GEOLOGICAL AND GEOCHEMICAL INVESTIGATION OF LATERITIC PROFILES AROUND KANO, WITH SPECIAL REFERENCE TO THE DISTRIBUTION OF BASE METALS (V, Cr, Mn, Co, AND Ni).

BY

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B.Sc. (Geology)

Thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfillment of the requirements for the award of the degree of Master of Science Geology (Mineral Exploration).

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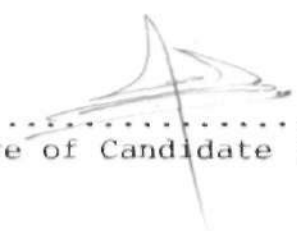
January, 1999

DECLARATION

I de_are that this thesis is my own work and has not been submitted in any other form for another d ee and information derived from published and unpublished work of others has been duly acknowledged in the text.



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Signature of Candidate (Date)

CERTIFICATION

This Thesis entitled **"GEOLOGICAL AND GEOCHEMICAL INVESTIGATION OF LATERITIC PROFILES AROUND KANO, WITH SPECIAL REFERENCE TO THE DISTRIBUTION OF BASE META S V, Cr, Mn, .o, AND Ni"** by **MAGDI OSMAN** meets the regulations governing the award of the degree of M.Sc. Geology (Mineral Exploration) of Ahmadu Bello University and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

To my mother,

HAJA, FADEELA

ACKNOWLEDGEMENT

Above all, I am grateful to the "Almighty Allah" for His inspiration, good health, care, love and protection over me throughtout the period of my study.

I wish to express my gratitude to my supervisor Dr. I.Garba who, despite the tight academic and administration schedules, devoted his time to the success of this work. His frank criticisms, advice and guidance throughout the period of this work are highly acknowledged.

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A B S T R A C T

The distinct lateritic profiles around "Kano Metropolis" were investigated using combined geological and geochemical methods. The area studied is a part of north-central basement complex of Nigeria, and is underlain mainly by the rocks of "Older Granite Suite" (Danbatta, 1985).

Laterization in the area was found to be controlled by lithology and drainage. Lateritic profiles studied were identified into three types:- high-land, low-land and foot-slope iaterites and were distinguished into four horizons from bottom to top; fresh bedrock, saprolite, mottled and indurated layers.

Multivariate statistical methods involving correlation and accumulation factor (AF) were employed in interpretation of geochemical data. The correlation pattern of elements in the lateritic profiles was found to vary with the type of bedrocks and maturity of lateritic horizons. The lateritic horizons are strongly depleted of K, Ca, Rb, and Sr and enriched by Fe, Zr, Mo, Cu, and Pb relative to the parent rock. Accumulation factor (AF) values indicate a possible concentration of V, Cr, Mn, Co, and Ni in lateritic profiles, especially in indurated and mottled horizons. In terms of their potential for mineralization, the mottled and indurated horizons of lateritic profile overlying

diorite hold good promise for concentration of V, Cr, Mn, Co and Ni.

The indurated layer of granite-derived lateriti profile also shows potential for concentration of Cu, Mo and Pb. Similarly, the saprolite layer of the same profile shows good promise for concentration of Zn.

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CHAPTER ONE

INTRODUCTION

1.1. LOCATION AND EXTENT OF THE STUDY AREA

The study area which forms part of the greater "Metropolitan Kano", covers an area of approximately 1825km^2 and is situated within latitudes 11°35' and 11°55'N and longitudes 8°15' and 8°45'E, extending from River Rafin Malam in the North, the village of Tamburawa to the South fig.(1.1 and 3.2).

1.2. GEOGRAPHY

The area of study lies on an altitude of 450 metres above sea level, comprising gently undulating plains, sloping to the northeast. There are two prominent hills, Goron Dutse and Dala, which rise 203m and 148m respectively above the surrounding plain.

The southern part of the area is drained by Challawa River and its main tributary the Kano River (fig. 3.2.). The remainder of the area also lies within the Challawa River basin with the river being joined on its left bank by a number of major tributaries, including Watari, Tatsawarki, Jakara and Tsakama stream system. Within the area no major stream joins the Challawa in its right bank.

The study area is influenced by tropical and continental

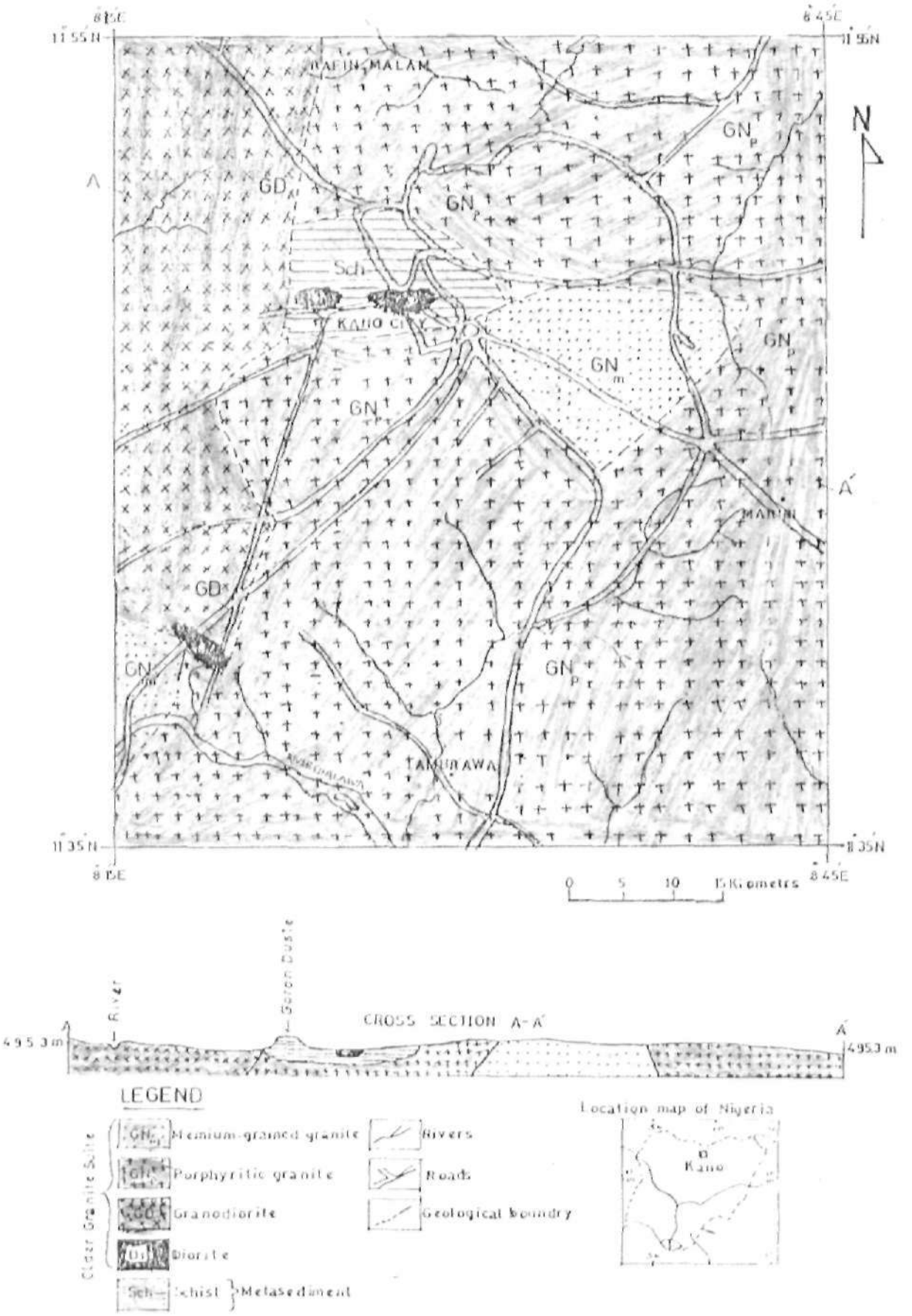

Fig1l Geological and location map of Kano Metropolis reproduced from a base map compiled at the scale of 1:25,000 (Magdi, 1999)

climate, evaporation is generally high and is in excess of rainfall, except in the months of July-August. The vegetation is the Sudan-Savanna type. The Land is used for agricultural, forestation and urban purposes.

1.3. ACCESSIBILITY

The area is accessible almost entirely by means of various motorable roads traversing it (fig.3.2.). Access to most parts of the area can be gained either by motorcars, motorcycles or by foot, because of the plain nature of the relief. However, there are difficulties in getting access to places owned by private or official sectors because of the cosmopolitan nature of the area.

1.4. NATURE OF OUTCROPS AND METHODOLOGY OF MAPPING AND SAMPLING

Few rock exposures are encountered in the study area. These outcrops are scattered and only few of them are of relatively great areal extent, e.g locality M10 at Tamburawa village in the south and locality M7 near Hadejia road to the north, where they form low hills (plate iii). The remaining exposures form either low-lying outcrops (plate iv, v, viii, and ix), or detached boulders (plate i & ii). However, exposures of lateritic profile are abundant everywhere in the area.

The traverse method was used for the geological mapping in the area. Traverses were taken with the aid of a

geological compass. The area was mapped on the scale of 1:25,000 on a base map provided by Geological Survey of Nigeria Kano Office. And compiled at the scale of 1:500,000 (fig. 1.1).

Rock samples were taken and described from outcrops along the traverses. Samples from laterite horizons we. taken along the vertical profiles.

1.5. DURATION OF PRESENT WORK

The literature review on the subject of lateritization in general was carried out in September 1996. Fieldwork started later in December 1997 lasting for two weeks for the reconnaissance and later another two weeks for the detailed work. Laboratory work started from mid-January to February 1998 for the preliminary analysis and again from mid-May to July 1998 for more geochemical analyses.

1.6. PREVIOUS WORK

There had not been much geological work done in the study area. The few workers that previously studied various aspects of the area include:

(i). Raeburn and Jones (1934), who while studying the hydrology of Chad drainage basin, gave general descriptions of the rock types found in the basement complex within the present Kano State.

(ii). Du Preez (1948), Du Preez and Richards (1958),

who worked in Gumel Emirate of Kano State, studied the hydrology and described the basement rocks.

(iii). Du Preez (1956), studied the origin, classification and distribution of Nigeria laterites and some of the examples used were from Kano State (formerly Kano Province).

1.7. AIMS AND SCOPE OF PRESENT WORK

Laterite has a wide distribution in the study area and hence, forms a high potential for economical exploitation Because in many places of the world interest have developed on the economic potential of laterite, such as Indonesian nickel laterite (Chadwick, 1992), some attempts have been made to find whether the laterite occurrence in the Kano area can have potential for economic mineral exploration.

Long time ago, the local inhabitants of this area were aware of the importance of laterite as a source of iron, for this reason they have for long been exploiting them for their local needs from the Dala hill (plate x)(E.D.R.E.S, 1997).

The scope of this work includes:

(a). The study of the general geology of the study area.

(b). The study of the types, distribution and

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classification of laterite profiles around the area.

(c). The study of the possible chemical trends and distribution patterns of both major and trace elements with special attention to base metals e.g V, Cr, Mn, Co and Ni in the lateritic profiles around the area.

(d). To assess the implication of the geochemical characteristics of lateritization for mineral exploration in the area.

CHAPTER TWO

LITERATURE REVIEW

2.1. INTRODUCTION

Prolific literature have developed since Buchanan (1807) gave the name "laterite" to the mantle of ferruginous deposits which cover large areas in Southern India. According to Maignien (1966) the reason for this abundance of literature seems to be that laterite - and its far more economically important variant, bauxite - is not uniquely identified with any particular parent rock, geological age, single way of formation, climate per se, or geographical location. The details of the mechanism of formation of laterite and bauxite have long been argued by soil scientists and geologists. Excellent reviews of all aspects of laterites (morphology, composition, distribution, classification, origin, etc) have been prepared by Sivarajasingham et al (1962), Maignanic (1966), Valenton (1972) and Bleakely (1964).

2.2. DEFINITION

According to Prescott and Pendlenton (1952) it was Buchanan (1807) who first gave the name "laterite, which is merely a translation from latin "later" meaning "brick" and so relating solely to the use to which these blocks are put. It seems that there is no unanimity among geologists upon the definition of the term "laterite", and this can be

cited from the works of Buchanan (1807), Babington (1821), Walther (1915), D'Hoore (1954), Maignien (1966), Sivarajasingham et al (1962) and Zeissink (1969). However, it has been generally accepted that, the term will embrace a highly weathered material, rich in secondary oxides of iron, aluminium, or both, it is nearly void of bases and primary silicates, but may contain large amount of quartz and kaolinite (Alexander and Clay, 1962). McFarlane, (1983) reported that, some types of laterite have the ability to harden irreversibly when exposed and dried (plinthite), whereas some are quite soft and remain so after exposure. The laterite may be few centimetres to tens of meters thick. It may rest almost direct on fresh rock, but is more commonly underlain by saprolites (weathered rock, commonly kaolinitic which retains the original rock structures and texture). Saprolite zone sometimes reaches over a hundred meters in thickness. Freyssinent et al (1990), distinguishes the lateritic profiles into five zones, these are from the base to the top, fresh bedrock, coarse-grained saprolite, fine-grained saprolite, mottled zone and an indurated pisolitic (ferricrete) fig.(2.1.).

Laterites are often recognisable by the segregation of Fe, Al, or both, to form a variety of structures and textures, ranging from discrete segregation (pisoliths or nodules) to continuous skeletons (vermiform or vermicular structures) (McFarlane, 1983).

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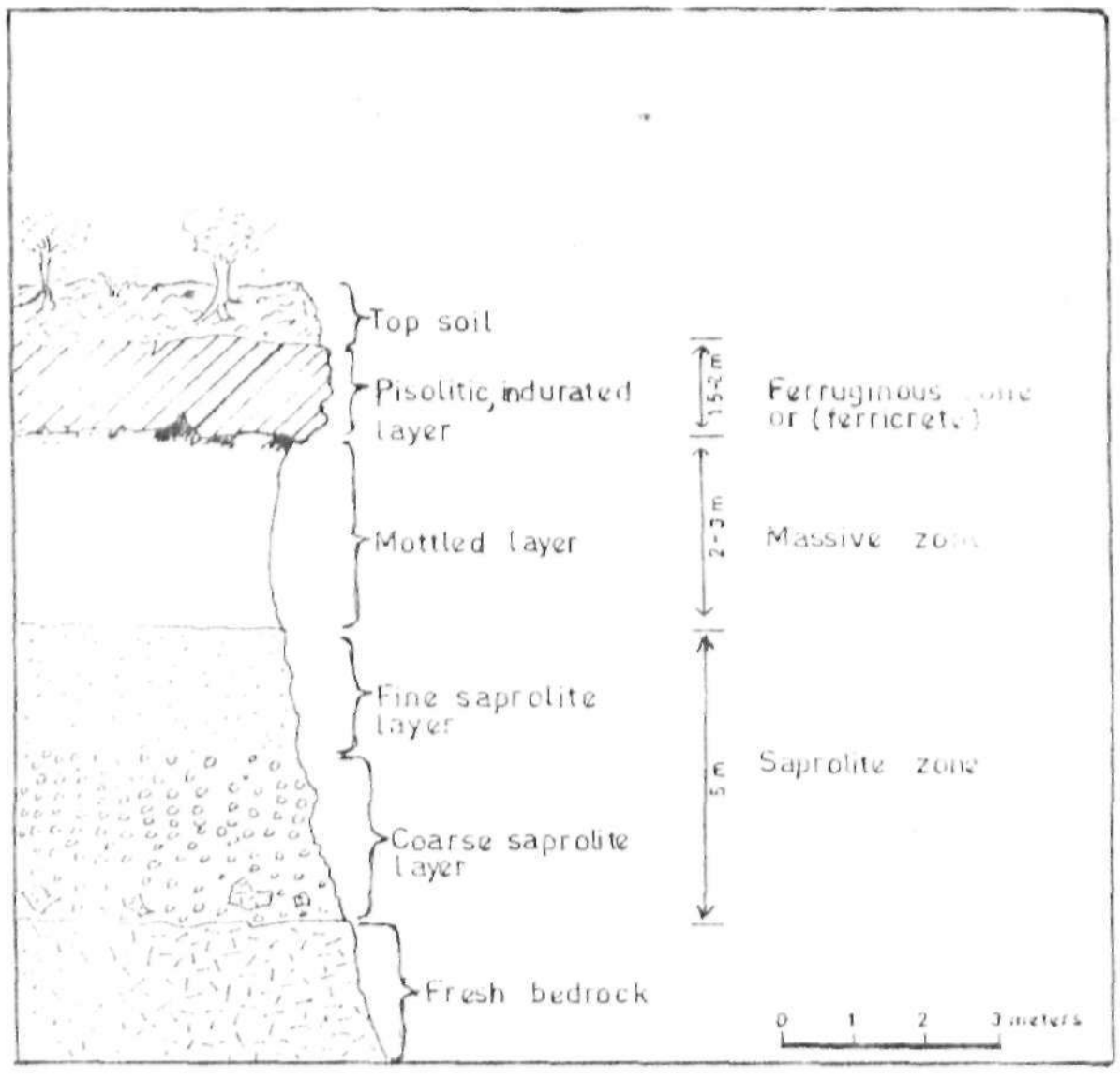

Fig 2.3 Schemmatic drawing showing a typical lateritic profile (Magdi, 1999).

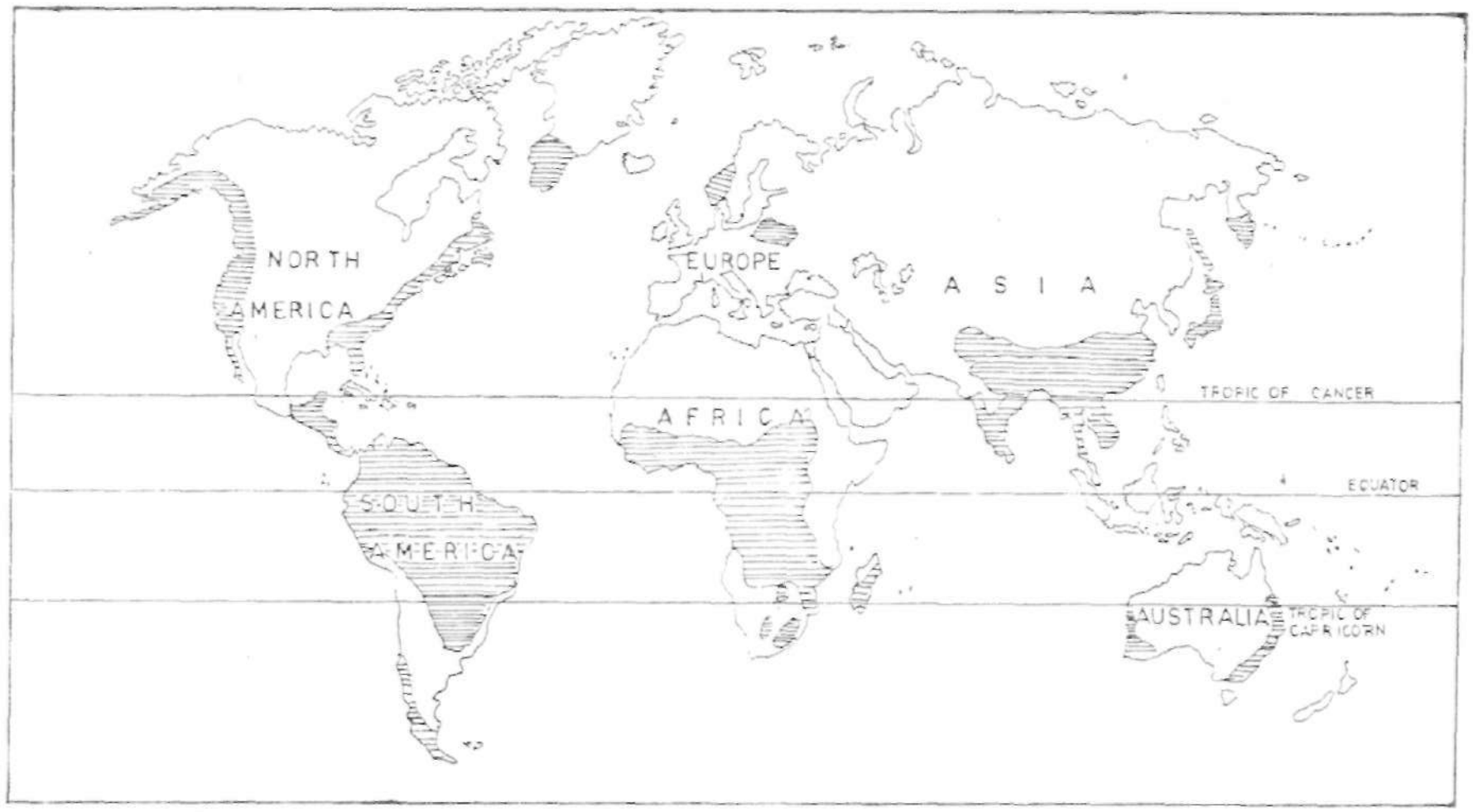

Fig 2.2 Schematic drawing of the world map showing the possible occurrence of laterite (After Magdi, 1999).

2.3. GLOBAL DISTRIBUTION

Laterites are widely distributed throughout the world (fig. 2.2.) but especially in the tropical and intertropical regions of Africa, Australia, India, Southeast Asia and South America. Distribution does not neccessarily correspond to existing conditions of genesis. Many of these occurrences are relics or fossils (Maignien, 1966). Maignien (1962) and Muckentiousen (1962) reported that the ferruginous soils in the USA can be largely classified as laterite. Some of the burried soils under the Condroze Sandy Loam (Belgium) have all characteristics of concretionary ferruginous tropical soils. There are many such examples. Laterites are widely distributed in semi-humid and humid regions of the globe and in fossil state are found in drier climates, and sometimes even in temperate climates. As indurated occurences, laterites extend beyond sub-humid tropical climate to desert regions. (The African and Australian deserts) where they are indication of more humid influence in the past.

2.4. LATERITIZATION

Elueze and Philip (1993) believe that the formation of laterites and lateritic profiles, that may contain ore-deposits of Fe, Al, Mn, Cr, Cu, Au, and Ni in several parts of the world is due to a climate which is both tropical and monsoonal, whose characteristics include long period of alternating wet and dry seasons. This variation results in a cyclic fluctuation of the groundwater-table that promote

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intense chemical weathering and also the presence of suitable source materials such as mafic and ultramafic rocks. This may lead to the residual concentration of base metals by leaching of mobile elements by meteoric water. This water may then carry those metals down the lateritic profiles or down slope. These deposits according to Elueze and Phillip (1993) are characterized as weathering-related supergene enrichment of more or less immobile elements. Poschl (1985) shares ideas with Levinson (1974) upon the various stages of lateritic formation. According to them during the first stage of lateritic weathering Al-Si-bearing minerals become "kaolinized" producing saprolite, followed by chemical reaction with tendency to mobilization of alkali and alkaline earths and silica (fig. 2. .). The end product consists of a mixture of mainly geothite, heamatite, and Al-hydroxides. Iron, after its release from mineral migrates upwards in the ferrous state, either with the rising water-table or by capillary action, where it is later oxidised to an insoluble ferric oxides intially geothite but later this may change to heamatite. As a result of the movement, iron becomes separated from aluminium. The largest concentrations of iron are found in the massive zone (mottled layer), which is at the highest level reached by water-table. The mottled colour is formed by periodic oxidation during fluctuation of water-table (Levinson, 1974).

In the ferruginous zone iron and aluminium are deposited

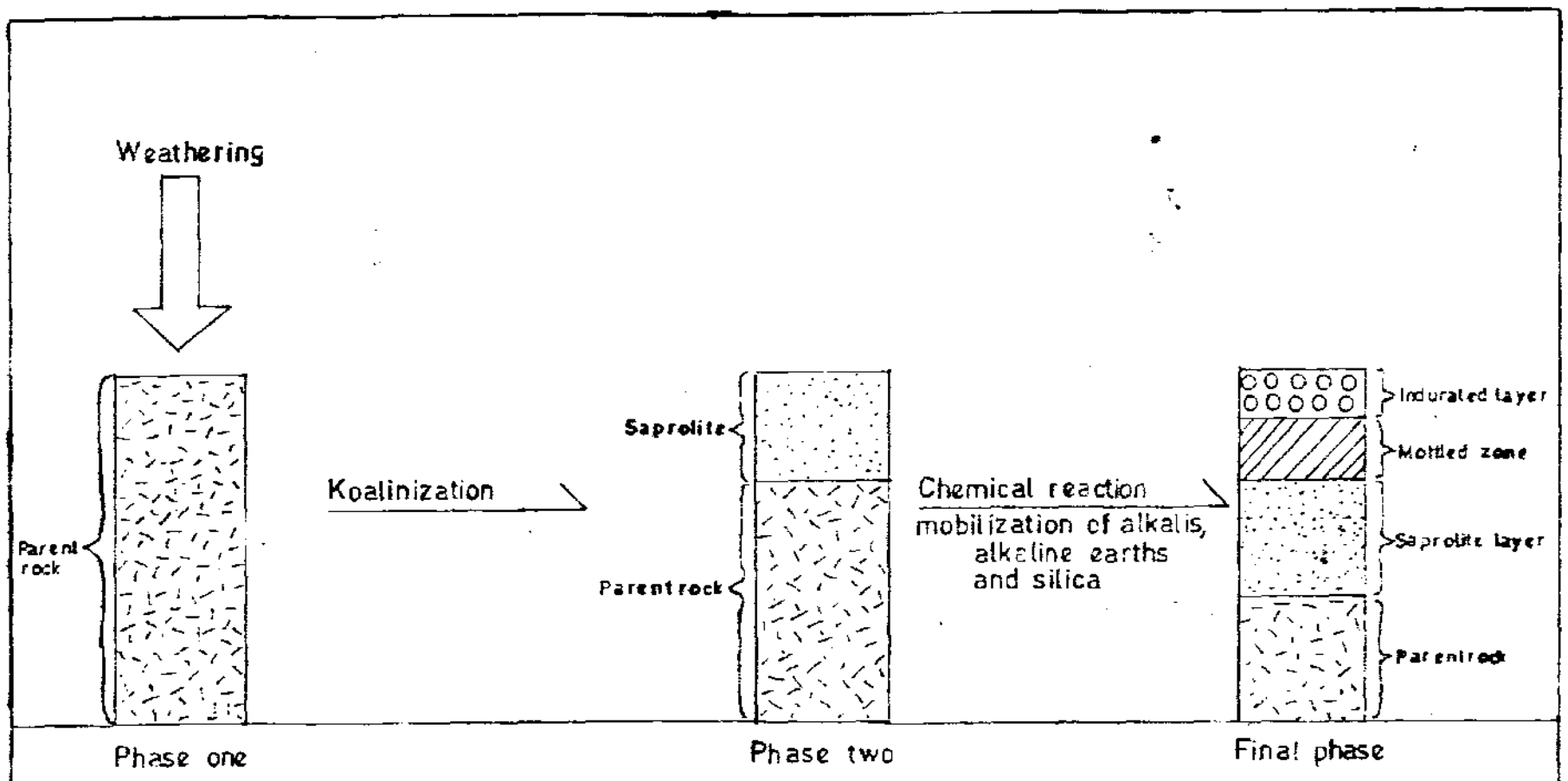

Fig2.3 Diagramma'ic represention of laterite formation.(Nagd',1999).

with a concretionary or pisolitic texture (fig. 2.1.). The iron in the two layers according to Levinson (1974) are different both in morphology (pisolitic versus massive) and processes of formation. Quartz appear to be stable in ferruginous layer because it is protected by coating of iron or aluminium oxides. Gibsite [$AlO(OH)^3$] is the first aluminium oxides to form, it slowly converts to boehmite [AlO(OH)] and eventually even diaspore [AlO(OH)] may form. Laterites are subjected to further changes with time, which may include erosion, a change in groundwater chemistry, and deposition of a wind-blown cover all of which result in variation from ideal structure described above (Levinson, 1974).

Thomas (1974) states that "laterite" developes near on the land surface, an interface in an ecosystem comprising atmosphere and biosphere above and lithosphere below. The accumulation of laterite occurs during the late stages of a land surface reduction cycle (McFrlane 1983). McFrlane (1976), distinguishes laterite into two main genetic classes. These are; ground-water laterites and pedogenetic laterite. In the case of ground-water laterites the iron segregation appear to be within the narrow range of oscillation of water table. Whereas, Thomas (1974) divides the laterites into two categories: viz, primary and secondary laterites, primary laterites are formed in situ whereas, secondary laterites are those formed as a result of erosion and transportation of the primary ones.

2.5. LATERITIC ORES

Laterites and their derivatives have been far exploited for ages for alluvial Au, Sn and diamond concentrates, zircon, apatite as well as Ni, Cr, Co mineralization. In some other cases, they have been eroded and segregated into massive clay-deposits as in Nigeria (Emofurieta et al, 1995; Coker, 1986; G.C.U. 1981; Emofurieta and Salami, 1988; Emofurieta et al 1992).

Avias (1978) provided a succint review of theories of nickel-lateritic formation. For economic accumulation of a nickelferous laterite, a high original content of Ni is a prequisite Kuhnel et al (1978) claims that the economic enrichment by laterites is restricted to a relatively nickel-rich ultrabasic rocks, with an average nickel content of 0.2%. The most favourable are considered to be Saxonite (harzburgite) and dunite in which Ni and Co have partially replaced Mg,especially in olivine (de Vletter, 1978). The nickelferous-laterite profile is divisible into two main parts: an apparent limonitic zone in which nickel is associated with iron oxides, and lower silicate zone in which nickel occurs combined with silica (garnierite). For formation of Mn-laterites, McFarlane (1983) reported that, the parent rock should be rich enough in Mn, see table 2.1 below.

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Table 2.1.: Manganese content of some parent rocks of Mn-laterite

Parent Rock	% MnO	Source
Gondites	13	Varentsov 1964
Manganese Carbonates	14 - 47	Varentsov 1964
Metasediments (phyllite, schists etc)	0.01 - 0.3	Nagell 1964 Varentsov 1964

Wember (1968) studied the manganiferous laterites of Gabon. Nagell (1962) has provided data on the process of manganese concentration in pisoliths (termed gronzon pellets).

