TITLE: THE ARCHEAN GRANITES OF MUMIAS–KAKAMEGA-KISUMU REGION OF WESTERN KENYA: PETROGRAPHY, PETROGENESIS AND ECONOMIC POTENTIAL.

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ABSTRACT

Western Kenyan greenstone belt which extends into Tanzanian is highly composed of Archean granites. The study area is concerned with the occurrence of the Kisian, Maragoli and the Mumias granites. These are generally referred to the Kisumu-Kakamega-Mumias Archean granites. These three granite formations are closely related to each other both microscopically and megascopically.

Their geochemistry confirms that they are closely related. Their geology can also be related to the geology of the Tanzanian Craton given the similarities in their elemental composition.

The Archean Maragoli granites and the Archean Mumias granites have been dated at 2504±48 Ma (Rb:Sr, Dodson et al.,1975) and at 2495±70 to 2577±100 Ma (K:Ar, Cahen and Snelling, 1966) respectively. According to Bell and Dodson (1981), the initial $^{87}Sr/^{86}Sr$ ratios derived from whole rock Rb-Sr isochrones and errorchrons are generally low indicating that the granitic magmas formed by partial melting of protoliths with short prior residence time in the crust thus the granitic crust underlying Tanzania and parts of Uganda and Kenya (with reference to western granites) formed about 2.8 Ga and 2.4 Ga.

Huddlestone et al. (1959), states that the Archean Maragoli granites in the south and the Archean Mumias granites in the north are intrusive into the rocks of the Nyanzian and Kavirondian systems. There is little however to distinguish them either in hand specimens or in thin sections and it is possible that they are part of one large batholiths.

Granites have widely been used globally for different purposes. These include the building and construction industries. Such areas include the building of roads, dams, bridges and houses.

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Finally my fellow students for their moral support and to my family that gave me the financial support and prayers that kept me focused and above all the Almighty God for His mercy throughout.

DEDICATION

This project is dedicated to my family in particular my mum Mrs. Amolloh, sisters Lucy, Nelly, Evelyn, niece Alyn and brothers Denis, Eric, Chrispine and Nicholas. I also dedicate this project to my uncle Mr. Sind and his entire family, my fellow students and least but not last is to my late dad may God rest his soul in peace.

DECLARATION

Student declaration

I hereby declare that this project report is my original work and have never been presented for examination by any other person.

SIGN………………… DATE ……………………

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Approval by the advisor

This report has been submitted for examination with my approval as the advisor.

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SIGN …………………………. DATE ………………………

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CHAPTER ONE: INTRODUCTION

1.1 Geographical setting

Kakamega, Kisumu and Mumias areas are found in the Western region of Kenya. Administratively Kisumu lies in Kisumu District in Nyanza province while Kakamega and Mumias are both located in Western province of Kenya. The areas are well supplied with roads such as the main Kisumu-Kakamega highway. The east African railway line also connects Kisumu to the other areas through to Uganda. Another form of communication within the region and connecting Kisumu to other east African towns is water transport through Lake Victoria. The map below shows the study area.

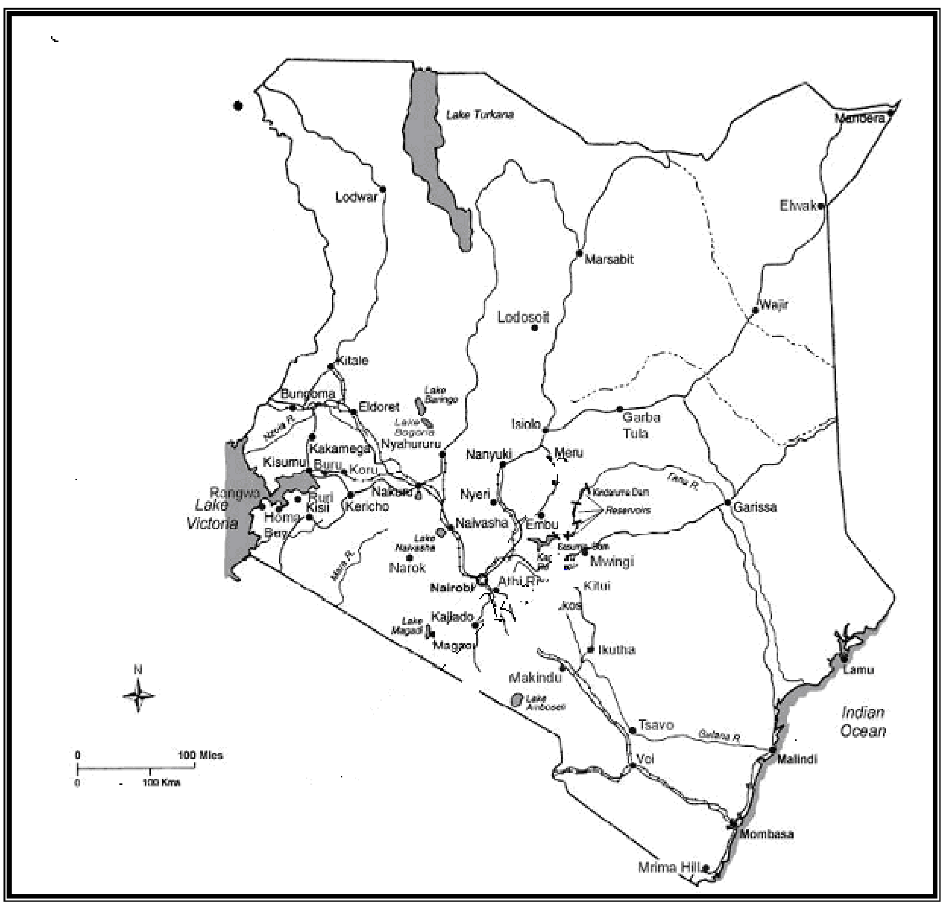

Figure 1. 1: Map of Kenya showing the western region as indicated on the map.

1.2 Geological setting

Kisumu-Kakamega-Mumias areas of Western region of Kenya are generally composed of highly granitized gneiss of the basement system, steeply-dipping acid to basic volcanic with minor pyroclastic developments comprising the Nyanzian system, conglomerates, grits and mudstones of the Kavirondian system, the Kisian Archean granites, the Maragoli Archean and Mumias Archean (goldfield) granites, altered dolerites of more than one age and others. There are several Archean granite formations within the area but the major Archean granite formations discussed in the subsequent chapters are the Kisian granites in Kisumu, the Maragoli granites in Kakamega and Mumias granites in Mumias.

The Archean Maragoli granites and the Archean Mumias granites have been dated at 2504±48 Ma (Rb:Sr, Dodson et al.,1975) and at 2495±70 to 2577±100 Ma (K:Ar, Cahen and Snelling, 1966) respectively. According to Bell and Dodson (1981), the initial $^{87}Sr/^{86}Sr$ ratios derived from whole rock Rb-Sr isochrones and errorchrons are generally low indicating that the granitic magmas formed by partial melting of protoliths with short prior residence time in the crust thus the granitic crust underlying Tanzania and parts of Uganda and Kenya (with reference to western granites) formed about 2.8 Ga and 2.4 Ga.

