THE DEMOCRATIC REPUBLIC OF THE SUDAN

MINISTRY OF ENERGY AND MINING
GEOLOGICAL & MINERAL RESOURCES
DEPARTMENT

Bulletin n° 35

EXPLANATORY NOTE
TO THE GEOLOGICAL MAP AT THE SCALE OF 1:2 000 000
OF THE DEMOCRATIC REPUBLIC OF THE SUDAN

1981 Edition

by

AHMED AWADALLA YASSIN
FATHI ALI KHALIL
Dr. ABDEL GADIR EL SHAFIE

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INTRODUCTION

Geological investigations by local prospectors and explorers (Russeger, 1937) were started very early in the Democratic Republic of Sudan. The first general geological map of the Sudan was produced by Dunn (1911). In 1947, the Geological Survey published the geological map of the Sudan at 1:4,000,000 scale which was followed by two editions in 1949 and 1963. In 1974, Professor J.R. Vail of Khartoum University drew up a 1:2,000,000 geological map of the Democratic Republic of Sudan.

In 1963 and 1968 the international geological and tectonic maps of Africa were published under the auspices of the African Geological Surveys and UNESCO. The adjacent countries also published their own national geological maps, e.g. Ethiopia (1:2,000,000 scale in 1971), Libya (1:2,000,000 scale in 1970), Central African Republic (1:5,000,000 scale in 1963), Egypt (1:2,000,000 scale in 1971), Uganda (1:5,000,000 scale in 1962), Zaire (1:2,000,000 scale in 1974), Chad (1:5,000,000 scale in 1974).

The publication of these maps showed that the geological map of the Democratic Republic of Sudan was obviously outdated and, hence, emphasized the necessity of updating and revising it. The large surface of the country, 1,000,000 square miles, and the lack of accurate basic maps were major obstacles. The Sudan is covered by 164 topographic map sheets at the scale of 1:250,000. These topographic maps were unsuitable for geological mapping as they were inaccurate and did not contain sufficient details. The small number of geologists in the country was another obstacle. However, a great number of geological data were available from the 1:250,000 scale topographic maps, Geological Survey Department files, published and unpublished papers and reports prepared by various geologists, United Nations reports, and unpublished university theses. Recent detailed geological maps, especially of the Red Sea Hills, the Bayuda desert, the Nuba mountains, and southern Sudan were also available. All this made it possible to extrapolate the geology of the unsurveyed parts of the country. Extrapolation was also possible from the published geological maps of neighbouring countries. More than 60 % of the country was covered by aerial photographs which were very helpful together with the Landsat imagery in the compilation of the present geological map.

Although, as mentioned above, some parts of the Sudan have been recently geologically mapped with some accuracy, great portions of the country have not been visited at all or only preliminary reconnaissance was carried out on them. Therefore the geological information plotted on the map varies widely from place to place.

These explanatory notes should be considered as a guide to the geological map of the Democratic Republic of Sudan at the scale of 1:2,000,000 (1981 edition).

Detailed information on the geology of Sudan is available in the book published by Whiteman (1971) and bulletins and theses published by the Geological and Mineral Resources Department. Many unpublished information is also available in the records of the Geological and Mineral Resources Department.

PART I - GEOLOGY

1 - "THE PRECAMBRIAN" BASEMENT COMPLEX

A - GENERALITIES

All the crystalline basal rock groups in the Sudan are generally termed Basement Complex rocks and classified as of Precambrian age. They cover vast areas all over the country and are mostly mapped as undifferentiated Basement Complex. This is mainly due to the fact that there are not enough detailed structural studies on these rocks to classify them in major tectonic units or groups, and age determination methods for rocks in the Sudan are not well-developed or well-suited. Only very few rock samples were taken for age determination in European laboratories and by interested individuals. Therefore, for the time being, any geochronological classification of the Basement Complex rocks in the Sudan is of a tentative nature.

However, with the work done in neighbouring countries and the data so far available in the Sudan, attempts were made to differentiate the Basement Complex into at least two groups :

- Gneiss Group,
- Schist Group.

These two groups were further differentiated into series in some parts of the country.

In view of the metamorphism types, mode of occurrences and contact of one group with the other it was concluded that all the rocks of the gneiss group do not belong to the same age or origin neither do the rocks of the schist group. Therefore, it was not possible to distinguish them into mapping units, especially when the contact between the two groups becomes progressive, as is the case in several localities, or when they are interbedded.