Initially small (less than 0.4cm in diameter) grozon pellets increase in size up to 2cm in diameter, and this physical growth is first accompanied by decrease in relative amount of silica, but as pellets continue to grow first iron and then aluminium are replaced by Mn. Since size and age are clearly related this pattern shows that pellets initially forming in upper parts of soil, subsequently move downwards. This processes of formation place them within the pedogenetic class of aterites (McFrlane, 1983). Nagell (1962) studied the Mn-laterite of Brazil protore.

Cr can also be brought to economic accumulation by lateritization. It has been concentrated to 5% in Western Australian laterite from an ultramafic parent rocks containing 0.3% Cr (McFrlane, 1983). Ti, Zr, V, are also known to accumulate in laterite (McFrlane, 1983).

Ward (1981) has described an economically variable titanomagnetite deposit at Barrambie Western Australia.

For Co the horizon of accumulation being usually a little above the Ni-silicate zone, concentration of 1. 5% are exploited in Greenvale, Australia, (McFrlane, 198?). Au, has sporadically been extracted from laterites but usually on small scale. Diamond have also been extracted from laterites where, they accumulate as residuum (McFrlane, 1983).

Poschl (1985) determined four types of lateritic ores as shown below (table 2.2.).

Table 2.2.: Types of laterite ore deposits

Types of Ore	Genesis	Example
1. Saprolite ore	"Release" of chemicaliy resistant mineral by saprolitization	Cassiterite, central Goidas, Brazil-gold Serra Pelada-Brazil semi-precious stone, Brazil.
2. Residual ore	Relatively concentration of chemically resistant minerals. through selective solution, particularly of alkali, alkaline earths, silica	Haematite-rich ore: Brazil, Australia chromite-Philipine-Papua New Guinea pyrochlore, apatite, anatase, zircon. mineral: Brazil Africa
3. Enrichment by vertical solution transport	Besides concentration in the residuum, vertical ion-migration play adecisive role in the formation of ore	Bauxites Ni-laterites. lateritic Mn ores weathering phosphates
4. Enrichment by lateral solution transport	Lateral ion migrations of metals	polymetallic concenrations in limonite crusts and saprolites: Australia Zn-oxides ores: Brazil Australia

In the practice of geochemical prospecting in laterite area according to Poschl (1985) marked anomalies of non-ferrous metals are frequently located. The examination of which does not, however, show any signs of mineralization in the bedrock. It is false anomalies which make exploration difficult and expensive. Instead of regarding this as a

hinderance for prospecting of primary ore bodies, Poschl (1985) believes that these false anomalies should be examined for economic concentrations within the laterites. According to Poschl (1985) systematic investigation are lacking. From limonitic crusts and saprolites in the Bandemall area in Western Australia, however, the following values are quoted by Moeskops (1980): Zn up to 1%, Pb up to 0.25%, Cu up to 0.1%. The weathering profile is 40 to 70 metres deep here. The bedrock is Proterozoic slates and dolomites without traces of mineralization (Poschl, 1985).

2.6. METALLOGENY OF LATERITIC ORE-DEPOSITS

2.6.1. Metallogenetic Epoch

The indurated laterite of Queenland Australia is of Pliocene times, while in Ceylon most of the crusts are probably of Pleistocene and Pliocene age or even older (Whitehouse, 1940). Fernando (1948) and Rule (1954) dated the laterites of Ituri (Congo) as Middle and Late Tertiary. Michel (1960) is of the opinion that, the first levelling surface of basin of Senegal and Upper Gambia is Lower Cretaceous, while the second is Eocene and Lower Ferruginous crust is of Neogene age.

The first major period of lateritization in Africa is probably in Tertiary, and developed on Cretaceous levelling surface (Maigien 1966). Pendelton and Shanasuvana (1946) attribute most soil lateritization to Tertiary period and principally to Pliocene and Miocene epochs. Invariably the

geological periods marked by high raifall and accompanying drought and absence of earth movements, are ideal for formation of laterite.

Though most of laterite deposits are easily postulated as prehistoric geological occurence requiring a great length of time, yet there is no evidence to support the hypothesis that lateritization must require millions of years to occur Persons (1970). And there are however many cases of laterite of present day formation (Harrison, 1910).

2.6.2. Metallogenetic Province

Laterites and lateritic deposits are a function of climate and rock-type, a climate which is both tropical and mansoonal, whose characteristics include long period of alternating wet and dry season, and rock which can easily be altered will favour the formation of laterite.

Intertropical regions of Africa, Australia, India, Asia and South America are the known metallogenetic provinces of laterites. Though, some deposits are recorded outside these provinces around the world.

2.7. EXAMPLES OF SUCCESSFUL EXPLORATION IN LATERITIC AREAS OF THE WORLD

2.7.1. Australia

Vast areas of Australia show substantial lateritic weathering. This applies to the central and western parts

of the country as well, with a geologically young cover of desert-soils. Until some decades ago the laterite areas were unexplored. The basis for the country's rise to its present position as a "raw material power" was in part, due to the discoveries of major lateritic deposits (such as, bauxites at Weipa in 1955 and the Hamersley iron-ore in 1957) and in part to the development of ability to locate primary ore bodies beneath lateritic covers. The discovery of nickel-copper sulphide deposits at Kambalada in 1966 was the beginning of long series of exploration (Poschl 1985).

2.7.2. Brazil

Early in 1967 prospecting of manganese deposits began in the tropical rain-forest of eastern Amazonia. In mid 1967 in the course of this campaign geologists landed w n their helicopter on a grass covered hill 200 meters above the surrounding jungle. The cause of this geobotonical anomaly proved to be heamatite ore. Meanwhile, 16 million tonnes of iron-rich ore have been found in Serra dos Carajas (Poschl, 1985).

Laterite nickel deposits have been known in Brazil since the last century, accounting for about 350 x 10^6 tonnes of ore with average of 1.5% Ni. These deposits are scattered throughout the country (Oliveira et al, 1992).

2.7.3. Indonesia

Indonesian nickel laterite resource is estimated to be 19.1Mt of contained nickel. It is the third largest in the world after New Caledonia (27.7Mt) and Cuba (27.3Mt). Annual national mine output is around 85,000t of nickel (Chadwick, 1996).

Chadwick (1996) reported that Saroako's (Indonesia) integrated mine and smelter complex is one of the largest lowest cost nickel laterite operation in the world.

2.7.4. Nigeria

According to Emofurieta et al (1995) the economic importances of laterites are numerous to list and cannot be over-emphasized. Unfortunately, their study has not received the proportionate attention they deserve and this resulted in downward trend in mineral exploration/exploitation programmes of many developing countries, especially Nigeria. However, some notable attempts have been made in the last few years by Matheis (1978) who identified the Cr-Ni-Co mineralization in amphibolite-derived laterites from Ife-Ilesha area of southwest Nigeria. Emorfurieta and Salami (1988) emphasized the economic importance of paper-white kaolin drived through chemical weathering of pegmatite body occuring in Ibadan area southwestern part of Nigeria. Bauxite occurence have also been reported to have formed through extensive lateritization in southern part of Jos

(Valenton and Bassner, 1986). Mesida (1978) found some laterites and lateritic clay quite useful for making high quality bricks in southwestern Nigeria. They have compressive strengh of between 4,200 KN/m² and 6,900KN/m². The study carried out by Elueze and Philip (1993) on the mineralogical and geochemical features of laterite profiles around ITA-OSAN, southwest Nigeria indicates possible metallization associated with the lateritization in the area. According to them the mineralogical characteristics and chemical trends indicate that the surfacial horizons are particularly leached of Fe, Mn, Ni, Co and Cr consequent to incipient decomposition of the bedrocks.

Accumulation Factor (AF) and gains and looses of element (K) as well as pH data indicate a possible concentration of Ni, Co, Cr and V down the profile essentially in the saprolite zone above mafic and ultramafic units.

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CHAPTER THREE

GENERAL GEOLOGY

3.1. REGIONAL GEOLOGY

The area of the study is in and around the city of Kano which falls within the basement complex of central Nigeria (fig.3.1). The Nigerian basement complex lies within the Pan-African mobile belt east of West Africa Craton. The belt comprises two sectors; Viz: The Tuareg sheild and Togo-Benin-Nigeria sheild. These two sectors are seperated by extensive Phanerozoic sediments. The Nigerian basement complex outcrops over large part of the country in broad sheilds which are separated by various sedimentary basins (fig.3.1). The complex comprises the northwest, north-central, northeastern, and southeastern parts of Nigeria. This sheild forms a continous terrain which extends eastwards from Republic of Benin to the Republic of Cameroon.

The Nigerian basement complex is classified into three main subdivision (McCurry, 1976, Ajibade, 1982):

(i). Migmatite - gneiss complex comprising biotite-hornblende gneisses, quartzites and quartz schists, small lenses of calc-silicate rocks, biotite-hornblende schists and amphibolites.

(ii). Low to medium grade metasediments which consist

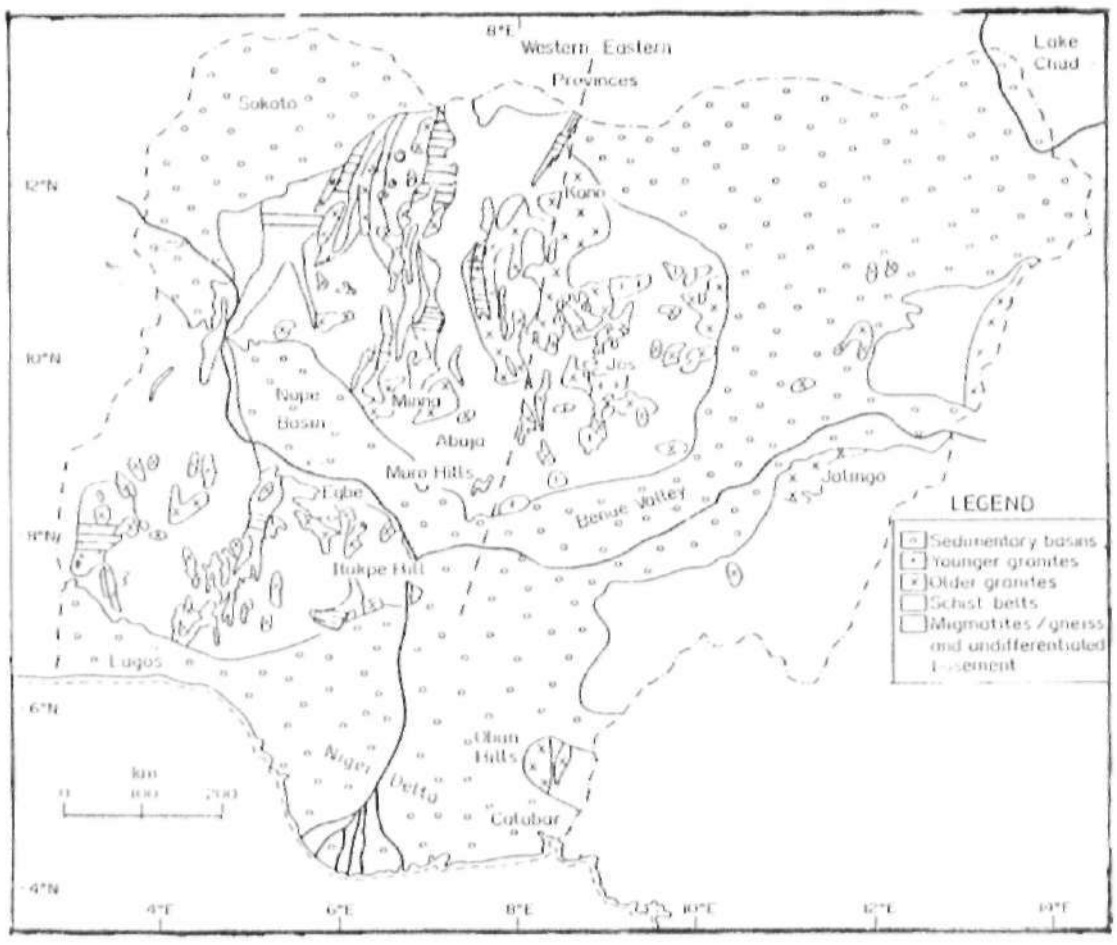

Fig. 3.1 Outline geological map of Nigeria (Rahaman et al, 1987)

of schists , phyllites, quartzites etc. They are mainly restricted to the western half of Nigeria (McCurry, 1976). They form belts known as schists belts, each belt is surrounded by the migmatite-gneiss complex and older granites.

(iii). Older granites which comprise rocks that are further subdivided into three subdivisions, basic and intermediate intrusives, migmatites and syntectonic to late tectonic granites.

3.1.1. Geologic Evolution

Generally, four orogenic events, namely Liberian (2800 ± 200Ma), Eburnian (1900 ± 250Ma), Kibaran (1100 ± 200Ma) and Pan-African (600 ± 150Ma) have affected the Nigerian basement complex giving it a polycyclic nature (Rahaman, 1989, Ajibade and Fitches, 1988). The migmatite - gneiss complex constitute the basement to schists and are accepted as the older rocks. They are considered to contain rocks of Archean age which have been deformed and modified several times prior to the Pan-African orogeny. Evidence from Ibadan area indicates that the Archean rocks include metasedimentary and metavolcanic which were deformed and modified before the emplacement of the Eburnian granite gneiss. The granite gneiss is also considered to have been derived from pre-existing rocks by partial fusion (Burke et al, 1976). The early Eburnian event was probably accompanied by sedimentation, deformation, metamorphism and

syntectonic igneous activity. However, no reliable evidence for this Eburnean plutonism is known yet, until more detail field and geochronological data become available from many parts of the basement. Some of the schist belts of NW Nigeria have yeilded ages varying from 600m.y to 700m.y which suggests a major Pan-African deformation in the region. Evidence for the Kibaran orogeny comes from Ile-Ife granite gneiss (Grant et al, 1972). The Pan-African orogeny is represented by rocks with ages in the range of 650 - 850 m.y with a predominant N-S structural trend. Table 3.1 shows the generalized succession of metamorphic rocks of the basement, affected by the four orogenic events.

3.1.2. Regional Structures

The majority of features have a N-S trend. Other trends are NE-SW and NW-SE. Infact, major rivers are structurally controlled by these main strike direction of features, an example being River Hadejia.

The predominant N-S trend is due to the Pan-African Orogeny 600 m.y which affected most West Africa (Grant, 1978). A few E-W trends exist. These are due to pre-Pan-African events. The regional strike of foliations in the rocks of the basement complex are well-defined N-S trends, while fold axes appear to maintain a N-S trend.

Table 3.1.: Generalized geochronology for metamorphic rocks of Nigeria

[illegible] Ma	Mid Cambrian	Uplift, cooling, fracturing, faulting, high level magmatic activity	
[illegible] Ma	L. Cambrian	Granite intrusion, pegmatite and aplite development	Older Granites
650-850 Ma	Pan-African	Orogenesis: deformation metamorphism and reactivation of pre-existing rocks	
900-1000 Ma	Kibaran?	Geosynclinal deposition, intrusion of hypersthene-bearing rocks	Kibaran metamorphics
[illegible] Ma	Eburnian	Granite intrusion Orogenesis: folding, metamorphism and reactivation of pre-existing rocks	Eburnian Granites
2500 Ma	Birimian	Geosynclinal deposition	Birimian metasediments
2600-3200 Ma	Liberian Cycle?	Possible formation of banded gneiss complex near Ibadan (Grant 1970)	
>2800 Ma	Archaean	Crystalline basement	

After Grant, (1971) and McCurry, (1976)

3.2. GEOLOGY OF KANO METROPOLIS

The main lithologic units mapped in the area of the study include:

6. Supercrustal deposits
5. Minor intrusions
4. Granites
3. Granodiorites
2. Diorites
1. Schists

The geology of the area is shown in Fig 1.1.

3.2.1. Schists

In hand specimen, the schists are fine to medium grained schistose rocks of argillaceous to arenaceous character. They are reddish (rusty) to greenish grey in colour, and are highly weathered (plate I). They are found associated with dioritic boulders at locality MI and M38 to the central north of the area (plate I & II). This association indicates that the schists have been intruded by small dioritic bodies, and hence, are considered older than diorites in the area. The schists occupy an area of about 52.5km^2 within the "walled city" to the northcentral part of the area (fig.3.2). This comprises approximately 5% of the total area mapped. The schistose units mapped consist of mica-schists and quartz-schists. No thin section was made.

3.2.2. Diorites

These are dark greenish-grey in colour, medium to fine-grained in texture. They outcrop as rounded to subrounded boulders, (plate I & II). These dioritic bodies occur in both the schists and granodiorites (fig 3.2). Their true attitude is difficult to ascertain because they are generally only seen as float or boulders (plate I & II). They occupy about 3% of the total area mapped, at the northcentral and southwestern parts (fig 3.2.).

In thin section the diorites are made up of mainly, plagioclase (An25-An40), biotite, hornblend, pyroxene, olivine and accessory, apatite and opaque minerals. Quartz

is completely absent (?). The feldspar form subhedral crystals, which intergrows with pyroxene and biotite. K-feldspar is represented by few crystal of orthoclase, which intergrow with biotite. The plagioclase constitute approximately 58-60% of the chemical composion of the diorites. Pyroxene crystals are seen intergrowing with olivine (fig 3.3.) (which alters along fractures to iron oxides). The pyroxene are mainly clinopyroxene, augite and aegirine. Biotite is seen intergrowing with hornblende. The opaque mineral are identified to be mainly magnetites with few tiny crystals of chalcopyrite.



Plate I: Photograph of a highly weathered schist, seen overlain by a diorite boulder. Locality M1 (fig.3.2).

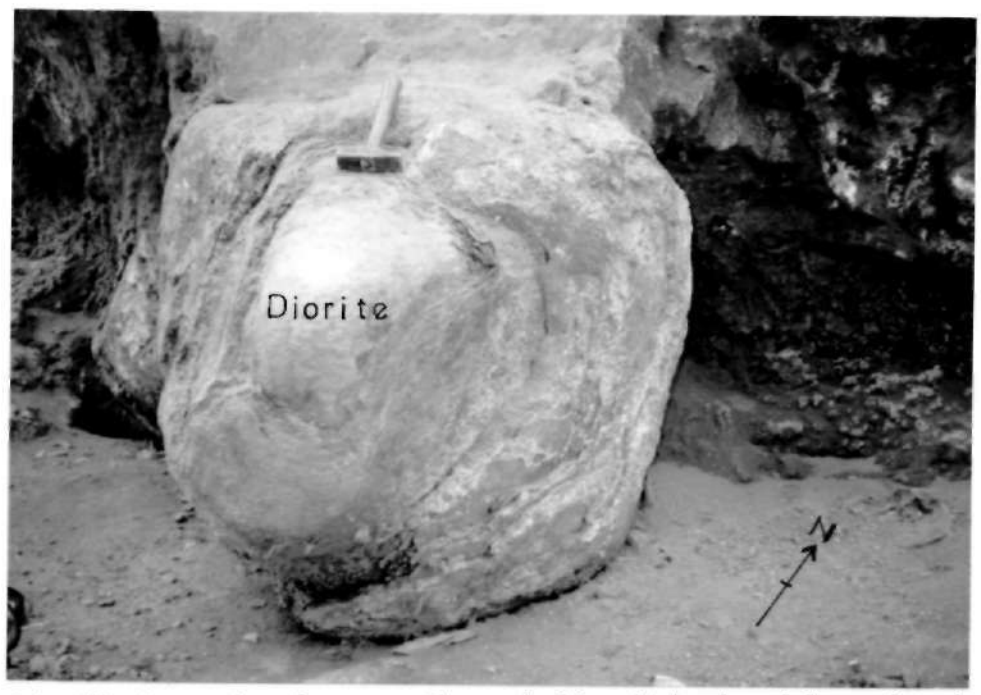

Plate II: Photgraph of a weathered dioritic boulder showing characteristic exfoliation. The dark reddish background is a weathered schist locality M38 (fig3.2).

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3.2.3. Granodiorites

The granodiorites constitute about one quarter of the total area mapped (fig 3.2.). They outcrop mainly in the western portion as large or massive boulders (plate I). At locality M14 they outcrop as low-lying bodies. Generally, the rocks look massive. In handspecimen, the rocks are porphyritic in texture, with phenocrysts of plagioclase easily recognisable on field outcrops and handspecimens. Generally, light in colour, however, look spotted with segregation or clots of more mafic portion which are mainly hornblende and biotite. In thin section, plagioclase (An17-An40) is the most abundant constituting about 55-60% of the total chemical composition of the rock. Quartz is seen intergrowing with plagioclase as a mermekite. Hornblende forms prismatic crystals intergrowing with biotite. The accessory minerals are mainly apatites and opaque minerals (fig 3.4).

3.2.4. Granites

The granites constitute about three quarter of the total area mapped (fig 3.2). They are of two types and may differ in age; these are the prophyritic granites and the medium-grained granites.

i. The porphritic granites

These are the most abundant granites in the study area (fig.3.2). They vary in colour from pink to light varieties. It appears that the proportion of the white milky or pink phenocrysts of feldspar is responsible for

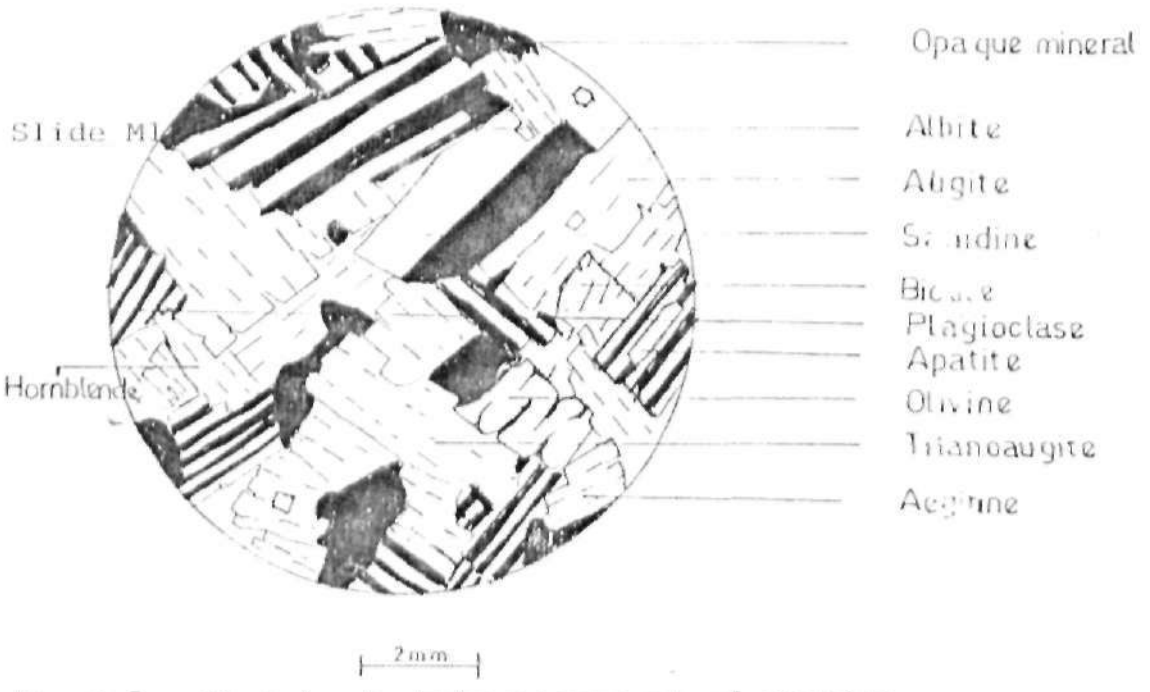

Fig 3.3.: Sketch of photomicrograph of diorite

Slide M14

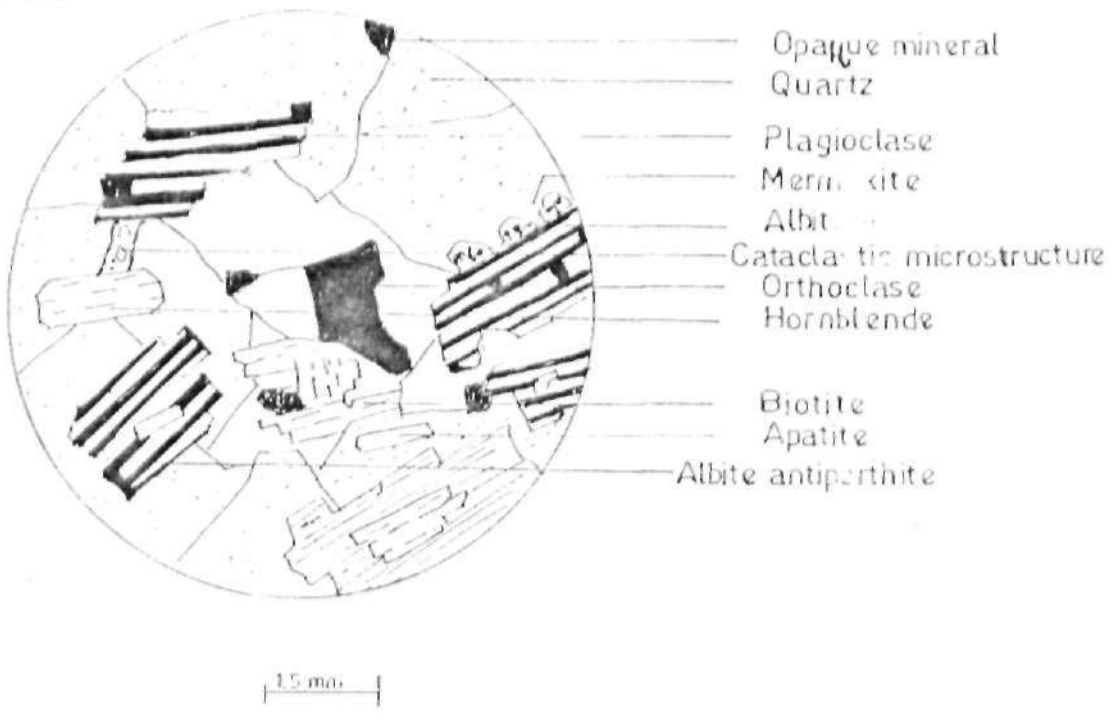

Fig 3.4.: SKetch of photomicrograph of granodiorite (XPL)

this variation in colour (plate IV & V). The areal extent of these rocks gives the impression that they are a part of a large batholith(?).

Alignment of feldspar phenocrysts and dark minerals is observed in outcrops to the south western part (part VI & VII), all in a N-S trend. Also observed are minor bodies of aplite dykes (plate VIII). In thin section quartz constitute the most abundant mineral, microcline occurs in a large phenocrysts (fig 3.5), and (fig 3.8).



Plate III: Photograph of typical field occurence of granodiorite. Locality M29.



Plate IX: Photograph of a contact trending N30°E between a foliated porphyritic granite (A) and a medium-grained granite (B).

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PlateIV: Photograph granitic outcrop at locality N10 (Tamburawa Dutse).



Plate V: Photograph of Challawa River with granitic outcrop at the two banks. Locality M4.



Plate VI: Photograph of highly wheathered and foliated porphyritic biotite granite. Locality M4.

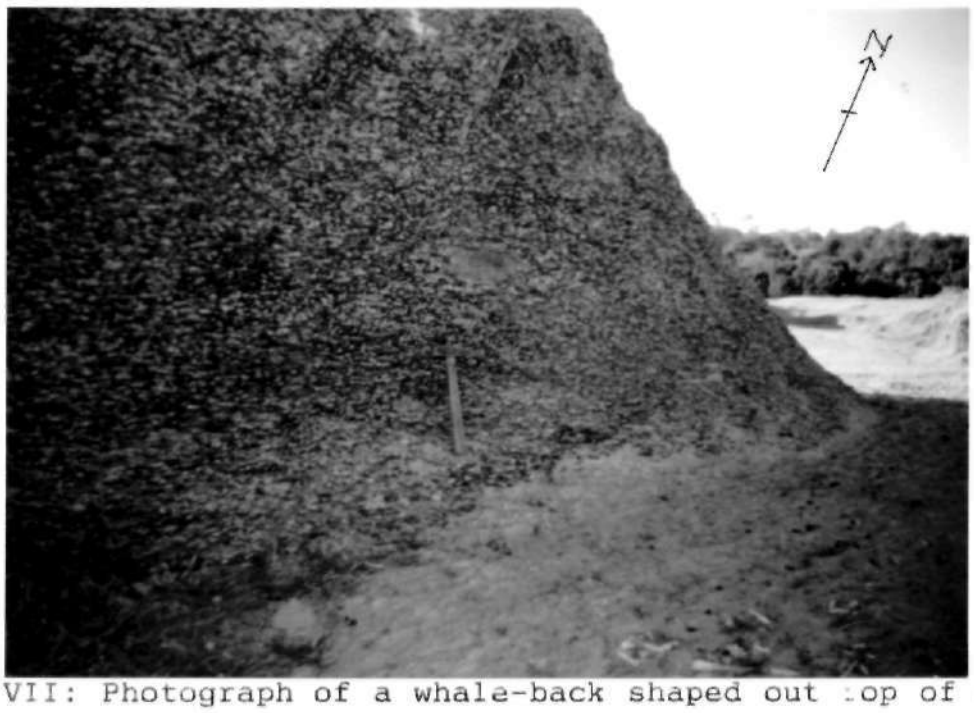

Plate VII: Photograph of a whale-back shaped out :op of a foliated porphyritic next to the outcrop in Plate VI above. Locality M4.

