

GEOLOGY AND GEOCHEMISTRY OF URANIUM MINERALIZATION IN MIKA
N. E. NIGERIA

BY

IDRIS ISA FUNTUA

A thesis submitted to the Postgraduate School, Ahmadu Bello
University, in partial fulfillment of the requirements for
the degree of Ph. D. (Geology).

Department of Geology
Faculty of Science
Ahmadu Bello University
Zaria

September, 1992

DECLARATION.

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma to any other University or Institution. Information derived from published or unpublished work of other workers has been acknowledged in the text.



Signature



Date

CERTIFICATION.

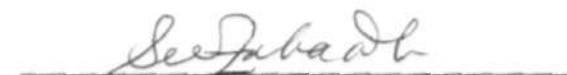
This thesis entitled Geology and Geochemistry of Uranium Mineralization in Mika, N.E., Nigeria by Idris Isa FUNTUA meets the regulations governing the award of the degree of Ph. D. Geology of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.



Chairman, Supervisory Committee.

21/12/92

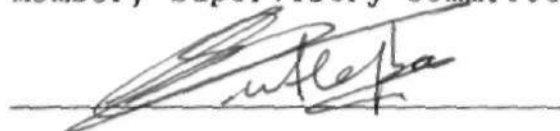
Date.



Member, Supervisory Committee.

06/01/93

Date.



Member, Supervisory Committee.

07-01-93

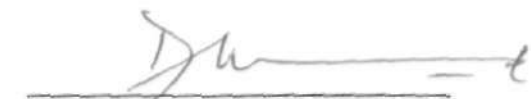
Date.



Head of Department.

06/01/93

Date.



Dean, Postgraduate School.

30/11/93

Date.

DEDICATION.

Dedicated to
LATE ALHAJI LAWAL ISA FUNTUA

ACKNOWLEDGEMENTS.

I express my profound gratitude to Dr. C. D. Okujeni for his advise and guidance throughout the period of this and other related works; Dr. S. I. Abaa for his criticism and advise and Dr. S. B. Elegba, the Director C.E.R.T for his intrest in the work and his help in many ways.

My sincere thanks goes to Dr. O. M. Ojo, Dr. U. M. Turaki, Mr. O. Ogunrinde and other staff members for their assistance in collection of information and samples at Nigerian Uranium Mining Company (NUMCO), Gombe. I am grateful to Paul and other people of Mika village for helping me during the fieldwork.

I acknowledge the assistance of International Atomic Energy Agency (IAEA) for the award of training fellowship to Debrecen, Hungary, which enabled me carry out most of the analytical work along with my training. I am grateful to Dr. Cs. M. Bucsko for her suggestions and very useful discussions during my stay at Debrecen. Thanks also to other staff members of the Institute for their assistance. I wish to also thank the members of the Nigerian Community at Debrecen for making my stay enjoyable.

Sincere thanks go to members of staff of CERT, Geology Department and all my friends for their help, discussions and sugessions.

ABSTRACT

The Mika uranium mineralization is located near Zing in Taraba State, N.E. Nigeria.

The host rock consists of a sheared Pan-African medium grained biotite granite which is in places intruded by rhyolites and siliceous veins. These are criss-cut by numerous joints, faults and fractures which are filled by hematized silica.

The ore occurs in two parallel N-S trending shear zones with the western limb hosting a rhyolite body. Drill section reveal a subsurface extension of the above. In the upper limb mineralization consisting of meta-autinite occurs associated with the rhyolite body. In the lower ore limb pitchblende and coffinite occur along a set of two parallel shear surfaces. The pitchblende occurs massive and as veinlets in hematized rocks in association with sulphides. The ore body is marked by distinct hydrothermal alteration zones which feature sericitization, silicification, K-feldspathization, hematization and kaolinization.

Three hundred rock samples consisting of host rocks and ores from surface and drill cores each of which was analysed for 25 elements using Neutron Activation Analysis, Natural activity counting and Radioisotope X-ray fluorescence techniques. The elements includes Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Sc, V, Cr, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Mo, Pb and U. The resulting data were evaluated using multivariate statistical techniques including principal component analysis.

U, Fe, P, Cu, Zn, Mo and Pb have higher values than the background values. These elements form distinct dispersion aureoles around the uranium occurrence which appeared to be most pronounced on the surface, perhaps owing to weathering and remobilization. Some elements like Na and K are depleted in the mineralized zone in relation to the intensity of hydrothermal alteration.

There are two distinct element associations in the ore zone and host rocks; the $Ti_{20}-Mg_0-Ca_0-K_{20}-Co-Sr-Rb-Zr$ and $Fe_{203}-P_{20s}-Cu-Zn-Mo-Pb-U$. The first which reflects mineralogy of the host rock forms a large cluster that includes Fe_{20a} , P_{20s} , Cu, Zn, Mo, Pb and U in the altered granites and rhyolites. This is fragmented into the two associations above in the mineralized rocks. The latter group, $Fe_{203}-P_{205}-Cu-Zn-Mo-Pb-U$ is a product of remobilization of the former and reflects the mineralogy of the ores.

Structures played an important role in the formation of the Mlka mineralization, as channel and or mechanical barrier. These structures are reactivated lineaments that are related to regional structures, which have undergone a prolonged history of geological development and several periods of activity.

The bimodal magmatism of the Burashika group is postulated to be related to the uranium mineralization, from the consistent presence of rhyolite bodies to the mineralization. The role of the magmatism is most likely the source of heat and the driving force of the mineralization fluid and sometimes as well as mechanical barrier for the fluids leading to the formation of the mineralization.

TABLE OF CONTENTS

CHAPTER	Page.
Title	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledgements	v
Abstract	vi
Table of Contents	viii
List of Tables	xii
List of Figures	xiii
List of Plates	xvi
List of Appendices	xvii
 1. INTRODUCTION	 1
1.1 Location and Accessibility.	8
1.2 Relief and Drainage.	9
1.3 Climate and Vegetation.	11
1.4 Population and Occupation.	12
1.5 Previous Work.	13
 2. REGIONAL GEOLOGY.	 17
 3. GEOLOGY OF THE MINERALIZED AREAS.	 26
3.1 The Gubrunde area.	27
3.2 The Ghumchi area.	29
3.3 The Monkin area.	33
3.4 Mineralization in sedimentary areas.	36
3.5 Characteristic features of the mineralizations.	38

4. FIELD AND LABORATORY METHODS OF INVESTIGATION.	40
4.1 Sample collection.	40
4.2 Sample preparation.	43
4.3 Analytical methods.	45
4.3.1 X-ray diffraction (XRD).	46
4.3.2 Isotopic X-ray spectrometry (XRF).	47
4.3.3 Neutron Activation Analysis.	54
4.3.4 Natural activity.	58
4.4 Detection limit.	62
4.5 Uncertainty of measured data.	63
4.6 Data analysis.	63
4.6.1 Correlation analysis.	66
4.6.2 Principal component analysis.	66
5. THE MIKA MINERALIZED AREA.	68
5.1 Geology of the Mika area.	68
5.1.1 Fine-grained granite.	72
5.1.2 Medium grained granite.	75
5.1.3 Porphyritic granite.	76
5.1.4 Sheared granite.	78
5.1.5 Brecciated rhyolite.	79
5.1.6 Olivine basalt.	79
5.2 Mineralization.	80
5.3 Alteration studies.	89
5.3.1 Sericitization.	92
5.3.2 Silicification	93

5.3.3 K-feldspathization.	94
5.3.4 Hematization.	94
5.3.5 Kaolinization.	94
5.3.6 Relationship between the alteration features and mineralization.	96
 6. THE GEOCHEMISTRY OF URANIUM MINERALIZATION IN MIKA.	
6.1 Major and minor element geochemistry.	102
6.1.1 Iron (Fe)	102
6.1.2 Magnesium (Mg)	103
6.1.3 Calcium (Ca)	103
6.1.4 Sodium (Na)	104
6.1.5 Potassium (K)	105
6.1.6 Manganese (Mn)	110
6.1.7 Titanium (Ti)	110
6.1.8 Phosphorous (P)	111
6.2 Trace element geochemistry.	116
6.2.1 Scandium (Sc)	116
6.2.2 Vanadium (V)	117
6.2.3 Chromium (Cr)	117
6.2.4 Cobalt (Co)	118
6.2.5 Nickel (Ni)	118
6.2.6 Copper (Cu)	119
6.2.7 Zinc (Zn)	124
6.2.8 Arsenic (As)	125
6.2.9 Selenium (Se)	125
6.2.10 Rubidium (Rb)	126

6.2.11 Strontium (Sr)	127
6.2.12 Yttrium (Y)	128
6.2.13 Zirconium (Zr)	129
6.2.14 Molybdenum (Mo)	130
6.2.15 Lead (Pb)	131
6.2.16 Uranium (U) geochemistry.	137
6.3 General patterns in the distribution of the elements	140
6.4 Element interrelations and associations.	148
6.4.1 Correlation coefficient.	149
6.4.2 Principal component analysis.	156
7. DISCUSSION.	171
8. CONCLUSION AND RECOMMENDATIONS.	177
REFERENCES.	
APPENDICES.	

LIST OF TABLES

TABLE	Page
2.1 The stratigraphical succession of N.E, Nigeria	17
4.1 Nuclear data for Si, Fe and Cr determination	56
5.1 Joint statistics of the mineralized area at Mika.	71
5.2 Approximate modal analysis of fine-grained granite	74
5.3 Approximate modal analysis of biotite granite	76
5.4 Approximate modal analysis of porphyritic granite	77
5.5 Approximate modal analysis of sheared granite	78
5.6 Approximate modal analysis of brecciated rhyolite	79
5.6 Approximate modal analysis of olivine-basalt	80
6.1 Statistical summary of element content in the various rock groups.	101
6.2 Correlation matrix of the unaltered granites	151
6.3 Correlation matrix of the altered granites	153
6.4 Correlation matrix of the mineralized granites	153
6.5 Correlation matrix of the altered rhyolites	156
6.6 Correlation matrix of the mineralized rhyolites	156
6.7 Principal components of the unaltered granites	158
6.8 Principal components of the altered granites	160
6.9 Principal components of the mineralized granites	162
6.10 Principal components of the altered rhyolites	164
6.11 Principal components of the mineralized rhyolites	165

LIST OF FIGURES

FIGURE	Page
1.1 Location map of mineralization area	7
2.1 Geological sketch map of the Upper Benue region	18
3.1 The geological map of the Gubrunde horst	27
3.2 Geologic and structural map of Ghumchi area and Ghumchi mineralization.	30
3.3 Geologic and structural map of the Monkin zone	34
3.4 The Bille and Passam hills anomalies, Mayo-lope syncline	37
4.1 Surface sampling plan at Mika mineralization	41
4.2 Location map of drill holes at Mika mineralization	42
4.3 Lithologic description of 18C, D20 and D21 core samples	44
4.4 Geometric arrangement of the XRF method	49
4.5 Calibration curve for average Z determination	53
4.6 Irradiation position for 14 MeV Neutron Generator	57
4.7 Calibration curve for uranium standards	59
4.8 Relative activities of ^{234}U , ^{230}Th , and ^{226}Ra to ^{238}U against time	61
5.1 Geology of part of Monkin (sheet 216NW).	69
5.2 Rose diagram for the joint trends.	71
5.3 Detailed geologic section of Mika mineralization through D21 and 18C drill cores (southern profile)	84
5.4 Detailed geologic section of Mika mineralization through D20 drill core (central profile)	85
5.5 Positions of samples selected for XRD (D) and those for thin and polished section studies in the D21 and 18C sections	91

	Page
5.6 Positions of samples selected for XRD (D), and those for thin and polished section studies in the D20 section	91
5.7 Alteration features; sericitization, silicification, hematization and kaolinization	97
5.8 Alteration features; sericitization, silicification, hematization and kaolinization	98
6.1 Distribution of Na ₂ O, K ₂ O, CaO and Fe ₂ O ₃ at Mika mineralization	106
6.2 Distribution of Na ₂ O, K ₂ O, CaO and Fe ₂ O ₃ through D21 and 18C core sections	107
6.3 Distribution of Fe ₂ O ₃ , CaO, K ₂ O and Na ₂ O in D20 drill core	108
6.4 Distribution of Fe ₂ O ₃ , CaO, K ₂ O and Na ₂ O in part of 18C drill core	109
6.5 Distribution of P ₂ O ₅ , TiO ₂ , Zr, and Rb at Mika mineralization	112
6.6 Distribution of P ₂ O ₅ , TiO ₂ , Zr and Rb through D21 and 18C core sections	113
6.7 Distribution of Rb, Zr, TiO ₂ and P ₂ O ₅ in D20 drill core	114
6.8 Distribution of Rb, Zr, TiO ₂ and P ₂ O ₅ in part of 18C drill core	115
6.9 Distribution of Zn, Cu, Mo and Y at Mika mineralization	120
6.10 Distribution of Zn, Cu, Mo and Y through D21 and 18C core sections	121
6.11 Distribution of Y, Mo, Cu and Zn in D20 drill core	122
6.12 Distribution of Y, Mo, Cu and Zn in part of 18C drill core	123
6.13 Distribution of U, Pb, V and Sr at Mika mineralization	133

	Page
6.14 Distribution of U, Pb, V and Sr through D21 and 18C core sections	134
6.15 Distribution of Sr, V, Pb and U in D20 drill core	135
6.16 Distribution of Sr, V, Pb and U in part of 18C drill core	136
6.17 Comparative distribution of Zn, Pb and U in part of 18C drill core.	139
6.18 Q - P diagram for the Mika granite	141
6.19 A - B diagram for the Mika granite	142
6.20 K ₂ O - Na ₂ O diagram for the rock groups	143
6.21 Sr - Rb and Sr - U diagrams for the rock groups	144
6.22 Y - U diagram for the rock groups	145
6.23 Zr - U diagram for the rock groups	146
6.24 Pb - U diagram for the rock groups	147
6.25 Plot of components I and II and I and III for elements in the unaltered granite	158
6.26 Plot of components I and II and I and III for elements in the altered granite	161
6.27 Plot of components I and II and I and III for elements in the mineralized granite	163
6.28 Plot of components I and II and I and III for elements in the altered rhyolite	165
6.29 Plot of components I and II and I and III for elements in the mineralized rhyolite	166

LIST OF PLATES

PLATE		Page
Plate I	Outcrop of fine-grained granite	74
Plate II	Outcrop of biotite granite	74
Plate III	Photomicrograph of biotite granite	77
Plate IV	Outcrop of sheared granite	77
Plate V	Outcrop of brecciated rhyolite	81
Plate VI	Part of the main Mika mineralization	81
Plate VII	Photomicrograph of mineralized granite	87
Plate VIII	Photomicrograph of mineralized granite	87
Plate IX	Secondary uranium mineralization in sheared brecciated granite	88
Plate X	Photomicrograph of mineralized granite	88

LIST OF APPENDICES

APPENDIX

Appendix I	Core sample positions
Appendix II	XRD charts and interpretations
Appendix III	Fundamental parameter method data
Appendix IV	Total uranium and U-234, Th-230 and Ra-226 activity values from Natural activity method.

CHAPTER 1

INTRODUCTION

Uranium deposits vary greatly in form and economic importance. Deposits have been classified by many schemes involving host rock types, structural setting, shape, mineralogy, alteration pattern, paragenesis, age constraints and spatial geotectonic distribution (Lang et al., 1962, Ruzika, 1971, McMillan, 1977, Dahlkamp, 1980, 1989). Although various classifications exist, there is a general understanding in relating the type examples of the deposits to the environments they occur.

World uranium reserves are distributed among more than a dozen types of deposits, but, over 70% occur in only three types; namely, the sandstone, quartz-pebble conglomerate and unconformity type deposits (Nash and Granger, 1981). Other types of uranium deposits are the ultrametamorphic, classical vein type, igneous associated and calcrete.

The uranium mineralization in the NE Nigeria can be classified as classical vein type (Oshin and Rahman, 1986). These consist of deposits that are predominantly structurally controlled. Included are uranium deposits that occupy relatively simple faults and fracture zones in a

variety of host rocks, but display mineralogical and geochemical similarities. Some well-known examples outside Nigeria include Fay-Ace-Verna, Saskatchewan; Schwartzwalder, Colorado; Shinkolobwe, Zaire and the intragranitic vein deposits of Massif Central, France (Nash and Granger, 1981).

The most well studied are the deposits of the French Massif as reported in the works of Poty et. al., 1974, Porty et. al., 1986, Cuney (1974), Leroy (1978) and Friedrich et. al., 1987. The importance of accessory minerals in the granites which are the source of uranium was emphasized. Uranium was leached out of the accessory minerals and subsequently concentrated. Leroy (1978) and Cuney (1978) suggest that the uranium was transported as uranyl-monocarbonate complexes and deposited due to loss of CO₂ by boiling as well as precipitation of hydroalumocalcite.

The key factors for the formation of uranium deposits in general include source rock remobilization, transport, deposition, reconcentration and preservation.

For source rock remobilization, regional uranium enrichment appears to be required. When uranium in a source rock is below the clarke value of 1-2ppm, most of it is located in accessory minerals such as zircon, apatite and monazite (Friedrich and Cuney, 1989). The uranium contained in these

minerals is difficult to remove by most hydrothermal solutions. In contrast, when the uranium content exceeds the clarke value, it strongly fractionates into the melt and may crystallize as uraninite (Cathelineau and Poty, 1989).

The transport of uranium depends on the geochemical characteristics of the fluids (temperature, pressure, oxygen fugacity (fO_2), concentration of complexing anions, pH) and the amount of fluid (water/rock ratio) which in turn is partly related to the number and size of channelways which are controlled by the tectonic activity (Pagel, 1982).

The deposition of uranium is related to solubility changes in response to chemical and/or physical gradients. One of the most important factors seems to be fO_2 gradients (Cathelineau et. al., 1989). Such gradients can be created, for example, by mixing between oxidizing brines carrying uranium and reducing brines. Variations of pH and/or complexing agent concentration may also occur, especially during reactions with wall rock.

For granitic environment like in NE Nigeria, processes such as leaching of accessory minerals in source rocks, uranium ore crystallization, dissolution and redeposition of elements along oxidation-reduction fronts and weathering of the uranium ores by further secondary processes, especially

surface may be particularly important in formation of deposits.

In similar environments for example the French Massif, the distribution of uranium along with other trace elements like Th, Zr, Nb, Ta is primarily controlled by the magmatic stage (Cuney and Friedrich, 1987). The trace elements are not incorporated in the main rock forming minerals, because of the low partition coefficients between magma and minerals such as quartz, feldspars, phyllosilicates and amphiboles (Rosler and Lange, 1972). Consequently their content in the whole rock is strictly dependent on the conditions which prevail for the crystallization of the minerals which contain them. Thus knowledge of the mineralogy and the thermodynamic properties of the accessory minerals in the source rocks is most important in understanding the geochemical features of the granites. It should also be clear that accessory phases are small sized and represent a negligible volume of the rocks, thus highly microfaulted areas are required in order to favour a sufficient circulation through rocks and increase the exchange surface between fluid and minerals.

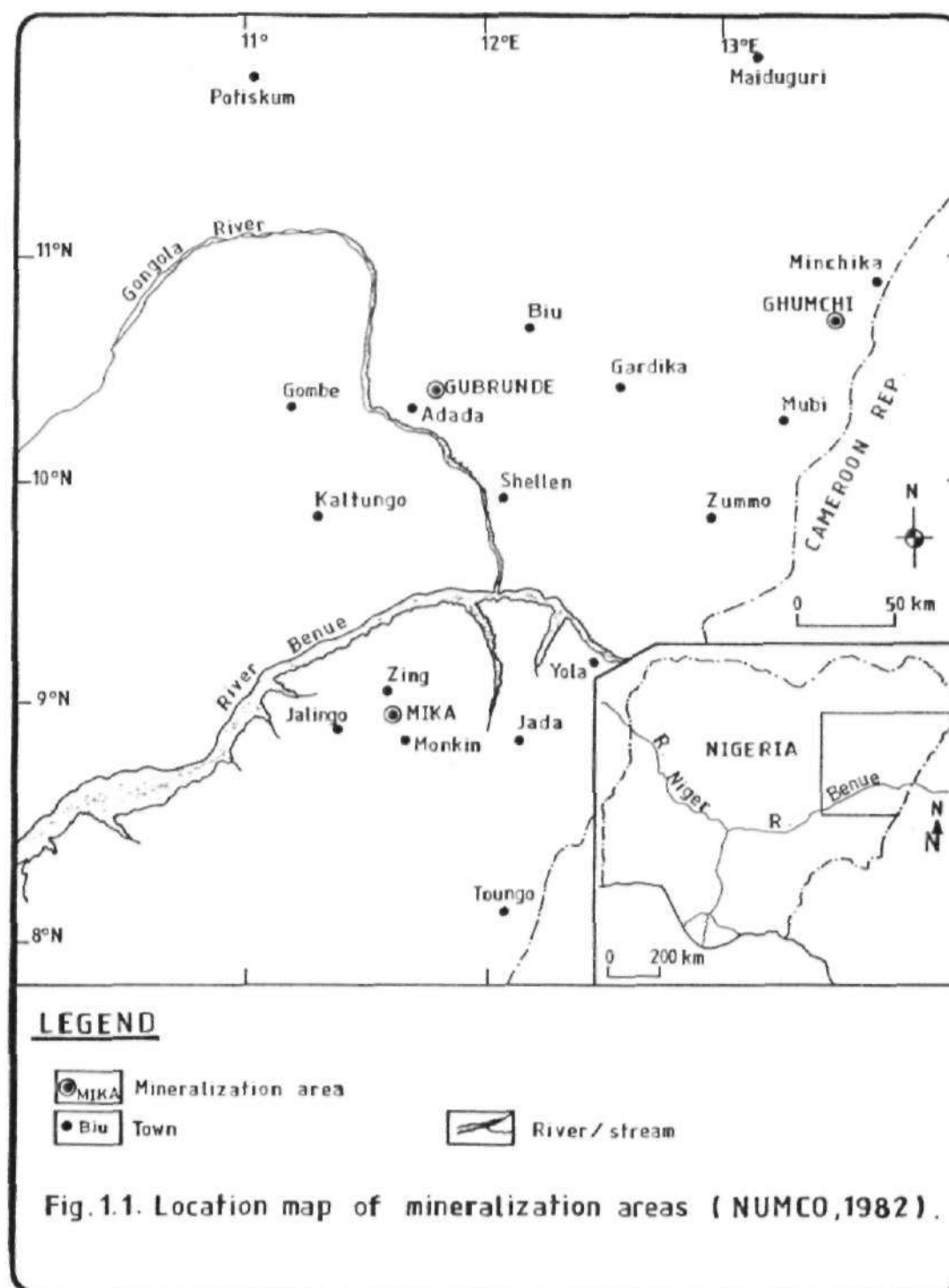
The main petrological characteristics of uranium rich granites (Bowie, 1977, Robertson et al., 1978, Smith, 1984 and Strong, 1985) include : i) They are evolved types and

in QAP diagram plot in the fields of alkali feldspar granite and granite. ii) Chemically they are characterized by high K, K/Na ratio and Rb/Sr ratio and low Ca, K/Rb and Ba/Rb ratios, compared to the average granite. iii) Most of the high uranium and mineralized granites are peraluminous with $Al_2O_3/CaO + Na_2O + K_2O$ mol. ratio of more than one. Peralkaline granites (like the younger granites of Nigeria) with $K_2O + Na_2O/Al_2O_3$ mol ratio of more than one are also enriched in uranium and thorium, but usually these elements tend to go into the structure of rare metal refractory minerals like pyrochlore and betafite instead of forming their own minerals. iv) Granites which have undergone alteration evolved by acidic volatiles and hydrothermal solutions. During this process, the uranium locked up even in refractory minerals like zircon is released and may be deposited as primary or secondary uranium minerals. Volatile activity manifest itself in the form of fluorite, topaz and fine aggregates of quartz and sericite. Kaolinization, chloritization and sericitization are common where hydrotherms have been active. The hydrothermal fluids could be deutric or ground waters, heated and mobilized due to heat generated by the abnormal radioactivity of the granite or due to tectonics.

Sizeable uranium mineralizations are known in three zones of NE Nigeria, these are the Gubrunde horst, the Monkin zone and the Ghumchi zone. All these mineralizations occur in basement rocks of Pan-African age. The sedimentary areas feature several uranium showings in the Kaltungo, Gubrunde, Dali, Mayo-lope areas and one major occurrence at Zona, all these occur in the Bima sandstone.

In this work the geology and tectonic setting of uranium mineralizations in associated with basement rocks of the Gubrunde host, Ghumchi and Monkin area and the few occurrences in the sedimentary areas are reviewed and interpreted with emphasis on Mika mineralization in the Monkin area. The geochemistry, alteration pattern and mineralogy of the Mika mineralization are studied in details.

A major aim of this study is to discern the subtle element patterns associated with the occurrences and based on this, predict the possible source of the uranium, mechanism for its transport as well as the factors responsible for its deposition. An attempt is also made to postulate a genetic model for the mineralization. Possible application of this and geochemical data in prospecting for more favourable areas, including the adjacent sedimentary basins is also looked into.



1.1 Location and Accessibility.

The study area is bounded by latitudes 11° and 8° and by longitudes 10° and 14° (Fig. 1.1). The areas fall within 1:100,000 sheets 153 (Wuyo) for the Gubrunde horst, 216 (Monkin) for the Monkin zone and 135 (Duhu) for the Ghumchi. The areas form part of Adamawa, Bauchi, Borno and Taraba States. Sheet 153 is bounded by latitudes $10^{\circ} 50'$ and 10° and longitudes $11^{\circ} 50'$ and 12° , sheet 216 is bounded by latitudes 9° and $8^{\circ} 50'$ and longitudes $11^{\circ} 50'$ and 12° and sheet 135 is bounded by latitudes 11° and $10^{\circ} 50'$ and longitudes 13° and $13^{\circ} 50'$.

A good road network connects the areas. For the Gubrunde horst a well-tarred road links the area from Gombe through Wuyo to Blu. Two motorable paths link Wuyo to the study area, one to Gubrunde which links Gwolemono through Kanawa and the other to Adada. A motorable road off Kwaya-Kusar - Peta road leads to Zona. Other paths interconnect small Fulani hamlets. For the Monkin zone, trunk A road links Yola, Numan and Jalingo. Access roads to the mineralizations are laterite roads and include at Zing for Gampu through Monkin and 12km outside Zing on the Zing - Jalingo road for Mika. The access road for the Ghumchi mineralization is through Garta Sama and Mbororo from Minchika.

1.2 Relief and Drainage.

The region provides a great diversity of interesting relief features. Rugged hills of granite and sandstone, volcanic plugs, sedimentary and volcanic plateaux and low swampy plains combine to form some of the most attractive scenery in the country.

The geological units are often demarcated by their topographic forms. The basement, the Cretaceous sandstones and the volcanic rocks all form prominent hill features.

The granites and migmatites of the basement form isolated rocky hills and low ranges of serrated outline. Amongst the sedimentary rocks the most impressive hill features are formed by the Bima Sandstone. The durable rocks of this formation often give a clear topographic definition of fold structures and provide some of the most impressive scenery in the region. The strong structural trends of the Bima Sandstone are reflected in linear and elliptical hill patterns particularly in the anticlines.

Cuestas are common landforms in the areas underlain by the Bima Sandstone. The great ranges of Bima and Wade are cuestas that dominate the landscape for hundreds of Km².

Numerous volcanic plugs and cones occur in the area. They frequently rise to 120m above surrounding country. Tangale peak is a spectacular spine that rises above the Bima

Sandstone south of Kaltungo. Billiri and Labore peaks are other prominent plugs. Another spectacular scenery is along Biu-Numan road with volcanic plug peak appearances on both sides of the road.

The Kerri-Kerri and Chad Formations underlie the low monotonous plateaux of the northern and north-western parts of the region. The Biu and Longuda basalt-capped plateaux are prominent and extensive features which rise to between 650 and 750m above sea level. The edges are deeply dissected.

The primary watershed of the Niger-Benue and the Chad basin, transverses the northern part of this area. The Benue and its largest right bank tributary, The Gongola river drains over 90% of the region.

The waterdivide between the Benue and the Gongola rivers runs across the Longuda plateau westwards to Tangale peak and thence northwards. The streams originating on the uplands south of the Benue River and flowing northwards to the Benue, include, from east to west, The Belwa, Mayo Lope, Kunni and Lamurde. The right bank tributaries flow off the longuda plateau-Tangale peak watershed towards the hill country in the south between Filiya and Lamurde. Along the base of the hills between Burak and Chum, the streams are gathered into the Mona and Dadiya systems. These join south of Bambam to form the Bolleri River which flows

southwards in narrow gorges through the highest parts of the rugged Filiya-Lamurde ranges and ultimately joins the Benue near Jen.

The left bank drainage of the Gongola may be subdivided into streams flowing southwards from the primary divide between Kadi and Damaturu and the streams originating on the Blu plateau. The Gungeru and Gaji Rivers are the two principal units of the first group. Those in the second group include Panana, Ruhu and Ndivana. The largest tributary, the Hawal River, joins the Gongola near Kombo. The right bank drainage can be subdivided into streams flowing eastwards from the Kerri-Kerri plateau and the streams flowing north and eastwards from Longuda-Tangale peak watershed. Important tributaries are the Majinyoru, Difa, Nono and Waja.

1.3 Climate and Vegetation.

The area has a mean annual rainfall of about 800-1000mm. It experiences two seasons, the dry and rainy seasons. It is hot and dry from September to April with temperatures up to 42° at noon, but normal temperatures are 35 - 38°C. The nights of the harmattan period temperatures drop to less than 20°C.

The vegetation of the area is of Sudan savannah type. This is characterized by relatively sparse trees and thorny bushes. Vegetation is green during the rainy season while the trees shed leaves annually. The vegetation is typical rearing land for the highly concentrated Cow-Fulani in the area.

The main tree species includes *Afromosia laxiflora*, *Buswellia dalzielii*, *Botrospermum paradoxicum*, which are tropical savannah trees. Others are *Combretum nigrum* var *elliottii* and *Isobertina* which are common in colluvial sites.

1.4 Population and Occupation.

The area is slightly densely populated most especially in the urban centres of Yola, Biu, Numan, Jalingo and Gombe. In other parts of the area the populations are in semi-urban areas and in farming communities.

The main occupation of the populace are farming and cattle rearing. The cattle rearing is carried out mostly by the Fulanis while the farming activities are carried out by the other tribal groups like the Hausas, Mumuye, Bura and Jarawa. Crops cultivated include guinea-corn, maize, millet, rice and root crops like yam and cassava.

1.5 Previous Work.

The first reported work in the region is Falconer (1911), in which some Cretaceous and Tertiary sedimentary Formations were described. Geological mapping of the area including adjacent sheets on a scale of 1:100,000 was conducted by Carter et. al. from 1954 to 1958. Carter compiled three 1:250,000 sheets (Potiskum, Gombe and Lau) from the 1:100,000 maps of the region as reported in Carter et al., 1963. Benkhelil (1986) in a two volume thesis produced geological map of part of the Upper Benue valley on a scale of 1:50,000 covering sheets 173, 174 and parts of 194 and 195. Guirad (1989) published geological of adjacent area on the same scale covering sheets 153 and parts of 152 and 154.

Different models of the evolution of the Benue trough (the Upper Benue inclusive) have been presented. These form important part of previous work. Stoneley (1966) and Wright (1968) proposed a graben genesis related to the Cretaceous opening of the Gulf of Guinea. Burke et al., 1972 suggested sea floor spreading model. Grant (1971) characterized the Benue basin as an aulacogen based on three-arm rift model. Subsequent models as reported in Benkhelil (1982), Benkhelil and Robineu, 1983, Benkhelil (1988) and Maurin et al., 1985 defined the Benue basin as a set of juxtaposed pull-apart basins initiated and formed by sinistral

displacement along NE-SW inherited transcurrent faults.

Many sedimentological studies of the Benue trough have been carried out. Sedimentological and tectonic aspects have been described by Jones (1963), Enu (1978), Lawal (1979), Kogbe (1981) Popoff et al., 1983 and Allix (1983). Offodile (1976) discussed the major stratigraphical subdivisions of the Cretaceous and Tertiary Formations.

Geophysical characteristics of the Benue trough based on gravimetric and aeromagnetic surveys are reported in the works of Ajakaiye (1981), Ajakaiye et al., 1986 and Cratchley et al., 1965.

Ojo (1982) conducted geological and stream sediment survey around the middle Gongola basin. He identified structurally associated element pattern which could be associated with mineralization of Cu-Zn mineralization along the northern flank of Gubrunde horst, notably the area east of Wuyo, which contains significant anomalies of Cu and Zn.

Orientation biogeochemical and soil survey on Zona, Kanawa and Dali occurrences was undertaken by Funtua (1985), Ogunmokuwa (1985) and Baba (1985) which showed anomalous content of Pb, Zn, Cu, Ag and Co in soils and in the bark samples of *Boswellia dalzielii* growing in and around these mineralizations. Further work by Okujeni (1987), Elegba et al., 1988, Okujeni et al., 1990 and Funtua et al., 1991

indicated the anomalous uptake of the above elements and uranium by *Boswellia dalzielii* and in soils around the uranium occurrences. An integration of geochemical and gamma spectroscopic techniques in monitoring uranium concentrations in plant samples was proposed.

General prospection for uranium in the region was started by the Nigerian Mining Corporation (NMC) particularly concentrated in the Gubrunde horst and the adjacent areas before the formation of Nigerian Uranium Mining Company (NUMCO) in 1978, which then took over the activity. The records are in NUMCO unpublished annual reports (1978 -85). Three major areas were identified, the Gubrunde horst, the Monkin zone and the Ghumchi sector, all in the Pre-Cambrian basement terrain. These works involved interpretation of aero-radiometric maps of the area, photogeological interpretation on a scale of 1:40,000, regional geological mapping and ground radiometric survey and then detailed geological mapping of selected areas. Percussion drilling was carried out at the Kanawa mineralization in the Gubrunde horst while both percussion and diamond drilling were performed at Mika in the Monkin and Ghumchi mineralized areas.

Later prospection was intensified in the zones of discordant between the basement and the Cretaceous sediments in search for discordant type deposits as

discontinuity can favour concentration of uranium of economic interest similar to occurrences in Northern Australia and Saskatchewan, Canada (NUMCO, 1981). The role played by fault zones in the crystalline basement is usually fundamental in pre-concentration and trapping of uranium at the zone of discordant. The Bima sandstone was well studied in this regard also the southern extension of the Chad basin.

Maurin (1985) undertook a structural geological study of the Ghumchi mineralization and also carried out U-Pb and Pb-Pb dating of both the Ghumchi and Mika mineralizations. This was further reported in Lancelot and Maurin (1985) and Maurin and Lancelot (1990).

Funtua (1988) studied the geology and genesis of the Kanawa mineralization. Other reports on Kanawa mineralization are presented in Funtua et al., 1992, Funtua and Okujeni, 1992 and Okujeni and Funtua, 1992. Ogunleye, 1991 carried out a detailed study of the geology and geochemistry of the Zona uranium mineralization and beneficiation study of the Kanawa uranium ore.

CHAPTER 2

REGIONAL GEOLOGY.

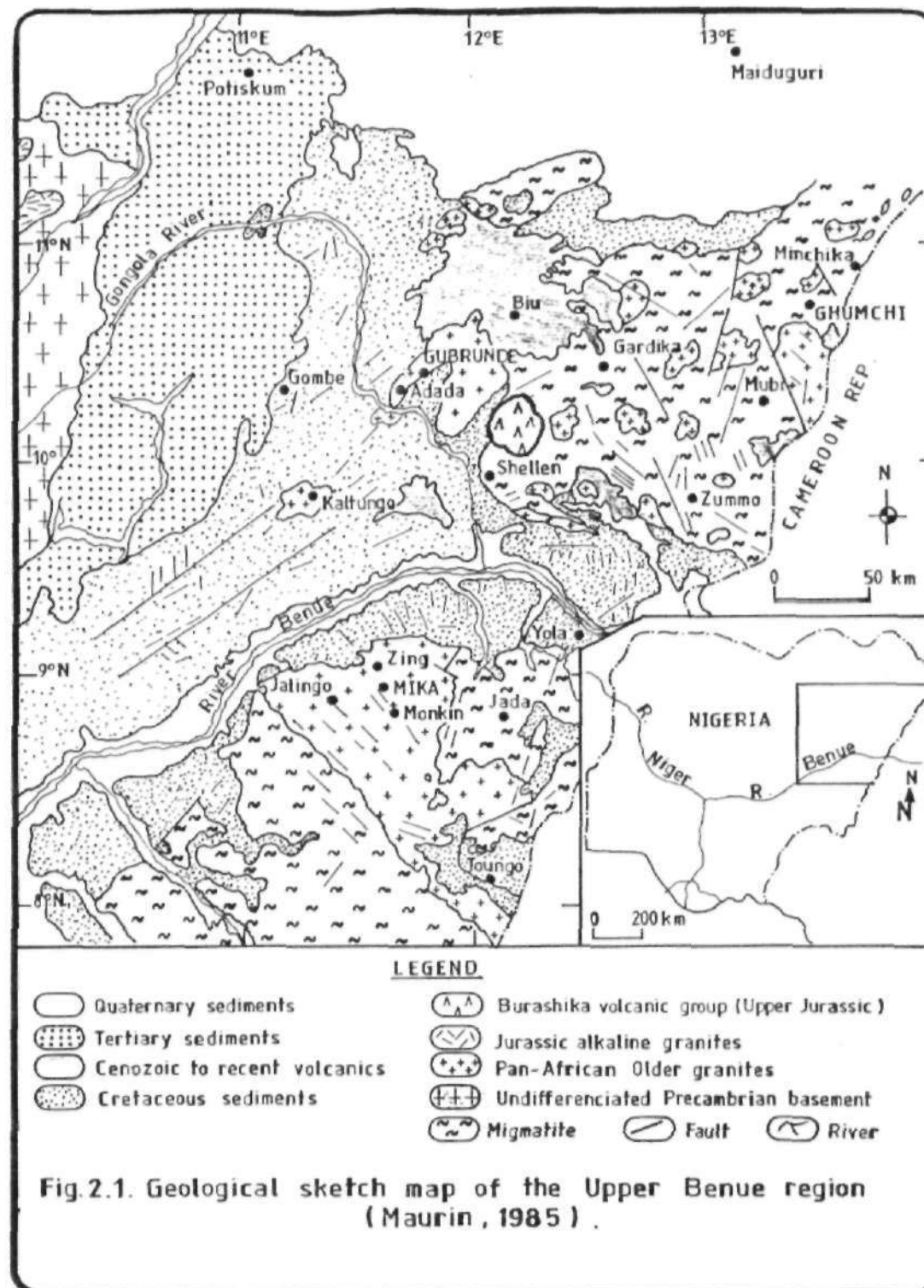
The geological features of the region are the crystalline basement, represented mainly by granitic rocks, sedimentary and volcanic rocks. Fig. 2.1 shows the general geology of the area.

The geological succession according to Carter et al., 1963 is tabulated below.

Table 2.1. The stratigraphical succession of N.E.Nigeria.

	Epoch	Stage	Benue Basin	Zambuk Ridge Gulani Area	Gombe	Chad Basin
Tertiary	Pleistocene					Chad Formation
	Paleocene					Unconformity
Upper Cretaceous	Maastricht		Lamja Sandstone			Kerri Kerri Formation
	Senonian	Campanian	Numanha Shales	Gulani Sandstone		Fika Shales
		Santonian	Sekule Formation			
		Coniacian				
	Turonian	Upper	Jessu Formation	Pindiga Formation		Gongila Formation
		Lower	Dukul Formation			
	Cenomanian		Yolde Formation			
			upper			
			middle			
			lower	Bima Sandstone		
				Unconformity		
L. Palaeozoic to Precambrian			Crystalline Basement			

(After Carter et al. 1963)



The oldest rocks in the region are remnants of ancient sedimentary series, migmatites and gneisses, of Pre-Cambrian age. Sedimentation and regional metamorphism were followed by a cycle of orogenic granite emplacement, during which the diverse and widely scattered Older Granites were intruded into the sediments and these transformed into anatectic migmatites. The granites, biotite, biotite-muscovite and porphyritic are very rich in pegmatites and their emplacement took place mainly along a NE-SW trend (Ojo, 1982). After a considerable interval an episode of high-level, magmatic activity ensued, granites accompanied by lavas, were intruded into the Older Granites near Burashika (Carter et. al, 1963). Similar rocks outcrop in the Kaltungo inlier and in Gubrunde horst. The basement rocks show two main tectonic-magmatic events: metamorphism and granitization of the early sedimentary rocks into migmatites and anatectic granites and a later metamorphic and tectonic event which transformed the old migmatites and granites into slightly crushed, roughly sub-horizontally foliated granite gneiss. U - Pb dating of the granitoids and migmatites from Mika and Adada areas (Tobosun, 1983) allows the distinction of the migmatites and the ante- to syn-kinematic granitoids with emplacement ages ranging from 680 to 620 Ma and post kinematic

granitoids with emplacement ages ranging from 620 to 590 Ma.

At the Southern end of the region, an area from Jalingo to Jada, a migmatite envelope enclose anatectic granite mass. Exposure is variable but more abundant on the Jalingo zone than the Jada area. The migmatite is distorted and rich in biotite banding. The neosome which is very quartzo-feldspathic with few black minerals developed. An interesting feature of the granite mass is the relative variation of the grain size and its porphyritic nature. The granite shows its typical anatectic nature by the variability of its facies type and the different stages of the evolution of the migmatization process leading eventually to a granitic core.

Pre-cretaceous lavas consisting of deeply weathered and silicified andesites and basalts also occur. The lavas are overlain by basal sediments. Mesozoic magmatism was also described by Popoff et al, 1982 and Baudin (1986). The initial magmatic activity took place from Late Jurassic to Neocomian times and was bimodal in nature, consisting of alkaline rhyolites (Burashika) and transitional alkaline basalts (Shani area). The second magmatic period took place from Albian to Turonian times and involved transitional alkaline basalts and theolitic basalts.

There is no record of sedimentation in the long interval between Pre-Cambrian and late Mesozoic times. Sediments started to accumulate in the Upper Cretaceous. There were two major basins of deposition, the Chad basin and the Benue basin, separated by the Zambuk ridge.

The oldest strata are a thick and widespread series of continental grits, sandstones and clays termed the Bima Sandstone. The formation is believed to be Cenomanian age (Ojo, 1982). These continental sediments were laid on uneven surface of basement rocks and attained great thickness. In the north these beds are wholly continental, but in the South marine shales occur and could be correlated to with the Asu River Group (middle to upper Albian) of middle and lower Benue (Offodile, 1976).

The Bima Sandstone can be subdivided into three main siliciclastic members, the lower, middle and upper Bima member (Carter et al., 1963, Ojo, 1982, Guirad, 1989). The lower and middle Bima members are separated by a regional angular unconformity that is assigned middle Albian age (Whiteman, 1982). The lower Bima member is 600m thick along the faulted margins of the early Cretaceous basins. It consists of basement - derived fanglomerates with granite boulders supported by muddy, sandy or gravelly matrix. They are characterized by faint clast

orientations, local inverse grading, rare sedimentary structures and a red to purple mottled colour associated with pedogenetic features suggesting sub-aerial conditions of sedimentation (Guirad, (1989). Clasts of basalt and rhyolite and volcanic sills are frequently present in the conglomerates indicating contemporaneous volcanic activity (Popoff et al., 1982). The features of the lower Bima suggest an alluvial fan environment of deposition under a semi-arid climate.

The middle Bima is 50 to 200m thick and consists of gravels to coarse-grained sandstones dominated by large scale trough cross-bedding (Carter et al., 1963). Its elementary sequences are very similar to those of the Lower Bima member and again show frequent pedogenetic features (Guirad, 1989). The middle Bima is overlain by the medium to fine-grained sandstones of the Upper Bima member which reach a maximum thickness of 600m in the Bima hills. The characteristic sedimentary profile of this member is highly homogeneous consisting of a succession of oblique planar cross-bedded deposits with only scarce trough cross-stratifications (Guirad, 1989). Transgression of the sea in the middle of Cenomanian marked the beginning of deposition of fine grained yellowish coloured, thinly bedded sandstones with some calcareous units. These have

been mapped as Yolde formation (Ojo, 1982).

A widespread, shallow, marine transgression occurred during Lower Turonian times, as evidenced by marine beds of clays, shales and limestones of Dukul, Pindiga and Jessu Formations. Elsewhere in the Benue trough alternating sequence of sandstones and shales was deposited to form Sekule-Numanha shales and Lamja sandstone formations. The marine conditions persisted until the Maestrichtian and were accompanied in the South by localized volcanic activity (Carter, et al., 1963). Over the northern and central areas the marine conditions gave way to deltaic and estuarine environments in which the Gombe sandstone was deposited.

A period of folding resulting in the development of great anticlinal structures in the Cretaceous followed (Carter et al., 1963). It is believed that the movements responsible for the folding commenced in late Upper Cretaceous times and were operating during the deposition of the Gombe Sandstone.

A younger sequence of continental deposits the Kerri Kerri Formation was laid down in the Paleocene (Adegoke, 1978). These are now restricted to the northern parts of the region and their original extent to the South is not known.

The continental sedimentation was followed by a period of extensive laterite formation overlying the Kerri Kerri Formation.

During the late Tertiary and Quaternary, widespread volcanic activity occurred in the Southern and Central areas. The extensive basaltic flows which now cap the Biu and Longuda plateaux were extruded. Also extruded are small volcanic plugs scattered over the area. Radiometric ages range from 7Ma to 1Ma (Grant et al., 1972).

The majority of the plugs are composed of fine-grained olivine-basalts, although a few are trachytic and phonolitic in composition (Carter et. al, 1963).

The structural pattern of the region is dominated by a series of large folds with axes trending NE - SW, following the trend of the Benue trough. The folding is widespread and affect the whole Cretaceous sedimentary pile. Folding and strike slip faulting results from a horizontal regional compression acting in a N160E mean direction. They have been related to a Late Cretaceous compressive tectonic phase (Benkheilil, 1982 and Benkheilil and Robineau, 1983). The folds are remarkable for their simplicity, narrowness and great length. From south to north the important folds are the Benue, Dadiya, Reme and Bobbini synclines which are separated by the Lamurde, Bwomian, Talasse and Guyuk

anticlines. The lowest member of the Cretaceous sequence, the resistant grits and sandstones of the Bima Formation forms the cores of the anticlines, while the overlying, less resistant marine sediments are preserved in synclinal troughs.

The basement rocks exhibit many joints, fractures and faults, the most dominant are the faulted boundary between the basement and the early cretaceous sedimentary basins which follows $N110^{\circ}$ to $N120^{\circ}$ "Chad" trend and $N60^{\circ}$ to $N70^{\circ}$ E "Benue" trend (Guirad, 1989). The "Benue " and "Chad" trending fractures spatially controlled the spatial distribution of the lower Bima member sediments and are regarded as lower Bima synsedimentary faults.

There is the N-S dominant structural trend of both foliation and joint directions and its extensional E-W direction. The NS trend in some places persist into the sedimentary rocks. N-S trending normal faults located around Gongola and Hawal Rivers are posterior to the late Cretaceous folding event (Guirad, 1989). An E-W extensional phase of Tertiary age may be related to the development of the volcanic centres of Biu and Longuda and the Cameroon line (Benkhelil, 1983 and Popoff et. al, 1983).

CHAPTER 3

GEOLOGY OF THE URANIUM MINERALIZED AREAS.

Major uranium mineralizations occur in four zones or areas in the N.E., Nigeria, namely; in the Gubrunde horst, at Ghumchi, Mika and those in adjoining sedimentary basins. The Biu plateau is the northern boundary of the Gubrunde horst while the River Benue forms the natural boundary between mineralized area at Ghumchi to the north and Mika to the south. The sedimentary mineralizations are known in two areas; Gubrunde horst at Zona and Dali and at Bille hill near Mayo Iope, these occur in volcano-sedimentary rocks of Bima Formation.

3.1 Gubrunde area.

The Gubrunde horst (Fig. 3.1) is bounded to the north by Tertiary basalts of the Biu Plateau and to the north-west and south-east by the sedimentary sequences of Bryel and Zange grabens respectively. The horst is underlain by and forms part of the crystalline basement of N.E. Nigeria.

Migmatites, gneissic complex, granitic complex of mafic to intermediate plutonic rocks (diorite and granodiorite), as well as fine-grained granite and syntectonic porphyritic and equigranular granites are the main rock types (Fig. 3.1).