However, two main metamorphic facies were recognised in the Gneiss Group : the granulite and the amphibolite facies. In some cases, the amphibolite facies appears to be the retrograde form of the granulite facies. Similarly, two main metamorphic facies were recognised in the Schist Group : the amphibolite schist facies and the greenschist facies.

Gneisses and schists of the same metamorphism grade are generally associated with each other, and of equally widespread distribution all over the country.

Studies carried out in northern Uganda, Kenya and Zaire indicated that relict blocks of granulite facies rocks are the oldest units. Patches of similar rocks are found in the southern, central and north-western corner of the Sudan. They consist of charnockites, enderbite gneisses and basic granulites with pyroxenes, amphiboles and garnets.

A wide range of compositions and structures is present within the Gneiss Group. They include granitic to granodioritic gneisses, hornblende gneisses and biotite gneisses. They are frequently associated with migmatites and quartzofeldspathic rocks. The gneisses are generally highly foliated with prominent gneissic textures, etc.. Augen and banding structures are often encountered in many parts of the country.

The Schist Group in both the amphibolite and the greenschist facies shows great variation in its mineral compositions and associations. The amphibolite facies includes micaceous schists, locally with garnet, quartz or feldspar, quartz amphibolite schists and hornblende schists. The micas are biotite and muscovite. Staurolite, kyanite and rare sillimanite may also be present.

Schists of the greenschist facies metamorphism are better studied in the Red Sea Hills area. However, they more likely extend westwards up to the Nile and southwards in the Butana plain. They occur also in the Nuba mountains, Kurmuk, Fazughli region of southeastern Sudan and perhaps in some other parts of western Sudan.

The greenschist facies consists of graphitic schists, sericite and chlorite schists, calc-silicate rocks, marbles, quartzites, epidiorites and metavolcanites. The metasedimentary sequences of the Nafirdeib Group are sometimes the dominant rock type within the greenschist facies.

The volcanites are mainly lavas of basaltic and andesitic composition with some rhyolites and tuffs. The sediments are locally poorly metamorphosed usually with well-preserved primary sedimentary structures, often grading into slates and phyllites.

Undifferentiated Basement Complex rocks

Basement Complex rocks which could not be classified into the above two groups either because of insufficient work in the area concerned or difficult field conditions are termed undifferentiated Basement Complex rocks.

B - DESCRIPTION BY AREA

The above classification of the Basement Complex rocks, although used in the map production, was actually found unmappable unless suitably modified. Therefore, within the classification of major groups, attempts were made to differentiate, delineate and correlate rock series in areas where more detailed studies could be carried out.

The Basement Complex is generally made up of several block masses partly covered by younger sedimentary and/or volcanic strata.

Some of these masses have been more extensively studied than others. In some places, more detailed mapping made it possible to distinguish definite units which were given local names, and occasionally correlated with defined units in other areas. Due to the lack of suitable detailed information, it was not possible to describe the Basement rocks on a systematic stratigraphic or even metamorphic basis. Therefore it was more convenient to consider the various areas of Basement rock outcrop, many of which form distinctive topographically and geologically mappable units.

The typical units taken into consideration were the Red Sea Hills region, the Bayuda area, and parts of the southern Sudan region.

a) <u>Red Sea Hills</u>

The area between the Red Sea coast and the Nile valley to the west is underlain by the Basement Complex rocks. A systematic mapping using aerial photographs at the scale of 1:40,000 and photomosaic at the scale of 1:100,000 was adopted in the decade 1970-1980.

It became evident that the Basement Complex rocks of the Red Sea Hills region consisted of the following units (Red Sea Hills maps by the 1978 Sudanese-Russian project, and by the Sudanese-French project) :

- the Kashebib Series is mainly made up of granite gneiss complex and is Lower Proterozoic in age ;
- the Nafirdeib and Odi Series are made up of metasediments, and acidic and basic metavolcanic rocks. Both series are classified as occupying the lower parts of the Upper Proterozoic ;
- the Homogar Series mainly consists of weakly metamorphosed acidic and basic volcanic rocks and tuffs ;
- the Awat Series is formed of weakly metamorphosed sedimentary and volcanic rocks of the uppermost part of the Upper Proterozoic.