Slide: M5

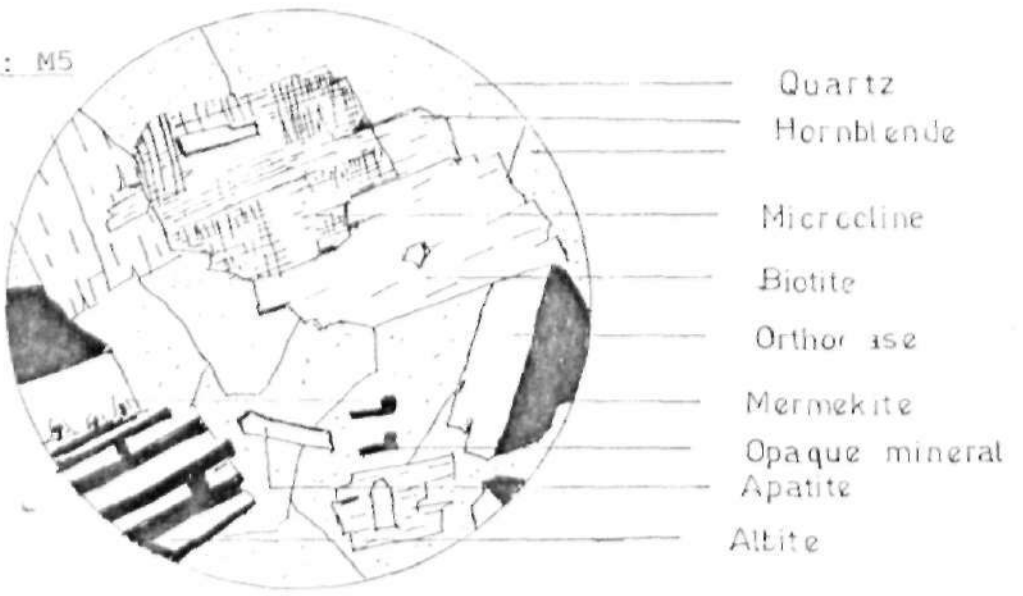

Fig 3.5.: Sketch of photomicrograph of granite (XPL)

Slide: M5.3

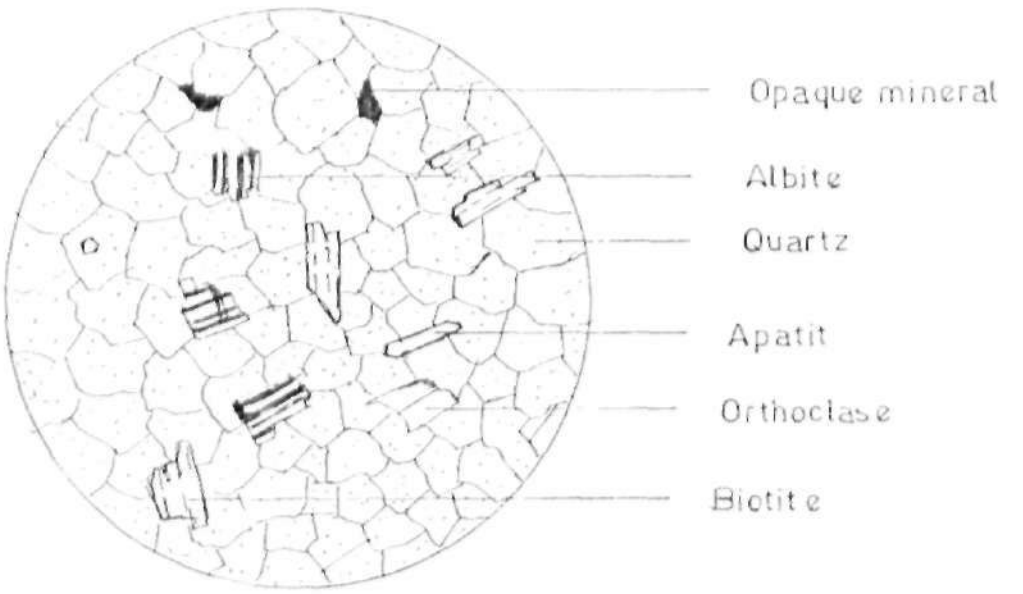

Fig 3.6.: Sketch of photomicrograph of aplite (XPL)

Plagioclase phenocrysts (An20-An40), and orthoclase are seen. Biotite is usually intergrowing with hornblende. The accessory minerals consist of apatite and opaque minerals. Intergrowth of quartz and Na-feldspar as a mermekite is also common, which indicates that the rock has been subjected to deformation.

ii. *The medium-grained granites*

These are equigranular and vary in colour from light to pink colour, obviously, the proportion of pink or white K-felspar is responsible for this variation in colour. They occupy small part (fig.1.1). It seems that they have *different crystallization history with the prophyritic* varieties. They outcrop at locality M41 (fig.3.2) in a big ditch as a highly jointed igneous body overlain by laterites. Blocks of rock are seen detached along this joints (plate XVII). The joints trend N-S, N20°W, N40°E, N60°E, N43°W. At locality M3 they form a small hill known locally as "Magwan" or "Dutse Magwan". The rocks at this locality are massive. At locality M8 it occurs as a high weathered igneous body (plate XVIII). At locality M27 to the southwestern part, the rocks appear foliated. The foliation trend is similar in direction as in the prophyritic varieties with which they form a sharp contact trending N30°E (plate IX). In thin section, crystal of microline, quartz, biotite, orthoclase and accessory minerals (apatite, opaque mineral) are seen. (fig 3.8.). The mineral assemblage of this rock is similar to the other granites (compare, fig 3.5 and 3.8).

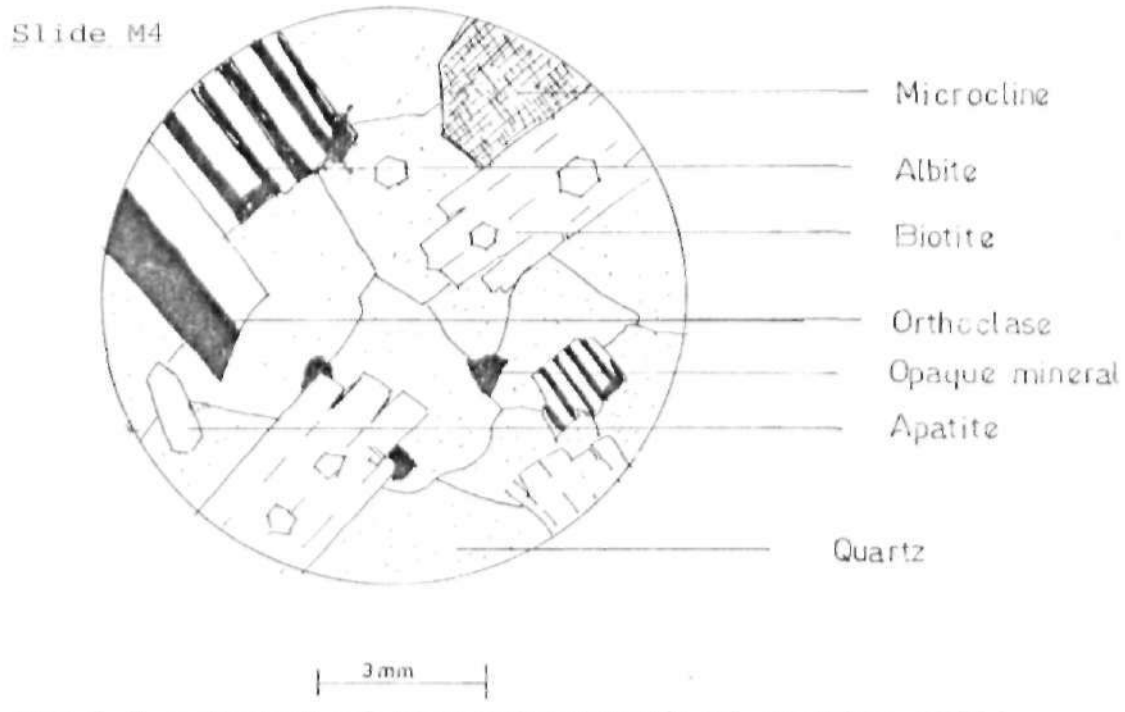

Fig 3.7.: Sketch of photomicrograph of granite (XPL)

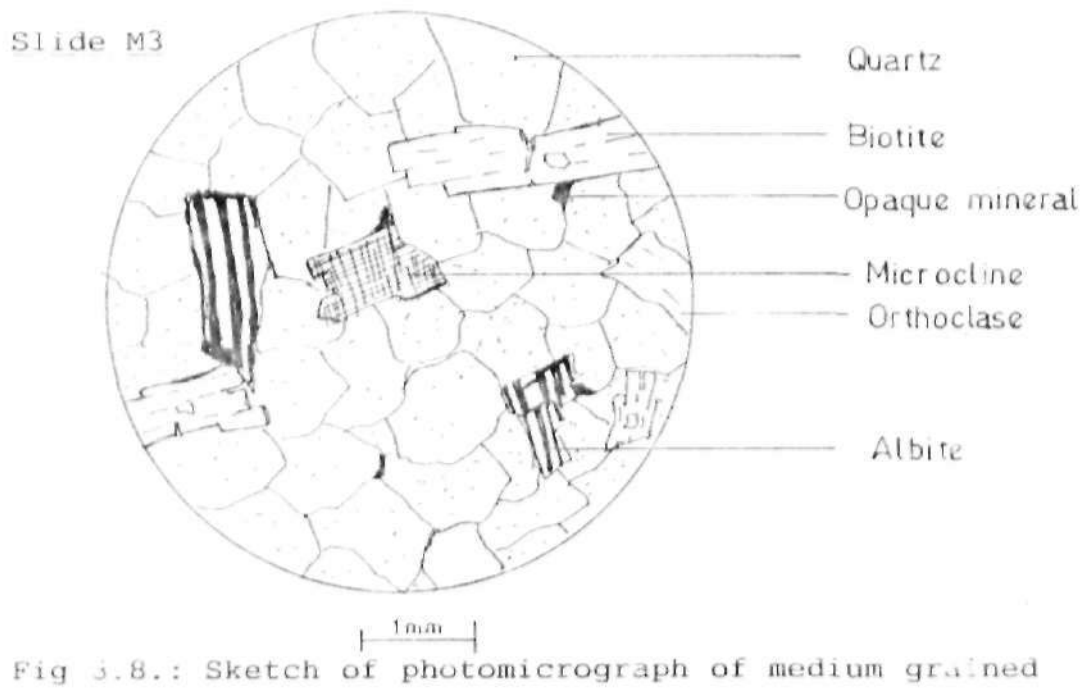

Fig 3.8.: Sketch of photomicrograph of medium grained granite



Plate VIII:Photograph showing a porphyritic biotite granite intruded by an aplite dyke to the left. Locality M5, along a big ditch near Yankaba "Motor Park".

3.2.5. Minor Intrusions

Some minor dykes and veins of aplite, quartz and pegmatite are found intruding the major rocks of the study area.

i. Aplite dykes

A major aplite dyke is seen intruding porphyritic granite at locality M5 (plate VIII). The dyke trends N26°E. Other aplite dykes are seen at locality M10 intruding porphyritic granite, and to the north of this locality, at locality M21 intruding the same rock type with similar trend i.e W-E. At locality M43 also is an aplite dyke intruding porphyritic granite but trending in N-S direction. The rocks are very fine-grained and individual crystals can not be identified with a naked eye. Generally, they are light in colour, but in some localities are stained and appear dark brown. This is due to surface weathering. In thin section, the mineral assemblage of these rocks is identical with that of the main granitic rocks (fig 3.6.).

ii. Quartz veins

Many quartz veins have been encountered during this work, but only few of these form mappable units. At locality M8 a quartz vein intruding a granitic exposure, with thickness of 6cm is seen (plate XIX). Veins are abundant in this area.

iii. Pegmatites

Pegmatites also occur in the study area. They seemed to be more confined to areas underlain by granodiorites(?). At locality M26 a pegmatite vein is observed intruding a highly weathered granodiorite rock. At locality M28 pegmatite vein is observed cutting an exposure of saprolite developed over granodioritic rocks. It has a relatively larger size (about 30cm) and consists of large crystals of quartz (10cm in diametre) with muscovite and large crystals of feldspar. The vein is vertical and strikes W-E. At locality M43, weathered pegmatite vein is seen cutting a saprolitic exposure. It consists of very large crystals of feldspar and quartz.

3.2.6. Superficial deposits

Superficial processes of weathering, erosion and deposition, have affected the study area and resulted in the formation of products which include, laterites, alluvial deposits, soils and clays.

Widespread lateritic developement has been observed, the discussion of which will be followed in the next chapter. Alluvial deposits are found mainly confined to valleys of major streams and rivers. Broad expanses of grey and brown sandy soils cover much of the ground. Such soils have widespread distribution in the area. The soils of the area are characterized by weathering profiles containing yellow-red sandy clays.

3.3. STRUCTURE

From the earlier descriptions, it is evident that the geological structures of the area of study are, fracture and foliation. The trends of these structures show a predominating NNE-SSW direction which is dominant over the E-W trends as can be seen from the rose diagram (fig 3.9). These NNE-SSW trends probably depict the final imprints of the Pan-African orogeny while, the E-W trends may depict earlier metamorphic episode (Grant, 1971). Hence, two tectono-metamorphic episodes can be assumed to have occurred in this area.

Foliation seems to be confined only to granitic and schistose rocks of this area. In granites, the predominant foliation trend observed is N-S. In the schists, schistosity is well developed and trend predominantly NE-SW.

Field mapping reveals the existence of fractures, some are infilled by quartz. Two sets of joints can be recognised: a predominant NNE-SSW trending joint set and a less predominant joint set trending almost E-W. The measured joints are: 0°, 20°, 0°, 18°, 20°, 22°, 21°, 22°, 24°, 30°, 32°, 31°, 38°, 40°, 30°, 35°, 60°, 42°, 41°, 80°, 85°, 87°, 90°, 90°, 98°, 100°, 300°, 310°. No major fault displacements have been observed from the fieldwork.

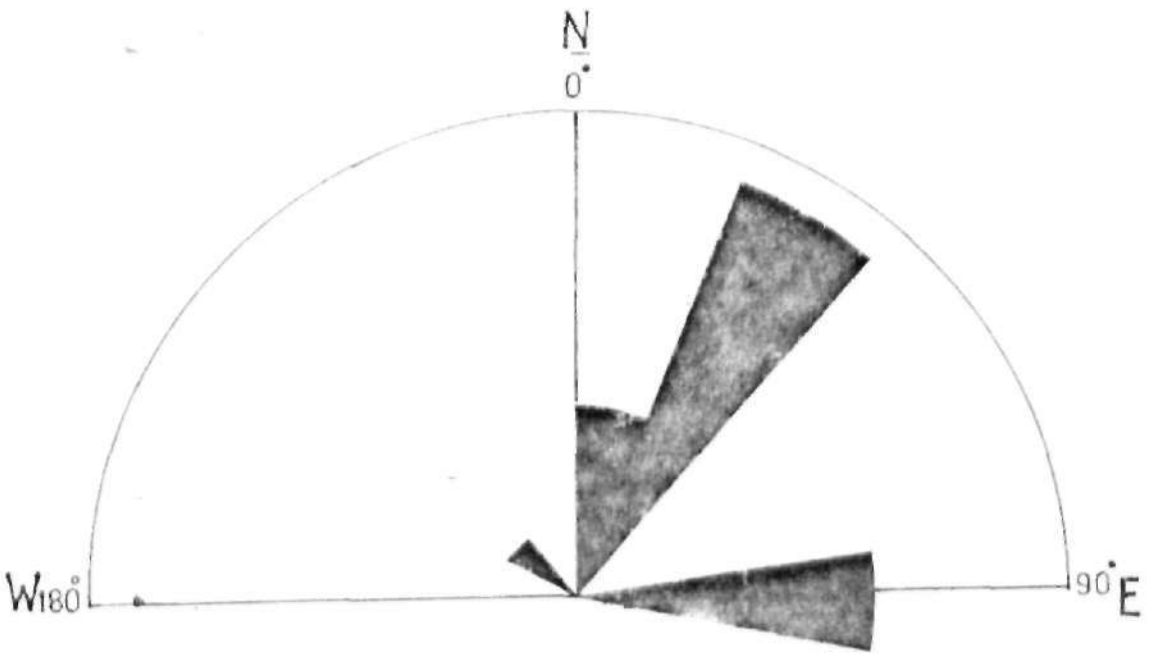

Fig 3.9.: Rossette plots of joint and foliation in granite, granodiorite and schists.

CHAPTER FOUR

LATERITES AND LATERITIZATION IN KANO METROPOLIS

4.1. INTRODUCTION

Laterite has a wide distribution in the area of study. It covers almostly all rock types of this area, but varies in intensity of development from one place to another.

4.2. TYPES OF LATERITES

Geomorphologically, the laterites encountered in this area can be distinguished into three types:

(i). High-level laterites which are found capping summits of high lands, ridges and hills (fig 4.1.) and (plate X and XI).

(ii). Low-level laterites found in low lands and usually exposed along banks of man-made pits, or ditches (fig 4.1.).

(iii). The foot-slope laterites which are found down slope (fig 4.1.).

4.3. STRUCTURES OF LATERITE

A variety of textures and structures are exhibited by these laterites. The high-level types encountered at locality M1 (Goron Dutse) and M2 (Dalla hill) show spaced-pisolithic structures which, consist of reddish brown discrete lisoliths of iron-rich materials. These pisoliths are loosely cemented and can easily be broken (plate XXI). As

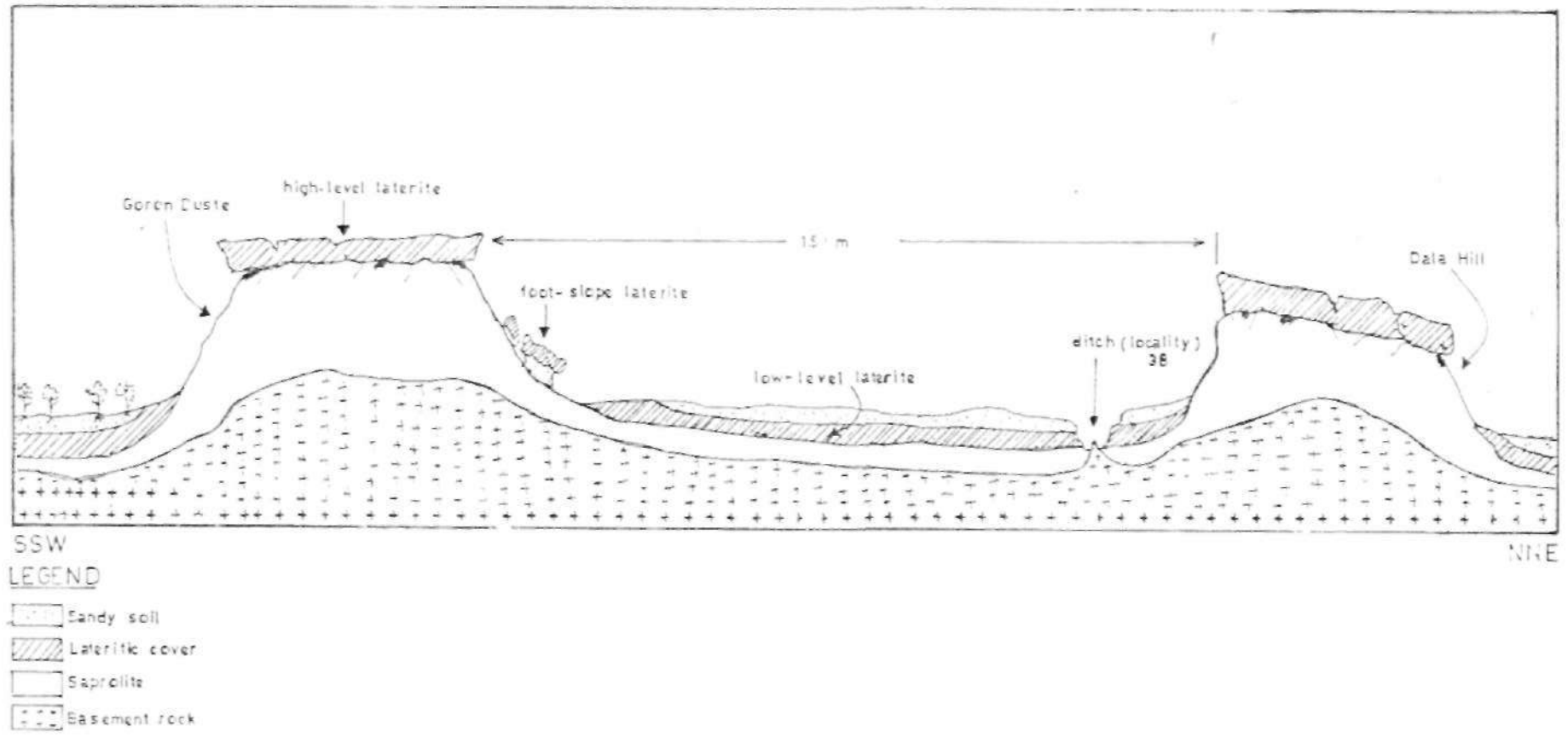

Fig 4.1 Schematic cross-section of the area between Goron Duste and Dala Hill showing distribution of laterite in relation to topography (Magdi, 1999).

indicated by their high altitute, these types can be assumed to be the oldest. The low-level laterites show two types of structures, the packed-pisolithic (plate XII) and also vermiform structures which are coherent and continous, without any apparent pisoliths. The variation in structures of these types may be mainly due to difference in environment of formation. The foot-slope types show packed pisolithic structures that consist of cemented pisoliths, the cementing materials are iron-rich and clayey in nature. These types are the products of cementation of fragments of high-level laterites that rolled down slope, and hence they are colluvial in nature. Another type of structure encountered in this area is the one exhibited by the laterite found at locality M41 (plate XX), which are only a few cm in thickness and lie directly on the fresh bedrock (plate XVII). They show gritty structure that consists of grains of quartz of almost equal size cemented by a reddish iron-rich clayey materials and a dark segregation which may be of manganese oxides. It seems that both intensity and duration of lateritization were not enough for the rock to alter, or likely, the laterites were transported from somewhere else and were deposited on the top of the bedrock which occupies a depression, or possibly lateritized alluvial deposits.



Plate X: Photograph showing Dala hill with a lateritic cap near the hill is a big ditch in which dioritic boul ers are seen scattered. Locality 38.



Plate XI: Photograph of Goron Dutse capped with laterite. Locality M1.



Plate XII: photograph of Badawa Ditch, showing a vertical lateritic profile at locality M8.

A = Ferruginous layer, or ferrcrete = thickness - 1.5m

B = Mottled layer = thickness = 2.5m

B = Saprolitic layer = thickness >6m



Plate XIII: Photograph of an indurated lateritic layer on top of Dala Hill at locality M2.

4.4. LATERITIC PROFILES

The laterite profiles encountered vary greatly from one locality to another following the intensity of lateritization (plate XIV, XV, XVI, XVII). All laterite profiles encountered are found to be underlain by saprolites, except the transported varieties. The typical laterite profiles in this area can be distinquished vertically into four zones (fig 2.1). These are from the base to the top, fresh bedrock, saprolite, mottled zone and an indurated pisolithic (or ferricrete) layer. The saprolite layer can further be recognised into, coarse and fine-grained zones. The field recognition of these four zones in the laterite profiles was based on, variation in colour, texture and composition of each zone. Letters, A, B, C and D were designated for each zone from top i.e indurated, mottled, saprolite and down to fresh bedrock zone (plate XIV, XV, and XVI). The thickness of the profiles varies from one locality to another following the intensity or degree of lateritization. It ranges between few cm (plate XVII) to tens of meters (plate XII, XIV, XV and XVI). Along some profiles decomposed pegmatites and quartz veins are present cutting the saprolite layers. These layers retain the structure of the pre-existing bedrock as found at locality M8 (plate XIX), where the decomposed bedrock can be recognised easily as a medium-grained granite.

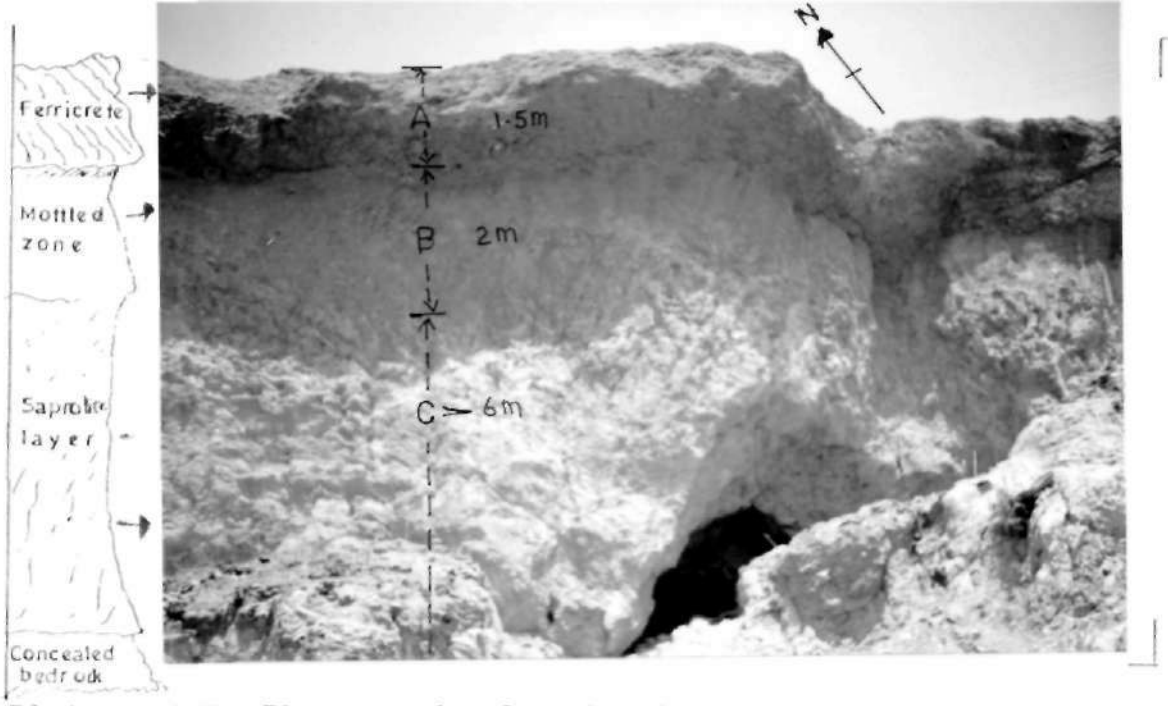

Plate XIV: Photograph of a developed vertical lateritic profile showing the various zonal succession;

A = indurated ferruginous layer (ferricrete)

B = mottled zone

C = saprolitic layer, with side sketch to illustrate this.

Samples were collected from each of these layers. Locality M8



Plate XV: Photograph of another well-developed lateritic profile at locality M28



Plate XVI: Photograph of a vertical laterite profile showing: A topsoil A mottled layer B. indicated ferruginous layer, C saprolitic layer, along with the height of each layer at locality 34.

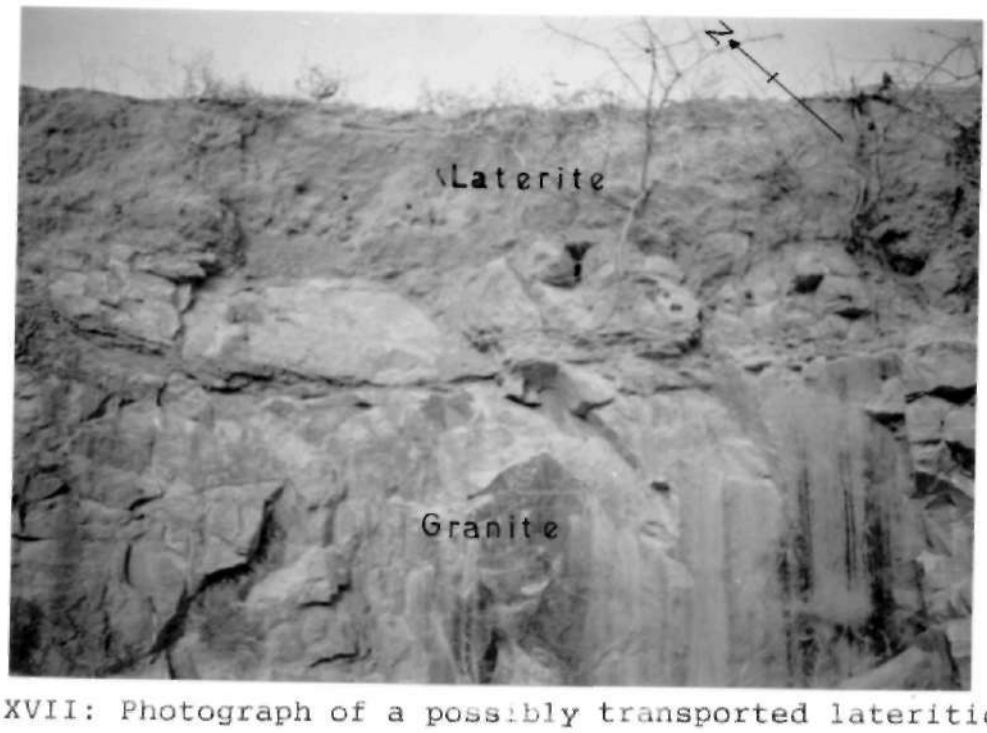

Plate XVII: Photograph of a possibly transported lateritic profile lying directly on a medium grain granite rock, note the absence of saprolite layer. Locality 23.

4.5. DEGREE OF LATERITIZATION

The intensity or degree of lateritization in any locality can be measured by comparing the depth of lateritic profile and maturity of the lateritized materials. As can be seen from the distribution map (fig 4.2.), the intensity of lateritization can differ even within the same rock types. Here the lithology does not play any role likely, the variation is due to the position of the profiles to the possible high or low drainage at that locality. A good example can be obtained from locality M8 (plate XIV) and locality M23 (plate XVII), where both profiles overlie the same rock type but still have different thickness and intensity of lateritization. However, at the central part (fig 3.2.) locality M1 and M2 and M38 (plate X), the degree of lateritization is very high compared to any other parts within the area. This part is underlain by schists which are associated with dioritic boulders (plate I & II). In this case the degree of lateritization can be explained in term of the ease with which these rocks alter during chemical weathing when compared with the other rock types especially, granitic rocks. Here the degree of lateritization is lithodependant (?).



Plate XVIII: Photograph showing a fresh bedrock (medium-grained granite). Locality M8, a big ditch (Bagawa).



Plate XIX: Photograph of a fresh bedrock with a quartz vein diping N60°E with another two veins to the left branching from it.