Huddlestone et al. (1959), states that the Archean Maragoli granites in the south and the Archean Mumias granites in the north are intrusive into the rocks of the Nyanzian and Kavirondian systems. There is little however to distinguish them either in hand specimens or in thin sections and it is possible that they are part of one large batholiths.

It is worth noting that the Kisian granites, Maragoli granites and Mumias granites are associated with diorites and diorite hybrids.

1.3 Statement of the project

Several metal ores are known to occur or form near intrusions of granites. Such metals include tungsten, molybdenum, copper and some other economically important trace elements. Generally many geological studies and mappings have been done in western Kenya. (Huddleston et al., 1951, Kitson et al., 1934, Pulfrey 1946, Ichang'i and Maclean 1991) are some of those who have carried out studies in western Kenya. Most of the reports have been published with just a few that were never published. However, the Archean granites of the study area are just mentioned in some of these reports with no particular report on these Archean granites. This study correlates these Archean granites through the use of these various reports and comparing the geology of the study area to other areas with the same geology to find out their petrogenesis and petrography especially the elements that are occurring in these granites.

1.4 General introduction to granites

Granites are defined as the intimate amalgam of quartz, feldspars and micas according to "the marbles and granites of the world" by Grant M.H. the most. It has crystals that tend to be easily seen due to its phaneritic texture although they are generally small. Granites are sources of many mineral specimens. Its durability, beauty and abundance make it preferable over other stones as a building material.

The crystals of granite form while the molten material inside the earth's crust cools relatively slowly. When this molten magma erupts onto the surface of the earth, it forms a rhyolite. A rhyolite has the same chemistry as granites but different texture and the crystals of a rhyolite are generally too small to see. Granites can sometimes have larger crystals than pebble thus called pegmatite.

Mineralogically, granites are composed primarily of quartz, plagioclase feldspars, potash feldspars, hornblende and micas. The plagioclase appears white with a porcelaneous luster. The K-feldspars generally give granite its variation in colours from yellow to pink or blue. The micas are muscovite which is silvery in colour, biotite black or brown in colour or lepidolite violet or pink in colour. Micas provide the sparkle that some granite has. Hornblende and biotite on the other hand provide granites with the black pepper portion of the famous and distinctive "salt and pepper" look to granites.

Like any other rock type, granites also contain accessory minerals. Most of these are precious gems such as tourmaline, beryl, topaz, zircon and apatite. Other economically important accessory minerals that occur in granites are phosphates and rare earth Oxides. Related to the rare earth elements is a significant concentration of element uranium in granites.

Some rocks are incorrectly referred to as granites such as the coarse grained metamorphic rocks. Many other igneous rocks are also incorrectly referred to as granites. These rocks however, have the "salt and pepper" look of granites but different mineral assemblages that preclude them from being classified as granites. Syenites, diorites, gabbros, monzonites and anorthosites have little or no quartz. Rocks with little or no K-feldspars but generally equal amounts of plagioclase feldspars and quartz are called tonolite. An igneous intrusive very rich in quartz (>90%) is called a quartzolite while those with little silica content are feldspathoids.

1.5 Occurrence and distribution of granites in western Kenya

Western Kenya is known for the widespread of granitic terrains. The Kisumu area is covered with the Kisian granites and minor granite formations such as Seme granites, Oyugis granites, Asembo granites, granites around Maseno amongst others. The major granite formations in Kakamega are the Maragoli granites while in Mumias it is the Mumias granites. These are largely characterized by the occurrence of the granitic tors.

CHAPTER TWO: LITERATURE REVIEW, METHODOLOGY, RESEARCH QUESTIONS AND OBJECTIVES.

2.1 LITERATURE REVIEW

Gregory and Scott Elliot (1895 pp. 677), reported that near Mumias, the Archean series by fine-grained syenetic gneiss almost identical in character with some in the Taita hills.

Gregory later (1921 pp. 125,126) recorded that the section North-east of Kisumu towards Kaimosi was a plateau consisting of a foundation of Eozoic gneiss with some granite and vogesite dykes.

Kritson (1932) noted that both north and south of the Karagwe –Ankolean rocks within the Kakamega District, granites of four different kinds and ages occurred as indicated in the geological report of Kakamega District by A. Huddleston (1959)

Dr. J. W. Gregory in 1919 undertook his celebrated safari in east Africa and visited kisumu, drawing attention (1921, pp. 123) to the northern scarp slope, the phonolites, the granites and the syenites of the Maseno area.

During 1928 the late A.D. Combe of the geological survey of Uganda carried out field work on the Katring plain south of the Maragoli hills (1929, pp. 10-11). He commented on the Maragoli, Kisian and Nyando scarps and inspected the phonolites of the area near Nyahera.

During the war W. Pulfrey (1946) geologically surveyed Maragoli, part of which is in the Kisumu District. C.S. Hitchen, while a member of the Mines and Geological Department, examined the ground west of the present area including a small portion of the north-western boundary on the north side of Kavirondo gulf, but his results have not been published.

Borg and Krogh (1999) reported that the geology of one of the larger greenstone belts of the Tanzanian Craton (Sukumaland Greenstone Belt), which is oval shaped and is defined by two intermittently exposed belts of metavolcanic and metasedimentary rocks that surround a core of granitoids and gneisses consists mainly of Archean volcanosedimentary sequences of the Nyanzian Supergroup thus indicating the similarity of the archean granites of the Tanzanian Craton and those of the study area.

2.2 OBJECTIVES

1. Discuss the general occurrence, distribution and the major granitic systems in Mumias, Kakamega and Kisumu areas.
2. Discuss the economic potential of the Archean granites of western Kenya occurring in the study area with reference to the modern applications of granites worldwide
3. Find out the method of formation, major and trace elements and the types of granites which occur in this region.

2.3 RESEARCH QUESTIONS

2.3.1 Objective 1

- What are the processes involved in the formation of granites in Mumias, Kakamega and Kisumu areas?
- How do the Mumias-Kakamega-Kisumu granites occur?
- How are the granites distributed in the study region?

2.3.2 Objective 2

- Discuss the major modern global applications of granites.

2.3.3 Objective 3

- Discuss the major granitic systems or formations in the study area
- Determine the possible ages of the granites in Mumias, Kakamega and Kisumu areas.
- Determine the major elements and trace elements composition of granites within the study area

2.4 APPROACH OR METHODOLOGY

Several geological studies have been done in the larger western region of Kenya. These include the study of the Kisumu and Kakamega Districts of which geological reports to the effect was written. These reports therefore are some of the major tools that shall help in the study.

The study of these reports and geological maps are very important in the determination of the occurrence and distribution of the Archean granites in the study area. From the geological reports and maps, the types of granites which are occurring in the region can be determined as well as the granitic terrains and to some extent the minerals which are associated with granites.