1) Kashebib Series

This series is mainly made of granite gneiss complex, of Lower Proterozoic age.

A granite gneiss complex including rocks of the amphibolite facies metamorphism and consisting of granite gneisses, crystalline schists, quartzites, migmatites and some associated anatectic granites forms the Lower Proterozoic rock group of the Kashebib Series. According to the K/Ar method (Vail, 1976), the gneiss complex age is some 1,950 M.y.

2) Nafirdeib Series - Odi Series

Both series are made up of sedimentary volcanic complex.

The metasedimentary volcanic rocks are of the greenschist facies with basic and ultrabasic intrusions, and calc-alkali batholith granitoids.

The Odi Series is made up of a variety of metamorphic schists, marbles, quartzites with rare intercalations of amphibolites and greenstone effusive rocks. The Nafirdeib Series is mainly made up of basic to intermediate altered effusive rocks and tuffs with intercalating siliceous schists, marbles and graywackes. In the upper part of the series, the sedimentary rocks are more common with intercalations of tuffs and basic greenstone effusive rocks. Both series are cut by intrusions of ultramafic gabbro, diorite and batholith granite complex. The isochron age of 1,195 to 1,193 M.y. for the greenschist rocks may correspond to the period of metamorphism (Meneiay, 1976).

The Odi and Nafirdeib Series are correlated with the Abu Zeran and Atalla Series in Egypt, Abu Baish Halaban and Hali Series in Saudi Arabia, Mormora and Txaliet Series in Ethiopia. Rocks of both series are deformed to linear folds, but the Odi Series is more intensely folded (isoclinal, often overturned folds) compared to the Nafirdeib Series.

3) Homogar Series

This series is mainly made up of weakly metamorphosed volcanic rocks and includes gabbro, granite and syenite intrusions.

The metavolcanic complex comprising the basic to acidic effusive rocks of the Homogar Series is confined to the boundaries of the Kajor tectonic blocks.

The series is more than 1,000 m thick. The lower age limit of the Homogar Series is marked by angular unconformity between the Homogar and Nafirdeib Series. The upper age limit is some 980 M.y. (K/Ar method) as determined from the coarse-grained biotite granites cutting the series.

The Homogar Series may be correlated with the Dokhan (Egypt) and the Shammer Series (Saudi Arabia). The Homogar rocks are weakly deformed into open folds with broad limbs. The bedding dips in the limbs range from 20° to 30°.

4) Awat Series

This series consists of a weakly metamorphosed sedimentary volcanic complex (molasse) with basic and alkali intrusions.

The Awat Series is composed of conglomerates, mudstones, andesites, rhyolites, trachyrhyolites and tuffs. It is from 1 to 2 km thick. The rocks are mostly horizontally lying with an angular unconformity on the Nafirdeib and Homogar effusive rocks and also fill minor troughs.

The Awat Series is apparently similar to the Hammamat Series in Egypt and the Abla and Fatima Series in Saudi Arabia. According to Meneiay (1976), the age of the post-origin granites within the Hammamat Series is 600 M.y.. The Basement Complex rocks in the Red Sea Hills are also intruded by gabbros, granites and syenites of Mesozoic and Cainozoic ages. The upper deposition stage is represented by platform formations which are locally distributed in the Red Sea Hills. These include the Jurassic to Cretaceous Nubian Sandstones, occurring in narrow longitudinally trending grabens, lagoons and other Red Sea littoral deposits of Tertiary - Quaternary age, and Mesozoic-Cainozoic volcanics.

b) Bayuda area

The first geological trip in the Bayuda desert was made by D.T.F. Munsey in 1945-46 (unpublished Report, Sheet NE 36 J, Geol. Dept. Khartoum). The Sudanese-German project in 1979 provided the first detailed study on the Bayuda area, comprising a very accurate set of maps and reports.

The stratigraphic succession made in the area was as follows :

6. Pleistocene and recent sedimentary formations	b. alluvial deposits a. superficial deposits
5. Cainozoic volcanic rocks :	- basaltic composite volcanoes, explosion craters and tuffs - basaltic shield volcanoes - basaltic to phonolitic plugs
4. Tertiary sedimentary formations	b. calcareous lacustrine sediments a. red earth (lateritic soil)
3. Paleozoic and Mesozoic sedimentary formations	b. Nubian Sandstone Formation a. Amaki Series
2. Paleozoic and Mesozoic igneous rocks	dyke swarms igneous ring complexes
1. Precambrian (Basement Complex)	c. ultrabasic rocks b. Bayuda Formation b 3. Absol Series b 2. Rahaba Series b 1. Kurmut Series a. Abu Harik Series.

