised by flow bands and each band is marked by a different colour, granularity and mineralogical composition from the next band. The sequences are marked by light coloured mineral band followed by dark coloured mineral band. The rocks are compact, hard and show no signs of recrystallization.

4.5.4.3 Phyllonites

These are fine grained, highly foliated rocks whose fine texture is derived from the brecciation of coarser grained rocks. The foliation normally results from closely spaced shearing. The rocks mainly occur between Wamage and Mulundu Schools where a minor shear zone about four kilometres long was recognised.

The thin sections of rock samples which were collected in this area show much sericite which occurs on the margins of bent and broken plagioclase. The rock contains low grade metamorphic minerals which include chlorite, sericite and graphite. Other minerals which occur as scattered crystals include andalusite, staurolite, garnet and biotite. Ichangi (1983) reported effects of dynamic metamorphism on the contact between Mumias granite and the country rocks where the rocks resemble augen gneisses and the feldspar and biotite crystals are elongated in one direction. This characteristic is usually more pronounced on the intrusion side of the contact at Kima mission.

4.6 Summary

The Kavirondian Group is composed of four formations. The four formations proposed in this study are from the lowermost in the succession, the Shivakala Formation, Igukhu Formation, Mroda Formation and Mudaa Formation which is stratigraphically highest in the succession.

The rock succession proposed for the Kavirondian Group in this work cannot be compared with other successions proposed by previous workers in the study area. Comparisons are not possible because previous workers proposed successions for all the rocks of the Nyanzian Shield and did not limit themselves to the lithostratigraphy of individual groups such as the Kavirondian.

Lithostratigraphical correlation of arenites and lutites is not possible because of their gradation from one facies to the other, intertonguing and thinning out to form lenticular bodies. Litho-correlation of the lutites was however possible.

In the study area, the primary structures which were apparently deposited as a result of instability in the basin of sedimentation were observed. These pre-consolidation structures include soft sediment intrusions, soft sediment mixing structures, pre-consolidation folds, graded bedding, flaser bedding and longitudinal furrows and ridges. Most of these structures are characteristic of turbidite or flysch deposits.

In most of the study area, the sediments are isoclinally folded. The fold axes of these isoclinal folds are approximately east-west. The strikes of the sediments over most of the studied area are also approximately east-west. Most of the dip measurements taken within the sediments are within 45^0 to 65^0. The faults encountered in the study area are mainly normal faults. The faults largely control the present river valleys.

On the Proterozoic granite margins, the Nyanzian and the Kavirondian rocks have undergone thermal, hydrothermal and dynamic metamorphisms. The effect of these metamorphisms is best observed on the Kavirondian mudstones which are close to the granite margins. Such mudstones have turned to phylonites and phyllites.

Chapter 5

GEOCHEMISTRY, GEOCHRONOLOGY AND PROVENANCE

5.1 Geochemistry

5.1.1 Introduction

In this section of the chapter, the results of geochemical analysis of the rock samples obtained from the outcrops of the Kavirondian Group sediments are presented. The rock samples include granitic boulders and pebbles, volcanic rocks pebbles, matrices of boulders and pebbles, greywackes and mudstones.

5.1.2 Conglomerate Pebbles

Conglormerate pebbles and their matrices in the study area are derived from granitic, volcanic and re-sedimented rocks. The pebbles are sometimes homogeneous but most often they are elongated, flattened and stretched along the direction of schistosity of the matrices. The chemical integrity of the sediments has often been retained as is indicated by the sharp boundaries between the pebbles and the matrices. This chemical integrity implies that only very mild or no reaction has taken place between the pebbles and the matrices.

The normative Or-Ab-An ratios of the pebbles (Fig. 12) show that most of the granitic pebbles are tonalitic and trondhjemitic in composition. Rocks of adamellitic and granodioritic affinities contribute minimally to the conglomerate composition. The modal compositions of K-feldspar - plagioclase - quartz ratios (Fig. 12) show that the granitic pebbles are mainly composed of quartz and plagioclase and the ferromagnesian minerals content of these pebbles varies from locality to locality. Granitic pebbles found near Shivakala, have comparatively more ferromagnesian minerals than the granitic pebbles found at Regea hill near Yala town.

On the ternary diagram (Fig. 13), it is observed that most of the granitic pebbles fall within the calc-alkaline field. This chemical trend has also been observed in the early Proterozoic granitoids and therefore the older granitoids (>2,600 Ma) and the younger granitoids (<2,500 Ma) evolved from magmatic sources which were relatively similar.

The variation diagrams (Fig. 14a-n) on which silicon oxide is used as a differentiation index show that sodium oxide, potassium oxide, iron oxide, magnesium oxide, calcium oxide and titanium oxide have negative correlations. Aluminium oxide shows a weak negative correlation in which aluminium enrichment decreases with the increasing silica. Athough the phosphorus pentoxide is strongly depleted in granitic pebbles it shows a gradual positive correlation in relation to silicon oxide. Depletion of phosphorus pentoxide in granitic pebbles suggests that the original rocks contained little apatite which would otherwise have influenced phosphorus pentoxide enrichment.

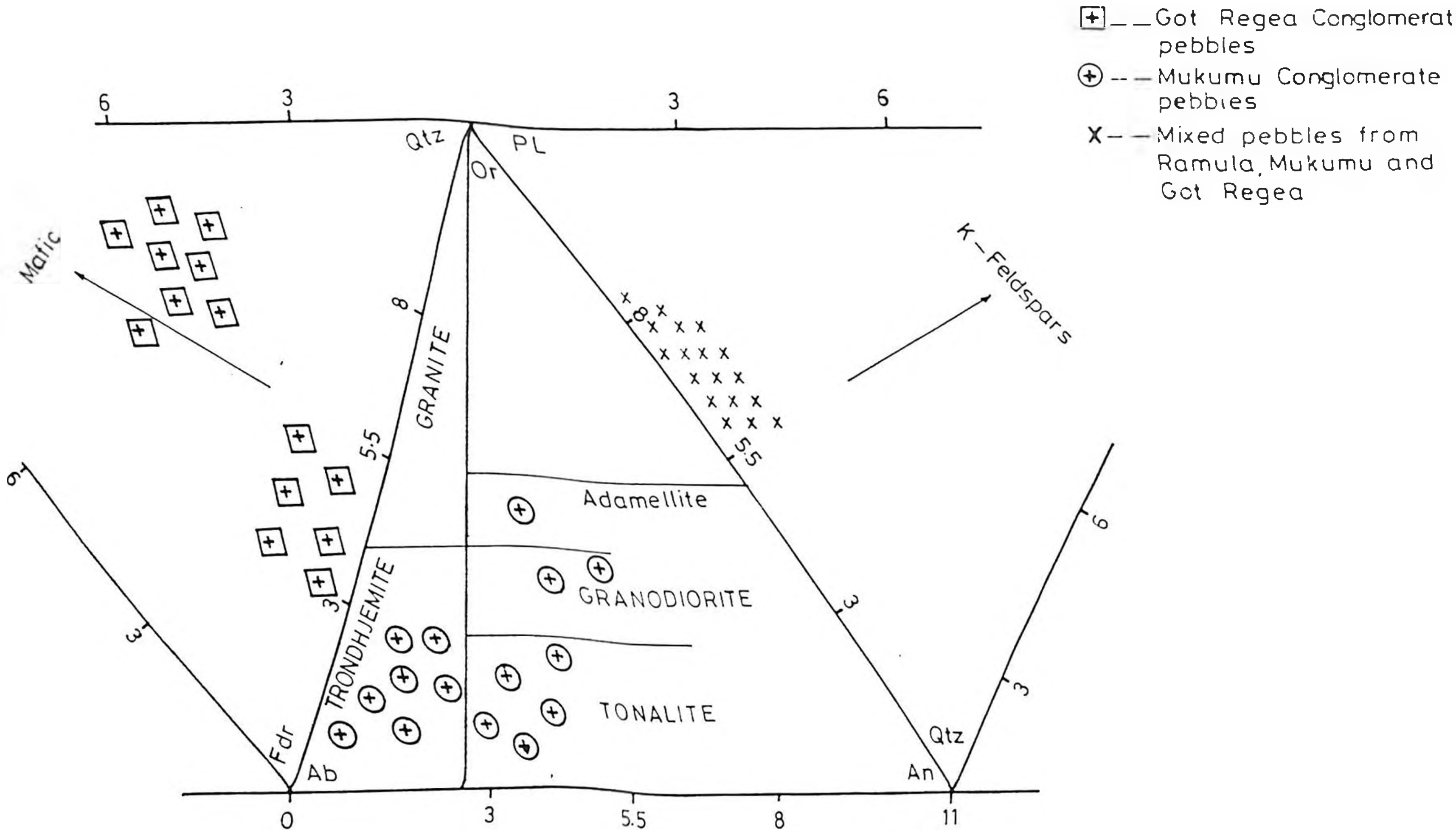


Fig. 12, Ab-or An (normative), b, Feldspar-quartz-mafics (normative) and plagioclese-quartz-K-feldspar modal composition of Conglomerate pebbles Ab-or-An ternary diagram is adopted from Glikson 1972.

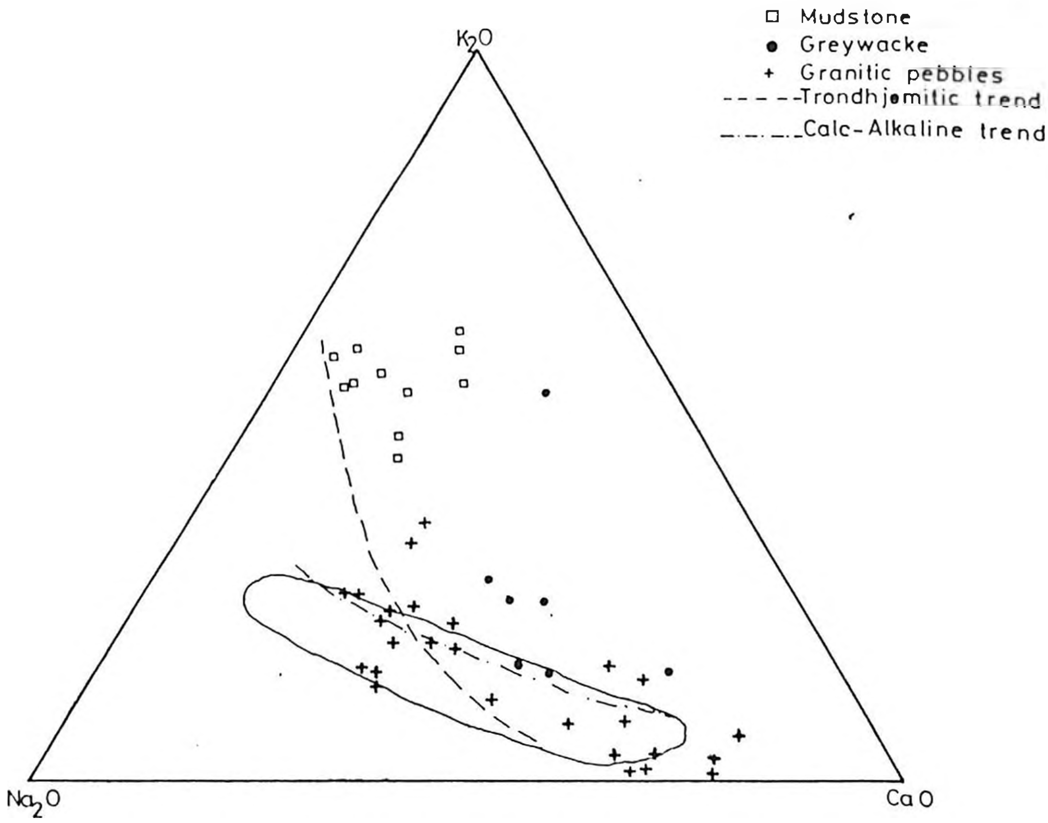


Fig. 13 Ternary compositional diagram showing the Calc-alkaline and troudhjemitic trends of the granitic pebbles within the Kavirondian sediments.

The binary plots of the trace elements contained in the granitic pebbles (Fig. 14i-m) show that rubidium, strontium and zirconium are generally scattered and show weak positive correlations in relation to silicon oxide. Similary, barium and yttrium show a weak positive correlation and the two elements are strongly depleted in the pebbles. The low barium and yttrium values are attributed to their early entry into potassium ion sites of the feldspars.

The compositional nature of volcanic pebbles is shown in potassium oxide versus silicon oxide (Fig. 15) in which it is observed that the pebbles are mainly derived from dacites, rhyodacites, rhyolites, andesites and basalts. These rocks were derived from both calc-alkaline and tholeiitic magmas. Basalts follow a tholeiitic trend with only a few samples plotting in the calc-alkaline field. They are generally strongly depleted in potassium and this indicates that during the alteration of hornblende to biotite, only a limited increase in potassium occurred. The andesites and dacites follow a calc-alkaline trend which is characterised by medium potassium content while rhyolites show a wide range of dispersion.

On (Fig. 16a-h) zircon has been used as fractionation index of volcanic pebbles because of its relative immobility during alteration (Turney et al., 1979) and due to its incompatible behaviour in most magmatic systems. It is observed that iron and titanium show a wide dispersion and negative correlation with the increasing zircon. A similar wide dispersion is indicated in the relationship between silicon oxide and zircon (Fig. 16d). The elements chromium, nickel, and calcium show positive correlation with increasing zircon. Vanadium show both weak positive correlation and a wide dispersion with increasing zircon. Like vanadium, strontium is widely dispersed and it also shows a positive correlation. The wide dispersion in most of the elements is attributed to mixing of pyroclastic ejecta which contributes

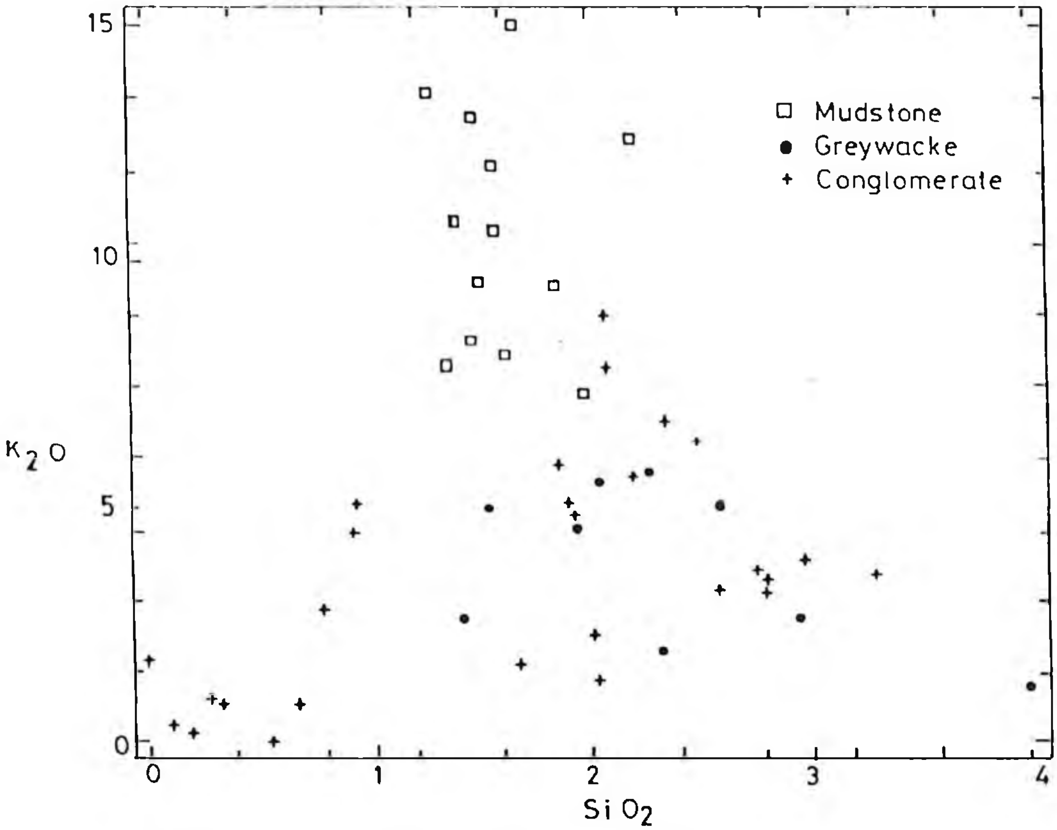
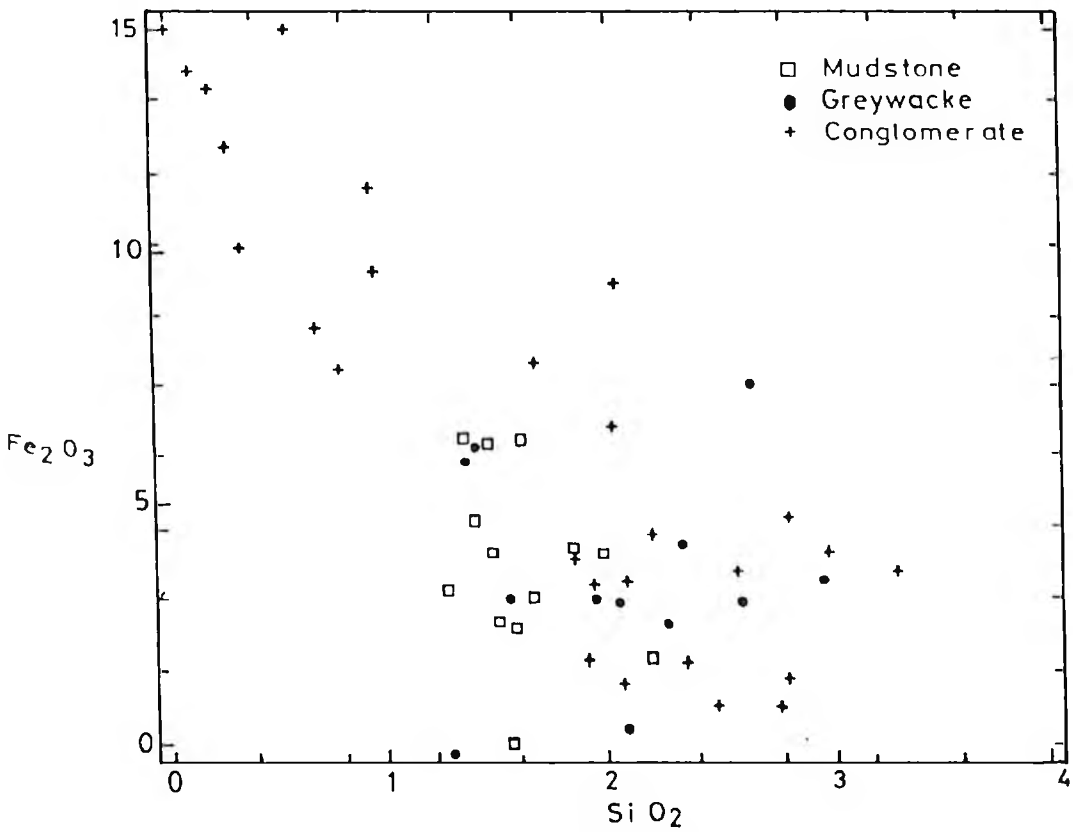