The petrographical and mineralogical analysis forms the basis in which the major elements and trace elements and major minerals occurring in the Archean granites and the granitic terrains respectively shall be explained and determined. This shall also help in the classification of the Archean granites into different types.

The cross-sections of the geological maps are of great importance in the possible determination of the ages of the granites.

Apart from the geological reports, geological maps and the cross-sections, the geology of Mumias-Kakamega-Kisumu region shall also be compared to the geology of other regions of the world with the same geology. Some of the regions believed to have the same geology include the Tanzanian craton which generally is inhabited by the Archean granites. These references will help in the understanding of the Archean granites of western Kenya region.

Other study shall also be carried out through the study of the available journals on the Archean granites where possible and the internet based data.

CHAPTER THREE: PETROGRAPHY

3.1 Mineralogical or geochemical composition of the Kisumu-Kakamega-Mumias granites

Mineralogically, the major Archean granite formations in the Kisumu-Kakamega-Mumias areas; the Kisian, the Maragoli and the Mumias granites are said to be of little distinguishable properties either in hand specimens or in thin sections. CIPW norm named after its inventers, Cross, Iddings, Pirsson and Washington is one of the methods used to calculate the mineralogical composition of a rocks. An example of the normative classification is the quartz-alkali-plagioclase-feldspathoid (QAPF) method as shown below.

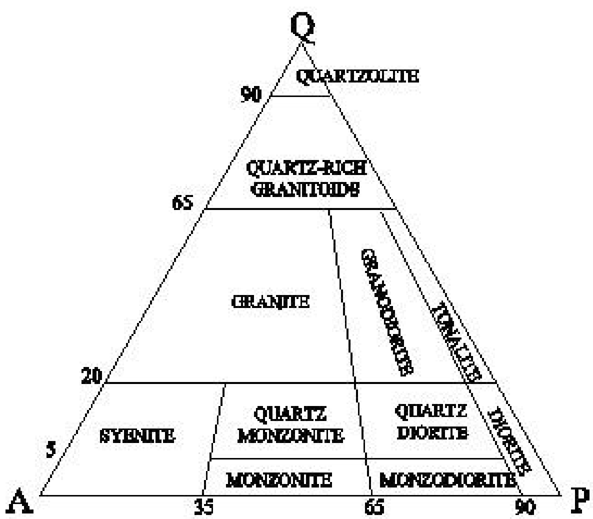

Figure 3. 1: QAFP diagram showing the percentage mineralogical composition of granites and other minerals using the CIPW norm method.

Maragoli granites.

In thin sections the pink phenocrysts in the Maragoli granites are recognized as mostly microcline with some microcline-microperthite, though orthoclase and plagioclase are also present. The phenocrysts are set in a course-grained matrix of hypidiomorphic granular texture which includes large tabular crystals up to 3 mm. in length of orthoclase, oligoclase (An_{30}) and rarely microperthite together with microcline. The microcline and orthoclase show less alteration than does the plagioclase according to Huddlestone et al., (1991) but all the feldspars are clouded and sericitized. Clots of epidote are also noticeable due to epidomitization and a little chloritization.

Hornblende is the predominant dark mineral occurring as long pleochroic blades often chloritized and associated with shreddy biotite flakes of granular biotite. The amphibole in some cases consists of small flakes of lamprobite with hornblende. In the leucocratic varieties the hornblende is not always conspicuous in the hand specimen and in slides is seen to consist of small ragged prisms. In the porphyritic hornblende bearing types the pale brown to greenish brown biotite is mostly associated with the hornblende and consists of dark-bordered shreddy bent plates. Accessory minerals include apatite, magnetite, sphene, rare allanite and ilmenite. Chlorite and epidote however occur as alteration products. (Huddlestone et al., 1991)

Kisian granites

The kisian granites contains olive green dark minerals of hornblende which are strongly pleochroic and exhibits slight zoning and when altered is associated with magnetite octahedral. Subsidiary small shreddy plates of biotite occur along the margins of the hornblendes. Quartz is generally interstitial and often occurs as a granular aggregate with the feldspars, though occasionally it forms large allotriomorphic crystals containing rows of bubble inclusions.

Accessory minerals include apatite, magnetite, occasional sphene and rare allanite.

3.2 Geochemistry of major and trace elements in the granites of the study area.

The geochemistry of the Kisian granites which are the representative of the Kisumu granites is similar to the geochemistry of the Maragoli and Mumias granites which are found in the larger Kakamega District. Therefore the geochemical analysis of the Kisumu represented in the table 3.1 below shows the elemental composition of the Archean granites of the study area at large.

Within the Tanzanian Craton, the whole rock compositions for samples from the Tulawaka East deposit shows closely related geochemistry. The metasedimentary rocks are largely intermediate in composition with average SiO_2 and Al_2O_3 concentrations of 60% and 20%, respectively. It decreases in MgO, TiO_2, K_2O and

Al_2O_3 and an increase in CaO with increasing SiO_2 among the metasedimentary rocks that may reflect a decrease in clay mineral content and an increase in quartz and feldspar content. It is noted by Shand et al., (1927) that the leucogranites are peraluminous (A/CNK = 1.7–2.0) and have average SiO_2, Al_2O_3 and Na_2O contents of 75%, 15% and 4.6%, respectively. From the reference of the Archean granites of the Tanzanian Craton which have shown that these granites are similar from the analysis of the major elemental compositions, it can be concluded that the trace element analysis in both cases is also the same and thus the major trace elements are as in table 3.3.

Table 3. 1: Geochemical analysis of the Archean granites of the study area.(Source; the geological 0report of Kisumu district).

Element	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	TiO_2	P_2O_5	MnO	Cl	F	SO_3	Total
Composition in %	65.10	15.66	1.54	2.07	1.90	3.64	4.31	4.52	0.60	0.35	0.14	0.06	0.005	0.065	0.2	99.92

Table 3. 2: Major element concentrations of the rock types from the Tulawaka East gold deposit (in %) in the Tanzanian Craton.

Sample	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**	**LOI**	**Total**
Metasedimentary rocks												
D0142-1	64.37	17.82	4.68	0.062	2.68	1.04	2.31	2.56	0.647	0.11	2.86	99.15
D0149-1	60.24	20.58	4.97	0.051	2.65	0.80	2.10	4.04	0.672	0.09	3.19	99.39
D0149-2	67.61	14.78	6.00	0.113	1.77	3.64	3.37	0.94	0.546	0.12	0.74	99.63
D0149-4	62.85	15.90	9.29	0.130	2.10	4.56	1.95	1.94	0.480	0.12	0.71	100.03
D0149-6	53.56	22.81	7.16	0.056	3.40	1.03	1.88	4.51	0.752	0.10	4.90	100.18
Leucogranites												
D0310-1	75.54	14.32	1.30	0.254	0.18	0.43	3.79	3.35	0.043	0.03	1.05	100.29
D0310-3	75.13	14.85	0.68	0.060	0.12	0.65	5.43	2.50	0.032	0.06	0.69	100.19

Table 3. 3: Minor element concentrations of the rock types from the Tulawaka East gold deposit (in ppm) of the Tanzanian Craton.