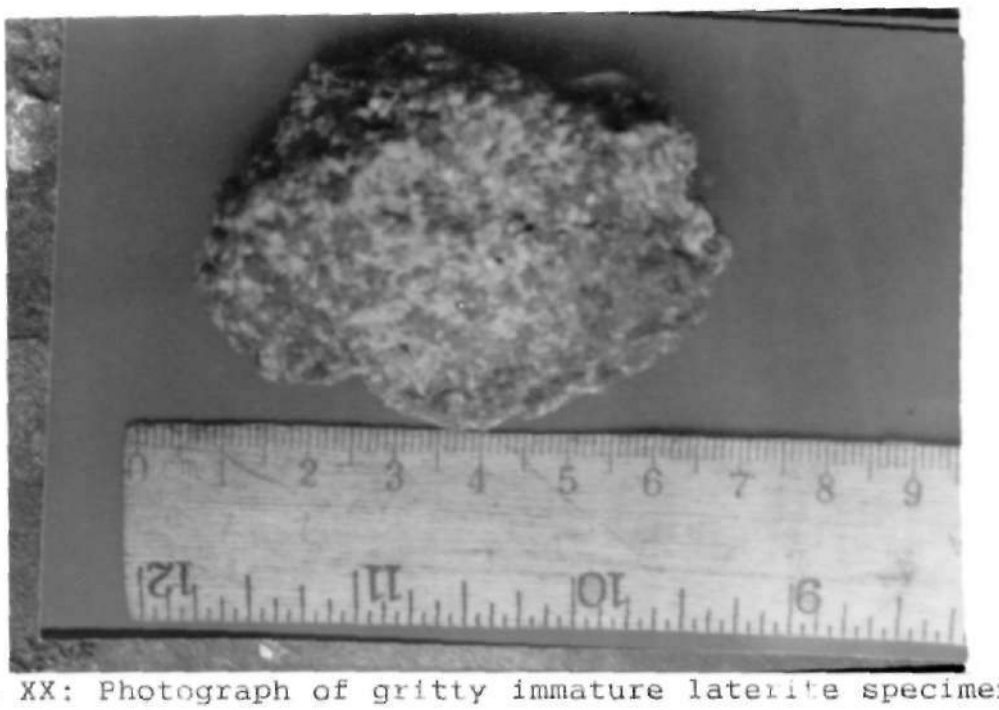

Plate XX: Photograph of gritty immature laterite specimen which shows quartz grains coated with iron-oxides (heamatite, red colour), clay (white colour manganese oxides (dark colours). Locality M41.

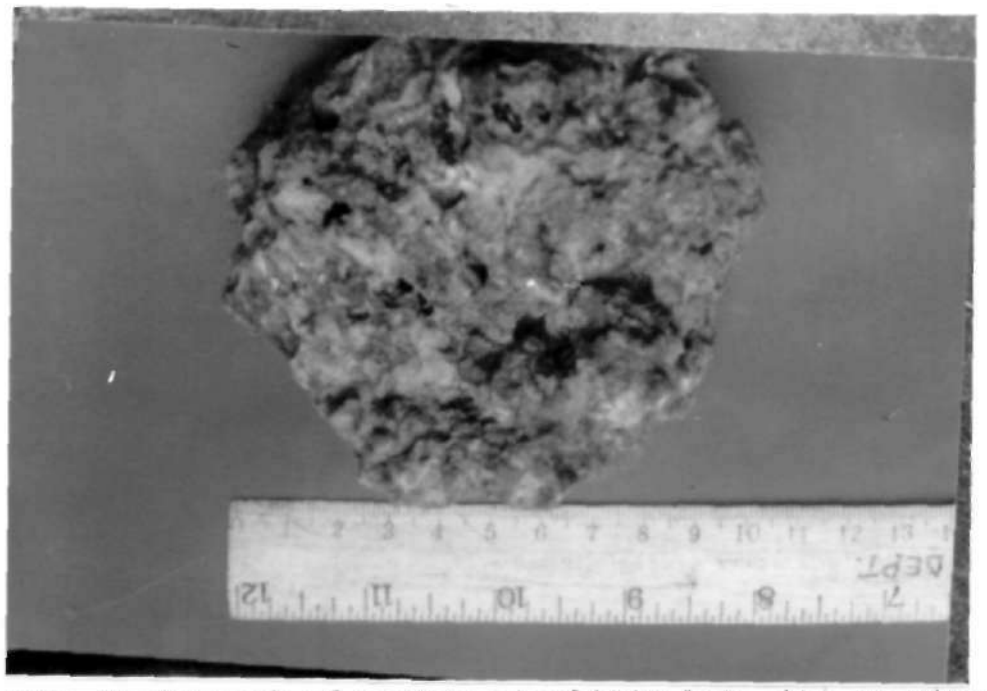

Plate XXI: Photograph of mature pisolitic laterite specimen showing (nodules, pisolith s) of iron oxides dark brown, manganese oxides (dark in colour). Locality M1.

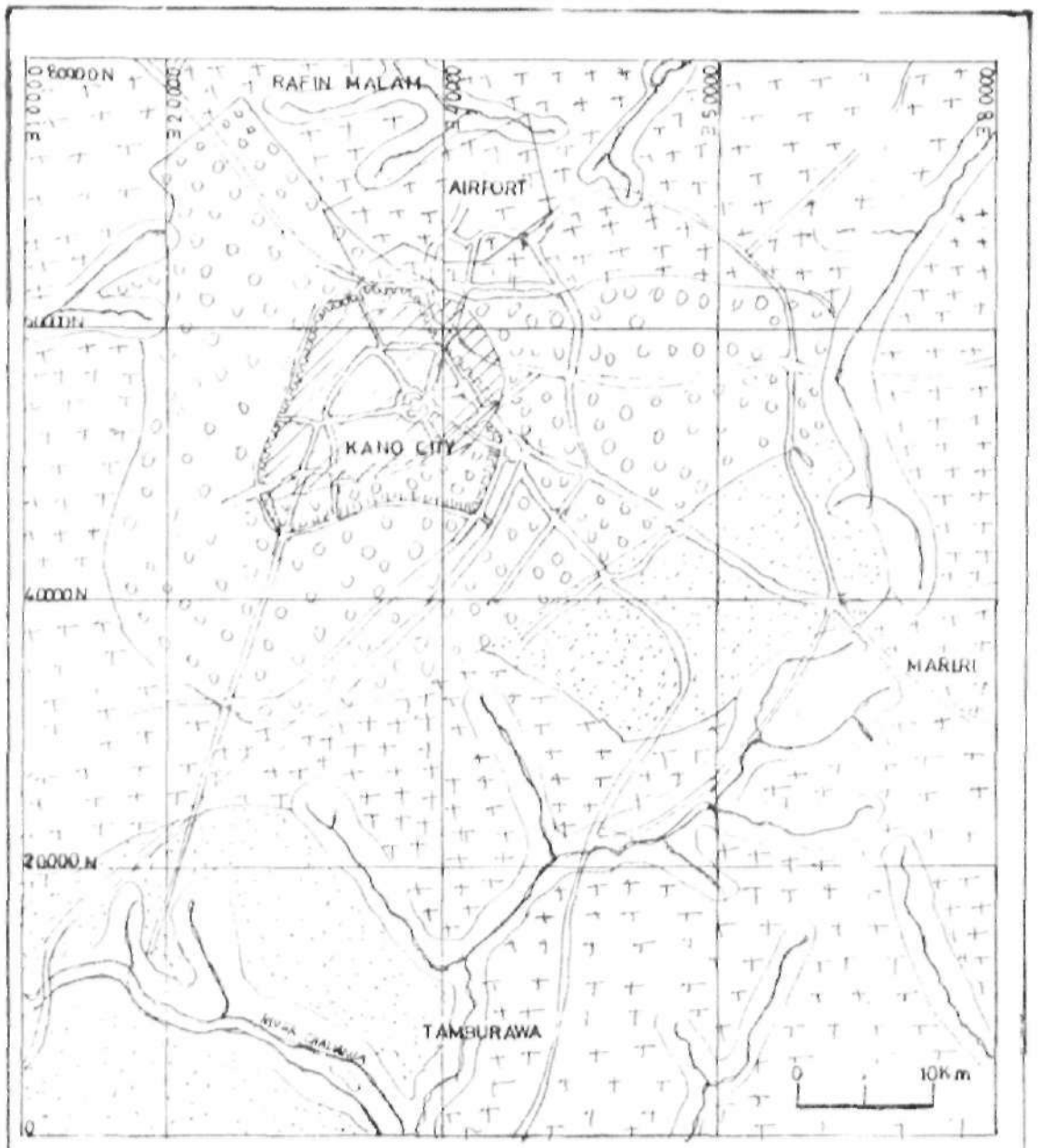

Fig4.2 Distribution map showing the degree of lateritization within the area of study.

Very high
High
Medium
Low
No lateritization

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[After Magdi,1999]

CHAPTER FIVE

GEOCHEMISTRY

5.1. INTRODUCTION

The major and trace element concentrations of the lateritic profiles in the study area were analysed. The distribution and association of such elements in the lateritic profiles are also discussed in this chapter.

5.2. FIELD AND LABORATORY METHODS

A total of 61 samples were collected along vertical profile from fresh bedrock, saprolite, mottled and indurated layers by means of plastic hand-shovel mainly from hand-dug pits. These samples were appropriately labelled and stored in sealed polythene bags. The samples were seperated into four categories according to the different types of parent rock-derived lateritic profile. These are: lateritic profiles developed over schist, diorite, granite and granodiorite.

The samples were dried in a low-temperature oven (105°C) and pulverized with a tungsten carbide spex mill to fine powder form at the laboratory of the Department of Geology, A.B.U. Zaria. Each powdered sample was prepared as pellet by homogenous mixing with 2-3 drops of an organic liquid binder. A SPECAC hydraulic press was used in making the pellets with a 19mm diameter disc using a pressure of

(204081.6Nm-^{2}).

The samples were analysed using an annular 925M q Cd-109 as an excitation X-ray source. The measuring sys em consists of the isotopic source and a Canberra® Si(Li) d tector with a resolution of 170ev for 5.90Kev line, coupled to a computer-controlled MAESTRO® Analog to digital convertor (ADC) card. The spectra was collected for 3000s each and evaluated using the AXIL computer program(After Van Espen, P.et al,1996). Quantification was carried out as outlined by Kump (1997).

A total of 18 major and trace elements including K, Ca, Fe (wt%) and Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo and Pb (ppm) were analysed in this manner for the fresh rocks and the overlying lateritic samples. Both the preparation of pellets and analysis of samples were carried out at the laboratories of the Centre For Ene gy Research and Training (CERT), A.B.U. Zaria.

5.3. STATISTICAL TREATMENT OF GEOCHEMICAL DATA

The data obtained from the geochemical analysi: (Appendices A-D) were subjected to simple statistical nalysis and interpretation . The statistical analysis of the data was carried out using the Statgraphics (5.1) a computer software.

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5.3.1. General Statistical Data

Tables 5.1 and 5.2 show some statistical data of importance obtained for 18 elements (K, Ca, Fe, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo, Pb) analysed in lateritic samples from schist (7 samples), diorite (12 samples) and granodiorite (7 samples) - derived lateritic profiles. And also samples from indurated (13 samples), mottled (14 samples) and saprolite (8 samples) layers of granite-derived lateritic profiles respectively.

5.3.2. Correlation Analysis

Correlation analysis is a measure of similarity between paired data. Correlation Coefficient (r) is a ratio, this is a unitless number . Correlation ranges from +1 to -1. A correlation of +1 indicates a perfect direct relationship between two variables; a correlation of -1 indicates that one variable changes inversely with relation to other. Between the two extremes is a spectrum of less-than perfect relationship including zero which indicates the lack of any sort of linear relationship. Correlation analysis was done *on different sets of data to study inter-element* relationship. The results are shown in Tables 5.3 to 5.8 as correlation matrices, showing the relationship between the elements in all group of lateritic profiles. The results are expressed, for each pair of elements, as correlation coefficients.

5.3.3. Accumulation Factor (AF)

Thorough determination of economic potentials of lateritic profiles may not be achieved by merely considering their absolute concentrations of major and trace elements. Consequently, there is a need to apply parameters that can establish elemental dispersion trends from bedrock to the overlying materials in relation to accumulation or otherwise (Elueze and Phillip, 1993). In this regard the index of accumulation factor (AF) was calculated as explained by Elueze and Phillip (1993).

Accumulation Factor (AF) is the ratio of the mean concentration of element in the lateritic horizon divided by its mean concentration in the fresh bedrock. AF value >1 indicates enrichment; and <1 indicates depletion. Accumulation Factor (AF) values for each of the successive layers of the schist-diorite-granite and granodiorite-derived lateritic profiles for 18 elements (K, Ca, Fe, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo and Pb) are shown in Tables 5.9 - 5.12.

5.3.4. Statistical interpretation

i. Elemental Interrelation and Association

The significant correlation (>0.63) of the 18 elements in different groups of lateritic profiles can be summarized as follows: The correlation matrix (Table 5.3) of the schist-derived lateritic profiles shows that K is negetively correlated with Fe, Ti, Co, Cu, Rb, and Nb. Based on the

positive significant correlation, the following element associations are present: [K-Rb], [Ca-V-Mn-Zn-Sr-Y-Cr] and [Fe-Cu-Co-Mo-Ni-Ti-Zr-Rb]. The most peculiar feature observed here is the absence of Fe-Mn correlation which is at variance with the behaviour of these elements in typical lateritic profiles. Usually they are positively correlated. The enrichment of one will lead to the enrichment of the second (Elueze and Phillip, 1993, McFrlane, 1983).

The correlation matrix of diorite-derived lateritic profile (Table 5.4) shows the presence of the following element associations, based on the positive significant correlations: [K-Nb], [Fe-Co-Ni-Cu]. The absence of the [Rb-Sr-Zr-Ca] correlation indicates difference in behaviour of these elements in this profiles. As they were expected to be leached together, some showed enrichment relative to the bedrock.

From the correlation matrix of lateritic profiles developed over granodiorite (Table 5.5), the following element associations (based on the positive significant correlation) are present: [K-Rb-Sr-Ca-Cr-Zn-V], [Fe-Co-Ni-Cu-Mo-Pb] and [Ti-Zn-Y-Nb]. Again in this profile Mn did not show significant correlation with Fe.

The abundance of lateritic profile exposures in areas underlain by granite, hence abundance of geochemical data

made it more convenient to consider separately each horizon of this profile for the correlation of the elements present. The correlation matrix of indurated layer of granite-derived lateritic profile (Table 5.6) shows that K is correlated positively with Rb and Sr. Based on this positive significant correlation the following element association: are observed; [K-Rb-Sr], [Ca-Ti-V-Zr-Cr] and [Mn-Co-Ni-Zn-Pb-Cu]. The correlation matrix of mottled zone of the granite-derived lateritic profile (Table 5.7) is characterized by the following element association, based on the positive significant correlation: [K-Rb-Sr], [Ca-Ti-Cr] and [Fe-Mn-Ni-Cu-Zn-Pb-Y]. The correlation matrix of the saprolite layer of the granite-derived lateritic profile (Table 5.8) shows the following element association, based on the positive significant correlation: [K-Ca-Zn], [Ti-Mn-Zn], [Co-Ni-Rb-Sr-Y] and [Mo-Pb-Cr-Cu-Zr-Nb]. Generally, the correlation pattern in the lateritic profiles vary with the type of bedrock and the lateritic horizons.

ii. Major features of elements distribution

Accumulation Factor (AF) values (Table 5.9 - 5.12) have shown that the absolute accumulation of the base metals V, Cr, Mn, Co, Ni, Cu and Pb relative to the parent rock occur in the dioritic-derived lateritic profiles, and also the favourable lateritic horizons for this enrichmnent are both the mottled and indurated ones. From AF values Zr has also shown strong enrichment especially, in the indurated layer

of the granodiorite-derived lateritic profiles. Co has also shown high enrichment relative to the parent rock in both the mottled and indurated layers of the granite-derived lateritic profiles. Zn has been enriched relative to the parent rock in the granite-derived lateritic profiles and been leached in all the other types. Mo ha shown absolute enrichment in the granite-derived lateritic profiles.

5.3.5. Graphs and Geochemical maps

Bar diagrams have been constructed by plotting the average concentration values (in ppm) of V, Cr, Mn, Co, Ni, Cu, Zn, Mo, and Pb in bedrock, saprolite, mottled and indurated layers against each of these layers, so as to show the vertical patterns (trends) of each of these elements. Fig 5.1, 5.3, 5.5, 5.7, 5.9 5.11, 5.13, 5.15 and 5.17 show these bar diagrams.

The analytical data obtained have been also plotted against each sample point in form of a geochemical map for each of the nine elements V, Cr, Mn, Co, Ni, Cu Zn, Mo and Pb. Concentration values for each element in all samples collected from the area of study, were arranged statistically, where four class-limits were obtained. These points were plotted to show the spatial patterns for each of the nine elements (Fig 5.2, 5.4, 5.6, 5.8, 5.10, 5.12, 5.14, 5.16 and 5.18).

Table 5.1: Statistical data for the elements analysed in lateritic profiles.

Schist-derived lateritic profiles (n = 7)

	K*	Ca*	Fe*	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
Mean	0.92	0.46	6.68	5695.5	546.29	268.52	452.08	284.24	71.94	59.42	56.03	26.17	49.07	21.75	308.34	17.20	5.64	38.10
S. Dev.	1.27	1.94	5.21	7238.6	201.58	52.17	384.47	126.75	28.99	14.86	37.10	54.43	143.78	37.63	126.43	9.89	1.28	20.20
Range	0.3-2.91	0.6-5.45	1.15 - 13.6	1350 - 18100	338-952	204-352	156 - 1280	127-970	38.3-110	38.2 - 76.5	30.7-135	7.96-147	7.49-419	8.82-116	116-489	7.41 - 32.6	4.16 - 8.18	22.4 - 70.2

Diorite-derived lateritic profiles (n = 12)

Mean	0.68	0.60	10.83	6624.4	624.64	317.21	114.21	335.52	109.76	74.25	52	14.14	28.3	25.6	80.1	21.94	5.95	44.26
S. Dev.	0.48	10.6	7.98	6789.5	206.8	432.7	3073.23	295.23	59.55	35.77	25.39	20.03	198.73	13.77	224.39	127.11	1.02	135.92
Range	0.4-2.12	0.21-37	1.2-26.4	1650 - 35300	393 - 1000	182 - 1760	183 - 11400	33 - 955	47.1-230	32.9-134	24.1-122	7.8-72.2	2.70-707	14.9 - 61.4	7.35-711	7.35 - 457.5	4.45 - 8.04	18.8 - 116

Granite and Granodiorite-derived lateritic profiles (n = 7)

Mean	1.36	0.32	4.45	2356.7	325.75	180	333.85	206.97	53	41.41	46.84	65.28	38.19	23.46	476.84	17.72	5.15	41.19
S. Dev.	1.62	0.45	6.019	586.22	143.199	66.10	115.6	162.6	37.02	22.16	25.67	63.24	70.01	22.24	204.47	8.604	1.86	17.96
Range	0.37 - 3.96	0.13 - 1.35	1.67 - 15.3	1480 - 3200	190-536	109-251	203-517	97 - 541	30-136	22.6-91	28.3 - 98.7	17.4-161	4.67-165	12.5-73	280-786	8.87- 32.5	209.1 - 7094	19.6 - 64.2

* Concentrations in wt. %
All others in ppm

Table 5.2: Statistical data for elements analysed in granite-derived lateritic profiles

A Indurated Layer (n = 13)

		[illegible]	Fe*	Ti	V	Cr	Mn	[illegible]	Ni	Cu	[illegible]	[illegible]	Sr	Y	Zr	Nb	Mo	Pb
Mean	0.74	0.26	5.75	2357.16	380.11	101.48	401.95	234.66	69.20	53.56	36.72	37.65	12.51	22.78	442.95	15.99	8.69	42.61
S. Dev.	0.73	0.10	0.64	1089.67	125.98	363.80	791.44	174.65	35.48	104.56	14.329	37.65	25.76	18.65	177.10	5.89	18.57	9.30
Range	0.32 - 3.11	0.19 - 0.44	0.19 - 19.9	643 - 5300	276-779	180-559	135 - 2340	83.4-535	45.3-151	32.9-421	241.1 - 65.8	18.1 - 135	8 - 87.4	11.1 - 81.1	224-771	8.48 - 31.5	4.59 - 71.4	19.8-133

B Mottled Zone (n = 14)

Mean	0.82	0.27	3.50	3038.54	403.88	238.36	363.44	204.91	57.79	44.72	36.55	30.13	20.25	27.05	470.45	14.33	8.28	31.28
S. Dev.	0.42	0.10	6.78	1814.48	137.83	46.22	877.20	257.01	29.55	24.34	11.50	30.28	8.57	61.45	189.46	6.52	15.65	28.90
Range	0.35-[illegible]	[illegible] - 1.81	0.51 - 22.1	1460 - 8460	254-774	126-316	127 - 3500	48.2 - 746	30.5-140	21.5-117	22.7 - 57.7	21.1-120	10.9 - 38.9	12.2-247	214-840	2.4-26.7	3.19 - 50.1	16.3-11

C Saprolite Layer (n = 8)

Mean	2.51	0.38	9.08	2903	423	258	205	154.5	60.13	49.21	52.12	116.13	30.19	27.53	402.47	23.14	6.53	28.77
S. Dev.	5.27	1.22	15.13	1372	68	45	134	60.67	31.11	17.59	48.023	224.45	108.16	41.27	537.03	35.62	6.66	24.89
Range	0.43 - 16.8	0.24-372	1.27 - 45.9	1680 - 5630	357-525	204-327	114-527	101-293	42.5-138	31.1 - 88.1	26.3-148	19.7-724	13.1-328	13.8-132	181 - 1770	13.8-119	4.68 - 24.2	18.1 - 82.9

* Concentrations in wt. %
All others in ppm

Table 5.3: Correlation matrix showing relationship between 18 elements studied in lateritic profiles developed over schist

K	Ca	Fe	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
1.00	-0.24	-0.89	-0.69	-0.41	-0.16	-0.23	-.88	-0.43	-0.89	0.58	0.96	-0.25	-0.22	-0.60	-0.85	-0.47	0.10
Ca	1.00	-0.16	-0.31	-0.85	0.10	0.82	0.10	0.80	-0.12	0.86	-0.17	0.99	0.99	0.17	-0.71	-0.17	-0.80
	Fe	1.00	0.64	0.03	-0.31	0.06	0.88	0.46	0.54	0.29	-0.88	-0.10	-0.01	0.58	0.82	0.72	0.02
		Ti	1.00	0.10	-0.17	-0.11	0.80	-0.17	0.12	0.17	-0.63	-0.24	-0.27	-0.61	0.95	0.19	-0.15
			V	1.00	0.05	0.59	0.23	0.02	0.07	0.31	-0.36	0.88	0.85	-0.00	0.10	-0.28	-0.32
				Cr	1.00	0.01	-0.10	0.31	-0.19	-0.20	0.21	-0.1	0.09	-0.11	-0.05	-0.06	-0.25
					Mn	1.00	0.30	0.23	0.18	0.81	-0.07	0.75	0.84	-0.15	-0.7	0.06	-0.25
						Co	1.00	0.19	0.24	0.52	-0.82	0.10	0.10	0.58	0.87	0.45	-0.29
							Ni	1.00	0.39	0.15	-0.46	0.22	0.30	0.11	0.15	0.72	0.32
								Cu	1.00	0.18	-0.94	-0.12	-0.10	0.52	0.81	0.68	0.08
									Zn	1.00	-0.48	0.88	0.88	0.10	0.22	-0.08	-0.16
										Rb	1.00	-0.48	-0.88	-0.10	-0.22	-0.08	0.46
											Sr	1.00	0.97	-0.16	-0.17	-0.24	-0.43
												Y	1.00	-0.06	-0.18	-0.08	0.25
													Zr	1.00	0.14	0.35	0.11
														Nb	1.00	0.28	-0.06
															Mo	1.00	0.17
																Pb	1.00

Table 5.4 Correlation matrix showing relationship between 18 element studied in lateritic profiles developed over diorite

K	Ca	Fe	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
1.00	0.27	-0.15	0.44	0.32	0.38	-0.02	0.41	0.22	-0.10	-0.02	0.17	-0.16	0.05	-0.32	0.86	0.66	-0.08
Ca	1.00	0.14	0.23	-0.17	-0.06	0.14	0.09	0.22	0.04	-0.23	-0.15	-0.14	0.01	-0.06	0.11	0.29	0.08
	Fe	1.00	0.23	0.43	0.08	0.55	-0.93	0.84	0.76	0.32	-0.55	0.03	0.01	-0.32	0.17	0.16	0.61
		Ti	1.00	0.01	-0.4	-0.04	0.24	-0.13	-0.11	0.09	-0.50	0.12	-0.14	-0.05	-0.27	-0.26	-0.24
			V	1.00	0.65	-0.06	0.32	0.66	0.51	0.27	-0.33	-0.26	0.25	-0.41	0.20	-0.01	0.52
				Cr	1.00	-0.18	0.07	0.52	0.39	-0.06	-0.02	-0.18	0.41	-.24	-0.01	-0.00	0.47
					Mn	1.00	0.05	0.49	0.30	-0.11	-0.31	-0.12	-0.28	-0.33	0.02	0.71	0.21
						Co	1.00	0.75	0.77	0.35	-0.58	0.14	0.13	-0.33	-0.45	0.68	0.69
							Ni	1.00	0.8	0.21	-0.18	-0.09	0.13	-0.36	0.03	0.64	0.73
								Cu	1.00	0.56	-0.58	0.33	0.48	-0.33	-0.15	0.54	0.85
									Zn	1.00	0.19	0.42	0.80	-0.42	0.07	0.53	0.49
										Rb	1.00	-0.15	0.01	-0.14	-0.00	-0.15	-0.13
											Sr	1.00	0.33	0.09	-0.09	-0.27	-.13
												Y	1.00	-0.36	0.05	0.22	0.57
													Zr	1.00	-0.05	-0.37	-0.05
														Nb	1.00	-0.04	-0.30
															Mo	1.00	0.56
																Pb	1.00

Table 5.5 Correlation matrix showing relationship between 18 elements studied in lateritic profiles developed over granodiorite.

K	Ca	Fe	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
1.00	0.13	-0.74	-0.08	0.83	0.69	0.11	-0.70	-0.28	-0.35	0.54	0.99	0.96	0.36	-0.46	0.04	-0.16	-0.57
Ca	1.00	-0.42	0.48	0.29	0.66	0.47	-0.34	-0.10	-0.07	0.94	0.72	0.88	0.87	-0.01	0.46	0.09	-0.68
	Fe	1.00	-0.14	-0.45	-0.28	-0.04	0.97	0.69	0.77	-0.42	-0.33	-0.66	-0.45	0.34	-0.43	0.77	0.63
		Ti	1.00	-0.41	0.06	0.47	-0.10	-0.13	-0.07	0.71	-0.02	0.16	0.78	0.61	0.88	-0.22	-0.60
			V	1.00	0.89	-0.24	-0.30	0.24	0.09	0.47	0.77	0.78	0.18	-0.24	-0.23	0.28	-0.32
				Cr	1.00	-0.19	-0.39	0.43	0.31	0.55	0.65	0.74	0.45	0.12	0.04	0.25	-0.44
					Mn	1.00	0.40	-0.50	-0.06	0.50	0.10	0.24	0.52	-0.29	0.21	-0.05	-0.10
						Co	1.00	0.52	0.62	-0.24	-0.79	-0.62	-0.34	0.26	-0.22	0.76	0.57
							Ni	1.00	0.96	-0.09	-0.48	-0.22	-0.32	0.42	-0.36	0.74	0.38
								Cu	1.00	-0.04	-0.46	-0.26	-0.20	-0.38	-0.34	0.74	0.43
									Zn	1.00	0.54	0.76	0.93	0.25	0.68	0.08	-0.80
										Rb	1.00	0.94	0.51	-0.42	-0.13	-0.24	-0.63
											Sr	1.00	0.65	-0.25	0.25	-0.07	-0.72
												Y	1.00	0.24	0.80	-0.16	-0.70
													Zr	1.00	0.61	0.20	-0.30
														Nb	1.00	-0.29	-0.80
															Mo	1.00	0.29
																Pb	1.00

Table 5.6: Correlation matrix showing relationship between 18 elements studied in indurated layer of a granite - derived lateritic profile.

K	Ca	Fe	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
1.00	-.04	0.93	-0.16	-0.07	-0.22	-0.32	-0.39	-0.38	-0.10	-0.39	0.80	0.63	0.10	-0.11	-0.03	-0.21	-0.31
Ca	1.00	-0.43	0.66	0.80	-0.06	0.15	0.43	0.38	-0.06	0.32	-0.25	-0.05	0.08	0.38	-0.09	0.01	0.47
	Fe	1.00	-0.56	0.5	-0.4	0.27	0.17	0.04	-0.35	0.25	-0.12	0.02	-0.21	0.15	-0.31	0.02	-0.06
		Ti	1.00	0.67	0.07	0.28	0.12	0.37	0.71	0.29	-0.12	0.04	-0.00	0.70	-0.08	-0.01	0.48
			V	1.00	0.30	0.40	0.31	0.53	0.90	0.42	-0.26	-0.10	0.10	0.42	-0.26	-0.20	0.67
				Cr	1.00	0.40	0.31	0.53	0.90	-0.42	-0.26	-0.10	-0.22	0.42	-0.06	0.10	0.34
					Mn	1.00	0.70	0.78	0.55	0.88	-0.15	-0.23	-0.13	-0.02	-0.51	-0.24	0.87
						Co	1.00	0.53	0.50	0.78	-0.54	0.24	-0.10	-0.10	-0.37	0.04	0.70
							Ni	1.00	0.71	0.76	-0.50	-0.37	-0.10	-0.04	-0.43	-0.12	0.89
								Cu	1.00	0.57	-0.33	-0.14	0.01	0.32	-0.34	-0.10	0.79
									Zn	1.00	-0.49	-0.34	0.02	0.01	-0.25	-0.12	0.84
										Rb	1.00	0.49	0.41	-0.25	0.36	0.47	-0.52
											Sr	1.00	-0.75	0.15	-0.04	-.02	-0.32
												Y	1.00	0.12	0.75	-0.06	-0.18
													Zr	1.00	0.09	0.06	0.02
														Nb	1.00	0.30	-0.46
															Mo	1.00	-0.11
																Pb	1.00

Table 5.7 Correlation matrix showing relationship betv.een 18 elements studied in mottled zone of a granite-drived lateritic profile.