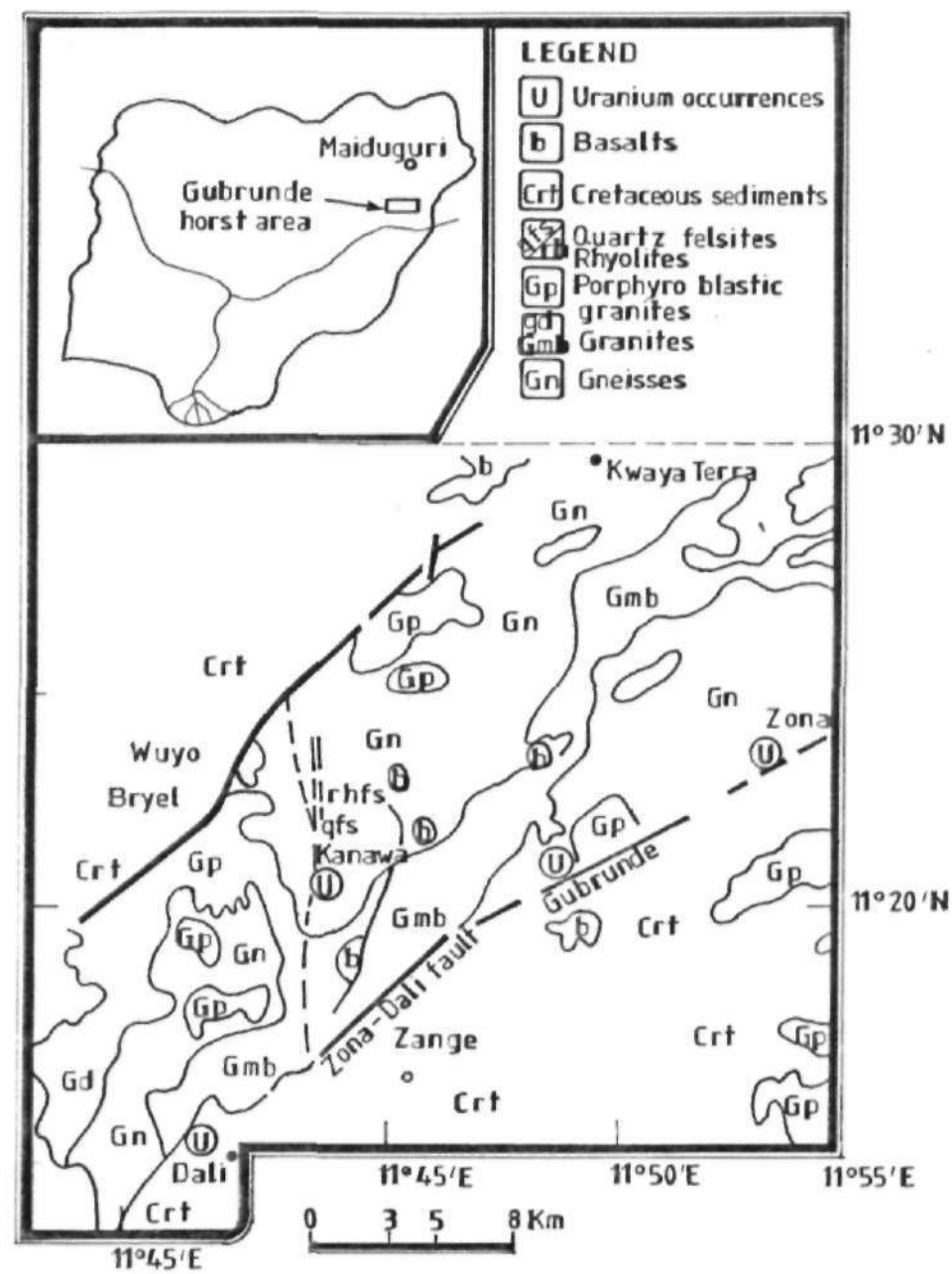


Fig. Location map and the geological map of the Gubrunde horst (Ojo, 1982, Funtua, 1988).

Prior to the cretaceous sedimentation, Gubrunde horst was subjected to metamorphism, granitization, feldspathization as well as tectonism (Ojo, 1982). The tectonic activities resulted in the intrusion of lava flows (Carter, et. al., 1963, Burke, et. al., 1970 and Ojo, 1982).

Granite and granitic rocks form the greater proportion of the basement rocks. Association with the basement are volcanic rocks such as rhyolites in veins and fracture zones.

Numerous uranium and thorium anomalies in the Gubrunde horst but only few mineralizations in three main areas at Kanawa, Gubrunde and Adada are of significant size (Funtua and Okujeni, 1992).

At Kanawa the host rock is a two-mica granite containing biotite, abundant pink potash phenocryst, plagioclase and interstitial quartz. The granites have been intruded in places by rhyolites, pegmatites and aplites bodies. Near the Kanawa village, uranium mineralization occurs along a nearly NS trending sheared zone which extends for more than 4km. Rhyolite centres form the peaks along the sheared ridge (Funtua, 1988). The uranium ores are located at the contact of the sheared rhyolite body and the granites (Funtua, 1988). The rhyolite body itself is zoned, with a central volcanic breccia and resilicified volcanic fragments, followed by altered, laminated and silicified volcanic

fragments which grades into altered granites at the sides (Funtua and Okujeni, 1992).

Ore minerals are phospho-uranylite, meta-autinite, kasolite with traces of galena and chalcopyrite (Okujeni, et. al., 1990).

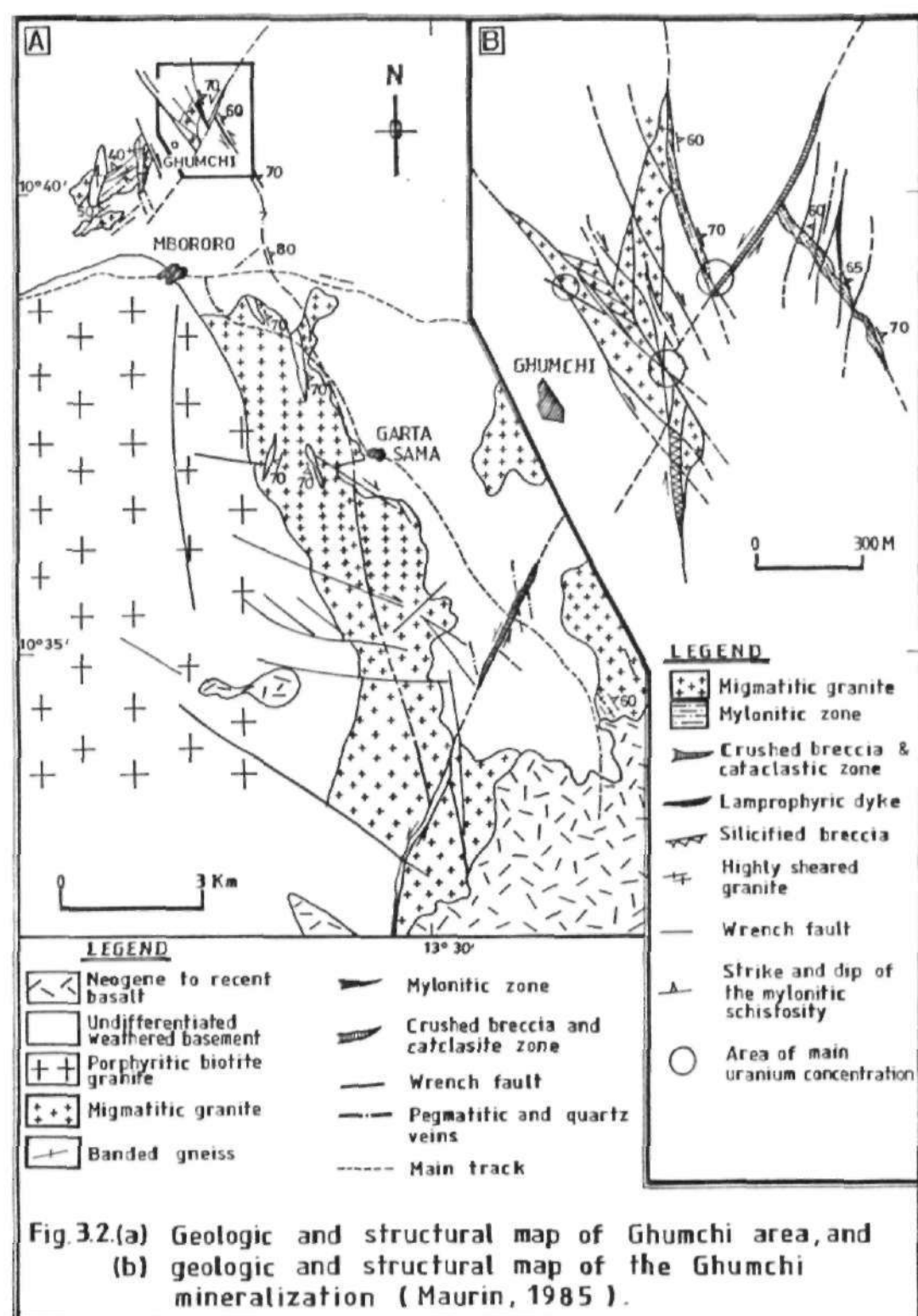
At Gubrunde uranium is also associated with siliceous breccia and rhyolite veins emplaced between the granite basement and the volcano-sedimentary formations of the Gubrunde complex (Funtua and Okujeni, 1992). The basement is a pink coarse grained biotite granite with abundant K-feldspar, interstitial quartz and plagioclase.

The mineralization is associated with varying pattern of alteration predominantly silicification and hematitization. Similar secondary uranium minerals of phospho-uranylite, meta-autinite, uranophane and kasolite are abundant.

The Adada occurrence is in nearly NS and NE-SW trending thoriferous pegmatites. These pegmatites have a simple mineralogy of microcline-microperthite, quartz and muscovite. Euxenite is the most common ore mineral in the pegmatites.

3.2 Ghumchi area.

The mineralization is located within a migmatic complex comprising mainly of poorly foliated migmatic granite and lenses of banded gneiss (Fig. 3.2). The migmatic complex



has been intruded by numerous quartz and pegmatite veins and by porphyritic granite. In the southern part of the area recent alkali basalts occur as thick lava flows covering the older units. These basalts are locally associated with trachytic plugs.

The migmatic complex have been affected by successive shear zones, faults and fractures especially concentrated in the mineralized area (Maurin, 1985).

The structural features of the area according to Maurin, 1985 include:

- 1). a ductile shear zone, 20 to 40m wide, trending N150E to N170E. The zone is characterized by a steeply dipping mylonitic rock whose schistosity is well defined by elongated micaceous (chlorite/sericite), quartz and feldspar ribbons.
- 2). a brittle shear zone, 10 to 20m wide, trending N30E, exhibiting faulted rocks of crushed breccia and cataclasite series.
- 3). lamprophyritic dikes of few metres thickness that cut across the mylonitic zone and locally the migmatic granite. The rocks are highly weathered and their emplacement is obviously post-mylonitic and post-cataclastic deformations as their dikes remain undeformed.
- 4). late vertical faults cross-cut the whole litho-structural units except the basaltic lava flows.

Within the mineralized zone the major faults trend mainly from N140E to N170E.

The mineralization occurs mainly within the mylonitic zone and along N140E to N170E dextral wrench faults while the cataclastic zones are sterile (Maurin and Lancelot, 1990). Within the mylonitic zone the mineralization is strongly concentrated where the mylonite intersects the cataclasite zone or at the contact with lamprophyritic dikes (Maurin, 1985).

In all cases the mineralization is located along preferential anisotropy planes such as mylonitic schistose and fault planes. The uraniferous minerals occur as cryptocrystalline coffinite within sterile chalcedonic silica infilling porous spaces left along both mylonitic schistosity and fault planes (Maurin, 1985).

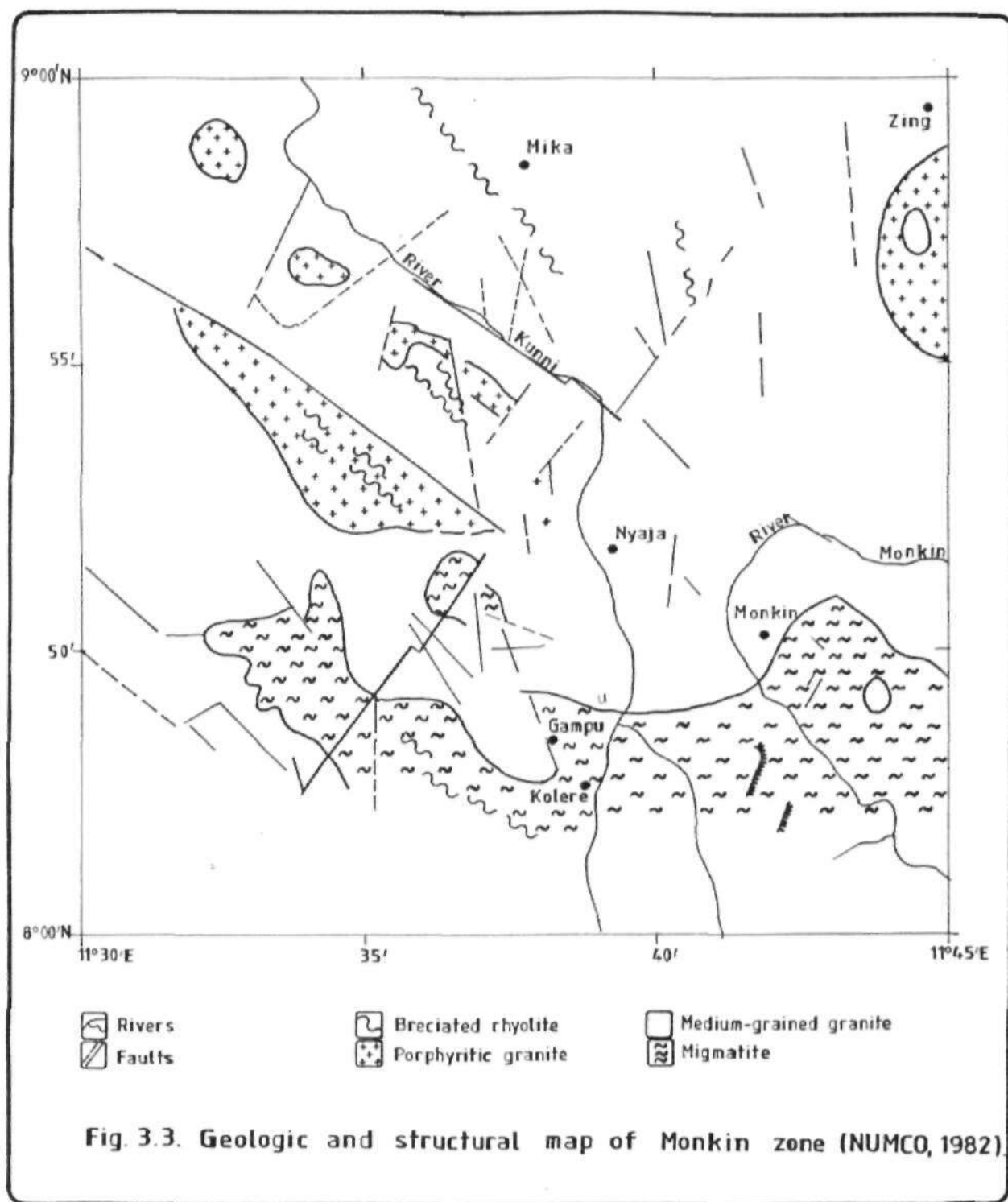
The mylonite and the fault planes appear to have acted as the preferential traps along which the uranium bearing solutions were channeled while the cataclasite zones acted as cohesive structures screening the uranium bearing fluids. Important also are the dikes which probably acted as physico-chemical traps for uranium concentration (Maurin, 1985).

3.3 Monkin area.

The rocks of the Monkin area can be divided into two main lithological units; the migmatite to the south and the granites in the northern parts (Fig. 3.3). The migmatite shows alternating mafic and quartzo-feldspathic material in thin bands. The bands strike $N70^{\circ}$ and dip 20° to the south. The migmatites are cut by the $N135^{\circ}$ fractures.

The granite is coarse-grained to porphyritic biotite granite which exhibit NS foliation. Numerous fault and fractures criss-cut the granitic body. The major ones are the $N130E$ and $N160E$. Several $N160E$ fracture zones are disposed "en echelon" along an average $N130E$ trend (Maurin, 1985). These zones are represented by network of open fractures filled by rhyolite and hematized silica.

The largest occurrence is located at Mika. Other several smaller mineralizations occur at Nyaja/Manza, Koko and Gampu. The Nyaja/Manza occurrence is located southeast of the Mika mineralization. The rocks are essentially granitic rocks, consisting of biotite and porphyritic granites. There are breccia zones in the granite with a width of about 5m and up to 2km long (NUMCO, 1982). In the centre of the breccia zones occurs a very fine red silica which is brecciated and contains rock fragments. Uranium ores are associated with these red silica in the fractured zones but are spotty in nature (NUMCO, 1982).



At Koko the uranium occurrence is located within two almost parallel brecciated granite bodies striking at 15° and spaced by about 80m distance. The western body is linear with grey silica fracture filling. The eastern body is filled with rhyolite and grey silica (NUMCO, 1982).

Gampu consist of widely separated spotty anomalies that are found in low lying outcrops of brecciated granites and silicified granites that are in some places faulted (NUMCO, 1982). A prominent one occurs 2km east of Kasa within sheared rhyolites, whose thickness varies from 1 - 3m on the south eastern part. On the northern part the mineralized shear zone is structurally more complex with a thickness up to 30m (NUMCO, 1982).

Numerous fault and fractures criss-cut the Mika area. The mineralization at Mika is closely related to the fracturing of the granite. The major fault trends are N130E and N160E. Several N160E fracture zones, about 100m wide, forms "en echelon" mega tension gashes with a N130E average trend (Maurin, 1985). Within this fracture network in the granites occur brecciated and hematized faults which are filled with rhyolitic material and in places with grey silica.

Details of the geologic setting and mineralogy of the Mika ore zone is presented in Chapter 5.

3.4 Mineralization in sedimentary areas.

The geologic setting of both the Bima and Keri-Kerri Formations would suggest that they are both potential hosts of uranium mineralization (Oshin and Rahman, 1986). Favourable features of the Bima sandstone include derivation from provenance of granitic terrain, lying on unconformity and other features indicating characteristics of reducing environment. The Keri-Kerri is cross-bedded, gently dipping and lies unconformably on older rocks.

In the sedimentary areas there are three fairly extensive mineralizations at Zona, Gubrunde and Mayo-lope areas and several radioactive anomalies at Kaltungo and Dali areas. These occurrences are located within the Bima Sandstone and in thin quartzite layers between basement and volcano-sedimentary Bima rocks.

The Zona occurrence is located on the NE flank of the Peta syncline along a NNE-SSW trending tectonic wedge or fault zone within the Upper Cretaceous Bima Sandstone. The mineralization is most intense at points of intersection of these NE/SW and N-S faults (Ogunleye, 1991). The ore consists primarily of secondary uranium minerals such as phospho-uranylite, uranophane and chalcocite (Okujeni, et. al., 1990).

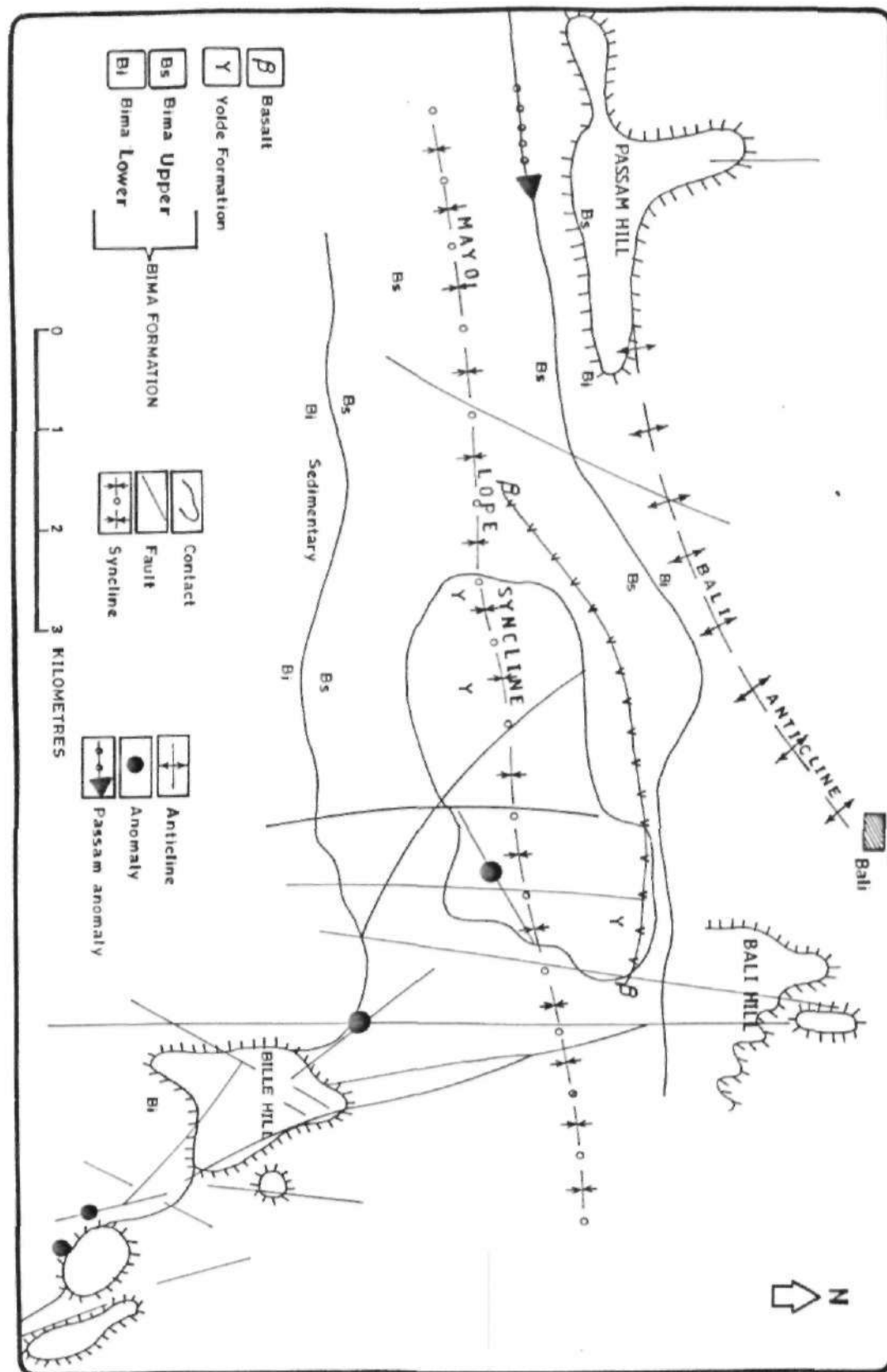


Fig. 3.4. The Bille and Passam hills anomalies, Mayo-lope Syncline (NUMCO, 1982).

Airborne radiometric survey in the Mayo-lope area revealed the Bille hill anomaly (NUMCO, 1982). The anomaly is located on the south limb of the Mayo lope syncline (Fig. 3.4). It is aligned along an open tension fault that is strongly hematized. The radioactive rocks are conglomeratic, very hard, siliceous with iron concretions. The control of the mineralization is both sedimentological (channel fill conglomerate) and structural, with the anomaly located at intersection of fault with a possible paleochannel (NUMCO, 1982). The Bille hill could be a good indicator of possible strata-bound uranium deposit in favourable beds of the Bima Sandstone in the Mayo-lope syncline with favourable structural features.

Another anomaly, Passam hill anomaly, is located to the north flank of Mayo lope syncline (Fig. 3.4) where the strata are dipping 15° - 20° towards N220-N230 (NUMCO, 1982). Higher radioactivity are located in finer sediments. The facies are oxidized and well cemented (NUMCO, 1982).

3.5 Characteristic features of the mineralizations.

The mineralizations in the basement rocks of the three areas; the Gubrunde horst, the Monkin and Ghumchi zones share several similarities, but also have a few differences.

All the mineralizations occur in basement rocks of Pan-African age. The Gubrunde horst and Monkin area are both underlain by more or less coarse-grained biotite granites. Rock types in the Ghumchi area are varied, where gneiss, quartzite, mylonites and migmatites are present.

The uranium mineralizations are associated with distinct hydrothermal activity (alterations include hematitization, silicification and argillization). Several phases of silicification and brecciation are commonly observed. Volcanic rocks are invariably present as veins and dikes, that are often brecciated.

Tectonic control is paramount in all the mineralizations. Uranium may occur in various rock types; at marginal contact with rhyolite at Kanawa (Funtua, 1988), silicified granite and rhyolite at Mika and migmatitic granite and foliated quartzite at Ghumchi (Maurin, 1985) but is always associated with brecciation and fractures (open and some cemented by silica).

Uranium minerals found are veinlets of pitchblende, meta-autinite and one or more generations of coffinite at Mika (Maurin, 1985). Others are uranium minerals consisting essentially of phospho-uranylite, kasolite with traces of pyrite, galena and chalcopyrite at Kanawa (Okujeni et. al., 1990).

CHAPTER 4

FIELD AND LABORATORY METHODS OF INVESTIGATION.

The field and laboratory methods employed during this study includes; sample collection, sample preparation, elemental analysis and data treatment. Samples were collected from surface outcrops in the field and logged drill core sections which were stored at the NUMCO office in Gombe, Bauchi State. Sample preparation in the laboratory involved preparation of thin and polished sections, crushing and grinding of rock samples for elemental analysis. The elemental analysis was carried out using Neutron Activation Analysis, Natural activity counting and Radioisotope X-ray analysis. Rocks were analyzed for their mineralogical content using X-ray diffraction.

4.1 Sample collection.

At Mika uranium mineralization a total of 89 surface rock samples were collected from the two low-lying outcrops of sheared granite and brecciated rhyolite. This represents the surface expression of the mineralization. The samples were collected at available outcrops from twelve east-west profiles with 10m spacing covering the areas of the mineralization (Fig. 4.1).

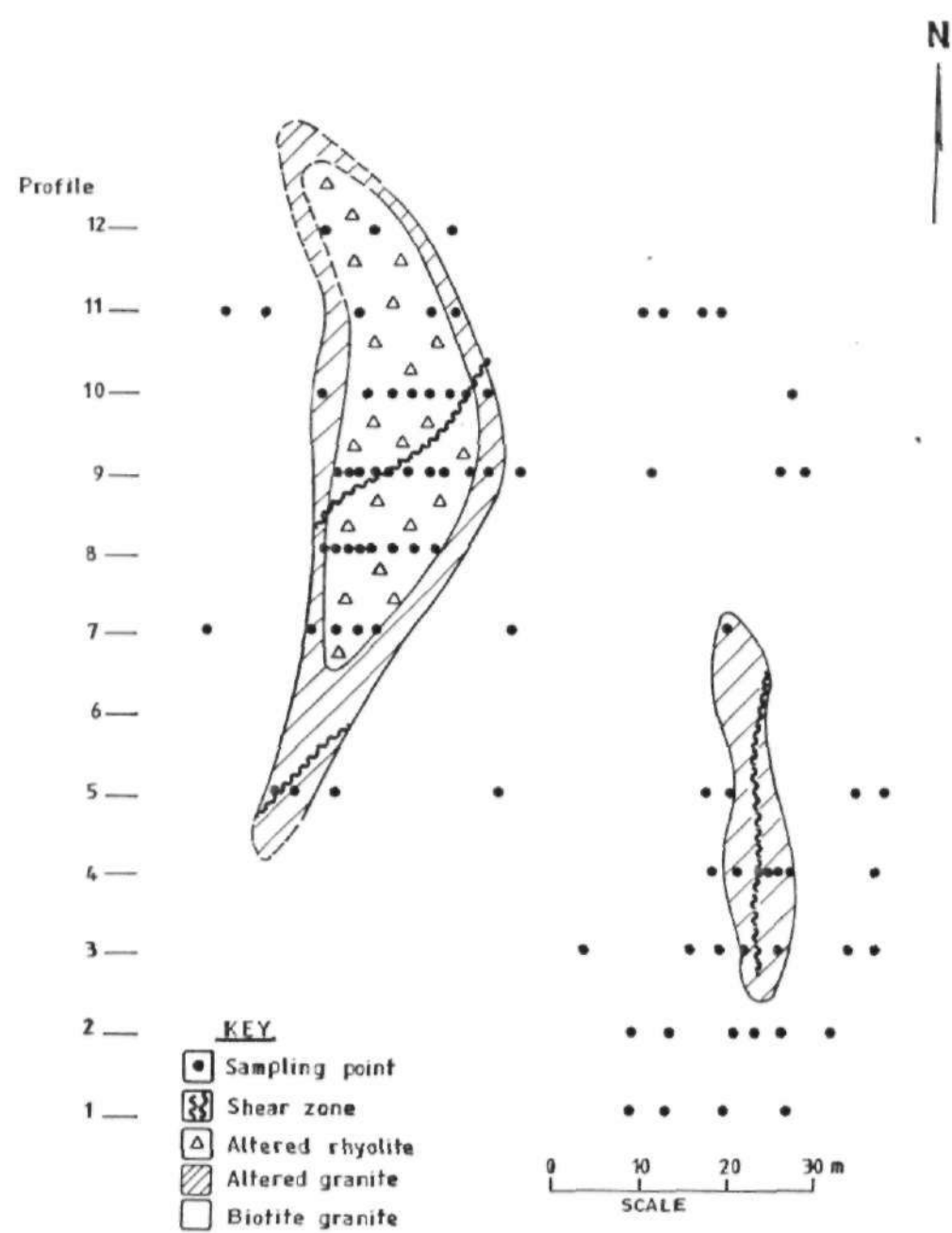


Fig. 4.1. Surface sampling plan at Mika mineralization.

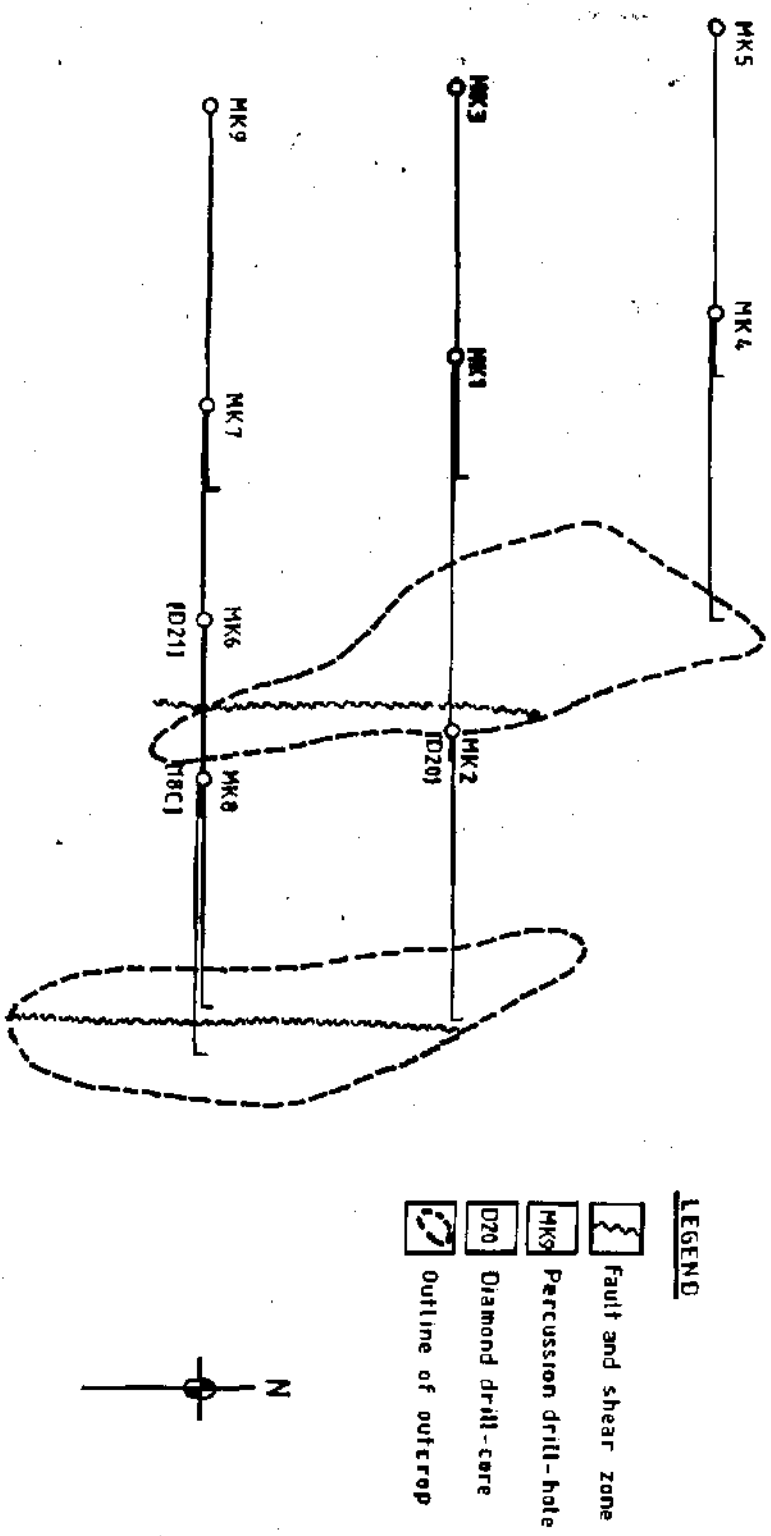


Fig. 4.2. Location map of drill-holes at Mika Mineralization (NUMCO 1982, unpublished).

Cores from three drill holes, 18C, D20 and D21 were logged and samples taken at close intervals of 0.25 metre in the mineralized areas and at wider sample spacing of one metre towards the unaltered country rock. The locations of the percussion and diamond drill holes, is shown on Fig. 4.2. The drilling was done on three profiles; the northern, central and southern profiles. Only the central and southern profile were cored (at D20, D21 and 18C). A total of 59 samples were taken from 18C, 241 samples at one metre interval from D20 with angular depth of 240 metres and 109 from D21 which is 124.6 metres deep. The positions of the core samples along the sections are indicated in Appendix I. The drill core are are shown in Fig. 4.3.

4.2 Sample preparations.

Some samples were selected for thin and polished sections. A total 40 thin and 10 polished sections were prepared. Both the surface and the core samples were split, crushed and ground to ± 45 microns grain size in a tungsten-carbide mill. These were bottled and labelled. Further preparations involved pelletizing with polyvinyl chloride (PVC) as binding material. 2g of sample was mixed with 2-3 drops of binding solution (PVC granules dissolved in analytical grade acetone) and pellitized to 19mm diameter with a

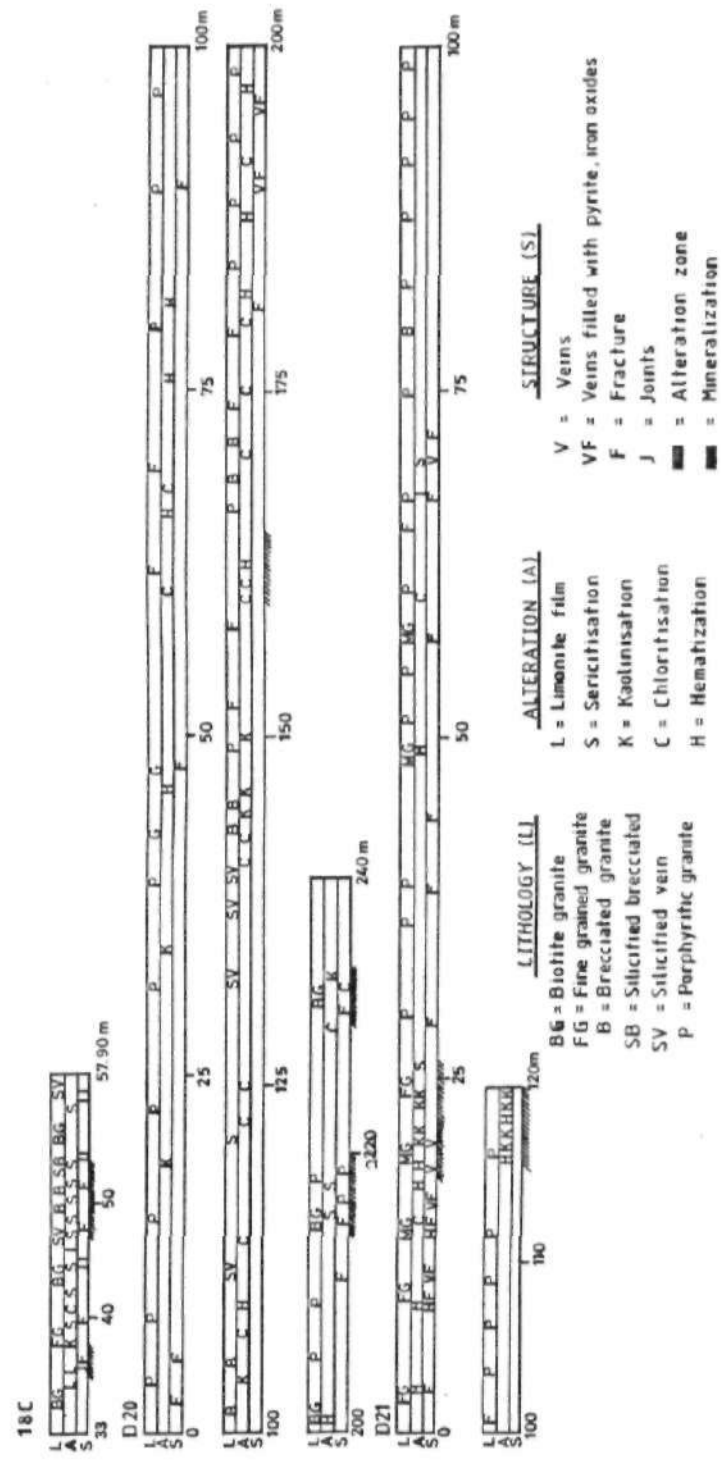


Fig. 4.3. Lithologic description of 18C, D20 and D21 drill cores.

hydraulic press machine using a pressure of about 10tons. Uranium standards of a wide range of concentrations were prepared in a pure silica matrix. This involved weighing to make 8g of each standard accompanied by mixing and homogenization process in a sealed container for two hours. Four duplicate standards were prepared for each standard. Reference standards used for other elements and lower uranium concentrations are IAEA SOIL 7 and SL 1 and USGS G-1 and G-2 granite standards.

4.3 Analytical methods.

X-ray diffraction analysis (XRD), X-ray fluorescence (XRF), Fast Neutron Activation Analysis (FNAA) and Natural gamma-ray spectrometry are the analytical methods used for this work.

X-ray diffraction analysis was performed on selected samples covering all the rock types and the outlined alteration zones. Isotopic X-ray Fluorescence Spectrometry was used for elemental analysis of all samples. Fast Neutron Activation Analysis was used to measure the element content of some samples and Natural radioactivity to determine the content of isotopes in selected samples.

4.3.1 X-ray diffraction (XRD).

The XRD machine used is a Philips PW 1390[®] system with nickel filtered Cu K α radiation (1.5418 Å). The X-ray tube was operated at 40kV and 30mA. Diffraction patterns were obtained by scanning samples from 3° to 60° at a goniometer speed of 1° 2 θ per minute at a chart speed of 0.1 mm/2 θ with ratemeter time constant of one second. Identification of minerals was made by comparing the *d*-spacings and intensities of reflection with the corresponding values of standards compiled in data cards published by the Joint Committee on Powder Diffraction Standards (JCPDS). The XRD charts and the interpretations are in Appendix II.

4.3.2 Isotopic X-ray fluorescence spectrometry (XRF).

X-ray spectrometry fluorescence analysis in general is based on the fact that the chemical elements emit characteristic radiations when subjected to appropriate excitation. The emission of characteristic line spectra can be induced either by impact of accelerating particles such as electrons, protons, alpha particles and ions or by the impact of high energy radiations from an X-ray tube or a suitable radiative source. Generally, direct electron excitation is used in Electron microprobe techniques while

radioisotope sources and proton generators are commonly associated with energy dispersion.

Radioisotopes are commonly used because of their stability and small size when continuous and monochromatic sources are required. Safety regulations require that X-ray emission from these sources is limited to about 10^7 photons s^{-1} steradian $^{-1}$ compared to 10^{12} or 10^{13} for X-ray tubes (Tertian and Claise, 1982), the difference is compensated for by the small size of the source, which allows very compact source-sample-detector assemblies to be constructed that are convenient due to their portability. On the other hand the low intensities preclude crystal dispersion so that these sources are used exclusively in energy dispersion techniques. Resolution of analytical line is sometimes done with selective filters but more often with pulse height analyzers in combination with high resolution Si(Li) semiconductor detectors.

The nearly monochromatic character of most radioactive sources makes them advantageous for the selective excitation of elements. The best choice for the exciting radiation is that slightly above the K edge (or L edge) of the element to be detected. The K-shell ionization cross section for a given element strongly decreases with

increasing energy above this edge (Derbetin and Helmer, 1988). Frequently used radionuclides in excitation sources are ^{55}Fe (Mn K X rays at 5.9 KeV), ^{57}Co (Fe K X rays at 6.4 KeV), ^{109}Cd (Ag K X rays at 22 KeV), ^{125}I (Te K X rays at 27.4 KeV), and ^{241}Am (γ rays at 60 KeV).

Sources of error in XRF can be grouped into two: one due to random errors which include counting statistics (dependent on time) and equipment errors. The second group is due to sample errors from absorption, enhancement, particle effects and the chemical state. These are also called matrix effects.

The experimental set-up for the isotopic XRF is shown on Fig. 4.4.

The Si(Li) detector is mounted at a sufficiently large angle to the direction of the exciting photons so that it can be effectively shielded against direct source radiation and the secondary radiation induced in assembly components other than the sample. Two sources were used, ^{55}Fe for determination of low atomic number elements, Na to Cr, using K lines and ^{125}I for determination of elements for Cr to Mo, using K lines and L lines for the determination of Pb and U. A vacuum system was incorporated in the experimental set-up when ^{55}Fe source was used. This is to prevent interference lines from X-ray scattering by light

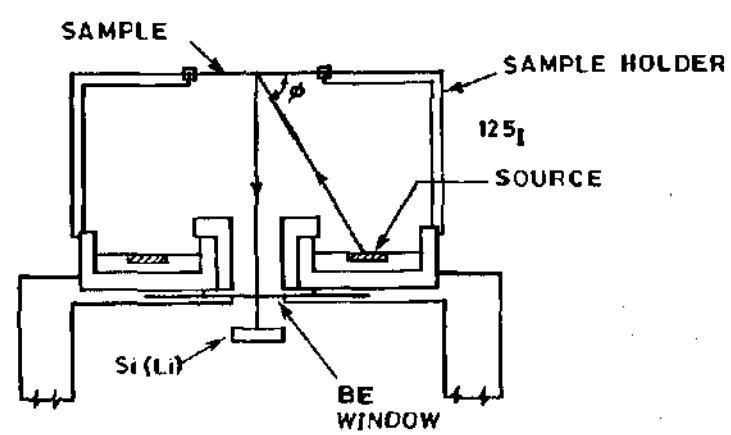


Fig. 4.4. Geometrical arrangement of XRF method.

elements and to reduce the background.

Spectra are collected with a Canberra[®] 40 MCA with detector resolution (FWHM) of 200 eV at 6.4 KeV and later transferred to DEC computer for spectral analysis. For some samples spectra are collected by computer based acquisition system, ACCUSPEC[®].

X-TOOL[®] program is used for the spectral analysis of spectra transferred to DEC[®] computer. Regions of interest are made for calibrated spectra, and for peaks without interference, processing is done directly while for overlapping peaks, a common feature with X-ray spectra, spectral decomposition is used. The process involved generation of library spectra and then applying it to the spectra to be processed, the advantage is it uses real peak shapes. Decay time is corrected for the intensity of the lines in the processing from the half-life of the isotope. Processed spectra are printed for concentration calculation or transferred to the quantitative analysis part of the programme where with calibration curves constructed from standard reference materials, concentration of elements for each sample can be evaluated.

For the computer based acquired spectra, the AXIL program is used both for the spectral analysis and concentration determination. Spectra is first converted to AXIL format

and then analyzed by creating a model spectra with all the elements to be processed. The program uses a library of elements with their energy and relative intensities values. Spectra processed can be saved and the data can be used by other parts of the program for concentration determination. Determination of elemental concentration in X-ray analysis can be classified into two main groups, the mathematical methods, where inter-element effects are essentially calculated and the comparative methods where these effects are, broadly speaking, compensated. In this work methods were employed. The principle of the fundamental parameter method consists of assuming an approximate composition for the unknown specimen, calculating the fluorescence intensities from fundamental equations, and comparing with the measured intensities. Successive adjustments of the composition are made until the theoretical and measured intensities are consistent. Theoretical intensities are obtained by calculating primary and secondary fluorescence, tertiary fluorescence are neglected (Demirel and Zararsiz, 1988).

A computer program based on the fundamental parameter method was developed by Chimoye (1989) in which pure element and sample spectra are collected using the same counting geometry with ^{55}Fe source and or ^{125}I source

depending on the elements to be analyzed and the composition of samples. With the pure element spectra, fluorescence intensities from fundamental equations are compared with the measured intensities and adjusted. The sets of concentration of the pure element and adjusted intensity values are used in a regression analysis to yield coefficients. Combination of these coefficients with the measured intensities and average mass number (Z) of sample, since most of the correction factors (molar mass of target element, K-shell ionisation cross section, K-shell fluorescence yield, full energy efficiency and the attenuation of the fluorescence radiation in the matrix) are a continuous function of the Z number, together gives an estimate of the concentration. The epsilon values of the coefficients can be varied to give better estimates of concentrations.

The ratio of elastic peak to that of inelastic peak is a function of the Z number of a sample. Average Z number used for samples were interpolated from a plot of the ratio of the elastic peak to that of the inelastic peak against average Z number for samples of known composition (Fig. 4.5).

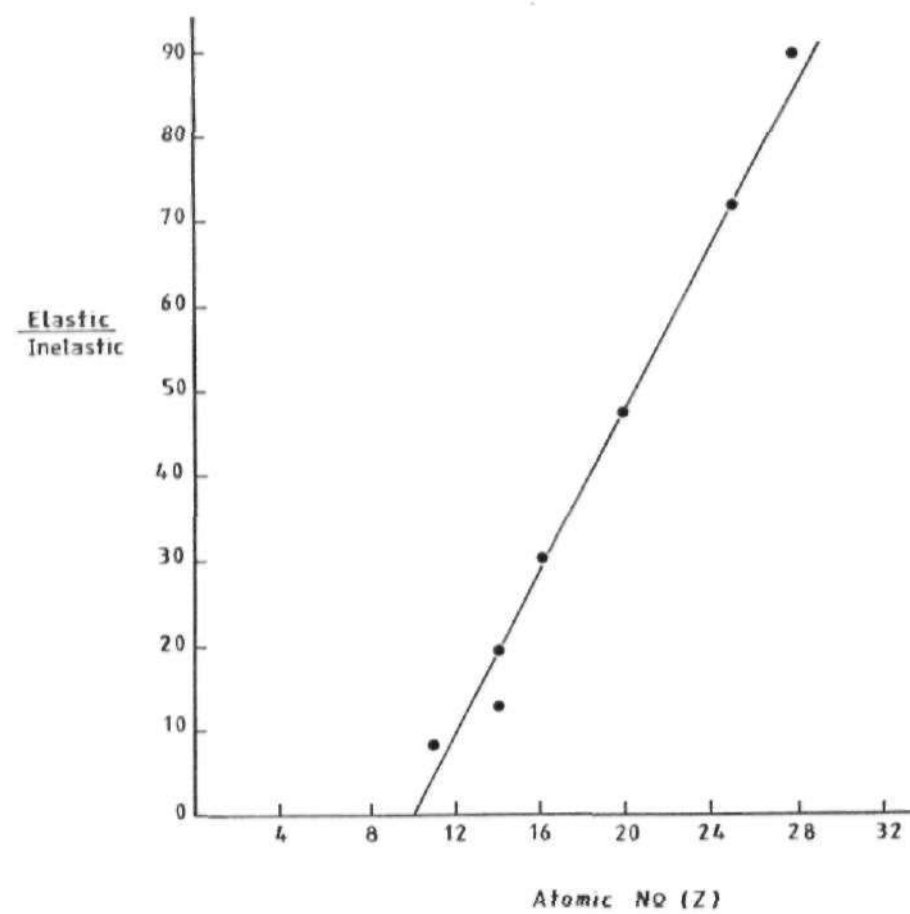


Fig. 4.5. Calibration curve for average Z determination of samples using elastic and inelastic peak ratio.

The fundamental parameter method was used as a check to the other two methods with some selected samples because of its simplicity, but, have higher error values. The data generated from the fundamental parameter method is presented in Appendix III. The concentrations of all the samples were evaluated with the AXIL[®] programme.

4.3.2 Neutron activation analysis.

The procedure involves the bombardment of a sample with a flux of neutrons which, upon interaction, converts the isotopes of the investigated elements in the sample to various radionuclides with activation cross section (cm^2). These nuclides can be identified by their half-lives and the energy of the emitted radiations. There are the absolute method, in which parameters like the neutron flux, decay constant of isotope, activation cross section, efficiency of detector, self absorption, branching ratio of the measured gamma line and the isotopic abundance of the target isotope are used for the calculation of weight of investigated element in the sample and the relative method in which standards containing well known amounts of the element to be investigated and the sample are irradiated under the same conditions. From the ratio of the measured

activity of sample and standard, the quantity of the investigated element in the sample can be deduced. To assure the same position during activation both for the sample and standard and to measure the neutron flux in the sample and standard position is very important. This can be achieved by the measurement of the neutron flux by thin foils activated together with the sample and standard.