Sample	Sc	V	Cr	Co	Ni	Rb	Sr	Ba	Zr	Hf	Y	Ta	Nb	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dv	Ho	Er	Tm	Yb	Lu	Th	U
Metasedimentary rocks																													
D0142-1	15	102	118	18	48	92	206	829	150	5.2	14.7	0.69	7.8	28.4	55.3	6.36	23.9	4.26	1.0	3.29	0.47	2.58	0.5	1.56	0.23	1.5	0.23	10.3	3.13
D0149-1	18	123	132	17	51	111	154	915	119	4.2	18.2	0.84	8.1	31.2	64.5	7.5	28.6	5.12	1.08	4.08	0.6	3.25	0.63	1.85	0.28	1.72	0.25	11.2	3.32
D0149-2	9	82	78	14	29	32	389	328	84	2.8	9.5	0.27	3.2	9.37	20.3	2.56	10.9	2.26	0.76	2.01	0.31	1.64	0.31	0.88	0.12	(1.79	0.11	1.6	0.47
D0149-4	12	79	83	12	39	105	231	540	83	2.9	12.8	0.36	4.3	18.8	38.1	4.48	17.5	3.26	1.01	2.76	0.39	2.13	0.41	1.19	0.17	1.11	0.17	6.28	1.85
D0149-6	25	152	170	20	88	147	229	848	104	3.8	18	0.73	7.9	36.3	76.9	9.21	36.0	6.64	1.23	5.06	0.69	3.46	0.63	1.85	0.27	1.71	0.25	9.67	3.77
Leucogranites																													
D0310-1	8	bd	54	bd	bd	393	8	24	31	2.7	46.8	2.26	20.1	5.72	13.5	1.83	6.9	2.40	0.07	2.92	0.82	6.25	1.37	4.82	1.03	7.84	1.23	8.5	2.00

3.3 Isotopic geochemistry of granites

Isotopic geochemistry is very common in the classification of granites according to their magmatic origin such as those resulting from partial melting of metasedimentary source rocks (S-types) through a process called anatexis or ultra metamorphism and those derived from source rocks of igneous composition that have not gone through the surface weathering process or from crystal fraction of magma (I-type)

An example of the isotopic studies which have been undertaken is the S- and I-type granites from Tasman Orogenic Zone of Eastern Australia studied in detail by Chappell and White (1974) and others. White, Chappell and their coworkers (1974, 1978, Hine et al., 1978) carried out a complete study of magma provenance in this area. They were able to recognize a group of early metamorphically harmonious plutons largely composed of S-type granites.

Water is perhaps the most component of silicate melts because of its profound influence on crystallization, movement and transport of magmas and mass transfer of rock and ore-forming components of magmas. The history of water in magmas can be traced in many cases through oxygen and hydrogen isotopes. For example hydrogen isotopes are especially useful in certain cases as the isotopic fractionations between water vapor and silicate liquids and silicate minerals are sufficiently large at magmatic temperatures to be useful in elucidating magmatic process.

Correlated variations in water contents and whole rock hydrogen isotope compositions provide a means of tracing the evolution of the aqueous vapor phase in high level granitic magmas and help define the hydrogen isotope composition of magmatic water. O'Neil et al (1977) and Taylor et al (1977) have illustrated the importance of oxygen isotope ratios and to a lesser extent hydrogen isotope I distinguishing the S- and I-type granites. O'Neil et al., studying the Berridale Batholiths determined that oxygen isotope compositions of whole rock samples are an excellent discriminant between the two types.

The Archean granites of Kakamega-Kisumu-Mumias areas have elements of the S- and I-type granites thus can be related to the above described granites given the fact that less isotopic studies has been done like the initial $^{87}Sr/^{86}Sr$ ratio (Bell and Dodson,1981)

CHAPTER FOUR: PETROGENESIS

4.1 Origin, occurrence and granitic terrain

Granite often occurs as relatively small, less than 100 km^2 stock masses (stocks) and in batholiths that are often associated with orogenic mountain ranges. Small dikes of granitic composition called aplites are often associated with the margins of granitic intrusions. In some locations, very coarse-grained pegmatite masses occur with granite.

In the 1930s, geologists were eagerly disputing the question as to whether granite was magmatic, metamorphic or metasomatic in origin. As late as the middle of the nineteenth century the notion lingered on that granites were produced by precipitation from an aqueous fluid.

Granite has been intruded into the crust of the Earth during all geologic periods, although much of it is of Precambrian age.

The Archean Maragoli granites and the Archean Mumias granites have been dated at 2504±48 Ma (Rb:Sr, Dodson et al.,1975) and at 2495±70 to 2577±100 Ma (K:Ar, Cahen and Snelling, 1966) respectively. According to Bell and Dodson (1981), the initial $^{87}Sr/^{86}Sr$ ratios derived from whole rock Rb-Sr isochrones and errorchrons are generally low indicating that the granitic magmas formed by partial melting of protoliths with short prior residence time in the crust thus the granitic crust underlying Tanzania and parts of Uganda and Kenya (with reference to western granites) formed about 2.8 Ga and 2.4 Ga.

Huddlestone et al. (1959), states that the Archean Maragoli granites in the south and the Archean Mumias granites in the north are intrusive into the rocks of the Nyanzian and Kavirondian systems. There is little however to distinguish them either in hand specimens or in thin sections and it is possible that they are part of one large batholiths.

4.2 Major Archean granitic formations in the study area

There exist several granitic formations with almost the same physical properties and mineralogical composition within this Archean region. These formations are believed to be all post-Nyanzian in age. The granitic formations of great concern which are found within Kisumu, Kakamega and Mumias are the Kisian granites, the Maragoli granites and the Mumias granites. These are greatly discussed below.

Apart from the above mentioned formations, western Kenya is inhabited with other several granite formations such as the Oyugis and the Asembo granites (Huddleston et. al., 1959), Migori granites (D.W. Ichangi and W.H. Mclean et al., 1991) and the Seme granites which border the Kisian granites amongst others.

4.2.1 Kisian granites

These are the most distinctive granites on the north of Lake Victoria in Kisumu District. It's a coarsely porphyritic type. They occupy the greater portion of the granite outcrop forming the Seme hills near the Kavirondo gulf and extends northwards. Its outcrops consist of enormous blocks or massive tors, some over 300 ft. high and forms strong features throughout its extent. This resistance to erosion is due to the stability of its microcline phenocrysts which in weathered hand specimens are practically unaltered and form outstanding crystals. (Huddleston et al., 1991)

The granitic tors of the Kisian granites are aligned along the major axis of the intrusion, i.e. from north-east to south-west.