1) Abu Harik Series

The rocks of the Abu Harik Series form a belt some 20 km wide striking N.NE in the southeastern part of Bayuda area. It is also found in three other localities (7, 8 and 9 km) N.NW of Atbara. The Abu Harik Series consists of highly metamorphosed, partly migmatised to granitised biotite-hornblende gneisses, hornblende gneisses and amphibolites with thin quartzite lenses.

The rocks of this series are probably part of the old Nubian Shield.

Along a traverse started from El Bayuda (north of Berber) and eastward as far as the western spire of the Red Sea Hills, the rocks of the Abu Harik Series may be traced across the strike over 60 km, east of the Nile before disappearing.

2) Bayuda Formation

This formation could be subdivided into three rock series :

- Absol Series,
- Rahaba Series,
- Kurmut Series.

The metasediments and metavolcanic rocks of the Kurmut Series are the oldest group and are found at the bottom of the Bayuda Formation. The Rahaba Series overlying the Kurmut Series interlocks with or is overlain by the Absol Series.

- Kurmut Series

The rocks of the Kurmut Series are exposed in the eastern and northern parts of the Bayuda area. They are well foliated and folded. The fold axes plunge to the west and southwest with north to northwest dipping axial planes in the southern two-thirds of the area. They plunge to the southeast and east, and northwest to west with southwest and south dipping axial planes in the northern part. The rocks of the Kurmut Series mainly consist of metasediments such as quartzites, quartzitic schists, paragneisses, mica schists, graphite schists, calc-mica schists, calc-silicate rocks and marbles with intrusions of metavolcanic rocks. Mixed metamorphic rocks indicate an origin of typical sedimentation in shallow epicontinental shelf areas. The degree of metamorphism of the Kurmut Series is not as high as that of the Abu Harik Series. It reaches the low-medium stage of the amphibolite facies.

- Rahaba Series

The rocks of the Rahaba Series are conformably overlying the Kurmut Series and in parts interfingering with this series. The Rahaba Series occupies almost the overall central and western parts of the Bayuda desert. In the basal parts of the series, biotite and hornblende gneisses predominate with numerous amphibolite intercalations. Acidic muscovite-bearing quartz feldspar gneisses, with amphibolite intercalations in thin layers, and lenses of calc-silicate garnetiferous quartzitic mica schists and graphitic schist, form the typical rocks of the upper parts of the Rahaba Series in the northeastern and central part of the Bayuda desert. The acidic gneisses contain many pegmatoids, and in parts thin out and are replaced by a monotonous sequence of biotite gneisses with rare intercalations of amphibolite. Anatexis and granitisation up to the stage of autochthonous granite formation are widespread and well developed in this series. The rocks of the Rahaba Series are generally well foliated and intensely folded. The fold axes dip west and southwest in the southern, central and western parts of the Bayuda desert, and southeast and northwest in the southern part of the area.

- Absol Series

In the area southwest, west and northwest of Al Shireik, the upper parts of the Rahaba Series interlock with or are overlain by the quartz micaschists, quartzites, graphite schists, manganese schists and rare intercalations of marbles and calc-silicate schists of the Absol Series. These metasediments contain lenticular bodies of amphibolites and hornblende gneisses, up to 1 km thick, which have probably been formed from basic volcanic rocks. The predominantly clastic rocks were likely originally deposited on a rise in the marginal basin and are typical, together with the volcanic rocks, of island arc facies. The rocks of the Absol Series generally strike northwest in the southern part but then bend round to the north-south, northwest or even west in the northern part of the area.