Both the absolute and relative methods were used. The absolute method was used to check uranium standards prepared in silica matrix and some few rock samples. The relative method was used for further selected surface samples with high activity. Standards used for the relative method are the prepared U standards and Chromite rock of known composition. Elements determined are U, Si, Cr and Fe.

Rock samples together with aluminium monitor foils were irradiated by 14 MeV in a geometry presented in Fig. 4.6. The neutrons were produced by a 200 kV neutron generator via the $T(d,n)^4He$ reaction. The aluminium foils were used to measure the neutron flux in the position of sample. BF₃ detector in a "long counter" geometry was used to measure the neutron flux as a function time. The counts were printed out every one minute during activation and was

used for the calculation of neutron flux correction. The irradiated sample and Al foils were measured by Ge (Li) detector connected to a computer based acquisition system. U was determined from its fission product, a gamma line with primary fission product, that decays directly to ground state was selected, the 358 KeV line for Tc-104 with abundance of 89% and half-life of 18.4 minutes was chosen. For the Si, Fe and Cr determination the nuclear data used are shown in Table 4.1.

Reaction	Cross section (mb)	Half-life	γ -energy (keV)
$^{24}\text{Mg}(n,p)^{24}\text{Na}$	181	14.959h	1368.5
$^{27}\text{Al}(n,p)^{27}\text{Mg}$	75	9.462m	843.7
$^{27}\text{Al}(n,)^{24}\text{Na}$	116	14.959h	1368.5
$^{28}\text{Si}(n,p)^{27}\text{Al}$	226	2.2405m	1779.0
$^{52}\text{Cr}(n,p)^{52}\text{V}$	102	3.760m	1434.1
$^{56}\text{Fe}(n,p)^{56}\text{Mn}$	98	2.5785h	846.8

Table 4.1. Nuclear data for Si, Fe and Cr determination.

There is a high error in the absolute method as expected which may be from the following sources : The neutron flux,

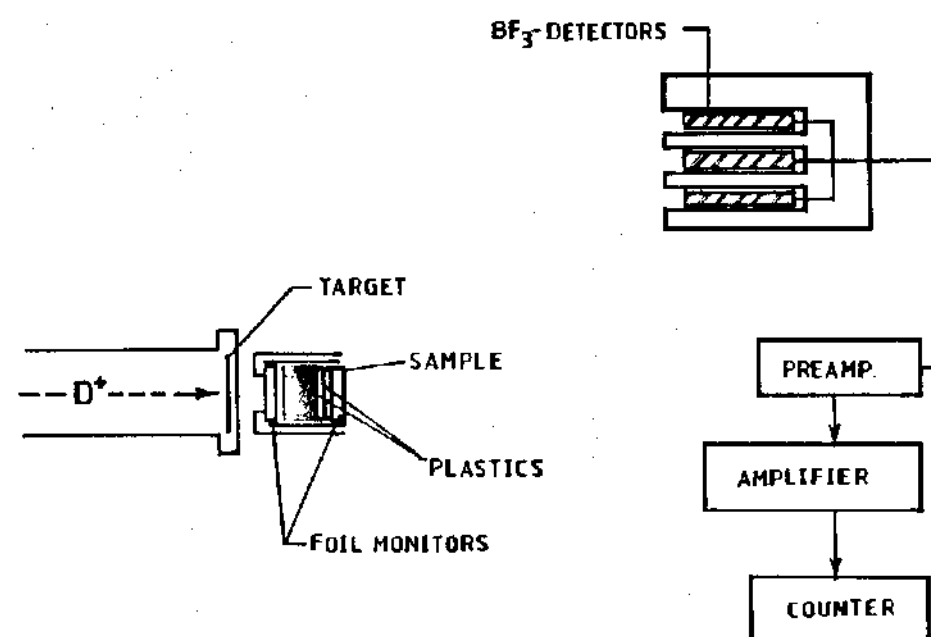


Fig 4.6. Irradiation position for 14 MeV Neutron Generator .

counting statistics, branching ratio, and detector efficiency. Corrections for the neutron flux fluctuation, dead time, random pile up and cascade coincidences were taken into account in the calculation.

4.3.4 Natural activity.

The natural activity of some samples identified to have high uranium concentration was counted. A GeLi and HPGe detectors were used. The GeLi detector was used for the measurement of the 183 KeV U-238 line. A calibration line was made from intensity count rates of prepared uranium standards after subtracting the background (Fig.4.7). The calibration curve was used to calculate concentrations for samples. The HPGe was used to measure low energy lines of U-238 and its daughters in an attempt to calculate their ratios and thereby calculating age of mineralization. The lines measured are 49.6 for U-238, 53.2 for U-234, 63.3 for Th-234 and 186.1 for Ra-226, all in KeV values.

The principle of the age determination considers a simple case where an active element B grows from its parent A.

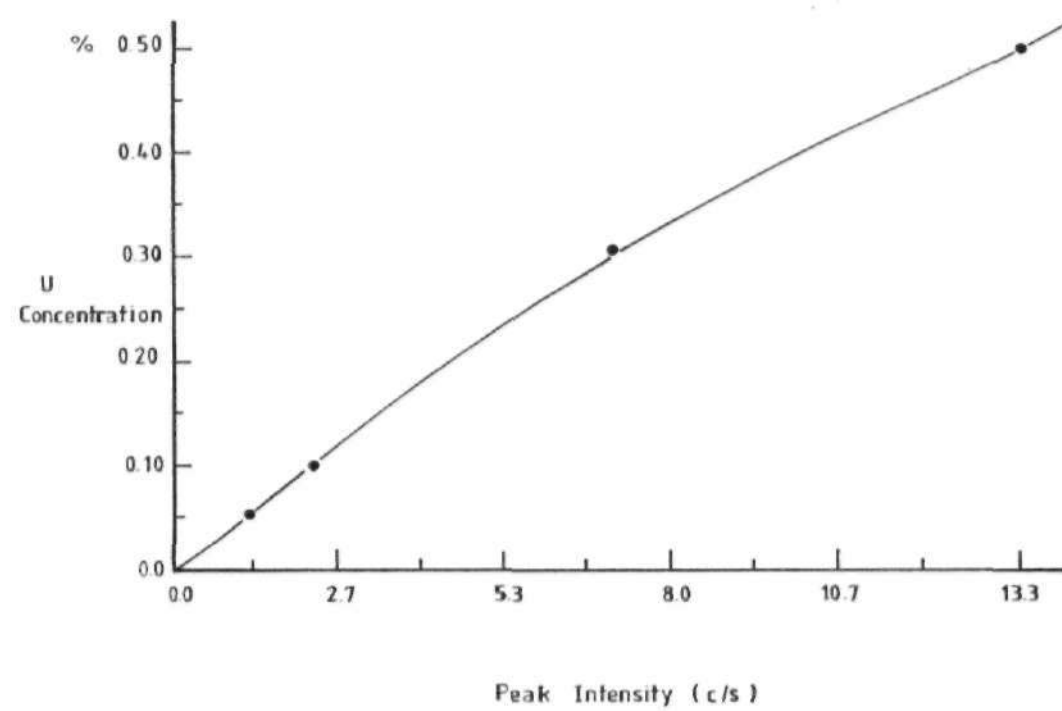


Fig. 4.7. Calibration curve for uranium standards.

For the decay of A $\frac{\delta N_a}{\delta t} = -\lambda_a N_a$

the growth of and decay of B $\frac{\delta N_b}{\delta t} = \lambda_a N_a - \lambda_b N_b$

where N_a and N_b are the number of atoms of A and B present at time t . At $t = 0$, $N_a(0)$ and $N_b(0)$

Activity of A = $\lambda_a N_a(0)e^{-\lambda_a t}$

Activity of B

$$= \lambda_b N_b = \lambda_b N_b(0) e^{-\lambda_b t} + \frac{\lambda_a \lambda_b}{\lambda_b - \lambda_a} N_a(0) [e^{-\lambda_a t} - e^{-\lambda_b t}]$$

if initially B is not present, $N_b(0) = 0$ and then at any time

$$\frac{\text{activity of B}}{\text{activity of A}} = \frac{\lambda_b}{\lambda_b - \lambda_a} [1 - e^{-e(\lambda_b - \lambda_a)t}]$$

A plot of relative activity of U-234, Th-230 and Ra-226 to the parent isotope U-238 can be plotted against time from the above equation as shown in Fig. 5.8.

The activity (A) of the isotopes from count rate n in a detector, with detector efficiency ϵ , emission probability p and a correction factor C (a product corrections for self-absorption, dead time, etc) is given by $A = C / (p \epsilon)$

The total uranium and U-234, Th-230 and Ra-226 results of the selected samples are presented in Appendix IV.

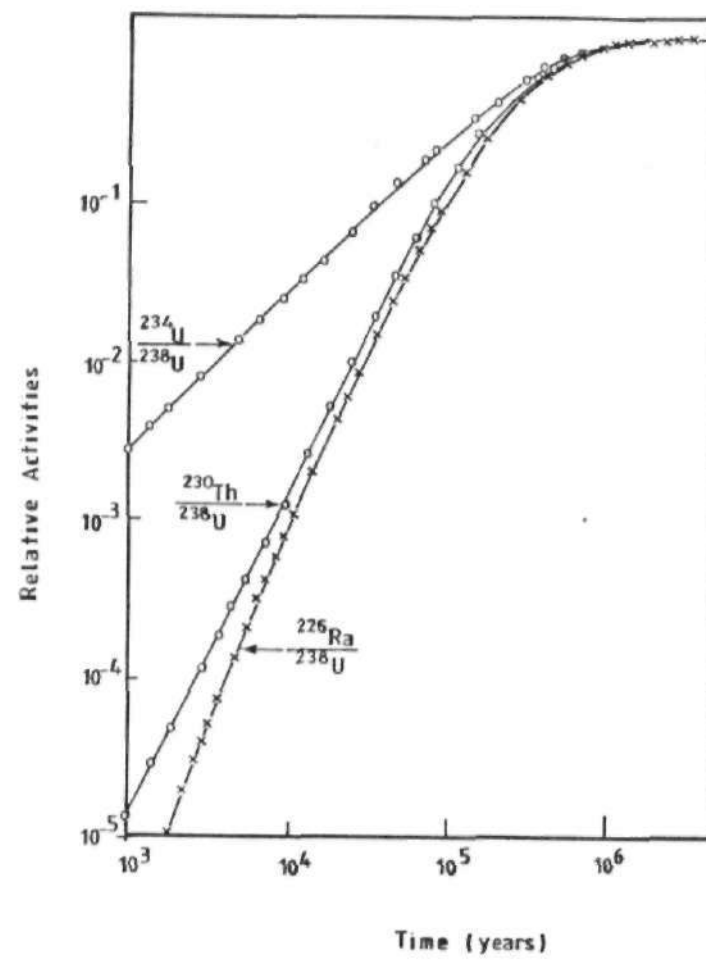


Fig.4.8. Relative activities of ^{234}U , ^{230}Th , and ^{226}Ra to point ^{238}U .

4.4 Detection Limits.

Detection limit also known as the minimum detectable emission rate depends on the sample composition, the energy of the radiation, the source - detector distance, the detector efficiency, the background and the available time for measurements. It is meant here to compare the sensitivity of the methods used. The measured number of counts, N , in the time interval T should be significantly larger than the number of background counts, N_b , in the same time interval T . N_b must be known from a measurement without the sample. The statistical fluctuation of N_b can be described by the standard deviation $S(N_b) = \sqrt{N_b}$ provided N_b was taken in the interval T as N . If the number of additional counts due to the photons from the sample, $N_s = N - N_b$ is of the order of the background fluctuation, that is, of $S(N_b)$, then there is no clear evidence of the existence of a sample effect. If on the other hand, N_s is larger than $3S(N_b)$, the probability of the presence of a sample effect is rather high. An estimate of the detection limit is here simply defined as $L = 3\sqrt{N_b}$ (Debertin and Helmer, 1988).

Detection limits for Neutron Activation Analysis, using (n, fission) reaction for U-235, Natural activity counting using 185.7 KeV line for U-235 and Isotopic XRF method

using L-lines for determination of U were calculated with measurement time ranging from 30 minutes to 24 hours. Determination of U using L-lines from isotopic XRF with ^{125}I excitation source and measurement time of four hours for surface samples and up to 24 hours for other samples was found to have better sensitivity than the other two methods.

4.5 Uncertainty of measured data.

The uncertainty characterizes the range around the measured value within which the true value is expected to lie. The values differs from the different methods and also for different elements in a sample for the same method. For the isotopic XRF the major elements may have uncertainty values of about 4% while for the trace elements it may be as high as 20% depending on the peak area used for the evaluation. 10,000 counts is considered very good although it can not be achieved for all elements within reasonable counting measuring time.

4.6 Data analysis.

Geological and geochemical data are commonly quantitative, complex and multivariate, consisting of many variables or attributes recorded in a large number of samples or objects. Multivariate data sets consist of a set of many

objects (samples) with each object described by several variables (attributes, characters).

Although multivariate data analytical techniques are applicable in many disciplines (e.g., geology, geochemistry, biology, ecology, anthropology, geography, sociology, psychology), the aims of multivariate data analysis are often very similar in these different subjects. There are many reasons why exploratory data analysis is most useful, these includes data simplification and reduction, easier display and description of complex data, hypothesis and prediction.

Rocks contain two categories of elements, not in terms of element abundances but, based on thermodynamic and mineral phase stability considerations, the major and trace elements. The major elements are mineral-forming elements, or "framework" elements, whereas trace elements substitute for major elements in existing minerals. As a consequence the behaviour of elements from each category will be controlled by different parameters. The behaviour of major elements is determined by their chemical potential and the mineral phase stability relationships interplay at a given pressure and temperature conditions (Ernst, 1976). The behaviour of trace elements is determined by their availability or abundance and by the nature of their

interaction with existing crystal structures as governed by ionic radii, electronegativity, as well as the crystal-field stabilization energy for transition elements (Crerar, et. al, 1985).

In data analysis, one is interested in causes of variation in the data. For major elements, causes for data variations can be simply in mineral proportions. This assumes that variations in the chemical composition of a given mineral are negligible, which is usually the case for a specific data set; if this assumption is wrong, then variations will likely become large enough to be explained in terms of two or more end-members which should be identifiable in the data patterns. For trace elements, however, causes for data variations are more complex and essentially involve three components: variations in mineralogy (and thus the major elements data), variations in availability of the trace elements in the geological situations under study or "rock specialization" and variations in the crystallization history of the rocks investigated, which relates to the geochemical signature of specific geological processes.

A statistical computer software package, the STATGRAPHICS 2.6[®] was used for the data analysis. Descriptive statistics of geometric mean and standard deviation, cumulative

frequency and plots, Pearson product moment correlation and R mode principal component analysis were calculated for the grouped data using the programme.

4.6.1 Correlation Analysis.

The correlation analysis procedure generates a matrix of correlation coefficients for a set of observed values. It is a measure of similarity between paired data. Correlation coefficients provide a normalized and scale-free measure of the association between two variables. The coefficient values fall between -1 and +1. A positive correlation indicates that the variables vary in the same direction while a negative correlation indicate that the variables vary in opposite direction. Statistically independent variables have an expected correlation of zero.

Correlation analysis often provides a preliminary view of the relationships between variables and can be used as input to other procedures like the principal components.

4.6.2 Principal Component Analysis (PCA).

PCA is a technique for reducing the number of variables in a data set by finding linear combinations of those variables that explain most of the variability.

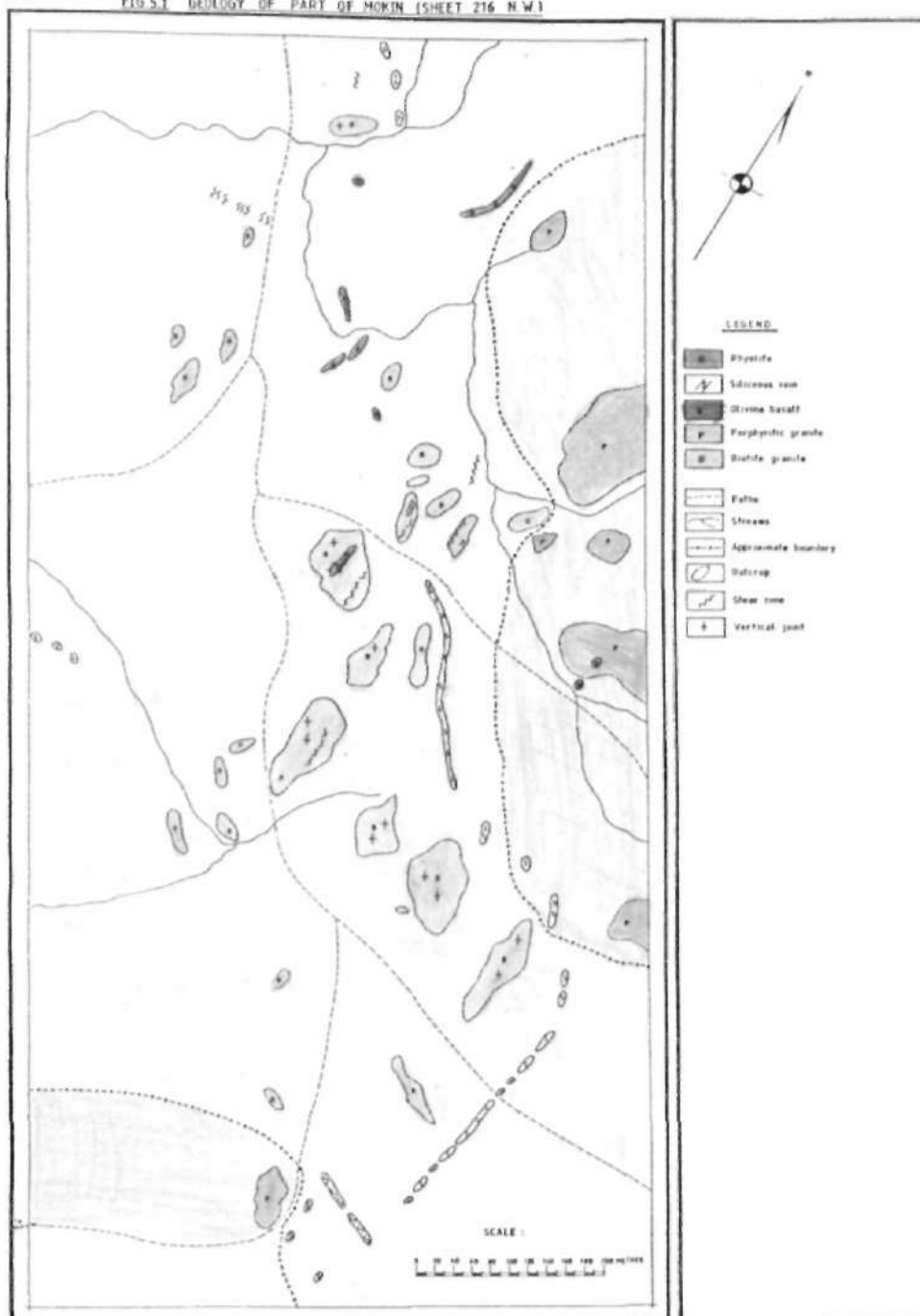
The goals for PCA are concerned with finding relationships between objects and for data reduction. In general, almost all data matrix can be simplified by PCA. The dominant patterns in a matrix are extracted in terms of a set of complementary set of score and loading plots. The results are explained in terms of geological phenomena based on inferred geological parameters.

CHAPTER 5
THE MIKA MINERALIZED AREA.

5.1 Geology of the Mika area.

The rock types of Mika uranium mineralization area is dominated by granites. The geologic map of the area is presented in Fig. 5.1. The rock types include the fine-grained granite, medium-grained biotite granite, porphyritic granite, sheared granite, olivine basalt, brecciated rhyolite and siliceous veins. The fine-grained granite outcrops could not be mapped as a separate unit, due to their small size, which are enclosed in the medium grained biotite granite bodies. The biotite granite underlies about four-fifth of the total mapped area. The rest area to the north, northeast and south are underlain by the porphyritic granite. Sheared granite occurs mostly as long ridges enclosing siliceous veins and rhyolites at the centre of the shear zone. The siliceous veins occur as the north-west trending ridges in the central parts and the almost north-south ridge at the lower part of the area, all measuring over 120m in width. Rhyolite veins occur in similar fashion to the sheared granite, but occur only in the northern half of the area with predominantly north-south alignment.

FIG. 5.1 GEOLOGY OF PART OF MOKIN (SHEET 216 N.W.1)



Olivine-basalt outcrops as small bodies within the porphyritic granite in the northern part of the mapped area.

The fine-grained granite is foliated with the alignment of ferromagnesian minerals. The biotite granites do not exhibit any preferred structural orientation. Parts of the porphyritic granite shows oriented feldspar phenocrysts and ferromagnesian minerals in a nearly NS direction.

From the emplacement of the granitic bodies, the geological events that can be inferred in the area are the formation of shear zone with quartz veins, mostly in the NE-SW direction; dilation of some of the shear zones and emplacement of rhyolite bodies and further shearing that affected part of the rhyolites and the granites.

The joint statistics of the mapped area is presented in Table 5.1.

Strike in degrees	No. of joints
0-20	80
20-40	18
40-60	22
60-80	30
80-100	46
100-120	14
120-140	24
140-160	62
160-180	20

Table 5.1 Joint statistics of the mineralized area at Mika.



Fig. 5.2 Rose diagram for the joint trends.

The joints have vertical dips and occurs as joint systems with predominantly NS and EW directions. Some of the joints are filled with secondary quartz material and some exhibit shearing effects.

The majority of the joints and fractures are in the following range $0 - 20^{\circ}$, $60 - 80^{\circ}$, $80 - 100^{\circ}$ and $140 - 160^{\circ}$ which correspond with the major lineaments of the area.

These major lineaments are the N-S subvertical foliation trend found in the porphyritic granite, which along with its conjugate E-W, are common features of the Pan-African basement, the NE-SW lineaments that are prominently observed in the Upper Benue area and the N140E and N170E trend of some sheared granite and rhyolite bodies.

Some of these fractures and joints, most especially the N140E to N170E are filled with volcanic material (rhyolitic) which are closely associated with uranium mineralizations in the area.

This group of fractures are also believed to be conjugate to the NE-SW sinistral faults contemporaneous with the genesis of the Benue trough (Benkhelil and Robineau, 1983 and Maurin et. al., 1986).

Many uranium ore veins occur in the Mika area which are associated with the granites and or the rhyolite enclosed in it. The distribution of these occurrences is restricted to a narrow most intensely fractured zone running north-east in the centre of the mapped area. The long sheared ridges in the lower part of the area feature silica veins and are barren of uranium. Most of the uranium occurrences in the Mika area are spotty and in some localities associated with red siliceous veins in shear zones hosted by altered granites and brecciated rhyolites. The full description of the rock types mapped in the area is presented below.

5.1.1 Fine-grained granite.

Fine-grained granites form small outcrops mostly in the area towards the west of the main mineralization at Mika. These could not be mapped as separate units due to their small size. They have gradational contact and show some

evidence of replacement at the contact zone with the porphyritic granite. In most places small pegmatite bodies are associated with the fine-grained granites. Plate I shows a low lying outcrop of fine grained granite.

Major constituents of the fine-grained granite are : Microcline, plagioclase, quartz, biotite and muscovite. Approximate modal analysis of the fine-grained granite is listed in Table 5.2.

Quartz	20%
Microcline	30%
Plagioclase	35%
Biotite	10%
Muscovite	trace
Accessories	rare

Table 5.2 Approximate modal analysis of fine-grained granite.

The plagioclase forms about 35% of the rock and it is sericitized. The plagioclase, usually oligoclase, occurs as euhedral crystals. Microcline is perthitic and occurs as anhedral plates found within plagioclase. Microcline accounts for 30% while quartz accounts for 20% of the rock. Biotite and muscovite occur in varying proportions but make up less than 10% of the rock.

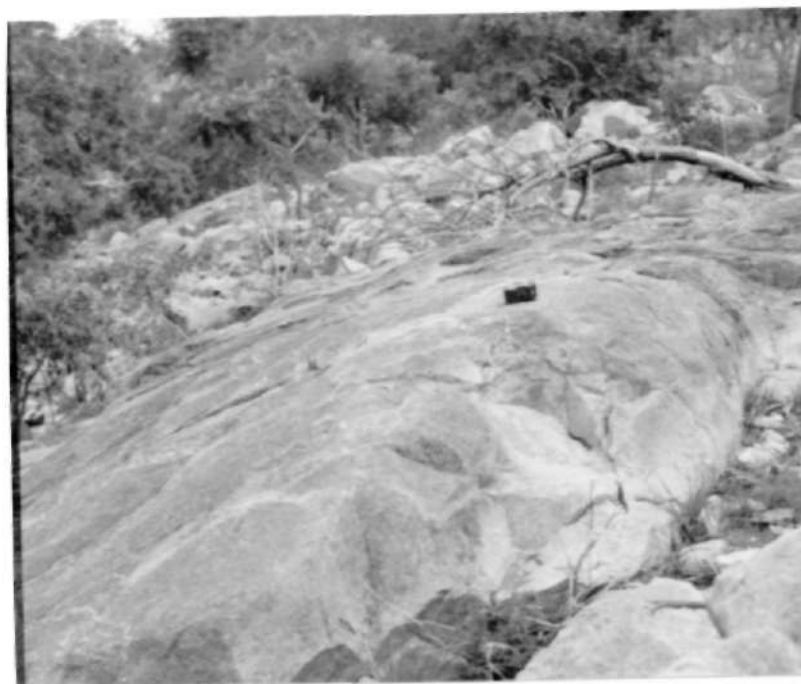


Plate I. Outcrop of fine-grained granite.



Plate II. Outcrop of biotite granite.

5.1.2 Medium-grained Biotite granite.

This is the single most dominant rock type in this area. Textural varieties exist but are difficult to demarcate. It is greyish to pink in colour with some orientation of the feldspar crystals. Plate II shows an outcrop of biotite granite. The rocks are essentially composed of quartz, K-feldspar (both orthoclase and microcline), plagioclase, represented by albite-oligoclase and biotite. Accessory minerals are sphene, zircon, magnetite, apatite and iron oxides. Mymerkitic and perthitic textures are common. Table 5.3 shows the approximate modal analysis of the medium grained granite.

Quartz	20%
K-feldspar	45%
Plagioclase	20%
Biotite	5%
Hornblende	3%
Accessories	2%

Table 5.3 Approximate modal analysis of medium grained granite.

K-feldspar occurs as tabular grains with no perthitic inclusions, plagioclase feldspar forms sub-hedral tabular grains, Quartz forms interstitial granular patches with simple grain boundaries. Biotite forms ragged flakes with extreme pleochroism from greenish brown to bright yellow.

5.1.3 Porphyritic granite.

The porphyritic granites were emplaced during the late stages of the Older granite cycle (Carter et. al., 1963). The most striking characteristic is a porphyritic texture formed by phenocrysts of perthitic microcline set in a medium grained matrix (Plate III). The mineralogy of the porphyritic granite consists of essentially microcline, oligoclase, quartz, biotite and rare appearance of hornblende. Accessory minerals are zircon, iron oxide, sphene and apatite. Table 5.4 shows the approximate modal analysis of porphyritic granite.

Quartz	24%
Oligoclase	20%
Microcline	42%
Biotite	4%
Hornblende	trace
Accessories	2%

Table 5.4 Approximate modal analysis of porphyritic granite.

K-feldspar forms tabular megacrysts some of which contain insets of subhedral plagioclase feldspar. Quartz occurs as polycrystalline aggregates or interstitial between the feldspar grains. Biotite forms patches associated with accessory minerals. Most grains are fresh while some are strained.

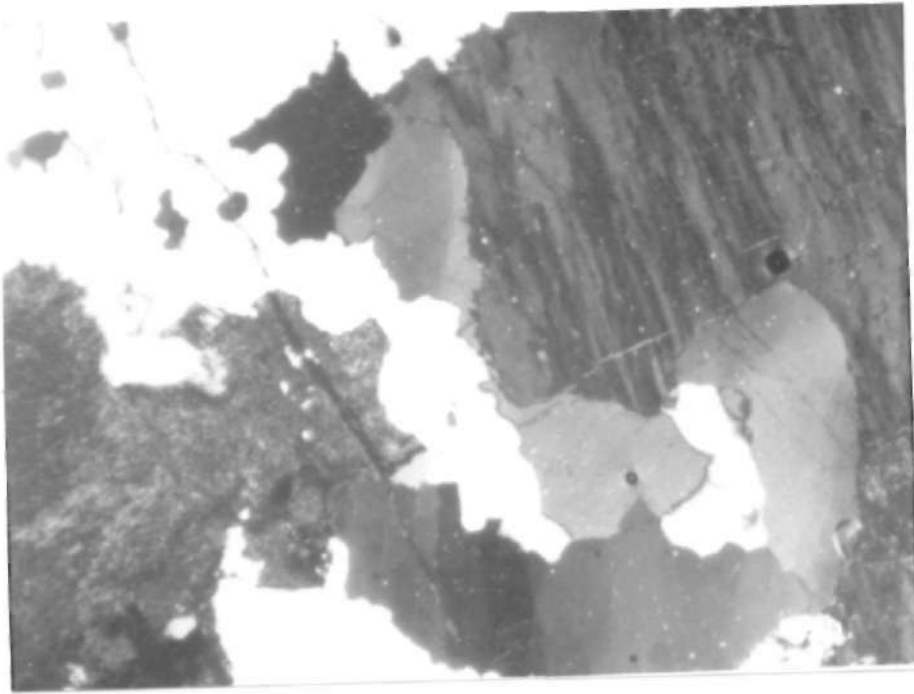


Plate III. Photomicrograph of biotite granite
(Magnification 6.3 crossed polar)
Q - Quartz, M - Microcline



Plate IV. Outcrop of sheared granite

5.1.4 Sheared granite.

The distribution of the sheared granites is restricted to the sheared zones as exemplified around the main mineralization at Mika and depicted by the ridges to the north of the mineralization. Plate IV shows an outcrop of sheared granite.

Phenocrysts are broken with no preferred orientation in a granulated matrix. The mineralogy is essentially the same with that of the granite but shows evidences of shearing and hydrothermal action as manifested by fracturing of feldspar, granulation of quartz, presence of impregnated silica which constitute up to 40% of the rock and clusters of sericite in cracks of feldspars. Other features are microscopic imperfections in quartz and the strain from extinction. Table 5.5 shows the approximate modal analysis of the sheared granite.

Quartz	40%
Oligoclase	10%
Microcline	12%
Sericite	15%
Accessories	2%

Table 5.5 Approximate modal analysis of sheared granite.

5.1.5 Brecciated rhyolite.

The brecciated rhyolite displays variable textural characteristics, with siliceous fragments occurring as "lumps" and as sheared fragments. The structural feature is also very complex, evidently it must have undergone many shearing episodes in different directions. Plate V shows brecciated rhyolite near the main uranium mineralization at Mika.

Phenocrysts of quartz, highly sericitized feldspar and mica shards are set in cryptocrystalline groundmass. There are clear patches of glass material. Hematite occurs in fine powder form and in cracks and fractures cutting across phenocrysts and groundmass. The approximate modal analysis of the rhyolite is presented on Table 5.6.

Quartz	50%
Sanidine	20%
Sericite	10%
Accessories	2%

Table 5.6 Approximate modal analysis of brecciated rhyolite.

5.1.6 Olivine-basalt.

The basalts are black, dense, fine-grained rocks in which individual olivine crystals are visible, occasionally concentrated in large pockets.

The thin sections consist of phenocrysts of olivine and augite, feldspar laths and iron oxides. Apatite is the common accessory mineral and there are occurrences of few flakes of pale brown biotite. Olivine occurs as phenocryst and as small, rounded crystals in the groundmass and augite is weakly zoned. The feldspars essentially labradorite, are cryptocrystalline laths while the groundmass is holocrystalline. Table 5.7 shows the approximate modal analysis of the olivine basalt.

Labradorite	50%
Augite	15%
Olivine	20%
Accessories	5%

Table 5.7 Approximate modal analysis of olivine-basalt.

5.2 The uranium mineralization at Mika.

The uranium occurrence in Mika is located in two parallel NS trending shear zones with the one to the east enclosing a rhyolite vein body which also like the granite is sheared, brecciated and hematized. Plate VI shows part of the mineralization at Mika.

The biotite granite enclosing the shear zone shows variable textures along its length, in places feldspathized (feldspar crystals up to 2cm with inclusions of biotite).



Plate V. Outcrop of brecciated rhyolite.



Plate VI. Part of the main Mika mineralization
(in the foreground is a dug out trench).

The sheared granite occurs as altered granite permeated by silica, or as a fractured granite with silica developed along the fractures in a ribbon-like manner. The rhyolite body shows a variable textural character, with siliceous fragments occurring as "lumps" at the core and sheared fragments at its contact with sheared granite. The detailed geologic cross section of the mineralization through the D21 and 18C drill cores (the southern profile) is presented in Fig. 5.3. The section shows three steeply dipping rhyolite bodies on the upper limb that intrudes sheared granite. The main rhyolite body and its satellites bodies with thickness of less than 5m occur at 48m and 60m down the hole. The mineralization at the lower limb is located in and around two parallel sheared zones which are enveloped by altered granites. The drill hole 18C intercepts fine-grained granite at 50m depth. No rhyolite body is encountered at the lower limb. Another section through D20, north of 18C (Fig. 5.4) shows intercepts of rhyolite bodies at 80m and 100m down the hole. Here there are three altered granite zones, instead of the two encountered in D21. The first zone, which occurs between 25m to 80m has two shear fractures that are filled by red silica and it terminates with an underlying rhyolite. The second zone overlain by a thin rhyolite body envelopes one shear zone. The third zone is narrow and not sheared.

Drill core sections show the host rock of these shear zones and rhyolite to be an intensely feldspathized biotite granite. The K-feldspar is mainly microcline, associated with quartz which occurs evenly distributed. At the periphery the microcline is associated with small plagioclase crystals.

In the mineralized zone the rock is altered and cut by numerous fractures that are filled with light grey and red hematized silica, microcrystalline pyrite and sericite. Some joints are kaolinized. In parts of D20 section weak mineralization occurs associated with red silica filling which cut into the altered biotite granite and rhyolite.

The rhyolite bodies are also sheared and brecciated. These are also mineralized at their contact zone to the altered biotite granite and from the upper limb of the uranium mineralization.

The geological section through D21 (Fig. 5.3) shows this steeply dipping rhyolite body (about 80°) in between sheared granite. In 18C on the lower limb is a 70° dipping shear zone consisting of two major fractures that are enveloped by altered granites. The mineralization is most intense within this zone which is also intercepted by D18 drill hole at a depth of 49 metres down the hole.

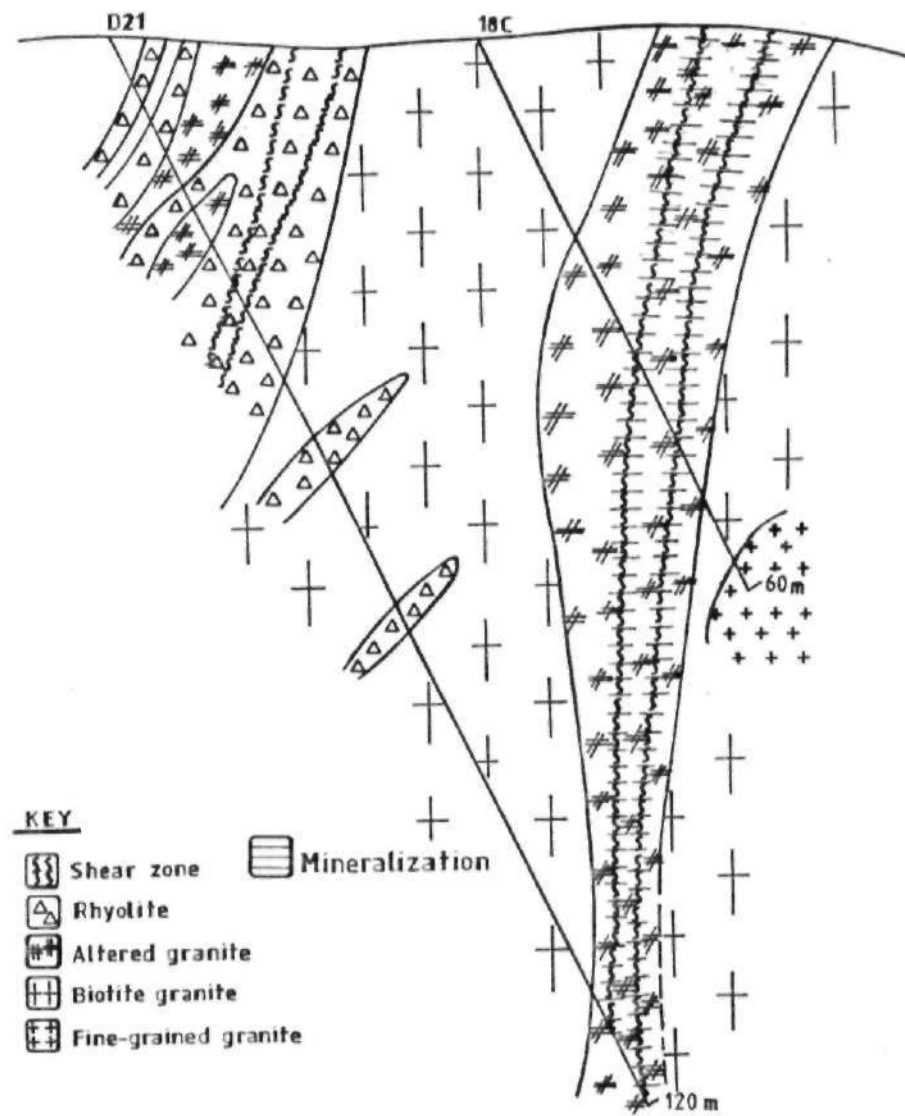


Fig.5.3, Detailed geologic section of Mika uranium mineralization through D21 and 18C .

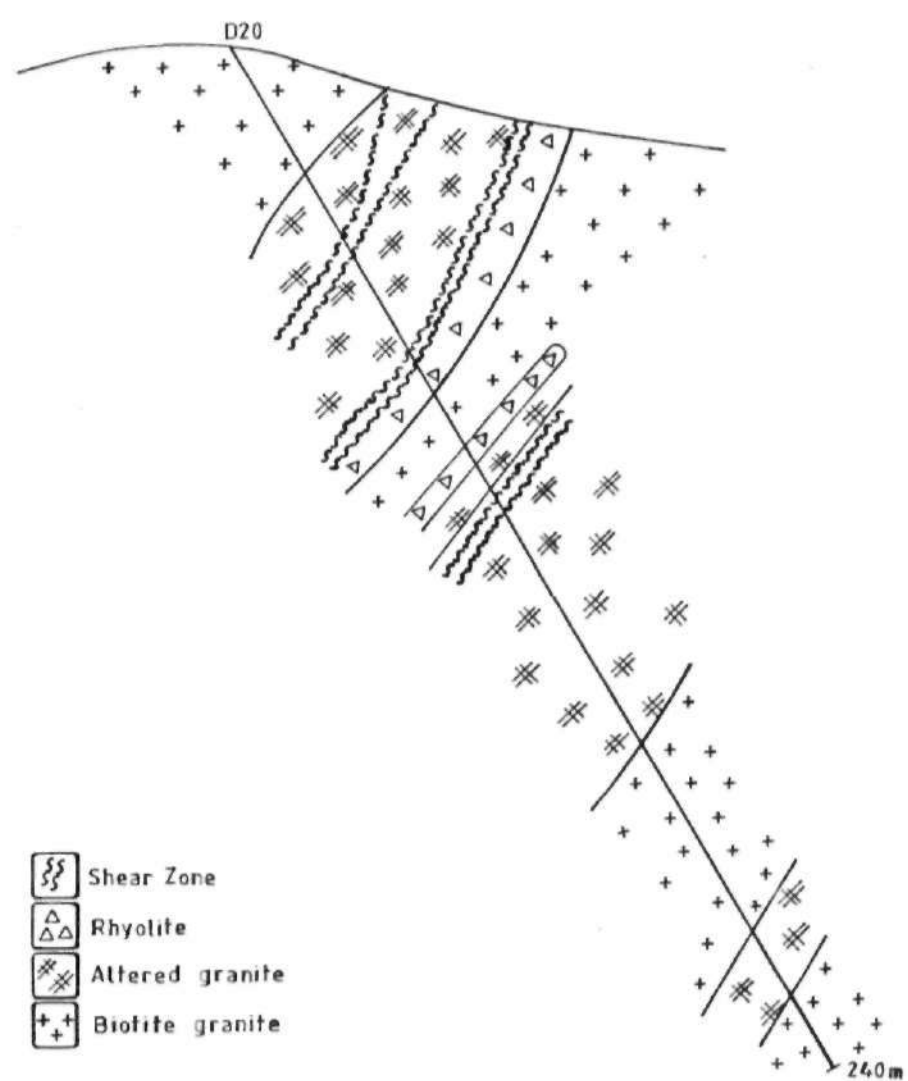


Fig 5.4. Detailed geologic section of Mika mineralization through D20 (Central profile).

There are two major types of ores at Mika uranium mineralization; the primary mineralization, these as pitchblende at sub-surface level in the granites and secondary mineralization mostly meta-autinite and coffinite occurring on the surface in both the granites and rhyolites.

Pitchblende occurs as two varieties; in a lenticular vein within open fractures in the granite and as veinlets and disseminations around the fracture zones. The lenticular veins throttlles with depth being widest at 18C drill core intercept and thins out at D21 intercept.

Pitchblende occurs associated with disseminated sulphides; siderite, pyrite and chalcopyrite and red silica veinlets. The pitchblende is spheritic with light grey colour exhibiting low reflectivity and dark brown internal reflections (Plate VII). Some of the pitchblende occur disseminated and others are embedded in secondary quartz. Hematite is invariably present in veins with microcrystalline quartz. The sulphides are finely disseminated in the rock matrix (Plate VIII).

The secondary uranium minerals are restricted in distribution to surface occurrence. The uranium ores occur in crushed and brecciated granite (Plate IX), in the brecciated rhyolite and also at its contact zone with the granites. Uranium ores identified in polished sections are

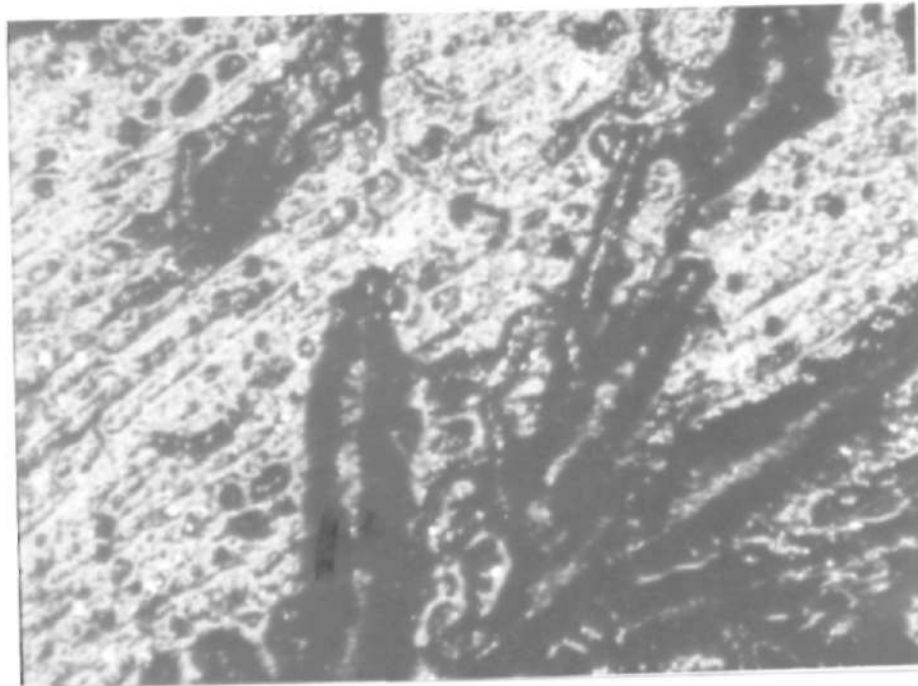


Plate VII. Photomicrograph of mineralized granite
(Magnification 10 polished section)
P - Pitchblende.

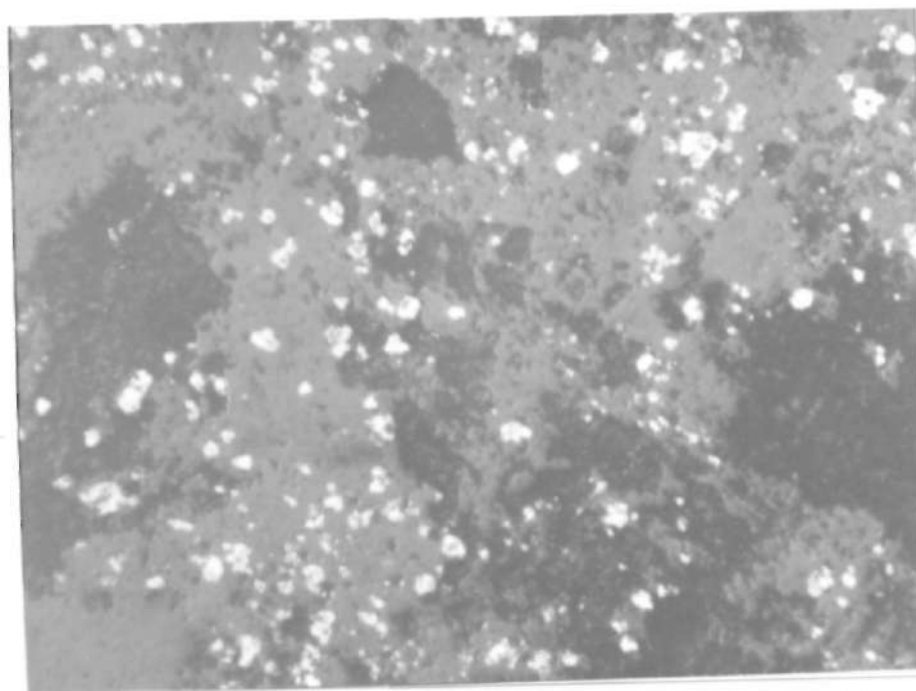


Plate VIII. Photomicrograph of mineralized granite showing
disseminated sulphides (white specks).
(Magnification 10 polished section)



Plate IX. Secondary uranium mineralization in sheared and brecciated granite.

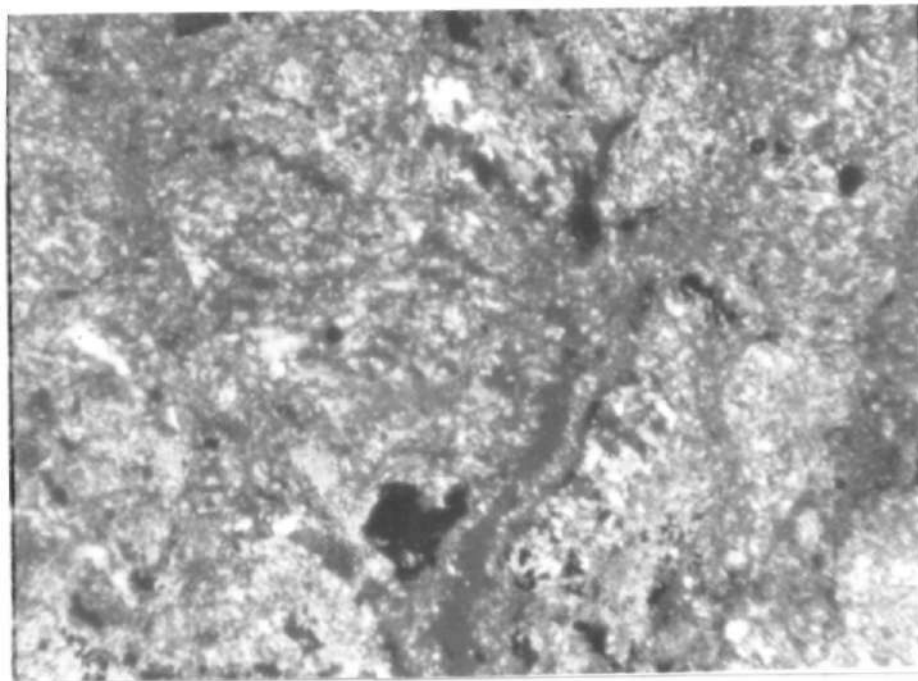


Plate X. Photomicrograph of mineralized granite.
(Magnification 6.3 crossed polar)

yellowish green meta-autinite and yellow coffinite. Coffinite occurs as sub-microscopic aggregates, in colloform textures showing low reflectivity with dull grey colour. Internal reflections are with brownish tints. Meta-autinite shows dull grey colour with no observed internal reflections. Both minerals occur as encrustations in hematite and quartz veins in the crushed and brecciated granite. Such rocks feature marked kaolinitic alteration of these rocks.

Ore minerals identification was further enhanced with XRD analysis of both the core and surface samples. The diffraction patterns with the evaluated peaks and the identified minerals are shown in Appendix II.