Fig.14(a) Plot of K_2O verses SiO_2



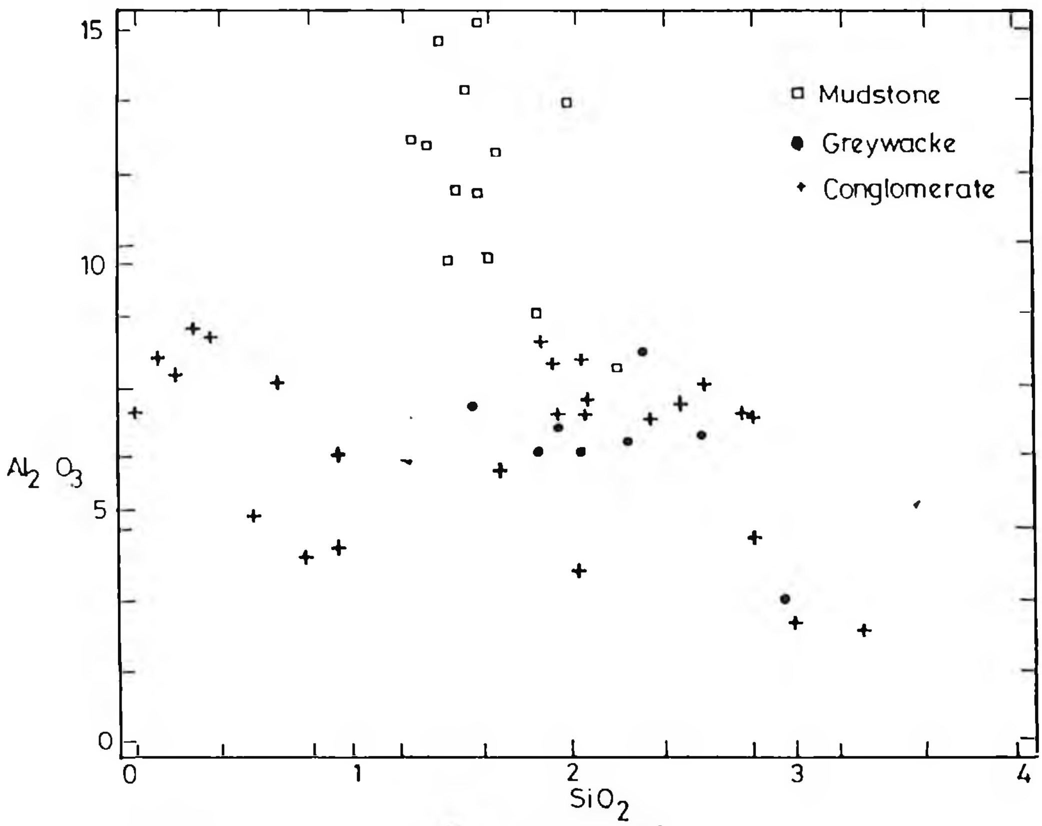


Fig. 14 (c) Plot of Al_2O_3 verses SiO_2

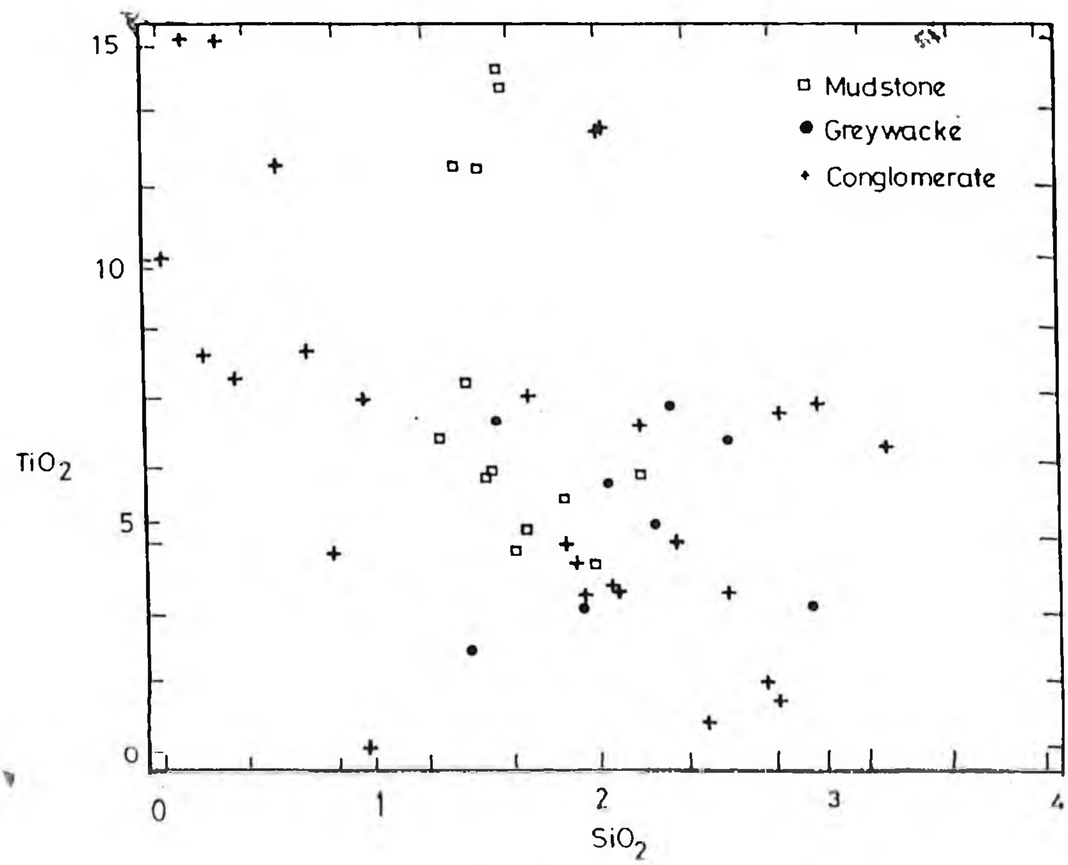


Fig. 14(d) Plot of TiO verses SiO_2

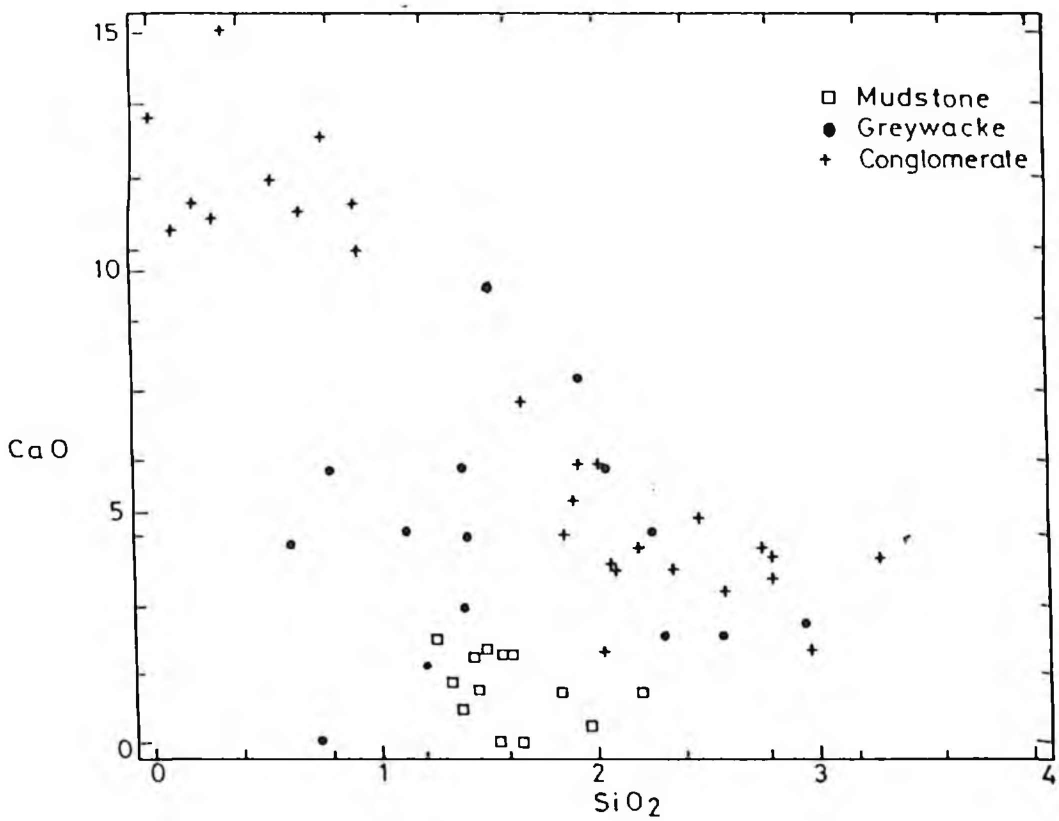


Fig.14(e) Plot of CaO verses SiO_2

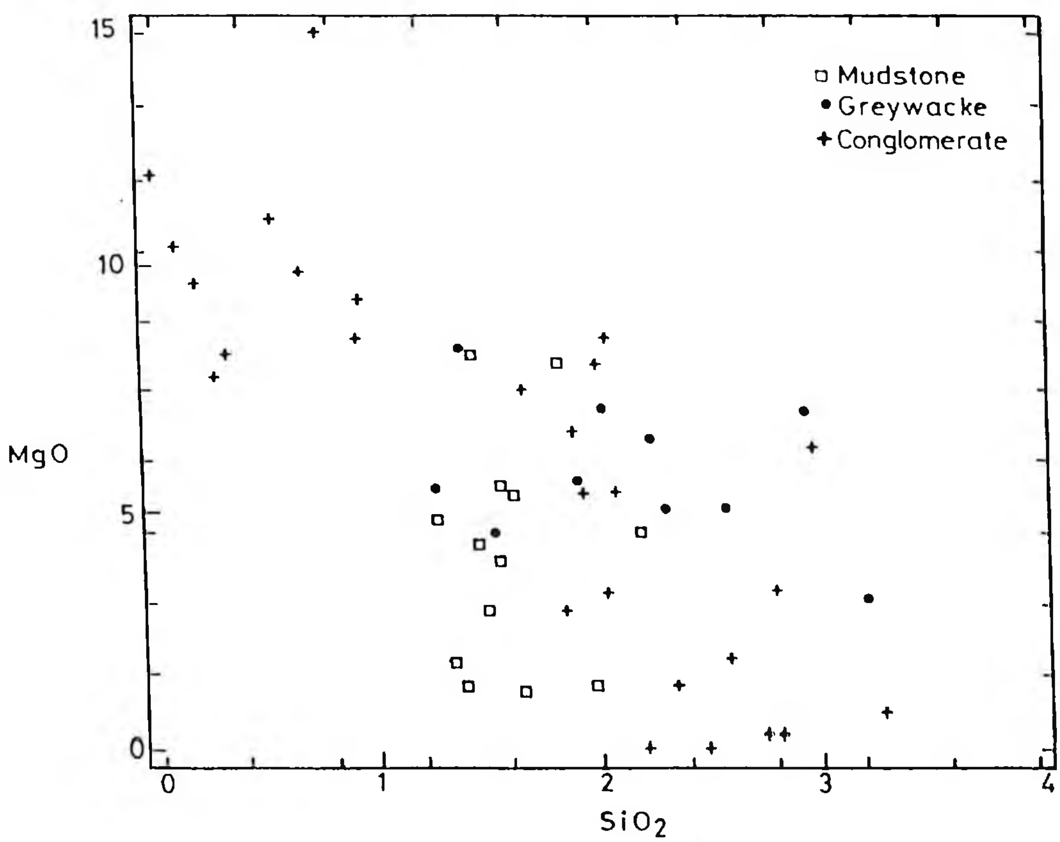


Fig.14(f) Plot of MgO verses SiO_2

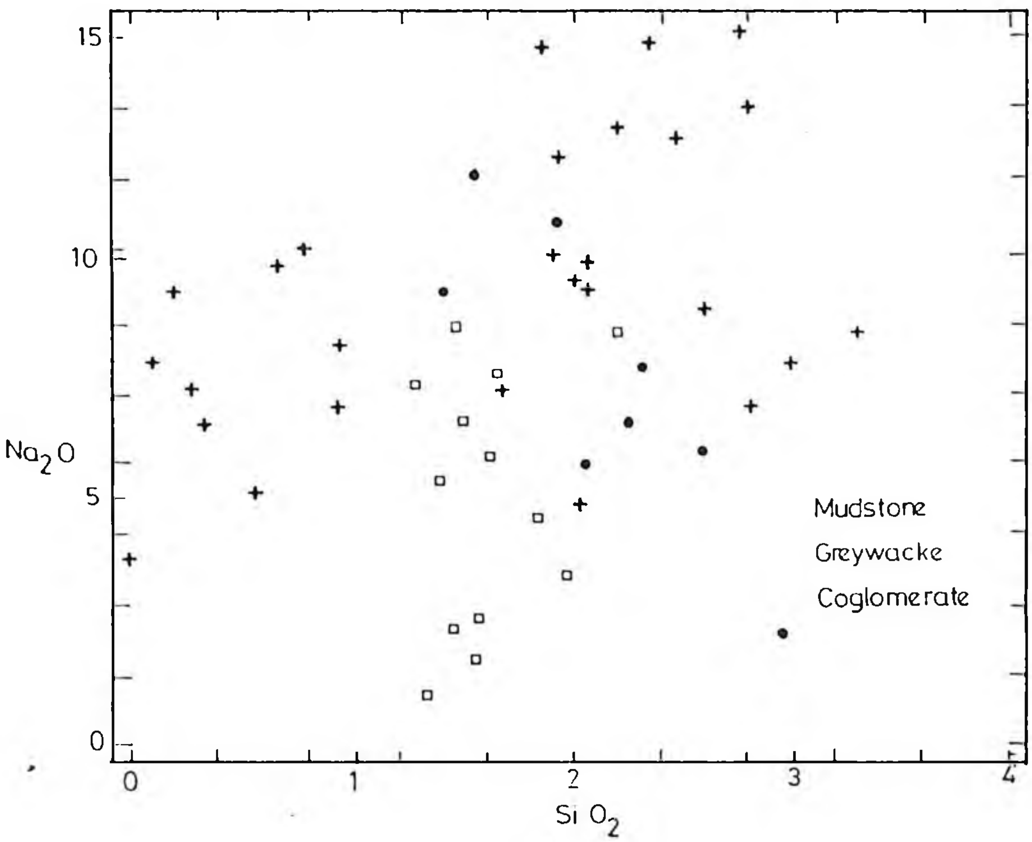


Fig.14(h) Plot of Na_2O verses SiO_2

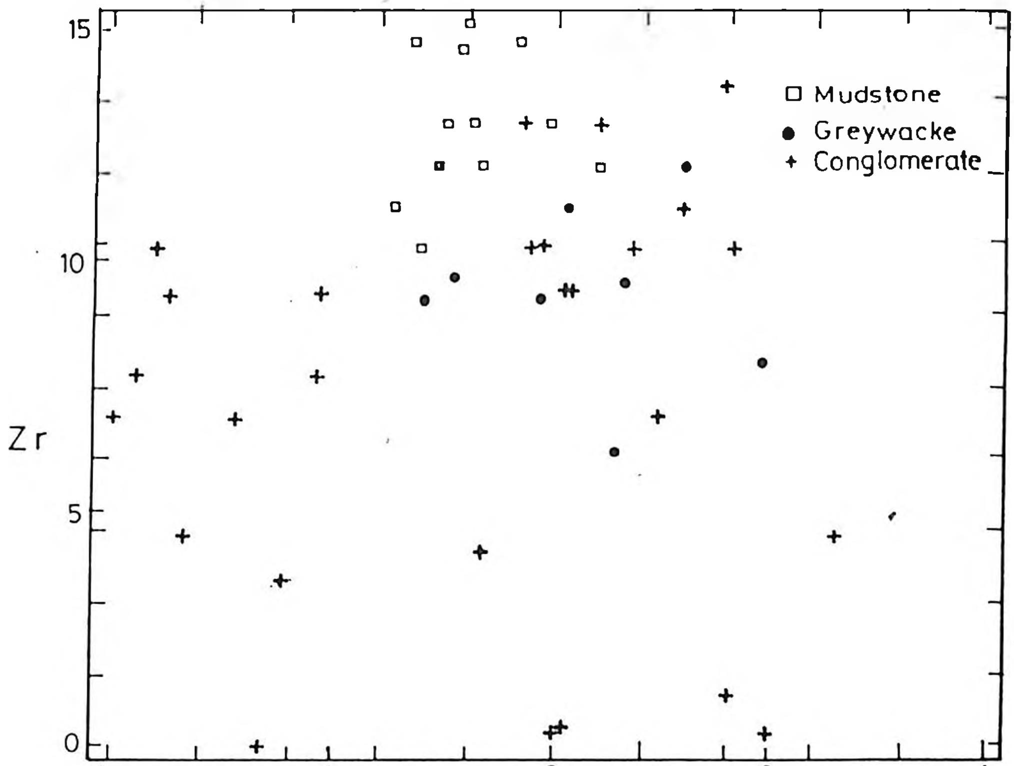


Fig 14(i) Plot of Zr verses SiO_2

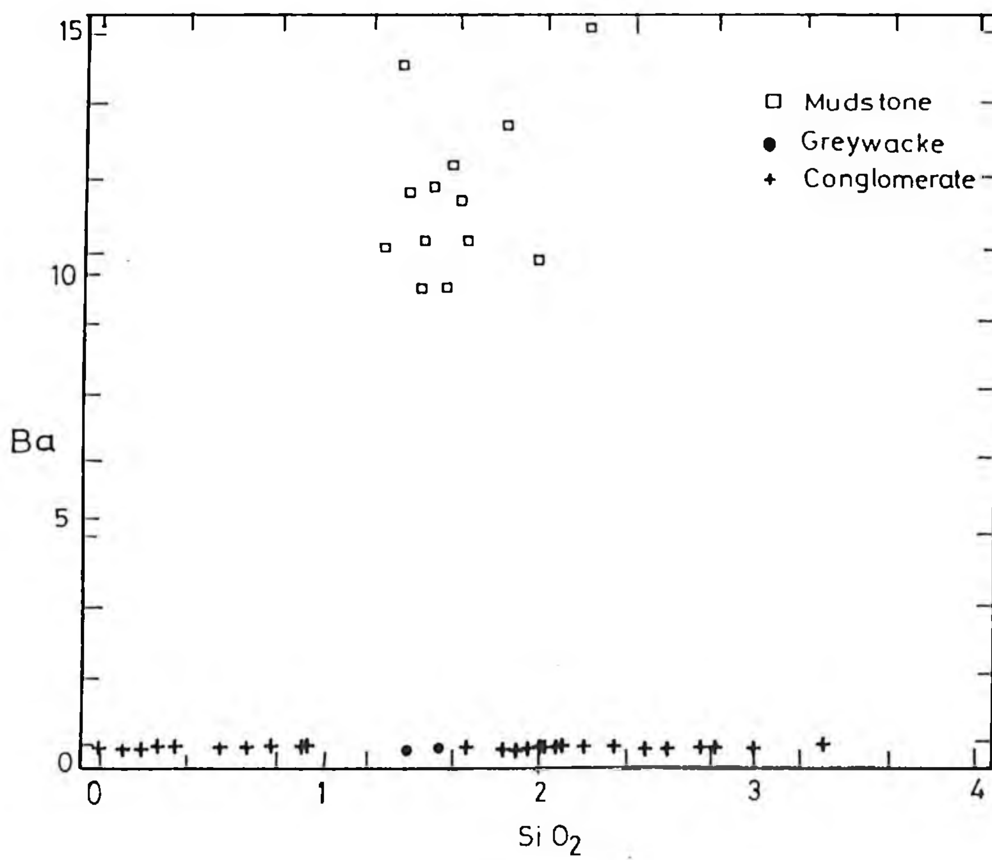


Fig. 14 (j) Plot of Ba verses SiO_2

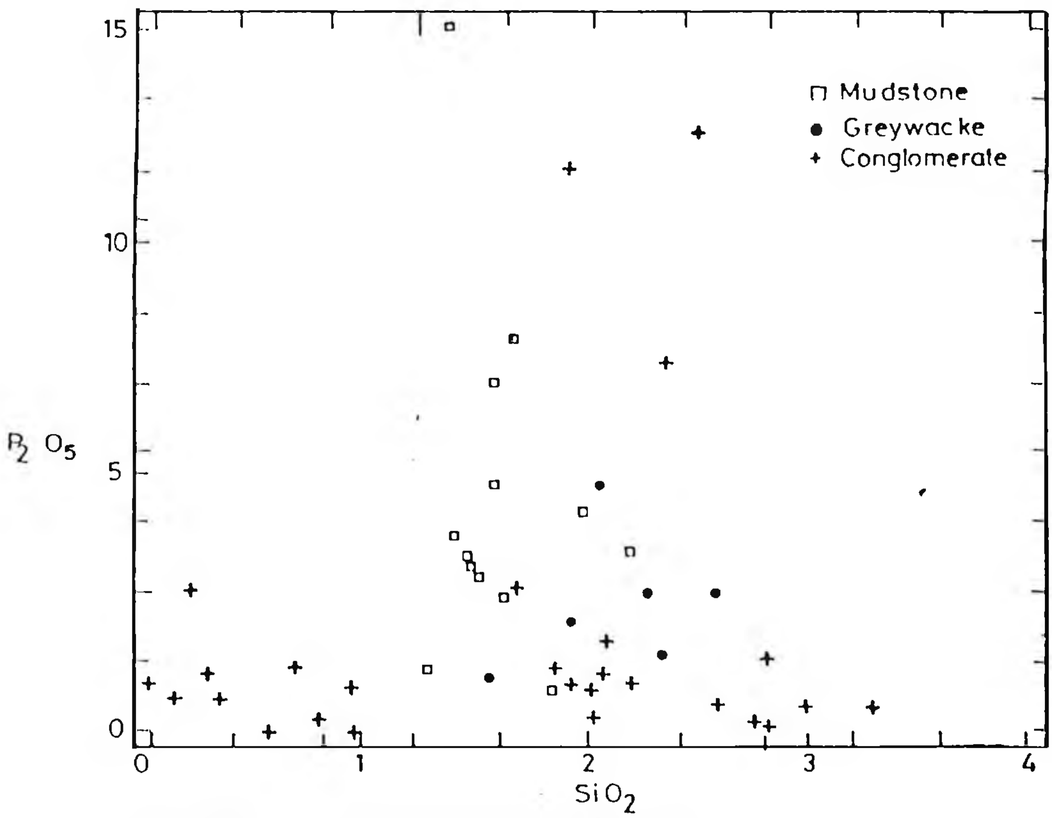


Fig.14(k) Plot of P_2O_5 verses SiO_2

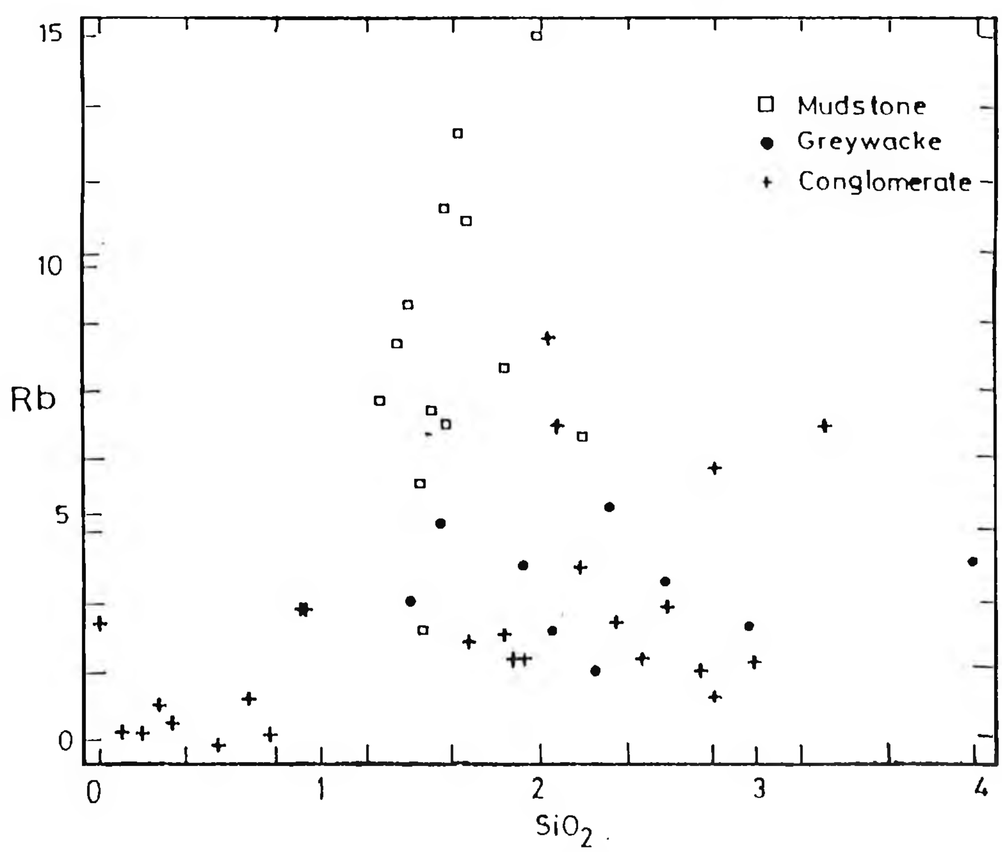


Fig. 14(l) Plot of Rb verses SiO_2

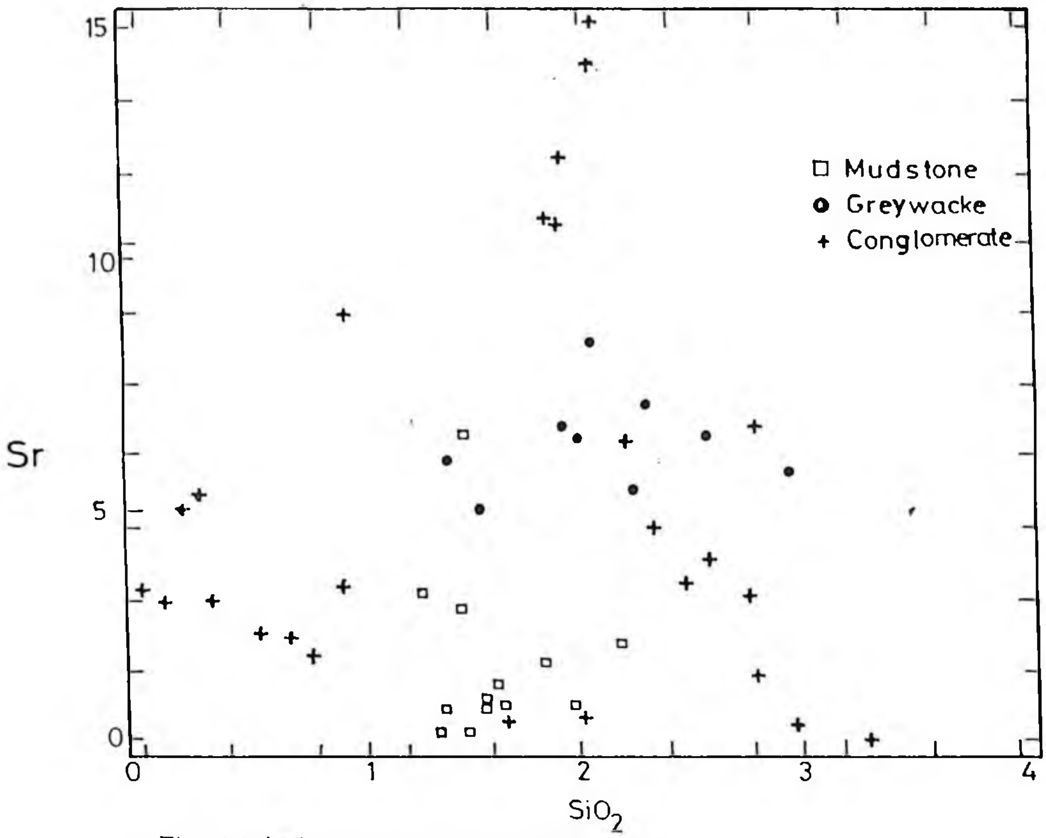


Fig. 14 (m) Plot of Sr verses SiO_2

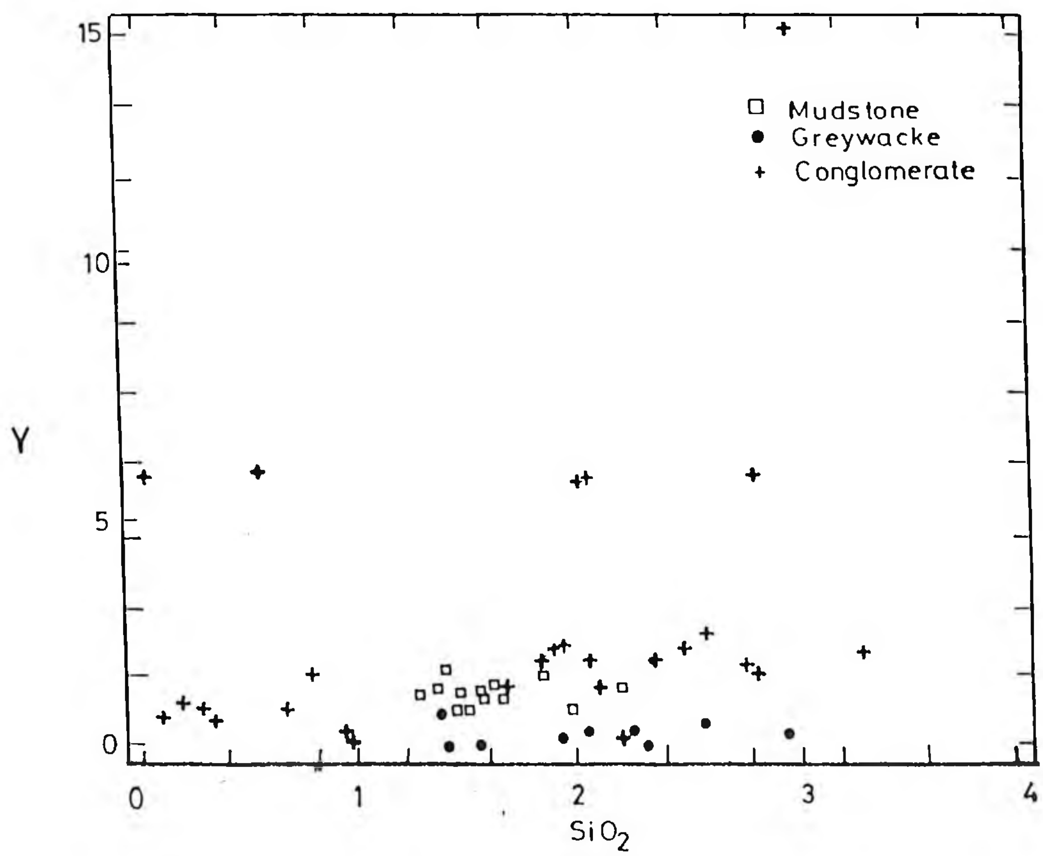


Fig. 14(n) Plot of Y verses SiO_2

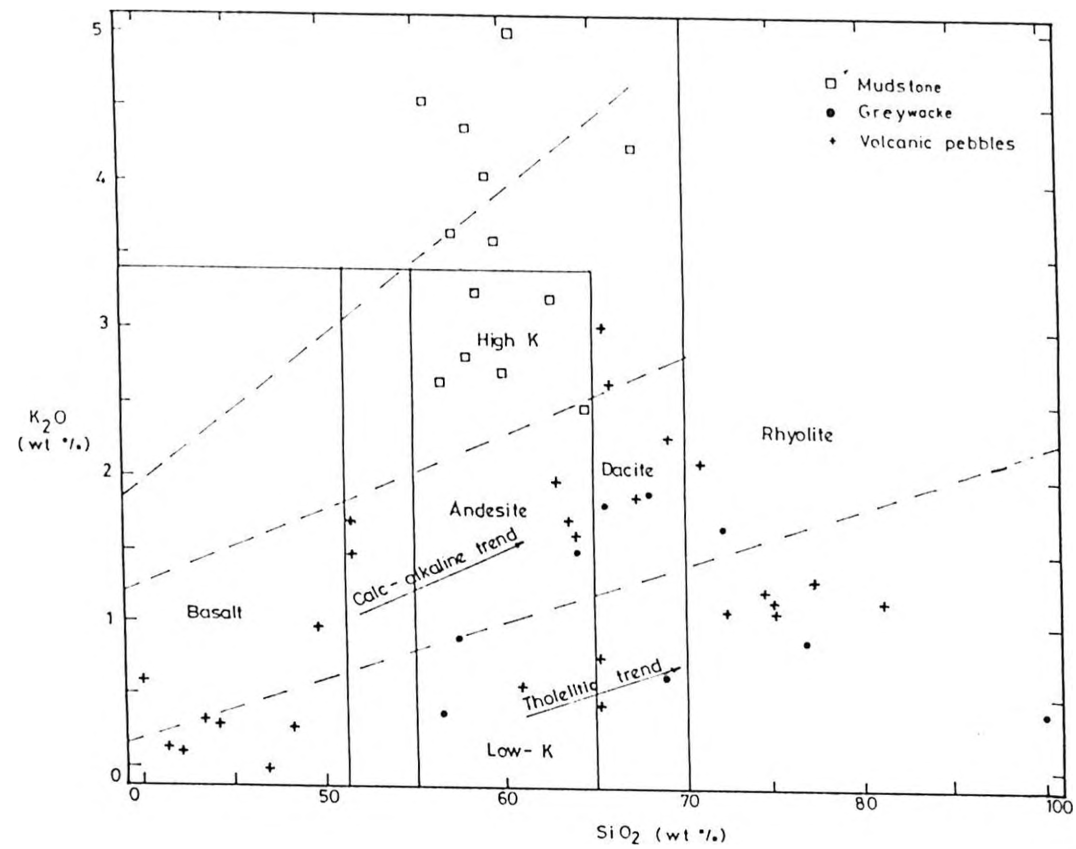


Fig. 15 Binary plot of K_2O verses SiO_2 showing the chemical trends of volcanic pebbles