K	Ca	Fe	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
1.00	-0.96	-0.95	-0.21	-0.49	0.35	-0.10	0.21	-0.20	0.27	-0.74	0.10	0.01	-0.47	-0.25	0.04	-0.01	-0.22
Ca	1.00	-0.99	0.29	0.23	0.20	-0.1	-0.2	0.12	0.10	0.69	-0.03	0.10	-0.42	0.27	0.11	0.10	-0.24
	Fe	1.00	0.26	0.43	0.08	0.67	0.23	0.95	0.92	0.66	-0.40	-0.44	0.51	0.16	0.31	-0.1	0.82
		Ti	1.00	0.76	0.42	0.00	0.10	0.32	0.44	0.49	0.00	-0.18	-0.10	0.13	-0.3	-0.11	0.42
			V	1.00	0.5	0.29	-0.1	0.51	0.53	0.34	0.23	-0.13	0.03	0.24	0.10	-0.13	0.44
				Cr	1.00	0.02	-0.12	0.28	0.30	-0.06	-0.13	0.40	-0.19	-0.04	-0.16	0.10	0.1
					Mn	1.00	-0.25	0.56	0.42	0.34	0.35	-0.23	0.90	0.01	0.01	0.02	0.87
						Co	1.00	0.28	0.29	0.48	0.63	0.11	-0.01	-0.2	0.10	-0.25	-0.05
							Ni	1.00	0.97	0.69	-0.37	-0.33	0.36	0.4	-0.15	0.10	0.72
								Cu	1.00	0.66	-0.36	-0.38	0.21	0.10	-0.42	-0.13	0.63
									Zn	1.00	0.1	-0.35	0.35	-0.11	-0.02	-0.35	0.37
										Rb	1.00	0.49	-0.15	-0.36	0.58	-0.38	0.33
											Sr	1.00	-0.29	-0.34	0.13	0.04	-0.13
												Y	1.00	0.20	20	0.11	0.63
													Zr	1.00	0.06	0.73	-0.04
														Nb	1.00	-0.30	-0.13
															Mo	1.00	-0.12
																Pb	1.00

Table 5.8 Correlation matrix showing relationship between 18 elements studied in saprolite layer of a granite-derived lateritic profile

K	Ca	Fe	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Pb
1.00	0.96	0.95	0.24	0.49	0.35	0.10	0.21	0.20	0.27	0.74	0.10	0.01	0.37	-0.25	-0.04	0.03	-0.22
Ca	1.00	0.99	0.29	0.25	0.20	0.1	0.2	0.12	0.10	0.69	-0.05	-0.30	0.12	-0.27	-0.11	-0.10	-0.24
	Fe	1.00	0.38	-0.21	0.20	0.10	0.27	0.17	0.10	0.74	0.01	-0.65	0.45	-0.25	-0.07	-0.02	-0.19
		Ti	1.00	-0.19	0.05	0.83	0.46	0.45	0.18	0.74	0.36	0.23	0.31	[illegible]	0.28	0.27	0.17
			V	1.00	0.65	-0.30	0.58	0.46	0.42	-0.19	0.49	0.59	0.21	0.48	0.55	0.56	0.83
				Cr	1.00	0.1	0.55	0.66	0.84	0.37	0.66	0.65	0.51	0.46	0.56	0.62	0.57
					Mn	1.00	0.22	0.37	0.28	0.62	0.41	0.22	0.13	0.10	0.24	0.22	-0.04
						Co	1.00	0.92	0.76	0.85	0.88	0.78	0.73	[illegible]	-0.80	0.89	0.81
							Ni	1.00	0.88	0.60	0.97	0.96	0.82	0.82	0.96	0.97	0.72
								Cu	1.00	0.53	0.92	0.87	0.71	[illegible]	0.82	0.85	0.54
									Zn	1.00	0.57	0.45	0.66	[illegible]	0.11	0.46	0.11
										Rb	1.00	0.97	0.72	0.81	0.96	0.96	0.71
											Sr	1.00	0.71	0.91	0.99	0.99	0.80
												Y	1.00	0.54	0.71	0.76	0.56
													Zr	1.00	0.93	-0.91	0.71
														Nb	1.00	0.99	0.78
															Mo	1.00	0.80
																Pb	1.00

5.4. DISTRIBUTION PATTERN OF ELEMENTS IN T. PROFILES

5.4.1. General Consideration

From an exploration point of view, it is necessary consider the distribution of the elements in individual horizons of the lateritic profiles (Levinson, 1974).

Iron has shown increasing enrichment from botto. to the top of the profile, relative to the parent rock (Table 5.9 - 5.12). This behaviour of the Fe is in agreement with its behaviour in a typical lateritic profiles.

Alkali metals K and Rb have shown irregular pat .rn. K has been enriched in saprolite layer of lateritic profiles developed over granodiorite and schist and has been depleted in profiles over gr. ite and diorite. Whereas, Rb has been enriched in mottled zone of lateritic profiles developed over diorite and saprolite layers of both schist and granodiorite-derived lateritic profiles, and has been depleted in lateritic profile developed over granite.

As expected alkaline earths and Sr have shown strong depletion in the lateritic profiles, relative to the corresponding parent rocks.

Zirconium has shown absolute enrichment in the lateritic profile, relative to all type of parent rock. while Ti has been enriched in lateritic profiles developed over schist,

diorite and granite, but has been depleted in lateritic profiles developed over granodiorite.

Niobium is been enriched in lateritic profiles developed over diorite, but depleted in profiles developed over schist, granite and granodiorite.

5.4.2. Distribution pattern of V, Cr, Mn, Co, Ni, Cu, Zn, Mo and Pb in the lateritic profiles

Both the vertical and areal variation patterns (trends) of these elements in schist, diorite, granite and granodiorite-derived lateritic profiles are presented here, in more detail.

i. Lateritic profile developed over schist

The average concentrations of V in the parent rock, saprolite, mottled and indurated layers are 925ppm, 485.5ppm, 529ppm and 517.5ppm respectively. The accumulation factor (AF) values for this element in the saprolite, mottled and indurated layers are 0.52, 0.57 and 0.56, which indicate that V has been depleted in the lateritic profile, relative to the parent rock. This vertical variation pattern of the element along the profile is represented graphically in fig 5.1, while the areal variation pattern is shown in fig 5.2.

Chromium has been inpoverished in both saprolite and indurated layers, relative to the parent rock, but has been

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enriched in the mottled zone. It has average concentration of 282ppm, 219.5ppm, 340ppm and 254ppm in the parent rock, saprolite, mottled and indurated layers respectively. The accumulation factor (AF) of the element in the mottled zone is 1.21 (Table 5.9). Fig 5.3 and 5.4 show the vertical and the areal distribution patterns of this element respectively.

Manganese has shown depletion in the profile, relative to the parent rock. It has average concentration of 1280ppm, 440ppm, 81.2ppm and 63.95ppm in the parent rock, saprolite mottled and indurated layers, respectively (Table 5.9). The vertical and areal varitation patterns of this element is shown in figs 5.5 and 5.6.

Cobalt has been enriched in the indurated layer, relative to the parent rock with accumulation factor of 1.18, and has been depleted in mottled and saprolite layer, relative to the parent rock. The average concentration of this element in the parent rock, saprolite, mottled and indurated layer are 325ppm, 303ppm, 236ppm and 383ppm respectively (Table 5.9). The vertical and areal variation patterns are shown in figs 5.7 and 5.8 respectively.

Table 5.9.: Accumulation Factor (AF) of elements in lateritic profiles developed over schist.

Element	Parent Rock	Saprolite Layer		Mottled Zone		Lateritic Layer	
(at.%)	X	X	AF	X	AF	X	AF
Al	9.7	1.70	2.56	1.70	2.62	9.[illegible]	1.1
Ti	5.4	6.03	0.81	0.79	0.1	[illegible]	0.1
Fe	8.0	7.13	0.89	6.66	0.86	11.0	1.50
[illegible]							
Ti	3050	9705	1.19	6995	2.65	[illegible]	0.17
Y	[illegible]	4655	0.57	539	0.57	5115	0.56
Cr	780	274	0.9	440	1.71	[illegible]	0.86
Mn	1760	410	0.34	81.2	0.063	61.95	0.05
Co	45	901	0.91	236.5	0.71	961	1.16
Ni	161.5	[illegible]	0.69	77.7	0.29	169.5	1.51
Cu	[illegible]	[illegible]	0.99	54.5	1.11	71.[illegible]	1.36
Zn	111	[illegible]	0.38	81.2	0.66	[illegible]	0.47
Ba	0.1	34.37	1.92	11.65	2.74	[illegible]	0.76
[illegible]	119	47.1	0.16	20.2	0.08	47.04	0.1
Y	11[illegible]	1.05	0.10	0.0	0.17	19	0.16
Zr	150	[illegible]	[illegible]	70.0	0.17	401.5	1.17
Sr	14.1	[illegible]	1.11	417	4.37	[illegible]	1.[illegible]
Mo	[illegible]	1.[illegible]	0.85	5.59	1.03	[illegible]	1.[illegible]
Pb	[illegible]	[illegible]	0.87	67.55	[illegible]	11.[illegible]	[illegible]

X = mean concentration

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Table 5.10.: Accumulation Factor (AF) of elements in lateritic profiles developed over di[illegible]ite.

[illegible]	[illegible]	[illegible] Layer		[illegible] Layer		[illegible] Layer	
[illegible]	[illegible]	[illegible]	AF	[illegible]	AF	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]							
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

X = mean concentration

Table 5.1.: Accumulation Factor (AF) of elements in lateritic profiles developed over granite.

Element	Parent Rock	Saprolite Layer		Mottled Zone		Laterized Layer	
	X	X	AF	X	AF	X	AF
Fe	2.9	5.5	0.63	1.91	0.11	2.0	0.17
Ti	0.1	0.1	0.50	0.5	0.20	0.2	0.75
Mn	0.1	0.04	0.31	0.91	1.41	0.01	0.09
Ni							
Cr	0.0	0.05	1.0	0.0	1.64		0.00
Co	0.0	0.0	0.87	0.1	0.81	0.0	0.25
Cu	0.0	0.1	0.67	0.2	0.54	0	0.00
Zn	0.0	0.1	0.50	0.0	1.55	0.1	1.50
Pb	0.20	1.2	0.33	0.4	11.40	0.0	11.1
Ba	0.0	0.0	0.47	0.0	0.30	0.0	0.10
Sr	1.0	0.4	0.11	0.0	0.0	0.0	0.00
Zr	0.0	0.4	1.79	0.0	1.0	0	1.1
V	0.0	0.0	0.71	0.0	0.10	0.0	0.0
Y		0.0	0.11	0.0	0.0	0	0.0
La	0.0	0.0	0.11	0.0	0.07	0.0	0.00
Ce	0.0	0.0	1.17	0.0	1.03	0.0	0.17
Nd	0.0	0.0	1.30	0.0	0.20	0	1.0
Sc	0.0	0.0	0.11	0.0	0.0	0.0	0.0
Th	0.0	0.0	0.0	0.0	0.0	0.0	1.0

X = mean concentration

Table 5.12.: Accumulation Factor (AF) of element in lateritic profiles developed over granodiorite.

X = mean concentration

Nickel has been enriched relative to the parent rock in the indurated layer with accumulation factor value of 1.91 (Table 5.9) and has been depleted relative to the p ent rock, in the mottled and saprolite layers. It has av rage concentration of 98.5ppm, 68.8pp, 77.7ppm and 188.3ppm in the parent rock, saprolite, mottled and indurated la ers respectively. This vertical trends of the element is hown in fig 5. and the areal trends is shown in fig.10.

Copper has been enriched relative to the parent rock in the mottled and indurated layer with accumulation factor value of 1.11 and 1.26 respectively. The average concentrations of this element in the parent rock, saprolite, mottled and indurated layers are 56.9ppm, 56.5ppm, 57.5ppm and 71.6ppm respectively. The vertical and areal trends are shown in figs 5.11 and 5.12 respectively.

Zinc has been leached in all the horizons of this profile, relative to the parent rock. The average concentrati ns of this element in the parent rock, saprolite, mottled and indurated layer are 135ppm, 50.95ppm, 81.2ppm and 63.95ppm respectively. Figs 5.13 and 5.14 show the vertical a d the areal tr nds of this element respectively.

Molybdenum has been enriched relative to the parent rock in the mottled and indurated layers with accumulation f ctor of 1.03 and 1.26 respectively, but h s been depleted i the saprolite layer. It has average concentrations of 5.4ppm,

4.84ppm, 5.59ppm and 6.84ppm in the parent rock, saprolite, mottled and indurated layers respectively. Figs 5.15 and 5.16 show the vertical and areal trends of this element respectively.

Lead has been enriched, relative to the parent rock in the mottled and indurated layers with accumulation factor of 2.32 and 1.42 respectively. But has been depleted in the saprolite layer. The vertical and the areal trends of this element are shown in figs 5.17 and 5.18 respectively.

ii. Lateritic profile developed over diorite

Vanadium has been enriched in the mottled zone relative to the parent rock with accumulation factor of 1.1, and has been depleted relative to the parent rock in the saprolite and indurated layers (Table 5.10). It has average concentrations of 772ppm, 452ppm, 822.5ppm and 638.3ppm in the parent rock, saprolite, mottled and indurated layer, respectively Figs 5.1 and 5.2 show the vertical and areal trends of this element.

Chromium has an accumulation factor of 1.48 in the mottled zone indicating enrichment in this horizon, but it has been depleted in the saprolite and indurated layer, relative to the parent rock. It has average concentrations of 421ppm, 287.8ppm, 632.75ppm and 254.3ppm in bedrock. Saprolite, mottled and indurated layers, respectively (Table 5.10). The vertical and areal trends of this element are shown in

figs 5.3 and 5.4 respectively.

Manganese has been enriched in the indurated layer with accumulation factor value of 2.0 (Table 5.10), relative to the parent rock. It has average concentration of 2520ppm, 1399ppm, 1035ppm and 5050ppm in bedrock, saprolite, mottled and indurated layers respectively. Figs 5.5 and 5.6 show the vertical and areal trends of this element respectively.

Cobalt has shown strong enrichment in this profile relative to the parent rock. It has average concentration of 33ppm, 381.1ppm, 537.75ppm and 641.6ppm in the parent, saprolite, mottled and indurated layers respectively (Table 5.10). The accumulation values are 11.55, 16.29 and 19.44 in saprolite, mottled and indurated layers respectively, indicating that the highest enrichment is in the indurated layer. The vertical and areal distribution of this element is shown in figs 5.7 and 5.8 respectively.

Nickel has been enriched in the mottled zone with accumulation factor values of 1.02 (Table 5.10), it has average concentrations of 128ppm, 94.96ppm, 131ppm and 14.80ppm in the parent rock, saprolite and indurated layers respectively. Figs 5.9 and 5.10 show the vertical and areal trends of this element.

Copper has been enriched relative to the parent rock. It has average concentration of 64ppm, 69.6ppm 91.76ppm and

90.6ppm in the bedrock, saprolite, mottled and indurated layers respectively. The accumulation factor values for this element in saprolite, mottled and indurated layers are 1.09, 1.43 and 1.42 respectively. Figs 5.11 and 5.12 show the vertical and areal trends of this element.

Zinc has shown absolute depletion in this profile, relative to the parent rock. It has average concentrations of 61.2 ppm, 47.1 ppm, 37.13 ppm and 51.77 ppm respectively. This variation is illustrated in Figs 5.13 and 5.14.

Molybdenum has been enriched, relative to the parent rock in the saprolite and indurated layers with accumulation factor values of 1.0 and 1.15. It has average concentration of 5.94ppm, 5.94ppm, 5.58ppm and 6.8ppm respectively. Fig 5.15 and 5.16 show the vertical and real trends of this element.

Lead has been enriched relative to the parent rock. It has average concentrations of 20.0ppm, 37.43ppm, 42.6ppm and 76.6ppm in the parent rock, saprolite, mottled and indurated layers respectively (Table 5.9). The accumulation factor values of the element in saprolite, mottled and indurated layers are 1,87, 2.13 and 3.83 respectively. This indicates progressive enrichment of the element from bottom to top of the profile. Figs 5.17 and 5.18 show the vertical and areal trends of the element.

iii. Lateritic profiles developed over granite

Vanadium has been impoverished in this profile relative to the parent rock. It has average concentration of 523ppm, 428ppm, 421.45ppm and 375.5ppm in the parent rock saprolite, mottled and indurated layers respectively. (Table 5.11). This vertical trend is shown in fig 5.2.

Chromium has been deplated in this profile, relative to the parent rock .The average concentrations of the element in the parent rock, saprolite, mottled and indurated layers are 329ppm, 227.17ppm, 243.2ppm, and 276ppm respectively (Table 5.11). Fig 5.3 and 5.4 show the vertical and areal trends of this element.

Manganese has been enriched, relative to the parent rock in the indurated and mottled layers with accumulation factor values of 1.58 and 1.55 respectively (Table 5.11). But it has been depleted in the saprolite layer. The average concentrations of this element in the parent rock, saprolite, mottled and indurated layers are 398ppm, 230.4ppm, 618.8ppm and 626ppm respectively, see fig 5.5 and 5.6.

Cobalt has shown strong enrichment in this profile relative to the parent rock. The average concentrations of this element in the parent rock, saprolite, mottled and indurated layers are 20.5ppm, 162.5ppm 235.4ppm and 288ppm respectively. The accumulation factor values (Table 5.11)

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in the saprolite, mottled indurated layers are 7.93, 11.48 and 14.1 respectively, indicating increasing enrichment of this element from bottom to top of this profile (fig 5.7). Fig 5.8 shows the areal trends of this element.

Nickel has shown depletion in this profile relative to the parent rock. The average concentrations of this element in the parent rock,saprolite, mottled and indurated layers are 155ppm, 64.53ppm, 59.61ppm and 75.3ppm respectively. This vertical trends is shown in Fig 5.9,while the areal pattern is shoown in Fig5.10

Copper has been enriched, relative to the parentrock. The average concentrations of this element in the parentrock, saprolite, mottled and indurated layers are 21.6ppm, 51.4ppm, 68.5ppm, 75.4ppm, respectively. The accumulation factor values in saprolite, mottled and indurated layers are 2.44, 3.25 and 3.57 indicating increasing enrichment from bottom to top of this profile. Fig 5.11 and 5.12 show the vertical and areal trends of this element.

Zinc has shown approximately, constant enrichment in all the horizons of this profile, relative to the parentrock. It has average concentrations of 36.6ppm, 65.4ppm, 38.2ppm, 40ppm in the bedrock, saprolite, mottled and indurated layers, respectively (Table 5.11). Fig 5.13 and 5.14 show the vertical and areal trends of this element.

Molybdenum has shown increasing enrichment from bottom to the top of this profile, as can be indicated from the accumulation factor values 2.41, 3.06 and 4.25 in the saprolite, mottled and indurated layers respectively, the average concentrations of this element in the parentrock, saprolite, mottled and indurated layers are 5.20ppm, 7.71ppm, 9.80ppm, 13.6ppm respectively. Fig,5.15 and 5.16 show the vrtical and real trends of this element.

Lead has been enriched relative to the parentrock in the indurated layer with accumulation value of 1.1 But has been deplated in the saprolite and mottled layers (Table 5.11). The average concentrations of this parentrock, saprolite, mottled and indurated layers are 49.7ppm, 34.36ppm, 38.63ppm, and 53ppm respectively. Fig 5.17 and 5.18 show the vertical and areal trends of this element.

iv. lateritic profiles developed over granodiorite

Vanadium has been enriched in the saprolite layer with accumulation factor of 1.18 (Table5.12). While, it has been deplated in the mottled and indurated layers. The average concentrations of this element in the parentrock, saprolite,mottled and indurated layers are 437ppm, 518.5ppm, 199.5ppm, and 302.5ppm respectively. This vertical trends is shown in fig 5.1, while the areal pattern is shown in fig 5.2.

Chromium has been impoverished in this profile relative to

the parentrock. It has average concentrations of 250ppm, 244ppm, 122.7ppm and 172ppm in the parentrock, saprolite, mottled and indurated layers respectively. Fig 5.3 and 5.4 show the vertical and areal trends of this element.

Manganese has been deplated in this profile, relative to the parentrock. The average concentrations of this element in the parentrock, saprolite, mottled and indurated layers are 517ppm, 268ppm, 365ppm respectively. Fig 5.5 and 5.6 show the vertical and areal trends of this element.

Cobalt has been deplated in this profile, relative to the parentrock. The average concentrations of this element in the parentrock, saprolite, mottled and indurated layers are 1560ppm, 113ppm, 176ppm, and 468ppm respectively (Table 5.12). The vertical and areal variation pattern is shown in fig 5.7 and 5.8.

Nickel has been enriched in the indurated and saprolite layers, with accumulation factor values of 1.7 and 1.02 respectively (Table 5.12). The average concentrations of this elemeent in the parentrock, saprolite , mottled and indurated layers are 53.7ppm, 54.55ppm, 31.15ppm and 93.65ppm respectively (Table 5.12). The vertical distribution is graphically represented in the Fig 5.9, while the areal distribution pattern is shown in Fig 5.10.

Copper has been enriched in the indurated layer with

accumulation factor values 1.50, while it has been deplated in the saprolite and the mottled layers relative to the parentrock. The average concentrations of this element in the parentrock, saprolite, motled and indurated layers are 46.7ppm, 36.2ppm, 27.9ppm, and 71.0ppm respectively. Fig 5.11, and 5.12 show the vertical and areal trends of this element.

Zinc has been deplated in this profile relative to the parentrock. The average concentrations of this element in the parentrock, saprolite, mottled and indurated layers are 98.7ppm, 51.1ppm,40.7ppm, 39.9ppm respectively. Figs 5.13 and 5.14 show the vertical and areal trends of this element.

Molybdenum has been enriched relative to the parent rock in the indurated layer with accumulation factor value of 1.34. The average concentration of this element in the parentrock, saprolite, mottled and indurated layers are 5.74ppm, 5.37ppm, 3.19ppm and 7.69ppm respectively. Fig 5.15 and 5.16 show the vertical and areal trends of this element.

Lead has shown increasing enrichment from bottom to top of this profile relative to the parentrock, as can be indicated fom the accumulation factor values in the saprolite (1.3), mottled (1.58) and indurated layer (2.2) (Table 5.12). It has average concentrations of 28.0ppm,

37.0ppm 44.1ppm and 61.6ppm in the parentrock, saprolite, mottled and indurated layers respectively. Fig 5.17 and 5.18 show the vertical and trends of this element.

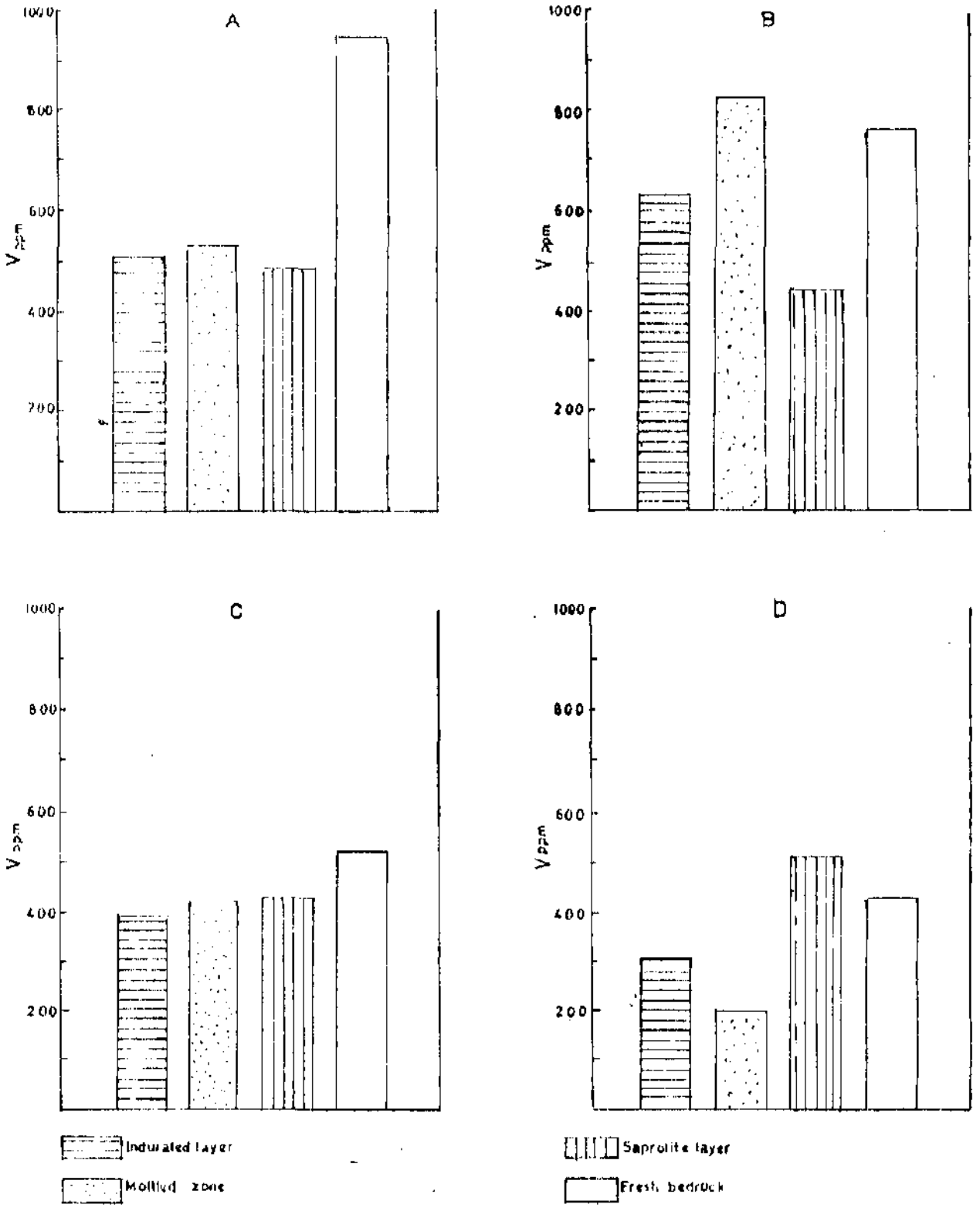
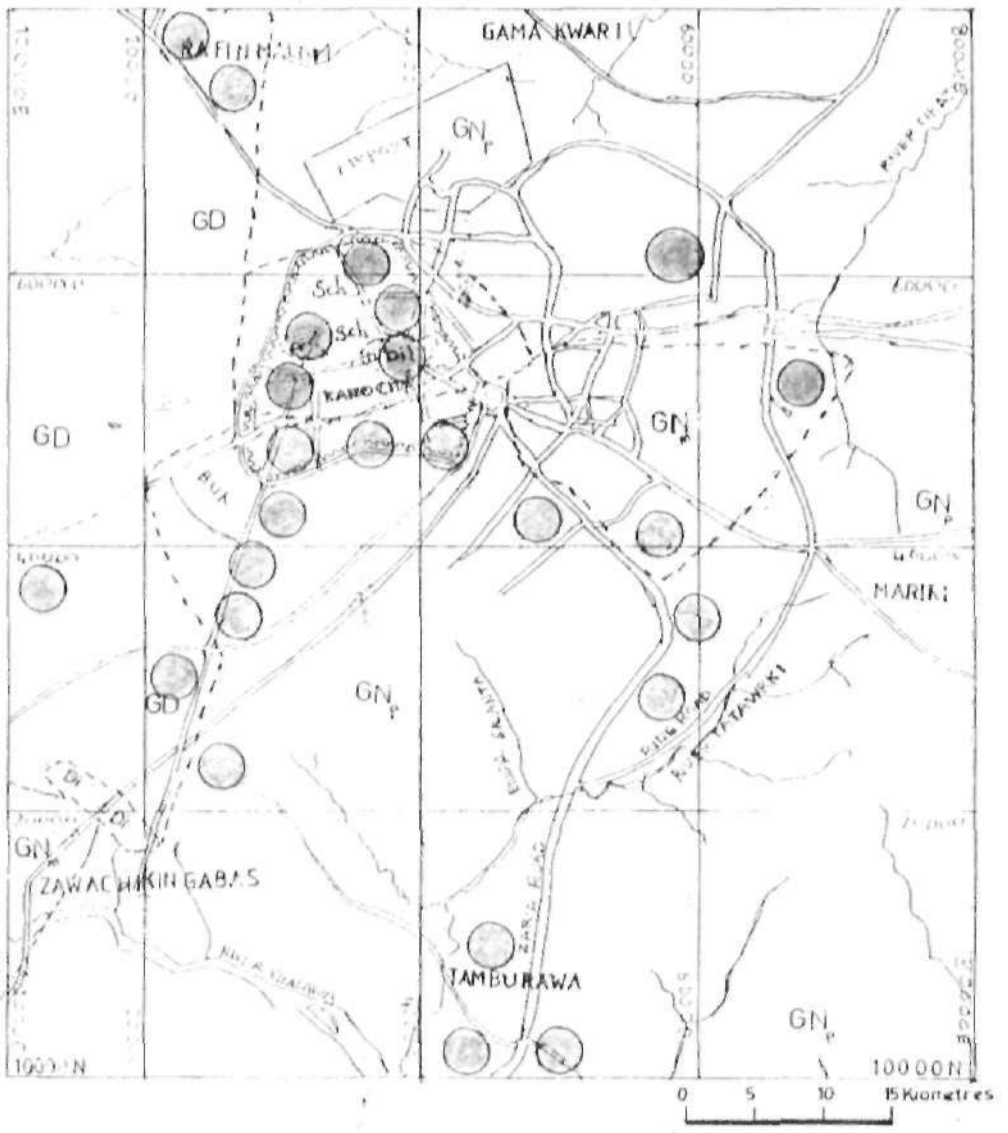


Fig 5.1 Bar diagram of V distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- GN Medium grand granite
- GN Porphyritic granite
- GD Granodiorite
- Di Diorite
- Sch Schist
- Rivers
- Roads
- Geological boundry
- Walled City

V ppm

- > 850
- 600 - 850
- 350 - 600
- < 350

Figs 2 Geochemical map of V distribution in the lateritic profiles in the study area.