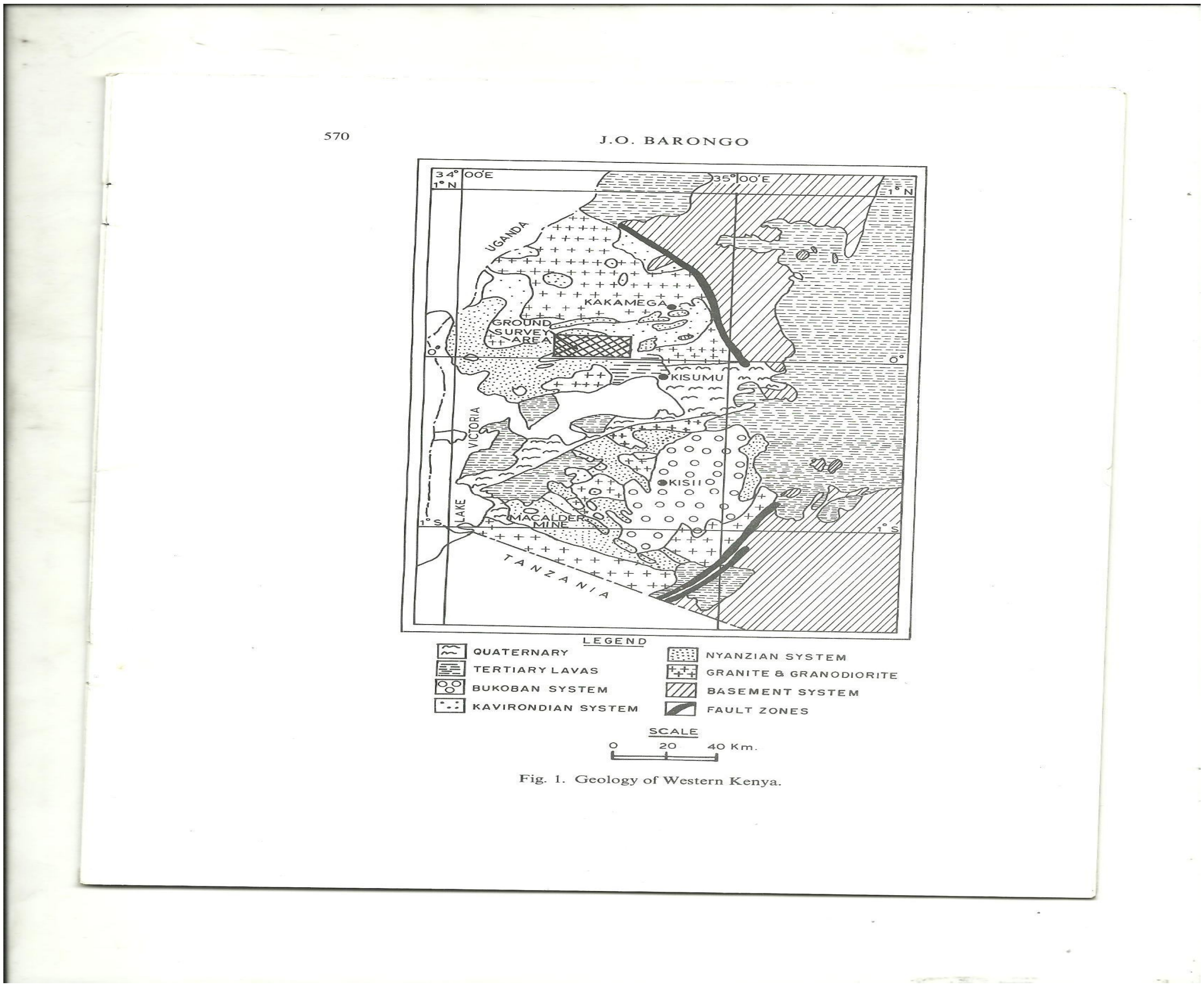

Figure 4. 1: Geological map of Kakamega-Kisumu area where the Maragoli, Kisian and the Mumias granites occur. (J.O. Barongo)

4.2.2 Maragoli granites

The Maragoli granite outcrops from Maseno in the west to Miwani in the east of Kisumu District. It forms part of a batholiths extending into the Kakamega District where it invades Nyanzian and Kavirondian rocks. The granite forms the Nyando and Maragoli fault-line scarps. It’s characterized by groups of granite joint-blocks isolated by erosion forming massive tors. Huddleston et al., (1959) noted that the major joint directions are nearly at right-angles to one another on bearings of 32° to 51° and 114° to 169° whilst a third direction strikes at 76°.

He also noted that the granite varies in colour and where pink the colour has been attributed in some cases to hematite flakes in the feldspars (Pulfrey et al., 1946, pg. 24)

The Maragoli granite is not uniform throughout but varies from syenites to granodiorites and to granites an indication of a complex intrusion or a number of intrusions. They are predominantly porphyritic and similar to the Kisian granites to which they are obviously related if not part of the same intrusion. Like the Kisian type they are unfoliated with no orientation of its phenocrysts but the uniformity of the Kisian type is not displayed by the Maragoli granite which are variably porphyritic or even and coarse-grained, and it is hornblendic or biotitic in character. In some areas it grades into a leucocratic variety with a saccharoidal texture, (Huddleston et al., 1991). The granites also show aplite veins and occasional quartz veins that are evidence of late-stage veining.

4.2.3 Mumias granites

According to A. Huddleston (1959), the Mumias granites outcrop over almost the whole of the northern half of Kakamega District except in the east where the Nyanzian volcanic occur. Megascopically and microscopically, the Mumias granites are mostly identical with the main types of the Maragoli granites.

However, there is a large development of a finer-grained leucocratic type in the Mumias granites and one occurrence between Sijuguju T.S and the Nzoia river, has a length of about eight miles and a width of some five miles.

Table 4. 1: Volumetric modes of typical Archean granites from the study area

	Maragoli granite Vol. in %	**Mumias granite Vol. in %**	**Kisian granite Vol. in %**
Quartz	20.1	15.3	18.0
Alkali feldspars	55.7	51.5	53.7
Plagioclase	7.6	17.0	11.1
Biotite	4.0	7.8	7.2
Hornblende	10.7	3.1	5.1
Muscovite	0.6	0.9	1.6
Accessories	1.3	4.8	3.1

4.3 Structural formations within the Archean granitic terrain

From the previous studies done in the area it is reported that the Archean granitic terrain of Kisumu-Kakamega-Mumias region might have gone through two major periods of deformation as stated by Huddleston et al., (1959). These major folding also occurs with several other minor folding or micro-folding throughout the study area.

Apart from the folds, there are several faults that are occurring in the study area. The major fault system in the area is the Nandi fault system. Pulfrey et al., (1938) also mapped a thrust fault in the study area as stated in his unpublished report. The Archean Maragoli granite forms the conspicuous Nyando and Maragoli fault-line scarps.

The major joint directions in the region have a characteristic property of nearly right-angle to one another on bearings of 32° to 51° and 114° to 169° and another direction striking at 76°. Horizontal jointing is evidenced in various parts of the Archean intrusions.