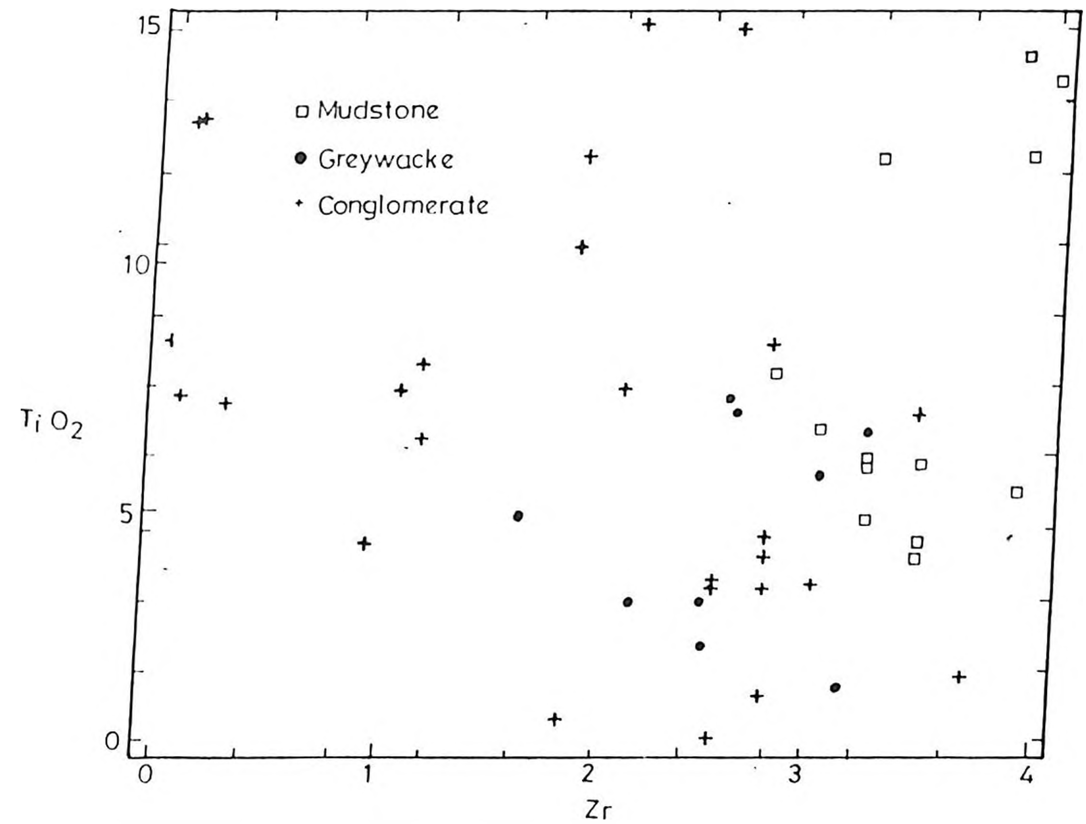


Fig 16(a) Plot of TiO_2 verses Zr

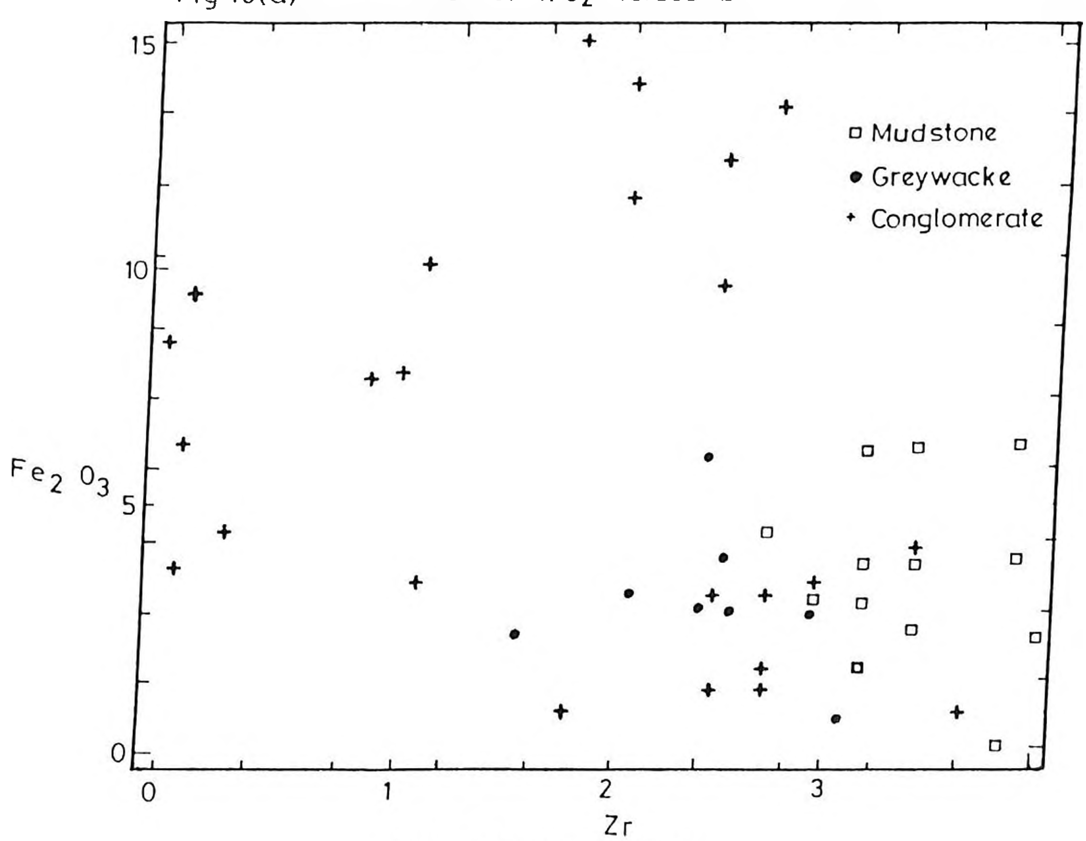


Fig. 16(b) Plot of Fe_2O_3 verses Zr

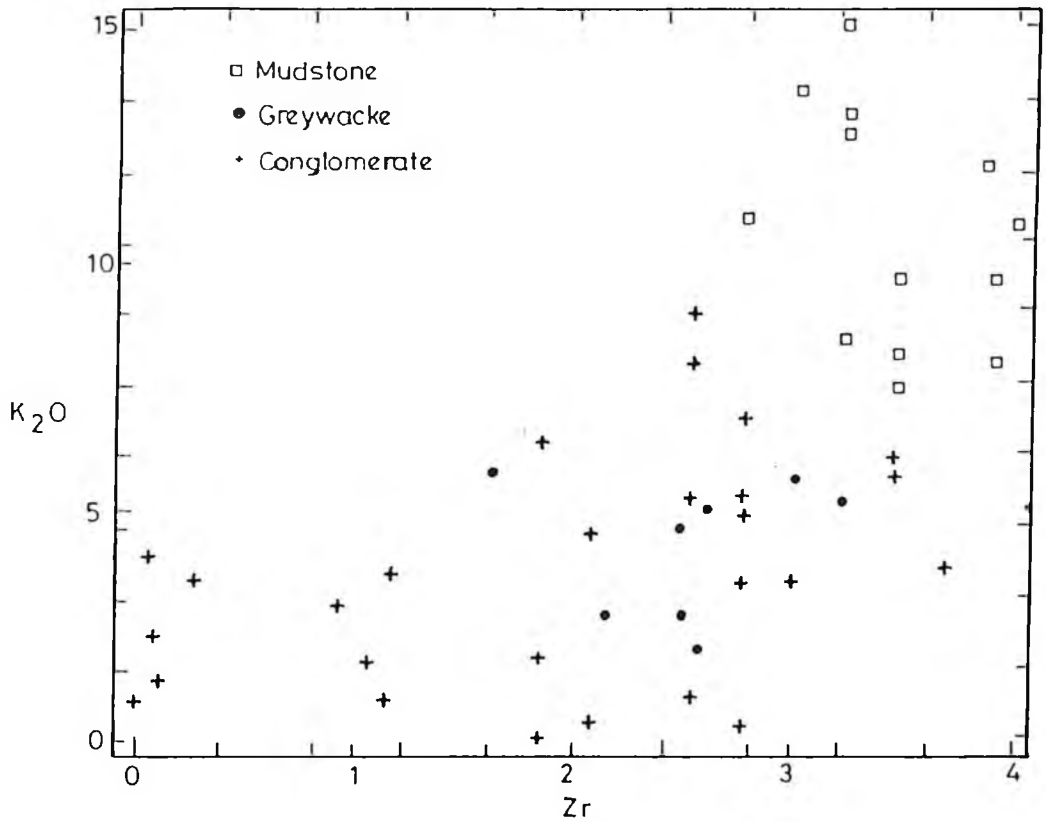


Fig 16(c) Plot of K_2O verses Zr

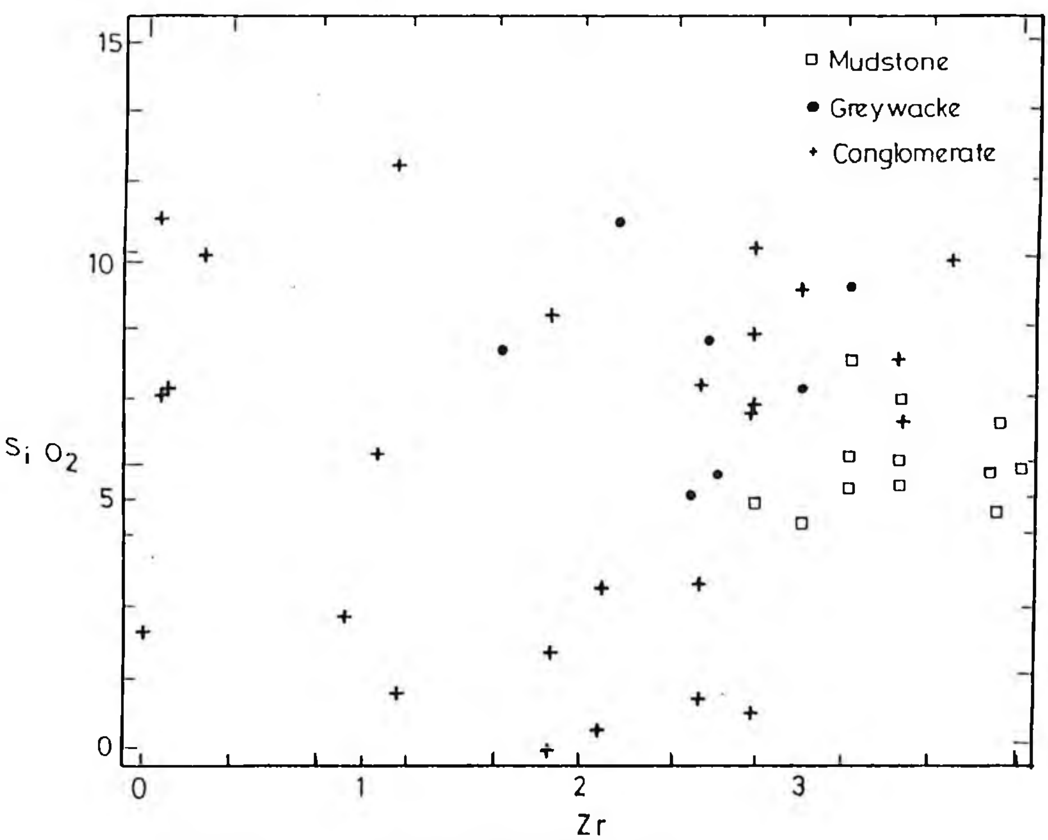


Fig. 16(d) Plot of SiO_2 verses Zr

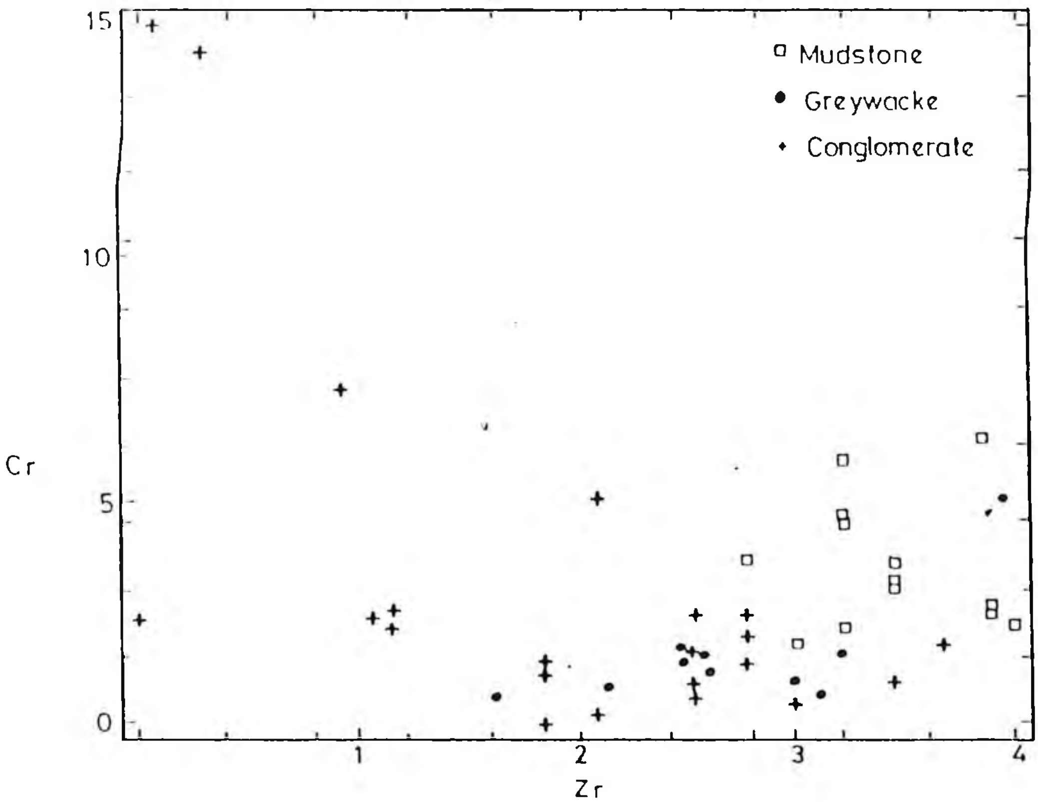


Fig 16 (e) Plot of Cr verses Zr

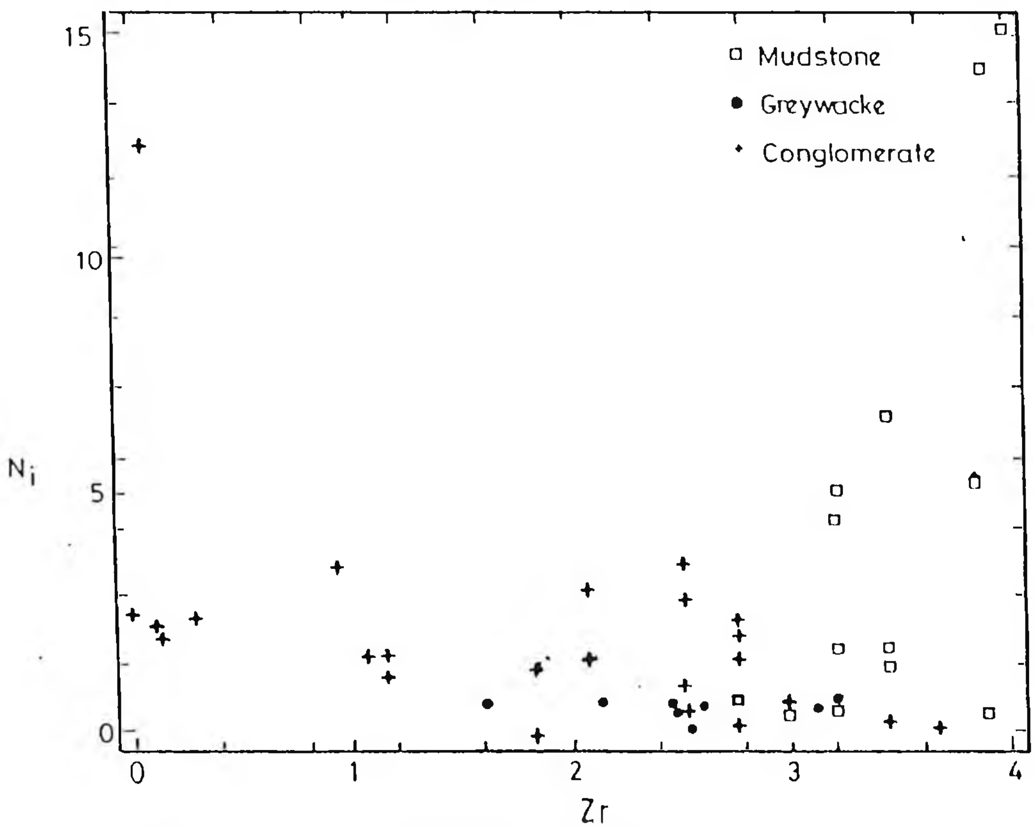


Fig. 16 (f) Plot of Ni verses Zr

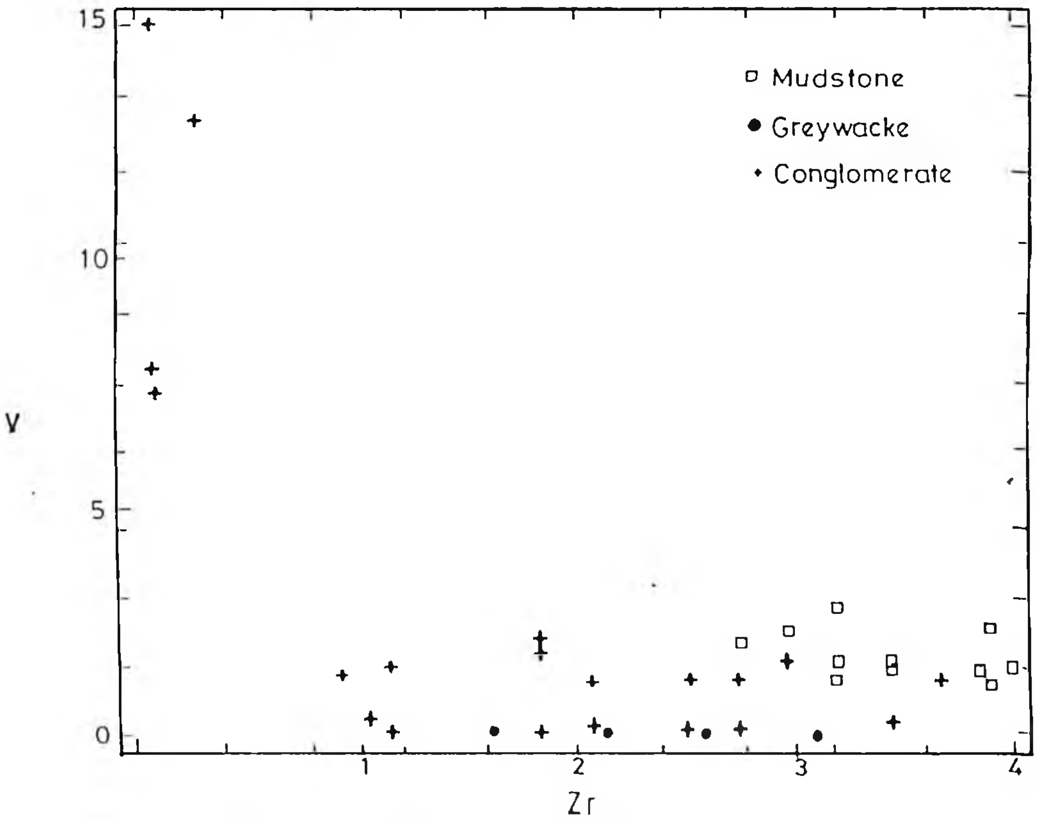


Fig 16(g) Plot of V verses Zr

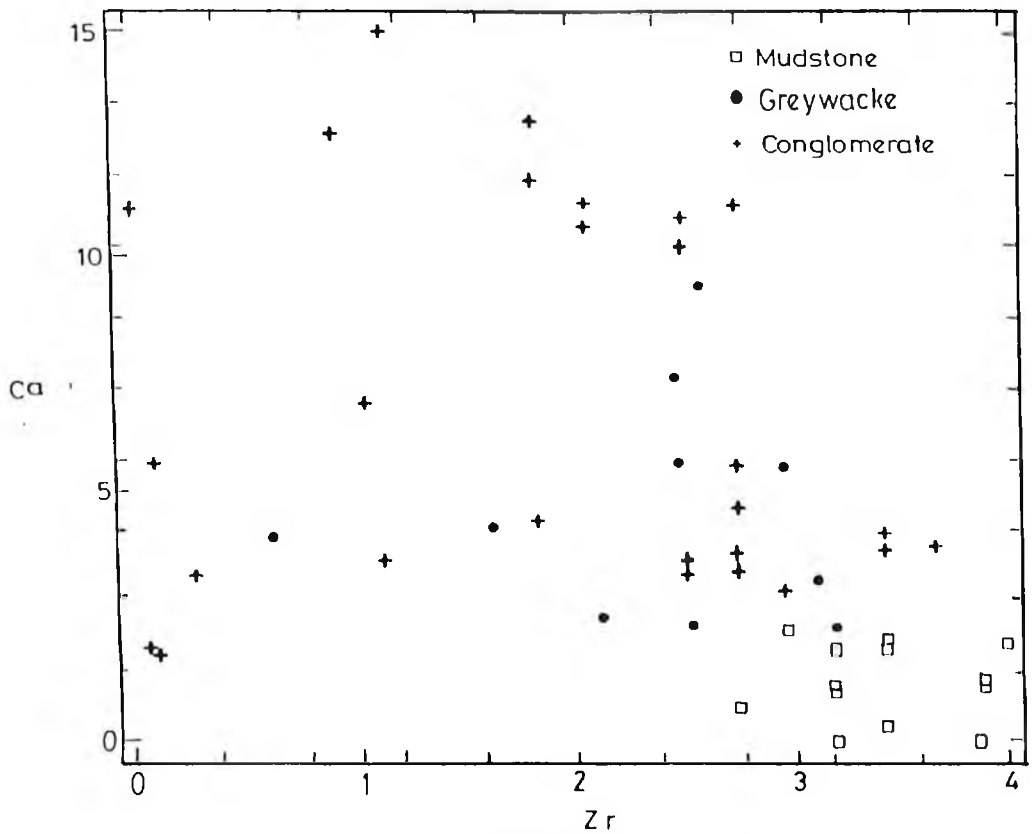


Fig 16(h) Plot of Ca verses Zr

immensely to the volcanic rocks of the study area. The rest of the chemical trends displayed by the elements are attributed to fractional crystallisation of the mafic magma phases which had a significant role in the variations in their compositions. On (Figs. 16c & g) vanadium and potassium oxide are observed as correlating positively with zircon. Their dispersions are, however, so wide that they cannot be explained by fractional crystallization. Their slopes and dispersions are probably related to liquid state differentiation.

Cherts are generally depleted in alkalis and highly enriched in iron oxide and silica. The cherts do not bear any chemical relationship to the volcanic rocks or sedimentary rocks.

5.1.3 Matrices

The distribution of oxides and trace elements in (Fig. 17a-m) show that the matrices of the conglomerate are particularly enriched in oxides such as silicon oxide, aluminium oxide, iron oxide, magnesium oxide and titanium oxide. The matrices are also enriched in trace elements such as cobalt, nickel and chromium and they show depletion in rubidium and strontium. The chemical trends of these oxides and trace elements suggest that most of the material which made the matrices, were derived from rocks which were rich in mafic minerals. Generally, elements derived from rocks, rich in ferromagnesium minerals like chromium, cobalt, calcium, magnesium and iron are more abundant in the matrices than in the individual conglomerate pebbles. The high ferromagnesium minerals composition of the matrices resulted from the high susceptability of mafic rocks (Naqvi et al., 1977) to both mechanical and chemical degradation on the earths surface.

A comparison of sodium oxide and potassium oxide ratios (Fig. 18), both in the conglomerate pebbles and matrices indicate that Archaean sediments are generally more enriched in sodium oxide than potassium oxide. The higher sodium oxide content is dependent on the detrital plagioclase which was derived from granitic rocks during the weathering stage prior to sedimentation . In typical Archaean conglomerate matrices, there is a direct correlation between detrital plagioclase content and sodium oxide content. High sodium oxide content in matrices is also related to the high amount of plagioclase contained in the source rocks. In sedimentary basins where only K-rich granite rock sources were available for erosion, the matrices of the conglomerate are rich in potassium oxide, however, Archaean conglomerate matrices are potassium oxide depleted bacause K-rich granitic rocks were absent from the surface of pregeosynclinal terrains (>2,600 Ma) of the Archaean continents.

Later granites (<2,500 Ma.) which include syn- and post-geosynclinal granites (Divakara Rao et al., 1972) are extremely rich in potassium due to renewed potassic magmatism.

5.1.4 Greywacke

The major and trace element geochemistry of grewacke closely follow the chemical trends of the conglomerate matrices. The greywackes show evidence of being derived from several lithologies which included mafic volcanic rocks, felsic volcanic rocks, granitic rocks, recycled metamorphic and sedimentary rocks. These lithological characteristics are similar to the Archaean greywacke found in other parts of the world (Baker and Peterman, 1974; Baker and Arth, 1976; Baker et al., 1981). The greywackes are enriched in oxides contained in quartz feldspathic materials like silicon oxide, sodium oxide, calcium oxide and barium. Like the

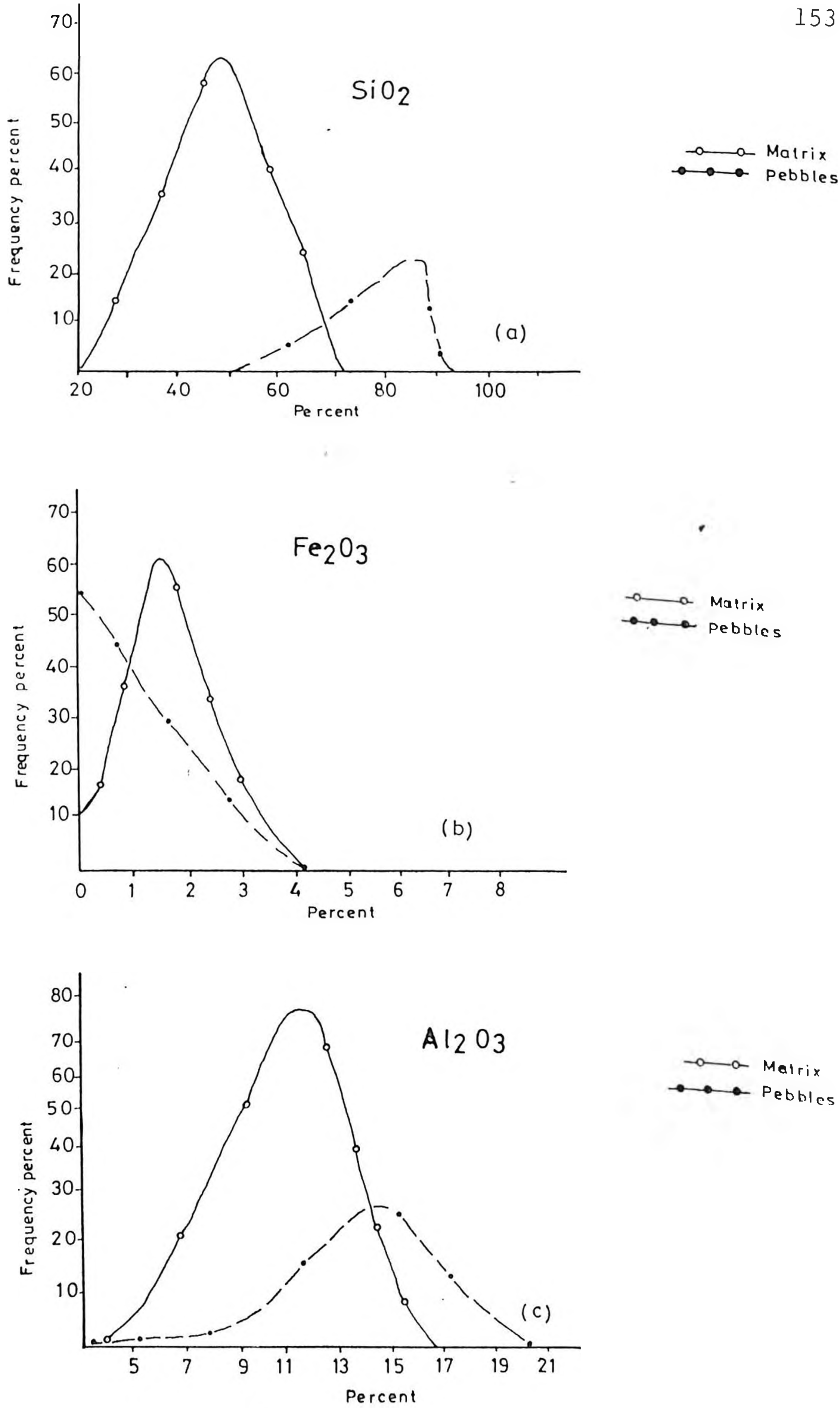


Fig.17(a-c) Frequency distribution of compositional constituents of pebbles and matrices of conglomerates

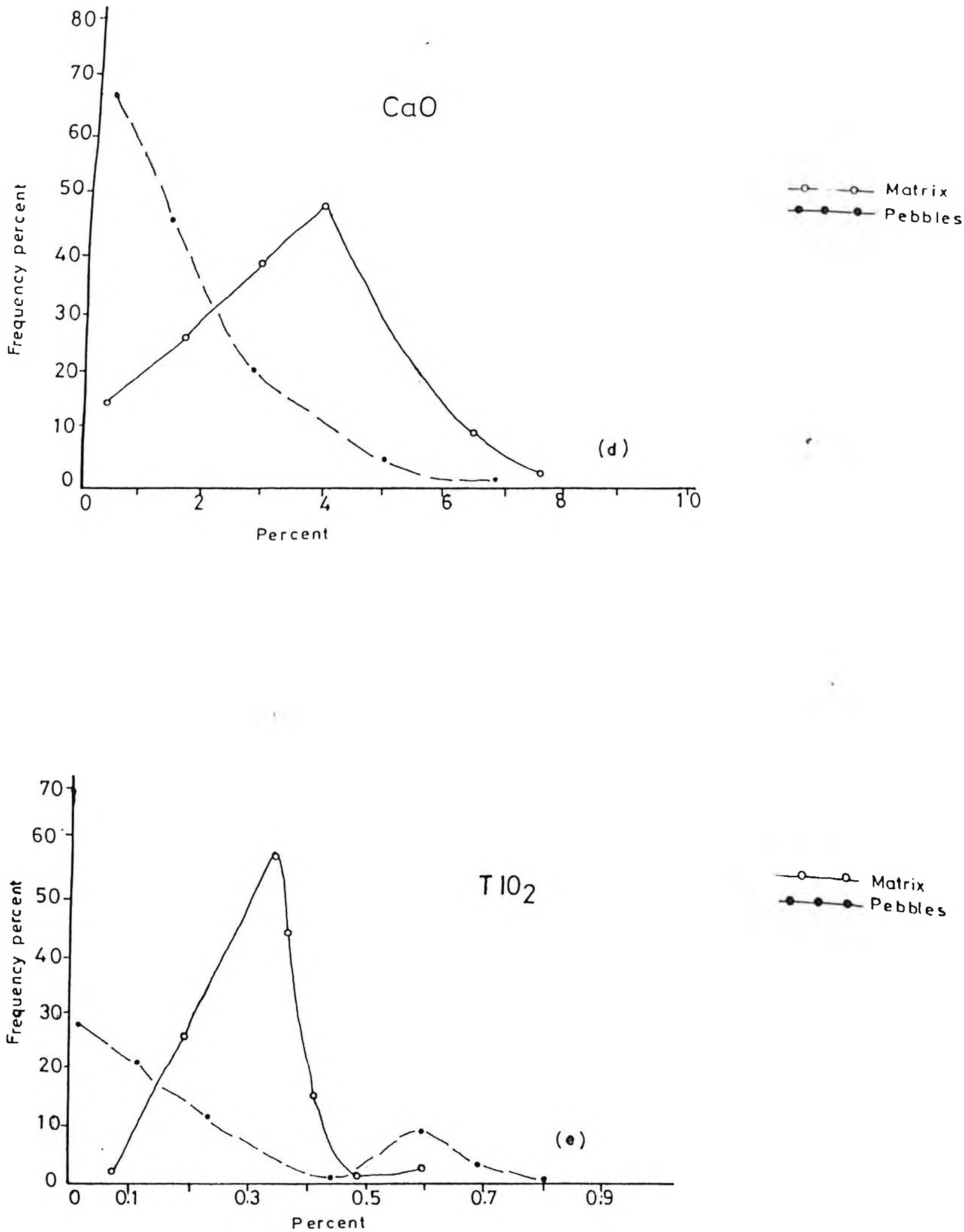


Fig.17(d-e) Frequency distribution of compositional constituents of pebbles and matrices of conglomerates.