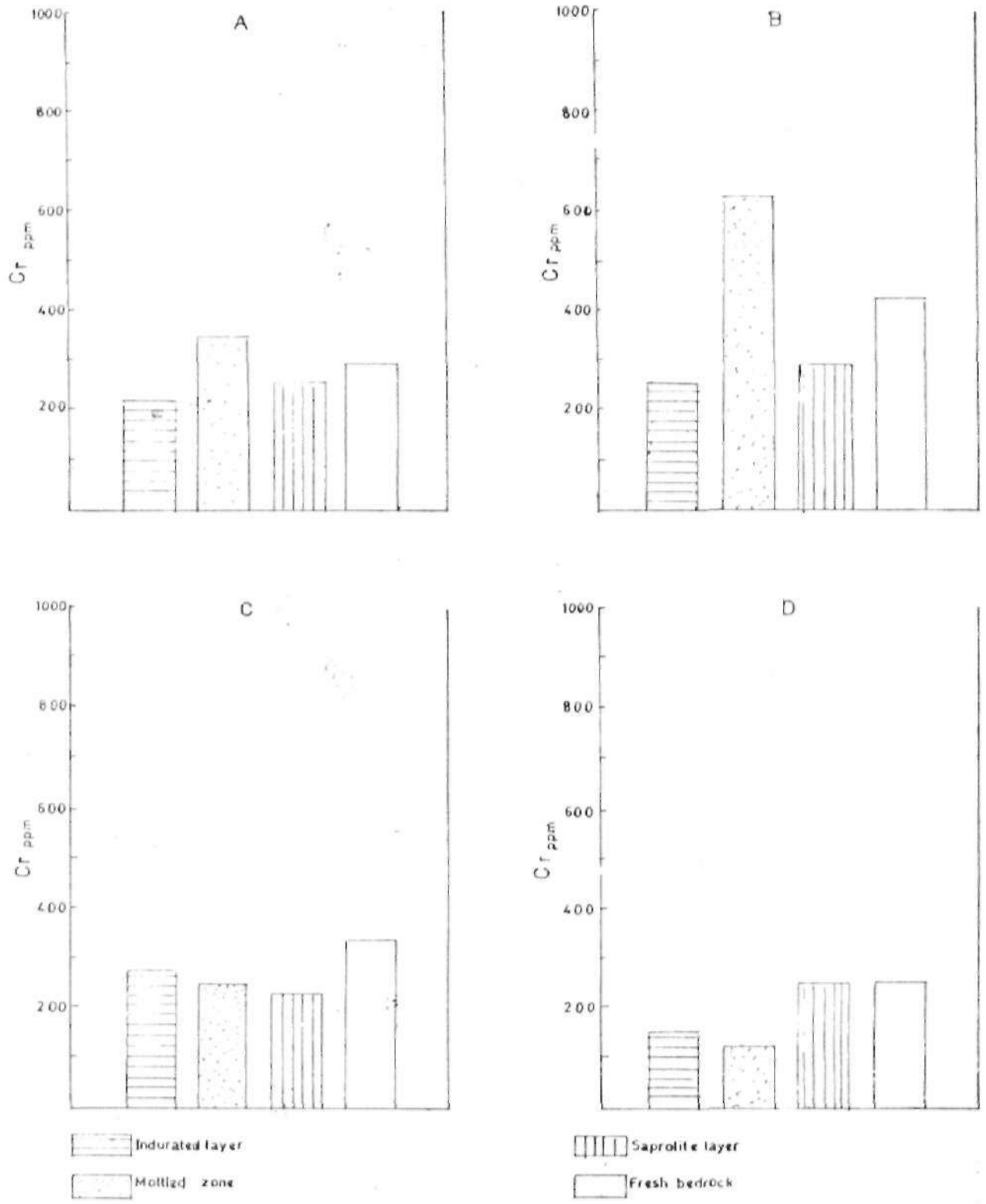
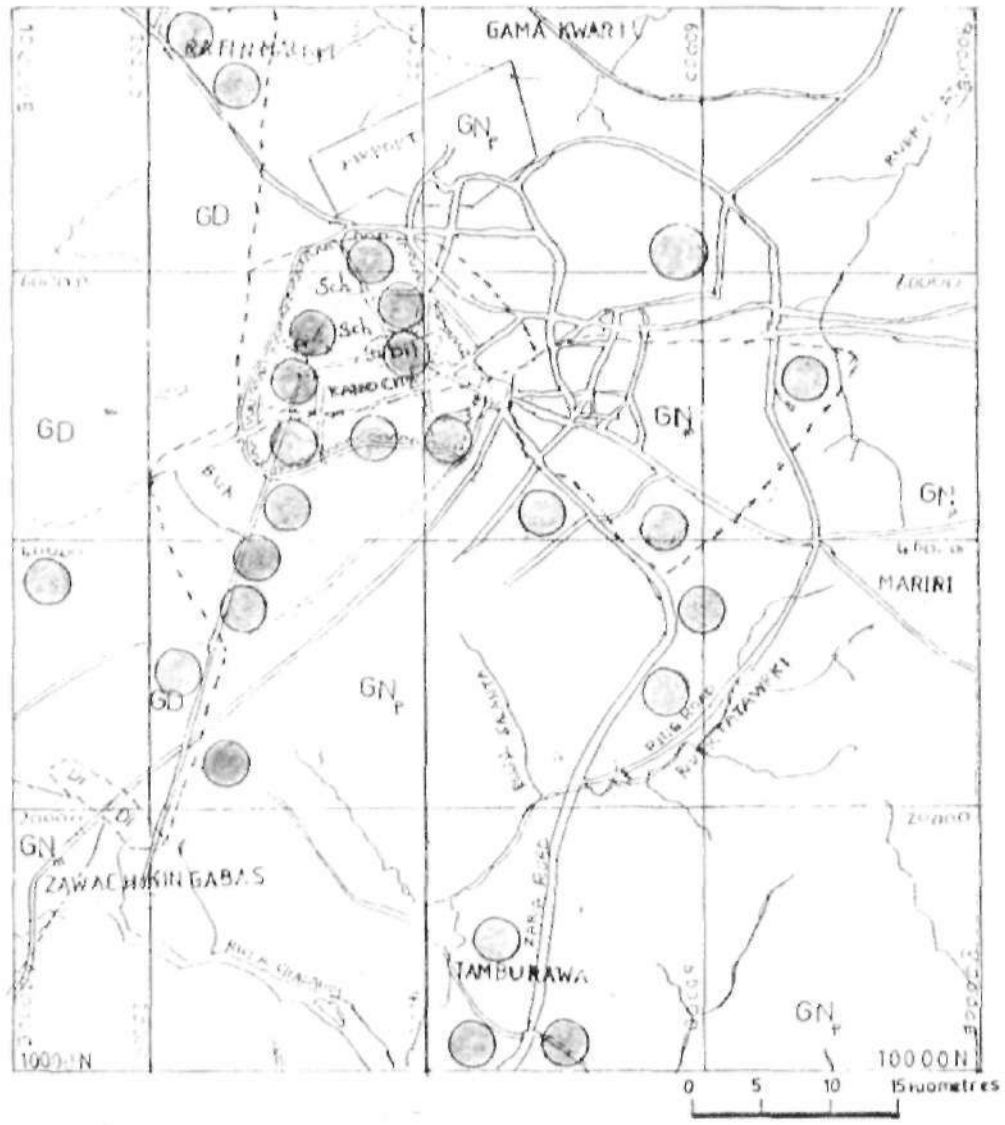


Fig 5.3 Bar diagram of Cr distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- GN_m Medium grand granite
- GN_p Porphyritic granite
- GD Granodiorite
- Di Diorite
- Sch Schist
- Rivers
- Roads
- Geological boundry
- Walled City

Cr ppm
- > 350
- 295 - 350
- 240 - 295
- <240

Figs.4 Geochemical map of Cr distribution in the lateritic profiles in the study area.

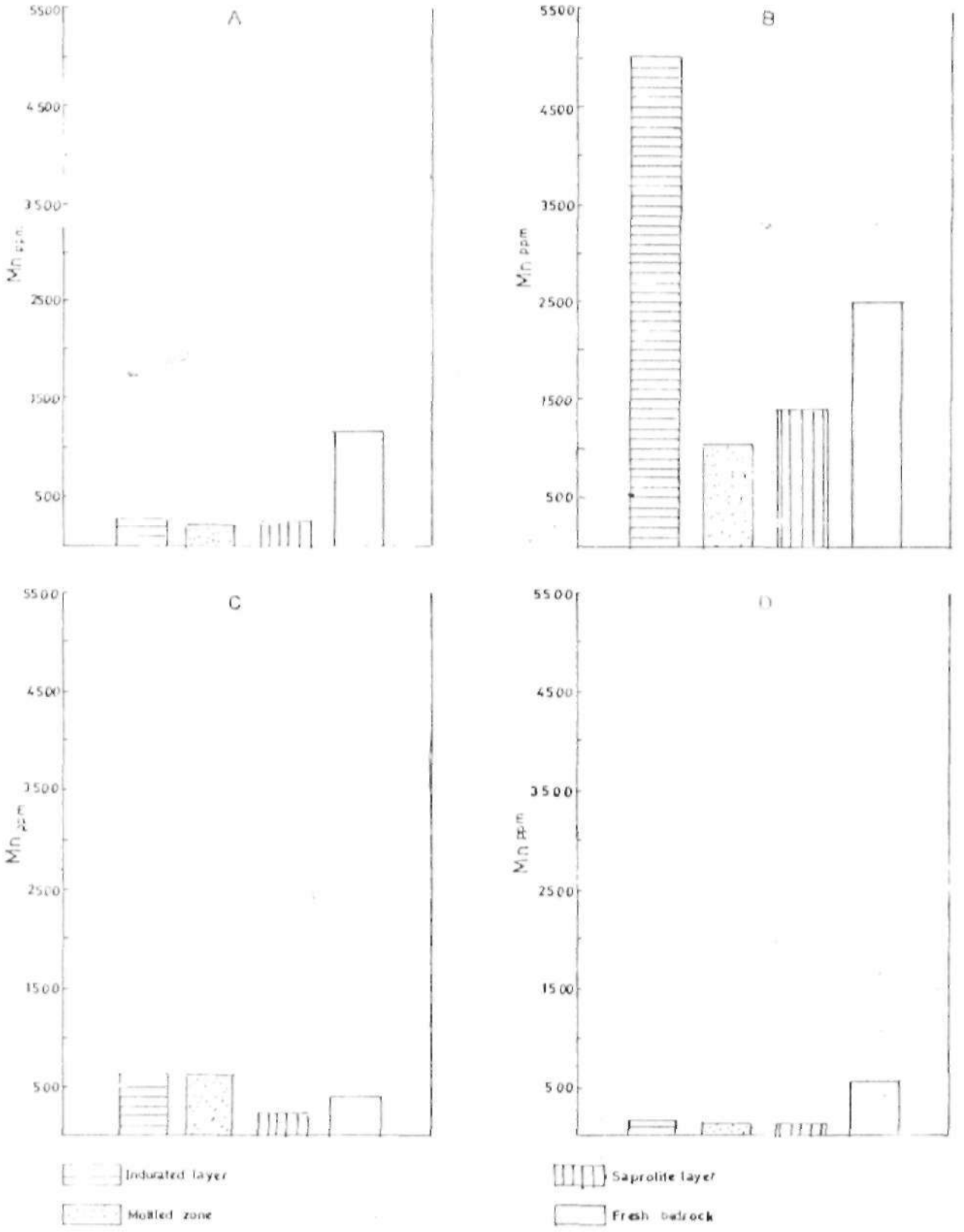
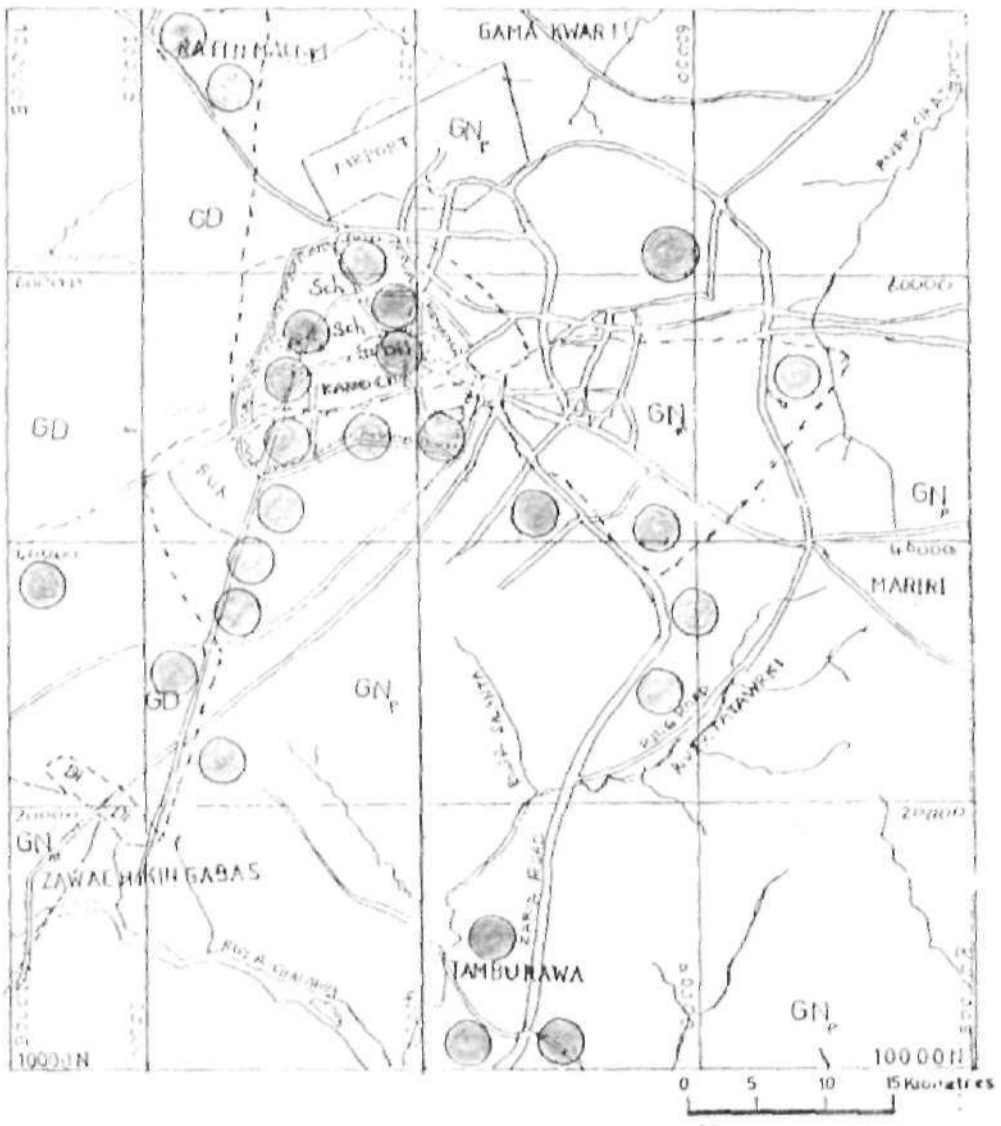


Fig 5.5 Bar diagram of Mn distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- GN_m Medium grand granite
- GN_p Porphyritic granite
- GD Granodiorite
- Di Diorite
- Sch Schist
- Rivers
- Roads
- Geological boundry
- Walled City

Mn ppm

- > 1020
- 690 - 1020
- 360 - 690
- < 360

Fig 5.6 Geochemical map of Mn distribution in the lateritic profiles in the study area.

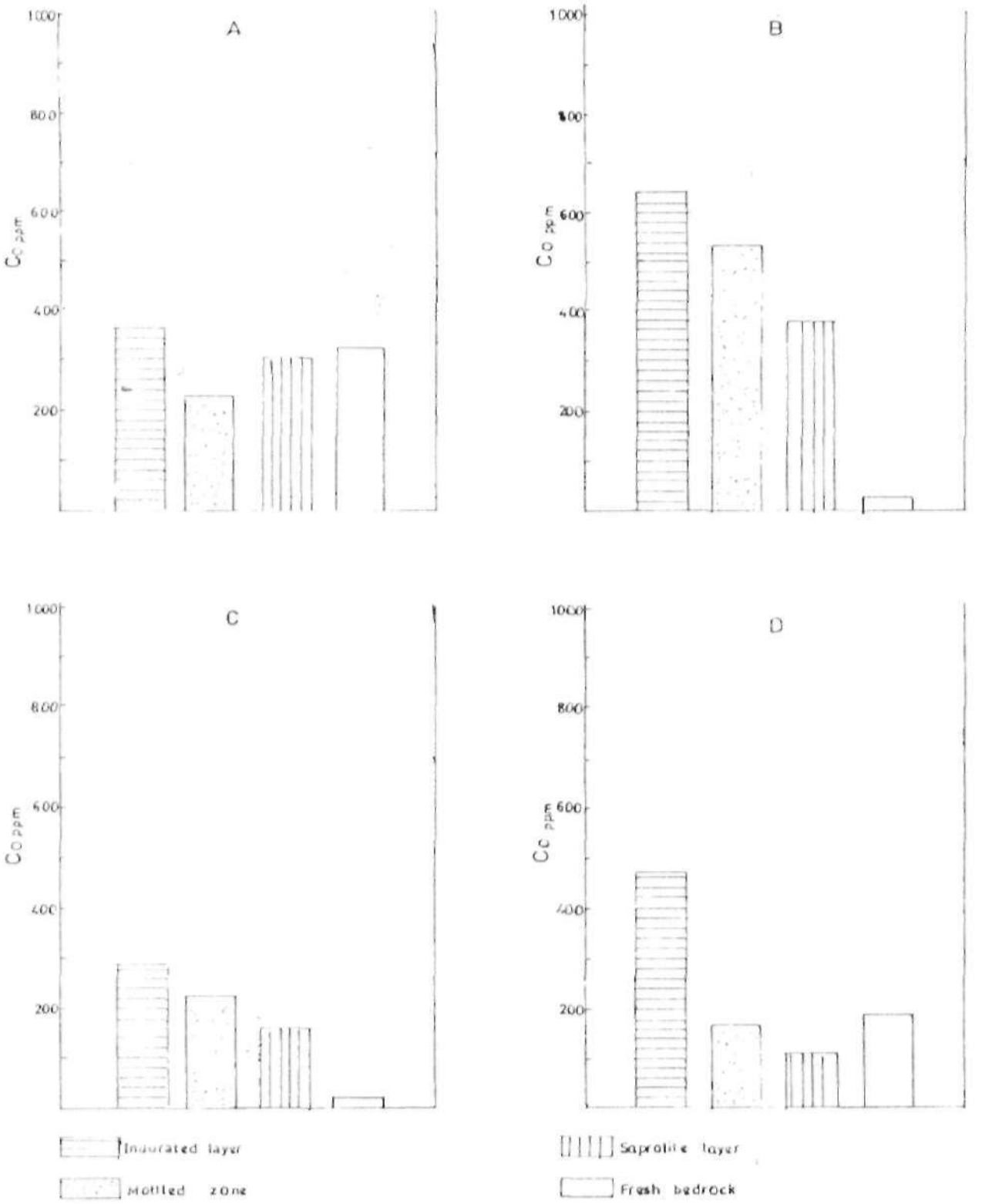
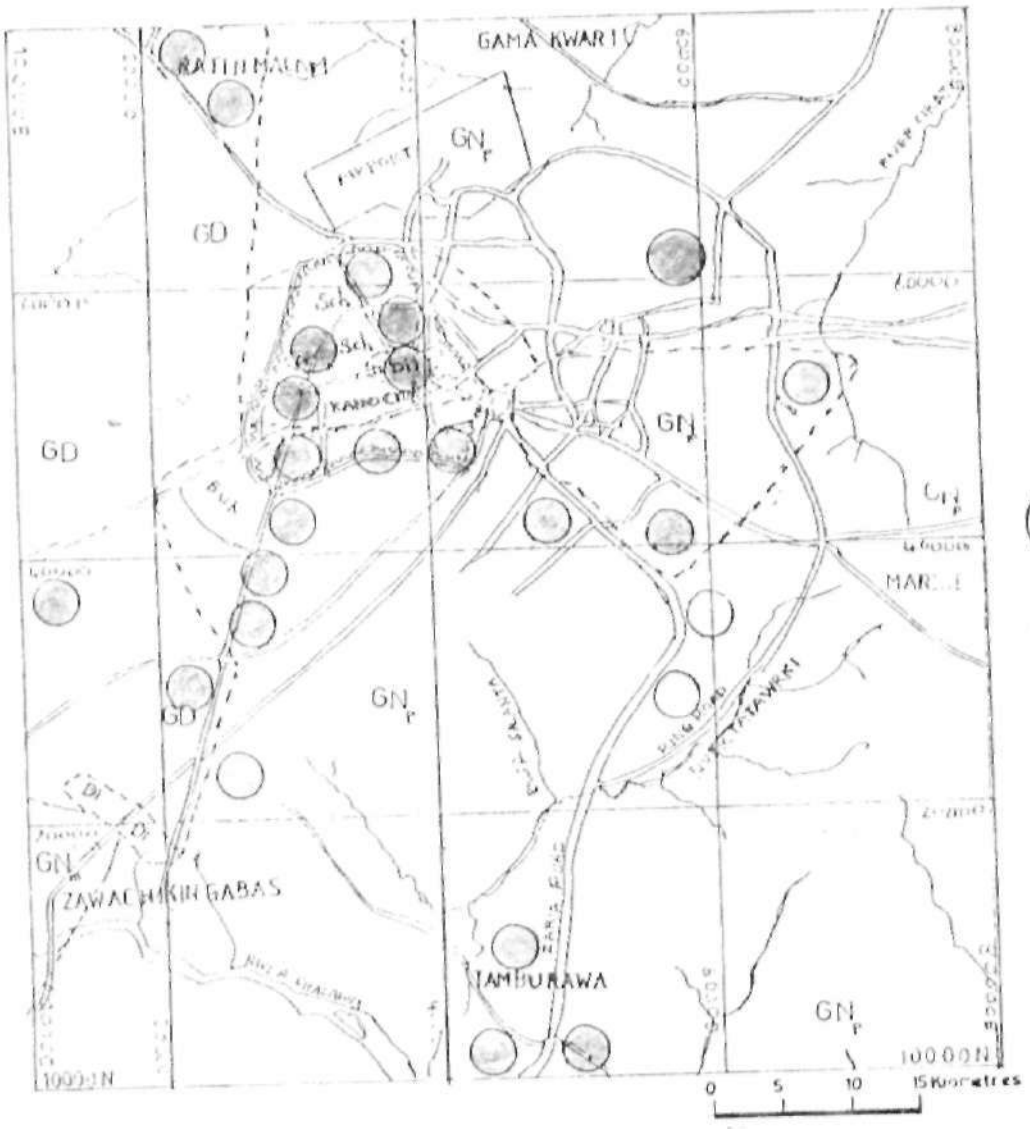


Fig 5.7 Bar diagram of Co distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



Figs 8 Geochemical map of Co distribution in the lateritic profiles in the study area.

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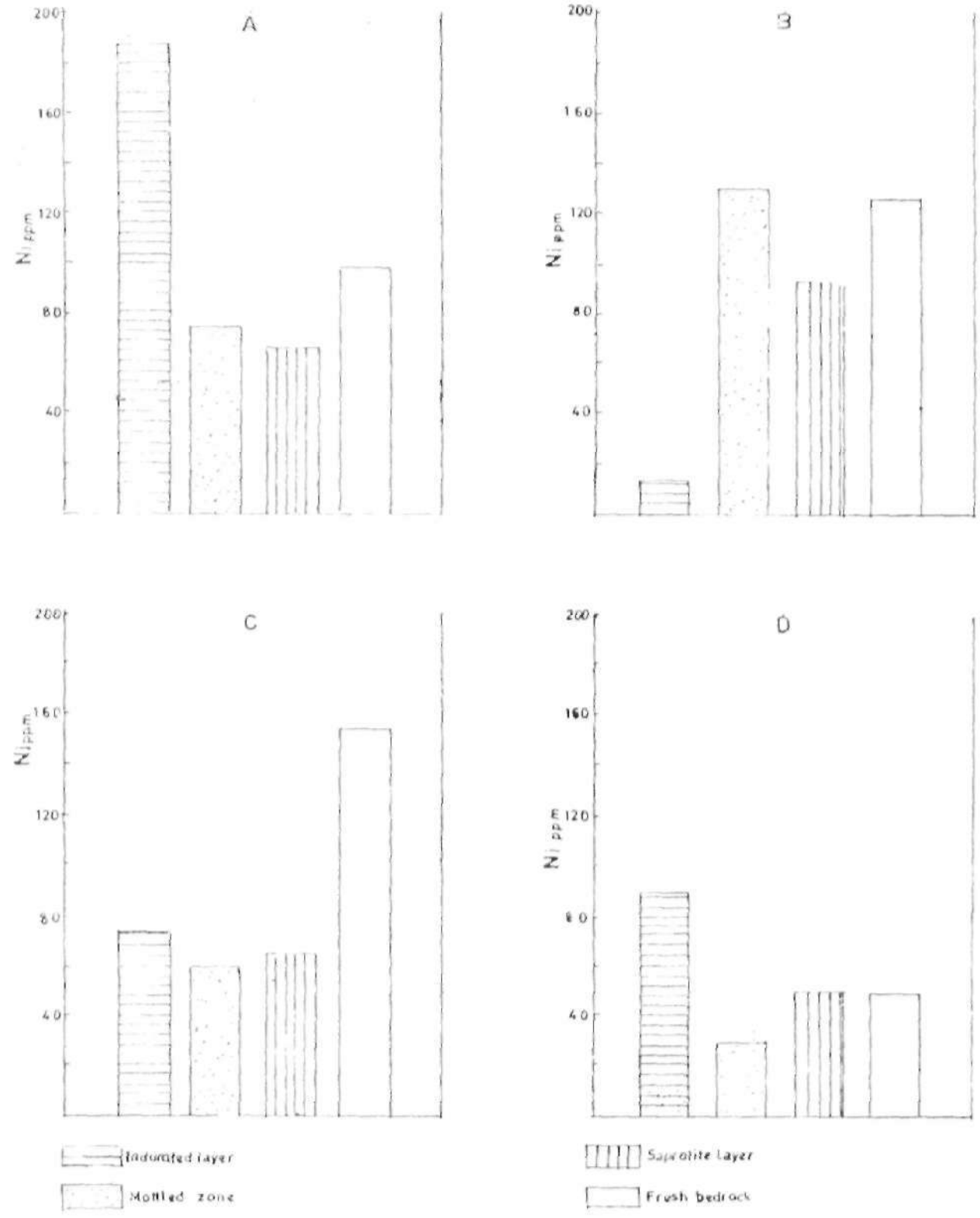
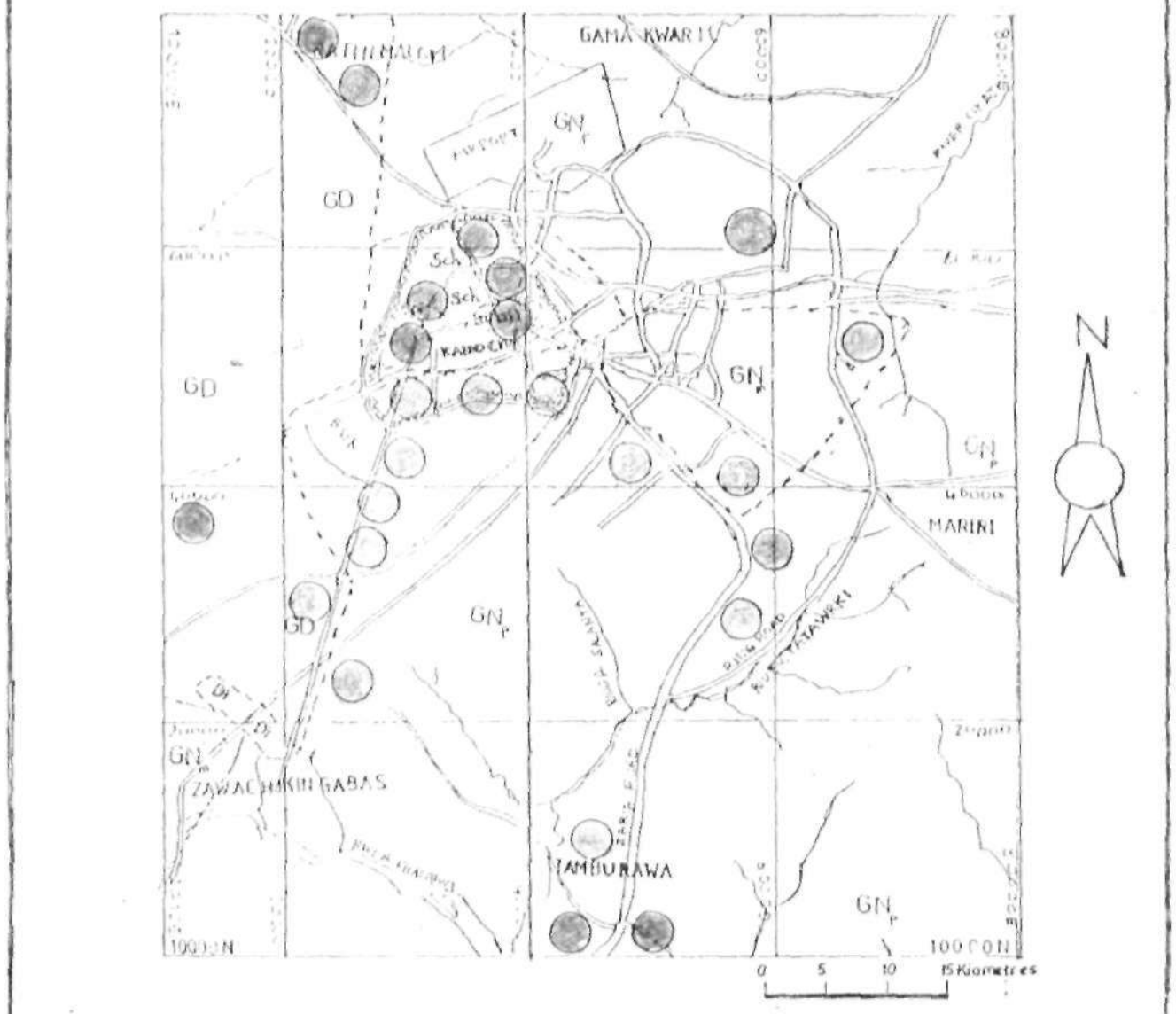


Fig 5.9 Bar diagram of Ni distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- Medium grand granite
- Porphyritic granite
- Granodiorite
- Diorite
- Schist
- Rivers
- Roads
- Geological boundry
- Walled City

Ni ppm

- >150
- 100-150
- 50 - 100
- <50

Figs10 Geochemical map of Ni distribution in the lateritic profiles in the study area.