The primary uranium mineral, pitchblende or uraninite, the more accepted name since there is no real distinction in powder diffraction pattern (Smith, 1984) was identified in core samples C9 and C43. The diffraction patterns of some of the surface ore samples (S29, S50) compare very well with reported values of meta-autinite and coffinite in terms of d -spacings and peak intensities (Appendix II).

5.3 Alteration studies.

Granites and rhyolite in the mineralized and or sheared zones are altered to different degrees of intensity. Thin section and XRD studies were undertaken to delineate these

alteration zones. The samples were selected to represent the rock types, the mineralization and or alteration zones. Locations of the samples from the drill core sections are shown in Figs. 5.5 and 5.6.

The altered granite is fine-grained to porphyritic in texture, some are highly silicified and vary in colour from dark brown to pink rocks. Phenocrysts of pinkish alkali feldspar and quartz are distributed throughout the rock. Essential minerals are quartz, orthoclase, microcline and muscovite. Quartz constitutes about 20% and occurs as bipyramidal crystals, some of which are fractured. Secondary quartz also occurs in veins cutting across the groundmass and orthoclase crystals. Alkali feldspar mainly orthoclase and microcline makes up to about 40% of the rock, usually highly sericitized. The groundmass is fine grained and consists of quartz and sericite grains.

The mineralized granite essentially has the same mineralogy as the altered granite, but is highly altered with near complete destruction of the feldspar and exhibits many veinlets that are filled with opaque minerals, most probably the ore (Plate X).

The major minerals in the altered rhyolite are quartz and feldspar (essentially sanidine). There are some mica shards and clear patches of glass. Quartz and sanidine occur as phenocrysts while the groundmass is crypto-crystalline.

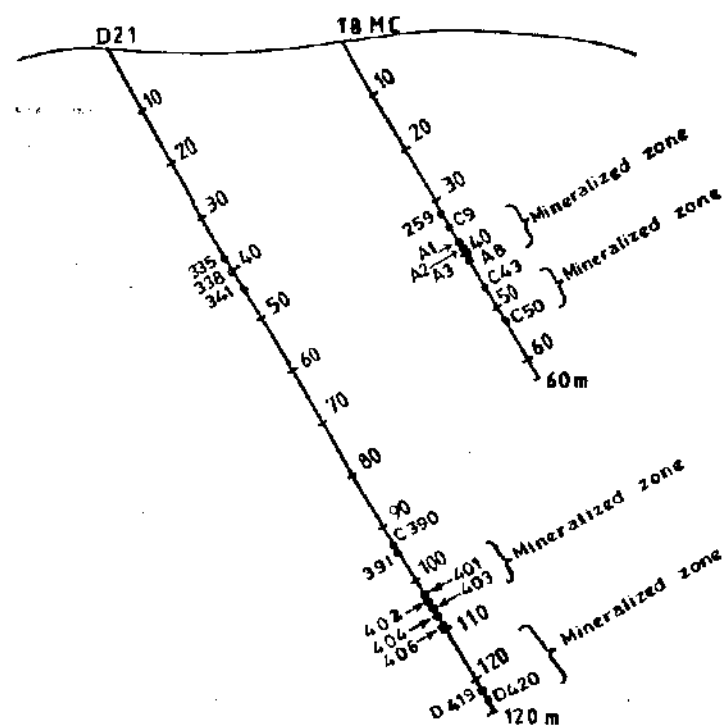
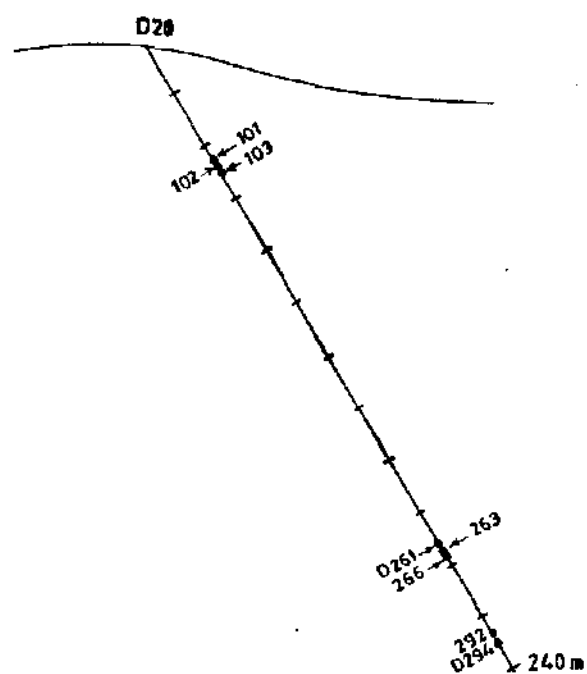


Fig. 5.5. Positions of samples selected for XRD (D) and thin and polished section studies on 18MC and D21 cross sections.



Accessory minerals are apatite, ilmenite and zircon.

The mineralized rhyolite shows fragments of quartz and feldspar phenocrysts set in a cryptocrystalline groundmass. There are many veinlets that are filled with silica and hematite. Hematite also occurs as fine powder.

The main alteration types observed are sericitization, silicification, K-feldspathization, hematization, devitrification of glass and kaolinization.

5.3.1 Sericitization.

Sericitization is an alteration process leading to the formation of sericite (secondary muscovite) from feldspars and micas. Both K-feldspar and plagioclase are converted to sericite and minor kaolinite may be present in sericitic alteration (Meyer and Hemley, 1967).

Sericitization is the most common of the alteration processes in the altered granite samples. The altered and sheared granite have sericite grains forming along cracks and replacing parts or whole feldspars with the outline of their former crystals still recognizable (pseudomorphic replacement). The same alteration features exist in the altered rhyolites. In the mineralized zones of the granites and rhyolite sericite occurs as cryptocrystalline and fine aggregates or finely distributed in the rock matrix.

The original rock matrix is obliterated and most primary minerals altered to sericite (principally plagioclase). Sericitization processes may have occurred during the emplacement and shearing of the rhyolites and aggravated further during shearing of both granites and rhyolites and subsequent mineralization processes.

5.3.2 Silicification.

Silicification is marked by the presence of impregnated grey silica in veins, mostly at the contact of the granites with rhyolite bodies. In thin sections abundant secondary quartz occurs in clusters, in veins and sometimes finely disseminated in the matrix of the rhyolites and granites.

The primary quartz sometimes contain small sericite grains and liquid inclusions. This primary quartz contrary to the secondary variety is always strained and shows pronounced undulatory extinction. Secondary quartz replaces highly sericitized plagioclase, resulting in a texture showing bands of original cloudy feldspar and sericite aggregates in a matrix of clear, anhedral secondary quartz. This quartz is fine-grained and rarely shows undulatory extinction.

There must have been several generations of the secondary quartz as exhibited by some of the sections, with many veins cutting across others.

5.3.3 K-feldspathization.

K-feldspathization is the process by which K^+ exchange for Na^+ in silicate minerals especially in feldspars and micas. K-feldspar and/or biotite is formed as an alteration product from plagioclase or mafic minerals. The exchange reaction between K^+ and Na^+ produces an increase of K^+ towards mineralization and a consistent decrease of Na^+ (Boyle, 1982). Thus the K_2O/Na_2O ratio usually show a consistent increase towards the mineralization.

K-feldspathization is marked by the reddened K-feldspar phenocrysts in the altered granite outcrops which is most prominent in the mineralized part of the granite body.

5.4.4 Hematization.

Hematization which is the most common alteration feature observed in surface outcrops feature most prominently in the rhyolite body. Red hematitic veins also accompany the uranium mineralization in the granite. In the D20 section elevated uranium values are associated with hematized silica veins that occur in altered zones.

5.3.5 Kaolinization.

Kaolinization is the process of formation of kaolin minerals. In the samples studied it may belong to Intermediate argillic type (Meyer and Hemley, 1987), where

there is the presence of important amounts of kaolinite, principally replacing plagioclase.

The kaolinization process is most marked in the mineralized granite, where there is complete alteration of the feldspars forming clay mineral. The presence of kaolin minerals produces a dark gray clouding in the drill sections.

5.3.6 Relation of alteration features to mineralization.

Among the alteration features, sericitization forms the widest zone through D21 and 18C section (Fig. 5.7a) on the two limbs. Sericitization decreases rapidly towards the mineralized fractures in the altered zones that envelope the fractures. Sericite is mainly from strong alteration of plagioclase as some of the K-feldspars are still fresh. Along the D20 section sericitization is also the most common feature in the altered zones (Fig. 5.8a).

Silicification is most intense at the fracture zones, with decrease in the appearance of secondary quartz outwardly. The silicified zones from the D21 and 18C drill sections are shown in Fig 5.7b. Most of the fractures are filled with grey silica material some of which are hematized or may be covered by limonite film.

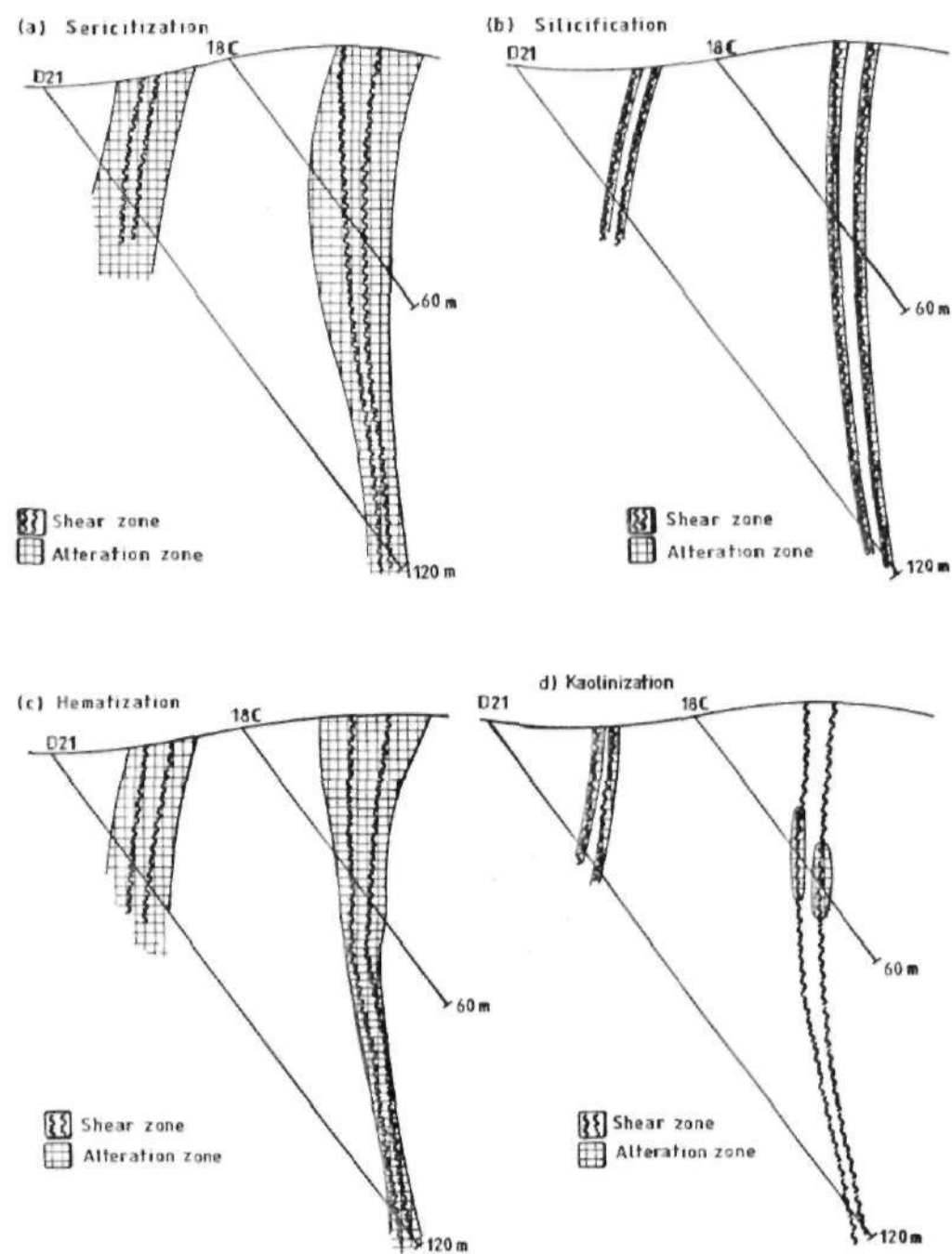


Fig. 5.7. Alteration zones (a) sericitization, (b) silicification, (c) hematization and (d) kaolinization through D21 and 18C section (southern profile).

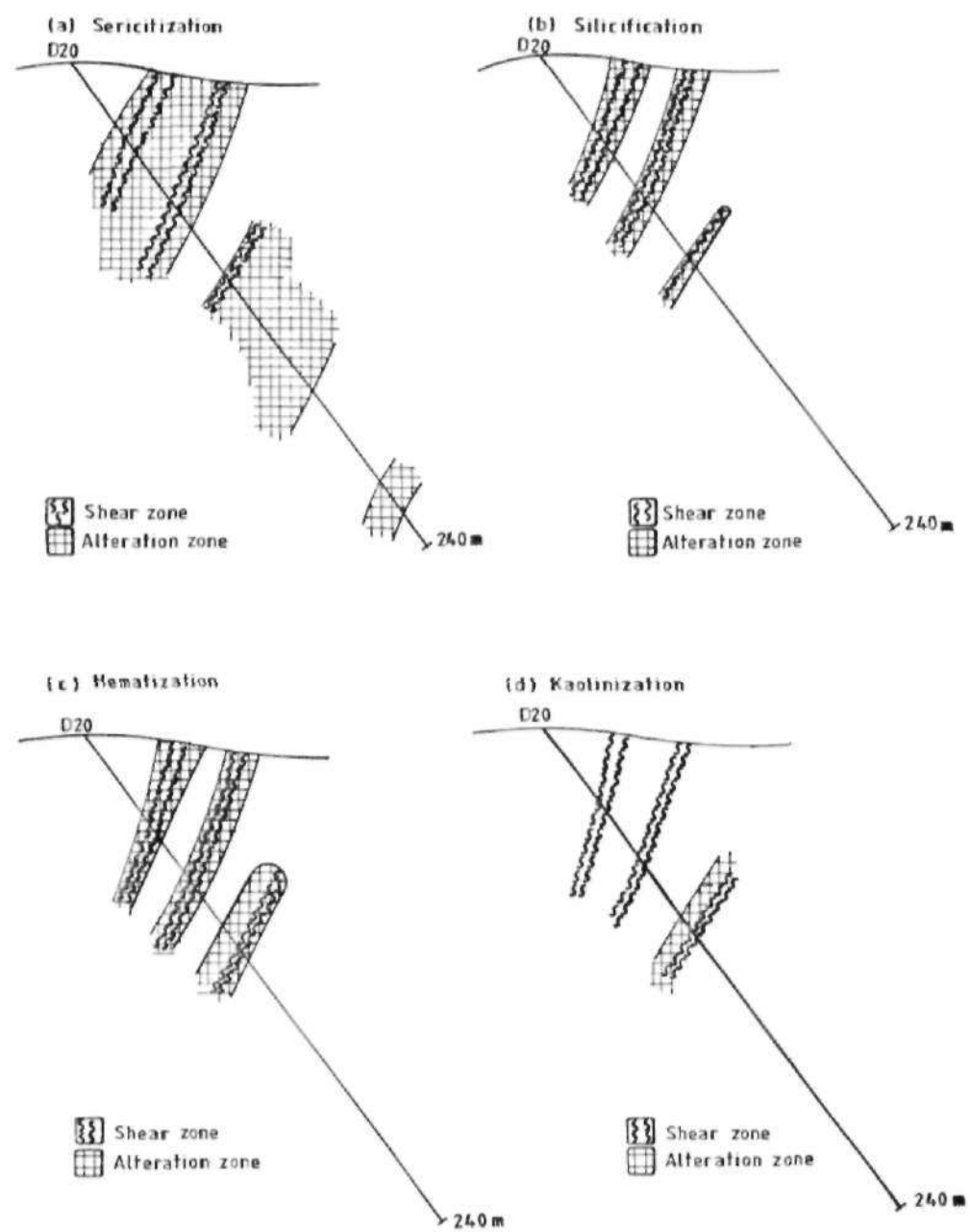


Fig. 5.8. Alteration zones (a) sericitization, (b) silicification, (c) hematization and (d) kaolinization through D20 section (central profile).

Hematite zones are outlined for the two profiles in Figs. 5.7c and 5.8c. The hematization zone centres around the mineralized fractures and the hematized silica veins that have elevated uranium values.

Kaolinite has a more restricted occurrence in the profiles (Figs. 5.7d and 5.8d), being present only within the mineralized fractures. In sections D21 and 18C kaolinite zone is limited to a small part of the upper limb and to a narrow zone coinciding with the trend of the mineralized fractures on the lower limb. In the D20 kaolinization is observed only near the third (lowermost) hematized silica veins.

The general pattern of the alteration zoning is a wider zone of sericitization and hematization, followed by narrower zone of sericitization, silicification and kaolinization at the centres. The narrower zone is associated with the mineralized fractures, thus depicting structural controlled alteration and the mineralization.

CHAPTER 6

THE GEOCHEMISTRY OF THE URANIUM MINERALIZATION IN MIKA.

Twenty five elements were analyzed in the samples, namely: Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Sc, V, Cr, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Mo, Pb and U. To outline the variation pattern of the elements, the data was classified into five identified rock groups; the unaltered granite, altered granite, altered rhyolite, mineralized rhyolite and mineralized granite to help in explaining the distributions.

Table 6.1 shows the concentration mean and standard deviation of the elements in the five rock groups. Histograms and cumulative curves were plotted and these were used to contour values on maps for some selected elements. Element distribution pattern alongside with corresponding histograms are shown in Figs. 6.1 to 6.4. Dispersion curve of the elements were plotted for D21-18C (Figs 6.5 to 6.8) and for D21 (Figs. 6.6 to 6.9). Detailed curves for the mineralized zone of 18C and D20 were as well plotted (Figs. 6.10 to 6.17). The distribution patterns of the various elements are explained below.

456313

	UNALTERED GRANITE		ALTERED GRANITE		MINERALIZED GRANITE		ALTERED RHYOLITE		MINERALIZED RHYOLITE	
	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.
SiO ₂	72.21	1.59	70.70	1.73	70.6	4.89	71.62	0.93	71.82	1.39
TiO ₂	0.26	0.10	0.27	0.12	0.3	0.09	0.29	0.09	0.33	0.09
Al ₂ O ₃	13.62	1.07	13.99	1.25	13.2	0.62	13.03	0.59	13.93	0.74
Fe ₂ O ₃	1.93	0.45	3.59	1.27	4.9	1.58	4.87	2.49	3.69	1.91
MnO	0.06	0.02	0.06	0.01	0.1	0.01	0.05	0.02	0.06	0.01
MgO	0.35	0.16	0.33	0.30	0.4	0.21	0.30	0.13	0.35	0.20
CaO	0.75	0.18	0.70	0.35	1.4	0.48	0.91	0.21	0.82	0.42
Na ₂ O	3.71	0.65	2.93	1.01	2.6	0.43	2.81	0.59	3.34	0.78
K ₂ O	5.06	0.72	5.17	1.05	5.5	1.35	4.30	0.72	5.50	0.92
P ₂ O ₅	0.13	0.09	0.17	0.08	0.6	0.31	0.25	0.15	0.24	0.22
Sc	6.8	2.31	10.3	5.93	9.5	6.00	8.30	3.30	9.0	2.88
Y	42.5	5.08	100.6	32.17	173.4	45.56	102.6	48.08	157.6	46.31
Cr	68.7	11.09	57.1	17.68	29.1	25.31	67.7	17.07	51.2	12.53
Co	8.7	2.99	29.5	24.72	19.6	13.03	32.6	2.04	36.3	7.95
Ni	13.0	2.33	19.2	10.76	22.2	10.17	15.4	4.43	18.7	7.25
Cu	22.0	3.83	33.6	10.38	55.4	17.78	51.8	36.53	42.7	23.53
Zn	82.7	19.37	97.9	24.91	239.2	65.80	111.3	23.17	154.2	84.60
As	5.2	3.46	5.4	4.52	5.9	3.62	5.5	2.53	6.7	3.86
Se	3.2	2.47	2.8	2.02	4.5	3.35	4.9	4.11	2.9	1.41
Rb	189.1	41.12	236.8	78.19	228.2	62.34	254.6	120.33	222.3	61.79
Sr	451.0	65.16	786.6	214.70	1093.6	145.36	1086.1	448.45	957.6	292.44
Y	34.6	3.35	56.4	12.36	108.8	65.78	72.0	18.08	64.8	24.37
Zr	257.1	29.74	236.5	82.52	332.2	61.61	279.7	118.43	316.0	92.93
Mo	23.1	8.83	43.0	24.12	36.9	15.76	44.2	21.37	51.1	17.41
Pb	31.4	8.17	92.4	47.34	1002.3	1130.53	41.5	42.85	415.1	876.80
B	10.4	2.79	113.7	146.77	5911.0	10838.30	106.0	150.78	1365.1	4745.76

Table 6.1 Summary statistics of the grouped data. Oxides are in percentage and the rest elements are in ppm.

6.1 Major element geochemistry.

At least seven cations (Si, Al, Na, K, Ca, Fe and Mg) are necessary to represent the major elemental chemical composition of a rock (Rosler and Lange, 1972). All these elements were analyzed along with others and their variation patterns presented in diagrams. The granite type and pattern of its alteration are also outlined.

6.1.1 Iron (Fe).

Iron was calculated as Fe_2O_3 . The range of concentration is 1.00%-7.87%. The mean value for the granite is 1.93% with a standard deviation of 0.45%. The altered granite with a mean value of 3.59% and a standard deviation of 1.27 features higher iron content than the mineralized granite which has an average Fe_2O_3 of 4.94% and a standard deviation of 1.50. Altered and mineralized rhyolites have higher iron content with mean values of 4.87% and 3.69% and standard deviations of 2.49 and 1.91 respectively.

The Fe_2O_3 values were further plotted in maps to relate hematization patterns to the outline of mineralization. The surface distribution of Fe_2O_3 is shown on Fig.6.1 and its distribution curves in the core section are shown in Figs. 6.2, 6.3. and 6.4. For the surface samples the mineralized areas are the most intensely ferruginized, showing clearly

the two centres of high Fe_2O_3 values concentrating on the altered and mineralized parts.

6.1.2 Magnesium (Mg).

Magnesium values were calculated as the oxide. The range of Mg concentration in the samples varies from 0.09%-4.22%, the high values are derived from olivine basalts. The mean Mg content for the unaltered granite is 0.38% with a standard deviation of 0.16%. The other rock groups have mean values with standard deviations as follows: altered granite 0.33% ± 0.18 , altered rhyolite 0.30% ± 0.13 , the mineralized granite 0.39% ± 0.20 and the mineralized rhyolite 0.35% ± 0.20 . There is little or no variation in Mg content within the rock groups.

6.1.3 Calcium (Ca).

In igneous rocks Ca is an important constituent of both the major and accessory minerals. Approximately one-half of the Ca in igneous rocks is present in the pyroxene and amphibole groups and the other half in plagioclase feldspars.

The Ca data are expressed as oxide. The Clarke values for granite and rhyolite are 1.33% and 1.13% respectively (Nockolds, 1954). Range of concentration of CaO in all

samples is 0.26%-2.46%. Variation of the average values in the groups is as follows: unaltered granite 0.75%, altered granite 0.70%, mineralized granite 1.41%, altered rhyolite 0.91% and mineralized rhyolite 0.82%.

The distributions of CaO are shown on Figs. 6.1 for the surface and Figs. 6.2, 6.3 and 6.4 for sub-surface. Higher concentration of CaO clusters around the two mineralized zones on the surface. Elevated values are found in the mineralized fractures of the sections (Fig. 6.7).

6.1.4 Sodium (Na).

The geochemical behaviour of Na in igneous rocks is controlled to a large extent by its ionic radius (0.98A) which is closer to that of Ca (0.99A) than to either K (1.33A) or Li (0.68A). Therefore Na is frequently associated with Calcium in silicate minerals rather than with the other alkali elements (Rosler and Lange, 1972).

Sodium values were calculated as oxide and its concentration ranges is from 1.62%-4.92%. Mean values for the rock groups are: 3.71% for the unaltered granite, 2.93% for altered granite, 2.60% for the mineralized granite, 2.81% for altered rhyolite and 3.34% for mineralized rhyolite. The mean values compare favourably with Clarke values of 3.08% and 2.99% for granite and rhyolite

respectively (Nockolds, 1954). The distribution pattern of Na_2O do not show variation in the unaltered rocks, but the values are generally depleted in the altered and mineralized zones, as a NW-SE trending zone on the surface, a narrow zone along the mineralized sheared zone/fractures in the drill core section D21 and 18C.

6.1.5 Potassium (K).

Potassium is a major element in most igneous rocks and petrographic classification is often defined from K concentrations or abundances of K-minerals.

Potassium values were converted to K_2O and the Clarke values for granite and rhyolite are 5.46% and 5.35% respectively (Nockolds, 1954).

Range of values of K_2O in all samples is 3.44%-7.65% and the rock groups have mean values as follows: unaltered granite 5.06%; altered granite 5.17%; mineralized granite 5.53%; altered rhyolite 4.80% and mineralized rhyolite 5.50%. The distribution pattern of K_2O in the surface samples and the sections are shown on Figs. 6.1, 6.2, 6.3 and 6.4. In the D20 section (Fig. 6.3) there is little or no variation of the K_2O values (averaging) about 5.0%. The mineralized part of the 18C drill core (Fig. 6.4) shows elevated values of K_2O , averaging about 7.0%, which is

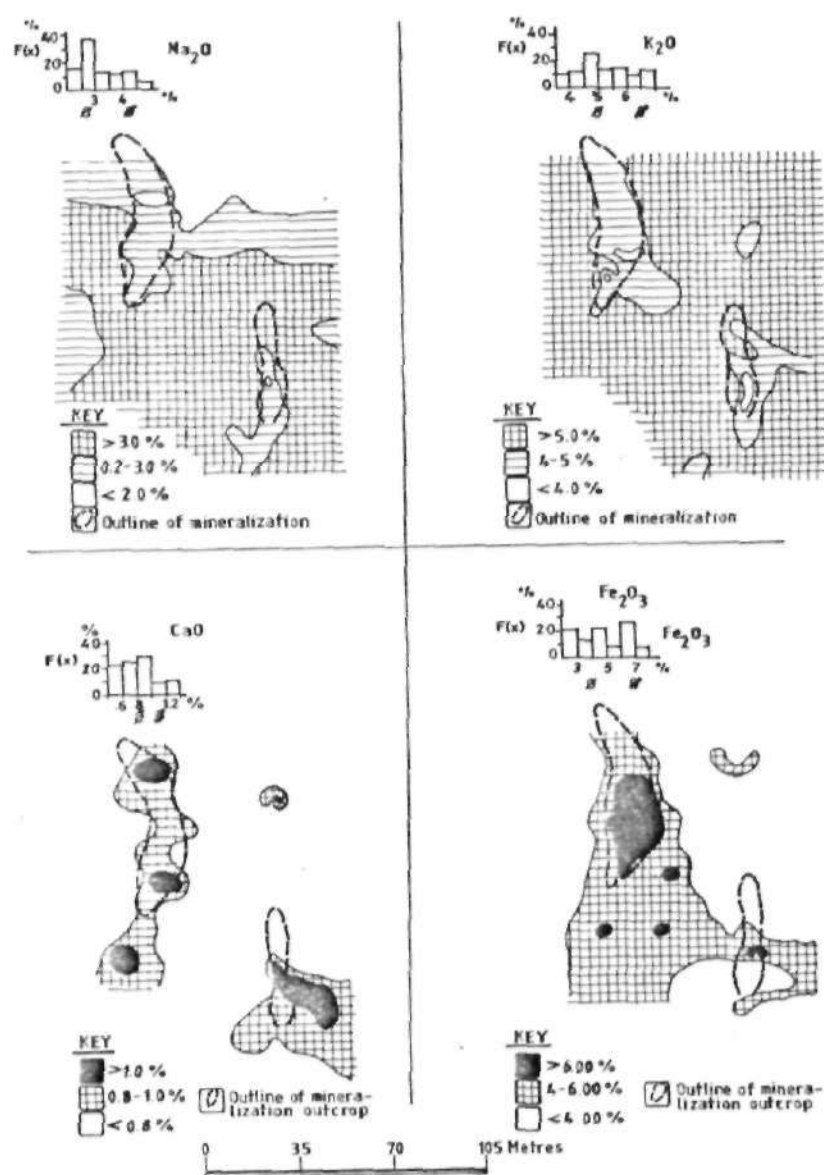


Fig.6.1. Distribution of Na₂O, K₂O, CaO and Fe₂O₃ in Mika uranium mineralization.

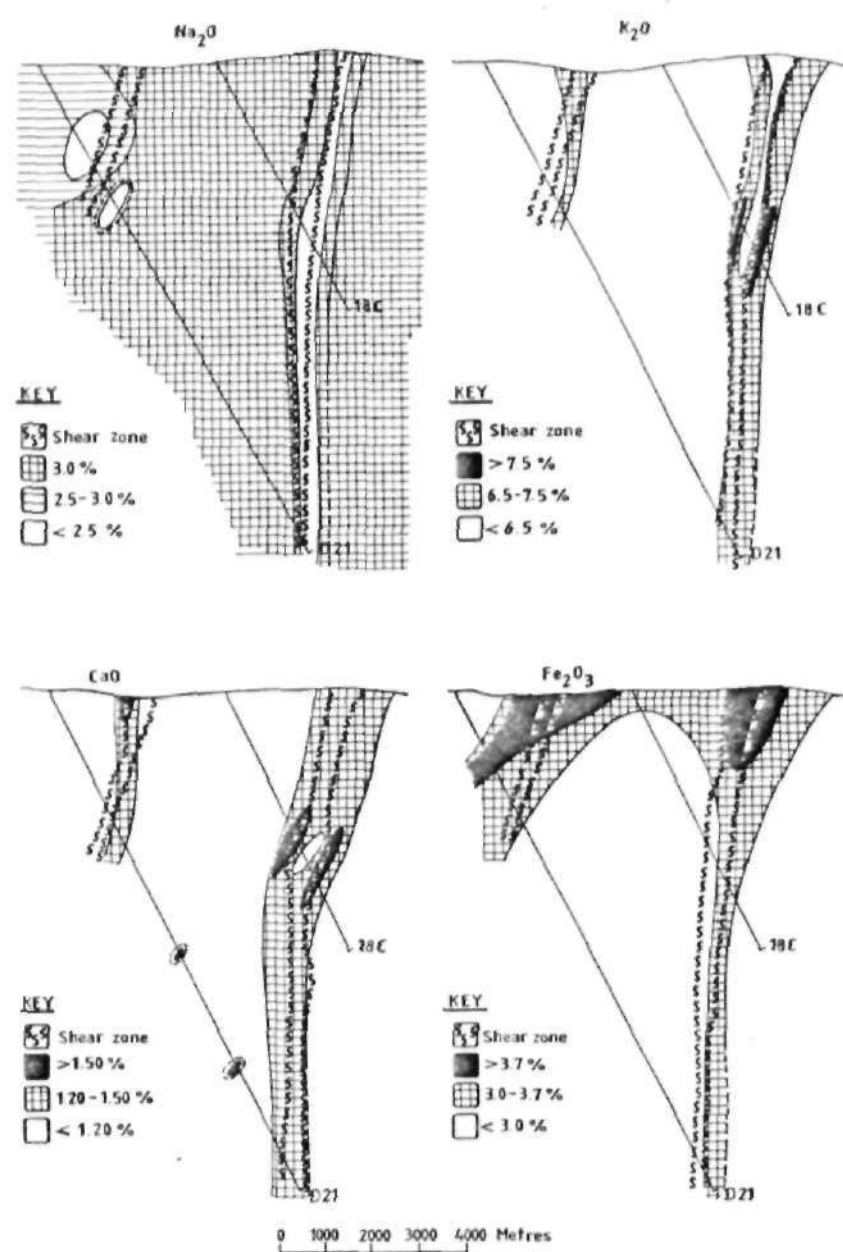


Fig.6.2. Distribution of Na_2O , K_2O , CaO and Fe_2O_3 through D21 and 18C drill core sections.

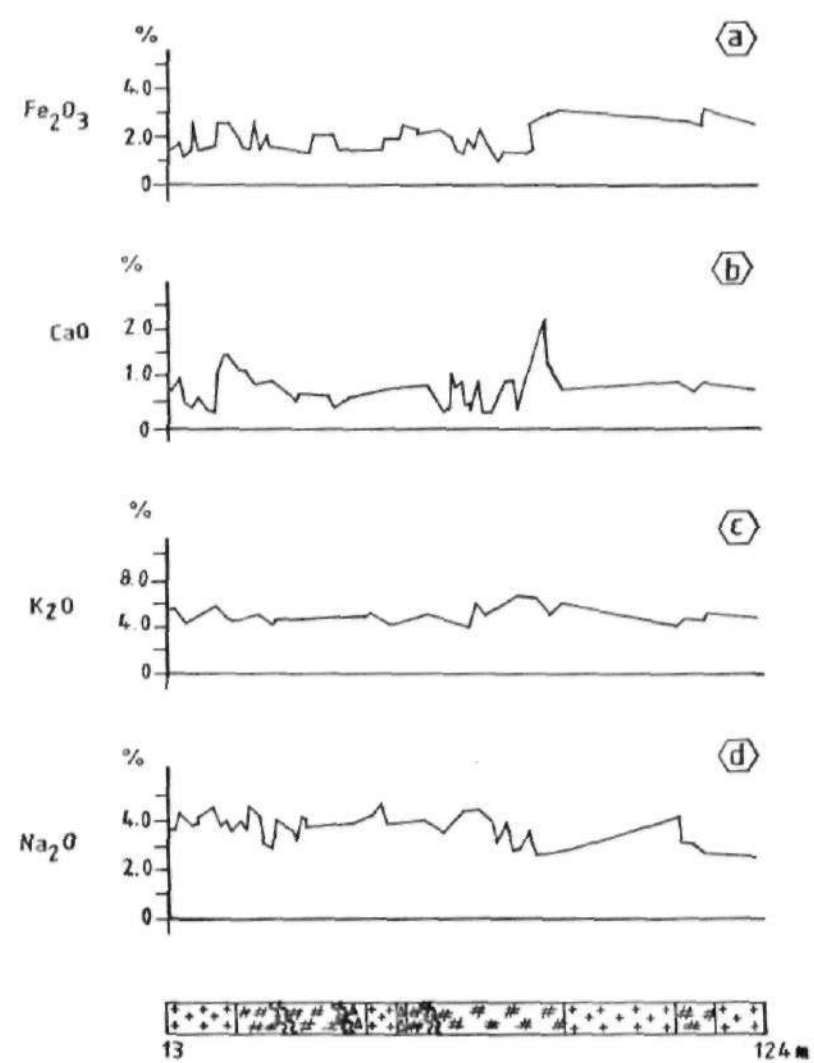


Fig.6.3. Distribution of a) Fe_2O_3 ; b) CaO ; c) K_2O ; and d) Na_2O in D20 drill core.

likely due to the introduction of K_2O by hydrothermal fluids in the altered and mineralized zones.

6.1.6 Manganese (Mn).

The Mn values were converted to the oxide. The range of values of MnO is 0.02%-0.17%. The rock groups have the same mean value of about 0.06% except the altered rhyolite with 0.05%. The distribution of MnO does not exhibit a particular pattern, which relates to alteration or mineralization.

6.1.7. Titanium (Ti).

The Ti values are expressed as oxide. The average content of Ti in igneous rocks is 0.44% (Taylor, 1964a). The content of TiO_2 ranges from 0.10% to 0.56% in all the samples. The unaltered granite has a mean average of 0.26%, the altered granite 0.27%, the mineralized granite 0.33%, altered rhyolite 0.29% and the mineralized rhyolite 0.28%. There is little variation in the average concentration of TiO_2 in the rock groups but its enrichment by a factor of more than two is found in some of the altered and mineralized samples.

The distributions of TiO_2 are shown on Figs. 6.5, 6.6, 6.7 and 6.8. The distribution does not show any remarkably variation in relationship either to the mineralization or to alteration features.

6.1.8 Phosphorous (P).

Phosphorous values were calculated to P_2O_5 . The Clarke values for granite and rhyolite are 0.18% and 0.07% respectively (Nockolds, 1954). The concentration range of P_2O_5 in all the samples is 0.03-0.99%.

Variations occur among the rock groups, the unaltered granite has a mean value of 0.13%; altered granite 0.17%; mineralized granite has a value of 0.60%; altered rhyolite 0.25% and mineralized rhyolite 0.24%. There is marked enrichment of P_2O_5 values in the mineralized granites/rhyolites when compared to the average values of the altered rocks. The distribution of P_2O_5 for both surface and core sample (Figs. 6.5, 6.6, 6.7 and 6.8) shows clearly higher values in the mineralized zones. Figs. 6.7 and 6.8 show relatively high background levels but still brings out clearly the mineralized parts, hematized silica veins in D20 and the mineralized fractures in 18C section.

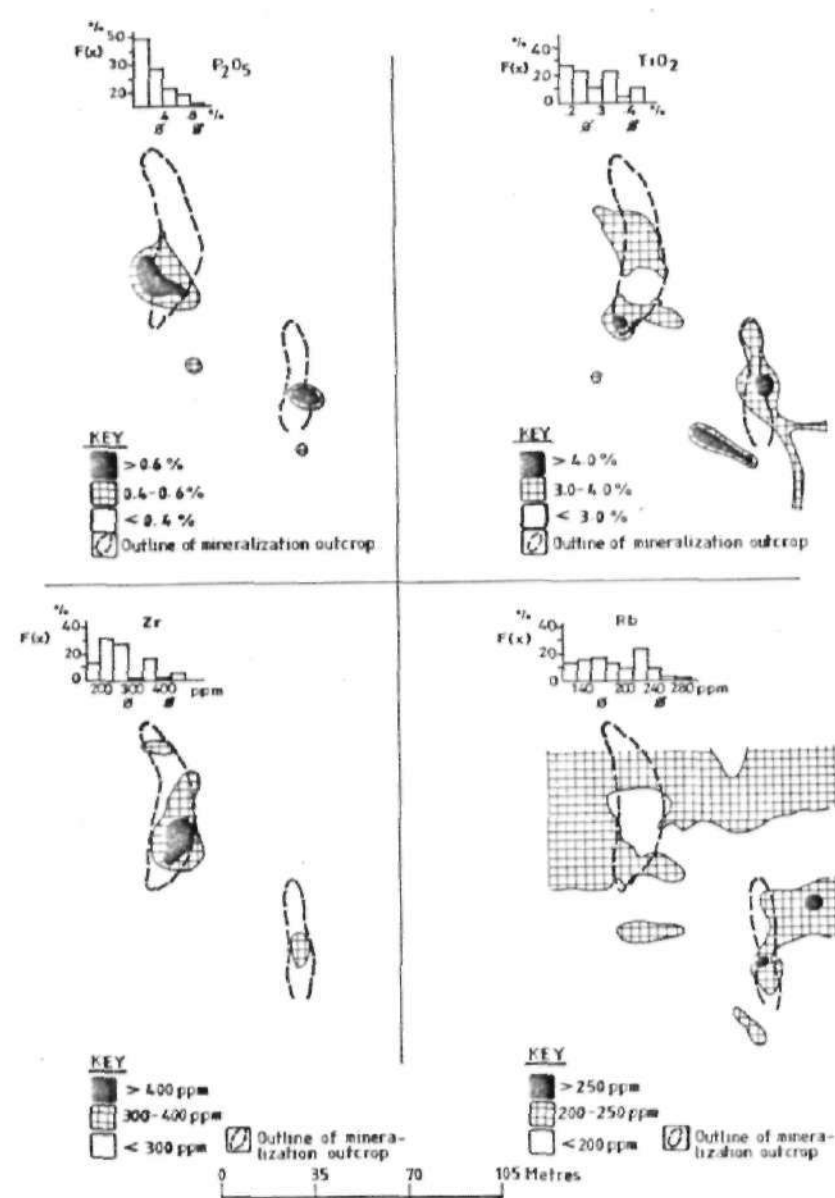


Fig. 6.5. Distribution of P_2O_5 , TiO_2 , Zr and Rb in Mika uranium mineralization.

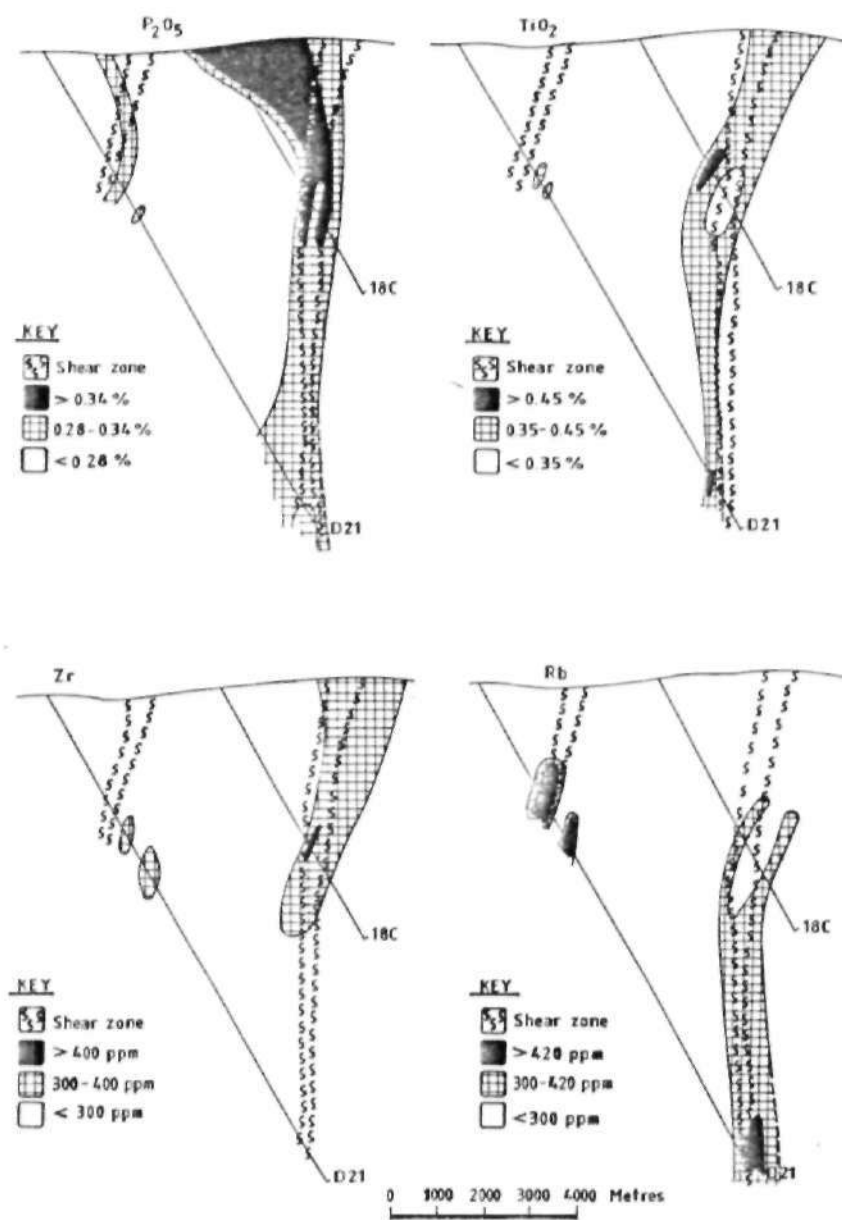


Fig. 6.6. Distribution of P_2O_5 , TiO_2 , Zr and Rb through D21 and 18C drill core sections.

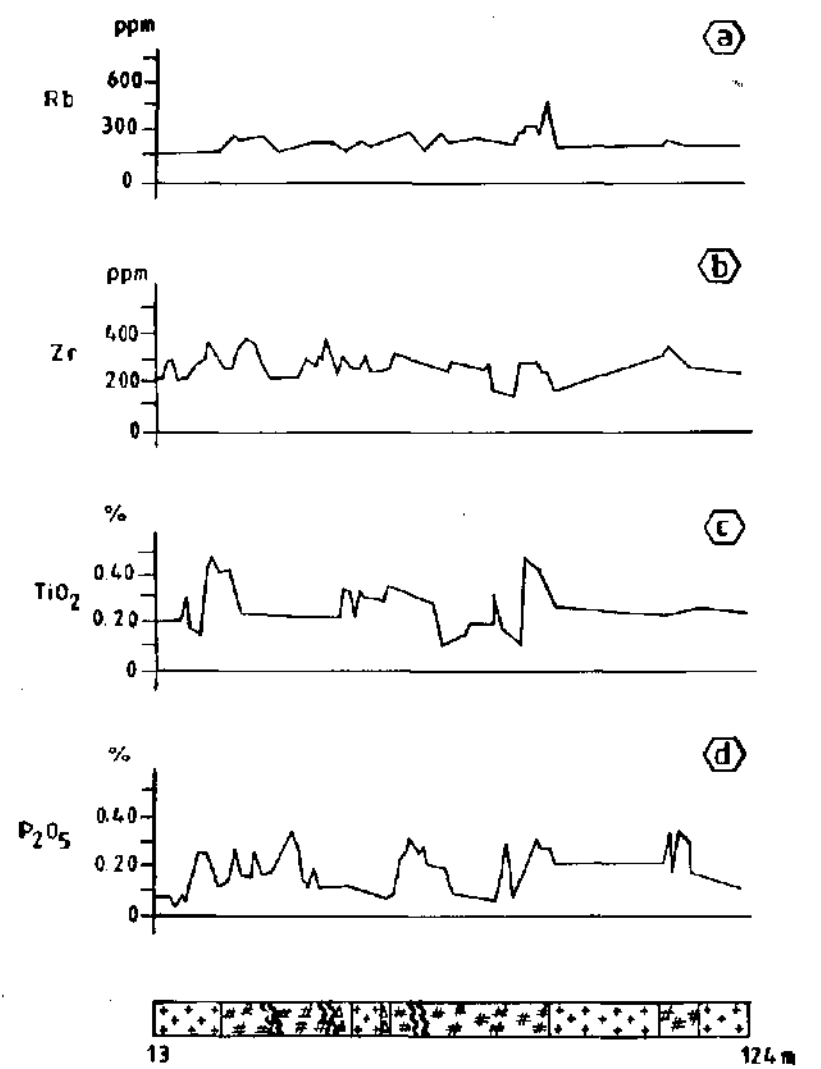


Fig.6.7. Distribution of a) Rb; b) Zr; c) TiO₂ , and d) P₂O₅ in D20 drill core .

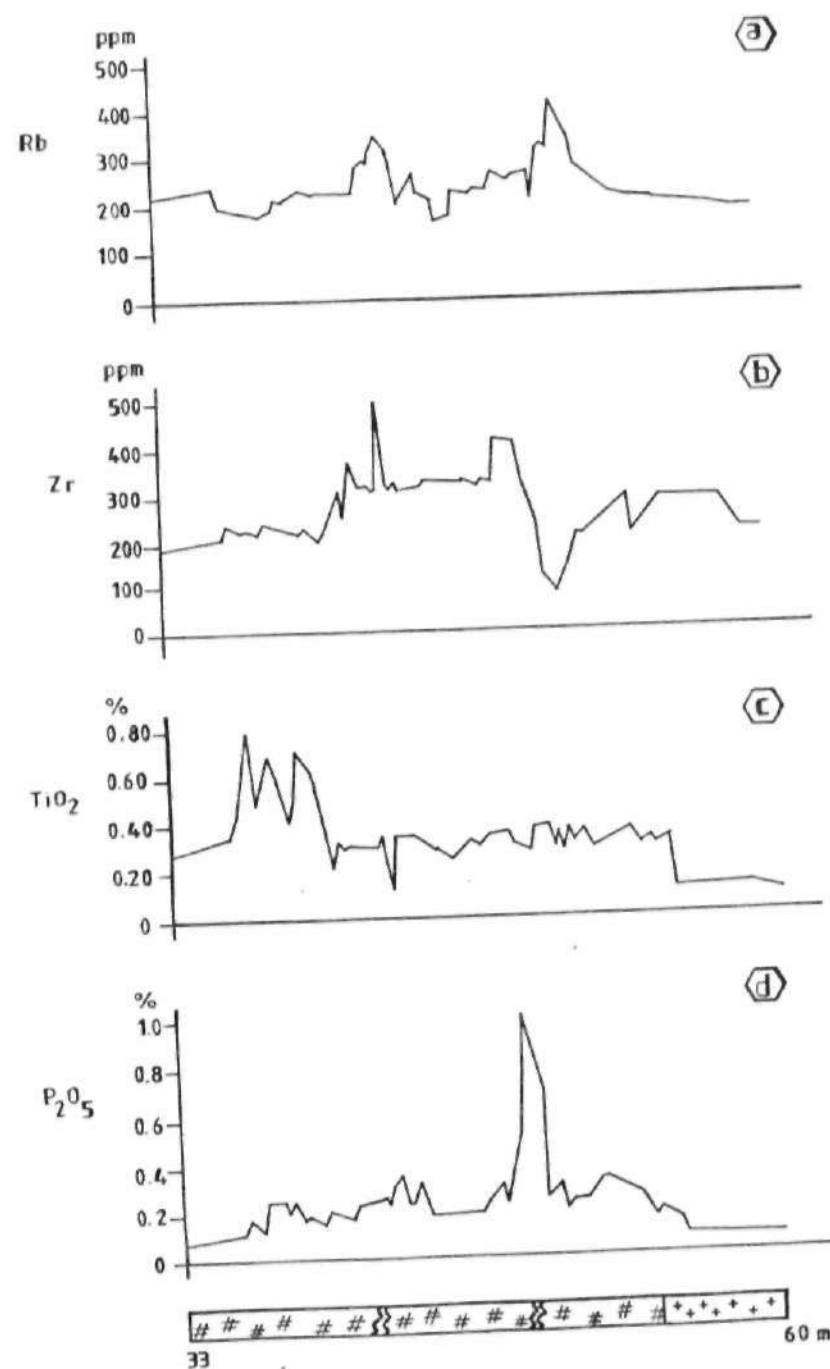


Fig. 6.8. Distribution of a) Rb; b) Zr; c) TiO₂; and d) P₂O₅ in part of 18C drill core.