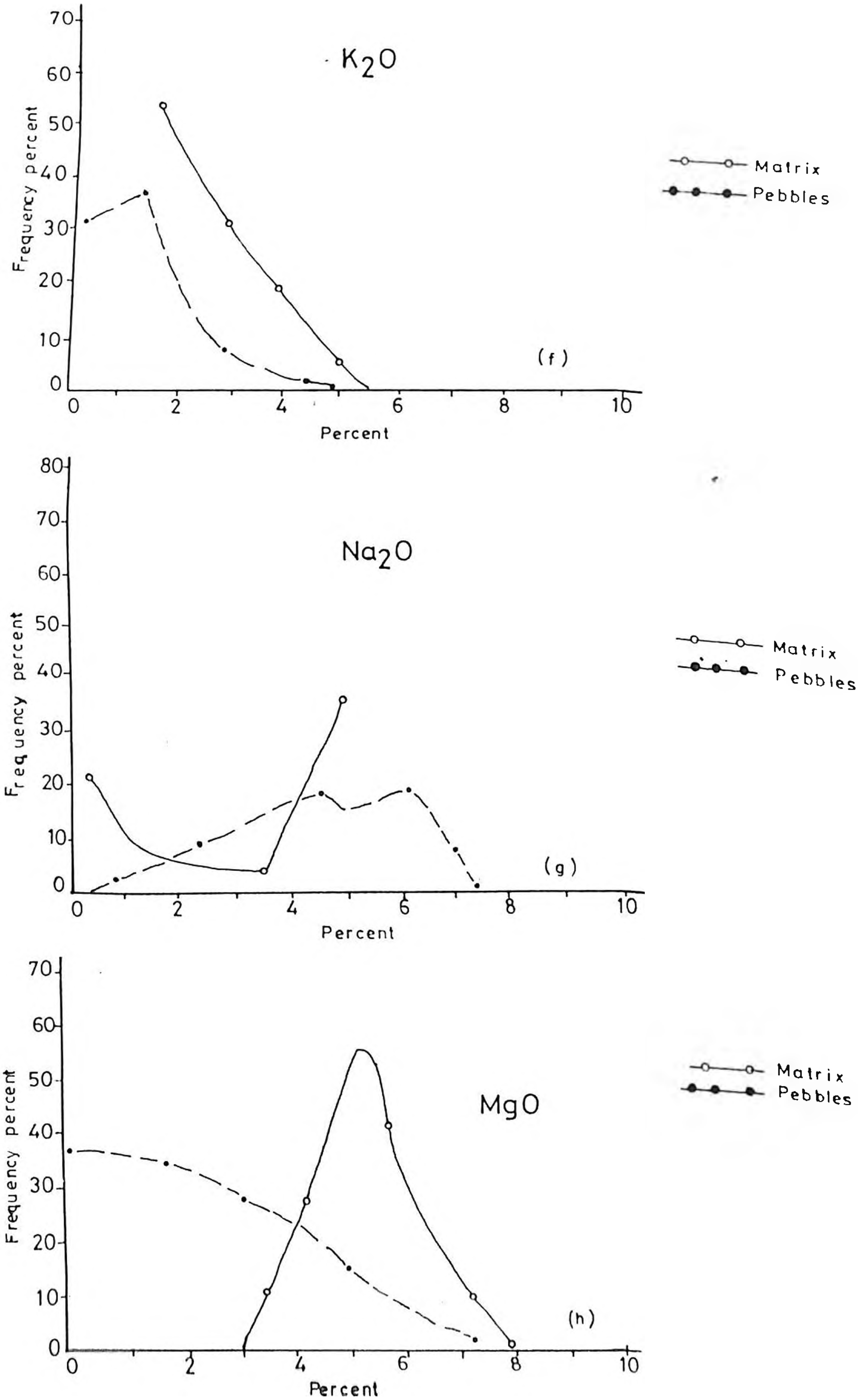


Fig.17(f-h) Frequency distribution of compositional constituents of pebbles and matrices of conglomerates.

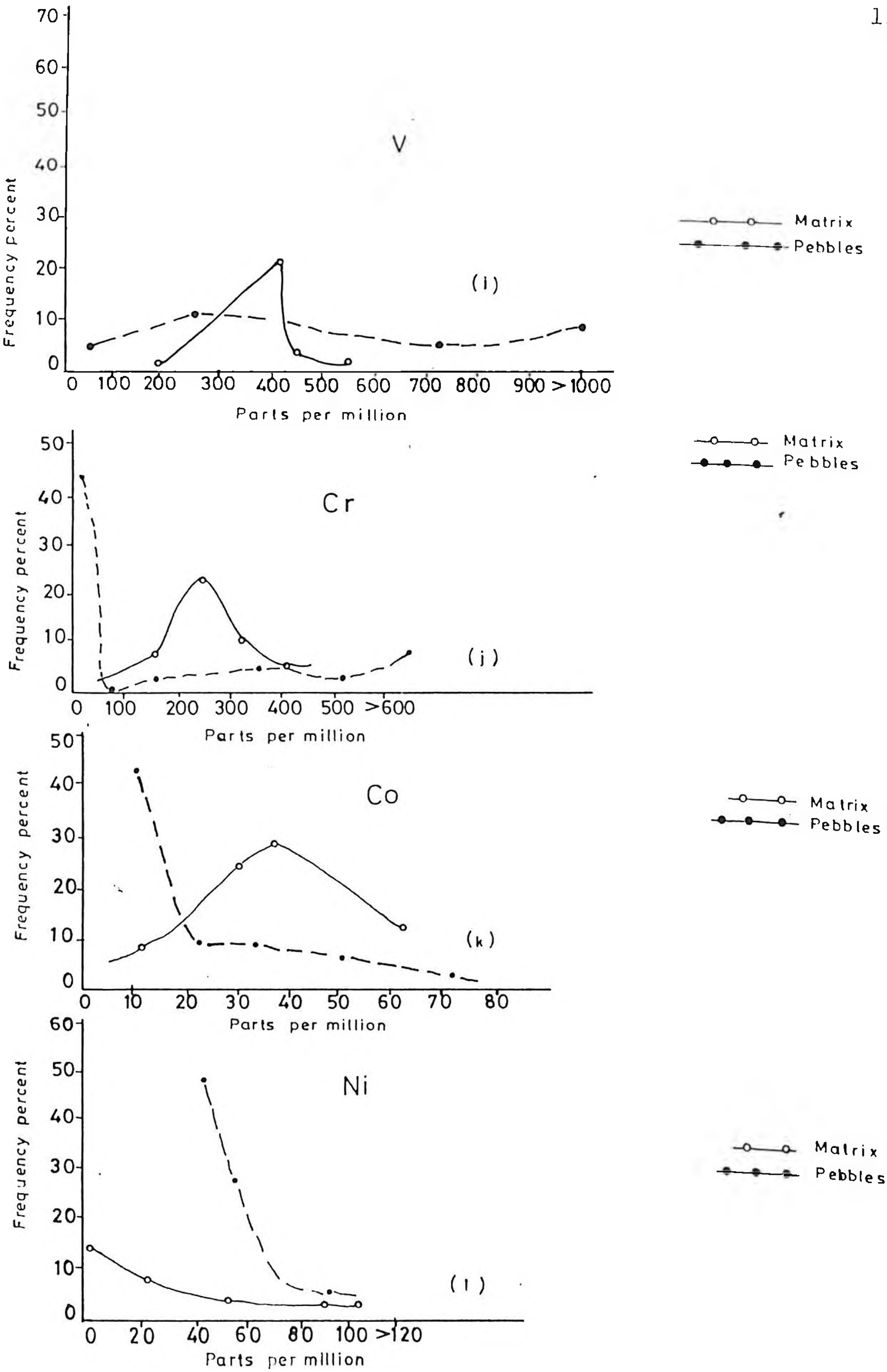


Fig.17(i-l) Frequency distribution of compositional constituents of pebbles and matrices of conglomerates.

matrices, greywackes are more enriched in sodium oxide than potassium oxide and this implies that granitic rocks were an important source of the sediments.

Potassium and sodium abundances (Fig. 18) show that in the Nyanzian Shield, quartz-intermediate greywacke are dominant (Crook, 1974) and most of the samples plot above $Na_2O/K_2O = 1.0$ (Fig. 18). According to Engle et al. (1974), the Na_2O/K_2O ratio is also an indicator of the degree of differentiation in igneous rocks and the immature sediments derived from them. Normally a ratio of $Na_2O/K_2O = 1.05$ is typical of greywake formed around 2.6 Ma. ago. The Na_2O/K_2O ratio of Nyanzian Shield greywacke is around 1.2 and therefore the sedimentation of greywackes in western Kenya took place around 2,600 Ma.

Ferromagnesium elements (Fe, Ti and V) and the small cation elements (Na, Ca and Sr) show negative correlation with silicon oxide, while large cation elements (K, Rb and Pb) show a weak positive correlation. The negative correlation of ferromagnesian elements and small cation elements with silicon oxide implies that the elements decrease proportionally with the decrease in chemically unstable components of the greywacke eg. feldspars and volcanic lithic grains. The weak positive correlation of the large cation elements with silicon oxide indicate that these elements are associated with the quartzose components which were strongly controlled by the nature of the source rock.

Generally, major element oxides of sediments undergo some changes during diagenesis. In most basins, silicon oxide is enriched while sodium oxide and calcium oxide are depleted. These changes are more often observed in greywackes (sandstones) rather than their source rocks. The major element oxides of sediments give clues of the provenance and the weathering conditions, both of which are controlled by the tectonic setting of the basin . Diagenesis also influences

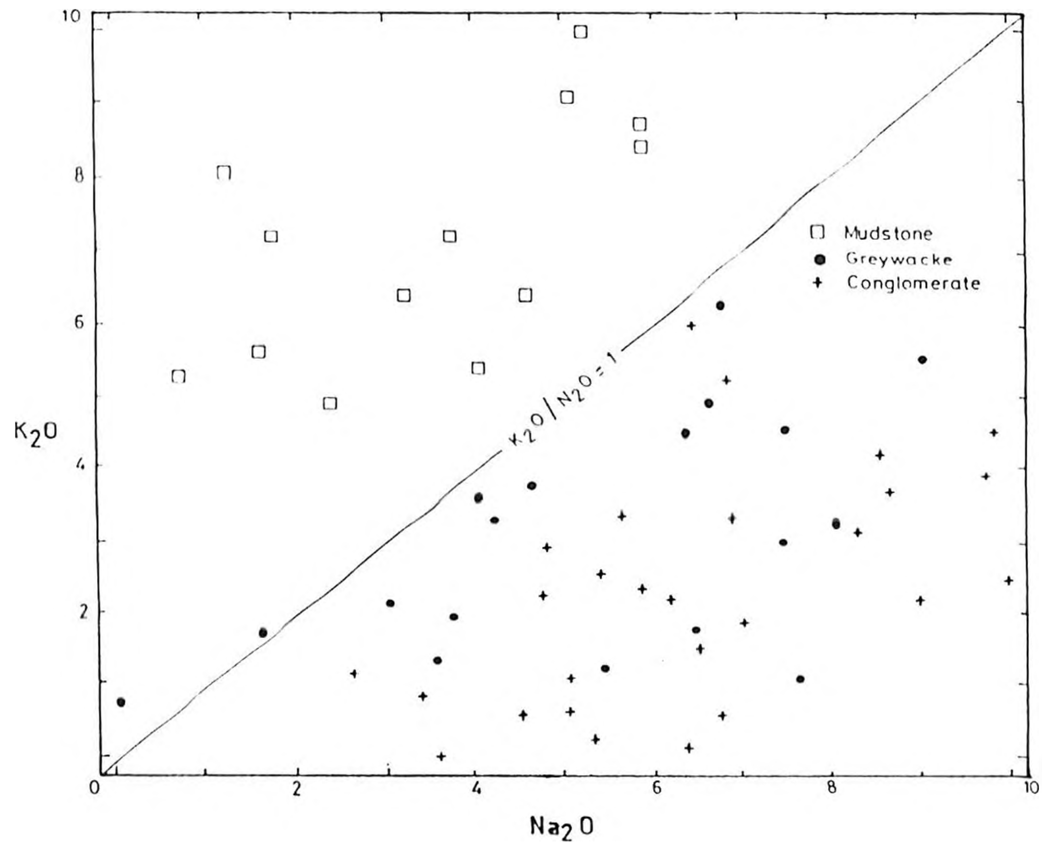


Fig 18 Plot of K_2O verses Na_2O showing the distribution of the oxides within the Kavirondian sediments. Note the high content of Na_2O in greywackes and conglomerate pebbles.

the chemical compositions of the sediments and the nature of diagenesis is itself dependent upon the tectonic setting of the basin. The oxides commonly used to discriminate the tectonic settings of sediments (Bhatia, 1983) include Fe_2O_3 + MgO %, TiO % and Al_2O_3/SiO_2, $Al_2O_3/(CaO + Na_2O)$, K_2O/Na_2O ratios.

5.1.5 Mudstone

The major elements composition in mudstone are characterised by high potassium oxide, moderate sodium oxide and low calcium oxide. These chemical characteristics are typical of most Archaean mudstone (Bavinton and Taylor, 1980). Archaean mudstone rarely have potassium oxide content in excess of 4% and potassium oxide:sodium oxide ratio in excess of 3.0 (Naqvi and Hassan, 1972; Nance and Taylor, 1977; Naqvi, 1978; Cameron and Garrels, 1980; Maclennan, 1981). It is also unusual for calcium oxide values to be less than 0.5 - 1.0%. Most of the Archaean mudstones in western Kenya are within these ranges except for a few deviations. The deviations are attributed to weathering, burial metamorphism and diagenesis.

The excessive potassium oxide enrichment is due to the presence of the original large quantities of illite which has already altered into muscovite. The potassium oxide enrichment gives rise to an increased $K_2O:Na_2O$ ratios with sedimentary maturity. According to Opiyo (1988), the potassium oxide concentration reflects secondary enrichment and bear little resemblance to the source rocks. The secondary enrichment of potassium oxide was also observed by Bavinton and Taylor (1980) when they examined early Precambrian weathering profiles and found that calcium oxide, sodium oxide, magnesium oxide and iron oxide were generally leached from the profiles while potassium oxide was commonly enriched.

Boron is often used as a paleo-sedimentation indicator. When boron concentration is compared with other trace elements, the western Kenya Archaean mudstones (in excess of 69-107 ppm) are quite enriched in the element. It has been observed that fine grained sediments usually have boron in excess of 150 ppm and usually the main source of boron in the fine grained sediments is volcanic emanations. This inference apparently agrees with the geochemistry of greywacke and conglomerate matrices which show that they were primarily derived from multiple sources of which volcanic sources had considerable contribution. High boron content in argillaceaous sedimentary rocks (Shaw and Burgry, 1966), in excess of 80-100 ppm depicts marine sedimentation. The mudstones of the western Kenya Archaean terranes has boron content which ranges from 69-107 ppm. This excess in boron content implies normal marine sedimentation.

The geochemical data of the various rock suites discussed is shown on Appendix A.

5.2 Provenance

5.2.1 Conglomerate

From the petrographic evidence, the Kavirondian conglomerates were derived from a mixed source which include volcanic, granitic and recycled sedimentary rocks. The conglomerates are generally polymictic and they are composed of disc shaped granitic, rhyolitic, dacitic, basaltic and andesitic boulders. The boulders derived from basic and intermediate rocks are, however, scarce. Some limited amount of quartzite and chert pebbles were also observed.

The chemistry of the boulders indicate that the basic rocks have high concentrations of MgO, MnO, TiO2, CaO, Ni, Cr and Co. The acid rocks, on the other hand, have greater concentrations of Zr, Y and Ba. The granitic pebbles contained comparatively higher Na_2O than K_2O. Granitic pebbles with this chemical characteristic are of trondhjemite-tonalite affinity and the absence of K-rich granitic pebbles in the conglomerate suggest that K-rich granites were absent from the surface of the shield nuclei during the pre-geosynclinal history of the initial unstable Nyanzian craton. The stabilization of the Archaean cratons (Naqvi, 1977) was associated with the development of K-rich plutonic rocks. The Nyanzian shield geosynclinal basin consequently attained its stability around 2,450 Ma when K-rich acid plutonic activity occurred. The intrusion of K-rich granites probably occurred as a result of crustal reactivation during which the major granite bodies such as the Mumias, Maragoli, Kitere and Wanjare were intruded.

Ferrugineous chert pebbles were derived from chemical precipitates which were apparently deposited prior to the sedimentation of the present western Kenya Archaean sedimentary belt. Opiyo (1988), suggested that ferrugeneous bedded cherts in western Kenya were connected with volcanic processes (hydrothermal activity) due to their close proximity to the basalts. Pettijohn et al. (1972), however, had pointed out that although some cherts are associated with submarine flows, many bedded cherts have no known association either with lava flows or infalls of volcanic ash. Due to lack of such associations therefore, volcanism cannot be appealed to, in order to provide for silica to form bedded cherts. The amount of silica normally found in sea water is adequate and therefore, cherts in the Archaean terrains of western Kenya apparently formed as a result of chemical precipitation of sea water through chemical differentiation.

The presence of quartzite pebbles in the conglomerate formations suggest that there existed pre-geosynclinal clastic rocks which, during one of the pre-Kavirondian Metamorphic phases, were altered into quartzite. The so formed quartzites were later mechanically weathered along with other rock types and deposited into the present Archaean basin.

5.2.2 Greywackes

The greywackes described in this study have been derived from different lithological sources which include mafic and felsic rocks, granitic rocks and recycled sedimentary rocks.

Rock fragments contained in the greywacke constitute about 20% of the total rock mass and provide ready information about the provenance. Granitic rock fragments consists of tightly interlocking crystals of quartz and plagioclase feldspars. These minerals are often accompanied by small grains of chlorite which represent altered hornblende and biotite. The fragments are generally fine grained because the coarser granitic fragments readily break into the individual minerals which are contributed to the sediment as individual quartz and feldspars. These minerals normally form the greywacke matrix.

Felsic rock fragments are very common in greywackes. These fragments are composed of tightly interlocking quartz-feldspathic minerals. The fragments are recognised by the diffuse outlines of their grains and the presence of widely scattered chlorite crystals and phenocrysts of quartz and feldspar.

Mafic rock fragments are less common and they are composed of basalt and andesite fragments. The fragments are characterised by the presence of small laths of fine plagioclase and abundant chlorite. These rock fragments are generally darker than the felsic ones.

Rock fragments of sedimentary origin consist of siltstones and mudstones and they are essentially of intraformational origin, thus being derived from erosion of earlier mudstone and siltstone formations within the same basin. They are distinguished from other types of fragments by their dark colour, high muscovite content and flattened outlines.

Feldspars in greywackes occur both as untwinned plagioclase and slightly altered fine grains which show well developed albite twinning. The two types of plagioclase suggest two types of provenances. Lack of K-feldspars in the greywacke and the matrix probably results from their decomposition during diagenesis and low grade metamorphism.

Quartz found in greywacke matrix is usually in form of monocrystalline, angular grains which exhibit undulatory extinction. Although Donaldson and Platt (1975) pointed that quartz is an indicator of several provenances which include volcanic, granitic, metamorphic and recycled sedimentary rocks, quartz bearing granites are a major source of the quartz in the western Kenya Archaean belt.

5.2.3 Mudstones

Mudstones have generally undergone low grade metamorphism and therefore, most of the original minerals have been recrystallised to biotite, quartz, muscovite and chlorite, consequently mudstone is not a useful indicator of provenance as compared to the conglomerate pebbles and greywackes.

5.3 Geochronology

5.3.1 Introduction

In this section of the chapter the results of the geochronological analysis are presented. The results presented were obtained from the analysis of rock samples from Wanjare granite, the Mosocho conglomerate, the Maragoli granite, the Kakamega conglomerate and Mumias granite. The analytical data of the five rock suites analysed are presented in Appendix B.

Rb - Sr whole rock determinations were carried out in order to determine the age relationship between the Nyanzian volcanic rocks, Kavirondian Group sediments and the surrounding granite intrusions.

Samples for radiometric dating were taken from the Kavirondian Conglomerates and from the surrounding granite intrusions (Fig. 19a and 19b).

During this study, whole rock Rb - Sr method was exclusively used. This method was found to have an advantage over other dating methods because whole rock samples are known to give usable Rb - Sr isochrons even where mineral fractions give discordant ages. When there are uncertainties regarding the source materials of the samples, the Rb - Sr mineral fractions method cannot independently resolve but the rubidium - strontium whole rock isochron still yield ages and initial $^{87}Sr/^{86}Sr$ ratios which are valid within the error limits, provided:-

1. There was no initial correlation between $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ at the time of granite emplacement which would give a rather old age.

2. That no process took place during which metamorphism effected homogenisation of the strontium isotopic composition.

3. That no process took place, during which radiogenic ^{87}Sr was selectively expelled - this would give rise to unrealistically young age.

4. That no process took place which subsequently added or substracted rubidium to or from the samples in exactly similar proportions to the rubidium which was in the samples at the time of the initial emplacement.

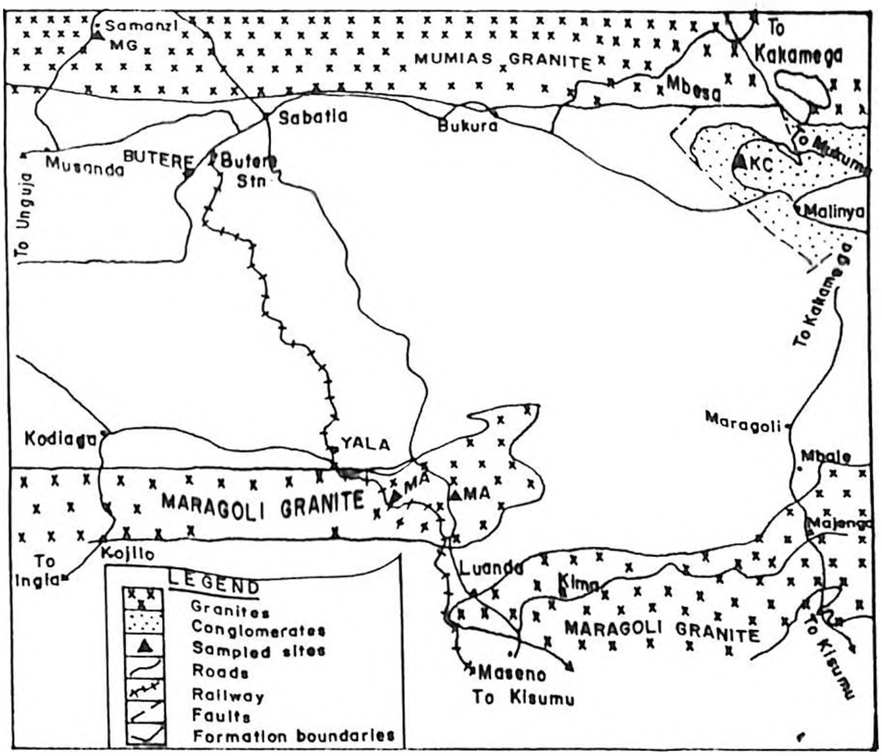


FIG. 19a. SKETCH MAP SHOWING AREAS WHERE SAMPLES FOR RADIOMETRIC ANALYSES WERE COLLECTED IN KAKAMEGA AREA.

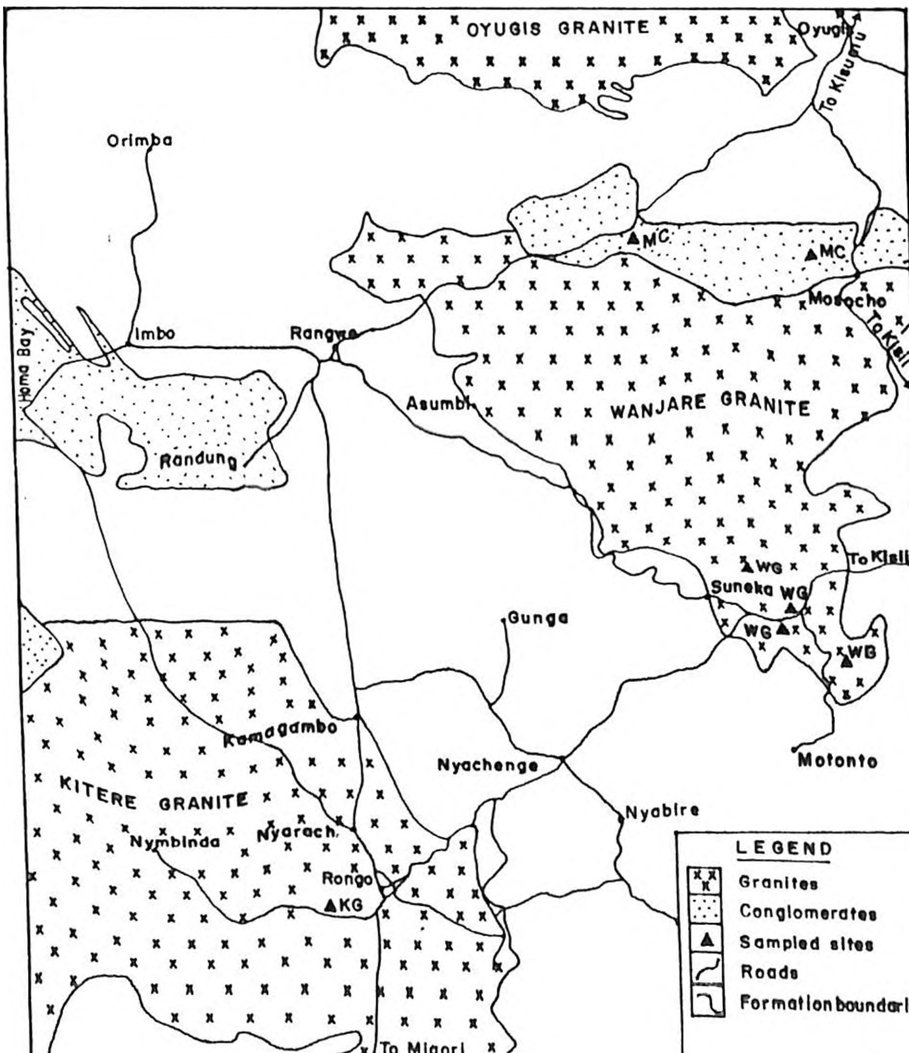


FIG. 19b. SKETCH MAP SHOWING THE AREAS WHERE SAMPLES FOR RADIOMETRIC ANALYSES WERE COLLECTED IN SOUTH NYANZA.

5.3.2 Results of the analysis

Six data points of Mosocho conglomerate yielded an age of 1,764±131 Ma. Initial $^{87}Sr/^{86}Sr$ ratio of 0.70706±0.0005 and a mean standard weighted deviate (MSWD) of 8.4 were obtained.

Analyses of six samples of the Kakamega conglomerate granodiorite boulders yielded an age of 2,611±311 Ma. The initial $^{87}Sr/^{86}Sr$ ratio was 0.70092± 0.0007 with a mean standard weighted deviate (MSWD) of 3.1. Due to the high MSWD a second regression model was applied and sample KC/88/2 was deleted. The second regression model yielded an age of 2,556±311 Ma and initial $^{87}Sr/^{86}Sr$ ratio of 0.70118±0.0008. The Mean standard weighted deviate was 1.9.

Six samples from Maragoli granite analysed yielded a range of ages from 2,206±46 Ma. An initial ratio of 0.70479±0.006 and Mean standard weighted deviate of 1.1 were obtained. The second regression model yielded 2,533± 75 Ma. Initial $^{87}Sr/^{86}Sr$ ratio of 0.70172±0.008 and Mean standard wighted deviate of 1.3 were obtained. During the second regression, one sample point was deleted from the original isochron curve.

The six samples collected from Mumias granite yielded 2,470±19 Ma. The initial ratio of $^{87}Sr/^{86}Sr$ was 0.70152±0.004 and the MSWD was 1.6.

The four points obtained from the analyses of six samples collected from Wanjare granite yielded an isochron fit of 2,361±339 Ma. The initial $^{87}Sr/^{86}Sr$ ratio was 0.71364±0.003 and the MSWD was 1.1.

5.3.3 Interpretations

5.3.3.1 Mosocho Conglomerate

The six data points of Mosocho conglomerate boulders yielded a poorly defined age T = 1,764±131 Ma. The initial $^{87}Sr/^{86}Sr$ ratio of 0.70706± 0.0005 and mean standard weighted deviated (MSWD) of 8.6. Much scattering of points is both depicted by the isochron curve and the high MSWD. The scattering of points is attributed to initial heterogeneous composition of strontium isotope or later metamorphic disturbances of the strontium isotopic systems. The points scatter may also be attributed to minor variations in the chemistry of the individual rock boulders. It is noted that since the chemistry of the boulders may not had been completely similar, it is possible that the boulders were derived from different granitic bodies whose initial strontium was variable. The points form three distinctive clusters (Fig.20) which implies that each cluster group represents one granite type contributing to the Kavirondian sediments. Similarly, around T = 1,764 Ma there was an apparent regional metamorphic phase which disturbed and redistributed the strontium isotopic systems of rock suites in the area.