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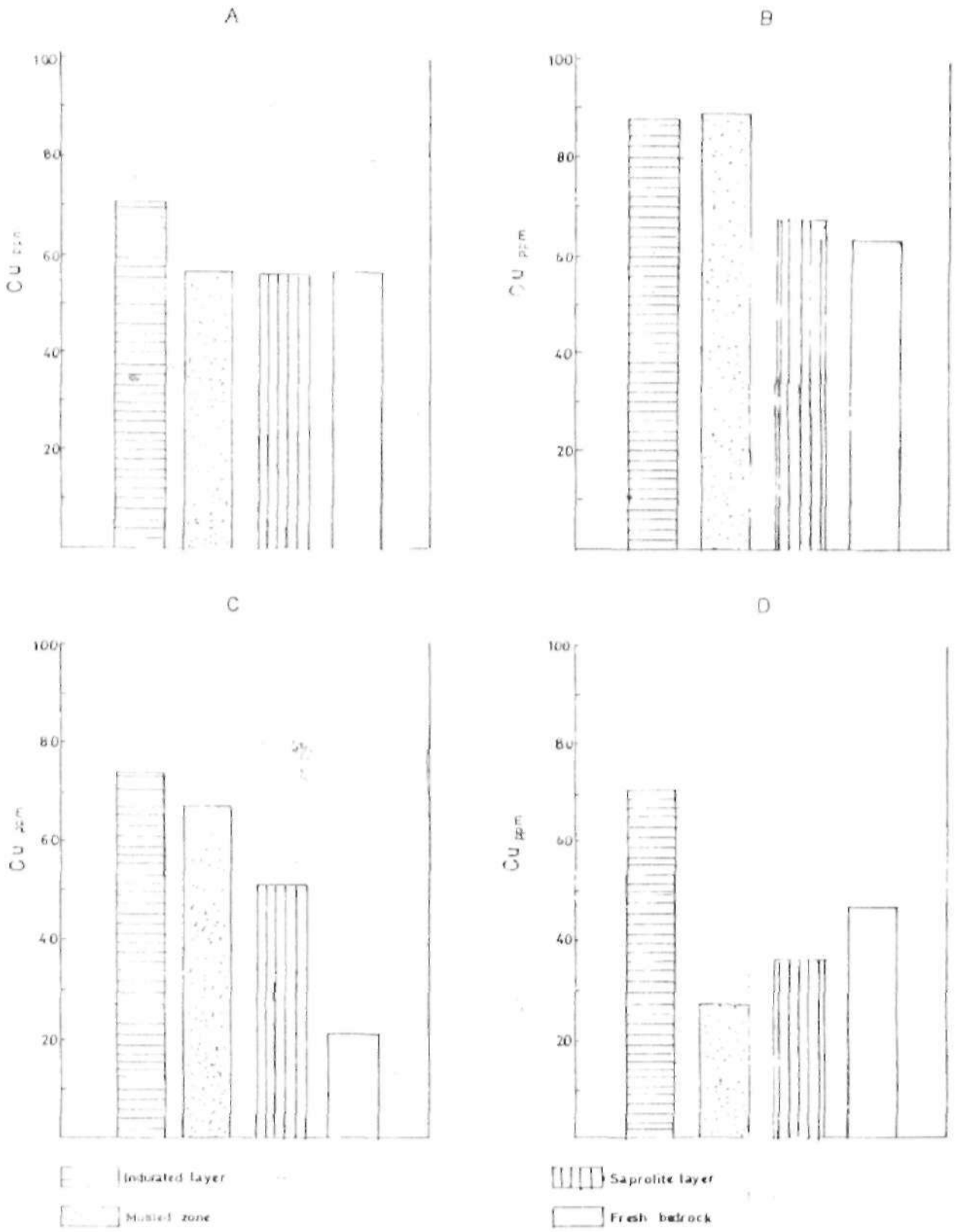
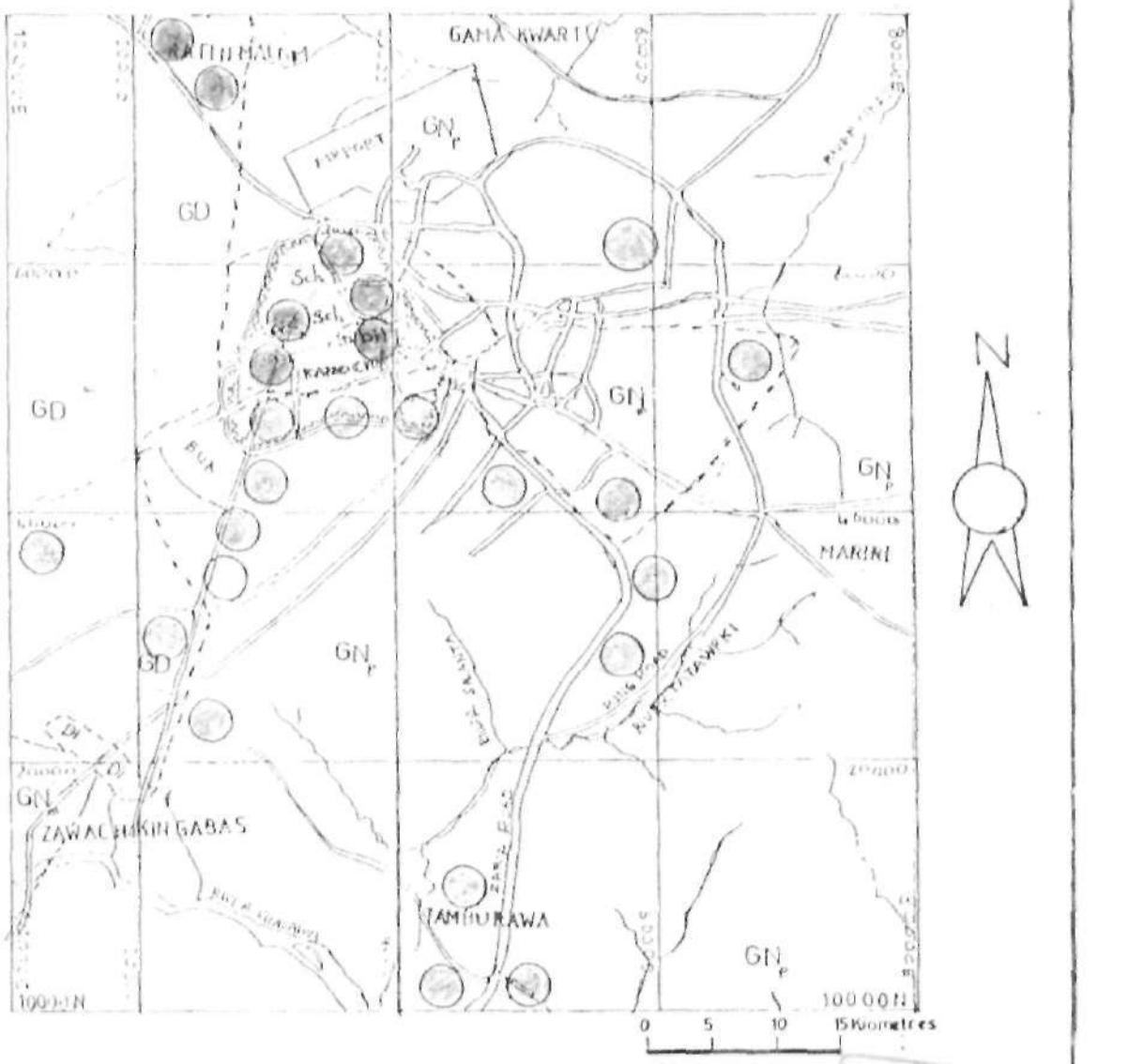


Fig 5.11 Bar diagram of Cu distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- GN Medium grained granite
- GN$_p$ Porphyritic granite
- GD Granodiorite
- Di Diorite
- Sch Schist
- Rivers
- Roads
- Geological boundry
- Walled City

Cu ppm
- > 140
- 90 - 140
- 40 - 90
- < 40

467902
QE
495

Fig 5.12 Geochemical map of Cu distribution in the lateritic profiles in the study area.

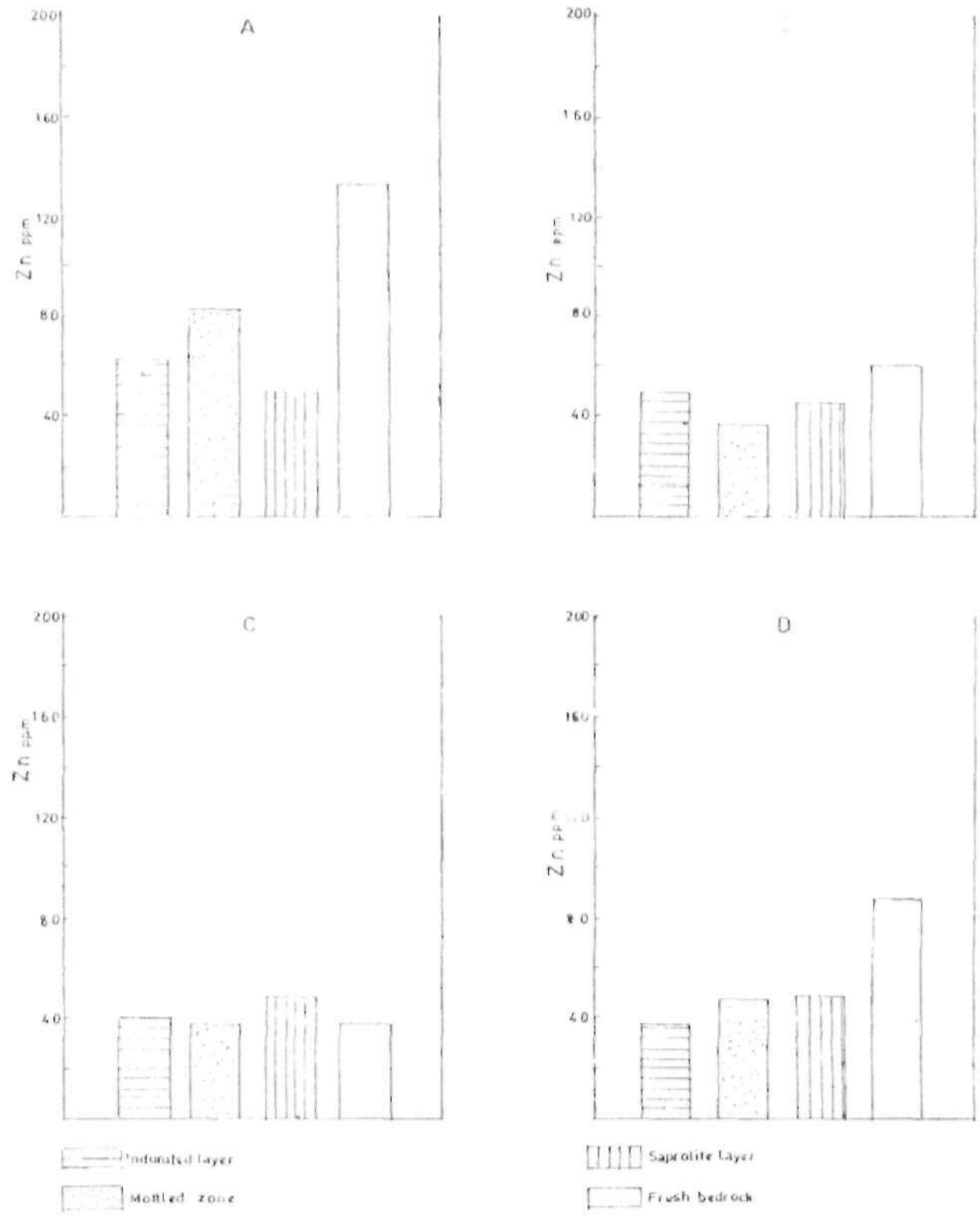
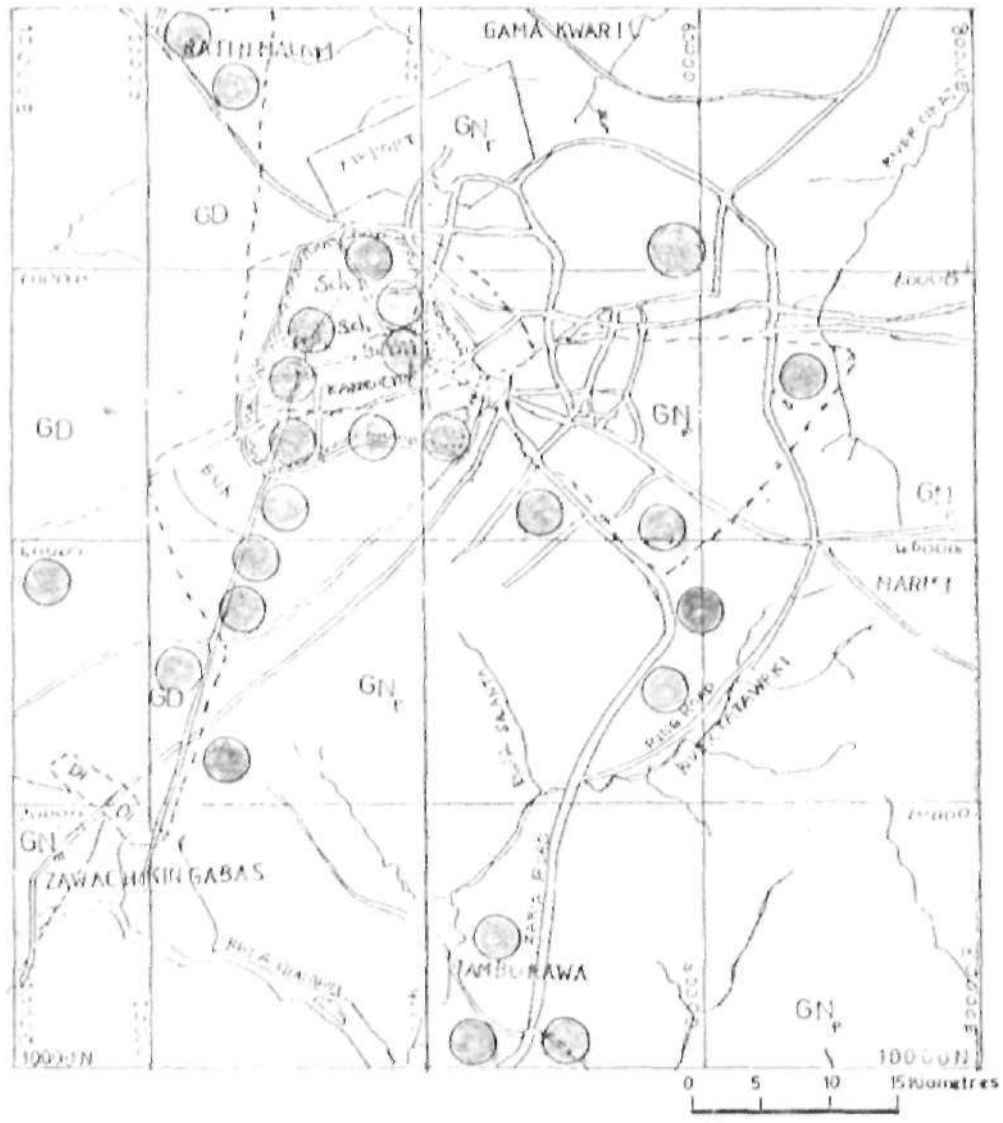


Fig 513 Bar diagram of Zn distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



Figs.14 Geochemical map of Zn distribution in the lateritic profiles in the study area.

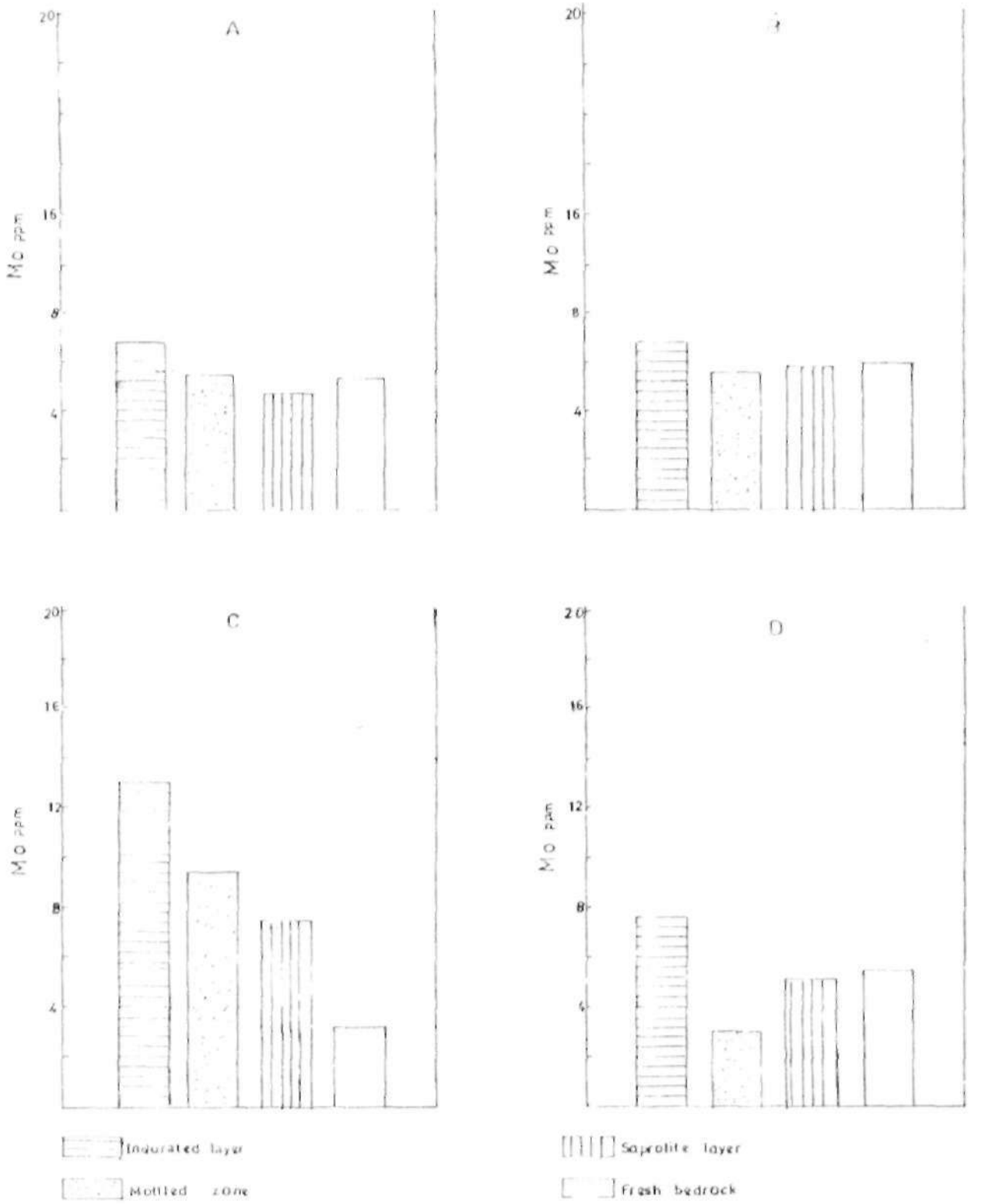
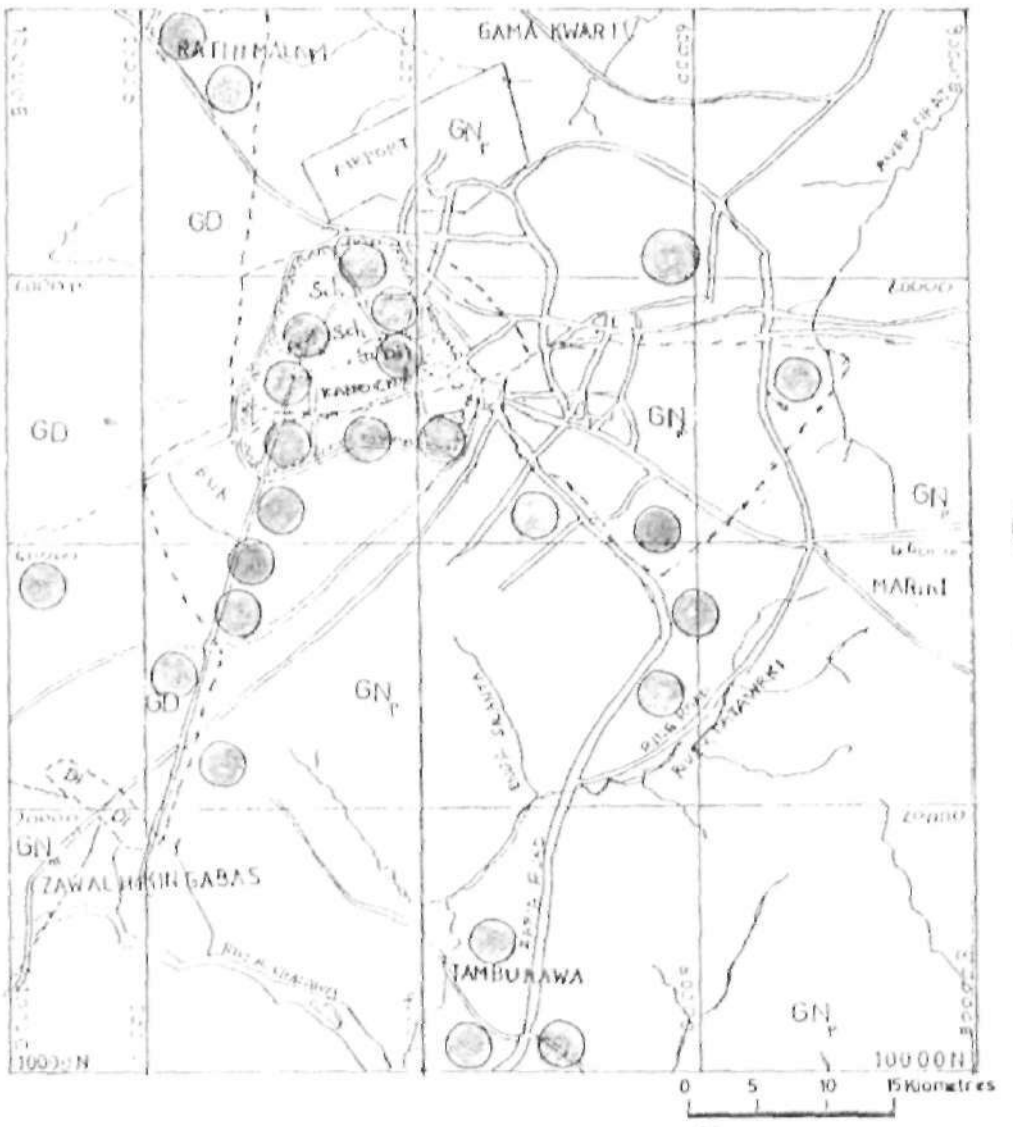


Fig 5.15 Bar diagram of Mo distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- GN_m Medum grand granite
- GN_p Porphyritic granite
- GD Granodiorite
- Di Diorite
- Sch Schist
- Rivers
- Roads
- Geological boundry
- Walled City

Mo ppm
- > 65
- 35-65
- 5 - 35
- < 5

Fig.16 Geochemical map of Mo distribution in the lateritic profiles in the study area.

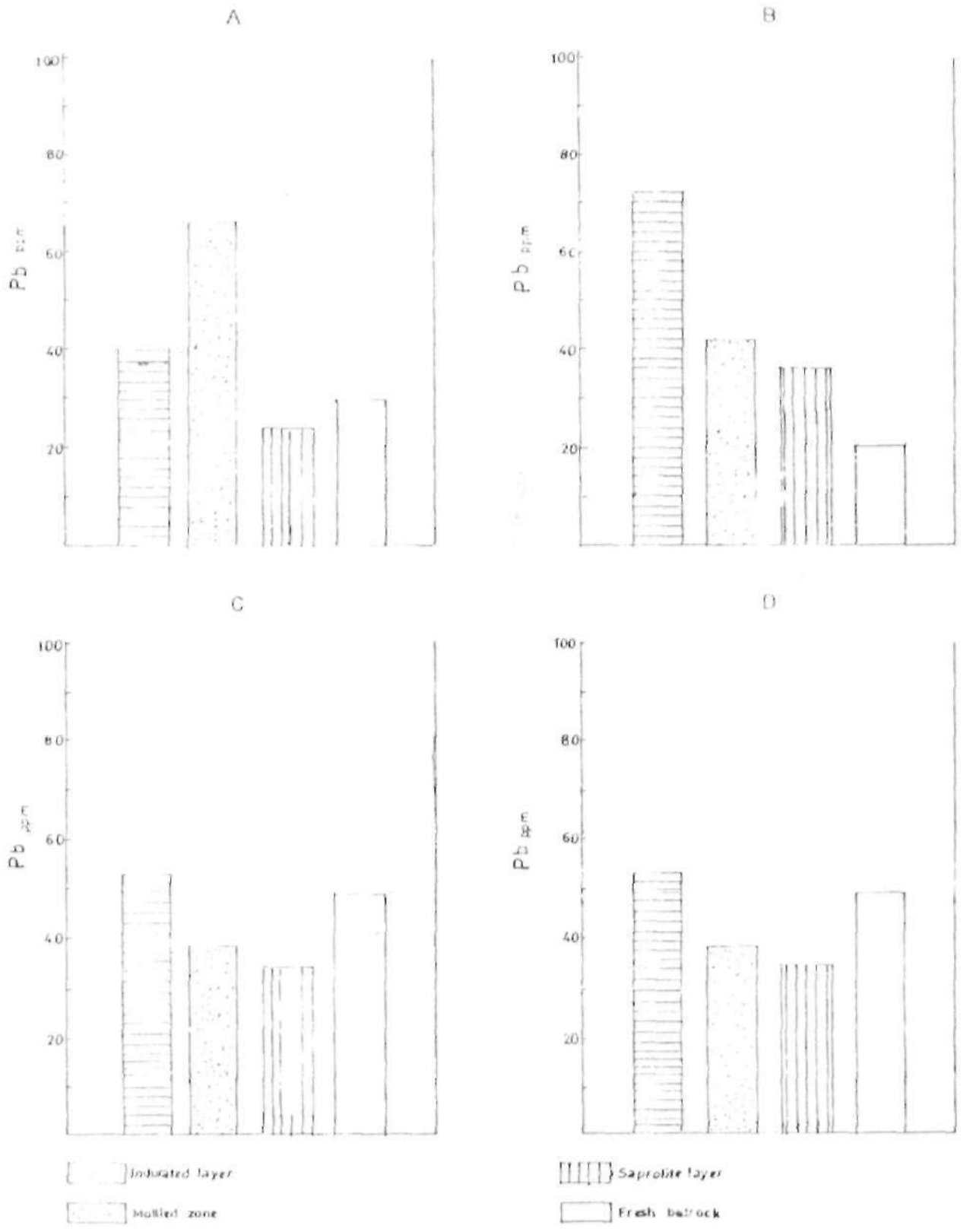
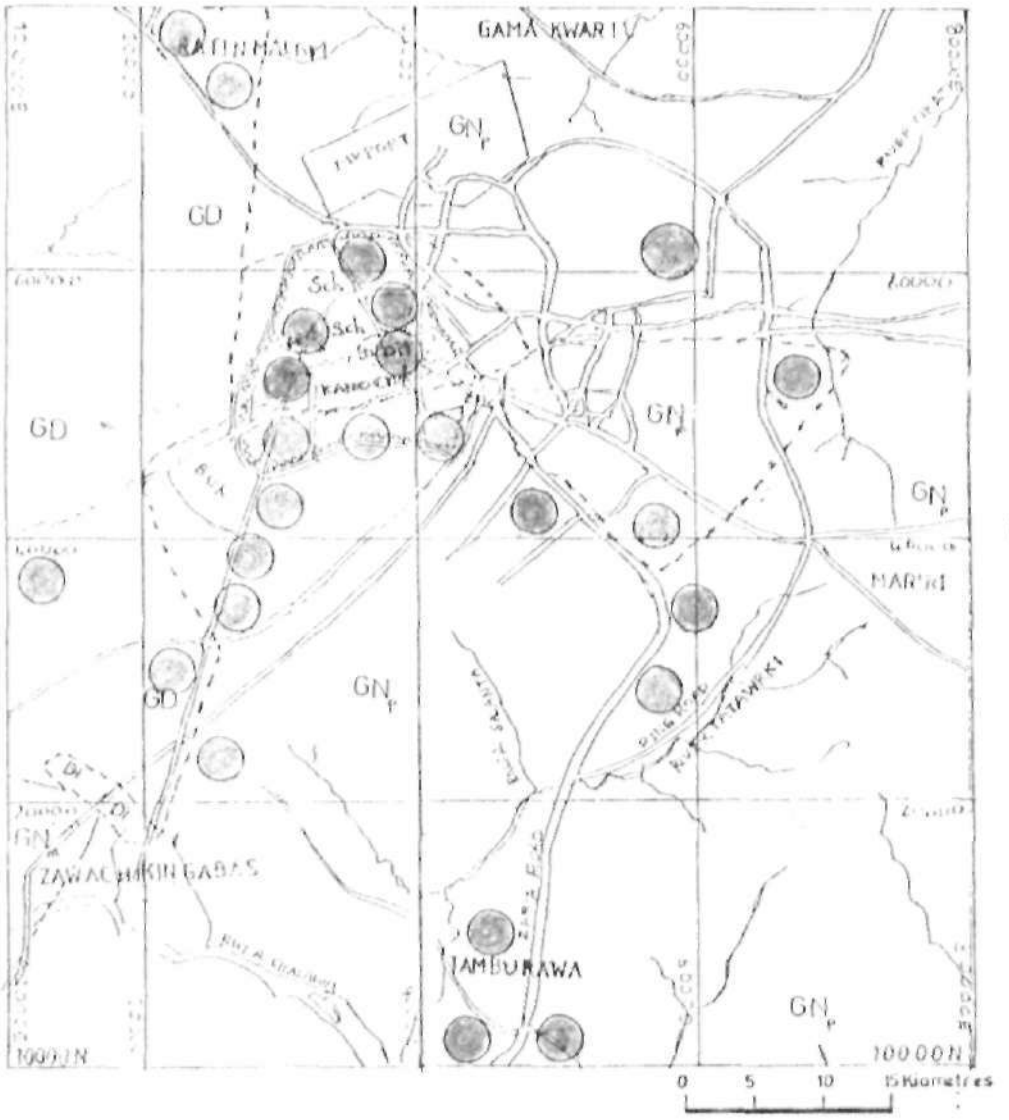


Fig 5.17 Bar diagram of Pb distribution pattern in lateritic profiles developed over schist(A), diorite(B), granite(C) and granodiorite(D).