The Archean granitic terrain is also characterized by a number of quartz veins. The Maragoli granites is characterized by such veins which have traces of gold probably due to their proximity to the several small gold mines which were mapped to be occurring in the region in relation to a report by Huddleston (1959)

4.4 Textural properties of the Archean granites

Texturally, granites depends on the process by which they are formed and the environmental conditions within and the surrounding. They are formed within the earth's surface under very high temperatures and pressures. Under these conditions the cooling process is slow thus the grains have ample time to grow compared to the magma ejected on to the earth's surface. As a result Archean granites are characterized by their coarse to medium-grained texture. However some granite occurs as fine-grained crystals. The texture can also be referred to as phaneritic texture because of its large crystals that can easily be seen by a naked eye.

Pulfrey (1946) noted that the Maragoli granite texturally varies from fine-grained to extremely coarse-grained. This was also noted in the Mumias granite which megascopically has the same characteristics as the Maragoli granites. The Kisian granites on the other hand are coarsely porphyritic in nature.

4.5 Types of the Archean granite

Granites are classified differently worldwide. Descriptive petrology is one of the classification methods. Some of the properties used in this classification include physical features such as colour, texture, minerals present in the rock (mode) etc. example of the descriptive method is the total alkali versus silica method (TAS). Another classification method is using their chemical composition like the chemical classification of igneous rocks developed by the International Union of Geological Sciences (IUGS).

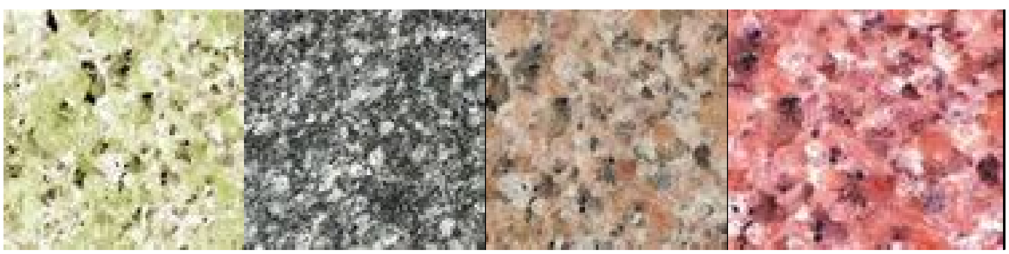

Fig. 4.2A *Fig. 4.2B* *Fig. 4.2C* *Fig.4.2D*

Figure 4. 2: Different types of granites with reference to their colours i.e. Fig. 4.2A is green granite, Fig.4.2B is grey granite, Fig. 4.2C shows pinkish granite and Fig. 4.2D is red granite.

4.6 Descriptive or modal classification

The Archean granites of Kisumu-Kakamega-Mumias region are classified as biotite granites, hornblende granites, leuco-granites and the alaskitic granites.

4.6.1 Biotite granites

Biotite granites are composed of majorly of biotite, quartz, plagioclase and potash feldspars. Apart from these minerals it also contains hornblende with the amount of hornblende being lower than that of biotite. It's well distributed within the Archean granites of Kisumu, Kakamega and Mumias areas.

4.6.2 Hornblende granite

Hornblende granites can also be called syenitic granites. The major component here is hornblende. The micaceous component is slightly lower than the hornblende. Hornblende granite are Pinkish-gray- to medium-buff-weathering, pinkish-white or light-pinkish-gray, medium- to coarse-grained, gneissic to indistinctly foliated granite and sparse granite gneiss composed principally of microcline microperthite, quartz, oligoclase, and hornblende.
According to Huddleston et al.,(1959) the Maragoli granites display the porphyritic hornblende-bearing granite types. The porphyroblastic hornblende granites also are prominent and are however reported within the Kisian Archean granites of Kisumu.

4.6.3 Leuco-granites

These Archean granites occur throughout Kisumu-Kakamega-Mumias areas. They are mostly composed of the felsic minerals.

4.6.4 Alaskitic granite

Alaskitic granite is a coarse-grained leucocratic rock carrying large quartz phenocrysts. The quartz to feldspar ratio in thin section is seen to be about 30:70, the feldspars being mainly cloudy orthoclase with only minor amounts of clear microcline and some finely twinned albite, about An_{8}. The large quartz phenocrysts often show strain shadows. The alaskitic granite occurs in small amounts in the Kakamega region of the study area. It's therefore a minor granitic type in the study area.

4.7 ECONOMIC POTENTIAL OF GRANITES

4.7.1 Modern applications of granites

Granites have a wide range of modern uses worldwide within the construction and building industries. Granites are known to be good durable construction materials. The high population growth rate has increased demand for more houses. In addition to their durability, granites also occur in different colours which are used to give a good look to different buildings. It is either used as a dimension stone or as flooring tiles in public and commercial buildings and monuments. Aberdeen in Scotland known as “The Granite City” is constructed principally from the local granites.

Granites have also been used in the building of roads, bridges and gabions in several countries and also in the construction of dams to prevent flooding or overflows of rivers. It has been used for cobblestones on the St. Louis River front. This can also be applied within the region to control the perennial effects of flooding of river Nzoia in the Budalangi area.

Polished granites are popular choice for kitchen countertops due to their high durability and aesthetic qualities.

Granites may also be useful for rock climbing. These granitic rocks such as the granitic tors can be setup as tourists’ attraction sites which are sources of revenue to the government.

The following photographs show some of the areas where granites have been used.

Fig. 4.3A **Fig. 4.3B** **fig. 4.3C**

Figure 4. 3: Photographs of some of the uses of granites. Fig.4,2A shows a bridge built using granites, Fig. 4.2B is a floor made using granite tiles and Fig. 4.2C is a house built using granite slabs.

CHAPTER FIVE: DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSIONS

Western Kenya is richly a greenstone belt. The region is home to the Nyanzian and the Kavirondian rocks. Within these two systems there occur several granitic terrains such as the Migori granites, Asembo granites, the Maragoli granites, the Kisian granites and the Mumias granites with the last three being the ones of concern to this study. The Archean granites of Kisumu-Kakamega-Mumias underwent through some tectonic movement of folding and faulting like the Nandi fault. The greenstone belt extends into the Tanzanian Craton and therefore some of the properties can be related microscopically and megascopically. This is explained by the close relationship in their geochemistry.

Archean granites of Kisumu, Kakamega and Mumias are believed to be post-Nyanzian in age and that all the above three mentioned have more similarities physically and geochemically. They are medium to coarse-grained in texture. They are also characterized by the occurrence of the massive granitic tors especially within the Kisumu (Kisian) granites and the Kakamega (Maragoli) granites.

The Archean granites of the Kisumu, Kakamega and Mumias are generally classified into four major groups with reference to their composition and appearance. These include biotite granites, hornblende granites, leuco-granites and the alaskitic granites. The biotite and the hornblende granites contain larger components of biotite and hornblende respectively.

Isotopic study of the Archean granites has however remained a challenge since very few has been undertaken in the area unlike the Tanzanian Craton. The geochemistry of the Archean granites in the study area was compared to those of the Tanzanian Craton.