5.3.3.2 Kakamega Conglomerate

The data of the Kakamega conglomerate boulders defines an isochron relationship of T = 2,611±311 Ma. An initial $^{87}Sr/^{86}Sr$ ratio of 0.70042± 0.0007 and MSWD of 3.1 were obtained. Due to one sample KC/88/2, this isochron relationship is poorly defined as is indicated by the rather high MSWD. When the sample was deleted and second regression applied the result become T = 2,556±311 Ma. The initial $^{87}Sr/^{86}Sr$ ratio becomes 0.70118±0.0008 and the MSWD becomes 1.9. Despite

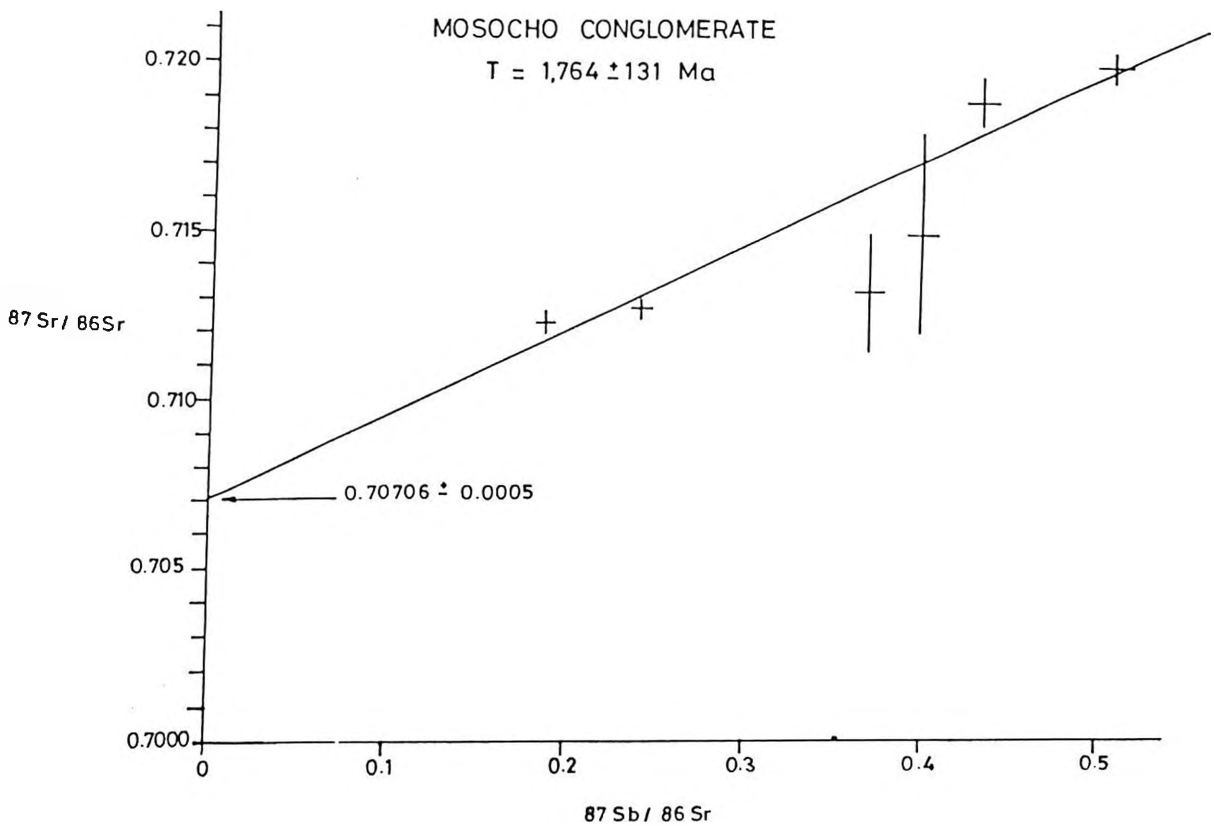


Fig. 20 Rb - Sr data plot for Mosocho conglomerate.

the low MSWD obtained after deleting sample KC/88/2, due to petrographic similarity among the analysed samples, it is still reasonable to examine the results of all the six samples together in terms of isochron relationship (Fig. 21). The two ages apparently represents the time of emplacement of the granitoid at T = 2,611±311 Ma and a major tectonic event at T = 2,556±311 Ma which immediately followed the emplacement of the post Kavirondian granite. The two ages are not significantly different when the widely overlapping error ranges are considered and therefore the two ages could as well reflect a single magmatic event. According to Dodson et al. (1975), this tectonic event occurred between 2,400 and 2,530 Ma. The low $^{87}Sr/^{86}Sr$ initial ratio implies that the trondhjemite - tonalite rock suites which formed the boulders had their sources in the upper crust.

The results are generally in good agreement with the findings of the previous workers in the Nyanzian Shield. Cahen and Snelling (1984) reported an age of 2,700 Ma for pre-Kavirondian Migori granite. Yanagi and Suwa (1981) also obtained an age of 2,700±3,400 Ma for the Nyanzian rhyolite. It is most likely therefore that the age of 2,611±311 Ma obtained for the Kakamega conglomerate represents the last stage of the emplacement of the older granite.

5.3.3.3 Wanjare Granite

Wanjare granite of which six point isochron fit yields 2,361±339 Ma., initial $^{87}Sr/^{86}Sr$ ratio of 0.71364±0.003 and MSWD of 1.1 (Fig. 22). The granite is characterised by low amounts of radiogenic rubidium and strontium. The granite is also characterised by high $^{87}Sr/^{86}Sr$ initial ratios compared with the other surrounding granite intrusives. This high ratio reflects the steep growth curve of ^{87}Sr resulting from high parental Rb/Sr. The average $^{87}Rb/^{86}Sr$ ratio for six

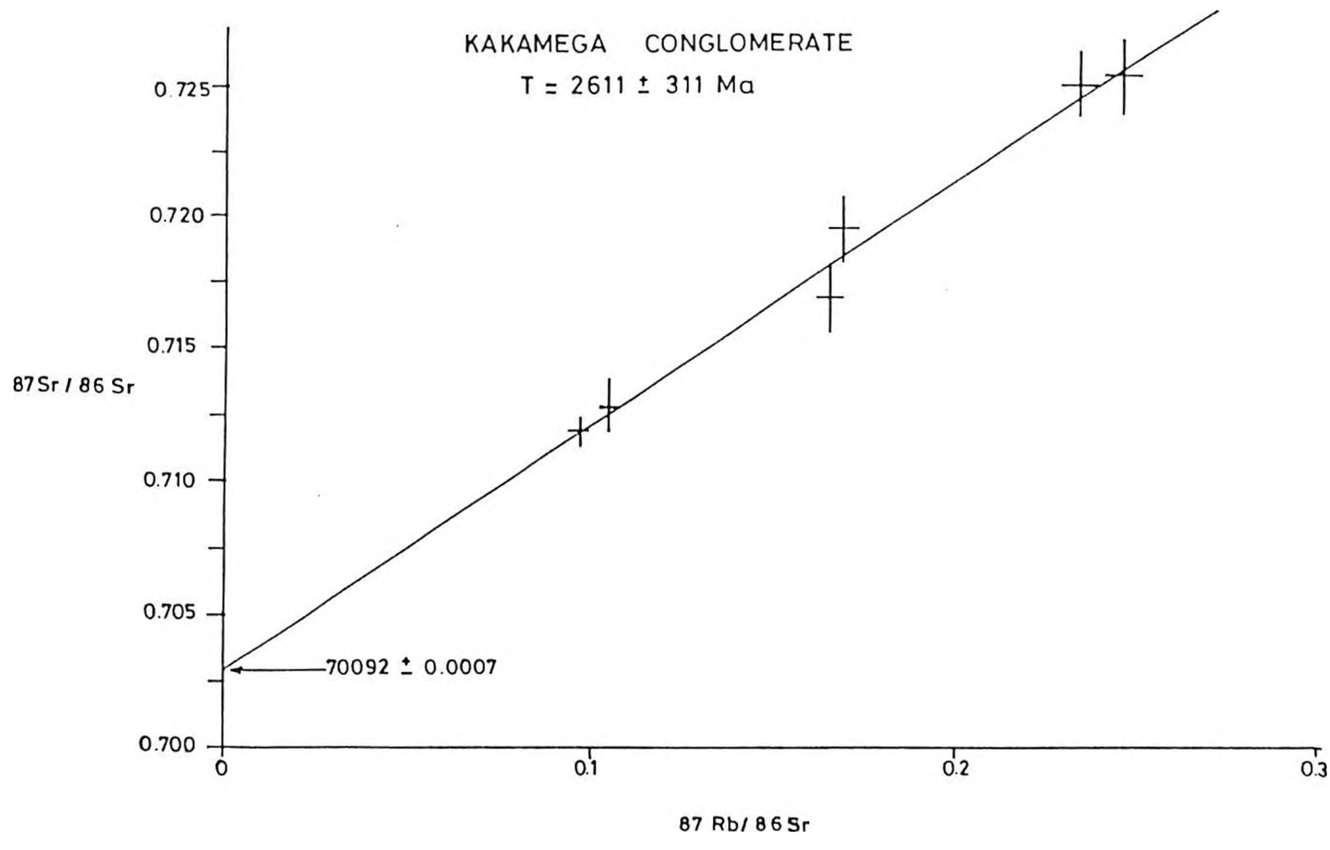


Fig. 21 Rb–Sr Data plot for Kakamega conglomerate.

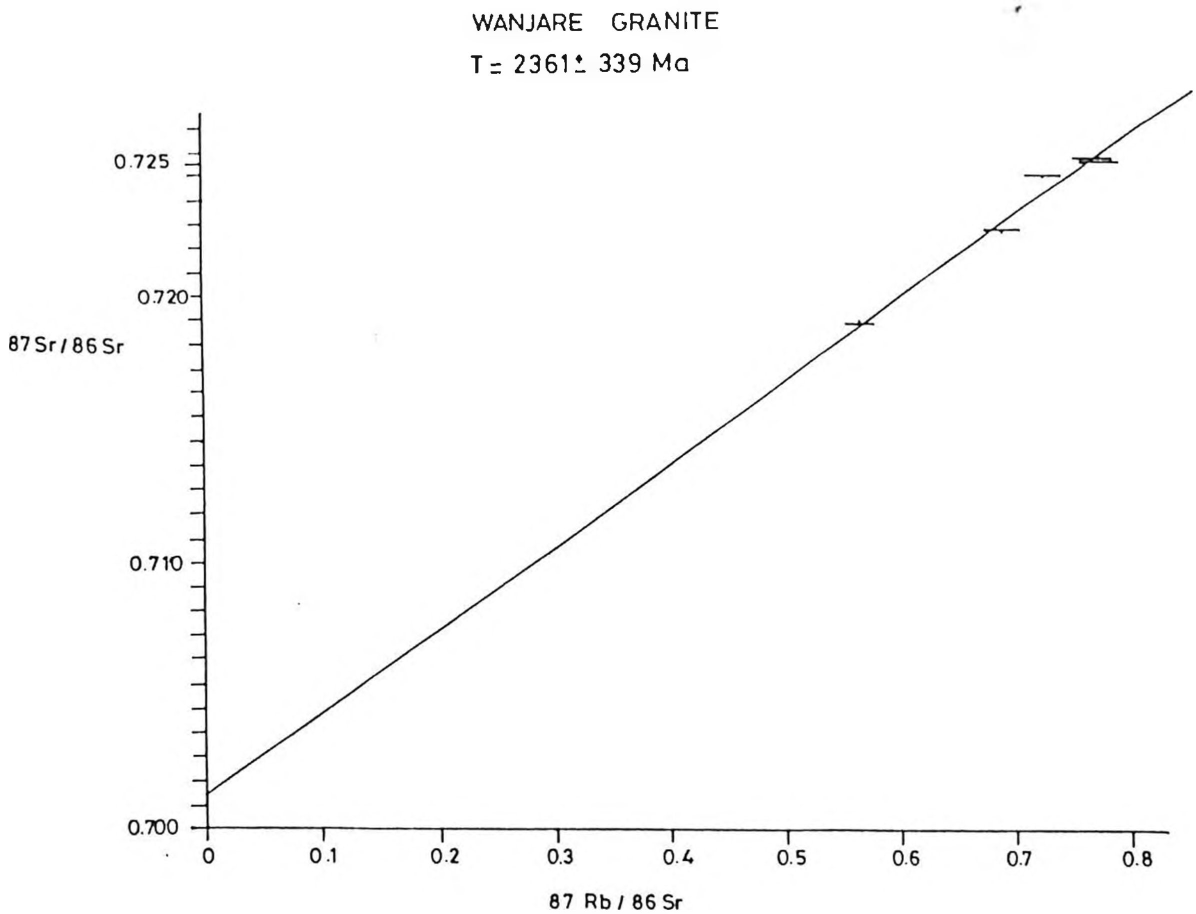


Fig. 22 Rb-Sr data plot for Wanjare granite.

samples of Wajare granite analysed is 7.2 and rocks with such a high $^{87}Sr/^{86}Sr$ ratio formed through crustal refusion. The initial $^{87}Sr/^{86}Sr$ ratio which formed as a result of metamorphism of pre-existing igneous rocks which resulted in complete homogenization of strontium isotopes or assimilation of metasediment material, may be expected to be significantly higher than those of igneous rocks formed by fractional crystallization of the primary magmas. The high initial $^{87}Sr/^{86}Sr$ ratio of Wanjare granite implies that the granite is a product of either crustal refusion or it was formed by metamorphism of pre-existing igneous rocks in situ. These sources could cause complete homogenization of strontium isotopes throughout the rock.

The petrographic similarity between Wanjare granite and the granitic boulders which make up the Mosocho conglomerate suggest that the boulders were probably eroded from the Wanjare granite. This view is also supported by the fact that during this study Wanjare granite was found to be 2,251±323 Ma old while the age of the boulders was found to be 1,764±131 Ma.

The young age of the Wanjare granite appears to disagree with the observation of the previous workers in the area that, the granite is one of the Archaean granitic intrusions. The determined age of 2,251±323 Ma is inclined more to early Proterozoic emplacement than Archaean intrusion.

5.3.3.4 Maragoli Granite

Maragoli granite samples produced two radiometric ages. The first one was 2,206 ±46 Ma, with initial $^{87}Sr/^{86}Sr$ ratio of 0.70479±0.006 and MSWD of 1.1 (Fig. 23). The second age was obtained after deleting one point which did not fit in the isochron curve and the new age was 2,533±75 Ma with initial $^{87}Sr/^{86}Sr$

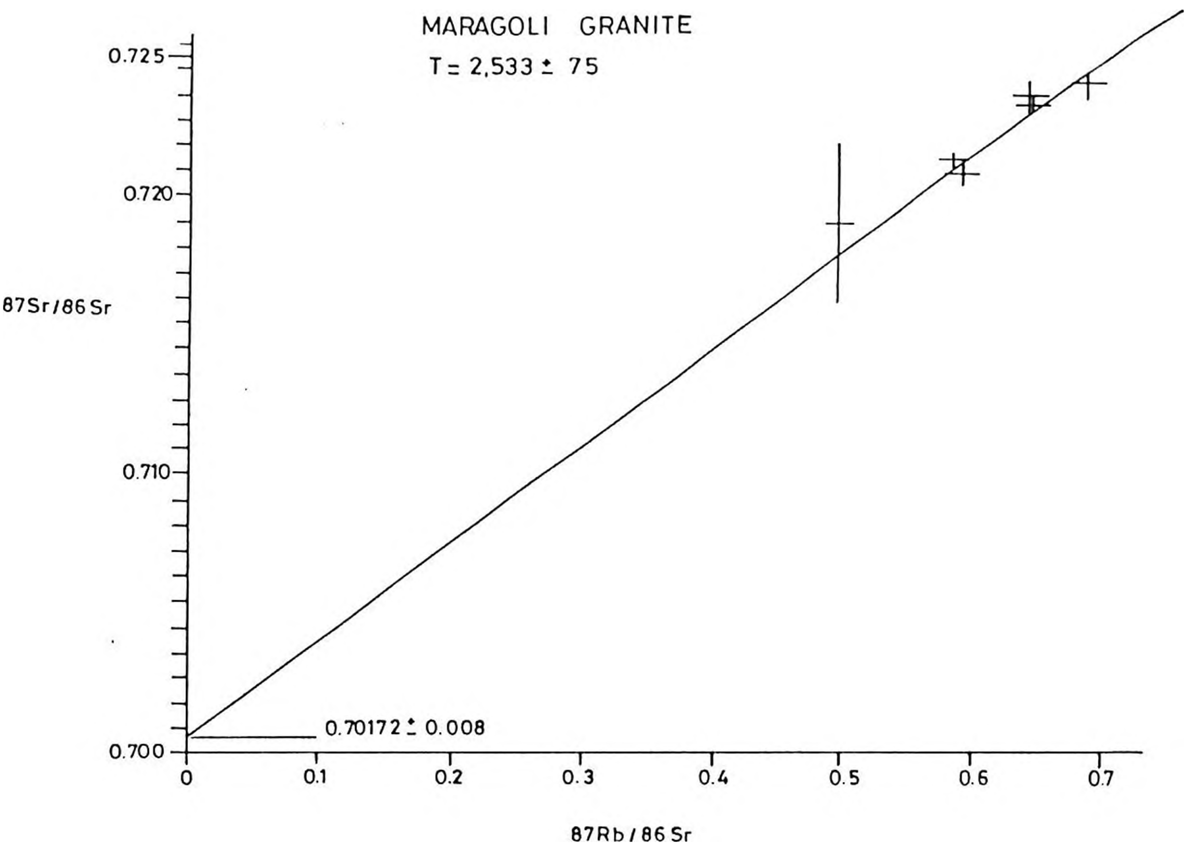


Fig. 23 Rb - Sr data plot for Maragoli granite.

ratio of 0.70172±0.008 and MSWD of 1.3. The low MSWD implies that the Maragoli granite has not undergone much metamorphic disturbance which could have affected the strontium isotopic systems.

Although the 2,533±75 Ma age appears to be rather high, it well agrees with the earlier date of 2,540 Ma (Cahen and Snelling, 1984) for the post Kavirondian granite intrusives. The deleted sample after the first regression could have undergone isotopic resetting due to local metamorphism in the sampling area.

If the two dates are accepted, the earlier date of 2,533 ± 75 Ma probably represents the age of granite emplacement while the later date of 2,206± 46 Ma probably represents a later major tectonic event.

5.3.3.5 Mumias Granite

The six samples of the Mumias granite analysed, yielded an age of 2,470± 19 Ma (Fig.24). The initial $^{87}Sr/^{86}Sr$ ratio was 0.70152±0.004 and the MSWD was 1.6.

Previous mineral and whole rock ages for the Buteba granite in south-east Uganda which is a westward extension of Mumias granite range from 1,850 Ma to 2,600 Ma (Cahen and Snelling, 1984). Those ages include Rb/Sr ratios ages of 1,850 Ma for biotite, 2,210 Ma for potassium feldspar, 2,535 Ma for whole rock and 2,600 Ma for muscovite. According to Old and Rex (1971) K : Ar ages for the same granite are 1,889 Ma for biotite and 2,175 Ma for muscovite.

Despite the wide range of ages given by various workers, in this study it is observed that an isochron of 2,430±100 Ma (Old and Rex, 1971) is closest to the correct age.

Dodson et al. (1975) reported an age of 2,400 Ma for Buteba granite and during the present study an age of 2,470±19 Ma was obtained. It is therefore

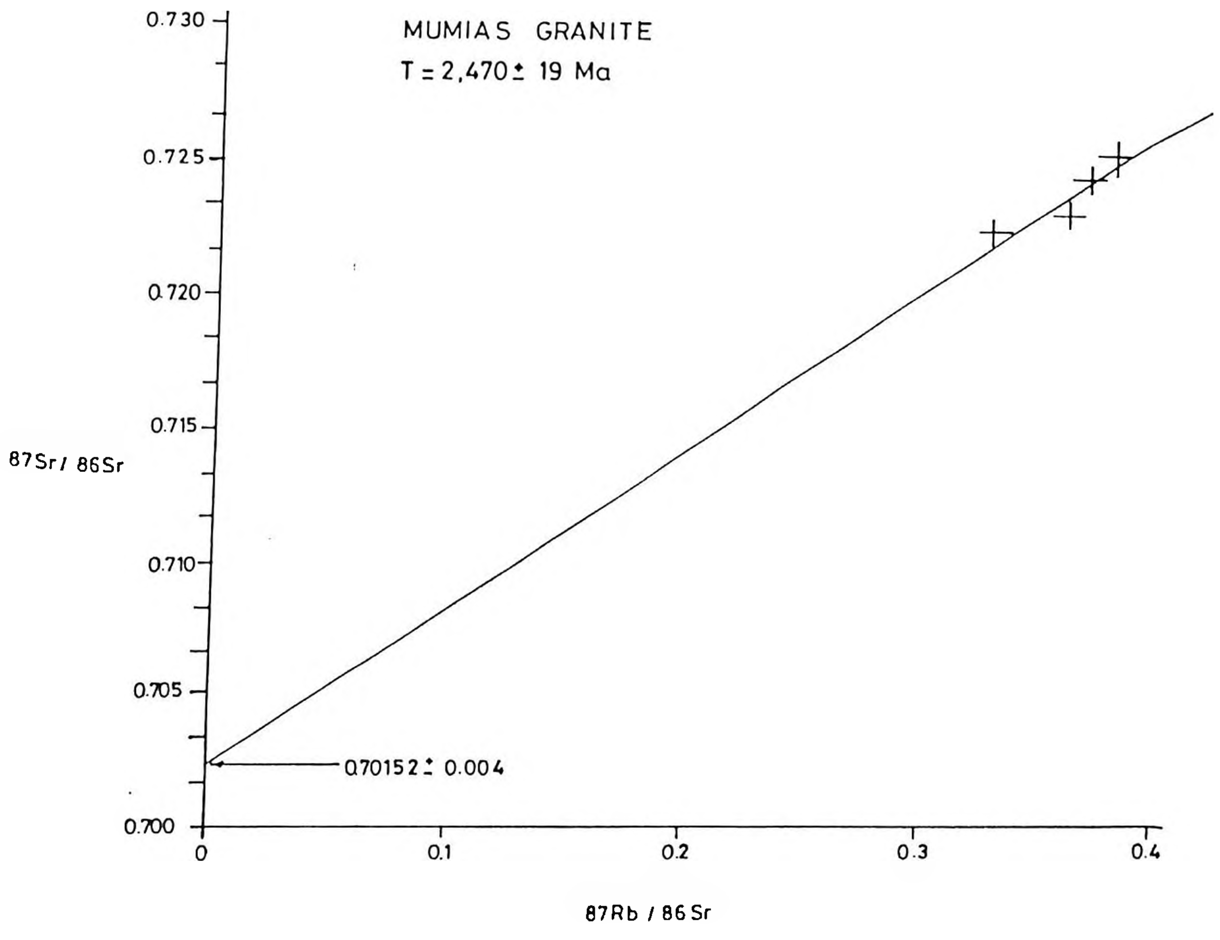


Fig.24 Rb-Sr data plot for Mumias granite.

concluded that the time of Mumias granite emplacement is between 2,400 Ma and 2,500 Ma.

The age of 2,600 Ma reported by Cahen and Snelling (1984) may have been erroneously obtained or the sampling was carried out on a much older granitic intrusion. The younger ages, Cahen and Snelling (1984) possibly represent a series of minor secondary intrusions or some small tectonic events which caused rubidium strontium resetting.

5.4 Summary

Chemical analysis of granitic pebbles which were obtained from the Kavirondian conglomerates, show that they were mainly tonalites and trondhjemites. They are characterised by higher plagioclase content than the presently intruding granites such as Mumias and Maragoli which are K-feldspars rich.

Chemical analysis of volcanic pebbles show that they were derived from basaltic, andesitic, dacitic and rhyolitic volcanic rocks.

Granitic and volcanic pebbles in the conglomerates show both tholeiitic and calc-alkaline trends and therefore they were derived from both tholeiitic and calc-alkaline magmas.

The chemical trends of oxides and trace elements of conglomerate matrices show that the matrices are enriched in ferromagnesian oxides and trace elements. These trends suggest that matrices were mainly derived from rocks which were rich in mafic minerals. The high ferromagnesian mineral composition of the matrices probably resulted from the high susceptibility of mafic rocks to both mechanical and chemical degradations on the earth's surface.

The Na_2O/K_2O ratios in the matrices indicate that the matrices are more enriched in Na_2O than K_2O. The hogher content of Na_2O is probably dependent on the detrital plagioclase which were derived from the weathering of granitic rocks during the weathering stage prior to sedimentation.

Archaean conglomerate matrices are K_2O depleted because K-rich granitic rocks were absent from the surface of Archaean terrains (> 2,600 Ma). Later granites (< 2,500 Ma) which include syn- and post-geosynclinal granites are extremely rich in K_2O probably due to renewed potassic magmatism.

The greywackes follow closely the chemical trends of matrices. The Na_2O/K_2O ratio is greater than 1.0. This ratio indicates the greywackes of the study area are mainly 'quartz intermediate'. Quartz intermediate greywackes are derived from granitic rocks. The quartz poor greywackes are derived from mafic rocks.

The calculated values of the Kavirondian greywackes show that on average the $Fe_2O_3 + MgO$ % is between 4.20 - 9.28 %, TiO_2 ranges between 0.20 and 0.80 %, Al_2O_3/SiO_2 ratio is 0.10 - 0.28, K_2O/Na_2O ratio ranges between 0.22 and 3.1. These values are similar to those accepted as depicting continental island arc type of tectonic setting.

The major element composition in mudstones are characterised by high K_2O, moderate Na_2O and low CaO. This excessive K_2O enrichment in mudstones is due to the presence of the original large quantities of illite which has already altered into muscovite. The mudstones are also enriched with boron (in excess of 69 - 107 ppm) as compared to other trace elements. High boron content in argillaceous sedimentary rocks in excess of 80 - 100 ppm depict marine sedimentation. The mudstones of western Kenya which are in excess of 69 - 107 ppm implies deposition in marine environment.

Chemical analysis of granitic and volcanic pebbles, conglomerate matrices, greywackes and mudstones show that they were derived from a multiplicity of sources which included older granitoids, volcanic rocks and recycled sedimentary rocks.

The results of radiometric dating indicate that the Mosocho conglomerate is 1,760 ± 131 Ma. The Kakamega conglomerate is 2,611 ± 311 Ma, Maragoli granite is 2,533 ± 75 Ma, Mumias granite is 2,470 ± 19 Ma and Wanjare granite is 2,361 ± 339 Ma.

Chapter 6

SEDIMENTOLOGY

6.1 Introduction

The Kavirondian Group sediments essentially consist of clastic rocks which show characteristics of fluvial and turbidity types of deposits. The clastic rocks which make up the Group have been derived from the erosion of the older rock suites in the area. On the basis of lithological variations, three major lithofacies have been recognised within the Group and they include the conglomerate, the greywacke and the mudstone. Sandstones occur as minor lenses within the greywackes and, therefore, are discussed as part of greywacke lithofacies in this section.

The conglomerate facies consists of clasts of volcanic rocks, granite pebbles, quartzite pebbles and a minor chert component. The conglomerate facies are subdivided into basal conglomerate sub-facies and resedimented conglomerate subfacies. These facies are described below in detail.

6.2 Conglomerate Facies

6.2.1 Basal Conglomerate Sub-facies

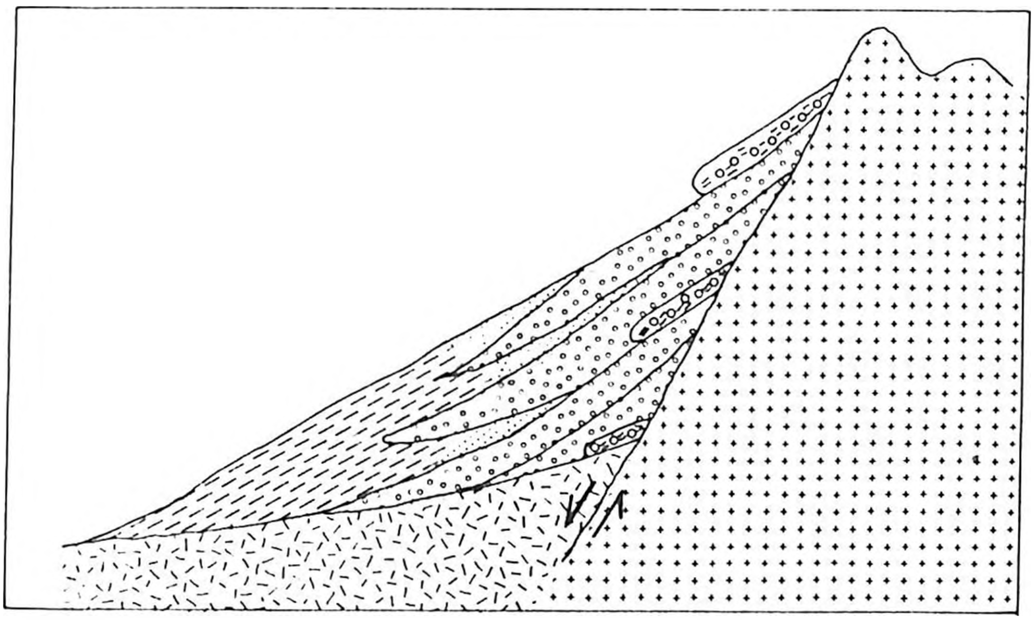
The basal conglomerate sub-facies are best observed both at Got Regea near Yala town and at Shivakala near Mukumu hospital. Got Regea forms a hill which is divided into two parts by a stream which follows a fault zone. On the northern side of the hill, this formation is made up of large boulders of granitic, gneissic and quartzitic origins. The cementing material of the boulders is largely medium sized pebbles, fine chert and quartz grains. On the southern side of the hill, the lithology consists of small pebbles which were derived from mafic and intermediate volcanic rocks. The pebbles are cemented by very fine matrix which is composed of sericite and chlorite. The boulders and pebbles which make up the sub-facies are well rounded but they are ungraded and poorly sorted. The maximum diameter of the boulders on the northern side of the hill is about 30 centimetres while the maximum diameter of the pebbles measured on the side of the hill is less than 17 centimetres.