6.2.2 Vanadium (V).

In granitic rocks, mica is an important host mineral for V (Evans, Jr. and Landergren, 1974) and the clarke value in granitic rocks is 40ppm (Vinogradov, 1962).

The V content for all the samples varies from 28-298ppm. The mean value varies within the rock groups as follows: unaltered granite 42.53ppm; altered granite 100.61ppm; mineralized granite 173.43ppm; altered rhyolite 102.60ppm and mineralized rhyolite 157.60ppm. High V coincides with uranium mineralization for both the surface and the primary mineralization (Figs. 6.13, 6.14, 6.15 and 6.16). The two centres of mineralization on the surface feature the highest vanadium values. The altered zones and mineralized parts of the sub-surface also exhibit the highest values of V.

6.2.3 Chromium (Cr).

As Cr may be found in minerals containing ferric iron (hornblende and biotite) it would decrease along with Fe content. The clarke value of Cr in granitic rocks is 25ppm (Vinogradov, 1962). The range of concentration for the samples is 25-99ppm. Chromium mean values in the rock groups show little variations and are as follows: unaltered granite 68.71ppm; altered granite 57.07ppm; mineralized

granite 29.05ppm; altered rhyolite 67.65ppm and mineralized rhyolite 51.21ppm. There appears to be depletion of Cr in the altered and mineralized rock groups.

6.2.4 Cobalt (Co).

Like Sc, Co occurs in ferromagnesian silicates. The bulk of the element is found in the olivines and pyroxenes. In granitic rocks, Co concentration is normally low, being depleted in rocks of increasing silica content. The clarke value of Co in granitic rocks is 5ppm (Vinogradov, 1962).

The concentration range of Co in all the samples is 4-36ppm. The mean values for the rock groups are: unaltered granite 8.71ppm; altered granite 29.45ppm; mineralized granite 19.58ppm; altered rhyolite 12.60ppm and mineralized rhyolite 16.31ppm.

Cobalt values in the samples present no meaningful variation which can be used to discriminate the rock groups or the alteration types or the mineralized from unmineralized rocks.

6.2.5 Nickel (Ni).

The Ni content varies between 10-41ppm. The clarke value for nickel in granite is 8ppm (Vinogradov, 1962).

The mean Ni content for the various groups are as follows:
unaltered granite 13.02ppm; altered granite 19.21ppm;
mineralized granite 22.18ppm; altered rhyolite 15.39ppm and
mineralized rhyolite 18.68ppm.

The distribution of Ni does not exhibit any meaningful trend and like cobalt can not be used to distinguish the unaltered, altered and mineralized rocks.

6.2.6 Copper (Cu).

The Cu values for all the samples vary from 16-107ppm. The clarke values for Cu in granite and rhyolite are 20ppm (Vinogradov, 1962) and 10ppm (Ewart, 1968) respectively. Mean value for the unaltered granite is 21.95ppm; altered granite 33.55ppm; mineralized granite 55.41ppm; altered rhyolite 51.76ppm and mineralized rhyolite 42.68.

The plots of Cu for surface and core sections show trends that are similar to uranium though the former exhibits high background levels (Figs. 6.9, 6.10, 6.11 and 6.12). The hematized silica veins in the D20 section record the highest values (Fig. 6.11) and the mineralized fractures in 18C section (Fig. 6.12) also have higher values than the unaltered and altered part of the section.

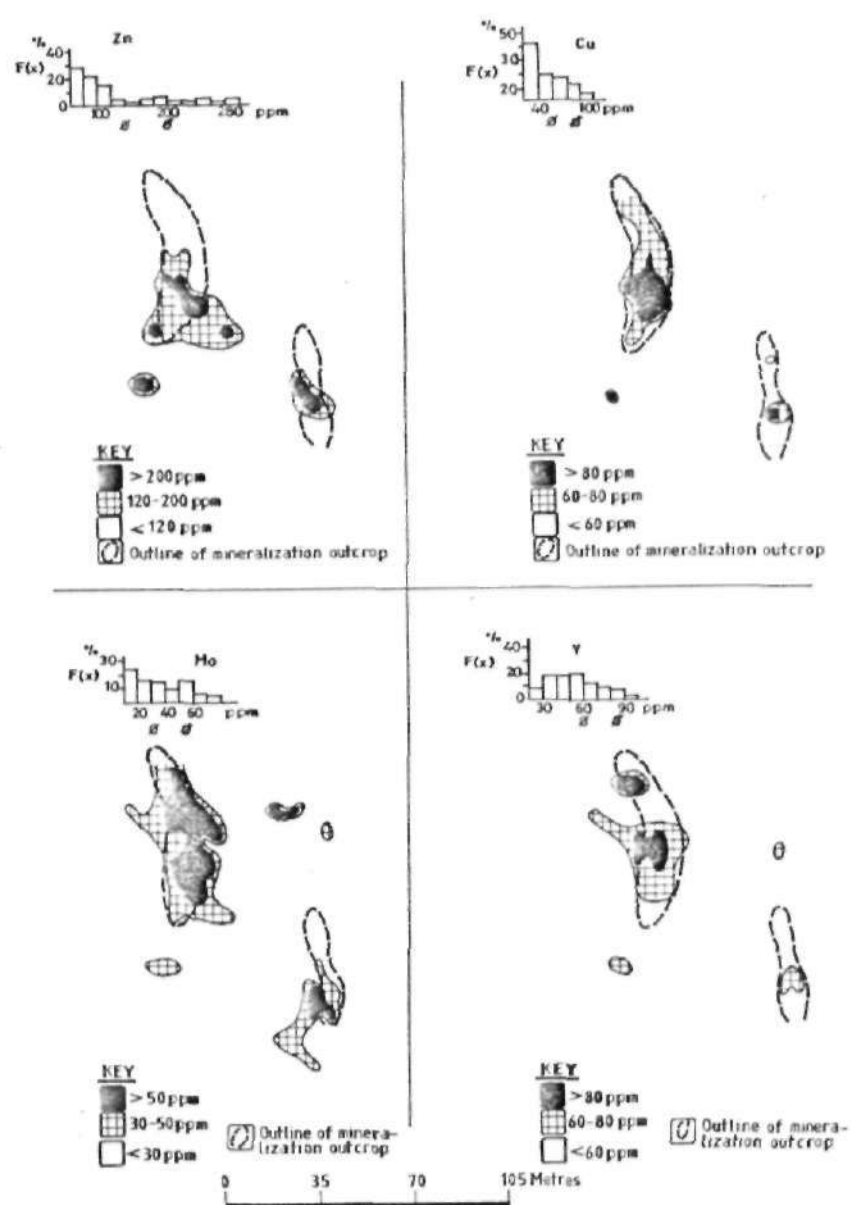


Fig. 6.9. Distribution of Zn, Cu, Mo and Y in Mika uranium mineralization

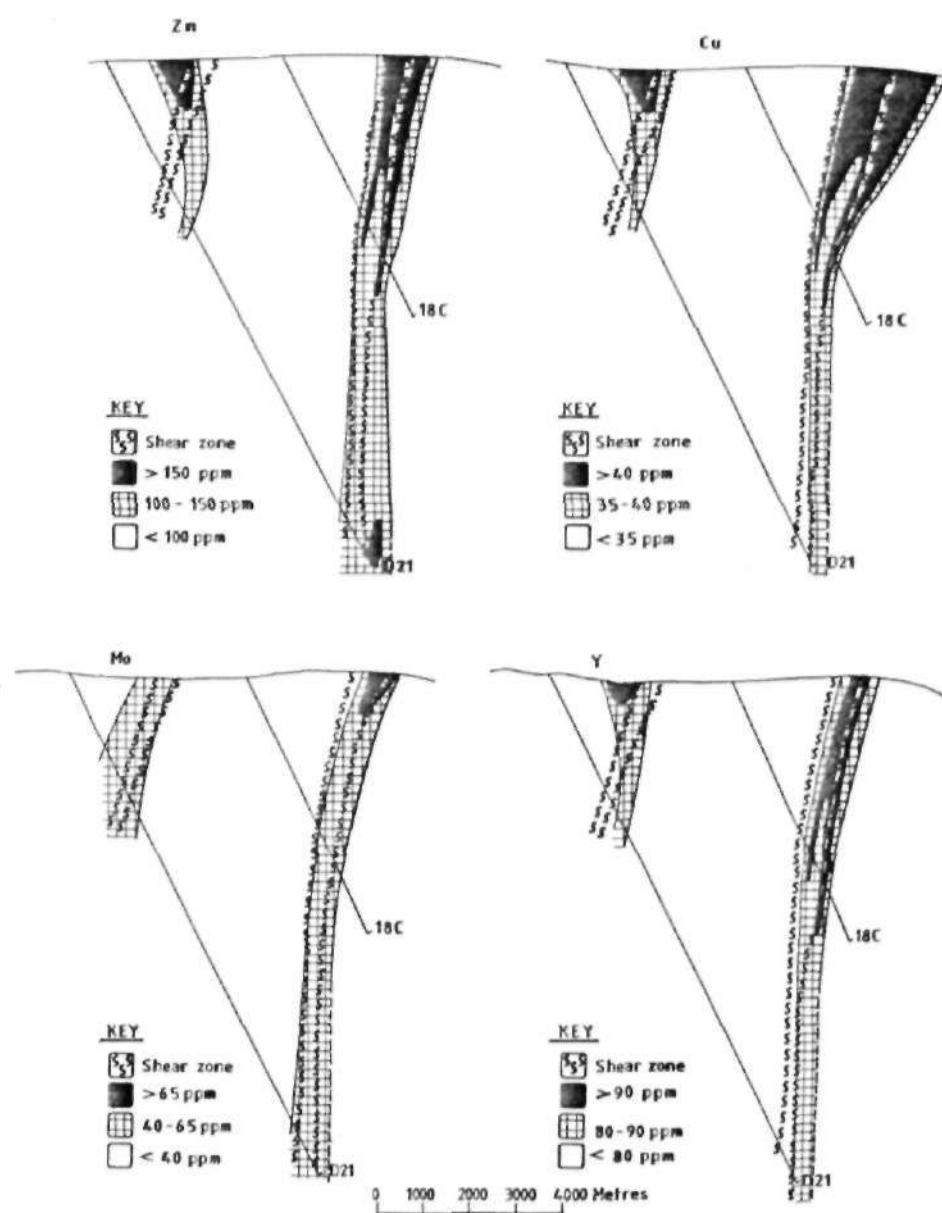


Fig.6.10. Distribution of Zn, Cu, Mo and Y through D21 and 18C drill core sections.

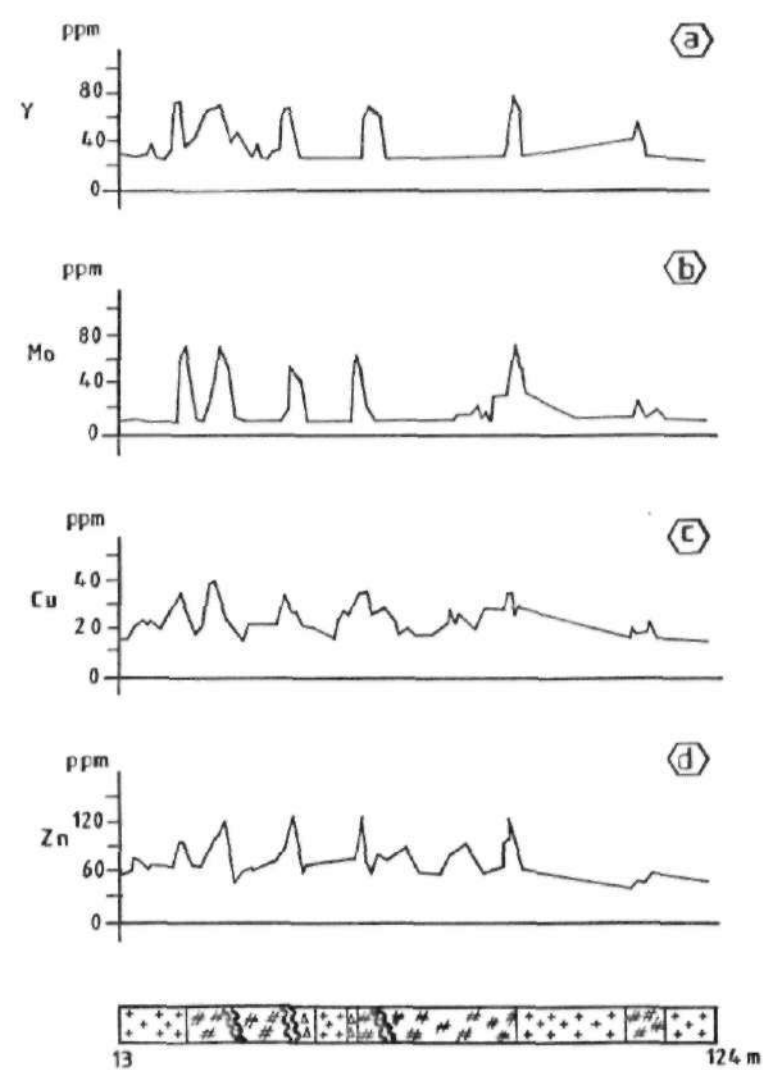


Fig. 6.11. Distribution of a) Y ; b) Mo ; c) Cu ; and d) Zn in D20 drill core .

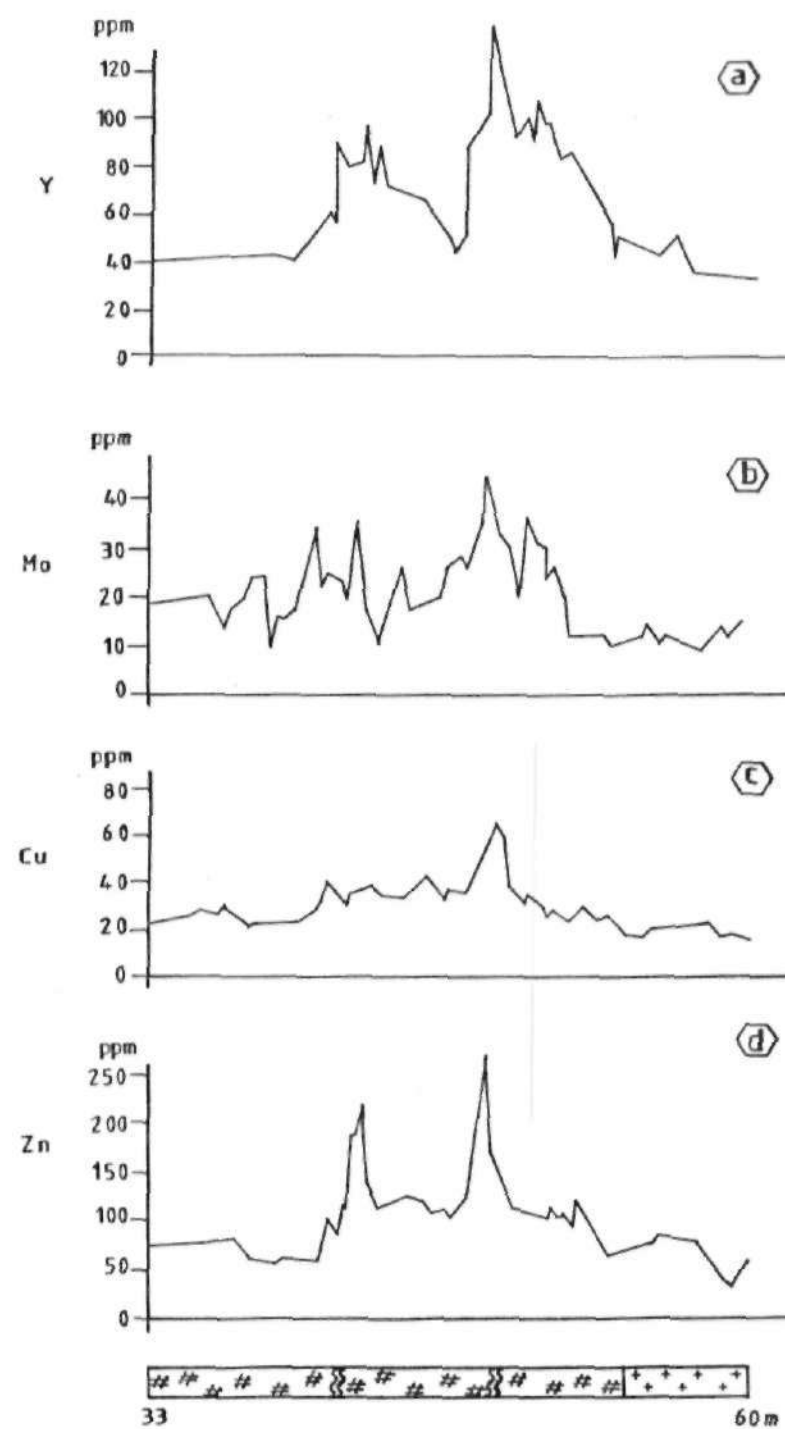


Fig. 6.12. Distribution of a) Y; b) Mo; c) Cu; and d) Zn in part of 18C drill core.

6.2.7 Zinc (Zn).

Zinc shows the tendency to be predominantly incorporated in certain structural positions of silicates and oxides. In this position Zn replaces ferrous iron and magnesium, favouring those with coordination numbers 4 and 6; with the later only if certain ligands like OH^- are available (Wedepohl, 1953).

The Zn abundance in granitic rocks is controlled by biotite and/or amphibole content; thus light coloured granitic rocks often have lower Zn concentration than dark varieties (Wedepohl, 1953).

The clarke value for zinc in granitic rocks is 60ppm (Vinogradov, 1962). Zinc content in the rocks investigated varies from 46-379ppm. The unaltered granite has a mean value of 82.74ppm; altered granite 97.91ppm; mineralized granite 239.16ppm; altered rhyolite 111.34ppm and the mineralized rhyolite 154.18ppm. Zinc shows high background values for both the surface and sub-surface distributions, but still the areas of mineralization are reflected by anomalous values. The three hematized silica veins in the D20 section (Fig. 6.11) are reflected by higher values of Zn, so also are the mineralized fractures of 18C (Fig. 6.12). The distribution pattern of Zn in surface and drill core samples is similar to those of Cu, Mo, Y (Figs. 6.9,

6.2.7 Zinc (Zn).

Zinc shows the tendency to be predominantly incorporated in certain structural positions of silicates and oxides. In this position Zn replaces ferrous iron and magnesium, favouring those with coordination numbers 4 and 6; with the later only if certain ligands like OH^- are available (Wedepohl, 1953).

The Zn abundance in granitic rocks is controlled by biotite and/or amphibole content; thus light coloured granitic rocks often have lower Zn concentration than dark varieties (Wedepohl, 1953).

The clarke value for zinc in granitic rocks is 60ppm (Vinogradov, 1962). Zinc content in the rocks investigated varies from 46-379ppm. The unaltered granite has a mean value of 82.74ppm; altered granite 97.91ppm; mineralized granite 239.16ppm; altered rhyolite 111.34ppm and the mineralized rhyolite 154.18ppm. Zinc shows high background values for both the surface and sub-surface distributions, but still the areas of mineralization are reflected by anomalous values. The three hematized silica veins in the D20 section (Fig. 6.11) are reflected by higher values of Zn, so also are the mineralized fractures of 18C (Fig. 6.12). The distribution pattern of Zn in surface and drill core samples is similar to those of Cu, Mo, Y (Figs. 6.9,

6.10, 6.11 and 6.12) and to Pb , V and importantly to that of U. (Figs. 6.13, 6.14, 6.15 and 6.16)

6.2.8 Arsenic (As).

In rock forming minerals As (ionic radii As^{3+} 0.58 and As^{5+} 0.46Å) can probably substitute for Si^{4+} (0.43), Al^{3+} (0.51), Fe^{3+} (0.64) and Ti^{4+} (0.68Å).

The global average content of As in granites of 1.6ppm does not differ much from that of basalts and gabbros with averages of 1.5 and 1.4ppm respectively (Onishi and Sandell, 1955). Arsenic values in the investigated samples vary from 2-16ppm. The mean values for the various rock groups are higher than the global average value for granites and are as follows: unaltered granite 5.20ppm; altered granite 5.42ppm; mineralized granite 5.94ppm; altered rhyolite 5.45ppm and mineralized rhyolite 6.69ppm. Arsenic distribution also exhibit no meaningful pattern in relation to rock types and the mineralization.

6.2.9 Selenium (Se).

Selenium has little lithophile tendency and silicates of Se are not known, instead it has strong chalcophile tendencies and thus its content in igneous rocks is low (Fischer and Lutwein, 1972). Selenium content in the investigated rocks

varies from 1-8ppm. The mean values for the various rock groups are the unaltered granite 3.20ppm; the altered granite 2.80ppm; 2.86ppm; the mineralized granite 4.51ppm the altered rhyolite 4.93ppm and the mineralized rhyolite. 2.86ppm The distribution of Se does not exhibit any meaningful trend in relation to the mineralization or the rock types both the surface and core samples.

6.2.10 Rubidium (Rb).

Though there are similarity in the geochemical characteristics of K and Rb ions as illustrated by the fact that the latter is always incorporated in the K-minerals, it still does not form minerals of its own. It follows that the most important Rb containing minerals are the micas and the K-feldspars and most of Rb in the crust is contained in these minerals (Heir and Billings, 1970).

K/Rb ratio in most rocks lies between 160 and 300 (Heir and Adams, 1964). Variation in K/Rb ratios outside these limits probably indicate abnormal values that are related to geological processes like alterations.

Rubidium content in the investigated samples range from 109-578ppm. The average Rb values in the investigated rock groups are as follows: unaltered granite 189.10ppm; altered granite 236.76ppm; mineralized granite 228.19ppm; altered

rhyolite 254.59ppm and mineralized rhyolite 232.30ppm.

The Rb contents in the investigated samples generally display the usual coherence with K, although there are some anomalously high values. The K_2O/Rb ratios of the samples are high (with range of 188 to 264) compared to the continental average of 170 (Erlank, 1968).

6.2.11 Strontium (Sr).

The distribution of Sr is affected to a certain extent by the presence of Ca which has an ionic radius of 0.99A, very close to that of Sr of 1.12A. The global average value for granites is 300ppm (Vinogradov, 1962). In the rock samples investigated the value of Sr varies from 311-1400ppm. The mean Sr values for the rock groups are: 451.03ppm for the unaltered granite; 786.58ppm for the altered granite; 1083.76ppm for the mineralized granite; 1086.08ppm for the altered rhyolite and 957.64ppm for the mineralized rhyolite.

Strontium values for the rock groups were plotted against Rb values (Fig. 21a). Strontium is incorporated in Ca-minerals and Rb in K-minerals and hence the Sr/Rb ratio amplifies any loss or increase in K or loss of Ca in hydrothermal alteration zones. Ore zones characterized by hydrothermal alterations such as sericitization,

silicification and chloritization commonly exhibit losses in CaO (and hence Sr) and gains in K₂O (and hence Rb) in the wall rocks (Plimer and Elliot, 1979). The Sr/Rb ratio decreases with increasing intensity of alteration and is most intense, with the lowest ratios where mineralization is present in the granites, as in Fig. 6.21a. Strontium values for the rock groups were also plotted against uranium values (Fig. 6.21b). There is a small linear relationship in the diagram for the unaltered and altered granite groups, with increase in Sr values there are corresponding increase in U values. No distinct patterns can be observed for the altered rhyolite and mineralized rhyolite and granite groups.

6.2.12 Yttrium (Y).

Yttrium is associated in all rocks with the REE because of similar chemical behaviour. In granitic rocks, Y is mainly in mafic rock-forming minerals, probably substituting for Ca²⁺ (ionic radius 0.99Å). Yttrium and other heavy REE form complexes and are transported in alkali, halogen and carbon dioxide rich hydrothermal fluids and mineralizations formed from such fluids may have high concentration of Y and higher ratios of Y to light REE than granites (Roberts, 1972).

The clarke value for Y in granites is 34ppm (Vinogradov, 1962). Concentration range of Y in the rock samples is 31-1400ppm. The mean Y concentration in the investigated rock groups is as follows: unaltered granite 34.60ppm; altered granite 56.44ppm; mineralized granite 108.40ppm; altered rhyolite 72.04ppm and mineralized rhyolite 64.81ppm. There is an increasing trend for Y distribution from the unaltered granite through the altered to mineralized granite. Its content in mineralized rhyolites are lower than the unmineralized variety. Yttrium values in the rock groups are plotted against uranium values (Fig. 6.22a and b) to illustrate their distributions patterns. For the unaltered and altered granite and rhyolite groups, there is a linearity in the relationship; with increase in Y there is corresponding increase in U values up to 100ppm. This linear relationship is not observed for uranium content above 100ppm (Fig. 6.22a). For the mineralized rhyolites and granites (Fig. 6.22b) there is no corresponding increase in Y content with appreciably increase in the uranium content.

6.2.13 Zirconium (Zr).

Zirconium is an element that is normally strongly concentrated in residual silicate melts, such that the most

silicic differentiates contain the most Zr (White and Martin, 1980). Zircon the most common Zr mineral is present as an accessory mineral in all types of igneous rocks particularly the more silicic types.

The global mean value of Zr for the granitic rocks is 200ppm (Vinogradov, 1962). Zr values in the investigated rock samples range from 97-498ppm. Average Zr content mean values in the rock groups are as follows: 257.08ppm for the unaltered granite; 238.51ppm for the altered granite; 332.15ppm for the mineralized granite; 279.72ppm for the altered rhyolite and 316ppm for mineralized rhyolite. Even though Zr is not a very mobile element there seems to be an appreciable increase of Zr with both altered and mineralized rocks.

Zirconium values for the five rock groups were plotted against U to show interdependence or otherwise (Fig. 6.23). The plot exhibit a weak linear trend of Zr with increasing U. Thus the mineralized rhyolite and granite groups have slightly higher Zr/U ratios.

6.2.14 Molybdenum (Mo).

At high temperatures Mo has a high affinity for Fe and to an extent for Ni, Ti, Mn and Mg. This suggest that Mo would

tend to concentrate in the Fe-Ni core of the earth (Mason, 1966). Mo has also a high affinity for sulphur and during hydrothermal crystallization, sulphides of other metals would only form after all the Mo has formed molybdenite (MoS_2). At markedly lower temperatures, particularly in the absence of sulphur, Mo ions show a significant affinity for Ca and Pb ions (Enzmann, 1972).

The clarke value of Mo for granite and granodiorite is 1ppm (Vinogradov, 1964). Molybdenum content in the investigated rocks varies from 7-74ppm. The unaltered granite has a mean value of 23.08ppm; altered granite 42.96ppm; mineralized granite 36.90ppm; altered rhyolite 44.19ppm and mineralized rhyolite 51.13ppm.

The distributions of Mo are shown on Figs. 6.9, 6.10, 6.11 and 6.12. Molybdenum distribution is sympathetic to the pattern of mineralization for both the surface and sub-surface samples. In Fig. 6.11, the distribution clearly outlines the zones of mineralization in D20 section while for Fig. 6.12 the zones are outlined for 18C section, but with higher background.

6.2.15 Lead (Pb).

The occurrence of Pb in magmatic rocks is governed primarily by its relationship to K. The Pb^{2+} has an ionic

radius of 1.20A, slightly smaller than that of K^+ (1.33A) and it is as a substitute for K that Pb is most abundant (Wampler, 1972). Micas and K-feldspars have, on the average 25-30ppm Pb (Taylor, 1964b). Lead may also occur in appreciable concentration in minerals with low K content, substituting for Ca (Ca^{2+} , 0.99A) in plagioclase, amphiboles and pyroxenes (Ahrens, 1964).

The concentration range of Pb in the rock samples is from 20-1560ppm. Unaltered granite has a mean value of 31.36ppm; altered granite 92.39ppm; mineralized granite 1002.27ppm altered rhyolite 81.47ppm and mineralized rhyolite 415.12ppm.

The distribution of Pb is clearly similar to that of U for both on the surface (Fig. 6.13) and in the sub-surface (Figs. 6.14, 6.15 and 6.16) samples. The dispersion curves of U, Fig. 6.15 for D20 section and 6.16 for part of 18C section clearly outlines the zones of mineralization with very low background levels.

Further relationship of Pb to U is shown in Fig. 6.24a and b, which is a plot of Pb-U. The plot shows linear relationship of Pb and U distribution values most especially in the altered and mineralized samples which indicates that the high values of Pb in the samples is most likely to be radiogenic.

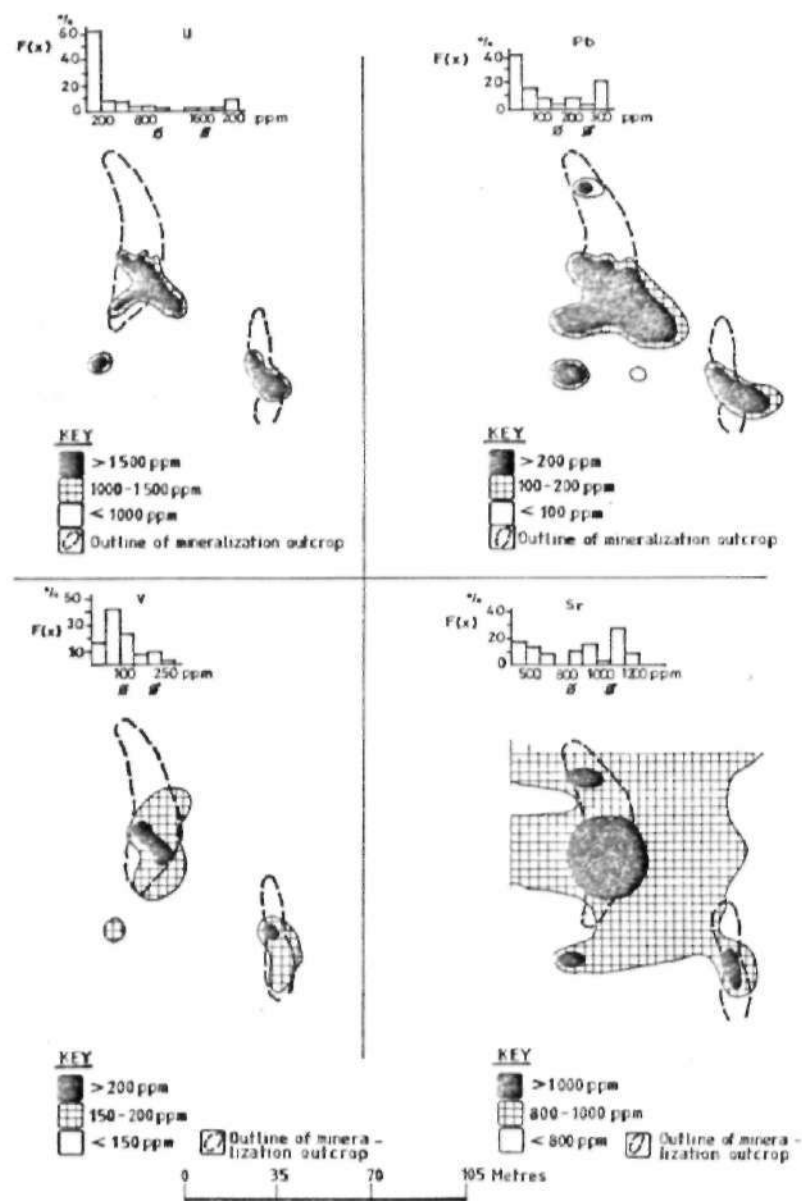


Fig.6.13. Distribution of U, Pb, V and Sr in Mika uranium mineralization.

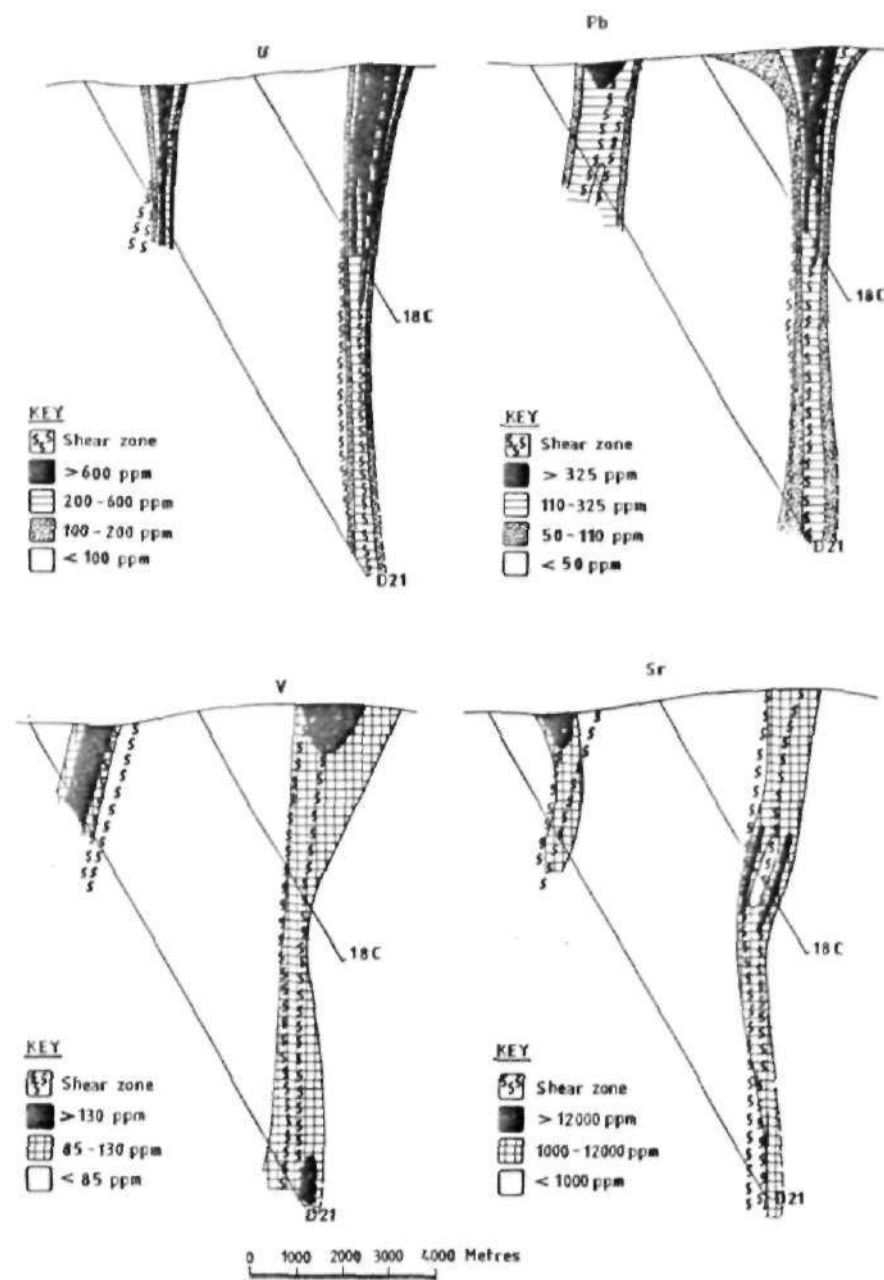


Fig. 6.14 Distribution of U, Pb, V and Sr through D21 and 18C drill core sections.

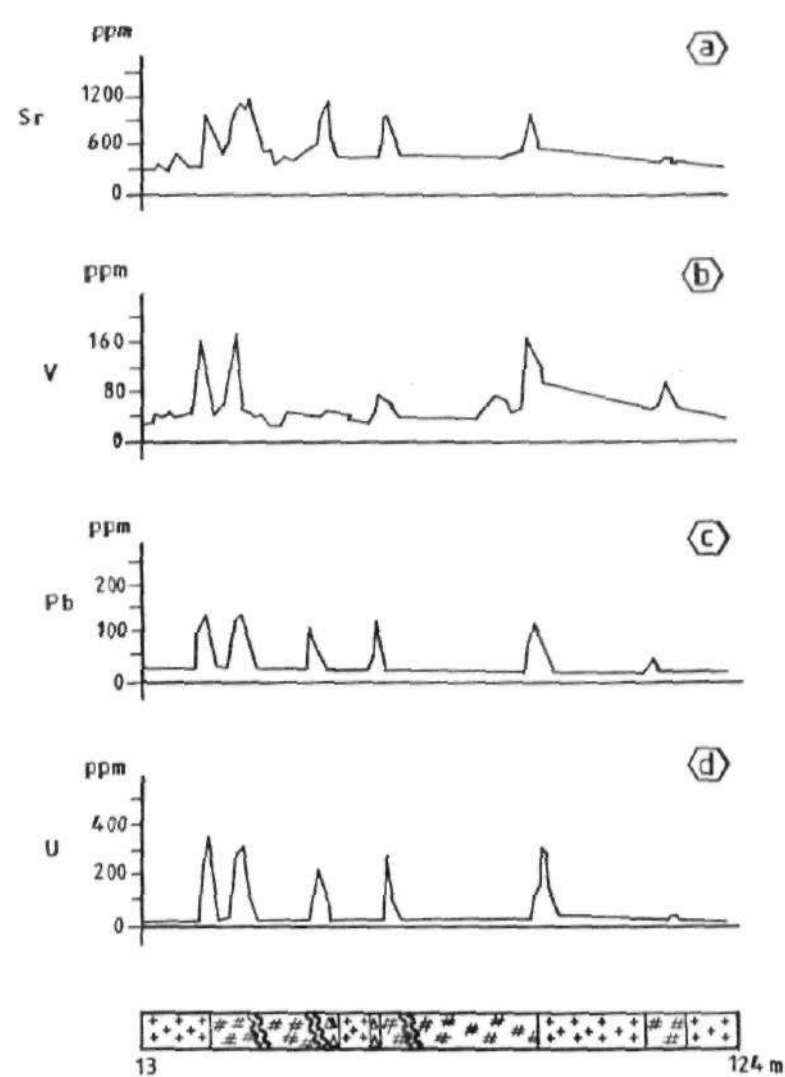


Fig. 6.15. Distribution of a) Sr; b) V; c) Pb; and d) U in D20 drill core.

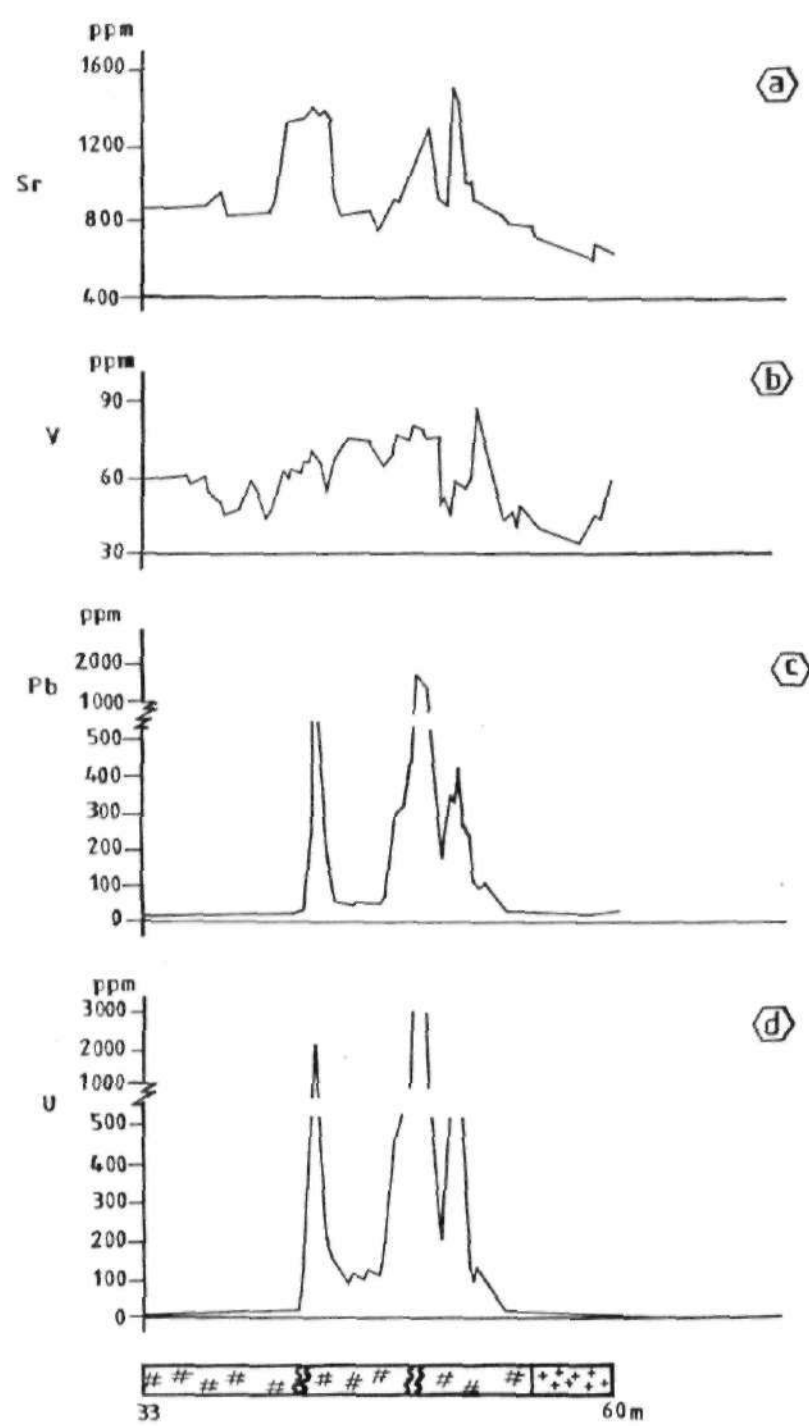


Fig. 6.16. Distribution of a) Sr; b) V; c) Pb; and d) U in part of 18C drill core.

6.2.16 Uranium (U) geochemistry.

In nature U occurs in the tetravalent (4^{+4}) and in the hexavalent (6^{+6}) state; in most subsurface environments U is present as U^{+4} , because the U^{+6} state is stable only under oxidizing conditions. The combination of the relatively large size and high charge of U^{+4} prevents it from entering the crystal lattices of the major rock-forming minerals except in trace amounts; however, significant quantities of U are found in accessory minerals such as thorite, allanite, xenotime, zircon, fluorite, apatite and barite.

Much of U is loosely held; this fraction of U probably occurs in films coating grains of rock-forming minerals and can easily be leached out by dilute acids (Larsen et. al., 1956 and Szalay and Samsoni, 1969). U^{+4} is readily converted to U^{+6} under oxidizing conditions. U^{+4} is readily converted to U^{+6} under oxidizing conditions. Leaching of U from weathered outcrops is rapid and enhanced by the formation of complex uranyl ions with carbonate and sulphate ions (Garrels and Larsen, 1959). Uranium can be precipitated efficiently from oxidizing solutions by reduction. In nature reduction is most frequent due to the presence of sulphide, ferrous iron, carbonaceous matter or hydrocarbons. Uranium can also be removed from aqueous

solutions by adsorption on clays, organic matter and Iron hydroxides (Rich et. al., 1997).

The clarke value of U in the crust is 2ppm, in granites 4ppm (Vinogradov, 1962). The concentration range of U in the investigated samples is 4-7961ppm.

The mean content of U in the various rock groups is as follows: unaltered granite 10.35ppm; altered granite 113.66ppm; mineralized granite 5970.96ppm; altered rhyolite 105.99ppm and mineralized rhyolite 1365.06ppm.

The distribution pattern of U is shown on Fig. 6.13 for the surface samples and Figs. 6.14, 6.15 and 6.16 for the sub-surface samples. For the surface samples the mineralization is clearly outlined by two zones: in the altered rhyolite and the sheared granite bodies. The distribution in the sub-surface samples relates very well with the sheared and altered zones (Figs. 6.14, 6.15 and 6.16). The U distribution in the altered and mineralized part of 18C section was further compared to the distributions of Pb and Zn in Fig. 6.17. The background for Zn is about 60ppm, with peak values of greater than 250ppm corresponding with the very high Pb and U values in the mineralized fractures. Zn showed wider halo compared to both U and Pb. The Pb distribution pattern depicts significantly the pattern of U.

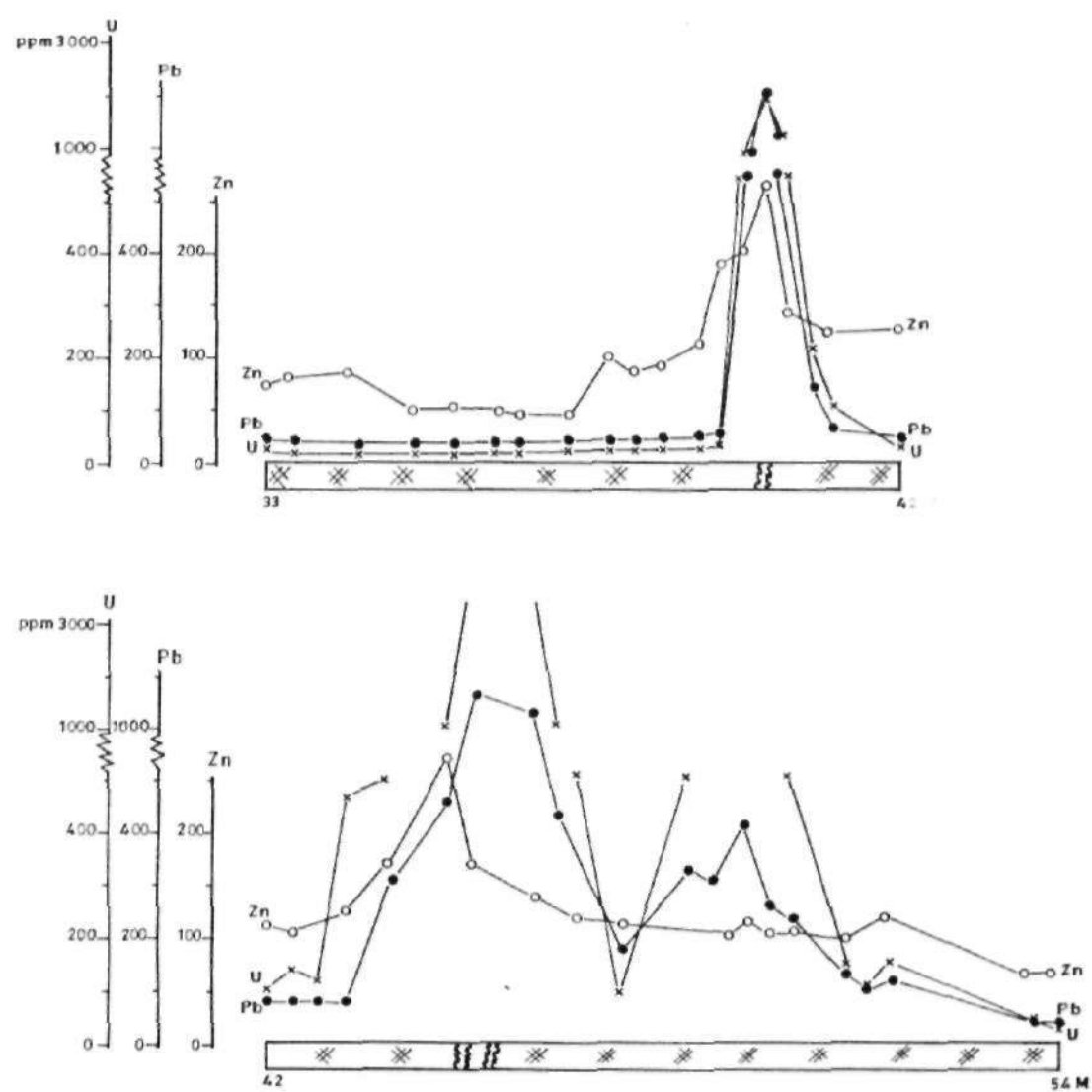


Fig. 6.17. Comparative distributions of Zn, Pb and U in part of 18 MC drill core.

6.3 General pattern in the distribution of the elements.

6.3.1 Major elements and minor elements.

Diagrams (Q-P, A-B, K_2O-Na_2O) were drawn from the concentration of the major elements in the samples to characterize them into rock typology, alteration types and possible effects of mineralization and other chemical controls.