The major elements are silica, aluminum oxide, iron oxide, calcium oxide and the oxides of potassium and sodium. Given the similarities in the geology of the study area and the Tanzanian Craton it can be concluded that the trace elements in the study area are similar as indicated in table 3.3.

Granite has been used for different purposes worldwide such as in the construction and building industries due to their durability and aesthetic qualities.

5.2 CONCLUSIONS

The study area of Kisumu-Kakamega-Mumias region is widely covered by Archean granites. These granites can be related to the Archean granites occurring within the Tanzanian Craton which is the extension of the Mozambique belt of East Africa. The major granite formations within the study area are the Kisian granites of Kisumu, the Maragoli granites of Kakamega and the Mumias granites. These Archean granite formations have the same characteristics. Geologically they occur within the Nyanzian and Kavirondian systems of western Kenya. There are three major types of granites that occur within the study area and one minor type. The major ones include biotite granites, hornblende granites and leuco-granites with the minor being the alaskitic granites.

The geochemical analysis show that they are largely composed of silica, aluminous oxide in larger quantities compared to the other elements as major elements. These compositions are closely associated to the Tanzania Craton. The trace elements composition is largely inferred to the studies done in the Tanzanian Craton due to the fact that less isotopic studies have been undertaken in the area. These studies can be used to determine the source material and the method of the Archean granites formation.

Granites have several uses in the modern world. The study area has enormous deposits or outcrops of granites that can be utilized to uplift the living standards especially of the locals.

5.3 RECOMMENDATIONS

- The Archean granites of Kisumu-Kakamega-Mumias areas have not been studied well enough thus more geochemical studies should be done to determine some of the major and trace elements that may be occurring in these granitic terrains.

- In order to understand the petrogenesis and petrography of these Archean granites deeper lots of isotropic studies may are required.

- Some of the granitic terrains especially the massive granitic tors should be protected for tourists' attraction.

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APPENDICES

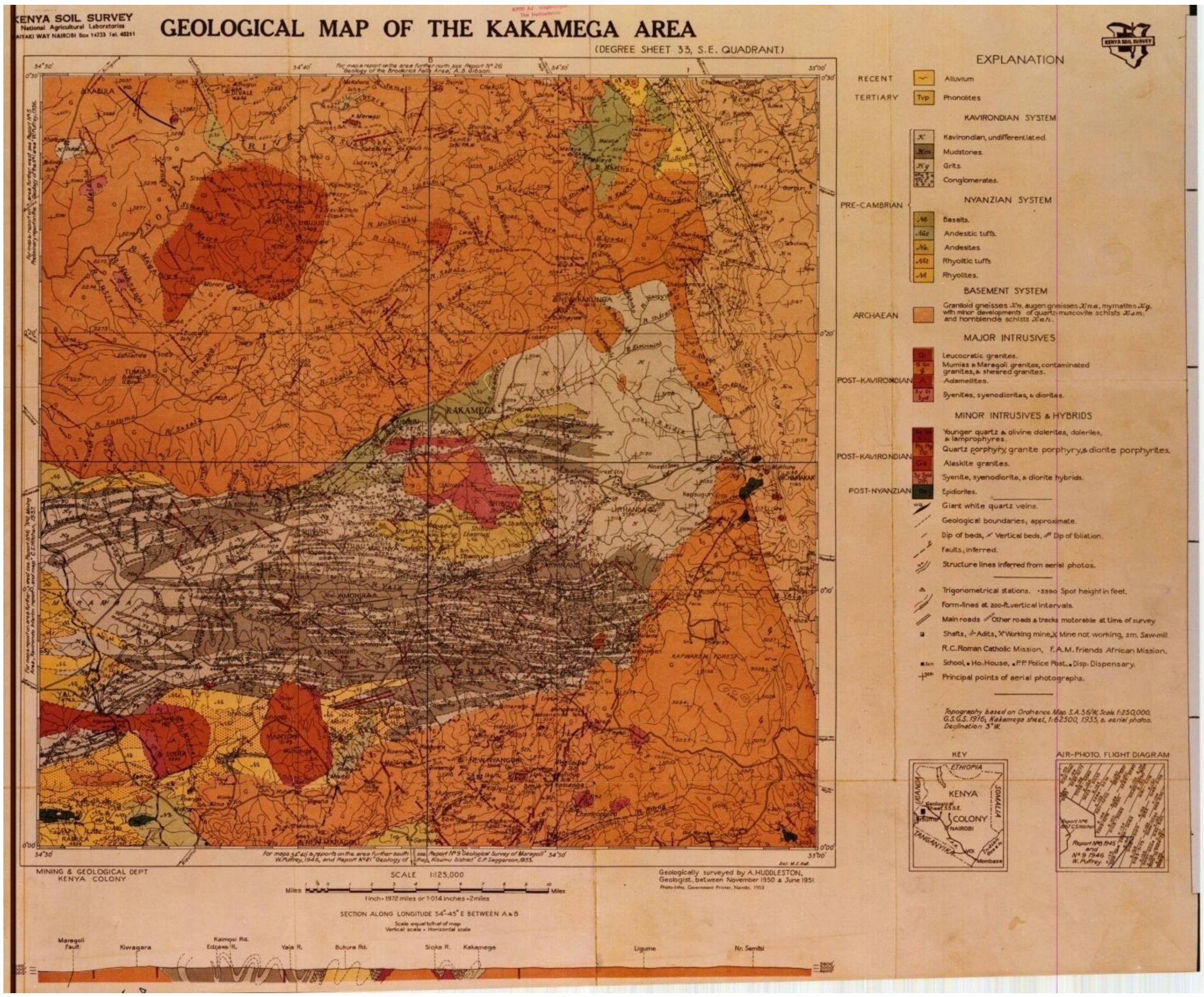

Figure 5. 1: Geological map of Kakamega area where the Maragoli granites occur and part of the Mumias granites. The north-west orange quadrant is the Maragoli granites and the orange in the south is the Mumias granites. (Huddleston, 1959)