The basal conglomerates found around Mukumu area consists of intermediate and felsic volcanic rocks which are cemented by fine volcanoclastic matrix. The individual beds of this formation reach a thickness of about 4 metres and their contacts with other beds are generally sharp. Imbrication is a common feature and the clasts are elongated with their long axes parallel to the bedding plane. The pebbles were probably stretched before sedimentation because it is unlikely that unstretched pebbles could have been tectonically rotated in a sandy matrix to lie with their long axes parallel to the bedding plane.

The middle bed of basal conglomerate in Mukumu area consists of conglomerates whose clasts are crudely bedded. The clasts vary from well-rounded rhyolite pebbles to rounded gneissic tonalite-granodiorite pebbles. This bed is about 8 metres thick. On an outcrop which is about 5 kilometres west of Mukumu hospital, the crudely bedded conglomerate is overlain by a bed of massive fine grained sandstone. This bed is about 5 metres thick. The thickness, linearity and the sedimentary structures of the basal conglomerate sub-facies indicate that its clasts were deposited in sub-aerial alluvial fan environment. The sedimentation of the basal conglomerates started as a result of vertical downward movements of the cratonic basement. The cratonic basement was composed of volcanic rocks of the Nyanzian Group and the early granite intrusions. The exposed, weathered crustal material and the debris formed were carried and deposited by braided rivers as alluvial fans, near the active tectonic faults. It was at this stage when the muddy matrix-supported gravel without imbrication or internal stratification and the clast supported commonly imbricated gravel with poorly defined sub-horizontal bedding (Fig. 25) were formed. During the second stage, the alluvial fans were apparently abandoned and a distal alluvial environment developed during which minor lenses of horizontally stratified and planar cross stratified sandstones were formed. In the third stage, there probably occurred a tectonic reactivation which again resulted in vertical movement. During this movement, the older mechanically and chemically weathered crust was eroded and redeposited as small alluvial fans. This debris was sorted into mature sandstones in the distal areas where it formed massive and sometimes laminated sandstones as indicated in Figure 25.

6.2.2 Re-sedimented Conglomerate Sub-facies

Resedimented conglomerate sub-facies are composed of well-sorted white quartz pebbles, brown pyritic quartz pebbles, red jasper and bedded cherts. The pebbles are covered by matrix of fine silica grains. The pebbles are rounded and form spherical to ellipsoidal clasts whose maximum diameter does not exceed ten centimetres. The pebbles form about 60% of the rock mass. The pebbles do not show signs of either compaction, deformation or grading although poor imbrication is



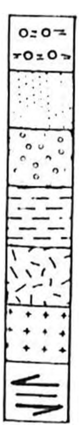


FIG. 25. DIAGRAMMATIC CROSS-SECTION OF ALLUVIAL FAN SHOWING PROXIMAL-DISTAL FACIES VARIATIONS BETWEEN MUKUMU AND YALA TOWN. (Modified from Rust and Koster, 1984)

recognisable. Dispersed granules and pebbles which form this sub-facies are matrix supported and point counting showed that 35% of one bed was composed of matrix. The contact with the underlying beds is sharp. The resedimented conglomerate sub-facies range in thickness from about half a metre to about twenty metres. At Muruanda school near Bukura, one outcrop has some clasts with long axes perpendicular to the bedding plane and on another bed, the largest clasts project above the top of the bedding plane. Sometimes, the beds of this sub-facies have their residual materials enriched with aluminium hydroxide and ferric oxides. These beds are, on the other hand, impoverished in lime, magnesium and alkalis. Silica is sometimes also removed. This process leaves little else than aluminium and iron oxide and the final product of the process is formation of laterite. Laterite is a common feature around Kwisero, Bukura and Muruanda (see Plate 28).

The primary structures recognised in the re-sedimented conglomerate sub-facies suggest that the pebbles were deposited during a mass movement. During the movement there was apparently no bedload rolling clasts and therefore the clasts were not free to move relative to each other. The movement and the fabric of the pebbles were controlled by the transporting medium. The pebbles generally show that the long axes are parallel to the direction of the flow and they normally dip upstream. When the debris flow finally reached the edge of the canyon, due to permeability created by the spaces between individual pebbles and infiltration of water through the sediments, its flow diminished rapidly. During the process of infiltration, most of the finer sediments were carried further a field into the mid-fan and beyond thereby giving rise to widespread lobes of unconsolidated clasts in the upper-fan (see Plate 29). Later, in course of burial the clasts interstices were filled with fine matrix. The resultant lithified sediments did not produce graded bedding,

PLATE 28. The photograph shows an outcrop of resedimented conglomerate near Bukura. The darker portions on the upper section of the photograph are zones of laterite.

PLATE 29. The photograph shows an inverse to normal resedimented conglomerate near Kwisero market. The darker portions are ridges formed by the cherts and quartz pebbles which are resistant to erosion.

cross-bedding or stratification. Some of the pebbles were, however, carried beyond the slopes of the basin into the supra-fan and the lower fan where they have been observed in sandstone, greywacke and mudstones. A schematic diagram of resedimented conglomerate at an outcrop near Ndiru School in South Nyanza is shown in Fig. 26. This is an outcrop which is about 11 metres long and about 5 metres wide. The outcrop consists of thinly to very thick bedded clast supported quartzite and chert gravels which typically display inverse to normal grading. On some beds, the gravels pass upwards into pebbly coarse-grained sandstones. The sandstones show sporadic stratification. The laterite zones on this outcrop are generally more brownish in colour than those which have not turned into laterite. The laterite zones apparently occur on the more fractured sections of the outcrop where minor faults have been observed. It appears that more water was able to pass through those fault lines thereby hastening the process of laterite formation.

6.3 Greywacke Facies

Greywacke facies identified in the study area include thickly bedded sub-facies and thinly bedded sub-facies. The facies are generally graded, and sometimes alternate with thin siltstone and mudstone beds. Graded bedding is the main primary structure in the greywackes. Graded bedding occurs in most of the outcrops where it is rendered conspicuous by darkening of colour concomitant with the upward decrease in grain size. Sole marks occur at the bases of some beds but they are not clearly visible because of induration that has suppressed the tendency to part along the bedding plane contacts. Other sedimentary structures include the flame and convolute structures. The close association of the flame and convolute structures within beds that show planar lamination imply that they were penecontempora-

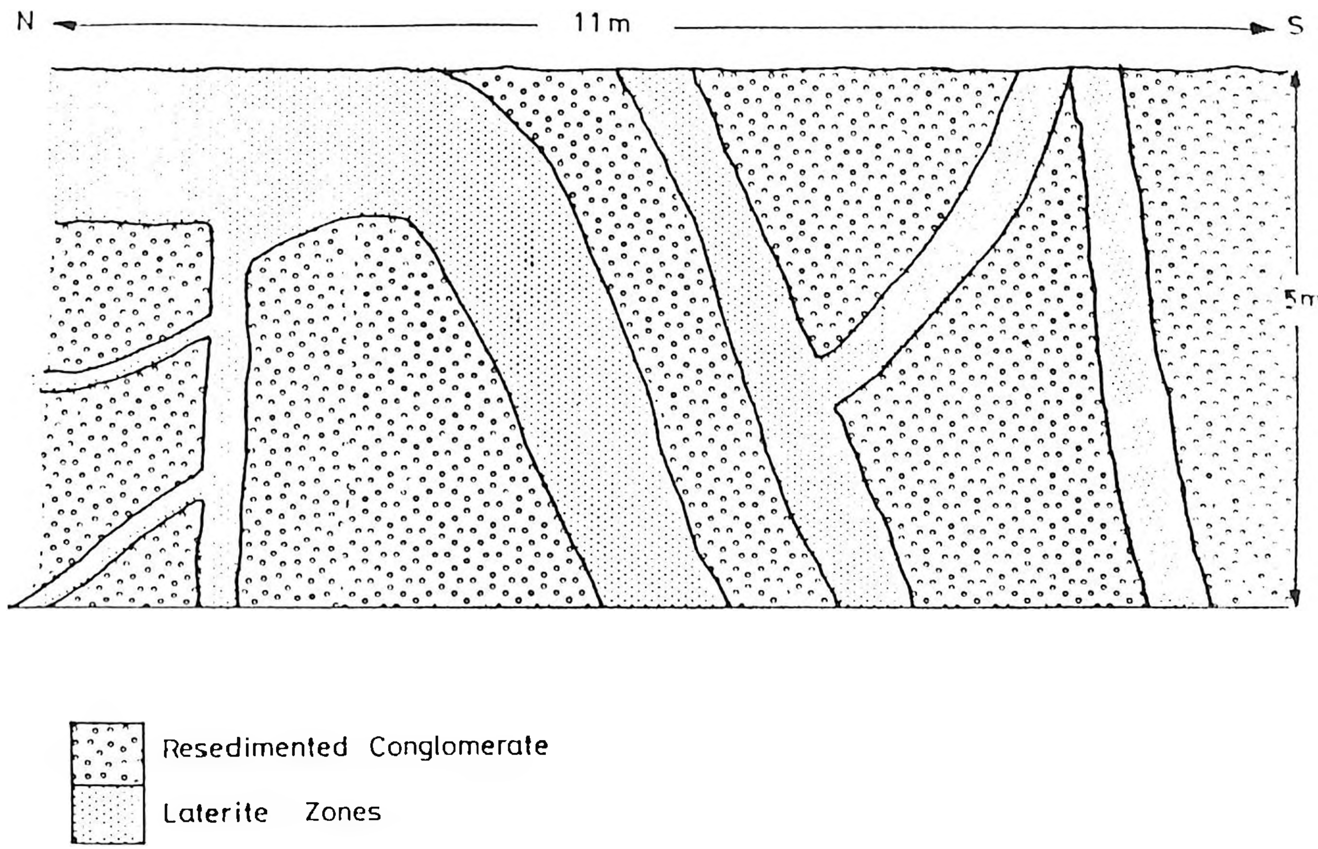


Fig. 26. A schematic diagram showing resedimented conglomerate which have partly altered into laterite at Ndiru swamp near Ndiru school.

neously formed within the soft sediments and that they are not post-consolidation structures. Bouma (1962) sequences of internal sedimentary structures are present in the greywacke beds. The sequences normally consist of basal graded division A, a lower parallel laminated division B, and a ripple laminated division C, followed by upper parallel laminated division D (see Plate 30). The sequence ends up at the top with pelitic division E. The divisions are best observed on the greywacke outcrops along the Yala river between Igukhu and Kwisero. On this stretch of the Yala river, divisions present on individual beds occur consistently in the sequences. Incompleteness of the Bouma sequences on individual outcrops suggest that sediments were deposited by waning turbidity currents. The turbidites that occur at the base with one of the higher divisions of the Bouma sequence, for example, division C, were deposited initially from a current during a lower flow regime than those beginning with the coarser graded division such as A.

Thickly bedded greywacke are found in a 47 metre wide transverse section at Igukhu where the sediments are coarse at the base and grade to finer textures at the top of the bed. This sequence of coarse grained sediments occurring at the base of the bed and fining upwards is repeated in several beds thus forming cyclic sedimentation. In general, the maximum framework grain size ranges from 0.1 to about 2 millimetres in diameter. The mean grain size is, however, between 0.3 and 0.7 millimeters. Though most of the beds are indurated, they appear to be smooth at the bottom surfaces and on some beds, flame structures and other load casts are well developed. At Igukhu, the thick bedded greywackes pass upwards into thin bedded siltstone and then mudstone.

The thickest bed measured on this section was about 4 metres and the greywacke-mud ratio on the bed was about 10:4. Mudstone fragments are common within the

PLATE 30. The photograph shows a greywacke outcrop which is found about two kilometres south of Kojero market. Observed on the top are graded beds which show A, B and C divisions of Bouma sequences. The visible black quartz veinlets have branched from a nearby "Giant Quartz Vein" at New Kisa.

PLATE 31. The photograph shows a block broken from graded greywacke beds near Khayega. The grains are coarse at the base of each bed and become finer up the bed as is indicated by the pencil. Some of the beds show complete Bouma sequence.

greywacke beds. The fragments are generally imbricated and appear to be aligned parallel to each other and to the bedding plane. On the upper parts of the bed, the greywackes are interbedded with mudstones and the interbeds show very fine laminae.

Within the thick bedded greywacke sub-facies, the graded division A of Bouma sequences is best represented. This division occurs mainly at the base of the massive beds (the lower few centimetres). The sequence then rapidly changes to division C without division B representation. On one outcrop on the banks of the Yala river about four kilometres south of Bushiangala School, division A, C and D weres observed. Division A started with coarse sediments which showed no distinct sedimentary structures. The contact between division A and C was sharp and division C consisted of fine scour structures at the base followed by a set of ripple marks in the middle of the bed and then continued gradually to division D.

The thinly bedded greywacke sub-facies beds are characterised by sharp and planar bases. The beds have a chaotic internal structure which apparently make them brittle, and therefore, break with subconchoidal fracture. These beds display graded bedding in the lower parts. The upper parts of the beds have parallel laminations which are sometimes interrupted by small scale folds. These microfolds sometimes covers a whole bed.

In the upper parts of the thinly bedded greywacke, the sediments grade to the upper laminated division and the silty laminations disappear. The colour of the sediments show faint darkening as the silt content decreases. On some beds, the contact between the silty mudstone and dark brown clayey mudstone is sharp The silt charged mudstone appear to represent the final fall-out of the materia brought in by the waning current while the clayey mudstones are a suspensio deposit.

The characteristic environmental feature of the greywacke facies is the repeated sequence of greywacke-mudstone couplets (see Plate 31). The greywacke which occur within the cyclic sequences resemble many recently described greywackes in modern environments (see Nilsen, 1980; Mutti and Rucci Lucchi, 1975; Walker, 1967). The petrography of greywacke and primary structure characteristics suggest that they were deposited by turbidity currents. Lack of primary structures in some greywacke beds suggest that some sections of depositional medium were non-agitated. The repeated cyclicity of the sediments from coarse grained greywacke facies to fine grained thin bedded facies imply that the turbidity currents were periodically revisiting the basin of deposition and that the fine grained facies were deposited as background sediments deep in the basin.

The beds of greywacke facies have an array of features which are characteristic of turbidity current deposition. Field relationship and the primary structures reveal that in the course of their accumulation the turbidity currents were restricted to marine fans in the deeper parts of the basin. The fan deposits resulted into thickly bedded deposits with proximal characteristics while the fine grained thin bedded turbidite deposits which were initiated from the local slumps within the fans and from the adjacent active valleys resulted into mixed proximal and distal facies composed of mixed silt beds and mudstones. This kind of sediment mixing was observed on the banks of the Yala river about 10 kilometres south-east of Kwisero where immature sandstones are mixed with mudstones thus forming amalgamated deposit which contained several syn-sedimentary faults. On the seaward side of the fans, distal deposits were exclusively deposited.

During this study, it has been observed that sediments which ultimately formed greywacke facies were emplaced by turbidity currents which flowed into the basin across a series of large sub-aqueous fans. On these fans, greywackes were deposited as monotonous regular successions of graded beds which show no features indicative of agitated water. The facies were therefore, deposited by turbidity currents in water that was too deep to experience regular disturbances generated by storms.

From the study of primary structures, it is clear that in the course of accumulation of the thickly bedded greywackes, the turbidity currents were restricted to depositional valleys on submarine fans. Here thickly bedded proximal sediments were deposited. The thin bedded greywacke sediments were, on the other hand, deposited within the intervalley basin beyond the fans as distal deposits.

Finally, there appears to be a transitional depositional environment between the thinly bedded greywacke beds and mudstones at the mid-fan. Here, both facies have similar distal characteristics. The turbidite fans on which the greywackes were deposited are indicated on Fig. 27. On this schematic diagram, the source of the sediments is shown to be the island volcanoes which formed the Nyanzian Group volcanic rocks. Another major source of the sediments were the early granite intrusions which have since been eroded and only rarely do they occur as outcrops today. The greywackes and other sediments were intially eroded from the uplifted island volcanoes and granite intrusions and transported in fluvial medium. The sediments initially formed alluvial fans at the bases of the elevated terraines. On these alluvial fans, basal conglomerates were formed. Later, some of the sediments on the alluvial fans were transported to palaeobasins which apparently existed at the bases of the volcanic islands. Once in the palaeobasin, the sediments were distributed throughout the basin by turbidity currents. It was during this stage of

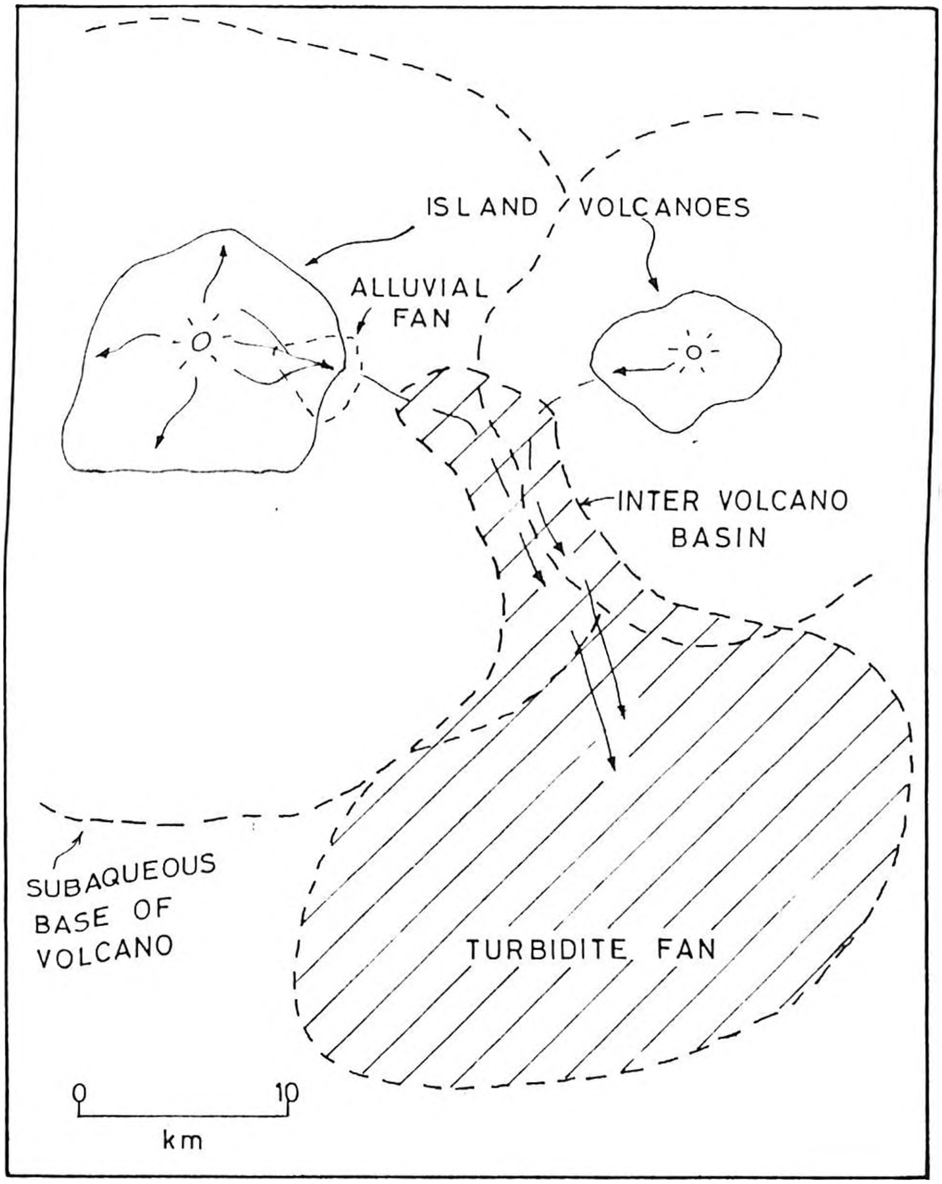


Fig. 27. A schematic diagram showing the distribution of sedimentary facies relative to coalescing and overlapping volcanoes, the tops of which form islands. (After Ayres and Thurston, 1985)

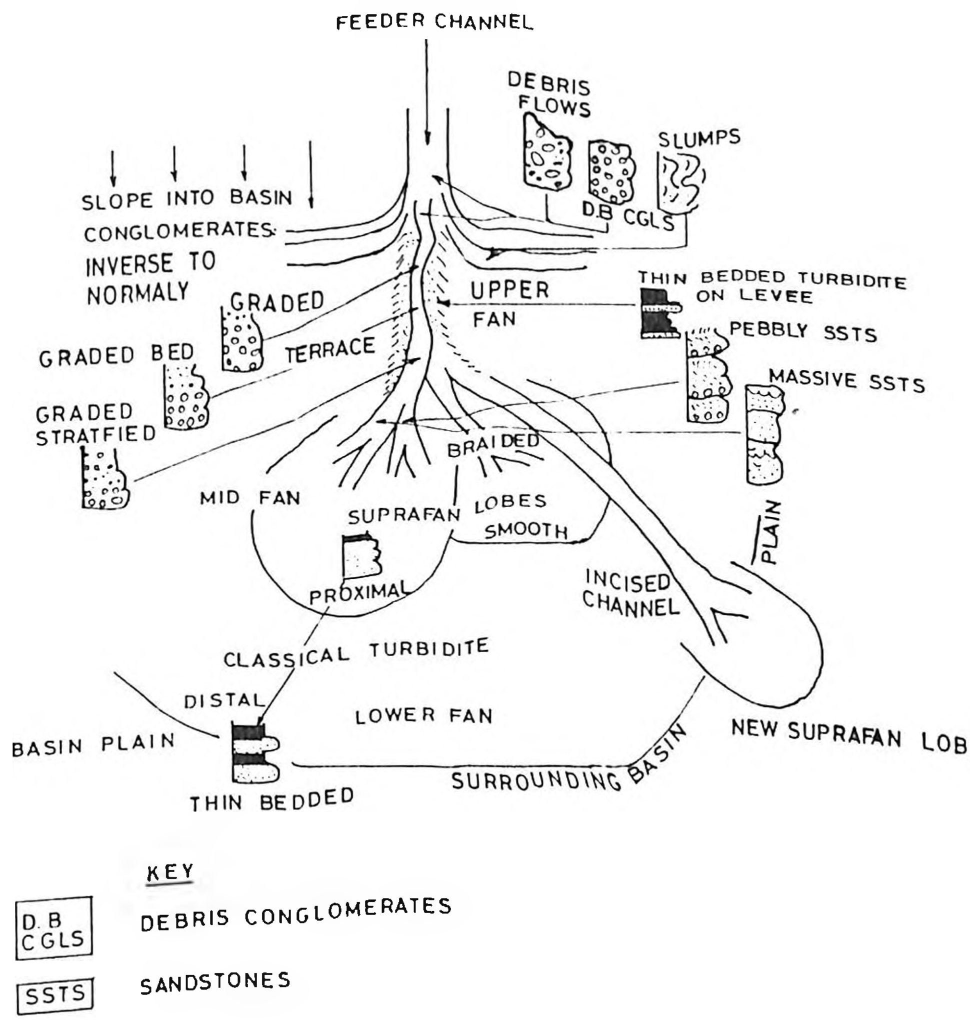


FIG. 28. MODEL OF SUB MARINE FACIES DISTRIBUTION WITHIN THE KAVIRONDIAN GROUP (model after walker, 1977)

sediments distribution by the turbidity currents that the resedimented conglomerates, lenses of sandstones, greywackes and mudstones were formed. On Fig. 28, a model of submarine facies distribution within the Kavirondian Group is shown. The model illustrates the divisions of a turbidite lobe which include the upper fan, the middle fan and the lower fan. The resedimented conglomerates were deposited on the margins of the feeder on the upper fan and the incised channels of the mid and lower fans. The greywackes and mudstones were deposited in the mid and lower fans.

6.4 Mudstone Facies

Mudstone facies are composed of soft, dark-grey to dark brown sediments which form the fine grained member of the Kavirondian Group. The sediments are sometimes accompanied by anomalously coarse detrital sediments which contain minute grains of pyrite and graphite. Mudstone outcrops near Mudaa School and Viyalo market are blocky and extensively jointed and they show colour change within the same beds laterally (see Plate 32). The primary structures encountered within this type of mudstone include convolute lamination, graded bedding and flame structures. Some of the beds persist laterally for over thirty metres after which they grade into silty mudstones and finally into greywackes. Most of the beds are about 40 centimetres thick. At one station near Emutsasa, it was observed that mudstone sediments are interrupted by intruding coarser graded greywacke which form lentils which are about 2 centimetres thick. The bases of these intruding greywacke beds contain quartz grains which measure up to gravel size.

The second type of mudstone is generally cleaved and show bands of lighter colours which alternate with darker ones. Along the bedding planes, mica flakes are

PLATE 32. The photograph shows an outcrop of thickly bedded mudstone near Mudaa school. The individual beds are blocky and are separated from one another by horizontal joints.

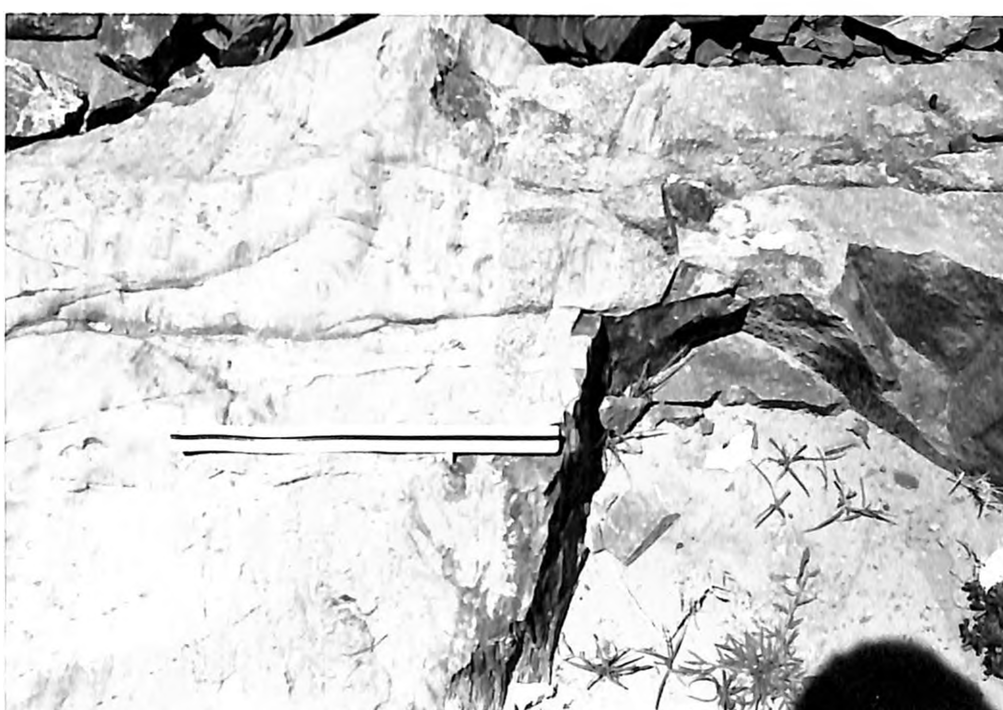


PLATE 33. The photograph shows finely banded mudstone beds which have been penetrated by coarse grained greywacke on the upper right hand side. The grains become coarser from the right hand side of the photo to the left side. Note the especially coarse band above the ruler. The photograph was taken on the Yala river banks about 2 kilometres south of Kojero market.

detrital gritty mudstones which laterally grade into greywacke. The beds have sharp bases and they are normally about 9 centimetres thick. Internal structures found in these mudstones include parallel lamination, cross lamination and a few ripple drifts. At Sianga, longitudinal ridges and groove marks were observed on an outcrop exposed by a road cut. Other structures commonly found on this type of mudstone are syn-sedimentary deformational structures such as small scale slumps, syn-sedimentary faults and clastic dykes (see Plate 33).