The diagrams involves two or three parameters representing linear combination of the major elements calculated in millications as proposed by Wang and Jiashu, 1980. The calculation of the parameters in millications leads to the same weight being given to to all the elements independently of their atomic mass.

The samples were first characterized in the "typologic" (Q-P) and "characteristic minerals" (A-B) diagrams of Debon and Le Fort, 1983 (Figs.6.18 and 6.19).

The samples correspond to peraluminous leucogranites and the compositions are similar to that of the two mica granites of the French Central massif (Cuney, et. al., 1989). Leucogranites are defined as containing less than 7.5 vol.% biotite (Debon and Le Fort, 1983). Hydrothermal alteration in form of K-metasomatism is exhibited by some samples, dominantly the altered and mineralized (Fig.

6.18). Argillic alteration is also indicated in the A-B diagram (Fig. 6.19) by high values of the A parameter (decrease of alkali content in relation to alumina) for the mineralized rhyolite samples.

Some other alterations of the rock groups are explained by the plot of K_2O-Na_2O (Fig. 6.20). The diagram indicates markedly K-feldspathization of most of the samples, most prominently the altered and mineralized groups. Some altered and mineralized granites plot in the field of argilization. None of the samples shows any Na-feldspathization.

Among the major elements, the distribution patterns of Fe_2O_3 , CaO , Na_2O , K_2O and P_2O_5 show some relationships to the mineralization. The two centres high Fe_2O_3 , CaO and P_2O_5 concentrations on the surface relates very well with the pocket-like occurrence of the mineralization. Similarly in the core sections, the high values of these elements are related to the mineralized fractures. Na_2O values are generally depleted in the altered and mineralized zones and low concentration of Na_2O define a narrow zone along the mineralized fractures in the drill core section of 18C and D21. K_2O shows elevated values in mineralized part of 18C drill core section which is likely due to the introduction of K_2O by hydrothermal fluids.

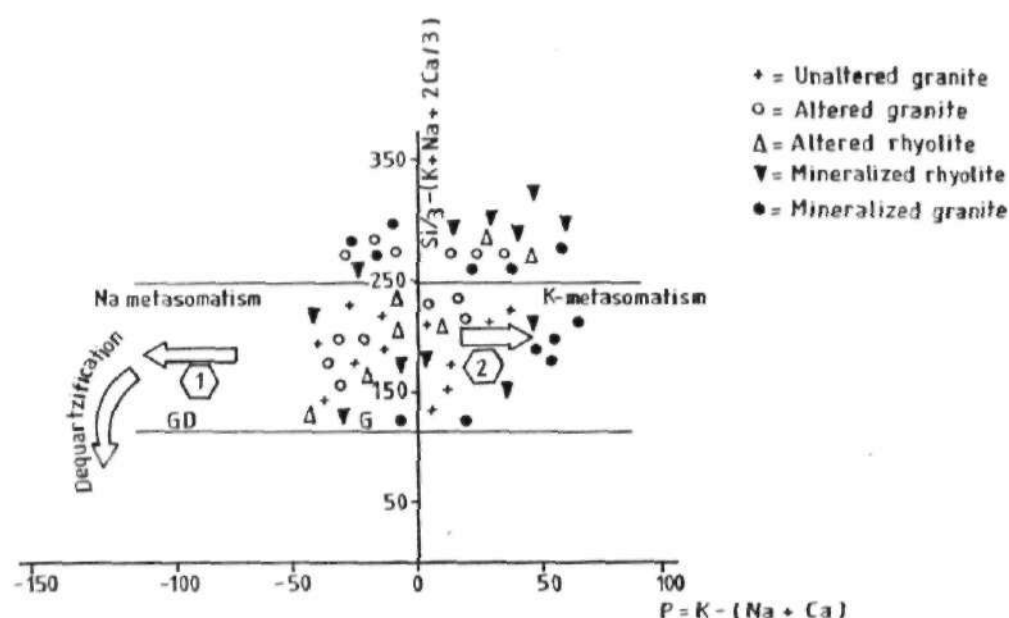


Fig. 6.18 Q-P diagram for the Mika granite; G-granite; GD-granodiorite trend 1) Na metasomatism; 2) K-metasomatism (Debon and Le Fort, 1983 and Cuney et al., 1989).

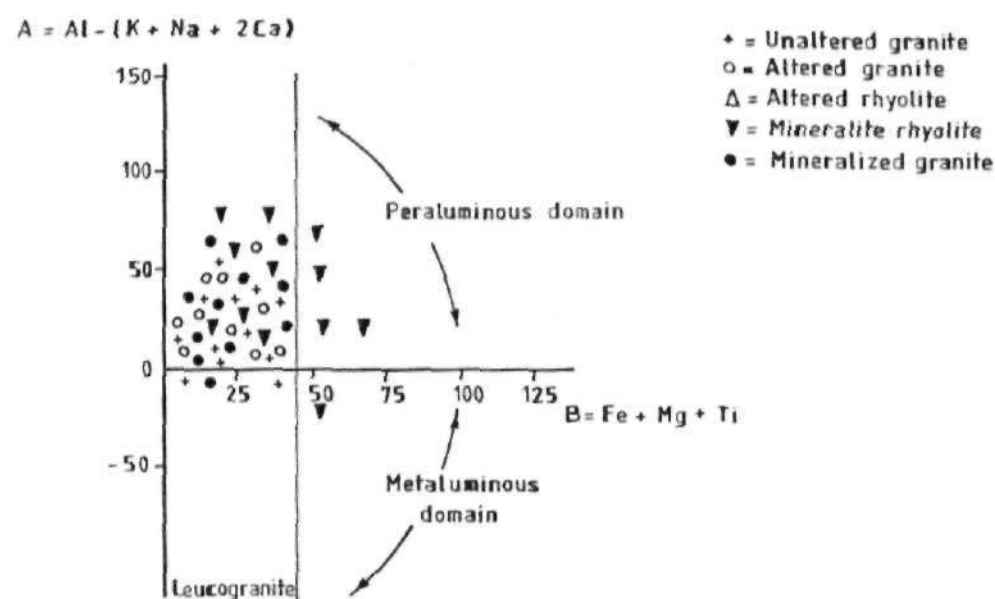


Fig. 6.19 A-B diagram for the Mika granite, leucogranites are defined as containing less than 7.5 Vol. % biotite (Debon and Le Fort, 1983).

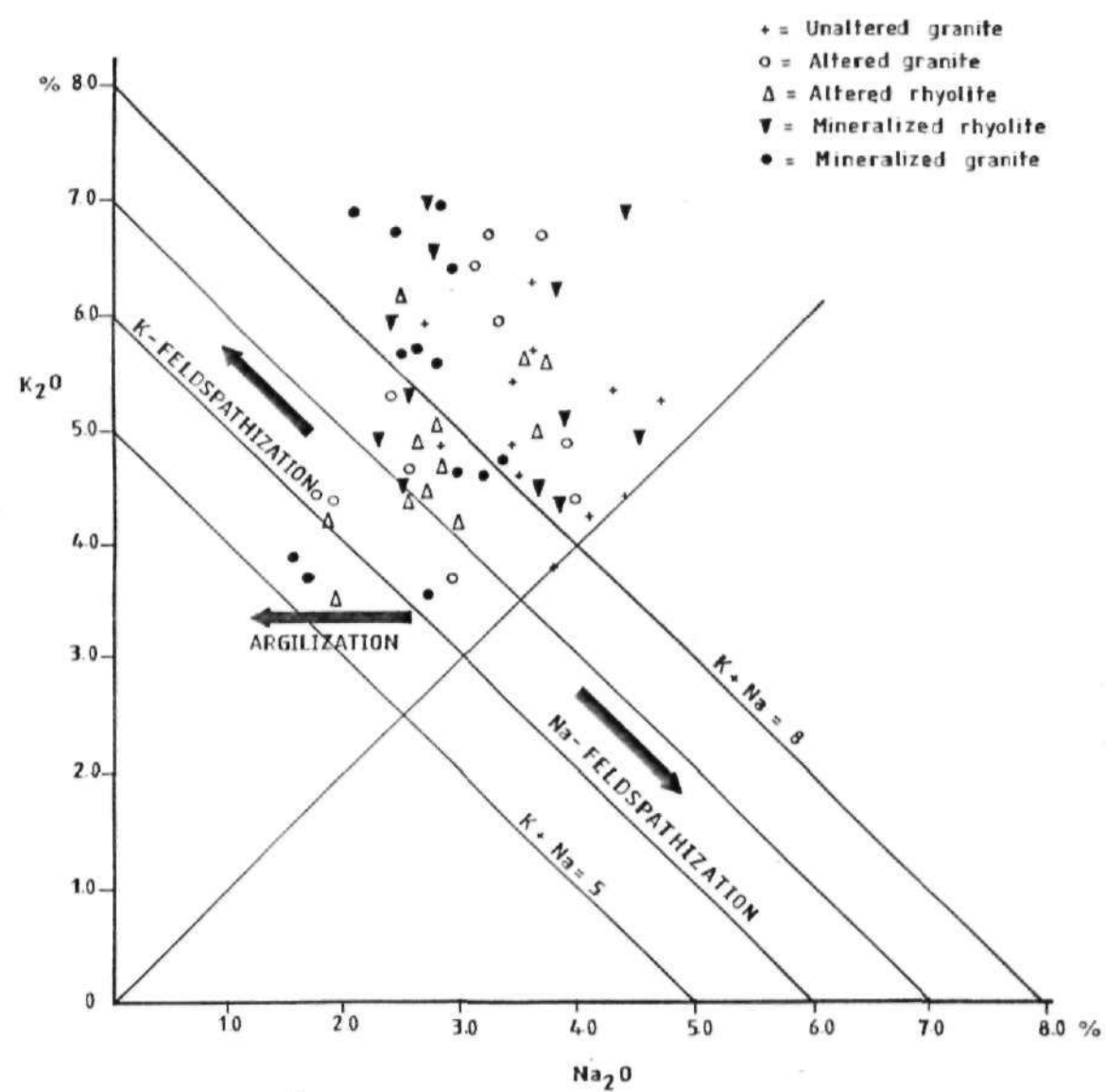


Fig. 6.20. K_2O - Na_2O diagram for the rock groups. Fields of alterations are indicated; after Cuney et al., 1989.

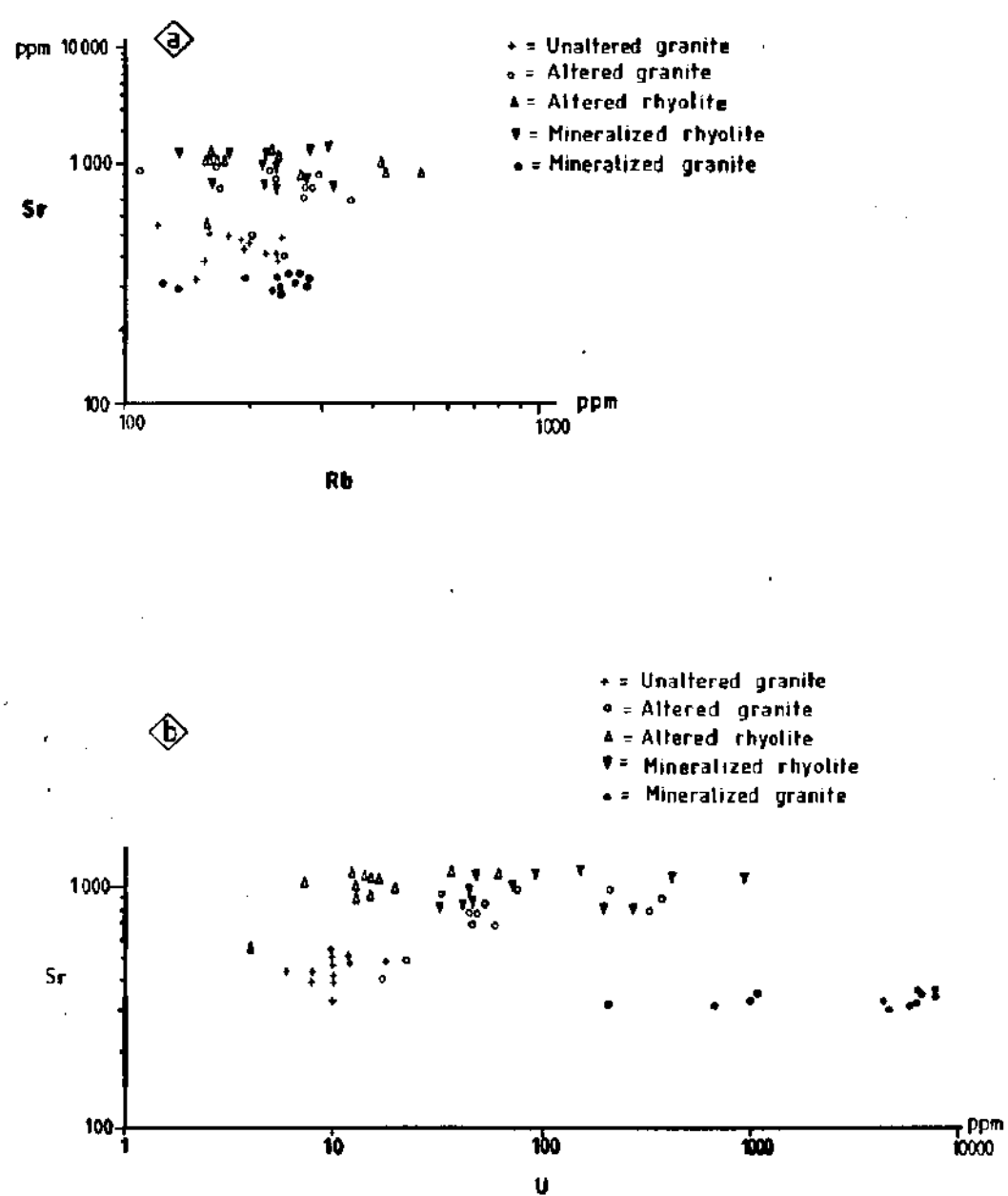


Fig. 6.21 (a) Sr-Rb diagram for the rock groups,
b) Sr-U diagram for the rock groups.

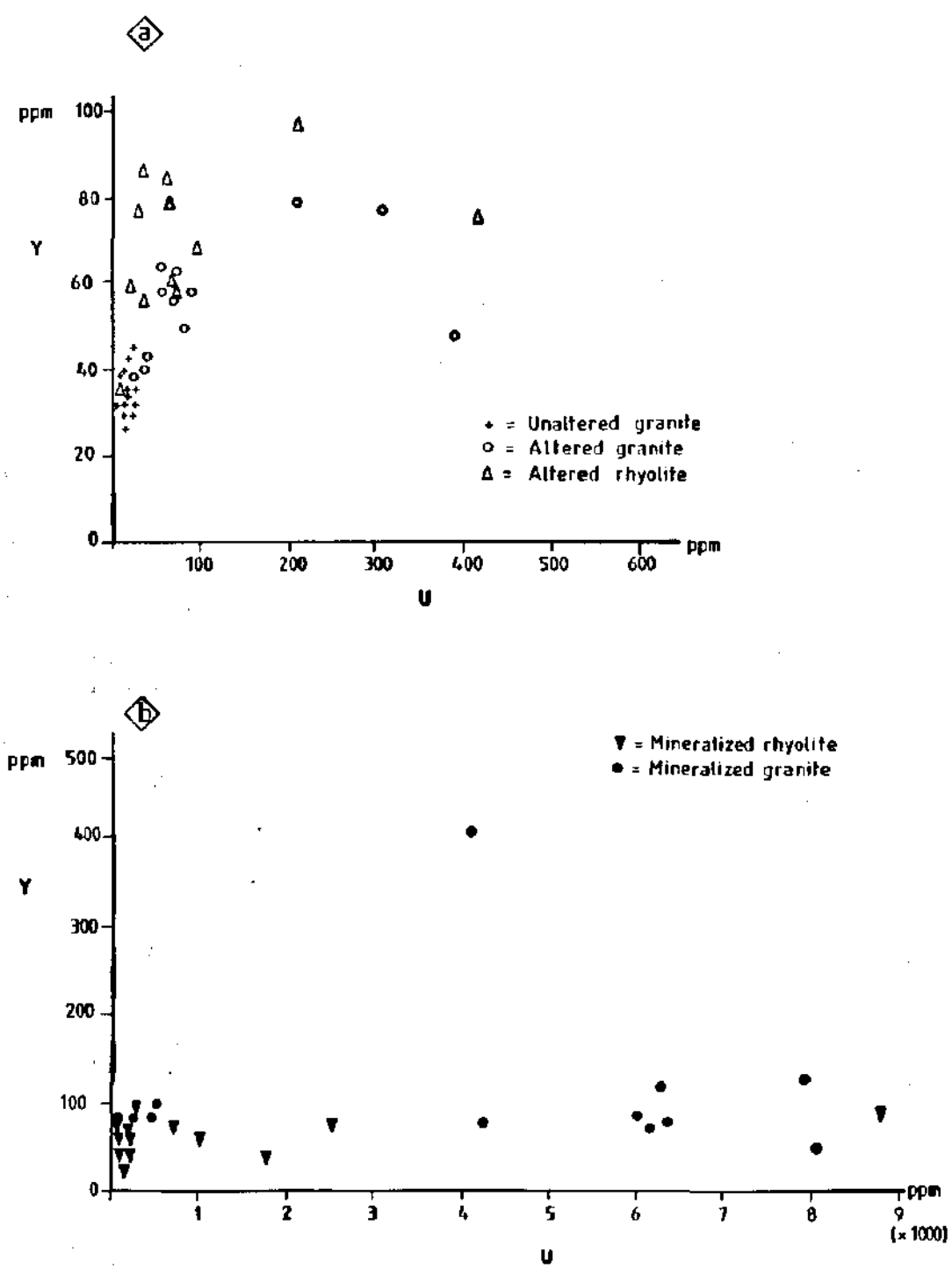


Fig. 6.22. Y-U diagram for the rock groups.

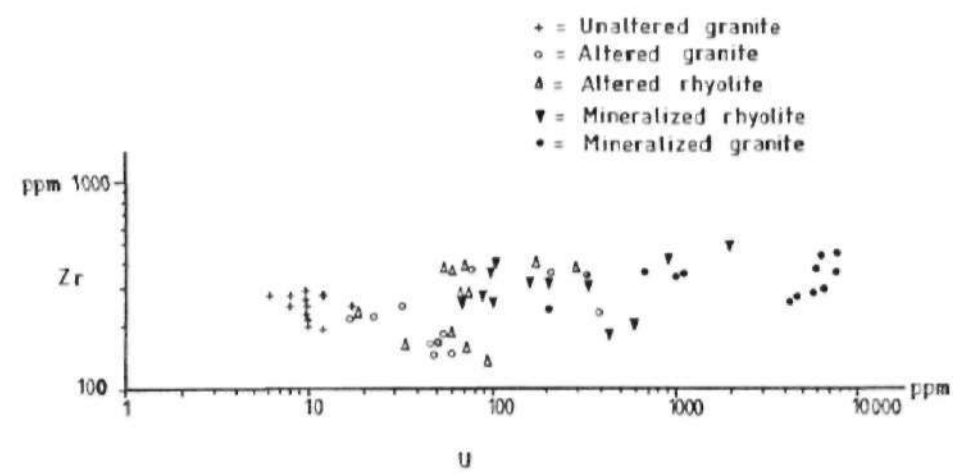


Fig. 6.23. Zr- U diagram for the rock groups .

6.3.2 Trace elements.

The trace elements exhibit many geochemical patterns that can be explained in relation to rock types, alteration or to mineralization. The distribution patterns of Zn, Cu, Mo, Y, V and Pb, for both surface and sub-surface consistently define pocket-like aureoles that can be related to confinement of the mineralization to "en echelon" pattern. The distributions can further be related to the structural setting of the mineralizations; the highest values of these mobile elements are found along the shear/fracture zones and their two expressions on the surface.

6.4 Element interrelations and associations.

The element interrelations and associations are exhibited in the paired element plots and in the correlation coefficient values and the factor analysis results calculated for the rock groups. Various plots in terms of scatter diagrams were drawn to explain the element interrelations and associations.

In the correlation and principal component analyses SiO_2 , Al_2O_3 , MnO , Sc , Cr and Ni were not included due to limitation of the ram memory of the Personal computer (2M bytes) used. These are the elements with least variations in the samples.

6.4.1 Correlation coefficient.

Correlation coefficients were calculated on the sub-groups of the unaltered granite; altered granite; altered rhyolite; mineralized granite and mineralized rhyolite in order to illustrate the changing patterns of element associations within the different groups.

A correlation value of more 0.60 is considered very good in the tables (Tables 6.2 to 6.6), while a value from 0.50 to 0.60 is considered good.

In the unaltered granite very good positive correlations of TiO_2 -Pb, Na_2O - P_2O_5 , Na_2O -Co, Co-As, Zn-As and Zn-S⁻ and very good negative correlations of Fe_2O_3 -MgO, Fe_2O_3 -CaO-Sr, Co-Sr, Co-U, As-Sr and Sr-Zr.

Good correlation exist positively for TiO_2 -Rb, Fe_2O_3 -Cu, Fe_2O_3 -Sr, Fe_2O_3 -Y, CaO-Zr, CaO-Mo, Na_2O -As, Na_2O -Se, K₂O-Sr, K₂O-Y, P_2O_5 -Cu, P_2O_5 -Pb and negatively for Na_2O -Zn, Na_2O -Sr, K₂O-Co, K₂O-As and Cu-Se.

The very good and good correlations are mostly between the major elements and trace elements likely from primary distribution and substitution in the major rock forming minerals. Isomorphic form of occurrence is decidedly predominant in Sr, Y, Mo, Zn, Cu, Co and Pb (Beus and Grigorian, 1977). Biotite is a concentrator of Rb, Co, Cu

	TiO2	Fe2O3	HgO	CaO	Na2O	K2O	P2O5	V	Co	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Mo	Pb	U
TiO2	1	-.35	.42	.43	-.01	.09	.32	-.32	.24	-.01	-.49	.17	.04	.54	-.19	.14	.32	.11	.60	-.39
Fe2O3		1	-.85	-.65	-.28	.33	-.22	.13	-.35	.51	.23	-.22	-.26	-.36	.52	.52	-.56	-.15	-.25	-.06
HgO			1	.37	-.42	-.19	.62	-.26	-.31	-.06	.22	-.17	-.37	.35	-.04	.05	.01	.21	.42	.34
CaO				1	.33	-.24	.19	-.29	.32	-.14	-.41	.40	.42	.37	-.67	-.27	.53	.55	.24	-.28
Na2O					1	-.30	.65	-.30	.79	-.39	-.57	.52	.56	.06	-.57	-.31	.31	-.20	-.31	-.43
K2O						1	.08	-.14	-.58	.05	.40	-.54	.36	-.29	.56	.54	-.19	.21	.47	.07
P2O5							1	.05	-.49	.50	.41	-.35	-.40	.39	.37	-.20	-.10	.29	.59	.38
V								1	-.07	.27	.23	-.23	-.30	-.36	.06	-.15	.34	.27	-.09	.12
Co									1	-.26	-.18	.66	.18	.21	-.63	-.44	.46	-.28	-.36	-.70
Cu										1	-.25	-.12	-.50	-.07	.39	-.11	-.15	.09	.24	-.08
Zn											1	.70	-.29	-.40	.70	.17	-.38	.09	.17	.74
As												1	.20	.23	-.80	-.36	.36	-.15	-.17	-.48
Se													1	.09	-.37	-.01	.25	.41	.07	-.17
Rb														1	-.12	-.27	-.19	.15	.11	-.02
Sr															1	.29	-.68	-.20	.09	.33
Y																1	-.31	.06	.10	.07
Zr																	1	.31	.33	-.37
Pb																		1	1	.08
U																				1

Table 6.2 Correlation matrix of unaltered granite.

and Zn while the feldspars are concentrators and carriers of Mo (plagioclase) and Pb (orthoclase). Isomorphic occurrence may thus explain NaO-Co, K₂O-Sr, K₂O-Y and CaO-Mo (in feldspars) while Zn-As correlation may from their chalcophile character.

For the altered granite very good positive correlations are found in TiO₂ with MgO, CaO, Na₂O, V, Sr, Y, Zr and U, MgO with CaO, Na₂O, Y and Zr, CaO with Se, Y, Zr and Mo, Na₂O with Zr and Pb, P₂O₅ with V and Cu. Other very good positive correlations are V-Zr, Co-As, Zn-U, Se-Mo, Y-Mo and Mo-U. Very good negative correlations are with Na₂O-Co, Na₂O-Rb, Co-Zr and Rb-Zr.

Good positive correlation exist as MgO-Sr, MgO-U, CaO-K₂O, K₂O-Sr, P₂O₅-Zr, V-Y, Co-Rb, Zn-Mo, As-Y, Sr-Y, Y-U and Pb-U. Negative good correlation is for TiO₂-Rb, Fe₂O₃-V, MgO-Rb, K₂O-As, P₂O₅-As, Co-Cu, Cu-As and Cu-Zr.

The correlation patterns surely changed from the unaltered granite to the altered granite group. TiO₂ positive correlations with many elements is the most pronounced. TiO₂ may have been mobilized along with these other elements in the alteration processes that affected the granite. Ti along with Mg, Ca, Na, V, Sr, Zr and U are transported either as O-complexes or oxyhalide complexes in acid solutions of pH < 6 (Rosler and Lange, 1972). The major

	TiO2	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	V	Co	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Mo	Pb	U
TiO2	1	-.41	.86	.65	.70	.32	.20	.66	-.43	.15	.30	.03	.37	-.51	.63	.63	.91	.37	.38	.61
Fe2O3		1	-.28	-.25	-.05	.40	.005	-.55	-.007	-.14	.26	-.42	-.47	.24	.24	-.27	-.37	-.23	.43	-.05
MgO			1	.81	.64	.71	-.005	.49	-.30	.003	.20	.19	.60	-.52	.57	.70	.75	.47	.45	.55
CaO				1	.59	-.14	.19	.58	-.29	.15	.01	.29	.62	-.51	.25	.71	.65	.60	.49	.52
Na2O					1	.53	.17	.25	-.70	.23	.06	-.26	.16	-.79	.46	.16	.74	.05	.66	.47
K2O						1	.09	-.22	-.56	.12	.39	-.57	-.34	-.31	.58	-.27	.33	-.21	.44	.22
P2O5							1	.66	-.55	.67	.23	-.56	.08	-.10	-.22	-.04	.51	.10	-.05	.26
V								1	-.22	.44	.15	.08	.45	-.24	.03	.55	.75	.42	-.10	.43
Co									1	-.52	-.11	.70	-.04	.54	-.10	.22	-.65	.08	-.34	-.27
Cu										1	-.36	-.50	.02	-.38	-.31	-.24	.50	-.31	-.26	-.31
Zn											1	-.22	-.03	.37	.40	.22	.15	.53	.26	.77
As												1	.43	.04	.06	.58	-.21	.66	-.06	.03
Se													1	-.39	-.05	.49	.38	.66	.09	.34
Rb														1	-.25	-.03	-.66	.09	-.34	-.07
Sr															1	-.50	-.41	-.09	.63	.41
Y																1	.42	.64	.37	.52
Zr																	1	.20	.27	.46
Mo																		1	.74	.75
Pb																			1	.56
U																				1

Table 6.3 Correlation matrix of altered granite.

	TiO2	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	V	Co	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Mo	Pb	U
TiO2	1	-.59	.28	-.65	-.45	.36	-.62	.43	-.02	-.48	.09	.01	-.31	-.04	.27	.02	.04	-.10	-.35	-.23
Fe2O3		1	-.62	.28	.13	-.86	.85	-.43	-.15	.87	.50	-.04	.01	-.04	.01	-.14	.12	.50	.60	.82
MgO			1	.27	.05	.83	-.35	.39	.65	-.58	-.24	.71	.09	.33	.48	.12	.48	-.39	-.15	-.37
CaO				1	.26	.09	.61	-.35	.67	.41	.03	.57	.28	.37	.35	-.07	.50	.06	.25	.10
Na2O					1	.03	.19	.15	-.05	-.06	.02	.15	.32	-.51	-.32	.24	.03	-.51	.57	.03
K2O						1	-.64	.24	-.40	-.71	-.53	.35	.17	.28	.20	-.08	.17	-.37	-.35	-.66
P2O5							1	-.34	.23	.80	.55	.32	.23	.01	.24	.06	.24	.38	.50	.67
V								1	-.13	-.70	.30	.29	-.12	-.48	.24	.83	-.01	-.47	.02	-.09
Co									1	.09	-.06	.78	.05	.54	.48	-.12	.67	-.09	-.09	-.16
Cu										1	.41	-.06	-.13	.19	.11	-.43	.25	.63	.36	.63
Zn											1	.28	-.24	-.44	.56	.37	.34	.32	.50	.76
As												1	.18	.24	.77	.24	.72	-.11	.29	.19
Se													1	-.06	-.15	.04	-.30	-.25	.17	.05
Rb														1	.29	-.57	.31	.32	-.34	-.18
Sr															1	.09	.68	.34	.16	.39
Y																1	-.18	-.43	.02	-.03
Zr																	1	.09	.45	.36
Mo																		1	-.03	.54
Pb																			1	.74
U																				1

Table 6.4 Correlation matrix of mineralized granite.

elements of CaO, Na₂O and K₂O still maintain good correlations as in the unaltered granite, which may be due to feldspars that are not completely altered. Other significant correlations are in the trace elements like Y-Mo, Mo-U, Sr-Y, Y-U and Pb-U. These are not present in the unaltered granite group and must have mobilized from alteration processes that affected the altered granite.

In the mineralized granite group the very good positive correlations are Fe₂O₃ with P₂O₅, Cu, Pb and U, MgO with K₂O, Co and As, P₂O₅ with Cu, Y and U, CaO with P₂O₅ and Co, Co with As and Zr, As with Sr and Zr. Others are As-Sr, Cu-U, Zn-U and Pb-U. The very good negative correlations are Fe₂O₃ with P₂O₅, MgO and K₂O, K₂O with P₂O₅, Cu and U, TiO₂ with CaO and P₂O₅, MgO-K₂O and V-Cu. The good positive correlations are Fe₂O₃ with Zn and Mo, CaO with As and Zr, P₂O₅ with Zn and Pb, Zn with Sr and Pb, Na₂O-Pb, Co-Rb and Mo-U. Negatively good correlations include Na₂O with Rb and Mo, TiO₂-Fe₂O₃, MgO-Cu, K₂O-Zn and Rb-Y.

The very good correlations in the mineralized granite depict elements associated with the mineralizations, that were easily mobilized.

Fe₂O₃ in the altered rhyolite group has the following very good positive correlations with P₂O₅, V, Cu, Sr, Zr, Mo, and negatively with Na₂O, K₂O, As, and Rb. P₂O₅ has very

good positive correlations with V, Cu, Se, Sr, Y, Zr, Mo and negatively with As. Other very good positive correlations are MgO-CaO, MgO-Rb, CaO-Y, Na₂O-K₂O, V-Zn, Cu-Sr, Cu-Y, Cu-Zr, Cu-Mo, Zn-Sr, As-Rb, Se-Zr, Sr-Y, Sr-Zr, Sr-Pb, Y-Zr, Y-Mo, Zr-Mo and Pb-U. The remaining very good correlations are negative and include Cu-As, Cu-Se, As-Se, As-Sr, As-Zr, As-Mo, Rb-Zr and Sr-Mo.

Good positive correlations in the altered rhyolite include TiO₂-V, TiO₂-U, Fe₂O₃-Se, Fe₂O₃-Y, CaO-Se, Na₂O-As, K₂O-As, K₂O-Rb, V-Cu, V-Sr, V-Y, V-Mo, Co-Zn, Cu-Se, Se-Mo, Y-Pb, Zr-Pb. The negative good correlations are As-Y and As-Pb.

Most of the significant correlation values of the altered rhyolite are not primarily mineralogical but may be due to remobilization by hydrothermal fluids. Worth noting are the associations of P₂O₅ with many trace elements and Fe₂O₃, with very good inverse correlations with Na₂O and K₂O, also the Pb-U correlation may be indicative of mineralizing fluid. Most of the trace elements are well positively correlated, which should also indicate their remobilization.

	TiO2	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	V	Co	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Mo	Pb	U
TiO2	1	-.07	.08	.11	.42	.32	.21	-.54	-.01	-.14	.39	.27	.11	.48	.04	.005	-.41	-.11	-.46	.53
Fe2O3		1	-.44	-.004	-.60	-.61	.87	.60	-.11	.89	.32	-.92	.34	-.66	.75	.59	.78	.78	.33	.11
MgO			1	.84	.27	.34	-.14	-.12	.22	-.39	.19	.30	.17	.65	-.08	.28	-.23	.05	.13	.30
CaO				1	.18	.15	.37	.13	.07	.07	.33	-.16	.57	.31	.23	.61	.24	.38	.37	.44
Na2O					1	.60	.29	-.36	-.54	-.41	.32	.58	-.03	.34	-.44	-.35	-.32	-.48	-.33	-.22
K2O						1	-.33	.02	.03	-.32	.19	.57	-.12	.50	-.39	-.22	-.46	-.32	-.24	-.11
P2O5							1	.68	-.17	.82	.43	-.84	.80	-.46	.68	.69	.75	.81	.29	.10
V								1	.26	.53	.79	-.40	.34	.06	.58	.59	.18	.58	-.03	-.19
Co									1	-.24	.57	.04	.50	.41	.04	.08	-.36	-.03	.26	.27
Cu										1	.37	-.84	-.66	-.63	.79	.66	.87	.76	.47	.29
Zn											1	-.24	.06	-.37	.64	.63	.06	.47	.39	.30
As												1	.74	-.61	-.56	-.87	-.77	-.52	-.34	
Se													1	.38	.33	.43	.62	.53	.20	.12
Rb														1	-.13	.003	-.74	-.32	-.17	-.04
Sr															1	.91	.60	.72	.60	.44
Y																1	.61	.85	.52	.45
Zr																	1	.72	.56	.44
Mo																		1	.40	.29
Pb																			1	.96
U																				1

Table 6.5 Correlation matrix of the altered rhyolite.

	TiO2	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	V	Co	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Mo	Pb	U
TiO2	1	.10	.48	.10	-.41	.54	-.04	-.41	-.11	-.21	-.14	-.01	-.18	.41	-.10	-.12	-.57	-.35	-.09	-.14
Fe2O3		1	-.14	.60	-.44	.08	.78	.48	-.74	.83	.81	-.61	-.17	-.54	.12	.09	.33	.22	.86	.78
MgO			1	.48	-.32	.72	-.28	-.16	.60	-.27	-.22	.26	-.24	.49	-.05	-.01	-.25	-.10	-.36	-.34
CaO				1	-.72	.32	.57	.57	-.03	.66	.52	-.03	-.28	-.04	.28	.26	.34	.48	.31	.35
Na2O					1	-.22	-.71	-.52	.01	-.58	-.37	-.09	.42	-.05	-.46	-.55	-.29	-.54	-.25	-.34
K2O						1	-.15	-.20	.23	-.24	-.02	.02	-.25	.25	.14	.18	-.07	-.22	.04	-.002
P2O5							1	.75	-.60	.93	.77	-.28	-.16	-.47	.56	.54	.63	.64	.70	.74
V								1	-.34	.74	-.42	.09	-.04	-.15	.55	.48	.85	.85	.44	.60
Co									1	-.55	-.62	.44	-.01	.58	-.12	.09	-.26	-.17	-.73	-.62
Cu										1	.84	-.43	-.15	-.57	.35	.38	.60	.55	.71	.72
Zn											1	-.60	-.28	-.78	.25	.28	.41	.22	.66	.52
As												1	.16	.75	.34	.03	-.02	.44	-.66	-.50
Se													1	.29	.24	-.16	.07	.10	-.12	-.03
Rb														1	.02	-.21	-.20	.05	-.64	-.48
Sr															1	.77	.70	.76	.19	.30
Y																1	.73	.54	.29	.41
Zr																	1	.74	.50	.64
Mo																		1	.21	.39
Pb																			1	.96
U																				1

Table 6.6 Correlation matrix of the mineralized rhyolite.

The mineralized rhyolite group shows many good to very good correlations of the elements. Very good positive correlations include Fe_2O_3 with CaO , P_2O_5 , Cu , Zn , Pb and U , P_2O_5 with V , Cu , Zn , Mo , Zr , Pb and U , Cu with Zn , Zr , Pb and U and Sr with Y , Zr , and Mo . Others are MgO with K_2O and Co , V with Cu , Zr and U . The rest are CaO-Cu , Zn-Pb , As-Rb , As-Pb , Y-Zr , Zr-Mo , Zr-U and Pb-U . The very good negative correlations are Co with Zn , Pb and U , Zn with As and Rb , $\text{Fe}_2\text{O}_3\text{-As}$, $\text{CaO-Na}_2\text{O}$, $\text{Na}_2\text{O-P}_2\text{O}_5$, $\text{P}_2\text{O}_5\text{-Co}$, V-Mo , and Rb-Pb .

The good positive correlations are CaO with P_2O_5 , V and Zn , P_2O_5 with Sr and Y , $\text{TiO}_2\text{-K}_2\text{O}$, Co-Rb , Cu-Mo , Zn-U and Zr-Pb . The negative good correlations are Na_2O with V , Cu , Y and Mo , $\text{TiO}_2\text{-Zr}$, $\text{Fe}_2\text{O}_3\text{-Rb}$, Co-Cu , Cu-Rb and As-U .

The mineralized rhyolite group shows element correlations related to the mineralization like Fe_2O_3 very good correlations with Cu , Zn , Pb and U , likely showing the mineralization is associated with the mobilization of Fe , Cu and Zn .

6.4.2 Principal component analysis.

Principal component analysis was performed to further explain the relationship between various correlated data that are difficult to interpret in terms of few

conceptually meaningful relatively independent factors. In a similar way to the correlation analysis principal component analysis was performed on the rock groups.

In the unaltered granite, three factors explain 61.8% of the total variance (Table 6.7). A plot of factors I and II and I and III (Fig. 6.25a and b) brings out MgO-P₂O₅-Se-Mo, TiO₂-CaO-Rb-Zr, Na₂O-Co-As-Pb and Fe₂O₃-K₂O-V-Cu-Zn-Sr-Y-U associations with slight shift of some elements in the plot of I and III.

Table 6.7 Principal component analysis of unaltered granite group. Components (FI, FII, FIII, FIV, FV, FVI) with percent of variance.

	FI	FII	FIII	FIV	FV	FVI
TiO ₂	0.12	0.33	0.11	0.13	0.29	-0.22
Fe ₂ O ₃	-0.21	-0.29	0.04	0.15	0.32	0.18
MgO	-0.07	0.40	-0.15	0.13	-0.16	-0.26
CaO	0.25	0.32	0.09	-0.19	-0.04	0.17
Na ₂ O	0.31	-0.17	0.11	0.02	-0.12	0.09
K ₂ O	0.21	0.02	0.51	0.03	0.16	0.04
P ₂ O ₅	0.18	0.40	-0.21	0.20	0.04	0.16
V	-0.09	-0.08	-0.21	-0.52	0.23	-0.03
Co	0.36	-0.12	-0.14	0.06	0.10	-0.04
Cu	-0.17	0.06	0.26	-0.006	0.48	0.34
Zn	-0.35	0.02	-0.001	-0.21	-0.21	-0.03
As	0.32	-0.04	0.12	0.09	0.10	0.05
Se	0.18	-0.006	-0.50	-0.11	0.16	0.32
Rb	0.12	0.27	0.12	0.36	-0.14	0.39
Sr	-0.35	-0.06	0.008	0.18	0.05	0.12
Y	-0.17	-0.07	0.36	0.21	0.12	0.32
Zr	0.23	0.15	0.05	-0.42	0.23	0.31
Mo	0.005	0.27	0.23	-0.35	0.07	0.40
Pb	-0.08	0.38	0.19	-0.03	0.22	0.18
U	-0.24	0.10	-0.06	-0.14	-0.48	-0.05
% variance	31.2	18.9	11.7	10.1	8.8	5.5
cumulative %	31.2	50.1	61.8	71.9	80.7	85.2

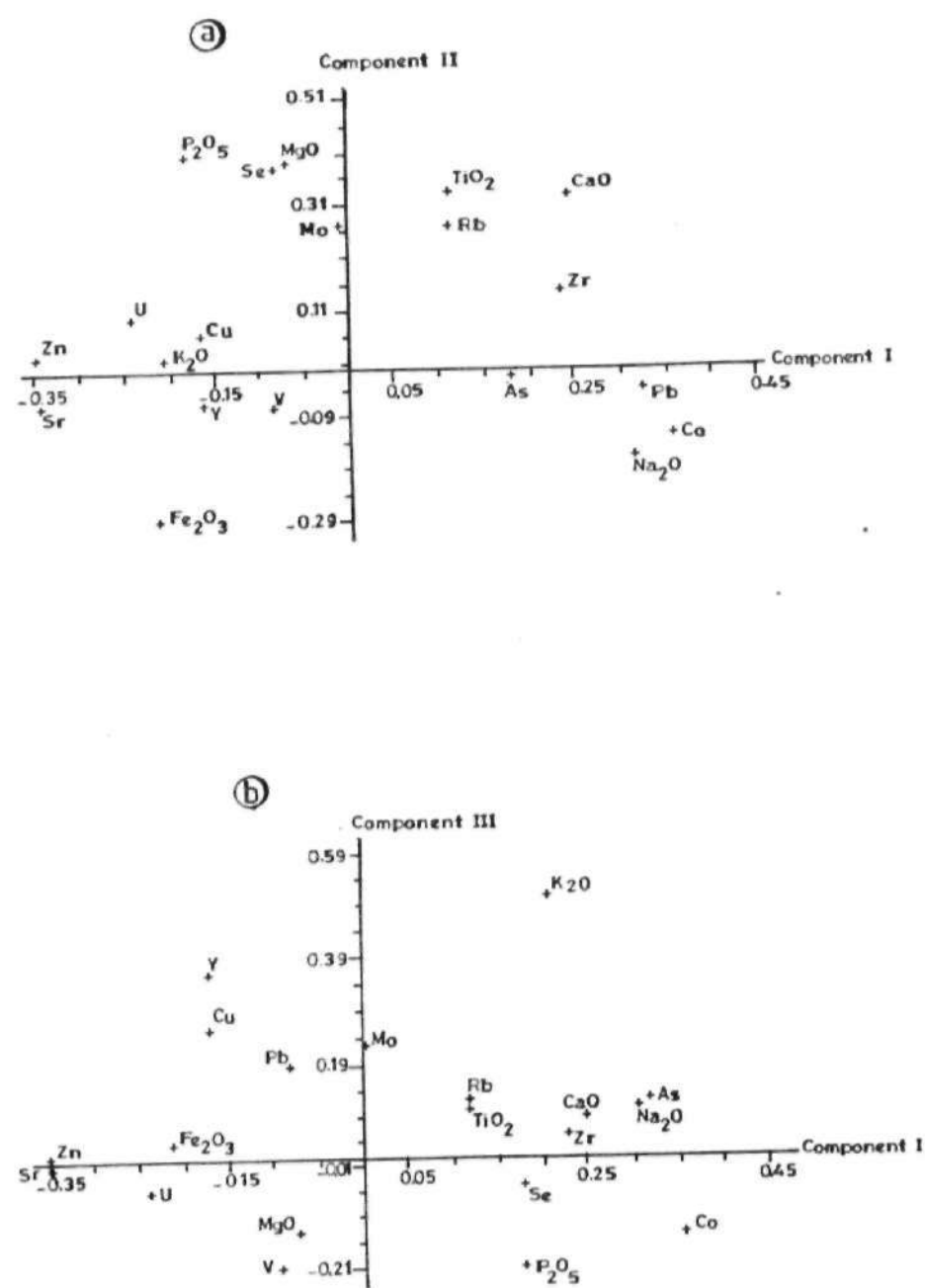


Fig.6.25. Plot of components (a) I and II, and (b) I and III for the elements in unaltered granite.

Three factors account for 73.0% of the total variance in the altered granite grouping (Table 6.8). Plot of factors I and II and I and III (Fig. 6.26 a and b) shows a large cluster of $\text{TiO}_2\text{-MgO-CaO-Na}_2\text{O-V-Zn-Se-Sr-Y-Zr-Mo-Pb-U}$ then $\text{K}_2\text{O-P}_2\text{O}_5\text{-Cu}$ and Co-Rb associations. Fe_2O_3 and As are in isolations in the plot of factors I and II while MgO and Rb isolates in the plot of factors I and III.

The principal component analysis of the mineralized granite group, has six factors explaining 93.5% variance of the data (Table 6.9). Plot of factors I and II and I and III (Fig. 6.27a and b) show the clusters of $\text{TiO}_2\text{-Na}_2\text{O-V-Se-Y}$, $\text{CaO-Co-As-Rb-Sr-Zr}$, $\text{Fe}_2\text{O}_3\text{-P}_2\text{O}_5\text{-Cu-Zn-Mo-Pb-U}$ and $\text{MgO-K}_2\text{O}$.

The first six factors in the principal component analysis of the altered rhyolite group account for 95.4% of the total variance (Table 6.10). The plot of factors I and II and I and III (Fig. 6.28a and b) shows clusters of $\text{TiO}_2\text{-MgO-CaO-K}_2\text{O-Co-Zn-Rb}$, $\text{P}_2\text{O}_5\text{-V-Se-Sr-Y-Mo-Pb-U}$, $\text{Fe}_2\text{O}_3\text{-Cu-Zr}$ and $\text{Na}_2\text{O-As}$ associations.

In the mineralized rhyolite, six factors account for 92.7% of the total variance of the data (Table 6.11). Plot of factors I and II and I and III (Fig. 6.29a and b) shows the $\text{TiO}_2\text{-MgO-K}_2\text{O-Co-As-Se-Rb}$, CaO-V-Sr-Y-Zr-Mo and $\text{Fe}_2\text{O}_3\text{-P}_2\text{O}_5\text{-Cu-Zn-Pb-U}$ and Na_2O plots in isolation.

Table 6.8 Principal component analysis of altered granite group. Components (FI, FII, FIII, FIV, FV, FVI) with percent of variance.

	FI	FII	FIII	FIV	FV	FVI
TiO ₂	0.08	0.06	0.05	0.19	0.20	-0.64
Fe ₂ O ₃	-0.03	-0.55	-0.33	-0.12	-0.16	-0.32
MgO	0.51	-0.09	-0.25	0.002	-0.04	0.51
CaO	0.17	0.31	-0.21	-0.29	0.49	-0.04
Na ₂ O	-0.04	0.04	-0.30	0.30	0.02	-0.02
K ₂ O	-0.30	0.39	0.15	0.06	0.16	0.31
P ₂ O ₅	-0.29	-0.24	0.11	-0.12	0.19	0.17
V	-0.24	-0.15	-0.17	-0.07	0.12	0.14
Co	-0.29	-0.07	-0.43	0.52	0.15	0.14
Cu	-0.02	0.44	-0.03	0.37	-0.12	-0.04
Zn	0.05	-0.002	-0.25	-0.05	-0.03	-0.10
As	-0.41	0.24	-0.01	-0.25	0.01	-0.05
Se	-0.01	-0.34	0.21	0.24	0.20	-0.16
Rb	0.40	0.20	0.26	0.22	0.34	0.02
Sr	-0.13	-0.16	0.14	-0.22	0.21	0.02
Y	0.08	0.04	0.31	0.07	-0.49	0.02
Zr	0.003	-0.05	-0.01	-0.08	-0.26	-0.06
Mo	-0.11	0.44	0.05	-0.06	-0.18	0.04
Pb	-0.12	-0.10	0.39	0.30	0.09	0.13
U	-0.12	-0.12	-0.15	0.16	-0.15	0.01
% variance	36.3	20.4	16.3	10.7	5.6	4.2
cumulative %	36.3	56.7	73.0	83.7	89.3	93.5

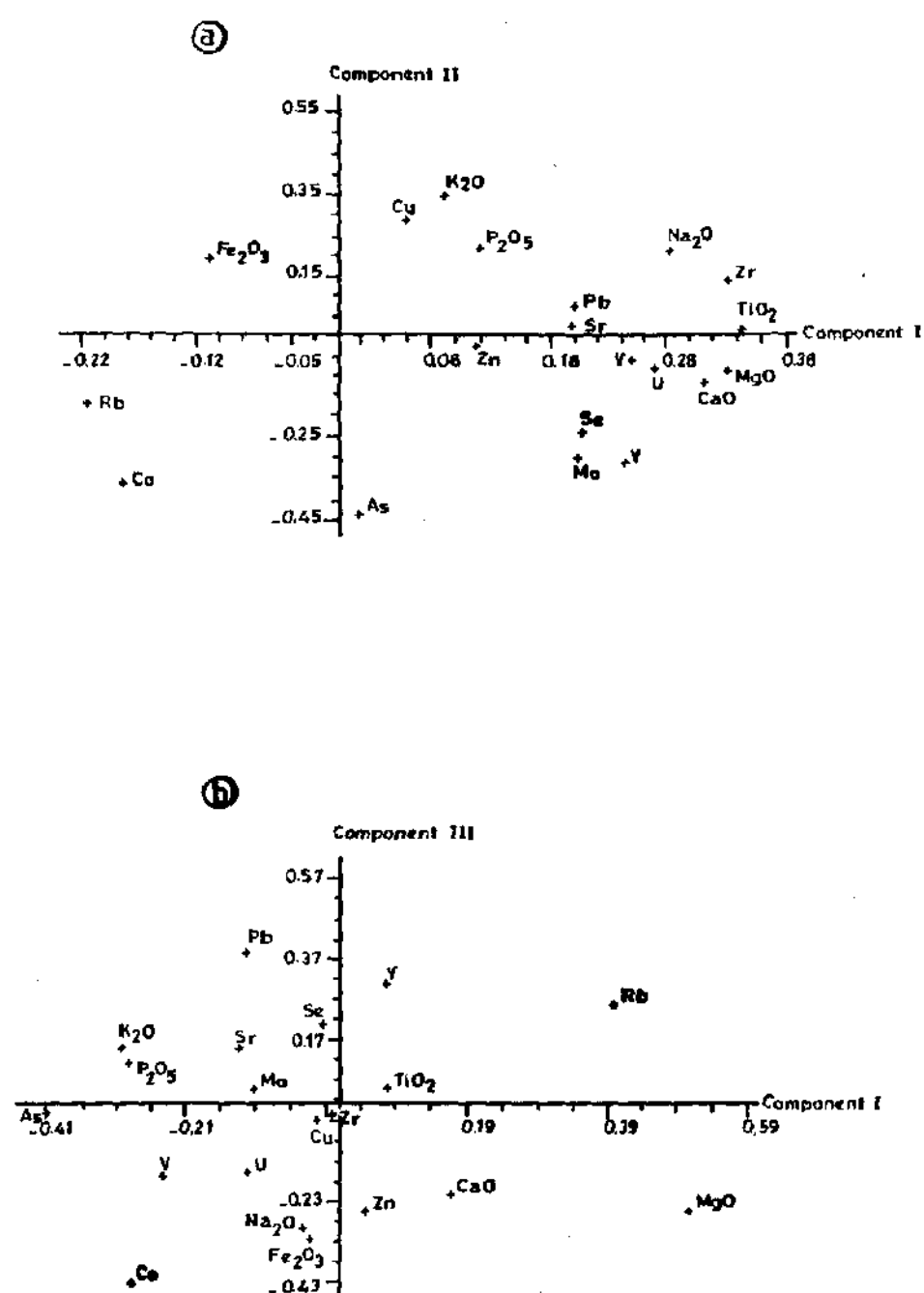


Fig. 6.26. Plot of components (a) I and II, and (b) I and III for the elements in altered granite.