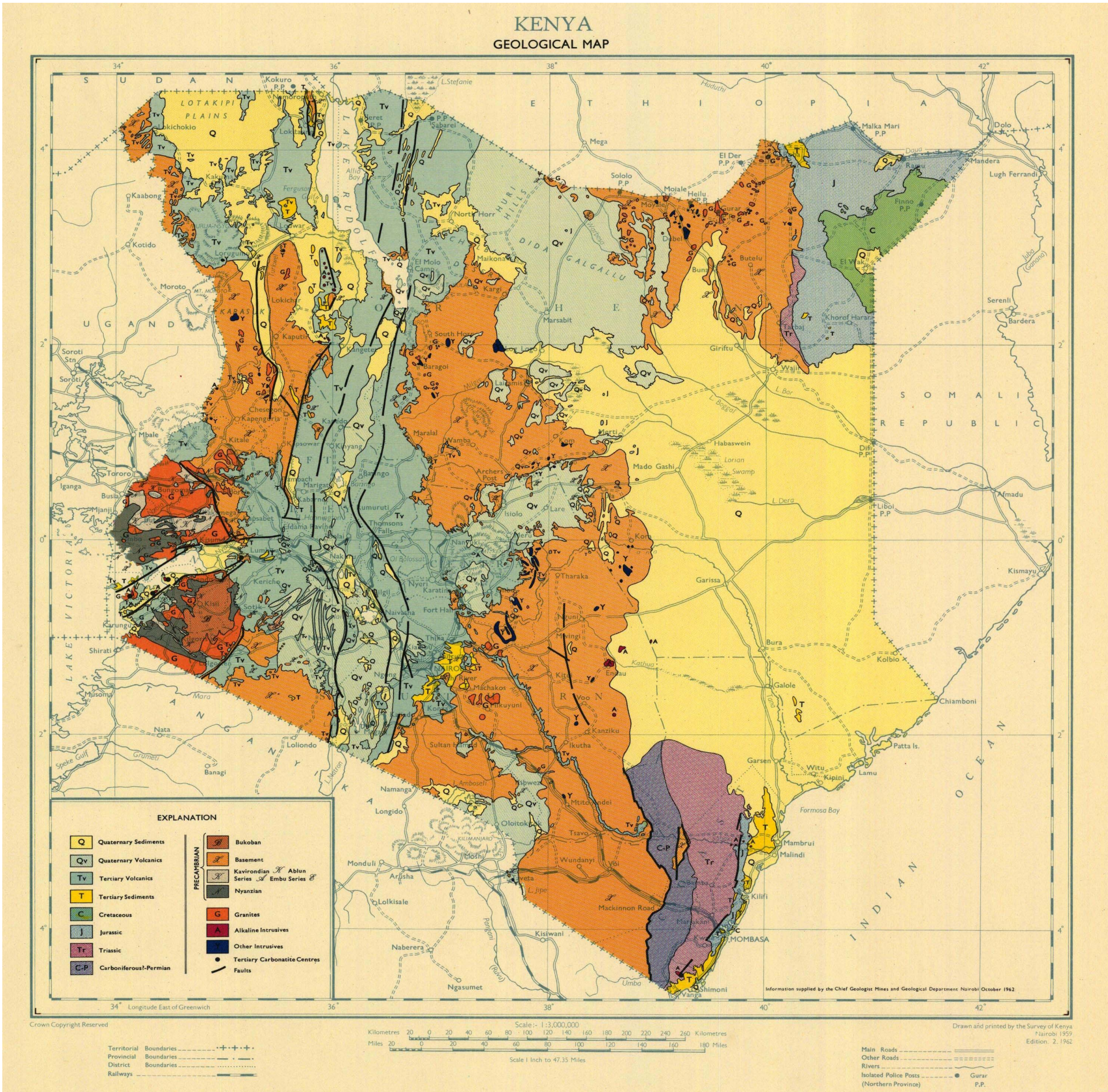

Figure 5. 2: Geological map of Kenya clearly showing the occurrence of Archean granites in western Kenya (orange in colour)

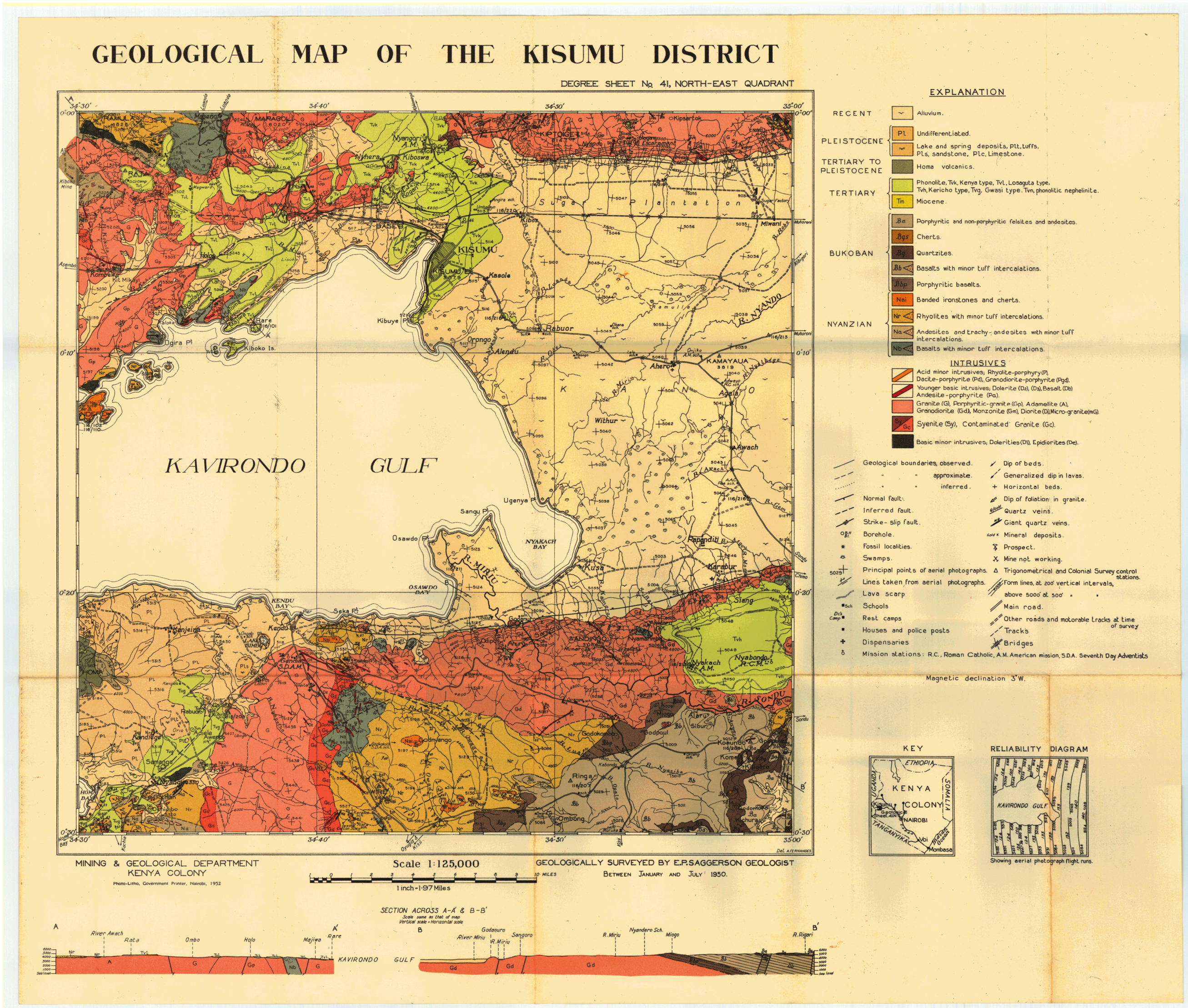

Figure 5. 3: Geological map of Kisumu where the Kisian Archean granites and part of the Maragoli Archean granites occur.