6.3 Development of the Kavirondian sediments in western Kenya

The western Kenya Archaean supracrustal succession differs markedly from the other better understood Archaean terranes in the southern hemisphere. Detailed geological mapping of the area indicates that, no komatiite or ultramafic rocks (Anhaeusser, 1969) which are commonly reported in the South African and Australian Archaean terrains were never intruded or at least revealed after progressive erosion of the younger rock suites (see Appendices C1, C2 and C3). The lower volcanic suites which are usually dominated by komatiite basalts in most of the other Archaean belts, especially in southern hemisphere, Engel et al. (1968), Anhaeusser et al. (1969), Engel et al. (1974) and Condie (1981) are curiously absent. The characteristic suites within the western Kenya Archaean terrain are minor tholeiitic basalts and thick calc-alkaline volcanic rocks which are dominated by andesite, dacite and rhyolite rocks. These rocks sometimes occur as individual rock type suites and at other times, they occur as pyroclastic deposits in which all the three rock types are represented. Condie (1981) proposed that the Archaean calc-alkaline volcanic rocks were largely formed between 2,700 and 2,600 Ma. This alkaline volcanic rocks were largely formed between 2,700 and 2,600 Ma. This age, however, can only be the lower age limit of the Nyanzian Group because the upper age limit of the diapiric granites which are younger than the Kavirondian Group is about 2,400 Ma (see chapter 5). The age of the Nyanzian Group therefore lies between 2,900 and 2,700 Ma. Goodwin and Smith (1980) attributed formation of the calc-alkaline volcanic rocks to down sagging and partial melting of earlier mantle derived volcanic rocks. Through sag-subduction the mantle derived volcanic rocks produced felsic magma in their lower parts.

The present model (Fig. 29) is built on the fact that the western Kenya Archaean belt formed in a parallel faults-bounded trough in unstable thin primitive sialic crust. According to Anhaesser et al. (1969), Viljoen and Vijoen (1969), and Glikson (1972), basins formed within such troughs could have developed as in situ depositories by progressive down sagging of the overlying heavy volcanic piles. The model starts with the extrusion of basaltic and andesitic rock suites which were surrounded by contemporaneous or older granites. A major mantle tapping fracture is proposed on the margins of the troughs through which felsic magma was later injected on to the underlying mafic volcanic rocks (see chapter 2). Presence of pyroclastic debris within the basins provokes the view that the basin was possibly subaerial. Due to the increasing weight of the volcanic piles, the basin started sagging downwards into a thin, unstable, primitive crust.

The downsagging process increased the depth of the basin and erosion commenced. During the next phase of development, argillaceous sediments eroded from the already existing volcanic rocks and older granites were deposited in the much deeper and wider basin (see chapter 4). The increased depth and width of the basin probably initiated turbidity currents which promoted turbidite sedi-

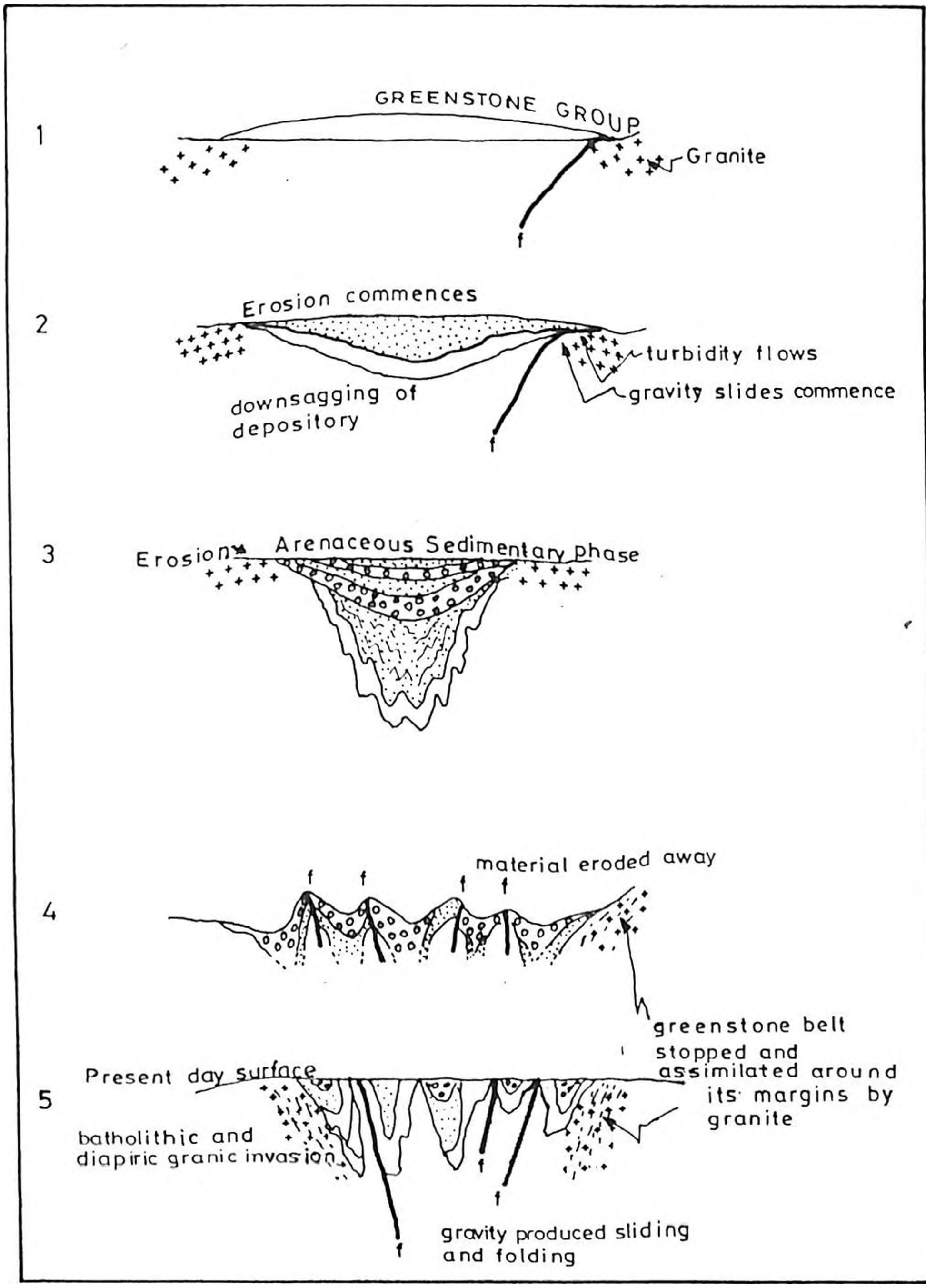


FIG. 29. DIAGRAMMATIC MODEL SHOWING THE EVOLUTIONARY DEVELOPMENT OF THE ARCHAEAN SEDIMENTS IN WESTERN KENYA.
(Modified from Auhaeusser, 1969)

mentation. On the basin margins, the older granites continued to be elevated in order to compensate for the down sagging volcanic rocks. Surface erosion of the older Archaean granites and the volcanic rocks could also have contributed to the Proterozoic granite elevation (see Appendix C1).

During the third stage of basin development, the basin continued to downsag thereby increasing the vertical compression on the volcanic rocks and the earlier formed sediments due to the force of gravity thereby causing gravity deformation. The rock suites in the central part of the basin started forming pronounced folds which are attributed to gravity deformation which resulted from increased vertical pressure of overlying sediments and the lateral compression from the margins of the brittle older granites. The increased depth of the basin due to increased sediment weight, coupled with increased elevation of older granites and reworking of the volcanic rocks gave rise to renewed phase of erosion, during which cratonic type, arenaceous, marine sediments were deposited. These sediments were deposited alternately as coarse and fine grains depending on whether they were regressive or transgressive deposits. The older granites were at this stage waning rapidly due to high rate of uplift and the consequential erosion. Cratonic type of sediments are also believed to have given rise to temporary basin stability. During this stage, all the older granites which were trondhemitic and tonalitic, which covered the basin margins, had been eroded into the basin. Their remnants could only be traced through boulders and pebbles within the arenaceous facies of sedimentary formations.

The basin continued down sagging and due to increased temperature and pressure, on the lower parts of the sagging depository, partial melting ensued. Partial melting gave rise to crustal weakness of the basin and along some points of weakness, gravitational sliding of the upper rock suites formed a series of almost vertical parallel faults. On the margins of the basins where the mantle tapping fractures had already been incorporated, renewed intrusion of batholiths and diapiric granites started. These are the present granite bodies observable on the fringes of greenstone belts in western Kenya (see Fig. 11).

In the final stage of the basin development, most of the upper parts of the basin which had initially well developed folds, which were separated among themselves by normal and thrust faults, were extensively eroded thereby leaving mosaics of the original volcanism, sedimentation and later tectonism (see Fig. 29).

6.6 Summary

In the Archaean Kavirondian sedimentary belt of western Kenya, two facies associations have been defined by the author. The facies associations include the continental association and the marine association.

The continental facies association is composed of basal conglomerates which were apparently transported in fluvial environments from regions of high relief to the basin margins where they were deposited as alluvial fans.

The marine facies association include resedimented conglomerate facies, greywacke facies and mudstone facies. The marine facies contain an array of primary structures which are characteristic of turbidity currents deposition. In the course of accumulation, the turbidites were restricted to some marine fans which resulted in thick beds which bear proximal signatures on the upper fan and the mid fan. The thin bedded fine grained distal sediments were deposited on the lower fan.

The Kavirondian sediments were formed in down-sagging basin which was initially covered by volcanic rocks and older granitic intrusions. Increased sagging of the basin made it deeper thereby initiating turbidity currents. These currents carried sediments from basin margins to the centre of the basin where they were deposited as turbidites. An unconformity was noted by the author between the continental facies association and marine facies association.

Chapter 7

DISCUSSION AND CONCLUSIONS

The Nyanzian Group volcanic rocks which are unconformably overlain by the Kavirondian sediments are the oldest rocks found in the study area. The Nyanzian Group, the Kavirondian Group and the older granite intrusives form a narrow belt of Archaean greenstone rocks which belong to the Nyanzian Shield. The Nyanzian Shield extends from Central Tanzania through the eastern margin of Lake Victoria to western Kenya and eastern Uganda.

The Nyanzian shield forms one of the twenty seven stable cratonic nuclei which were recognised by Goodwin (1977a) throughout the world. Like in the other shields, the western Kenya greenstone belt went through a transition during or at the end of Archaean, from crustal instability to relative crustal stability. This cratonization process was marked by transition from earlier granitoid plutonism which is today marked by very few isolated outcrops, through extensive marine volcanism and the preceding sedimentation to the late Archaean/early Proterozoic plutonism. The greenstone development apparently started around 2,800 Ma and came to an end around 2,400 Ma (Dodson et al., 1975). During the cratonic development prior to the final craton stabilization, silica-magnesium to silica-aluminium transformation process took place and through this process, a stable cratonic crust was eventually produced.

The granite pebbles have been observed to contain higher Na_2O than the post-Kavirondian granites. The latter granites are more enriched in K_2O. The higher Na_2O in the pre-Kavirondian pebbles suggests that the pre-Kavirondian granites were especially rich in plagioclase. Geochemical data show that these rocks were mainly trondhjemites and tonalites. The pre-Kavirondian sodium rich granites are associated with the early unstable developing craton while the K-rich post-Kavirondian granites are associated with stable craton which was undergoing renewed activation.

The petrographical and chemical characteristics of the Kavirondian conglomerate pebbles indicate that they were derived from a multiple of sources which include volcanic rocks, granitic rocks and recycled sedimentary rocks. The petrographic compositions of the volcanic pebbles resemble those of the rocks of the Nyanzian Group and therefore it is observed that the Nyanzian volcanic rocks which flanked the basin of deposition partly provided the coarse clastic material which formed the conglomerates. The volcanic pebbles show that the Nyanzian .volcanic rocks were formed as a result of a progressive bimodal development of volcanism which involved early tholeiitic basaltic magma through intermediate magma to dacitic-rhyolitic calc-alkaline magma. The major and trace element distributions indicate that the volcanic rocks evolved by fractional crystallization which proceeded from mantle derived high iron tholeiitic magma to low iron andesitic magma. Other sources of the generally scarce intermediate rocks in the greenstone belt could have been fractionation of basalts, mixing of basaltic and felsic magmas or direct mantle melts. The areally extensive felsic volcanic rocks were probably generated in fractionated felsic magma chambers with variable amounts of major and trace elements zonation. These zoned felsic magma chambers could have been produced by large scale anatexis of older sialic crust. The granitic pebbles are also very common in the conglomerate facies. Geochronological data which were obtained after analysing the granitic pebbles show that the pebbles are older than the granites of the presently existing granite intrusions such as the Mumias and Maragoli granites and therefore hinterland of granitoid rocks existed prior to the deposition of the Kavirondian sediments. These pre-Kavirondian granite rocks contributed immensely to the Kavirondian sedimentation as they were weathered and eroded. They are, however, very rarely found as outcrops today. Presence of bedded cherts, jasper and chalcedony as pebbles and matrices in the conglomerate facies indicates previous diagenetic differentiation of chemical precipitates, especially siliceous muds which led to the formation of the bedded cherts and other chemical precipitates prior to the Kavirondian sedimentation. These chemically formed rocks were probably formed in a basin with reducing conditions as is indicated by presence of chamosite, siderite and pyrite in the mudstones. The geochemical data of the mudstones, greywacke and the matrices of different rock types indicate that the basic, intermediate and felsic volcanic rocks and the older granitoids were the main contributing components for the Kavirondian sediments. Presence of recycled sedimentary fragments in the greywacke suggest sedimentation cyclicity. The cyclicity was also noticed during field mapping through sudden lateral and vertical changes of lithofacies within short distances.

According to Bhatia (1983) major elements undergo some changes during sedimentary processes. In most sedimentary basins, silica oxide is enriched while sodium oxide and calcium oxide are depleted in sandstone and greywacke compared to the source rock composition due to plagioclase albitization. The major element compositions give clues as to the provenance type and the weathering conditions, both of which are controlled by the tectonic setting of the basin. Diagenesis also influences the bulk composition of sandstone but the nature of diagenesis is itself dependent on the tectonic setting of the basin. In order to discriminate the tectonic setting, the most useful discriminating parameters are Fe_2O_3 + MgO, TiO_2, Al_2O_3/SiO_2, K_2O/Na_2O and $Al_2O_3/(CaO + Na_2O)$ ratios. Iron and titanium are also useful because of their low mobility and low residence time in sea water. Although magnesium has a high residence time in sea water, it will remain unchanged in the continental margin type sandstone deposited by turbidites during burial because of the low permeability of the rocks. The ratio of Al_2O_3/SiO_2 gives indication of the quartz enrichment in sandstone. The K_2O/Na_2O is a measure of the K-feldspar and mica versus plagioclase content in the rock and the $Al_2O_3/(CaO + NaO_2)$ parameter is a ratio of the mobile elements. In principle, there is a decrease in Fe_2O_3 + MgO, TiO_2, Al_2O_3/SiO_2 and an increase in K_2O/NaO_2 and $Al_2O_3/(CaO + Na_2O)$ as tectonic setting changes from oceanic island arc, to continental island arc, through active continental margins to the passive margin type.

The oceanic island arc sandstone are conventionally characterized by high Fe_2O_3 + MgO (8-14%); high TiO_2 (0.8-1.4%); high Al_2O_3/SiO_2 (0.24-0.33); low K_2O/Na_2O (0.2-0.4) and low $Al_2O_3/(CaO + Na_2O)$ (1-2). The continental island arc sandstone are conversely discriminated from the oceanic island arc type by their lower Fe_2O_3 + MgO (5-8%); lower TiO_2 (0.5-0.7%);lower Al_2O_3/SiO_2 (0.15-0.20); higher K_2O/Na_2O (0.4-0.8) and higher $Al_2O_3/(CaO + Na_2O)$ (0.5-2.5).

The calculated values of the Kavirondian greywacke and sandstone show that Fe_2O_3+MgO ranges between 4.20 - 9.28%. The TiO_2 ranges between 0.2 - 0.8%, Al_2O_3/SiO_2 ranges between 0.10 - 0.28 and K_2O/Na_2O ranges between 0.28 - 0.81, $Al_2O_3/(CaO + Na_2O)$ is 0.22 - 3.1.

The values of the discriminating parameters obtained for the Kavirondian greywacke suggest that the sediments were deposited in a continental island arc type of tectonic setting. The continental island arcs are sedimentary basins adjacent to island arcs formed on a well developed continental crust or on thin continental margins. These correspond to detached and noncontracted type arc-trench systems, respectively. The arcs of this tectonic setting are continental fragments detached from mainland. Sediments are deposited in inter-arc, back-arc and fore-arc basins and are mainly derived from felsic volcanic rocks. Back-arc basins formed on the continental side of the island arc are included in this setting.

Due to the dynamic changes which have taken place in the recent years in stratigraphic terminology, some of the older stratigraphic terms which are used to describe the lithological units of the study area have been revised in this work. The term "system" which has been used over the years to describe the Nyanzian, the Kavirondian and the Dodoman has been replaced with the term "Group". The term "Group" has been found to be more suitable and informative because it has a pure lithostratigraphical connotation. Groups are normally defined using lithological variations criteria. The term "Group" has furthermore been internationally accepted as the formal term which describes a combination of two or more "Formations". The "Kavirondian Group" has therefore been proposed in this work as the formal name for the sediments of the Archaean age which are exposed in western Kenya. The Kavirondian Group was divided into four formations on the basis of lithological variations. Formations are the primary formal units of lithostratigraphic classification and are the only formal lithostratigraphic units in which the stratigraphic columns everywhere should be divided completely on the basis of lithology. The names of the formations are adopted from local geographical features where stratotypes are found.

The Shivakala Formation is the stratigraphically lowest in the Archaean sedimentary succession. It is characterised by conglomerate beds and unconformably overlies the older Nyanzian volcanics. Two distinct types of conglomerates have been observed in the study area. One variety contains abundant granitic boulders. The granitic boulders are certainly not derived from the presently outcropping granite intrusions. The absolute age of the granitic pebbles within the conglomerate is about 2,600 Ma while the age of the presently outcropping bodies is about 2,400 Ma. Furthermore the presently outcropping granite bodies intrude the conglomerate beds and some conglomerate pebbles have been observed in the younger granite bodies where they occur as xenoliths at Maragoli. The other variety of conglomerate contains pebbles of volcanic material and some pyroclastic rocks.

Another Formation of the Kavirondian Group is the Igukhu Formation. The formation is characterised by greywacke beds. The term "greywacke" has been used in this work to replace the term "Grit" which has been used by the previous workers in the area over the years. The term "greywacke" has been adopted because it implies an indurated sedimentary rock which is composed of rock fragments, angular or rounded grains and splinters of quartz and feldspars which occur in hard matrix. This definition apparently matches the rocks which have been observed in the field as opposed to "grit" which is simply a coarse sandstone whose main distinguishing characteristic is angular grains. The Igukhu Formation overlies conformably the Shivakala Formation. Two types of greywacke have been recognised in the study area. The first one is highly feldspathic and contains quartz, feldspar and abundant biotite grains. Its matrix is composed of recrystallised fragmental quartz, feldspars, biotites and sericites. These minerals were recrystallised during low-grade metamorphism. The second type of greywacke contains varying proportions of different rock fragments which include mudstone fragments, volcanic rock fragments and some granitic rock fragments. The rock has a fragmental texture and contains large quartz and feldspar grains which are embedded in the fine grained matrix of quartz, feldspars, biotite and flakes of sericite and chlorite.

Mroda Formation is composed of sandstone. The name of the stratotype section is derived from a small locality where sandstone crops out between greywacke beds and mudstone beds. The sandstone beds are also widely scattered as minor lenses and tongues between conglomerate beds and greywacke beds. Due to the scattering of the sandstone lenses, they cannnot be easily assigned to a specific lithostratigraphical position in this succession. Sandstones are light green in colour. The rocks contain black clear grains of quartz and white feldspars. The rocks are feldspathic and most of the ferromagnesian minerals have altered into chlorite. Few grains of augite have, however, been observed and epidote occurs in fairly large quantities.

Mudaa Formation which is characterised by mudstone forms the upper-most part of the sedimentary succession. However, mudstones sometimes occur as minor lenses interbedded with greywacke thereby forming cyclic sedimentation. The mudstones are bluish green rocks which consist of rounded to sub-rounded grains of quartz and feldspars. The accessory minerals include chlorite and epidote. On the contacts with the major intrusives, the mudstone has developed metamorphic aureoles which are marked by formation of honfels. Near the mudstone-granite contacts, andalusite and cordierite are the main minerals.

Metamorphism in the fine grained members of the Kavirondian sediments has led to the development of sericite, chlorite and biotite. These minerals impart schistosity to the argillaceous sediments especially those close to the major intrusions. Major reconstitution by metamorphic minerals was, however, not noticed in the coarser grained sediment varieties such as the greywackes, although their fine grained matrix has developed schistose structures.

Within the more mafic conglomerate pebbles, the original mineral assemblages have undergone re-crystallization leading to the development of metamorphic minerals characteristic of greenschist facies. The minerals include chlorite, epidote and tremolite. Characteristically, these minerals indicate abundance of water throughout metamorphism. In the more felsic varieties, epidote and actinolite have been replaced by hornblende and micas. A general observation on all the sediment types is that they have been affected by post-crystallization catalysis which was accompanied by hydrous retrogressive metamorphism. This is especially so along the granite and sediments contacts and along the 'Giant Quartz Veins' and sediments contacts.

During this metamorphism which is attributed to the last stage hydrothermal solutions which were produced during the emplacement of the early Proterozoic granites and probably giant quartz veins, most of the feldspars were altered into sericite and epidote.

Through radiometric dating, Windley (1976) divided all the greenstone belts in the world into two major temporal groups. The older greenstone terrains formed between 3,500 Ma and 3,000 Ma. These greenstone belts are preserved in Pilbara block in Australia and Barberton Mountainland in South Africa. The younger greenstone belts were formed between 3,000 Ma and 2,700 Ma and the western Kenya greenstone falls in this group. The data obtained by the previous workers show that the western Kenya greenstone belt dates from 2,800 Ma. Pre-Nyanzian granite indicates an age of about 2,800 Ma (Dodson et al., 1975). An age of 2,700 Ma for the pre-Kavirondian Migori granite was reported by Cahen and Snelling (1984). Data obtained during this study show that the age of the Shivakala Conglomerate pebbles which were derived from Pre-Kavirondian intrusives are 2,611 Ma old. Although the latter age appears to be rather young compared with the one reported by Cahen and Snelling (1984) for the pre-Kavirondian granites, low Mean Standard Weighed Deviate and error margin considerations make the age equally authoritative and a reasonable base for the correct estimation of the actual period of Kavirondian sedimentation.

The ages of the post-Kavirondian granites obtained during this study include Maragoli granite 2,533 Ma, Mumias granite 2,470 Ma. and Wanjare granite 2,361 Ma. These ages agree with the earlier recorded ages for the post-Kavirondian Kitosh granite (Dodson et al., 1975) which lie between 2,400 and 2,530 Ma. It is observed that although the strontium-rubidium whole rock dating method has its limits and sometimes rather high error margins, three ages mentioned above are significant. The age of 2,800 Ma. for the Pre-Nyanzian granite given by Dodson et al., (1975), the age of 2,700 Ma. for the Pre-Kavirondian Migori granite given by Cahen and Snelling (1984) and the age of the Shivakala granitic conglomerate pebbles, obtained during this study, suggest that the Pre-Kavirondian granites were intruded in phases and the products of one intrusive phase were not necessary petrographically and chemically similar to the previous ones. This observation is supported by the presence of tonalitic, trondhjemitic and granite pegmatite pebbles within the basal conglomerate formations. The weathering and erosion of granites gave rise to some of the coarse and fine grained members of the Kavirondian Group. The deposition of the Kavirondian sediments apparently started between 2,800 Ma. and 2,700 Ma. and came to an end around 2,533 Ma.

The ages of the younger granite intrusions which include Maragoli, Mumias and Wanjare, suggest that these granite bodies could not have contributed to the Kavirondian sedimentation.

The Mosocho conglomerate in Kisii shows an age of 1,764 Ma. Although this age is marked by a rather high Mean Standard Weighed Deviate, the age of this formation is much younger than the Kavirondian sediments. It is proposed that although this formation has previously been mapped as belonging to the Kavirondian Group, it belongs to the Kisii Formation and that the Kisii Formation is considered to have been formed during mid-Proterozoic.

In the Kavirondian Group, two facies associations have been identified. The facies associations include the continental facies association which is composed of basal conglomerates and the marine facies association which consists of resedimented conglomerate facies, the greywacke facies and the mudstone facies. The continental basal conglomerate sediments were transported in a fluvial environment from regions of high relief to the basin margins where they were deposited as alluvial fans. The sedimentary basin was supplied with sediments by several alluvial channels as is indicated by the sporadic setting of the basal conglomerate facies. The marine facies association contains an array of primary structures which are characteristic of turbidity current deposition. Among the characteristic structures are the pre-consolidation folds, soft sediment mixing structures, graded beds, flaser beds and longitudinal furrows and ridges. In the course of their accumulation, the turbidites were restricted to the sub-marine fans which resulted in coarse grained, thick bedded beds which bore signatures of proximal depositions on the upper fan and the mid-fan. The fine grained thin beds were formed as distal deposits on the lower fan. The differences between the proximal and distal turbidites are due to the grain segregation during the flow of the turbidity currents. Lateral grading does not develop during the early stages of the current flow and as a result, proximal turbidite facies tend to be poorly graded. When the turbidity currents flow over very low slopes, lateral grading does, however, occur and the distal turbidites formed tend to be well graded.

Basal conglomerate facies encountered in the Kavirondian Group were deposited on alluvial fans which were formed within the river channels. The sediments were deposited during the early stages of waning stream discharge when the sediment load apparently exceeded the carrying capacity of the streams.

Alluvial fans generally develop where streams confined in narrow valleys emerge into a plain. According to Denny (1967) and Twidale (1979) alluvial fans may develop in response to a sharp decrease in transport efficiency as the channels emerge from their confined valleys. According to Boothroyd and Ashley (1975), fans develop from a mid-channel nucleus which forms during the early stages of waning stream discharge. This happens when the sediment load exceeds the carrying capacity of the stream and once formed, the semi-conical landforms have their slopes radiating from the mouths of the source valley. The sizes of the pebbles decrease rapidly down the fan but the degree of roundness tends to increase due to corrasion as the pebbles are transported down slope. Miall (1981) also observed that the coarsest sediments occur on the upstream edge of the fan and the proportion of the finer sediments increase down the fan slope. Sometimes the alluvial fans merge together to form continuous landforms which may be separated by minor channels. This phenomenon was observed at Got Regea where a small channel follows the trend of a fault which separates a granite pebbles conglomerate member in the northern side of the hill and a volcanic pebbles conglomerate member in the southern side of the hill.

According to Dickinson (1974), deposition of large boulders and thick sedimentary beds requires a prior existence of a deep basin in which the sediments are initially deposited. The deposition is then followed by progressive subsidence of the substratum in order to accommodate the successive increment of the sediments. Considering the size of the boulders and the thickness of the Kavirondian basal conglomerate sub-facies, a basin of sedimentation similar to the type proposed by Dickinson (1974) is proposed for the sub-facies sedimentation. The basins of this nature were apparently adjacent to uplifted areas which provided large pebbles and boulders. Church and Ryder (1972) noted that channel fans form adjacent to regions of high relief which, with time are eroded in order to provide for the sediments which build up the fan. Hooke (1967) observed that alluvial fan sediments are deposited by water or debris flow. The water lain sediments may be deposited from sheet-floods, storm surges, sieve deposits or may be back filled by incised channels. The Kavirondian sediments are water lain probably through sheet-floods and storm surge mechanisms. During these depositional mechanisms, the flow spreads out from the channel end and spread laterally. Later, due to very rapid renewed deposition within the channels and distributary channels, the sediments plugged-up and shifted to different positions. This shift apparently accounts for the differences in the thicknesses of the conglomerate beds within the same sub-facies.

Although the basal conglomerates are water laid, there is no evidence of steady water flow which would have produced gravel bars in braided streams. Gravel bars usually have cross-bedding on their avalanching face. Since no such cross-bedding has been observed within the basal conglomerate facies, the sub-facies is unlikely to have been produced by gravel bars in the braided stream. The position of the sediments on the fan in relation to the major channels indicates that there was a tendency for the boulders and pebbles to be deposited closer to the mouths of the major channels while finer sandy sediments were deposited laterally and further downstream.