LEGEND

- GN_m Medium grand granite
- GN_p Porphyritic granite
- GD Granodiorite
- Di Diorite
- Sch Schist
- Rivers
- Roads
- Geological boundry
- Waller City

Pb ppm
- > 130
- 75 – 130
- 20 – 75
- < 20

Fig 5.18 Geochemical map of Pb distribution in the laeritic profiles in the study area.

CHAPTER SIX

IMPLICATION FOR MINERALIZATION AND MINERAL EXPLORATION

6.1. INTRODUCTION

Following the combined geological and geochemical investigation some areas of supergene enrichment of V, Cr, Co, Mn, Ni, Cu, Zn, Mo and Pb, due to lateritization have been delineated in the study area. The potential or prospect of these anomalies for the base metals mineralization will be evaluated in this section, in order to assess the prospectivity of the laterites in this region to ore-mineralization. The most prolific prospects are lateritic profiles that developed over diorite and granite.

6.2. LEVEL AND SIGNIFICANCE OF THE SUPERGENE ENRICHMENT

The Clarke of concentration (Table 6.1) is used here to evaluate the level and significance of the supergene enrichment of the base metals V, Cr, Mn, Co, Ni, Cu, Zn, Mo and Pb in the lateritic profiles developed over diorite and granite.

Vanadium has concentration value in the range 861ppm-1145 - 343ppm- lod. It has been enriched 5.7 times over its average crustal concentration (0.02%). The element has attained an average grade of 0.1%, which means that it has reached 5% of its lowest ore-grade (2%). In fact, this level of enrichment of the element is not significant, but,

is promising.

Chromium concentration value is in the range 1760ppm ± lod - 218ppm ± lod. The element has been enriched 5.6 times over its average crustal concentration (0.01%). It has reached an average grade value of 0.06%, indicating that it has reached only 1% of its lowest ore-grade (32%). This enrichment is of no economic significance.

Manganese concentration is in the range 11400ppm ± 809 - 127ppm ± 37.8. It has been enriched 11.4 times over its average crustal concentration (0.1%). The element has attained an average grade of 1.14%, which indicates that it has reached approximately 4% of its lowest ore-grade (35%). In fact this enrichment although, not significant, can be promising.

Cobalt concentration value is in th range 955ppm± 94.5 - 70.2ppm± lod. This element has been enriched 38.2 times over its average crustal concentration (0.003%). The element has reached an average grade of 0.1% indicating that it has reached 2% of its lowest ore-grade (5%). This level of enrichment is also promising.

Table 6.1.: The clark of concentration of 9 base metals

Element	* Average Concentration in Earth Crust (X)	Lateritic Prospect (Y)	* Minimum Mineable Grade	Clarke of Concentration (Y/X)
V	0.02%	0.1%	2%	5.7
Cr	0.01%	0.06%	32%	6.23
Mn	0.1%	1.14%	35%	11.4
Co	0.003%	0.1%	5%	38.2
Ni	0.008%	0.013%	1.5%	1.63
Cu	0.005%	0.04%	0.7%	8.42
Zn	0.008%	0.02%	3%	1.85
Mo	0.0002%	0.001%	0.4%	47.6
Pb	0.0016%	0.013%	3%	13.3

* Average Concentration in Earth's Crust (After Rose et al 1979)
* Minimum Mineable Grades (After Bateman, 1951).

Nickel concentration value is in the range 195ppmt lod - 47.1ppmt lod. The element has been enriched 2.5 times over its average crustal concentration (0.008%). It has reached an average grade of 0.02%, which indicates that it has reached 1.5% of its lowest ore-grade (1.5%). This level of the enrichment of the element is not significant.

Copper values are in the range 421ppmt lod - 34ppmt lod. The element has been enriched 8.42 times over its average crustal concentration (0.005%). The element has reached approximately 6% of its lowest ore-grade (0.7%). This level of enrichment is promising.

Zinc values are in the range 148ppmt 17 - 20.4ppmt lod. This element has been enriched 1.85 times over its average crustal concentration (0.008%) it has attained an average grade of 0.02%, which is equivalent to 0.7% of its lowest

ore-grade (3%). This shows that the level of enrichment of this element is of no significant.

Molybdenum values are in the range 71.4ppm± lod - 4.91ppm± lod. This element has been enriched 47.6 times over its average crustal concentration (0.0002%). It has attained an average grade of 0.001%, which is equivalent to 0.3% of its lowest ore-grade. Although the level of enrichment of this element is not significant, but still carries some promise.

Lead values are in the range 1.3ppm± lod - 19.8ppm± lod. This element has been enriched 13.3 times over its average crustal concentration (0.0016%). It has reached an average grade of 0.013%, which is equivalent to 0.5% of its lowest ore-grade (3%). This level of enrichment is also promising.

6.3. DIORITE-DERIVED LATERITIC PROFILES

The diorite exposures in the study area are very rare, making it difficult to estimate the area occupied by this rock and its corresponding lateritic profiles. The main zone of the lateritic profiles is in the area between Goron-Dutse and Dala hill (plates X and XI) extending for approximately, 10,000m^2 contains the most significant values of V, Cr, Mn, Co and Ni.

6.3.1. Economic Evaluation

The sampling and analysis of the lateritic samples (as discussed in Chapter 5) have enabled the identification of the main metal-rich horizon of the diorite-derived lateritic profiles. The main V-Cr-Ni-enriched horizon is the mottled zone, while, the most Mn-Co-enriched horizon is the indurated layer.

The following average grades of the metals have been calculated

V = 0.1%

Cr = 0.2%

Mn = 1.14%

Co = 0.1%

Ni = 0.02%

It can be observed that none of these grades is significant for mineralization, but they are indicators of enrichment. The amount of the source material (diorite) seems to be not quite enough to supply the enriched metals (V, Cr, Mn, Co and Ni) to the overlying lateritic profile, in quantities that would be enough to reach the mineable grades. Therefore, a volume of the same source material 30 times greater than this, would be enough for these enriched metals to reach mineable grades. In other words, lateritic profiles overlying dioritic rocks that occupy an area of 300,000m^2, with similar or higher degree of lateritization, would make a very good prospect of these metals.

6.4. LATERITIC PROFILES DEVELOPED OVER GRANITE

Unlike diorite, the granite exposures in the study area are very prominent. Almost, three quarter of this area is underlain by this rock, and the lateritic profiles developed over them are exposed at many locations (plates XII, XVII, XIX, XX). The main zone of these lateritic profiles which contains significant values of Cu, Zn, Mo and Pb is in the area between the eastern side of the Old City and Badawa to the east extending for approximately 40,000m².

6.4.1. Economic Evaluation

From the geochemical data (discussed in Chapter 5) it has been found that the main Cu-Mo-Pb-enriched horizon of the granite-derived lateritic profiles is the indurated layer, while the Zn-enriched horizon is the saprolite layer.

The following average grades of the metals have been calculated

Cu = 0.04%

Zn = 0.02%

Mn = 0.001%

Pb = 0.013%

Although, these metals have been enriched in the lateritic horizons, but the enrichment have not reached any mineable grade. The only plausible explanation for this seems to be the degree of lateritization, because the source rock (granite) is abundant and more than enough to supply these

enriched metals to the overlying lateritic profiles. Therefore, the degree of lateritization must have not been enough to extract these element from the source rock in quantities that would have reached mineable grades.

A lateritic profile overlying granitic rocks that occupy similar or greater area to the one occupied by this prospect, but have attained higher degree of lateritization would make a very good prospect of these metals.

CHAPTER SEVEN

SUMMARY, CONCLUSION AND RECOMMENDATION

7.1. SUMMARY

Field study has revealed that the study area is underlain by schists, diorites, granodiorites and granites. These rocks vary in their areal extent. Granites occupy three quarter followed by granodiorites which occupy approximately one-third of this area. Diorites and schists were found to occupy only small part. Large part of this area was found to be covered by laterites.

Geological structures are essentially, fractures and foliations. Trends of these structures show a predominating NNE-SSW direction which is dorminant over minor E-W trends. These NNE-SSW trends depict the final imprints of the Pan African orogeny , while the E-W trends depicts possibly an earlier metamorphic episodes (Grant, 1971).

The lateritization also observed in the area varies in intensity from one place to another. It has been found that both the lithology and drainage play major role in this variation. The lateritic profiles in this area can be distinguished into four zones from the base to the top. Fresh bedrock, saprolite, mottled and indurated pisolithic (or ferricrete) layers. The saprolite layer can be further

recognised into coarse and fine-grained zones.

The statistical interpretation has led to the recognition of some element association within the different lateritic profile horizone. The application of the accumulation factor (AF) was found very helpful in establishing elemental dispersion trends from bedrock to the overlying materials in relation to accumulation or deplation.

An examination of the accumulation factor (AF) values indicate that the base metals V, Cr, Mn, Co, Ni vary in trend from one rock- type-derived lateritic profiles to another. Generally, in diorite-derived lateritic profiles they show absolute enrichment especially in the mottled and indurated layers. In the schist- derived lateritic profile V-Mn have shown absolute depletion relative to the parentrock, while, Cr has shown enrichment in the mottled zones and Co-Ni have been enriched in the indurated layers. In the granodiorite-derived lateritic profile Cr-Mn-Co have shown absolute depletion relative to the parentrock, but Ni has been enriched in both the mottled and indurated layers.

Following the combined geological and geochemical investigations some areas of supergene enrichment of V, Cr, Mn, Co, Ni, Cu, Zn, Mo, Pb due to lateritization have been delniated in the study area. The clarke of the concentration of elements was used to evaluate the significance of this enrichment. It has been found that the

most prolific prospects are lateritic profiles that developed over diorite and granite. The secondary enrichment in the lateritic profiles has reached 5.7 fold for V, 6.23 fold for Cr, 11.4 fold for Mn, 38.2 for Co and 1.63 fold for Ni over their primary enriched contents in the diorite bedrock. In case of granite-derived lateritic profiles it has reached 8.42 fold for Cu, 1.85 fold for Zn, 47.6 for Mo and 13.3 fold for Pb over their slightly primary enriched contents in this rock.

7.2. CONCLUSION

1- Lateritization within the area studied has been found to be controlled by both lithology and drainage.

2- Based on the zonation, the lateritic profiles in this area are well developed.

3- The application of the accumulation factor (AF) is very usefull in assessing the enrichment or deplation of elements within the different lateritic profile horizons. AF values point to the fact that Fe, Zr and the base metals V, Cr, Mn, Co,Ni,Cu, Zn,Mo and Pb have been enriched in these profiles, while the alkaline earth alkali metals and some of trace element were susceptible to leaching, relative to the parentrocks.

4- Some unusual trends were noticeable in the behaviour of the elements. Attempts have been made to offer

plausible explanations for these erratic behaviours.

5- This work has ended up in delineating some prospective targets for the base metal secondary mineralization. These include: diorite and granite-derived lateritic profiles.

6- The potential lateritic horizon for mieralization of V-Cr-Ni is the mottled zone of the diorite-derived lateritic prifile and for mineralization of Mn-Co is the indurated layer of the same profile. The potential horizon for the mineralization of Cu-Mo-Pb is the indurated layer of the granite- derived lateritic profile, while for mineralization of Zn the potential horizon is the saprolite layer of the same lateritic profile.

7.3. RECOMMENDATION

Geologists usually, have a frustrated relationship with laterites which, according to them mask the bedrock and make mapping and exploration difficult. But, as has been revealed by this work and other cited studies the laterites themselves can be sought for secondary ores. Therefore, systematic geochemical sampling in areas covered by a well developed lateritic profiles overlaying productive bedrocks such as, diorites and granites, coupled with an appropriate statistical interpretation to assess the potentials for the possible secondary mineralizatior of the base metals (V, Cr, Co, Mn, Ni, Cu, Zn, Pb) are highly recommended.

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APPENDIX A

Analytical results (in ppm) except where indicated) of 7 samples from lateritic profiles developed over schists

Sample No.	Fe	Mn		Cr	Mo	Zn	V	Rb	Ni	Y	Sr	Zr	Ti	Nb	Pb	Sc	Co	Mg
	T	N	D	A	R	A	T	L	D		L	A	Y	E	R		(A)	
M2A	1.258% < lod	0.416% < lod	32.9% < 0.9%	294 < lod	454 ± 50.7	57.3 ± 16.2	997 ± 1.60	7.96 ± lod	76.6 ± 6.9	23.2 ± 3.2	38.3 < lod	3.45 ± 2.1%	1770 ± 1.66	28.6 ± 3.2	29 < lod	440 ± 68.3	72 < lod	5.50 < lod
M4A	1.21% < 0.19%	0.20% < lod	33.6% < 0.05%	224 < lod	489 ± 84.7	42.6 < lod	938 < lod	46.1 4.74	7.49 < lod	15 < 1.39	33.0 lod	369 < 27.7	2920 374	16.2 2.83	53.4 12.0	326 ± 66.3	73.2 < lod	8.38 2.61
Average	0.82%	0.358%	12.8%	219.5	471.5	63.95	437.5	22.03	42 ± 4	19.1	100.3	80.45	1400.75	22.4	41.2	383	73.6	6.84
	M	O	T	T	L	E	D				Z	O	N	E		(B)		
M2B	0.484% < lod	0.03% < lod	1.2% < 0.7%	352 < lod	176 ± 154	43.7 ± 17.5	601 < lod	8.13 < lod	33.5 ± 4.1	18.2 ± 31.0	164 < lod	32 < 9.0	27.3 ± 3.1	70.2 ± 17.8	292 ± 62.1	76.8 < lod	76.8 < lod	6.55 < lod
M3B	2.85% 0.3	0.316% < lod	2.57% < 0.38	328 < lod	680 ± 91.6	87.5 ± 12.2	457 < lod	147 ± 11.2	18.9 ± 4.2	21.8 ± 4.12	41.2 < lod	42 < 4.8	10.1 ± 22.5	64.6 ± 9.43	187 ± 42.0	18.2 < lod	36.7 lod	4.95 < lod
Average	1.667%	0.2895%	6.88%	34 <	431 ±	83.2	529	77.65	26.2	20	77.7	41.7	80.65	38.7	67.55	236.5	67.5	5.59
	S	A	P	R	O	L		T	E		L		Y	E	R		(C)	
M2C	1.488% < lod	0.244% < 0.3	13.3% < 0.92	249 < lod	721 ± 96.7	71.2 ± 16.7	488 ± 16.7	8.66 ± lod	62.9 ± 5.8	15.3 ± 3.1	84.2 < lod	486 ± 35	18100 ± 1140	32.6 ± 3.5	24.9 < lod	479 ± 71.6	68.2 < lod	5.42 < lod
M3C	2.91% < 0.3%	0.283% <	1.35% < 0.09	249 < lod	149 < lod	80.3 < lod	485 < lod	100 < 7.9	71.3 < 5.9	8.82 ± 2.3	43.4 lod	316 < 8.7	1450 ± 353	7.43 ± 3.6	27.4 < 7.11	127 < 36.3	44 < lod	4.16 < lod
Average	1.699%	0.2685%	7.125%	234	440	80.15	486.5	52.33	67.1	12.05	63.8	401.5	9725	20	25.85	303	56	4.84
	F	R	E	S	H				B	E	D	R	O	C	K		(D)	
M3D	0.739% < 0.18	5.43% < 0.43	8.02% < 0.36%	292% lod	1280 ± 134	134 ± 20.9	952 ± 222	28.3 ± 32.3	439 < 80.3	116 ± 9.03	66.5 < lod	13 < 3.1	3165 ± 2230	34.4 < 27	29.1 < lod	325 < 65.4	66.9 < lod	5.42 < lod

lod = level of detection

APPENDIX B

Analytical results (in ppm except where indicated) of 11 samples from lateritic profiles developed over diorites.

Sampl. No.	K	Ca	Fe	Cr	Mn	Zn	V	Rb	Sr	Y	Ni	Zr	Ti	Nb	Pb	Co	Cu	Mo
	I	N	D	U	R	A	T	E	D		L	A	Y	E	R		(A)	
M38A	0.572% ± lod	0.44%	26.4% ± 1.8	278 ± lod	3490 ± 266	61.2 ± 24.1	861 ± 145	10.8 ± lod	19.5 ± 4.0	16.8 ± 3.49	190 ± lod	457 ± 32.8	8310 ± 662	15.8 ± 2.93	86.6 ± 15.5	707 ± 94.5	121 ± 36.6	6.27 ± 2.7
M38.1A	0.509% ± lod	0.323% ± 0.07	24.6% ± 1.73	182 ± lod	11400 ± 809	43.3 ± lod	595 ± 114	7.81 ± lod	7.01 ± lod	17.2 ± 2.98	195 ± lod	305 ± 21.6	6500 ± 517	7.35 ± 2.2	81 ± 12.7	955 ± 91.6	111 ± lod	8.04 ± 2.24
M1.1A	0.904% ± 0.23	0.36% ±	4.32% ± 0.35	308 ± lod	261 ± 70.2	50.8 ± 12.9	456 ± lod	72.2 ± 6.2	31.7 ± 3.2	31.7 ± 3.6	60.8 ± lod	384 ± 27.5	1650 ± 333	17.2 ± 2.5	59.2 ± 9.3	173 ± 44	39.8 lod	6.09 ± 2.3
Average	0.662%	0.343%	18.44%	254.3	5050.3	51.77	638.3	30.27	14.07	21.9	14.86	382	5486.7	13.45	75.6	641.67	90.6	6.8
		M	O	T	T	L	E	D			Z	O	N	E		(B)		
M38B	0.653% ± lod	0.481% ± 0.09	15.8% ± 1.11	297 ± lod	1710 ± 147	54.3 ± 18.5	647 ± 148	7.99 ± lod	11.1 ± 3.13	14.9 ± 2.91	93.3 ± lod	479 ± 343	12000 ± 919	18.5 ± 2.7	25.2 ± 10.7	468 ± 69.9	61.7 ± [illegible]	5.47 ± lod
M38.1B	0.503% ± lod	0.276% ± 0.007	11.1% ± [illegible]	226 ± 0.79	854 ± 86.4	38.3 ± 13.1	706 ± 140	11.9 ± 2.8	17.3 ± 2.7	17.8 ± 2.5	87.8 ± lod	340 ± 24.3	25300 ± 1820	20.0 ± 2.4	18.8 ± lod	396 ± 52.3	42.5 ± 18.4	4.45 ± lod
M1.1B	0.403% ± lod	0.207% ± lod	15.2% ± 1.1	212 ± lod	719 ± 523	122 ± 22.4	757 ± lod	9.11 ± lod	131 ± 3.5	61.4 ± 5.57	113 ± lod	582 ± 41.5	11600 ± 895	19.4 ± 2.97	105 ± 14.5	633 ± 80.5	131 ± 31.0	6.18 ± lod
M1B	1.18% ± lod	0.383% ± lod	17.9% ± 0.017	1760 ± lod	860 ± 523	55.9 ± 22.5	1090 ± lod	14.[illegible] lod	14.2 ± 3.5	43.5 ± 5.57	230 ± lod	578 ± 41.5	1800 ± 895	8.27 ± 2.97	116 ± 14.5	642 ± 80.5	134 ± 31	6.20 ± lod
Average	0.683%	0.337%	15% ±	623.75 ±	1035.8	37.13	822.5	10.7[illegible]	43.3	34.4	131	494.75	12575 ±	16.54	42.63	537.75	91.55	5.58
	S	A	P	R	O	L	I	T	E		I	A	Y	E	R		(C)	
M38.C	1.4[illegible] ± lod	0.32% ± 0.0[illegible]	5.5% ± 0.39	294 ± lod	543 ± 79.9	31.3 ± lod	339 ± [illegible]	9.73 ± 2.[illegible]	22.9 ± 2.77	19.4 ± 2.[illegible]	57.3 ± lod	407 ± 21.9	8360 ± 689	1[illegible].4 ± 2.[illegible]	19.6 ± lod	191 ± 15.0	74.7 ± 18.2	4.58 ± lod
M38.1C	0.643% ± lod	0.23% ± lod	1.3% ± 0.01	345 ± lod	183 ± lod	24.1 ± lod	485 ± [illegible]	47.7 ± 2.5	30.6 ± 2.6	22 ± 2.1	47.1 ± lod	711 ± 20.1	2640 ± 12[illegible]	16.4 ± 2.[illegible]	24.4 ± lod	83.4 ± 9.1	32.9 ± lod	5.25 ± lod

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX C

Analytical results (in ppm except where indicated) of 36 samples from lateritic profiles developed over granites

Sample No.	F	Ca	Ti	Cr	Mn	Zn	V	Co	Sr	Y	Ni	Zr	Ti %	Sn	Pb	Cu	Ga	Mo
	I	N	D	I	R	A	T	P	D		L	A	Y	T	R		A	
40A	0.6809% ± -	0.219% ± 0.09	19.9% ± 1.38	212 ± lod	1840 ± 0.04	65.8 ± 22.4	377 ± lod	43.3 ± 5.4	30.9 ± 6.3	32.5 ± 4.2	99.3 ± lod	233 ±	2680 ± lod	14.6 ± 2.47	87.2 ± 14.5	57.0 ± 7.8	78.1 ± lod	14.7 ± 2.98
M41A	0.581% ± -	0.292% ± 1.2	12.7% ± 0.85	298 ± lod	251 ± 71.8	40.5 ± -	480 ± 143	20.6 ± 4.0	3.94 ± lod	4.4 ± 3.9	74.8 ± lod	270 ± 19.7	643 ± lod	22.0 ± 3.32	42.6 ± 10.5	85.1 ± 69.4	55.1 ± lod	27.9 ± 8.4
M34A	0.51% ± 0.15	0.292% ± 0.04	9.0% ± 0.64	396 ± 68.0	206 ± 51.1	47.1 ± 11.2	346 ± 1.11	27.0 ± 3.1	13.8 ± 2.3	15.1 ± 2.2	52.0 ± lod	571 ± 40.5	3230 ± 321	21.3 ± 2.22	41.3 ± 7.8	309 ± 43.4	37.0 ± 15.4	4.88 ± 1.74
M35A	0.643% ± 0.19	0.230% lod	1.32% ± 0.09	345 ± lod	183 ± lod	24.1 ± lod	495 ± 3[illegible]	47.7 ± 4.6	30.6 ± 8.4	22.0 ± 2.86	47.1 ± lod	733 ± 40.5	2940 ± 379	16 ± 2.4	24.4 ± 7.4	83.4 ± lod	32.9 ± lod	4.25 ± lod
M21A	0.318% ± -	0.19% ± lod	13.2% ± 0.92	559 ± 85.4	1200 ± 107	45.9 lod	341 ± lod	27.8 ± 3.6	8.29 ± lod	11.1 ± 2.6	142 ± lod	342 ± 24.4	2240 ± 27[illegible]	15.4 ± 2.16	80 ± 10.3	384 ± lod	60.1 ± lod	11.7 ± 2.1
M23A	1.07% ± -	0.255% ± 0.08	8.27% ± 0.58	180 ± lod	135 ± lod	26 ± lod	267 ± lod	41.3 ± 4.03	19.9 ± 2.7	17 ± 2.44	59.7 ± lod	561 ± 39.8	2740 ± 309	15.7 ± 2.1	30.3 ± 7.5	242 ± 43.8	45.9 ± lod	8.91 ± 2.2
M28A	3.31% ± 0.51	0.25% ± lod	15.2% ± 0.11	272 ± lod	344 ± lod	27.1 ± 33.1	377 ± lod	135 ± 10.4	87.4 ± 7.0	17.3 ± 2.87	45.3 ± lod	224 ± 16.9	1760 ± 342	12.3 ±	20.7 ± 2.28	109 ± lod	44.7 ± 75.2	4.90 ± lod
M37A	0.515% ± -	0.269 ± 0.1	1.40% ± 0.45	291 ± lod	387 ± 71.5	30.7 ± lod	352 ± lod	36.6 ± 8.1	79.8 ± lod	21.9 ± 3.0	62.3 ± lod	598 ± 42.8	3280 ± 395	21.6 ± 2.7	35.5 ± 9.1	334 ± 52.9	46.5 ± lod	71.4 ± lod
M12A	0.564% ± 0.2	0.257% ± lod	16.2% ± 0.19	257 ± lod	210 ± 69.5	26.1 ± lod	391 ± lod	39.5 ± 4.2	17.8 ± 2.99	33.9 ± 3.4	51.4 ± lod	597 ± 42.4	2240 ± 380	15.0 ± 2.4	19.8 ± 7.6	88 ± lod	34.9 ± lod	6.13 ± lod
M6A	1.41% ± 0.22	0.230% ± lod	2.08% ± 0.35	218 ± lod	147 ± lod	33.9 ± 11.2	357 ± lod	118 ± 9.1	17.4 ± 2.7	81.1 ± 6.5	58.2 ± lod	528 ± 37.2	2650 ± 366	31.5 ± 3.3	22.0 ± 7.4	103 ± lod	33.6 ± lod	5.1 ± lod
M32A	1.17% ± 21	0.239% ± [illegible]	2.65% ± 0.8	23[illegible] ± [illegible]	423 ± 72.1	26.4 ± lod	344 ± lod	71.1 ± 6.12	35.8 ± 7.01	36.0 ± 2.77	48.8 ± lod	528 ± [illegible]	2350 ± 35[illegible]	18.2 ± [illegible]	57.8 ± 67.8	235 ± 41.3	36.2 ± lod	4.92 ± lod
M8A	0.716% ± -	0.444% ± lod	0.193% ± -	348 ± lod	1930 ± lod	62.4 ± lod	774 ± lod	18.1 ± lod	17.9 ± lod	28.6 ± lod	151 ± lod	192 ± lod	5800 ± lod	11 ± lod	133 ± lod	535 ± lod	421 ± lod	4.98 ± lod

APPENDIX D

Analytical results (in ppm except where indicated) of 7 samples from lateritic profiles developed over granodiorites.

Sample No.	Ca	Fe	Cr	Mn	Co	V	Pb	Sr	Ba	Zr	Ti	Ni	Th	Cu	Mo
	I	N	D	U	R	A	T	E	D		L	A	Y	E	R	(A)	
M42/1A	0.374% ± lod	0.215% ± 0.09	14.9% ± 1.1	235 ± lod	276 ± 73.9	43 ± lod	347 ± lod	17.4 ± 3.91	13.9 ± 3.4	12.7 ± 3.1	126 ± lod	771 ± 54.8	2510 ± 333	15 ± 2.7	59.0 ± 12.2	398 ± 67.1	91.0 ± 28.3	7.44 ± 2.8
M48A	0.492% ± 0.04	0.157% lod	15.3% ± 1.1	109 ± lod	397 ± 48.5	34.8 ± 10.5	258 ± 77.1	19.9 ± 2.52	4.67 ± -	13.4 ± 1.87	61.3 ± lod	429 ± 30.4	1950 ± 207	13.8 ± 1.7	64.2 ± 7.79	541 ± 51.4	51.0 ± 15.2	7.94 ± lod
Average	0.433%	0.186%	15.1%	172	334	38.9	302.5	18.65	9.285	13.050	93.65	600 ±	2231	14.4	61.6	468	71.00	7.69 1.53
	M	O	T	T	L	E	D				Z	O	N	E		(B)		
M42/1B	0.617% ± 0.11	0.193% ± lod	3.92% ± 0.76	136 ± lod	259 ± 30.2	47.9 ± 7.7	196 ± lod	52.9 ± 4.2	18.8 ± 2.11	38.2 ± 3.16	31.9 ± lod	786 ± 55.5	295 ± 273	3.5 ± 2.7	31 ± 5.1	189 ± 26.3	22.6 ± -	3.48 ± lod
M48B	1.53% ± 0.15	0.133% ± lod	3.43% ± 0.24	118 ± lod	472 ± 49.9	3.7 ± -	195 ± lod	76.2 ± 5.7	36.9 ± 3.0	15.2 ± 1.87	30.4 ± lod	280 ± 19.9	2420 ± 233	14.5 ± 1.54	57.2 ± 5.9	163 ± 24.6	33.3 ± 9. -1	2.91 ± lod
Average	1.1%	0.163%	3.675%	127	365.5	40.7	192.5	64.55	27.85	28.2	31.15	533	2705	23.5	44.1	176	27.95	3.1950
	S	A	P	R	O	L	I	T	E		L	A	Y	E	R	(C)		
M42/1C	3.96% ± 0.36	0.70r% ± 0.14	2.1% ± 0.15	251 lod	333 ± 75.6	73.8 ± 13.5	501 ± lod	161 ± 12.2	167 ± 12.3	36.2 ± 3.9	50.5 ± lod	497 ± 35.5	2400 ± 386	22.5 ± 2.8	19.6 ± lod	129 ± lod	36.9 ± lod	5.65 ± lod
M48C	3.55% ± 0.34	0.8a3% ± -	1.67 ± 12	247 ± lod	203 ± lod	28 ± lod	586 ± lod	149 ± 11.2	98.4 ± 7.7	12.5 ± 2.5	58.6 ± lod	245 ± 21.1	1480 ± 344	8.87 ± 2.0	54.6 ± 8.3	97.0 ± lod	35.5 ± lod	5 ± lod
Average	3.76%	0.565%	1.89%	244	268	51.05 ±	518.50	155	130.2	24.35	54.55	345.5	1940	15.69	37.1	113	36.2	5.325
	F	R	E	S	H				B	E	D	R	O	C	K	(D)		
M14/D	3.57% ± 0.33	1.35% ± -	3.23% ± 0.25	268 ± -	51 ± 85	98.7 ± 15.5	437 ± -	151 ± 11.5	162 ± 12.2	73.0 ± 6.11	53.7 ± -	527 ± 37	3219 ± 421	28.2 ± 3.7	28 ± 8.5	196 ± 17.2	46.7 ± -	5.74 ± -