Table 8.9 Principal component analysis of mineralized granite group. Components (FI, FII, FIII, FIV, FV, FVI) with percent of variance.

	FI	FII	FIII	FIV	FV	FVI
TiO ₂	0.25	0.01	0.04	0.42	0.15	0.19
Fe ₂ O ₃	-0.39	-0.06	0.01	-0.04	-0.01	-0.01
MgO	0.23	0.37	0.04	-0.03	-0.05	0.06
CaO	-0.16	0.31	-0.08	-0.30	-0.18	-0.16
Na ₂ O	-0.04	-0.001	0.29	-0.42	0.32	-0.12
K ₂ O	0.32	0.23	-0.07	-0.08	0.14	0.19
P ₂ O ₅	-0.36	0.10	0.05	-0.11	-0.29	0.0001
V	0.19	0.04	0.44	0.16	-0.13	-0.05
Co	0.01	0.41	-0.12	-0.08	-0.11	-0.21
Cu	-0.37	-0.002	-0.17	0.02	0.02	-0.14
Zn	-0.24	0.06	0.31	0.30	-0.08	-0.006
As	-0.02	0.44	0.15	-0.02	-0.08	0.09
Se	0.004	0.02	0.04	-0.40	-0.22	0.73
Rb	0.009	0.22	-0.43	0.03	-0.08	0.02
Sr	-0.07	0.36	0.07	0.31	-0.12	0.20
Y	0.07	-0.007	0.44	0.004	-0.48	-0.20
Zr	-0.11	0.39	0.02	0.12	0.38	-0.21
Mo	-0.23	-0.02	-0.24	0.30	-0.12	0.21
Pb	-0.25	0.07	0.27	-0.12	0.47	0.19
U	-0.34	0.03	0.16	0.18	0.14	0.26
% variance	36.3	20.4	18.3	10.7	5.6	4.2
cumulative %	36.3	56.7	73.0	83.7	89.3	93.5

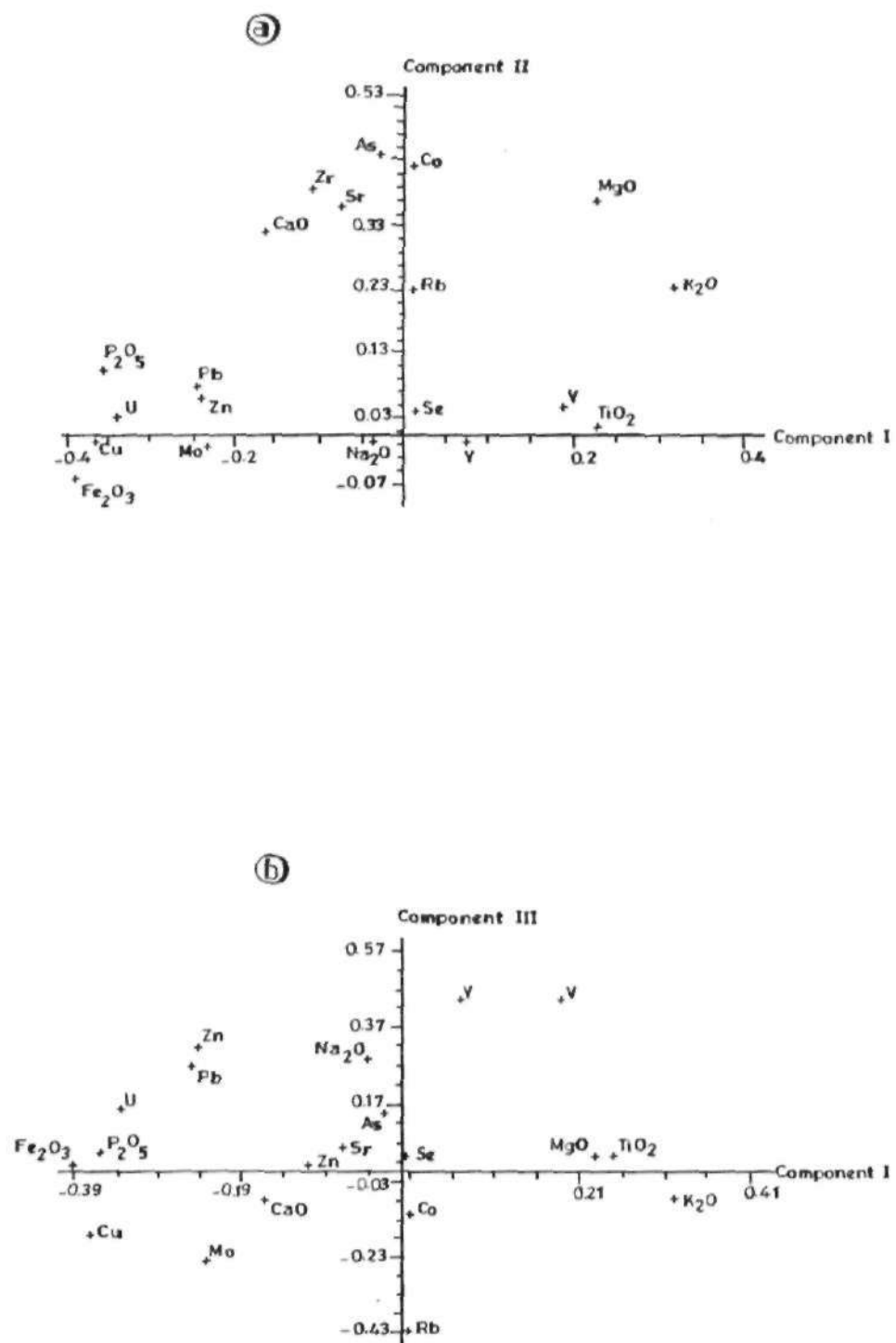


Fig. 6.27. Plot of components (a) I and II, and (b) I and III for the elements in mineralized granite.

Table 8.10 Principal component analysis of altered rhyolite group. Components (FI, FII, FIII, FIV, FV, FVI) with percent of variance.

	FI	FII	FIII	FIV	FV	FVI
TiO ₂	0.08	0.23	-0.48	-0.04	0.08	0.07
Fe ₂ O ₃	-0.32	-0.13	-0.14	0.08	-0.06	0.05
MgO	0.06	0.40	0.20	-0.24	-0.33	0.10
CaO	-0.10	0.36	0.14	-0.35	0.26	-0.01
Na ₂ O	0.19	0.08	-0.10	-0.45	0.36	0.05
K ₂ O	0.17	0.24	-0.09	-0.15	0.41	-0.51
P ₂ O ₅	-0.31	0.03	-0.21	-0.14	-0.08	-0.10
V	-0.19	0.20	-0.39	0.20	0.006	-0.11
Co	0.01	0.25	0.14	0.49	-0.25	-0.35
Cu	0.32	-0.09	-0.08	-0.03	0.30	-0.03
Zn	-0.16	0.38	-0.11	0.26	0.20	-0.17
As	0.32	0.13	-0.02	0.007	0.13	0.22
Se	-0.21	0.05	-0.11	-0.38	-0.26	-0.35
Rb	0.18	0.41	-0.02	0.09	0.02	0.29
Sr	-0.28	0.12	-0.02	0.11	0.28	0.39
Y	-0.27	0.24	0.03	-0.04	0.004	0.33
Zr	-0.30	-0.15	0.11	-0.20	0.09	-0.02
Mo	-0.30	0.08	-0.04	-0.03	-0.11	0.13
Pb	-0.20	0.10	0.41	0.05	0.29	-0.10
U	-0.14	0.14	0.49	0.001	0.25	-0.08
% variance	42.9	18.7	13.8	11.4	5.0	3.6
cumulative %	42.9	61.6	75.4	86.8	91.8	95.4

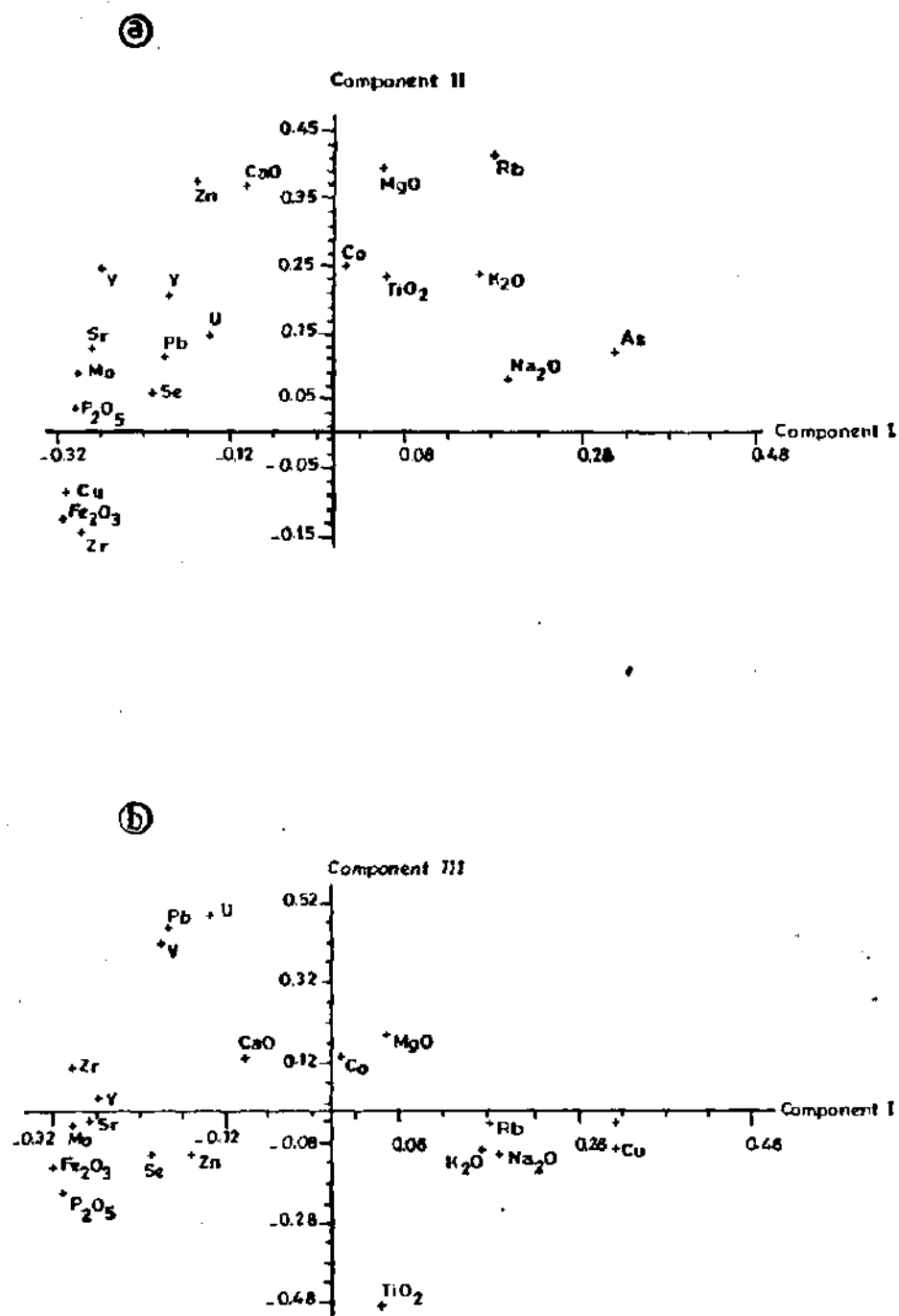


Fig. 6.28. Plot of components ③ I and II, and ④ I and III for the elements in altered rhyolite.

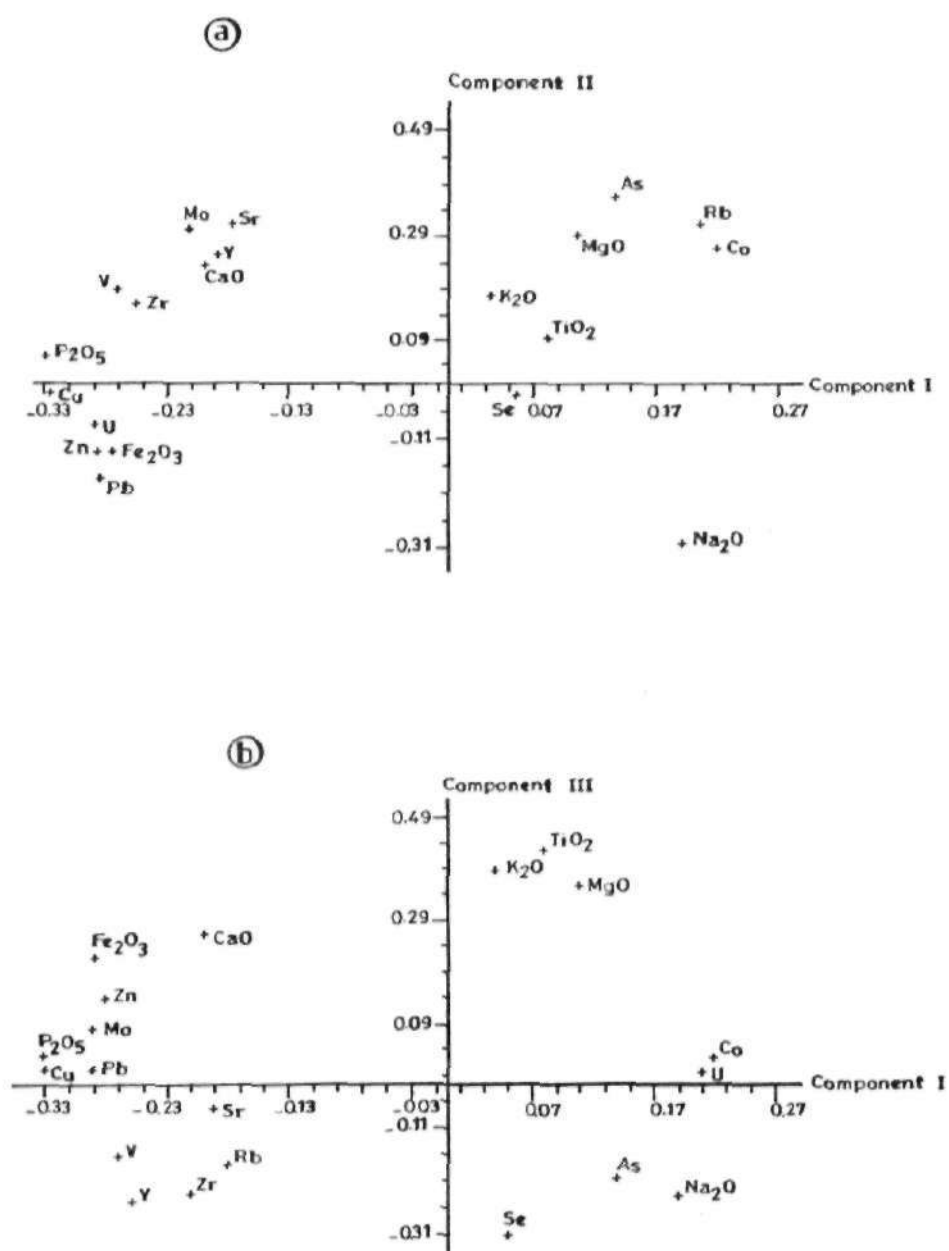


Fig. 6.29. Plot of components (a) I and II, and (b) I and III for elements in mineralized rhyolite.

Table 6.11 Principal component analysis of mineralized rhyolite group. Components (FI, FII, FIII, FIV, FV, FVI) with % of variance.

	FI	FII	FIII	FIV	FV	FVI
TiO ₂	0.08	0.09	0.43	-0.15	0.36	-0.41
Fe ₂ O ₃	-0.29	-0.14	0.22	-0.20	0.13	0.13
MgO	0.11	0.30	0.36	0.04	-0.07	0.36
CaO	-0.20	0.23	0.26	-0.22	-0.20	0.36
Na ₂ O	0.19	-0.30	-0.24	0.14	0.09	0.35
K ₂ O	0.04	0.18	0.39	0.35	0.30	0.27
P ₂ O ₅	-0.33	0.06	0.03	-0.12	0.02	-0.24
V	-0.27	0.19	-0.16	-0.17	-0.11	0.18
Co	0.22	0.27	0.03	0.22	-0.25	0.13
Cu	-0.33	-0.02	0.03	-0.18	-0.15	0.02
Zn	-0.28	-0.14	0.14	0.03	-0.18	-0.008
As	0.14	0.38	-0.21	-0.21	-0.006	-0.10
Se	0.05	-0.01	-0.31	-0.19	0.54	0.28
Rb	-0.18	0.32	-0.18	0.19	0.28	-0.17
Sr	-0.19	0.26	-0.07	0.54	0.01	-0.25
Y	-0.26	0.15	-0.25	0.27	0.02	0.22
Zr	-0.21	0.31	-0.24	-0.19	0.04	-0.007
Mo	-0.29	-0.18	0.09	0.10	0.26	0.09
Pb	-0.29	-0.08	0.01	0.07	0.28	0.12
U	0.21	0.32	-0.002	-0.30	0.26	0.05
% variance	41.8	18.8	15.2	6.3	6.1	4.5
cumulative %	41.8	60.6	75.8	82.1	88.2	92.7

The principal component plots shows many different associations in the rock groups; the unaltered granite show associations of major oxides with the trace elements like the MgO-P₂O₅-Se-Mo, TiO₂-CaO-Rb-Zr, Fe₂O₃-K₂O-V-Cu-Zn-Sr-Y-U and Na₂O-Co-As-Pb. These associations are probably due to mineralogical controls

like isomorphic form of occurrence of these elements in biotite and the feldspars.

The associations in the altered and mineralized groups differ much from those of the unaltered granite. The associations includes, $K_2O-P_2O_5-Cu$, $Co-Rb$ and isolation of Fe_2O_3 and As in altered granite which may be due to mobilization of these elements by fluids during alteration processes. In the mineralized rhyolite there is the isolation of Na_2O from the groupings of the elements and the most likely explanation of these is that of removal, while the other elements got concentrated.

The most prominent associations in the altered and mineralized groups are the $TiO_2-MgO-CaO-K_2O-Co-Se-Rb$ and the $Fe_2O_3-P_2O_5-Cu-Zn-Mo-Pb-U$ associations.

$TiO_2-MgO-CaO-K_2O-Co-Se-Rb$ association.

This association is present in the altered granite and rhyolite as a big cluster with other elements like Zn , Sr , Y , Zr , Mo , Pb and U and in mineralized granite and rhyolite it is fragmented into two associations. Possible explanation of this association is that of remobilization during alteration processes and associated fluid action.

like isomorphic form of occurrence of these elements in biotite and the feldspars.

The associations in the altered and mineralized groups differ much from those of the unaltered granite. The associations includes, $K_2O-P_2O_5-Cu$, $Co-Rb$ and isolation of Fe_2O_3 and As in altered granite which may be due to mobilization of these elements by fluids during alteration processes. In the mineralized rhyolite there is the isolation of Na_2O from the groupings of the elements and the most likely explanation of these is that of removal, while the other elements got concentrated.

The most prominent associations in the altered and mineralized groups are the $TiO_2-MgO-CaO-K_2O-Co-Se-Rb$ and the $Fe_2O_3-P_2O_5-Cu-Zn-Mo-Pb-U$ associations.

$TiO_2-MgO-CaO-K_2O-Co-Se-Rb$ association.

This association is present in the altered granite and rhyolite as a big cluster with other elements like Zn , Sr , Y , Zr , Mo , Pb and U and in mineralized granite and rhyolite it is fragmented into two associations. Possible explanation of this association is that of remobilization during alteration processes and associated fluid action.

Fe₂O₃-P₂O₅-Cu-Zn-Mo-Pb-U association.

The Fe₂O₃-P₂O₅-Cu-Zn-Mo-Pb-U association is present in the mineralized granite and rhyolite groups. The association results from fragmentation of the big cluster of elements in altered granites and rhyolites. The fragmentation of this association occurred with increasing alteration and mineralization.

The association likely represent the mineralizing fluid composition. The association also reflect the linkage of the uranium mineralization with hematization (Fe₂O₃), associated phosphatic secondary uranium minerals (P₂O₅) and the association of the mineralization with sulphides; pyrite, chalcopyrite, galena and possibly the other chalcophile minerals of Cu, Zn and Mo.

CHAPTER 7.

DISCUSSION.

7.1 General features of the mineralizations.

The mineralizations in the basement rocks of the three zones; the Gubrunde horst, the Monkin and Ghumchi zones share several similarities, but also have a few differences.

All the mineralizations occur in basement rocks of Pan-African age. The Gubrunde, horst and Monkin area are both underlain by more or less coarse-grained biotite granites. Rock types in the Ghumchi area are varied, where gneiss, quartzite, mylonites and migmatites are present.

The uranium mineralizations are associated with distinct hydrothermal activity (alterations include hematization, sericitization, silicification and argillization). Several phases of silicification and brecciation are commonly observed.

Volcanic rocks are invariably present as veins and dikes (rhyolites at Kanawa and Mika and basalts at Mika), that are often brecciated. Brecciated rhyolite bodies are intimately related to the mineralizations at both Kanawa and Mika.

Tectonic control is paramount in all the mineralizations. Uranium may occur in various rock types; at marginal contact with rhyolite at Kanawa (Funtua, 1988), silicified granite and rhyolite at Mika and migmatitic granite and foliated quartzite at Ghumchi (Maurin, 1985) but is always associated with brecciation and fractures some (open and some cemented by silica).

Uranium minerals found are veinlets of pitchblende, meta-autinite and one or more generations of coffinite at Mika. Others are uranium minerals consisting essentially of phospho-uranylite, kasolite and traces of pyrite, galena and chalcopyrite at Kanawa (Okujeni et. al., 1990) and pitchblende and two or more generations of coffinite at Ghumchi (Maurin, 1985).

7.2 Geochemistry.

As hydrothermal solutions pass along a channel they may add or subtract elements or rearrange elements already present in new minerals. These changes may indicate the character of the solutions.

Considering the K₂O component involved in hydrothermal alteration, K₂O content of microcline is 18.9% and that of sericite is 11.8%. In the host rock, biotite granite there is sufficient K₂O (4 - 6%) to permit extensive sericitization without introduction of K₂O by hydrothermal

solutions, since the rock contains 30 - 40% of K-feldspar. The K₂O of the unaltered granite is less than 6.5% for all samples, but the altered and mineralized rhyolites and granites contains more than 7.5%, for most samples. It is therefore probable that some K₂O was introduced by hydrothermal solutions. Besides addition of K₂O there is also increase in Fe₂O₃, depicted by the marked hematization of the altered and mineralized rocks. Soda was leached in the alteration zones. The loss of soda is usually related to replacement of plagioclase by sericite.

The elemental distributions and associations continue to point at remobilization of some elements in the altered and mineralized rocks. The associations could be grouped into two, one that is related to alteration processes that occurred before and after the mineralization and the second that is directly related to the mineralization. The TiO₂-MgO-CaO-K₂O-Co-Sr-Rb-Zr association in the altered granite and rhyolite groups represent mobilization of these elements by alteration processes not necessarily associated with the mineralization as the association forms large cluster with other mobile elements that are later separated from this cluster while the Fe₂O₃-P₂O₅-Cu-Zn-Mo-Pb-U association likely represent the mineralization fluid composition.

7.3 Model of mineralization.

The potential geologic settings of hydrothermal vein deposits are limited by the chemical constraints which uranium oxidation, transport and deposition impose on the origin and migration of the ore-forming fluids. Three different generalized models for the formation of hydrothermal vein uranium deposits are implicit (Barbier, 1974, Langford, 1974, Knipping, 1974, Leroy, 1978 and Cuney, 1978). The three cases are supergene, deep meteoric water and non-meteoric water models; in all the cases, pitchblende is precipitated through the reduction of the fO_2 of the ore fluid. The supergene model has very shallow uranium leaching by oxidizing surface waters, followed by pitchblende precipitation at depth. In deep meteoric water model uranium is leached by deeply circulating oxidizing waters of surface origin, followed by pitchblende deposition. The non-meteoric water origin is where uranium is leached by deeply circulating oxidizing waters which are not of direct surface origin (magmatic, metamorphic and sedimentary formation waters), followed by pitchblende deposition.

Study of hydrothermal vein uranium deposits associated with leucogranites shows that ore forming fluids are not issued from earlier magmatic stages (as is the case with non-meteoric model), circulations are those of meteoric

water set in motion by heat flows of varied origins as late basaltic magmatism (Leroy, 1978 and Maurin and Lancelot, 1990), granitic U-Th-K heat flow (Fehn et. al., 1978) or shearings in important tectonic zone (Cathelineau, 1983).

The Mika mineralization has already been described as vein type. That was controlled in formation, first by tectonics, faults and shearings of the granite and rhyolite body and second by lithology, rhyolite acting as chemical or mechanical barrier to mineralizing fluids, with the subsequent mineralization forming at marginal contact of the rhyolite body. The structural control of the mineralization is emphasized by the confinement of the mineralization to pocket-like occurrences with "en echelon" pattern of outcrops.

The Mika mineralization model can thus be described as vein-type in which the emplacement of the rhyolite body acted as source of heat and driving power of the mineralizing fluid (could be meteoric or non-meteoric in origin) that were mobilized from the granitic terrain (with average uranium content of 10ppm). The fault structure acted as channel and mechanical barrier for the mineralizing fluids. In some instances, the rhyolite body acted as the mechanical with the mineralization forming at marginal contact of the rhyolite body with the granite.

water set in motion by heat flows of varied origins as late basaltic magmatism (Leroy, 1978 and Maurin and Lancelot, 1990), granitic U-Th-K heat flow (Fehn et. al., 1978) or shearings in important tectonic zone (Cathelineau, 1983).

The Mika mineralization has already been described as vein type. That was controlled in formation, first by tectonics, faults and shearings of the granite and rhyolite body and second by lithology, rhyolite acting as chemical or mechanical barrier to mineralizing fluids, with the subsequent mineralization forming at marginal contact of the rhyolite body. The structural control of the mineralization is emphasized by the confinement of the mineralization to pocket-like occurrences with "en echelon" pattern of outcrops.

The Mika mineralization model can thus be described as vein-type in which the emplacement of the rhyolite body acted as source of heat and driving power of the mineralizing fluid (could be meteoric or non-meteoric in origin) that were mobilized from the granitic terrain (with average uranium content of 10ppm). The fault structure acted as channel and mechanical barrier for the mineralizing fluids. In some instances, the rhyolite body acted as the mechanical with the mineralization forming at marginal contact of the rhyolite body with the granite.

Both regional and local structures must have played an important role in the formation of this mineralization. Intersections of regional fault zones with faults of different direction control the occurrence of volcanics of different types, like the Biu and Longuda basalts, while local steeply inclined conduct the ore bearing hydrothermal solutions from deep to shallow sites. Secondary uranium mineralization formed with the surface leaching of the pitchblende and occurs within the altered granite (mostly hematized).

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS.

8.1 CONCLUSIONS.

The uranium mineralization in Mika is located within biotite granite that has a Pan-African age of 657 ± 12 Ma (Tobosun and Lancelot, 1983) and an intruded rhyolite body that may belong to the Burashika group, with an age of 147 ± 7 Ma (Popoff et. al., 1982). Numerous faults and fractures filled with hematized silica cross cut the granite. The rhyolite body itself is commonly brecciated and hematized, so also is the granite within the mineralization area. The major trends of the faults are $0-20^{\circ}$, $140-160^{\circ}$ and $80-100^{\circ}$. The fracture network has been interpreted to be dextral wrench mechanisms (Maurin, 1990). These dextral wrench faults may as well be conjugate with the NE-SW sinistral wrench faults that were contemporaneous with the genesis of the Benue trough (Benkhelil, 1982, Benkhelil and Robineau, 1983 and Maurin et. al., 1986).

The uranium mineralization in Mika occurs both in primary and secondary forms. The primary mineralization is pitchblende, finely disseminated or occurring as veinlets in open fractures of the altered granite. It is associated with finely disseminated sulphides of siderite, pyrite, chalcopyrite and galena. The secondary mineralization

occurs in crushed and brecciated granite and at the marginal contact with the altered rhyolite. Secondary uranium minerals are meta-autinite and coffinite.

The mineralization is associated with distinct hydrothermal alterations of sericitization, silicification, K-feldspathization, hematization and kaolinization. sericitization forms the widest zone with the other forms being more restricted to the shear zones that are associated with the mineralization. Also present are hematized red silica fillings that have elevated uranium content (6 - 10 times the background).

The element distributions and associations in the Mika mineralization shows evidences of remobilization of elements related to alterations of the rocks and the subsequent mineralization. There are two distinct associations, the $\text{TiO}_2\text{-MgO-CaO-K}_2\text{O-Co-Sr-Rb-Zr}$, that most likely represent mobilization of these elements due to alteration processes and the $\text{Fe}_2\text{O}_3\text{-P}_2\text{O}_5\text{-Cu-Zn-Mo-Pb-U}$ that represent the remobilization of these group in the formation of the mineralization.

The factors favourable for the formation of this mineralization are the biotite granite that must have acted as the source rock; the combinations of regional and local structures and the volcanic activities that affected the area.

The biotite granite with an average uranium content of 10ppm, have high silicic and low mafic component which makes them suitable source rocks. It should also be noted that multistage tectomagmatism (as it affected the Older granite series) is able to create the favourable condition of providing sufficient uranium sources for igneous rocks and post-magmatic hydrothermal solutions (Yu, 1989).

Structures played an important role in the formation of the uranium mineralization in Mika, likely as channel and or mechanical barrier. There is evidence for a distinct structural control of the mineralization, by its association with fractures and shear zones. These local structures are reactivated lineaments that are related to regional structures, which have undergone a prolonged history of geological development and several periods of activity. The structures have already been related to the regional tectonics that led to the formation of the Benue trough by the studies of Benkhelil and Robineau, 1983 and Maurin and Lancelot, 1990.

The bimodal magmatism of the Burashika group is postulated to be related to the uranium mineralizations in the Kanawa area (Ojo, 1982 and Funtua, 1988) and the Mika area (Maurin, 1985 and Maurin and Lancelot, 1990), from the invariable presence rhyolite bodies to the mineralizations. The role of the magmatism is most likely as a source of

heat and driving power of the mineralizing fluid, sometimes as well as mechanical barrier for the fluids leading to the formation of the mineralization. No evidence is found that would suggest the associated rhyolite bodies acted as source for the uranium as suggested by Maurin and Lancelot, 1990.

8.2 RECOMMENDATIONS.

From the study of the Mika and other uranium mineralizations in the N.E. Nigeria, the following recommendations are put forward in locating similar mineralizations of possibly bigger size and grade:

1. Detailed study of the granitic rocks of the region that could act as source rocks. Such studies should include uranium distribution and accessory mineral paragenesis in these rocks with possible implications for uranium metallogenesis. This can possibly lead to the establishment of the so called fertility of the granitic bodies.
2. The mapping of regional and local structures, most especially regional deep faults with prolonged history of geological development and local fault intersections that are steeply inclined, especially the N-S and N170E conjugates in both the basement and sedimentary rocks;

these can conduct ore bearing hydrothermal solutions from deep to shallow sites.

3. The distribution of the associated volcanic rocks both in space and time should also be studied. It is not all the volcanic rocks that are associated to the mineralizations, but a more careful study of these volcanics can establish some relationships.

4. Sedimentary basins adjacent to these areas can host uranium mineralizations. Many regional and local fault structures can be traced from the basement rocks onto the adjacent sedimentary rocks (Benkhelil and Robineau, 1983 and Maurin et. al., 1986). Detailed structural and geological mapping of the adjacent sedimentary areas may reveal bigger than the Bille and Passam hills anomalies.

REFERENCES.

- Ahrens, L. H. (1964). The significance of the chemical bond for controlling the geochemical distribution of elements. In: *Physics and Chemistry of the Earth, Part I* (Ahrens, L. H. ed.). vol.5, Oxford, Pergamon Press. pp1-54.
- Allix, P.(1983). Environments mesozoïques de la partie nord-orientale du fosse de la Benoue (Nigeria), Stratigraphie- Sedimentologie- Evolution geodynamique. *Unpublished Thesis Marseille St-Jerome (B)*, 21 200p.
- Ajaikaiye, D. E. (1981). Geophysical investigations in the Benue trough- A review. *Earth Evolution Sciences*.vol.2, pp110-125.
- Ajakaiye, D. E., Hall, D. H., Millar, T. W., Verheijen, P. J. T., Awad, M. B. and Ojo, S. B. (1986). Aeromagnetic anomalies and tectonic trends in and around the Benue Trough, Nigeria. *Nature Phys. Sci.* vol.319, pp582-584.
- Baba, I. (1985). The geology and soil geochemical investigation of mineral occurrences in Dali area (Sheet 153), NE, Nigeria.
- Barbier, J. (1974). Continental weathering as a possible origin of vein-type uranium deposits. *Min. Deposita*, vol.9, pp271-288.
- Baudin, Ph. (1986). Magmatisme Mesozoïque du fosse de la Benoue (Nigeria) - Caractéristiques pétrologiques et géochimiques, signification géodynamique. *Unpublished D.E.A Aix Marseille I*. 76p.
- Benkhelil, J. (1982). Benue trough and Benue Chain. *Geol. Mag.*, 119, pp155-168.
- Benkhelil, J. and Robineau, B.(1983). Le fosse de la Benoue est-il un rift?. *Bull. Centres Rech. Explor.-Prod. Elf Aquitaine* 7, pp315-321.
- Benkhelil, J. (1988). Structure and geodynamic evolution of the Benue trough. *Bull. Centres Rech. Explor.-Prod. Elf Aquitaine*, vol 12, pp29-128.

Beus, A. A. and Grigoryan, S. V.(1977). *Geochemical Exploration methods for Mineral Deposits*. Applied publishing Ltd., Wilmette, Illinois. 287p.

Bowie, S. H. U.(1977). Uranium distribution and availability. In M. J. Jones(ed.), *Geology, mining and extractive processing of uranium*. London, Inst. Mining and Metallurgy, pp76-82.

Boyle, R. W.(1982). Geochemical methods for the discovery of blind mineral deposits. *CIM Bull.*, vol. 75, no. 844, pp123-132.

Burke, K. C. A., Dessauvage, T. F. W. and Whiteman, A. J.(1971). Opening of the Gulf of Guinea and geological history of the Benue Depression and the Niger delta. *Nature*. vol.233 pp51-55.

Cathelineau, M.(1983). Potassic alteration in French hydrothermal uranium deposits. *Min. Deposita*. vol. 18, pp89-97.

Cathelineau, M. and Poty, B.(1989). U-Th-REE mobility in the granitic environments at the hydrothermal stage. In: *Metallogenesis of uranium deposits*. Proc. Tech. Comm. Meeting, IAEA, Vienna. pp63-91.

Carter, J. D., Barber, W., Tait, E. A. and Jones, J. P.(1963). The geology of parts of Adamawa, Bauchi and Bornu provinces in Northeastern Nigeria. *Bull. Geol. Surv. Nigeria*, 30, 109p.

Chimoye, T. (1989). Fundamental parameter method. A manual.

Crerar, D., Wood, S. and Brantley S.(1985). Chemical controls on solubility of ore forming in hydrothermal solutions. *Canadian Mineralogist*, 23, pp333-352.

Cuney, M.(1978). Geologic environment, mineralogy and fluid inclusions of the Bois-Limouzat uranium vein, Forez, France. *Econ. Geol.*, vol.72 pp1567-1610.

Cuney, M. and Friedrich, M.(1987). Physiochemical and crystal-chemical controls on accessory mineral paragenesis in granitoids: implications for uranium metallogenesis. *Bull. Mineral.* 110 2 pp235-247.

Cuney, M., Leroy, J., Valdiviezo, P. A., Daziano, C., Gamba, M., Zarco, A. J., Morello, O., Ninci, C. and Molina, P.(1989). Geochemistry of the uranium mineralized Achala granitic complex, Argentina: Comparison with Hercynian peraluminous leucogranites of western Europe. In: *Metallogenesis of Uranium Deposits*. Proc. Tech. Comm. Meeting, IAEA, Vienna. pp211-231.

Dahlkamp, F. J.(1978). A classification of uranium deposits. *Min. Deposita*, vol.13, pp83-104.

Dahlkamp, F. J. (1989). Classification scheme for uranium ore deposits - A state of the art review. In: *Metallogenesis of uranium deposits* (Proc. Tech. Comm., Vienna, 1987), IAEA, Vienna.

Davis, J. C.(1973). *Statistics and Data Analysis in Geology*. Wiley, New York, 2nd ed., 646p.

Elegba, S. B., Okujeni, C. D. and Mustapha, A. O.(1988). Geobotanical uranium exploration based on bark samples from Savanna trees - Feasibility study. *Uranium 4*, pp219-225.

Enu, E. I.(1978). Contribution a l etude sedimentologique des formations Cretaces dans la haute valle de la Benoue. *Unpublished thesis Nice*, 178p.

Enzmann, R. B.(1972). Molybdenum: Element and Geochemistry. In: *The Encyclopedia of Geochemistry and Environmental Sciences* (Fairbridge, R. W. ed.). Van Nostrand Reinhold Company, New York.

Erlank, A. J.(1968). The terrestrial abundance relationship between K and Rb. In Ahrens, L. H. (ed.) *Origin and distribution of the Elements*. Int. Ser. Mon. Earth Sci. 30, pp871-888.

Ernst, W. G.(1976). *Petrologic Phase Equilibria*. Freeman, San Francisco, 333p.

Evans, Jr., H. T. and Landergrén, S. (1974). Vanadium. In K. H. Wedepohl (ed.) *Handbook of Geochemistry II-4* - Springer-Verlag, Berlin.

Ewart, A.(1968). Trace and minor element geochemistry of the rhyolitic volcanic rocks, Central North Island, New Zealand. In: K. H. Wedepohl(ed.) *Handbook of Geochemistry I*. Springer-Verlag, Berlin.

- Falconer, J. D.(1911). *The geology and geography of northern Nigeria*. McMillan, London, 295p.
- Fehn, U., Catholes, L. M., Holland, H. D. (1978). Hydrothermal convection and uranium deposits in abnormally radioactive plutons. *Econ. Geol.* vol. 73, pp1556-1566.
- Fischer, R. and Lutwein, F.(1972). Selenium. In K. H. Wedepohl (ed.) *Handbook of Geochemistry* II-3 - Springer-Verlag, Berlin.
- Friedrich, M. and Cuney, M.(1989). Uranium enrichment processes in peraluminous magmatism. In: *Uranium Deposits in Magmatic and Metamorphic Rocks* (Proc. Tech. Comm. Salamanca, 1986), IAEA, Vienna.
- Freidrich, M., Cuney, M. and Poty, B.(1987). Uranium geochemistry in peraluminous leucogranites. *Uranium*, 3, pp353-385.
- Funtua, I. I.(1985). An orientation biogeochemical survey on some mineral occurrences in the Peta syncline, Sheet 153 (Wuyo). *Unpublished B. Sc. Thesis. Ahmadu Bello University, Zaria, Nigeria.* 42p.
- Funtua, I. I.(1988). Geology and genesis of uranium mineralization at Kanawa, Gubrunde horst, N.E. Nigeria. *Unpublished M. Sc. Thesis. Ahmadu Bello University, Zaria, Nigeria.* 88p.
- Funtua, I. I., Okujeni, C. D., Elegba, S. B. and Mustapha, A. O.(1991). Biogeochemical technique applied in uranium exploration. *Journ. Min. Geol.* vol.27
- Funtua, I. I., Okujeni, C. D., Abaa, S. I. and Elegba, S. B.(1992). Geology and genesis of uranium mineralization at Kanawa, Gubrunde horst, N.E. Nigeria. *Journ. Min. Geol.* vol.28.
- Funtua, I. I. and Okujeni, C. D. (1992). An overview of the geological and structural setting of the uranium mineralization of Gubrunde horst, N. E. Nigeria. *Journ. Min. Geol.* (Submitted).
- Garrels, R. M. and Larsen, E. S.(1959). Geochemistry and mineralogy of the Colorado Plateau uranium ores. *U.S. Geol. Survey Prof. Paper* 320, 236p.

- Grant, N. K.(1971). South Atlantic, Benue Trough and Gulf of Guinea Cretaceous triple junction. *Bull. geol. Sur. Amer.* 82, pp2295-2298.
- Grant, N. K., Rex, D. C. and Freeth, S. J.(1972). Potassium-Argon Ages and Strontium Isotope Ratio Measurements from Volcanic Rocks of North-Eastern Nigeria. *Contr. Miner. and Petro.*, vol.35, pp277-295.
- Guiraud, M.(1989). Explanation to geological map of parts of the Upper Benue valley. *Elf Nigeria Ltd.*
- Heier, K. S. and Billings, G. K.(1970). Rubidium. In K. H. Wedepohl (ed.) *Handbook of Geochemistry II-2* - Springer-Verlag, Berlin.
- Jones, G. P.(1963). Deformed cross-stratification in Cretaceous Bima sandstone, Nigeria. *J. Sed. Pet.* vol. 32, pp231-239.
- Knipping, H. D. (1974). The concepts of supergene versus hypogene emplacement of uranium at Rabbit Lake, Saskatchewan, Canada. In: *Formation of Uranium Ore Deposits*. IAEA, Vienna. pp531-549.
- Kogbe, C. A. (1981). Major transgressive episodes in the Benue Valley of Nigeria. *Earth Evol. Sci.* vol. 1, pp144-148.
- Lancelot, J. R. and Maurin, J. C.(1985). Occurrence of upper Jurassic and Neogene uranium mineralizations in NE, Nigeria as indicated by U/Pb dating. *13th Colloquium of African Geology, St. Andrews, Scotland.*
- Lang, A. H., Griffith, J. W. and Steacy, H. R.(1962). Canadian deposits of uranium and thorium. In *Canada Geol. Survey Econ. Geology Rept.* 161 (2nd. ed.), 324p.
- Langford, F. F. (1974). A supergene origin for vein-type uranium ores in the light of the Western Australian calcrete - carnotite deposits. *Econ. Geol.* vol.69, pp516-526.
- Larsen, E. S., Phair, G., Gottfried, D. and Smith, W. S.(1958). Uranium in magmatic differentiation. *Int. Conf. Peaceful Uses of Atomic Energy*, vol.6, pp240-246.

Lawal, O.(1979). Microbiostratigraphie des formations Cretaces de la region de Gombe, Nigeria Nord-Orientale. *Unpublished thesis Nice*, 62p.

Leroy, J.(1978). The Margnac and Fanay uranium deposits of the La Crouzille District (western Massif Central, France): Geologic and fluid inclusion studies. *Econ. Geol.*, vol. 73 pp1611-1634.

Mason, B.(1966). *Principles of Geochemistry*. Third ed., New York, John Wiley and Sons. 329p.

Maurin, J. C.(1985). Analyse de zones décrochantes dans la fosse de la Benoue(Nigeria) et systematiques U-Pb et Pb-Pb appliquees aux mineralisations uraniferes et Pb-Zn associees. *Unpublished thesis,Academie de Montpellier, Montpellier*.

Maurin, J. C. and Lancelot, J. R.(1990). Structural setting and U-Pb dating of uranium mineralizations from the NE, Nigeria (Upper Benue Trough). *Journ. African Earth Sci.* vol. 10 pp421-433.

Maurin, J. C. and Lancelot, J. R.(1987). Origine des Mineralizations de Pb-Zn de la vallee de la Benoue (Nigeria) d'apres la composition en Pb des galenes et de L'enceissant. *Min. Deposita* vol. 22 no.

McMillan, R. H.(1977). *Uranium in Canada*. Canadian Petroleum Geology Bull., vol.25, pp1222-1249.

Meyer, C. and Hemley, J. J.(1967). Wall rock alteration. In: *Geochemistry of Ore Deposits*, H. L. Barnes (ed.) New York, Holt, Rinehart and Winston, pp166-235.

Nash, J. T. and Granger, H. C. and Adams, S. S.(1981). Geology and concepts of genesis of important types of uranium deposits. *Econ. Geol.* 75 Anniversary Volume. pp63-116

Nockolds, S. R.(1954). Average chemical composition of some igneous rocks. *Geol. Soc. Am. Bull.* 65, pp1007-1032.

Norman, J. C. and Haskin, L. A.(1968). The geochemistry of Scandium. *Geochem. Cosmochim. Acta.* vol.32, pp98-108.

NUMCO. (1978, 1979, 1980, 1981, 1982). *Unpublished Annual Reports*.

Offodile, M. E.(1976). The geology of the middle Benue, Nigeria. *Unpublished Ph.D thesis, Uppsala.*

Ogunleye, P. O.(1991). Geology and geochemistry of Zona uranium mineralization and laboratory beneficiation study of uranium ore from Kanawa, N.E., Nigeria. *Unpublished M. Sc. thesis. Ahmadu Bello University, Zaria, Nigeria. 97p.*

Ogunmokuwa, O. Z. (1985). The geology and soil geochemical investigation around some mineral occurrences in parts of the Peta syncline (Sheet 153), NE, Nigeria. *Unpublished B. Sc. thesis. Ahmadu Bello University, Zaria, Nigeria. 69p.*

Ojo, O. M.(1982). Geology and stream sediment geochemical survey of middle Gongola basin (Upper Benue Trough) of Nigeria. *Unpublished Ph.D thesis. University of Ibadan, Ibadan, Nigeria. 386p.*

Ojo, O. M.(1984). Pre-Turonian structural control of base metal mineralization in Gongola basin. *Nig. Journ. Min. Geol. vol. 21 nos. 1 & 2. pp13-17.*

Ojo, O. M.(1988). Stream sediment geochemistry of Gubrunde horst, Gongola basin, Upper Benue trough, Nigeria. *Journ. African Earth Sci. vol.7. no.1 pp91-101.*

Okujeni, C. D.(1987). Biogeochemical investigation into possible use of leaf and bark samples of some savanna trees in prospecting uranium in the Upper Benue Trough. *Nig. J. Sci. Res. vol.1 pp57-64.*

Okujeni, C. D. and Funtua, I. I.(1992). Geochemical and Gamma spectrometric analysis of ores and host rocks of the Kanawa uranium occurrence, NE, Nigeria. (Submitted).

Okujeni, C. D., Funtua, I. I., Ogunmokuwa, O., Baba, I. and Edegbo, S.(1990). A geochemical Orientation survey for uranium in the Peta syncline and Gubrunde horst, Upper Benue Trough, Nigeria. *Nig. J. Sci. Res. vol.3*

Onishi, H. and Sandell, E. B.(1955). Geochemistry of Arsenic. *Geochem. Cosmochim. Acta. vol.7, 1*

Oshin, I. O. and Rahman, M. A.(1986). Uranium favourability study in Nigeria. *Journ. African Earth Sci. vol.5 No.2 pp167-175.*

Pagel, M.(1982). The mineralogy and geochemistry of uranium, thorium and rare earth elements in two radioactive granites of the Vosges, France. *Min. Mag.* 46, 339, pp149-161.