The basal conglomerates rest unconformably on the bedrock which is composed of the older Nyanzian Group volcanic rocks. Since the petrography and the chemistry of some of the boulders and pebbles is very similar to that of the bedrock, a local deviation of the sediments is suggested.

Presence of granite and chert pebbles in the Kavirondian basal conglomerates suggest a mixture of a local derivation and long distant source areas. Small bands of chert have been reported within the Nyanzian volcanic rocks. The bands are thought to be a likely source of the cherts in the basal conglomerates. The granite intrusives which surround the Kavirondian sediments are younger than the granite boulders within the conglomerates, therefore a pre-Kavirondian sedimentation granite intrusion is proposed as the source of the granite pebbles and boulders found in the basal conglomerate sub-facies. The characteristic lithology of the facies is composed of poorly sorted, matrix supported boulders and pebbles in which relatively few primary structures are represented.

The study of the field lithological relationships indicate that a sedimentological gap from the alluvial fan deposition of the basal conglomerates to the turbidity currents deposition of the turbidite facies in the Archaean sedimentary sequences of western Kenya is indicated by the lack of low angle, seaward dipping laminations which would occur in a storm beach, seaward dipping laminations which would occur in the berm, high angle landward dipping laminations which would be produced by ridge migration and trough cross-bedding which would be characteristic of low tide terraces. The lack of the shelf sediments is attributed to (Dimroth and Rocheleau, 1979; Blackburn, 1982) syn-sedimentary faulting at the junction of the alluvial deposition environment and the marine depositional environments. Similarly, a pronounced difference in gradient between the two environments would produce a sedimentological gap. According to Ojakangas (1985), in places where explosive volcanoes emerged as islands and in places where such islands were located along the craton margins, broad shelf deposits should not be expected. During this study, no syn-sedimentary faults were observed at the junction between the alluvial fans and the turbidite facies and therefore, combination of active tectonism and volcanic islands which consisted of volcanic rocks appear to be the main causes for the lack of shelf environments type of deposition. Active tectonism would promote constant differential downwarping and uplift between the palaeobasin and its hinterland thereby keeping the basin margin steep and allowing only temporary accumulation of unstable sediments which were soon subjected to slumping and generated turbidity currents.

The resedimented conglomerate facies were deposited as turbidite deposits on the basinward side from the alluvial fans. The sieve deposits formed when the permeable older deposits caused the flow to diminish rapidly when water passed through the larger pebbles, in the process, as these larger pebbles acted like a filter, the finer sediments were carried by water farther into the basin. This process gave rise to a hummocky of well rounded unconsolidated pebbles which were mainly quartzitic. The spaces between unconsolidated individual pebbles were later filled by on coming fine sediment clasts which finally lithified within the larger pebbles and formed the clast supported resedimented conglomerates. Deeper in the basin, the resedimented conglomerates were formed on the sub-marine fans. Some of the unconsolidated sediments were carried during a mass flow that begun as viscous debris flow and later became turbidity current farther down the basin. This type of resedimented conglomerate is generally matrix supported and varies from unsorted to normally and inversely graded sediments. These sediments are generally mixed so that they are sometimes interbedded with greywackes or sandstones. The mixed resedimented conglomerate sediments may have occurred as a result of slumping on the margins of the basin without necessarily forming submarine fans.

The greywacke facies were deposited in the deeper parts of the basin where it was too deep for regular disturbances by storm generated currents. The resulting sediments were characterised by both thick-bedded proximal deposits and fine grained thin bedded distal deposits. Greywacke was deposited both in the inner and outer fans. In these environmental positions, greywacke facies did not experience slumping and therefore no slump structures or syn-sedimentary faults were observed. However, graded bedding, soft sediment intrusions and some flaser beds are common.

Pettijohn (1943), publishing before the advent of the turbidity currents theory, observed that greywacke deposited in Archaean sedimentary basins are non-agitated and usually show limited signs of reworking. He also noted that there was parallelism between Archaean sedimentary basins and classic eugeosynclines because the sediments deposited in both environments are petrographically and texturally similar. Kuenen (1953) also pointed out that the importance of turbidity currents in transporting detritus into eugeosynclines has been widely recognised and there need not be any doubt that turbidity currents mechanism was operative during Archaean sedimentation. Collinson (1970 a), publishing after the global acceptance of the turbidity currents theory, noted that graded greywacke, deposited by turbidity currents are rarely reworked and therefore, their basins of deposition are usually quiet.

Walker (1967) compiled a number of criteria proposed by various workers as indicative of the locus of deposition of turbidites relative to the source of the depositing turbidity currents. Indicators of distal sediments include thin, fine grained beds, beds with sharp boundaries, beds which show graded bedding and those which show crude laminations. Other indicators include lack of composite beds , lack of channels within the beds and low sand-mud ratio. Mudstones facies in the study area show most of these characteristics and therefore they are interpreted as distal sediments. Distal sediments are produced by turbidity currents on the outer fan and such turbidites have base-missing sequences which consist of Bouma C, D and E intervals. In the study area, the D and E intervals are not clearly defined because they form alternating depositional cycles.

The mudstones were deposited by turbidity currents in the outer-fan. The environment was generally unagitated thereby allowing suspended fine sediments to settle down slowly. The source of the fine suspended sediments was apparently not providing the sediments continuously and consequently, the facies so formed were characterised by thin parallel laminations. It has been observed that, in some places, the mudstone is mixed with coarser grains thereby forming beds of fluxo-turbidite type. The common primary structures in these thin laminated and mixed mudstones are the slump structures, soft sediment mixing structures and syn-sedimentary faults. These structures were probably as a result of shock waves generated by mild earthquakes or other earth movement phenomena which irregularly occurred in the basin of sedimentation.

The depositional environment of the blocky mudstone is not clearly understood but rapid deposition of suspended fine grains in completely unagitated basin would produce blocky sediments as no time was available for development of sedimentological breaks.

The Kavirondian sediments in the study area are characterised by rapid lithological changes and do not represent laterally continuous units of wide extent. Therefore, a strictly lithostratigraphic regional correlation appears to be of limited value. Local lithostratigraphic correlation has however, been attempted. The best correlating lithostratigraphic units are the basal conglomerate and resedimented conglomerate lithological units. Conglomerate lithostratigraphic units found at Mukumu, Got Regea and Ramula correlate effectively. Intra-basinal lithostratigraphical correlation of the argillaceous sediments is, however, rendered difficult by the common lenticular bodies which are found within given lithostratigraphic units and the sudden lateral changes which occur in them.

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APPENDIX A

Chemical Compositions of rock samples from the study area.

Conglomerate pebbles:

Major oxides Wt%	CL/1/87	CL/2/87	CL/3/87	CL/4/87	CL/5/87
SiO_2	63.57	62.15	62.45	63.74	69.49
TiO_2	0.45	0.51	0.43	0.43	0.22
Al_2O_3	15.95	17.18	15.92	16.31	16.08
Fe_2O_3	3.53	3.97	5.29	5.39	3.11
MnO	0.05	0.05	0.86	0.03	0.26
MgO	5.31	4.07	3.23	3.26	0.15
CaO	3.00	3.95	4.60	2.87	3.18
Na_2O	4.04	4.26	4.96	4.23	5.81
K_2O	3.91	2.23	2.12	3.46	1.64
P_2O_5	0.16	1.60	0.13	0.26	0.04
Total	99.97	99.97	99.98	99.98	99.98

Sample number

Trace Elements in PPM	CL/1/87	CL/2/87	CL/3/87	CL/4/87	CL/5/87
Li	42	10	10	34	10
B	12	6	11	16	15
V	130	142	143	136	129
Cr	125	148	172	173	131
Co	63	70	58	62	11
Ni	108	82	87	137	7
Cu	8	11	9	23	29
Ca	4	10	5	7	19
Ge	2	15	4	5	43
Zn	167	107	114	141	43
Rb	54	16	16	54	14
Sr	651	498	566	685	138
Y	40	45	47	28	37
Zr	110	120	120	110	160
Ba	1070	707	558	885	414
Pb	17	16	18	19	18

Major oxides	Sample number				
Wt%	Cl/6/87	Cl/7/87	Cl/8/87	Cl/9/87	Cl/10/87
SiO_2	66.02	69.93	67.07	61.77	51.81
TiO_2	0.55	0.17	0.12	0.56	1.02
Al_2O_3	15.99	15.94	16.35	17.83	16.83
Fe_2O_3	3.85	3.64	3.16	5.82	10.06
MnO	0.24	0.05	0.01	0.43	0.61
MgO	0.70	0.15	0.05	1.69	6.17
CaO	2.85	3.11	3.65	3.44	8.70
Na_2O	5.75	5.31	5.80	5.69	4.18
K_2O	2.97	1.49	2.79	2.58	0.43
P_2O_5	1.07	0.21	0.98	0.18	0.19
Total	99.99	100	99.98	99.99	100

Trace Elements in PPM	CL/6/87	CL/7/87	CL/8/87	CL/9/87	CL/10/87
Li	64	12	12	28	12
B	17	8	15	12	14
V	140	138	27	32	19
Cr	102	102	91	73	166
Co	13	10	12	14	15
Ni	10	12	3	13	90
Cu	32	30	15	17	16
Ga	27	23	2	3	5
Ge	36	39	4	3	2
Zn	54	34	29	37	141
Rb	22	10	16	20	10
Sr	207	305	156	504	101
Y	41	35	45	41	19
Zr	120	120	80	150	135
Ba	441	960	164	269	39
Pb	24	28	72	63	19

Major oxides	Sample number			
Wt%	Cl/11/87	Cl/12/87	Cl/13/87	Cl/14/87
SiO_2	47.96	47.15	48.64	49.05
TiO_2	1.01	1.75	1.75	0.96
Al_2O_3	16.97	17.36	18.24	17.98
Fe_2O_3	14.38	14.76	13.33	11.46
MnO	0.22	0.16	0.64	0.15
MgO	6.02	6.52	4.79	5.12
CaO	8.85	8.46	8.63	11.63
Na_2O	3.99	3.48	3.32	3.08
K_2O	0.19	0.23	0.48	0.44
P_2O_5	0.41	0.10	0.17	0.11
Total	100.00	99.97	99.99	99.98

Trace Elements in PPM	CL/11/87	CL/12/87	CL/13/87	CL/14/87
Li	30	24	34	32
B	14	32	26	23
V	23	33	26	31
Cr	108	345	49	180
Co	23	22	31	27
Ni	60	116	40	63
Cu	14	17	19	16
Ga	6	3	4	3
Ge	3	5	6	4
Zn	90	113	196	146
Rb	4	4	8	6
Sr	225	135	236	140
Y	22	16	19	15
Zr	120	90	110	50
Ba	84	57	144	75
Pb	15	15	17	16

Major oxides	Sample number			
Wt%	Cl/15/87	Cl/16/87	Cl/17/87	Cl/18/87
SiO_2	52.72	64.75	74.04	67.94
TiO_2	0.54	0.84	0.79	0.44
Al_2O_3	12.60	16.97	10.67	16.77
Fe_2O_3	9.32	6.22	5.60	5.59
MnO	0.19	0.22	0.11	0.12
MgO	9.24	0.01	0.38	1.09
CaO	9.92	3.18	3.01	2.53
Na_2O	4.32	5.15	3.74	3.91
K_2O	1.29	2.47	1.59	1.49
P_2O_5	0.05	0.15	0.08	0.08
Total	100.19	99.96	100.01	99.96

Trace Elements in PPM	CL/15/87	CL/16/87	CL/17/87	CL/18/87
Li	6	16	28	10
B	18	6	22	27
V	145	163	167	168
Cr	505	74	158	43
Co	62	66	60	63
Ni	135	66	46	24
Cu	31	37	45	41
Ga	10	32	43	46
Ge	5	8	6	5
Zn	76	64	92	62
Rb	4	30	54	24
Sr	85	288	130	178
Y	35	9	42	51
Zr	40	150	50	130
Ba	92	375	235	307
Pb	18	48	81	52

Major oxides	Sample number			
Wt%	Cl/19/87	Cl/20/87	Cl/21/87	Cl/22/87
SiO_2	54.13	54.01	50.88	46.26
TiO_2	0.07	0.91	1.45	1.24
Al_2O_3	14.89	12.78	13.43	16.02
Fe_2O_3	11.10	12.62	15.52	15.52
MnO	0.18	0.24	0.01	0.20
MgO	5.78	5.28	6.83	7.42
CaO	8.09	8.84	9.22	10.23
Na_2O	3.64	3.21	2.59	2.13
K_2O	2.25	1.96	0.07	0.83
P_2O_5	0.01	0.14	0.01	0.15
Total	100.14	99.99	100.01	100

Trace Elements in PPM	CL/19/87	CL/20/87	CL/21/87	CL/22/87
Li	24	28	24	32
B	16	21	23	17
V	136	127	192	213
Cr	74	26	11	104
Co	51	43	18	15
Ni	20	58	0	51
Cu	29	21	4	7
Ga	16	19	10	11
Ge	9	7	32	29
Zn	111	138	100	122
Rb	24	24	2	22
Sr	412	154	106	151
Y	5	7	121	120
Zr	110	90	80	80
Ba	506	321	200	181
Pb	19	21	10	12

Conglomerate Matrix:

Major oxides	Sample number				
Wt%	Cl/23/87	Cl/24/87	Cl/25/87	Cl/26/87	Cl/27/87
SiO_2	71.43	60.25	63.35	69.86	63.16
TiO_2	0.89	0.91	1.54	0.87	1.53
Al_2O_3	10.90	14.58	17.32	13.02	12.01
Fe_2O_3	5.92	9.45	10.87	6.52	8.20
MnO	0.15	0.08	0.19	0.24	0.27
MgO	3.82	4.58	0.94	2.00	4.92
CaO	1.57	5.62	1.52	2.72	4.61
Na_2O	3.52	3.32	2.52	3.19	4.08
K_2O	1.73	0.78	0.62	1.55	1.03
P_2O_5	0.08	0.42	0.05	0.03	0.13
Total	100.01	99.99	99.92	100.00	99.94

Trace Elements in PPM	CL/23/87	CL/24/87	CL/25/87	CL/26/87	CL/27/87
Li	37	28	31	38	33
B	32	21	28	31	35
V	1550	53	765	1340	810
Cr	1020	171	976	985	968
Co	71	38	33	30	31
Ni	463	61	83	93	89
Cu	10	357	137	145	139
Ga	5	10	12	8	13
Ge	4	5	19	9	18
Zn	114	143	124	107	112
Rb	15	19	70	47	68
Sr	21	26	28	69	31
Y	305	29	118	120	117
Zr	3	46	5	12	4
Ba	352	407	360	192	340
Pb	13	7	14	10	15

Greywacke:

Major oxides	Sample number					
Wt%	GY/1/87	GY/2/87	GY/3/87	GY/4/87	GY/5/87	GY/6/87
SiO_2	63.50	63.4	68.0	65.2	71.26	79.9
TiO_2	0.60	0.7	0.8	0.6	0.43	0.2
Al_2O_3	17.50	15.0	15.3	15.3	11.3	7.9
Fe_2O_3	6.30	4.95	5.0	4.6	5.4	3.0
MnO	0.13	1.1	0.3	0.8	1.5	1.9
MgO	2.80	4.33	3.0	4.0	4.3	1.2
CaO	2.70	4.52	1.8	3.5	2.0	2.7
Na_2O	4.90	2.8	2.9	3.1	2.6	0.8
K_2O	1.32	2.4	2.2	2.5	1.2	0.6
P_2O_5	0.20	0.7	0.4	0.4	0.9	1.7
Total	99.95	99.8	99.8	100	99.8	99.8

Trace Elements in PPM	GY/1/87	GY/2/87	GY/3/87	GY/4/87	GY/5/87	GY/6/87
Li	6	12	6	14	11	8
B	16	12	15	21	6	9
V	9	12	18	13	14	10
Cr	117	72	113	46	67	55
Co	24	15	22	17	12	24
Ni	14	20	27	24	22	19
Cu	7	3	10	12	8	6
Ga	9	4	7	5	3	8
Ge	39	20	32	33	23	36
Zn	73	95	57	67	70	56
Rb	26	20	28	14	31	31
Sr	262	382	295	240	281	241
Y	10	10	13	11	9	9
Zr	119	130	140	70	93	136
Ba	405	456	481	506	460	502
Pb	21	14	21	18	15	13

Major oxides			Sample number		
Wt%	GY/7/87	GY/8/87	GY/9/87	GY/10/87	GY/11/87
SiO_2	57.47	64.4	65.75	58.1	59.2
TiO_2	1.6	0.4	0.88	0.3	0.85
Al_2O_3	15.0	15.6	17.50	13.2	16.20
Fe_2O_3	8.6	5.1	5.0	7.9	5.02
MnO	1.15	0.13	0.5	1.08	0.35
MgO	4.8	3.4	3.0	5.2	2.74
CaO	5.14	6.0	1.9	4.5	7.5
Na_2O	4.20	4.5	3.5	4.0	4.8
K_2O	1.73	2.0	0.89	1.91	2.13
P_2O_5	0.23	0.32	0.23	1.10	0.16
Total	99.85	99.85	100.1	99.99	99.95

Trace Elements in PPM	GY/7/87	GY/8/87	GY/9/87	GY/10/87	GY/11/87
Li	6	7	9	8	13
B	10	12	16	9	16
V	13	8	14	10	6
Cr	95	125	113	101	88
Co	20	27	13	10	15
Ni	23	22	19	15	20
Cu	5	3	12	9	8
Ga	9	11	6	8	4
Ge	34	33	41	31	27
Zn	72	82	50	56	75
Rb	28	31	40	25	38
Sr	290	303	325	272	223
Y	12	7	5	5	4
Zr	103	107	111	108	113
Ba	520	542	397	417	412
Pb	17	24	31	27	22

Mudstone:

Major oxides	Sample number			
Wt%	MD/1/87	MD/2/87	MD/3/87	MD/4/87
SiO_2	59.36	57.50	59.42	58.82
TiO_2	1.68	1.45	1.63	0.72
Al_2O_3	25.51	22.63	21.44	23.93
Fe_2O_3	2.42	8.07	4.50	4.62
MnO	0.97	1.01	1.01	0.85
MgO	0.97	1.07	3.31	1.71
CaO	0.03	1.01	1.52	1.59
Na_2O	1.42	1.16	1.70	3.10
K_2O	5.23	3.45	4.68	4.20
P_2O_5	1.00	2.00	0.70	0.44
Total	99.97	99.35	99.91	99.98

Trace Elements in PPM	MD/1/87	MD/2/87	MD/3/87	MD/4/87
Li	46	14	48	14
B	69	102	87	84
V	150	127	152	166
Cr	430	190	161	252
Co	23	21	26	20.5
Ni	200	517	547	251
Cu	66	67	79	104
Ga	25	30	28	17
Ge	11	22	17	14
Zn	13	68	39	107
Rb	90	68	54	56
Sr	36	13	44.4	13
Y	26.7	28.3	24.1	19.4
Zr	168	170	174	150
Ba	1020	1259	1170	455
Pb	10.5	20.7	22.1	21.5

Major oxides	Sample number			
Wt%	MD/5/87	MD/6/87	MD/7/87	MD/8/87
SiO_2	60.12	62.87	58.48	59.85
TiO_2	0.59	0.51	1.44	0.54
Al_2O_3	22.42	23.53	19.79	19.79
Fe_2O_3	5.12	5.89	7.94	8.06
MnO	0.02	0.21	0.13	0.18
MgO	0.69	0.75	5.02	3.24
CaO	0.01	0.29	1.46	1.54
Na_2O	3.42	2.05	1.62	2.84
K_2O	6.47	3.22	3.66	3.53
P_2O_5	1.13	0.63	0.5	0.39
Total	99.99	99.95	100.04	99.96

Trace Elements in PPM	MD/5/87	MD/6/87	MD/7/87	MD/8/87
Li	16	16	46	28
B	76	73	69	82
V	168	153	132	162
Cr	396	225	314	211
Co	28	30	29	33
Ni	170	53	192	66
Cu	93	103	82	125
Ga	26	17	17	12
Ge	23	15	14	17
Zn	162	152	108	78
Rb	88	118	44	102
Sr	37	38	131	59
Y	22.8	29.2	19.3	30.1
Zr	140	150	140	150
Ba	560	797	290	822
Pb	19.2	16.7	18.7	32.2

Major oxides			Sample number		
Wt%	MD/9/87	MD/10/87	MD/11/87	MD/12/87	MD/13/87
SiO_2	56.92	57.88	61.65	64.68	58.51
TiO_2	0.81	0.94	0.66	0.72	0.71
Al_2O_3	22.66	25.19	18.52	17.16	21.42
Fe_2O_3	5.19	6.49	5.98	4.04	5.86
MnO	0.28	0.07	0.62	0.06	0.00
MgO	2.93	0.78	4.96	2.75	2.58
CaO	1.78	0.56	0.87	0.86	0.92
Na_2O	3.35	2.68	2.43	3.75	3.75
K_2O	5.89	4.73	4.17	5.47	5.65
P_2O_5	0.18	0.56	0.12	0.51	0.47
Total	99.99	99.88	99.98	100.00	99.96

Trace Elements in PPM	MD/9/87	MD/10/87	MD/11/87	MD/12/87	MD/13/87
Li	30	20	20	36	24
B	75	83	93	107	76
V	234	210	242	283	168
Cr	134	251	173	156	300
Co	30	18	46	44	28
Ni	15	28	16	65	17
Cu	137	72	56	123	79
Ga	21	25	15	23	21
Ge	23	21	10	19	16
Zn	42	110	48	75	76
Rb	58	74	64	52	20
Sr	146	36	80	100	295
Y	25.1	36.3	32.4	29.3	25.5
Zr	130	120	170	4.0	140
Ba	885	781	931	512	356
Pb	42.5	25.3	16.3	18.6	18.2

Late Archaean/Proterozoic granites:

Major oxides	Sample number				
Wt%	Ma/1/87	Ma/2//87	Ma/3/87	Ma/4/87	Ma/5/87
SiO_2	68.02	67.07	67.02	63.53	67.52
TiO_2	0.49	0.12	0.47	0.51	0.44
Al_2O_3	16.26	16.5	16.77	17.85	16.70
Fe_2O_3	3.47	3.82	3.73	4.56	3.55
MnO	0.02	0.02	0.03	0.03	0.03
MgO	1.37	1.60	1.49	1.69	1.47
CaO	3.42	3.46	3.78	4.67	3.38
Na_2O	4.34	4.66	4.31	4.34	4.08
K_2O	2.67	2.60	2.24	2.65	2.72
P_2O_5	0.14	0.12	0.16	0.14	0.14
Total	100.2	99.97	100.00	99.97	100.03

Trace Elements in PPM	Ma/1/87	Ma/2//87	Ma/3/87	Ma/4/87	Ma/5/87
Li	34	54	58	30	50
B	Nd	Nd	Nd	6	9
V	32	22	29	29	33
Cr	86	109	124	98	104
Co	Nd	6	14	Nd	20
Ni	60	9	74	41	15
Cu	Nd	17	6	11	10
Ga	16	14	13	15	17
Ge	Nd	5	3	14	12
Zn	89	75	104	74	51
Rb	70	78	72	70	74
Sr	501	459	481	478	413
Y	17	18	22	19	23
Zr	Nd	130	120	120	130
Ba	486	405	546	506	428
Pb	18	14	16	13	21

Major oxides	Sample number			
Wt%	Mu/6/87	Mu/7/87	Mu/8/87	Mu/9/87
SiO_2	69.09	64.98	65.00	67.42
TiO_2	0.43	0.50	0.48	0.43
Al_2O_3	15.76	18.40	19.03	16.66
Fe_2O_3	3.30	4.02	3.92	3.56
MnO	0.03	0.02	0.03	0.03
MgO	1.36	1.63	1.42	1.52
CaO	3.21	3.77	3.31	3.37
Na_2O	4.34	4.10	4.23	4.10
K_2O	2.31	2.46	2.38	2.75
P_2O_5	0.17	0.12	0.13	0.15
Total	100.00	100.00	99.93	99.99

Trace Elements in PPM	Mu/6/87	Mu/7/87	Mu/8/87	Mu/9/87
Li	36	28	44	50
B	10	12	16	9
V	16	15	17	29
Cr	117	112	111	102
Co	8	5	16	13
Ni	122	21	28	31
Cu	6	8	14	5
Ga	14	12	12	16
Ge	11	5	Nd	8
Zn	128	74	85	86
Rb	48	52	48	78
Sr	644	616	641	375
Y	73	67	68	20
Zr	120	110	90	120
Ba	727	798	683	508
Pb	28	23	27	17

Major oxides Wt%	Sample number				
	W/10/87	W/11//87	W/12/87	W/13/87	W/14/87
SiO_2	79.92	77.21	79.99	80.44	75.49
TiO_2	0.09	0.14	0.07	0.08	0.09
Al_2O_3	11.93	12.96	11.96	11.59	12.89
Fe_2O_3	1.92	2.86	1.57	1.42	1.77
MnO	Nd	0.01	Nd	Nd	0.13
MgO	Nd	0.08	Nd	Nd	0.08
CaO	Nd	0.43	Nd	0.17	0.61
Na_2O	3.80	3.77	3.64	3.80	4.48
K_2O	2.33	2.53	2.79	2.60	4.42
P_2O_5	0.03	0.01	0.01	Nd	0.03
Total	100.02	100.00	100.03	100.01	99.99

Trace Elements in PPM	W/10/87	W/11//87	W/12/87	W/13/87	W/14/87
Li	8	4	4	8	20
B	17	9	11	12	14
V	3	4	3	2	3
Cr	133	147	165	133	22
Co	9	12	15	17	19
Ni	107	185	5	109	14
Cu	6	14	13	7	17
Ga	15	16	14	18	15
Ge	11	23	21	28	25
Zn	97	150	35	97	45
Rb	34	44	42	34	76
Sr	9	17	13	9	170
Y	200	183	47	193	44
Zr	210	220	170	210	70
Ba	388	511	587	388	213
Pb	46	34	31	62	71

APPENDIX B

Rubidium-strontium whole rock analytical data

Mumias granite:

Sample No.	Rb PPM	Sr PPM	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Mu/88/3	98.00	772.91	0.3670	0.7146 + 0.0002
Mu/88/4	94.00	718.54	0.3780	0.7151 + 0.0003
Mu/88/5	85.44	720.62	0.3430	0.7145 + 0.0005
Mu/88/7	94.27	831.76	0.3270	0.7134 + 0.0002
Mu/88/9	82.71	749.91	0.3190	0.7125 + 0.0002
Mu/8814	91.30	736.06	0.3590	0.7138 + 0.0002

Maragoli granite:

Sample No.	Rb PPM	Sr PPM	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Ma/88/1	138.3	625.2	0.6410	0.7259 + 0.0006
Ma/88/4	125.3	615.0	0.5900	0.7227 + 0.0004
Ma/88/5	136.2	576.9	0.5840	0.7263 + 0.0005
Ma/88/7	126.4	628.1	0.5830	0.7233 + 0.0002
Ma/88/9	132.8	598.9	0.6430	0.7255 + 0.0003
Ma/88/15	109.5	640.7	0.4950	0.7208 + 0.0031

Wanjare granite:

Sample No.	Rb PPM	Sr PPM	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
W/88/1	57.68	24.76	6.890	0.9445 + 0.0002
W/88/4	81.87	43.72	5.650	0.90714 + 0.0007
W/88/5	63.25	24.19	7.750	0.91615 + 0.0002
W/88/9	77.92	30.17	7.670	0.97406 + 0.0005
W/88/10	76.83	31.48	7.240	0.96794 + 0.0006
W/88/12	61.78	23.73	7.730	0.97364 + 0.0005

Kakamega Conglomerate:

Sample No.	Rb PPM	Sr PPM	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
KC/88/1	36.4	624.0	0.1685	0.70778 + 0.0005
KC/88/2	35.3	667.4	0.1527	0.70606 + 0.0005
KC/88/5	20.4	564.0	0.1045	0.70512 + 0.0004
KC/88/11	49.0	578.8	0.2450	0.71011 + 0.0006
KC/88/13	40.5	709.8	0.1649	0.70675 + 0.0005
KC/88/15	45.4	562.1	0.2334	0.70999 + 0.0005

Mosocho Conglomerate:

Sample No.	Rb PPM	Sr PPM	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
MC/88/1	32.71	189.00	0.501	0.71984 + 0.0003
MC/88/2	28.04	221.00	0.367	0.71314 + 0.0018
MC/88/3	39.17	614.30	0.185	0.71225 + 0.0003
MC/88/6	20.95	253.20	0.239	0.71271 + 0.0005
MC/88/8	42.41	310.70	0.395	0.71487 + 0.0003
MC/88/13	28.70	194.40	0.428	0.71881 + 0.0007

APPENDIX C

Geological Maps of the Study Areas

I. Geological Map of the Kakamega-Yala Area (see pocket).

II. Geological Map of Oyugis and the surrounding Area (see pocket).

III. Geological Map of Awendo and the surrounding Area (see pocket).