Plimer, I. R. and Elliott, S. M.(1979). The use of Rb/Sr ratios as a guide to mineralization. *Journ. Geochem. Explor.* No.12, pp21-34.

Popoff, M., Kampuzu, A., Coulon, C. and Esquevin, J. (1982). Decouverte d'un volcanisme mesozoique dans le Nord-Est du Nigeria: datations absolues, caracteres magmatiques et significations dans l'evolution du rift de la Benoue. In: Popoff M. et Tiercelin, J. J.; ed. Rifts et fosses anciens. *Trav. Lab. Sci. Terre; Fac. St Jerome, Marseille, B, 19, pp47-49.*

Popoff, M., Benkheilil, J., Simon, B. and Mote, J. -J.(1983). Approche geodynamique du fosse de la Benoue (NE Nigeria) a partir des donnees de terrain et de teledetection. *Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine, vol.7, No.1 pp323-337.*

Poty, B., Leroy, J. and Cuney, M.(1974). Les inclusions fluid dans les mineraux des gisements d'uranium intragranitico du Limousin et du Foret (Massif Central, France). In: *Formation of Uranium Deposits*. IAEA, Vienna. pp569-582.

Poty, B., Leroy, J., Cathelineau, M., Cuney, M., Friedrich, M., Lespinasse, M. and Turpin, L. (1986). New metallogenic concepts on the genesis of uranium vein type deposits in the French Hercynian Chain. In: *Vein Type Uranium Deposits*. IAEA, Vienna. pp215-246.

Rich, R. A., Holland, H. D. and Petersen, U. (1977). *Hydrothermal uranium deposits*. Developments in Economic Geology, 6. Elsevier Scientific Publishing Company, 264p.

Robert, K.(1972). Yttrium: Element and Geochemistry. In: *The Encyclopedia of Geochemistry and Environmental Sciences* (Fairbridge, R. W. ed.). Van Nostrand Reinhold Company, New York.

Robertson, D. S., Tilsley, J. E. and Hogg, G. M.(1978). The time-bound character of uranium deposits. *Econ. Geol.* vol.73, pp1409-1419.

Rogers, J. J. W. and Adams, J. A. S. (1967). Uranium in Wedepohl, K. H. (ed.) *Handbook of Geochemistry*, vol. 2, pt1, Springer-Verlag, Berlin.

Ruzika, V.(1971). Geological comparison between east European and Canadian uranium deposits. *Canada Geol. Survey Paper 70-48*, 196p.

Smith, D. K., Jr(1984). Uranium mineralogy. Dept. of Geosciences Publ. Pennsylvania State Uni., Pennsylvania, U.S.A. 88p.

Stoneley, R.(1966). The Niger delta region in the light of the theory of continental drift. *Geol. Mag.* vol.103, pp385-397.

Strong, D. F.(1985). A review and model for granite-related mineral deposits. Recent Advances in the Geology of Granite-Related Mineral Deposits. *Proc. CIM Conf. on Granite-Related Mineral Deposits*. pp424-445.

Szalay, S. and Samsoni, Z. (1989). Investigation of the leaching of uranium from crushed magmatic rock. *Geochem. International*, vol.6, pp613-623.

Taylor, S. R.(1964a). Abundance of chemical elements in the continental crust: a new table. *Geochem. Cosmochim. Acta*, 28, pp1273-1285.

Taylor, S. R.(1964b). The application of trace element data to problems in petrology. In: *Physics and Chemistry of the Earth* (Ahrens, L. H. ed.), vol. 6, Oxford, Pergamon Press. pp133-213.

Tubosun, I. A. (1983). Geochronologie U/Pb du socle precambrien du Nigeria. *These 3 cycle, Montpellier II*, 110p.

Vinogradov, A. P.(1962). Average contents of chemical elements in the principal types of igneous rocks of the earth crust: a new table In: *Geochemical Tables*. - Rosler, H. J. and Lange, H. (1975).

Wampler, J. M.(1972). Lead: Element and Geochemistry. In: *The Encyclopedia of Geochemistry and Environmental Sciences* (Fairbridge, R. W. ed.). Von Nostrand Reinhold Company, New York.

Wang, Y. and Rong, J.(1980). A new method of petrochemical calculation developed for granitoids. In: *Metallogenesis of Uranium*. Proc. 26th Int. Geol. Congr. Paris.

Wedepohl, K. H.(1953). Untersuchungen zur Geochemie des Zinks. *Geochim. Cosmochim. Acta*, vol.3, 913.

White, M. V. W. and Martin, R. F.(1980). The metasomatic changes that accompany uranium mineralization in the nonoregenic rhyolites of the Upper Aillik group, Labrador. *Can. Min. vol.18*, pp459-479.

Whiteman, A. (1982). Nigeria: its Petroleum Geology resources and potential. *Graham and Troman, London*, 394p.

Wright, J. B.(1968). South Atlantic continental drift and the Benue trough. *Tectonophysics*, vol.6, pp301-310.

Yu, S. (1989). Characteristics and regional geological environments of uranium deposits in Mesozoic volcanics in East China. In: *Uranium Deposits in Magmatic and Metamorphic rocks* (Proc. Tech. Comm., Salamanca) IAEA, Vienna.

APPENDIX I.

CORE SAMPLES POSITIONS IN METRES.

DRILL CORE 18C

Sample	Position.	Sample	Position	Sample	Position
c14	33.0	c21	41.15	c33	49.75
c13	33.5	c22	41.4	c34	50.0
c12	34.0	c23	41.65	c35	50.25
c11	34.5	c24	41.9	c36	50.50
c10	35.0	c25	42.15	c37	50.75
c9	35.5	c26	42.3	c38	51.0
c8	36.0	c27	42.8	c39	51.25
c7	36.5	c28	44.3	c48	53.0
c6	36.9	c29	44.8	c49	53.3
c5	37.4	c30	45.3	c50	53.55
c4	37.9	c47	45.5	c51	54.05
c3	38.4	c46	46.0	c52	54.55
c2	38.9	c45	46.5	c53	55.05
c1	39.4	c44	47.0	c54	55.55
c15	39.65	c43	47.5	c55	56.5
c16	39.9	c42	48.0	c56	59.0
c17	40.15	c41	48.5	c57	59.5
c18	40.4	c40	49.0	c58	60.0
c19	40.65	c31	49.25	c59	61.0
c20	40.9	c32	49.50	c60	61.5

DRILL CORE D21

Sample	Position	Sample	Position	Sample	Position	Sample	Position.
c310	13	c325	28	c340	43	c342	45
c311	14	c326	29	c362	65	c347	50
c312	15	c327	30	c390	93	c352	55
c313	16	c328	31	c410	113	c357	60
c314	17	c329	32	c411	114	c361	64
c315	18	c330	33	c412	115	c367	70
c316	19	c331	34	c413	116	c372	75
c317	20	c332	35	c414	117	c377	80
c318	21	c333	36	c415	118	c382	85
c319	22	c334	37	c416	119	c387	90
c320	23	c335	38	c417	120	c392	95
c321	24	c336	39	c418	121	c397	100
c322	25	c337	40	c419	122	c402	105
c323	26	c338	41	c420	123		
c324	27	c339	42	c421	124		

DRILL CORE D20

Sample	Position	Sample	Position	Sample	Position	Sample	Position.
c61	4	c112	57	c155	100	c193	143
c63	6	c114	59	c157	102	c199	144
c65	8	c116	61	c159	104	c200	145
c67	11	c118	63	c161	106	c201	146
c69	13	c120	65	c163	108	c202	147
c70	14	c122	67	c165	110	c203	148
c74	18	c124	69	c168	113	c204	149
c76	20	c126	71	c170	115	c205	150
c78	22	c128	73	c172	117	c206	151
c80	24	c130	75	c174	119	c215	156.5
c82	26	c132	77	c176	121	c216	157
c85	28	c134	79	c178	123	c217	157.5
c88	33	c136	81	c180	125	c218	158
c90	35	c138	83	c182	127	c219	158.5
c93	38	c140	85	c185	130	c220	159
c95	40	c142	87	c187	132	c221	159.5
c98	43	c144	89	c190	135	c222	160
c100	45	c146	91	c192	137	c223	160.5
c102	47	c148	93	c194	139	c224	161
c105	50	c150	95	c195	140	c225	162
c108	53	c152	97	c196	141	c226	163
c110	55	c154	99	c197	142	c276	209
						c277	210
						c278	211
						c279	215
						c280	217
						c281	217.5
						c282	218
						c283	219
						c284	220
						c285	221
						c286	222

APPENDIX II

XRD DIFFRACTION DATA OF SAMPLES

A SURFACE SAMPLES.

329		350		380	
d value	I/I ₀	d value	I/I ₀	d value	I/I ₀
9.83	31.1	9.83		9.83	
7.13		7.13		7.14	
4.46		4.50		4.50	
4.27	30.3	4.27		4.27	
4.00		3.83		4.00	
3.59	26.7	3.71		3.71	
3.48		3.59		3.59	
3.35	100	3.48		3.48	
3.10	11.7	3.35	100.0	3.35	100.0
2.56	11.1	3.26		3.26	
2.47	23.3	3.01		3.01	
2.38	8.3	2.95		2.95	
2.34	13.3	2.90		2.90	
2.29	15.0	2.49		2.51	
2.24	10.0	2.33		2.49	
2.19	15.0	2.28		2.38	
2.13	11.1	2.23		2.28	
1.98	10.0	2.15		2.24	
1.90		2.11		2.13	
1.82	10.3	1.97		1.98	
1.72	8.3	1.81		1.82	
1.60	10.0	1.67		1.67	
		1.54		1.54	

Mineral.	Prominent Peaks.									
Quartz	3.35	4.27	2.46	2.20	2.24	1.82	2.13	1.98	1.54	
K-feldspar	3.26	3.71	4.00							
Kaolinite	7.13	2.49	2.33	3.59						
Hematite	2.69	2.51	2.19	1.60						
Meta-sulfite	4.30	3.30	2.56	2.13						

B CORE SAMPLES.

C9 (ALTERED GRANITE). C15 (MINERALIZED GRANITE). C20 (ALTERED GRANITE).

d value	I/Io	d value	I/Io	d value	I/Io
9.83	13.0	9.83		9.83	
7.13	9.0	7.13		7.13	
4.44	12.0	5.12		4.44	
4.23	38.0	4.44		4.23	
3.45		4.26		3.38	
3.38	10.0	3.97		3.35	100.0
3.35	100.0	3.80		3.06	
3.12	9.0	3.68		2.82	
3.06	8.0	3.56		2.66	
2.98	7.0	3.45		2.60	
2.70		3.38		2.54	
2.55	10.0	3.35	100.0	2.46	
2.46	21.0	3.32		2.41	
2.43	7.0	3.23		2.33	
2.28	19.0	3.12		2.28	
2.23	12.0	3.02		2.23	
2.21	7.0	2.92		2.21	
2.13	17.0	2.88		2.13	
1.97	12.0	2.84		1.97	
1.91	6.0	2.82		1.91	
1.81	29.0	2.70		1.81	
1.87	13.0	2.62		1.78	
1.65	8.0	2.46		1.72	
1.63	7.0	2.43		1.70	
1.54	20.0	2.33		1.67	
1.50	6.0	2.28		1.65	
		2.23		1.63	
		2.19			
		2.13			
		1.97			
		1.92			
		1.88			
		1.81			
		1.70			
		1.68			

Mineral	Prominent Peaks.							
Quartz	3.35	4.27	2.46	2.28	2.24	1.82	2.13	1.98
K-feldspar	3.26	3.71	4.90					
Kaolinite	7.13	2.49	2.33	3.59				
Hematite	2.69	2.51	2.19	1.68				
Granulite	3.12	1.91	1.66	2.74				
Meta-autinite	4.30	3.30	2.56	2.13				

CORE SAMPLES

C35 (ALTERED GRANITE).		C43 (MINERALIZED GRANITE).		C314 (ALTERED RHYOLITE).	
d value	I/Io	d value	I/Io	d value	I/Io
9.83		9.83		9.83	
7.13		7.13		7.13	
5.42		6.42		4.46	
4.23		4.46		4.23	
3.97		4.23		3.97	
3.80		3.92		3.80	
3.68		3.80		3.68	
3.56		3.68		3.46	
3.45		3.56		3.35	100.0
3.35	100.0	3.45		3.23	
3.23		3.35	100.0	3.12	
3.06		3.22		3.02	
2.98		3.12		2.88	
2.92		3.02		2.69	
2.70		2.92		2.55	
2.65		2.88		2.50	
2.62		2.69		2.48	
2.55		2.59		2.46	
2.50		2.55		2.41	
2.48		2.43		2.28	
2.46		2.33		2.23	
2.43		2.28		1.97	
2.33		2.23		1.88	
2.30		2.15		1.81	
2.28		2.04		1.67	
2.23		1.97			
2.13		1.88			
2.11		1.86			
2.04		1.78			
1.97		1.76			
1.91		1.67			
1.86		1.66			
1.81		1.61			
1.79		1.54			
1.69		1.51			
1.64					
1.61					
1.54					
1.51					

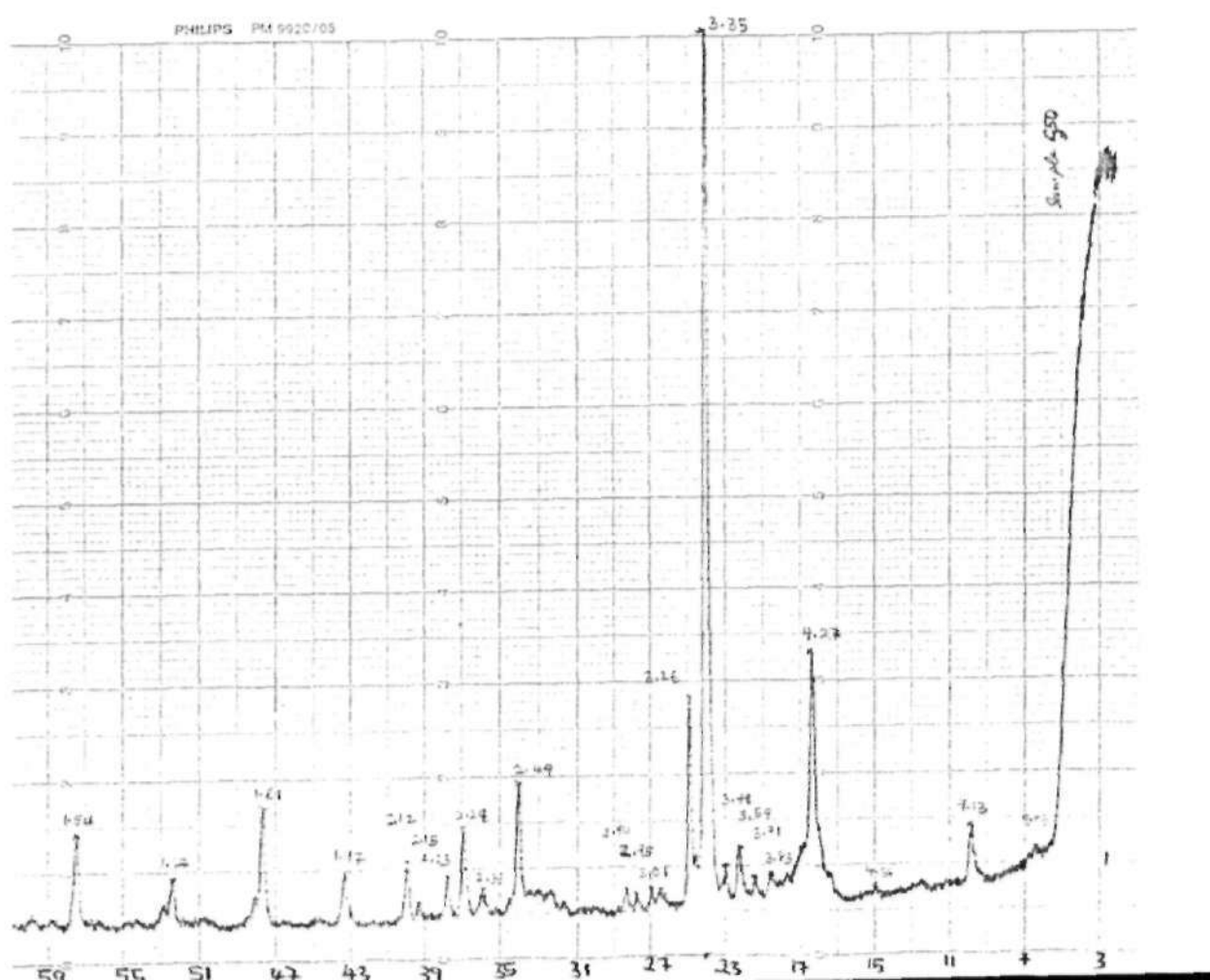
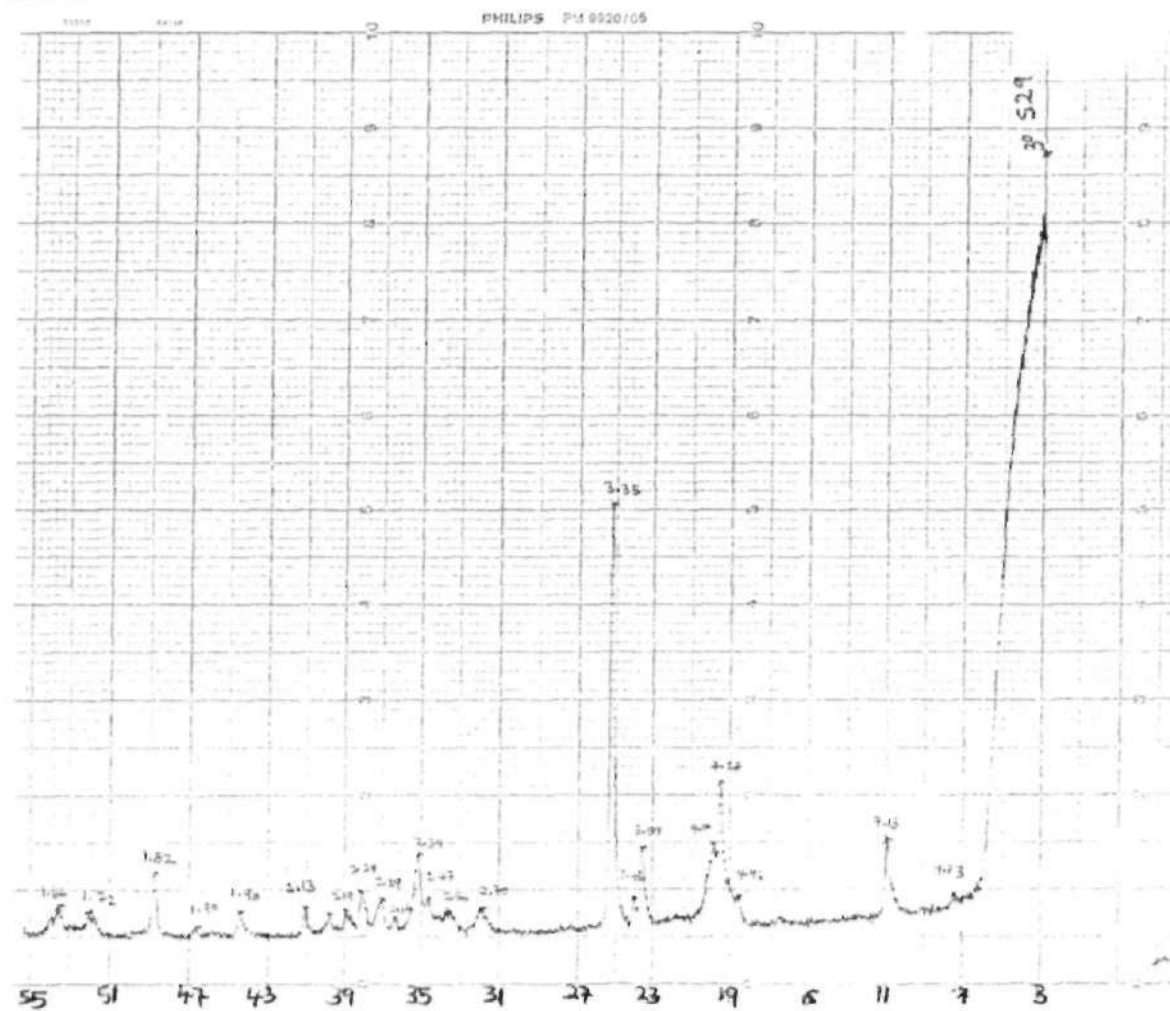
Mineral	Prominent Peaks.									
Quartz	3.35	4.27	2.46	2.23	2.24	1.82	2.13	1.33	1.54	
K-feldspar	3.26	3.71	4.00							
Kaolinite	7.13	2.49	2.33	3.59						
Hematite	2.69	2.51	2.19	1.68						
Traninite	3.12	1.91	1.68	2.74						
Mica-antinite	4.30	3.30	2.58	2.13						

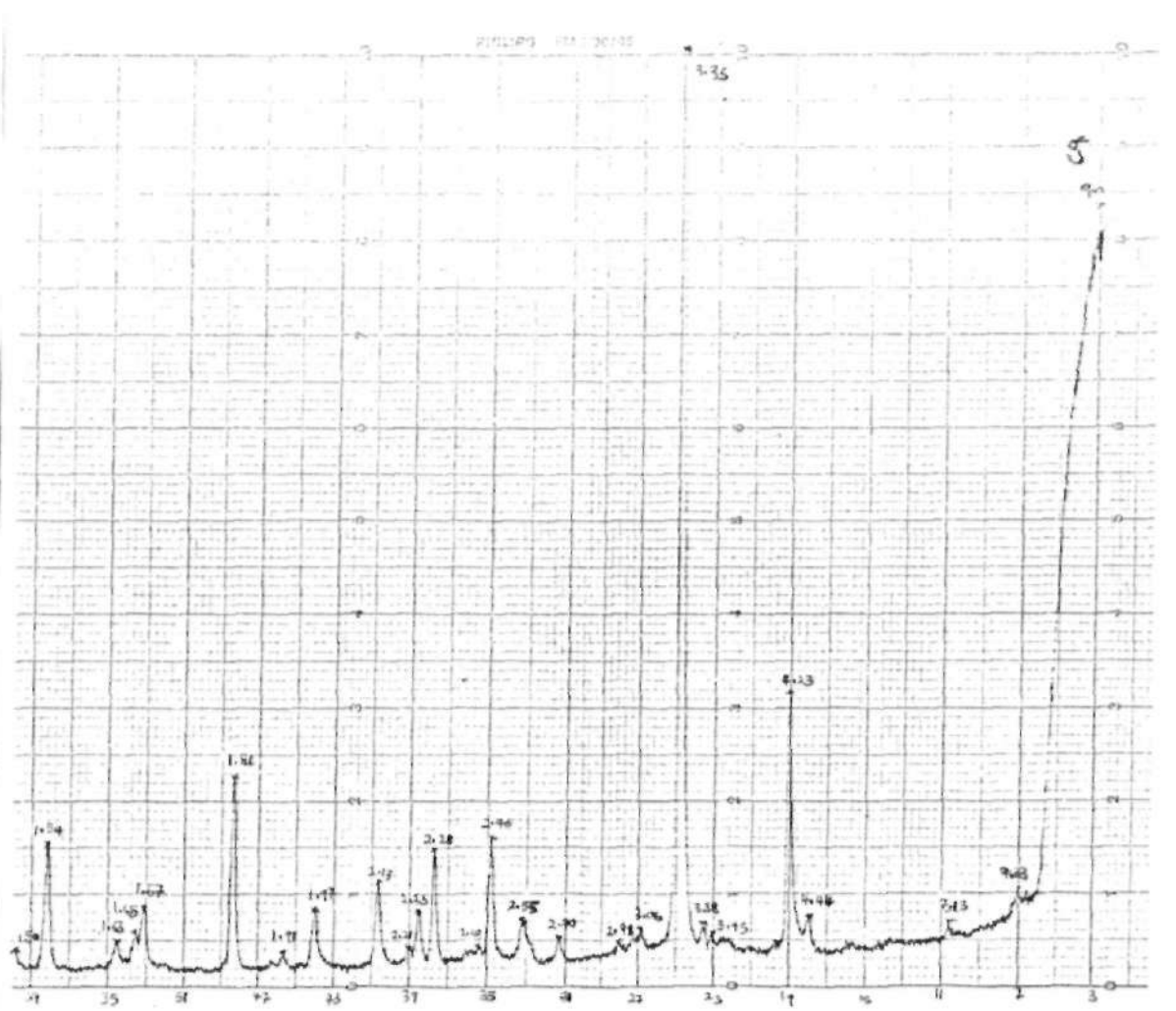
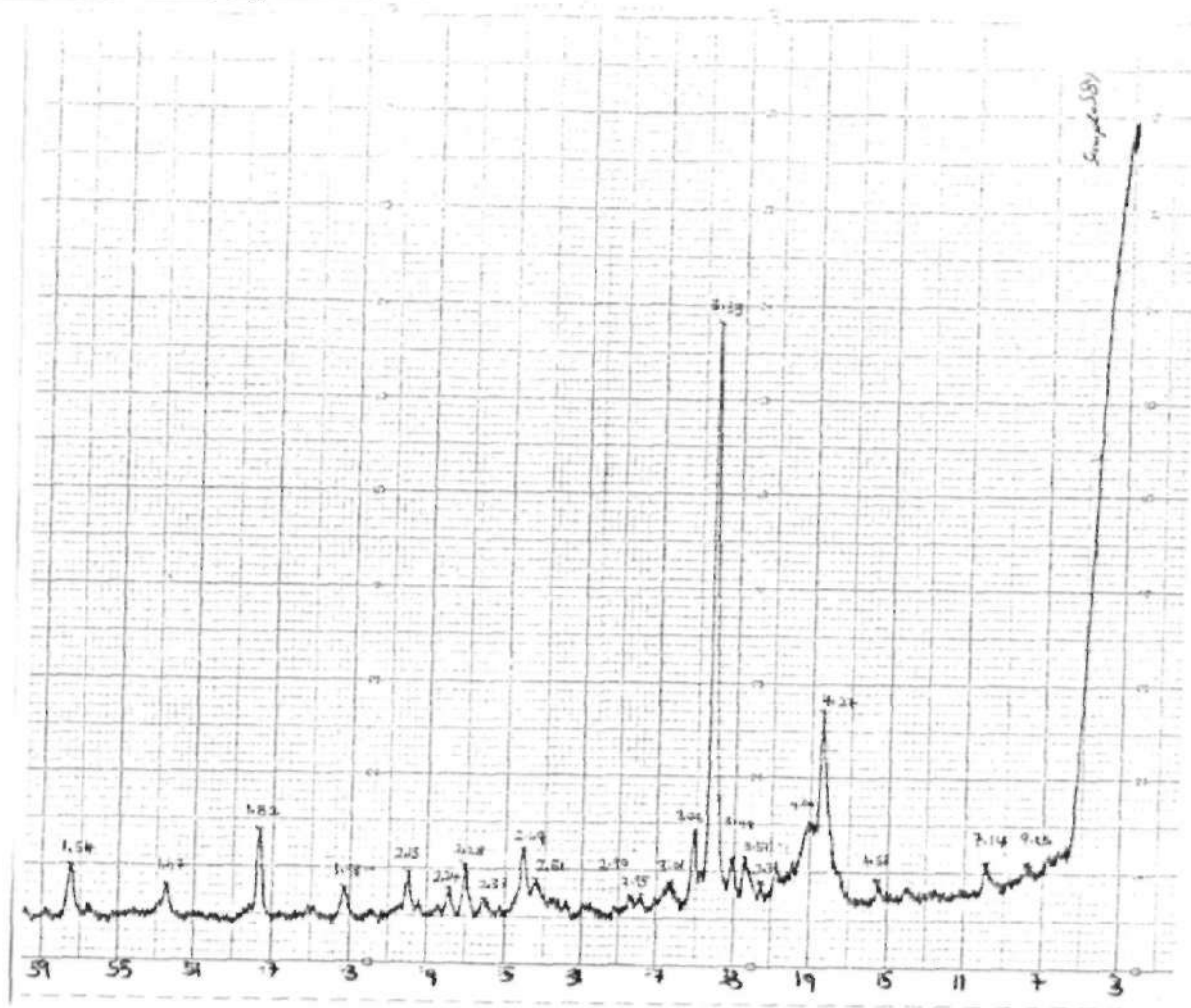
C390 (OLIVINE BASALT).		C410 (ALTERED GRANITE)		C420 (ALTERED GRANITE)	
d value	I/I ₀	d value	I/I ₀	d value	I/I ₀
9.61	47.1	9.83		7.13	
4.44	35.3	7.13		4.46	
4.00	47.1	4.44		4.23	
3.90	29.4	4.23		3.97	
3.74	52.9	3.97		3.80	
3.62	29.4	3.80		3.68	
3.35	17.6	3.68		3.56	
3.19	100.0	3.56		3.45	
3.12	41.2	3.45		3.35	100.0
3.02	58.8	3.35	100.0	3.23	
2.92	36.3	3.32		3.12	
2.83	17.6	3.23		3.02	
2.78	58.8	3.12		2.92	
2.62	64.7	3.02		2.86	
2.43	17.6	2.92		2.84	
2.37	11.6	2.86		2.82	
2.23	11.6	2.70		2.70	
2.12	11.6	2.62		2.62	
1.96	17.6	2.54		2.46	
1.87	11.6	2.40		2.43	
1.72	23.5	2.43		2.33	
		2.33		2.19	
		2.28		2.13	
		2.23		1.97	
		2.15		1.94	
		2.12		1.92	
		2.04		1.89	
		1.97		1.82	
		1.91		1.81	
		1.88		1.78	
		1.81		1.76	
		1.80		1.67	
		1.70		1.58	
		1.67		1.54	

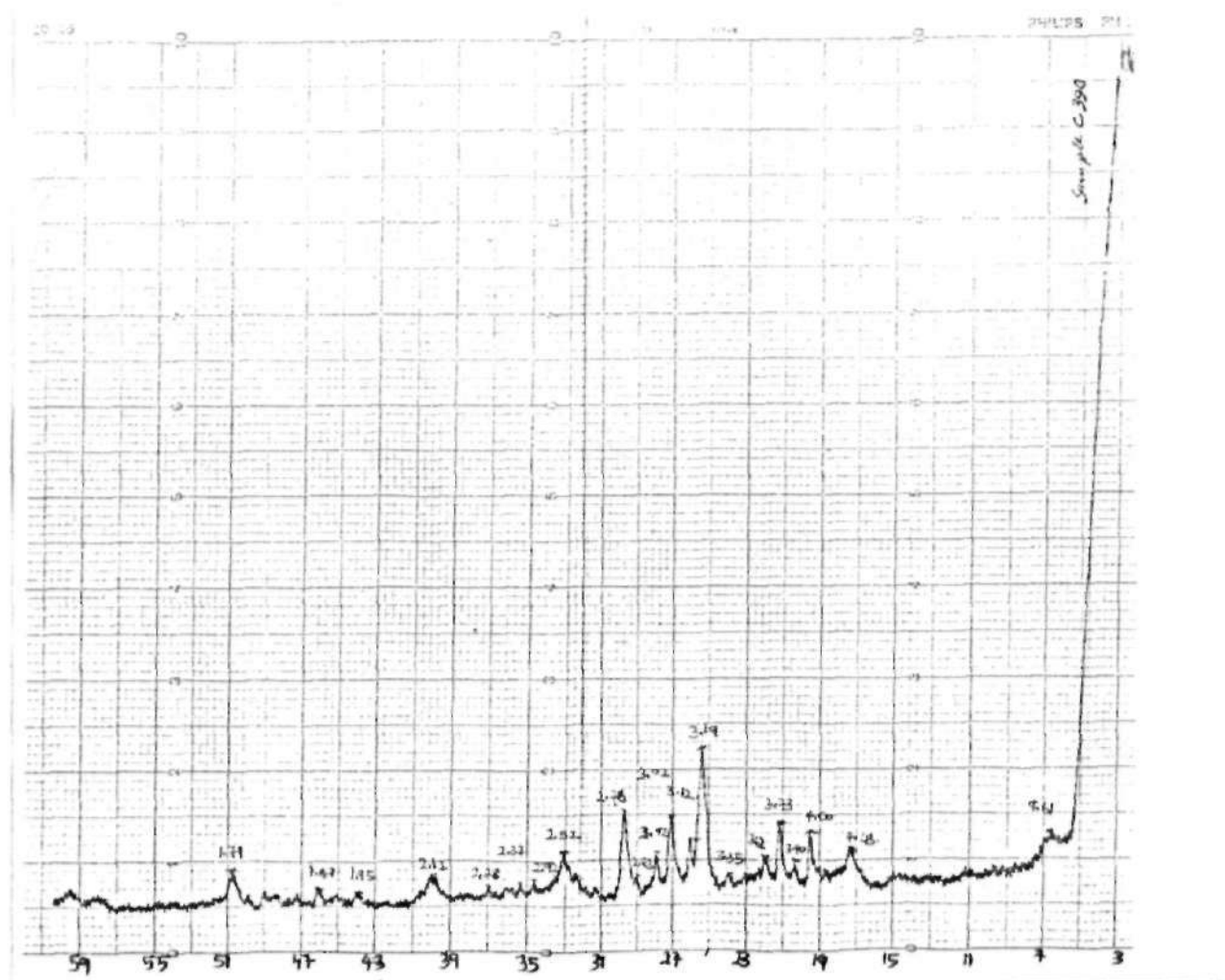
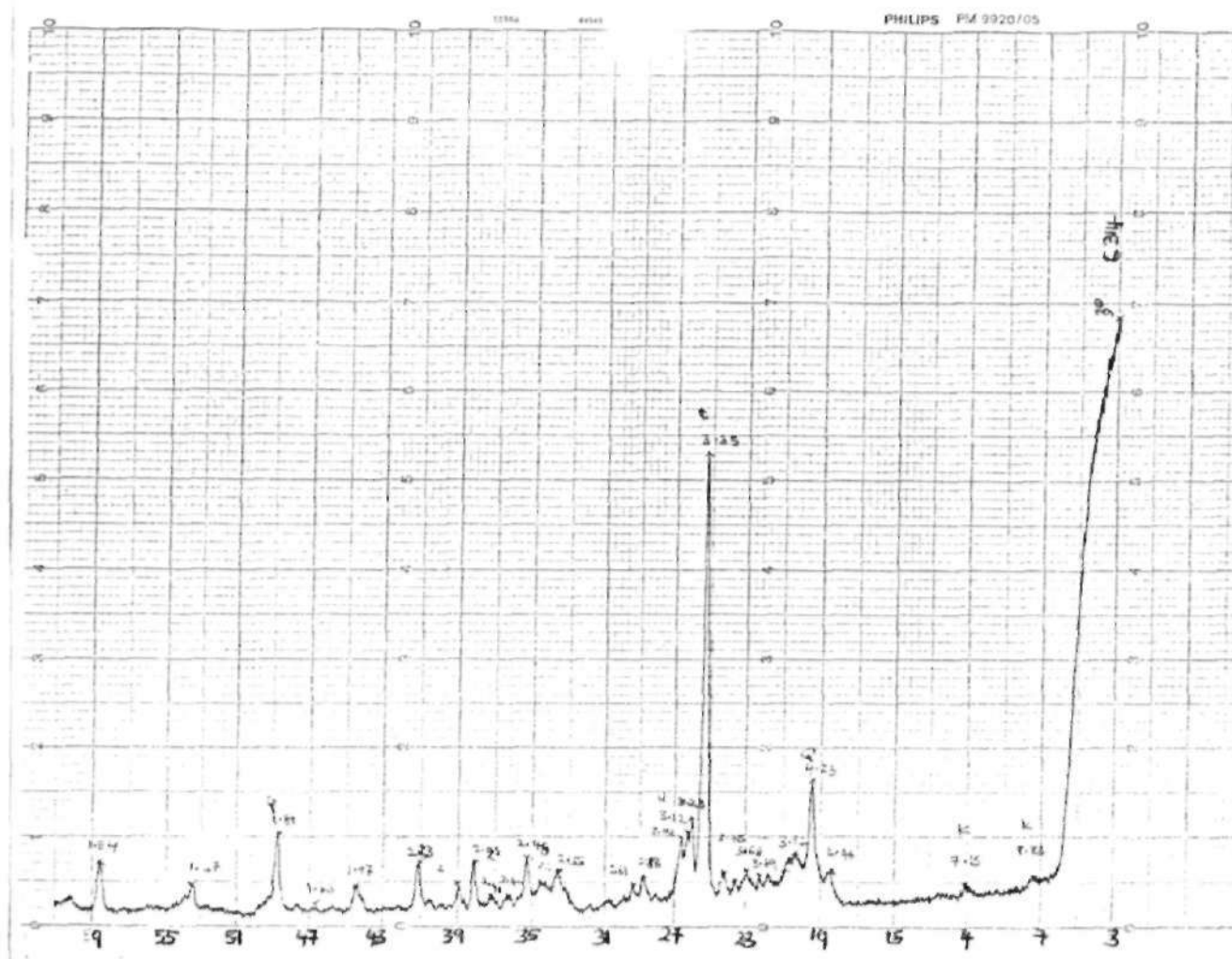
Mineral	Prominent Peaks.									
Quartz	3.35	4.27	2.46	2.28	2.24	1.82	2.13	1.98	1.54	
K-feldspar	3.28	3.71	4.00							
Kaolinite	7.13	2.49	2.33	3.59						
Monite	2.69	2.51	2.15	1.68						
Uraninite	3.12	1.91	1.56	2.74						
Augite	3.01	2.32	2.52	3.35	(C390)					
Labradorite	3.18	3.74	4.00	3.92	"					
Fayalite	2.33	2.42	1.77	3.61	"					
Hornblende	3.12	2.76	9.6		"					

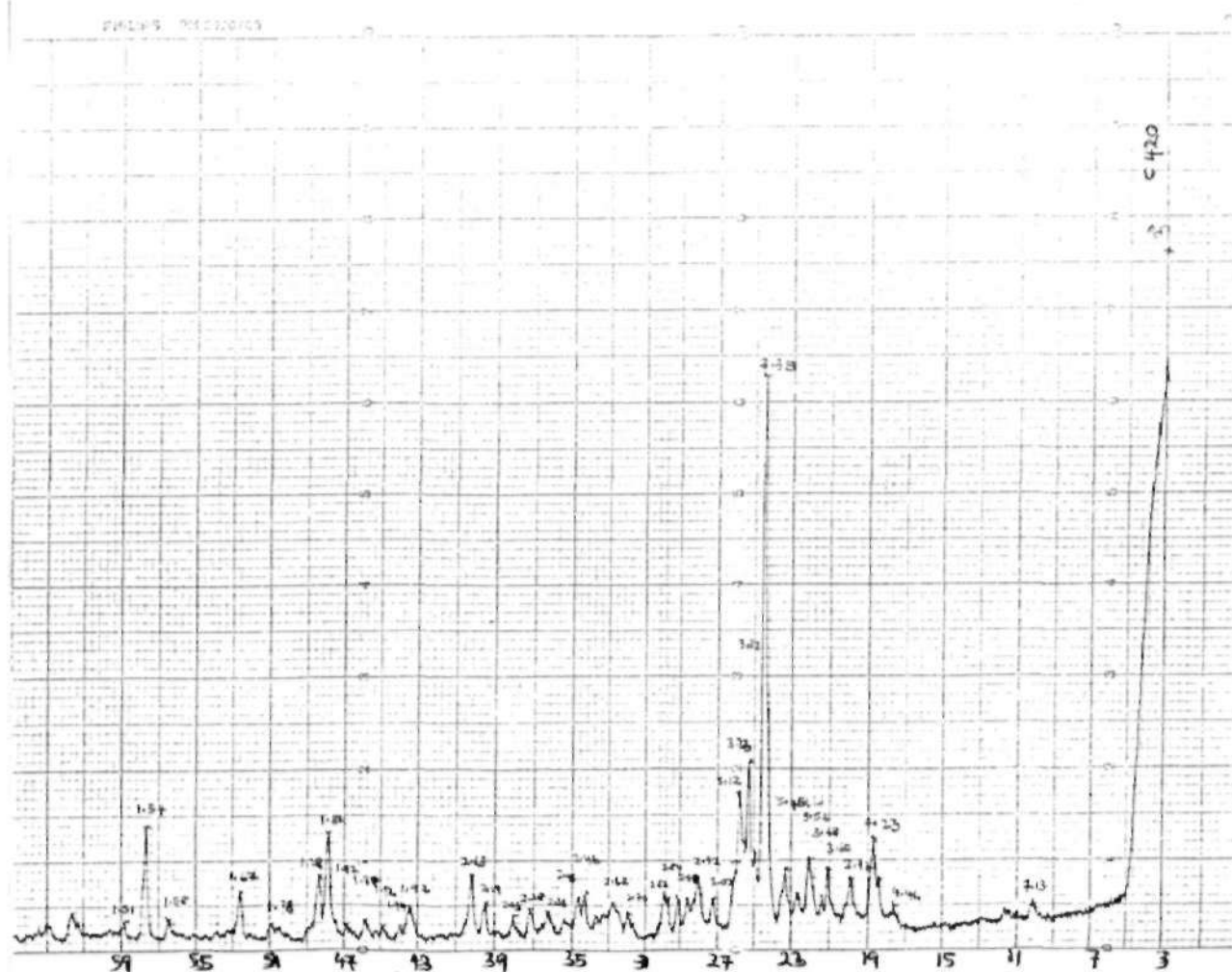
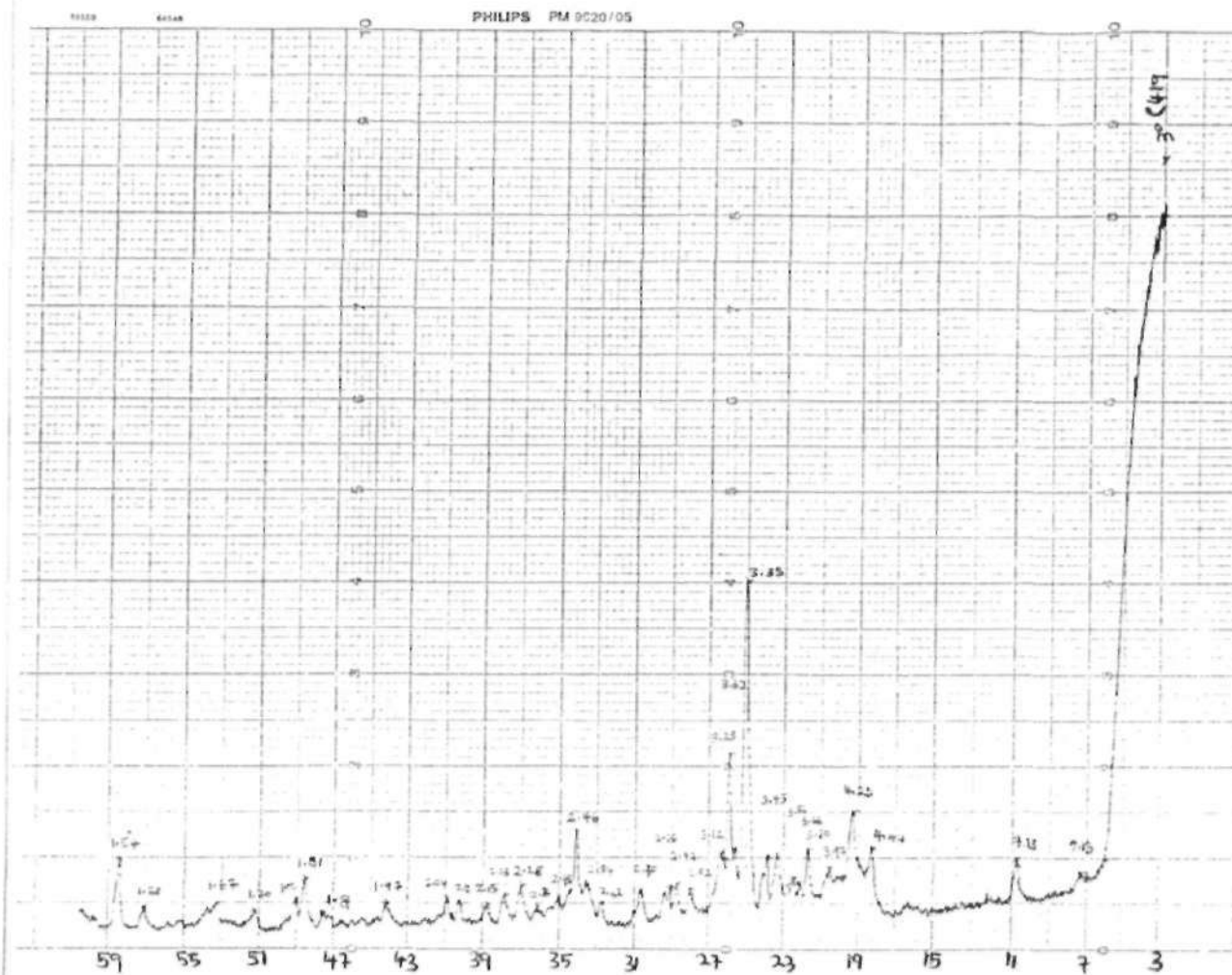
C CHARTS.

(ATTACHED)









APPENDIX III

FUNDAMENTAL PARAMETER METHOD DATA.

I. Average Z determination.

	elastic peak	inelastic peak	ratio	average Z
A. Compounds.				
NaNO ₂	7.146	176.930	0.0408	8.7966
Bi	5.268	9.696	0.5434	28.0
Po	4.361	8.820	0.551	28.0
S	6.798	42.318	0.1606	18.0
K ₂ CO ₃	5.354	57.60	0.093	14.05

B. Samples.

s20	40.191	272.980	0.14723	13.1
s47	17.291	140.636	0.12289	12.6
s50	17.962	131.232	0.13611	12.8
s51	16.778	148.612	0.11289	12.0
s52	17.994	181.435	0.09912	12.3
s53	16.796	118.113	0.14220	13.6
s55	17.459	144.730	0.12063	12.5
s57	17.555	153.620	0.11428	12.1
s59	10.705	53.771	0.19909	15.0
s61	8.496	39.871	0.09468	11.5
s62	8.528	69.982	0.12359	12.7
s67	42.732	360.316	0.11859	12.5

II. Concentration determination.

Peak intensities (I) and concentrations (C) of Fe, Zn and Zr from fitting with the fundamental parameter method.

Sample.	Fe		Zn		Zr	
	I	C (%)	I	C (ppm)	I	C (ppm)
s29	9.578	3.58	0.9776	337	0.193	159
s47	10.699	4.12	0.2670	121	1.788	361
s50	11.496	4.93	0.7699	224	2.559	490
s51	10.720	4.77	0.9917	379	2.467	416
s52	10.557	4.34	0.9834	331	2.357	398
s53	11.537	5.04	0.2532	198	2.286	387
s55	11.293	4.90	0.4050	290	1.890	378
s57	11.024	4.69	0.4118	227	1.476	367
s59	12.710	5.50	0.2316	106	2.524	454
s61	10.229	4.21	0.2599	113	2.474	417
s62	11.303	4.95	0.2316	105	2.285	406
s87	8.742	3.18	0.2910	121	2.211	378

APPENDIX IV

DATA FROM NATURAL ACTIVITY METHOD

A. Formulae

$$\text{Activity} = \frac{n C}{(P E)}$$

A = activity

n = count rate (cps)

E = detector efficiency

P = emission probability

C = corection factor (self-absorption, etc.)

B. Standards.

	Intensity (cps)
0.5%	0.19
0.3%	0.13
0.1%	0.04
0.05%	0.02

C. Samples

	Concentration (ppm)
s49	500
s51	2600
s53	6500
s55	3700
s60	350

D. Radionuclides.

	Energy (E_γ)	Yield (I_γ)	E	C
Th-234	63.3 KeV	0.0381	0.053964	0.44751
Pb-210	46.5 KeV	0.04	0.029342	0.2742
Ra-226	186.1 KeV	0.0328	0.053964	0.7874

1. Count rate (n) of the radionuclides in samples (cps).

Sample	Th-234	Pb-210	Ra-226
s25	0.62924	0.724569	0.31394
s27	0.00485	0.00485	0.0026350
s34	0.663567	0.740078	0.0319645
c20	0.207460	0.015407	0.0036963
c21	0.005666	0.004517	0.0023961
c36	0.005821	0.000955	0.0032459
c41	0.135597	0.120974	0.0587909
c43	1.019951	0.647294	0.4235636
c47	0.032318	0.030509	0.0161219

2. Activity (A) of the radionuclides in samples (Bq/kg).

Samples	Th-234	Pb-210	Ra-226
s25	68497	87664	119933
s27	286	681	2625
s34	72216	86442	119623
c20	2237	1800	4437
c21	617	528	2259
c36	633	1116	1312
c41	13165	15840	22118
c43	134890	154689	212235
c47	160	167	272