The degree of the amphibolite facies metamorphism is indicated by the presence of staurolite, kyanite and garnet in the schists, and of garnet, hornblende and diopside in the amphibolites and hornblende gneisses. The only signs of slight anatexis are indicated by the presence of some thin pegmatoid layers and associated tourmaline in parts of the schists.

c) Southern and southwestern Sudan

Only limited systematic geological work has been recently carried out in these regions. The early work done was summarised by Whiteman (1971) and more fully described in the unpublished reports of the Geological and Mineral Resources Department. These sources contain brief descriptions of the igneous and metamorphic rocks at selected localities. In 1974, Professor Vail of the University of Khartoum prepared a geological map of Sudan using all available information, and extrapolating data from adjacent countries. Geologists from the University of Khartoum studied the gold occurrences in the Luri River basin and the Kapoeta district and made observations on the geology along the roads between Juba, Yei and Mundri (Eyobo, 1974, Badri El Din). The geological and structural outlines were presented in a paper by L. Cirvetta and others. The more systematic geological work in the region was carried out by HUNTING Geology in 1976.

However, the southern and southwestern regions of the Sudan are mainly underlain by Archaean and Proterozoic rocks which are generally of medium to high metamorphic grades. The Basement Complex in these regions include four major groups of rocks identified in the adjacent neighbouring countries.

1) The Madi Sequence

The Madi rock Sequence was recognised by Berry and Whiteman in 1968 and by HUNTING Geology in 1976. The Madi Sequence was originally described in northern Uganda (Mathews, 1952, Hepworth and Macdonald, 1966), in the Abu Satta Hills and to the northwest of Ragor along the boundary with the Central African Republic. The Madi Sequence of northern Uganda continues into southern Sudan and is exposed on the Juba - Yei road about 53 km southwest of Nimule.

The Madi Sequence consists of muscovite quartzites interbanded with muscovite schists, quartz-feldspar-biotite-hornblende gneisses and amphibolites. The Madi Sequence originated as a succession of arenaceous and argillaceous clastic sediments with minor calcareous beds and probably with some volcanic rocks. Deposition age predates the Miriam and Chuan deformations, but probably postdates Aruan (HUNTING, 1976).

2) **Karasuk Group** (Miriam Group, Hepworth, 1967)

The term Karasuk Group was used in East Africa by Macdonald (1961), Almond (1969) and applied to the Mozambique Belt of Eastern Africa (Holmes, 1951).

The Karasuk Group of the Precambrian basement rocks occupies a broad area covering the eastern extremity of southern Sudan and extends northwards as far north as Daga Post (HUNTING, 1976). The rocks of the Karasuk Group are an assemblage of both sedimentary and igneous origin, and include amphibolites, biotite-hornblende gneisses, marbles, quartzites, chlorite and graphite schists, altered granites, ultrabasic rocks and metagabbros. According to Almond (1969), most of the Karasuk rocks fall within the amphibolite facies metamorphism, while the rest are of the greenschist facies regional metamorphism.

3) Gneiss Group

According to HUNTING Geology (1976), this group includes :

a - massive weathered foliated granites and poorly banded gneisses,
b - biotite-hornblende gneisses with minor amphibolite and quartzite gneisses,
c - muscovite-biotite gneisses.

The gneissic rocks cover much of the southern region of the Basement Complex in Sudan.

On the basis of field observations (HUNTING, 1976), all the rocks of the Boya Hills area in the Yambio region and areas northwest of Yambio, the Lafit mountains, areas west of Mundiri, near Wau, along areas west of Raga, southwest and southeast of Juba, and west of Nyamlell, are included in this group. Lithologically, the foliated granites and the poorly banded gneisses (a) are rich in medium-grained quartz. The feldspar-biotite-bearing rocks and the biotite-hornblende gneisses (b) show minor amphibolite lenticles and isolated narrow beds of muscovite quartzites. The muscovite-biotite gneisses consist of quartz, potash feldspar plagioclase, muscovite and biotite (c). This muscovite-biotite gneiss may be correlated with similar rocks of the gneiss de la Garamba in Zaire (Lavreau, 1975). Vail, in 1978, spoke of two rock units in this group. Charnockite-granulites (pyroxene granulite enderbite amphibolite facies) are considered to be an older unit within the Basement Complex. These rocks was referred to in Uganda as Watian (Hepworth and Macdonald, 1966, and Hepworth, 1967). The second type of gneissic rocks includes granitic gneisses, rare quartzites, quartzo-feldspathic rocks and banded metagabbros. This group was referred to in Uganda as Kitaum Group by Almond (1969) and as Aruan by Hepworth and Macdonald (1966).

4) **Strongly banded rocks, gneisses, migmatites and locally metasedimentary rocks**

This unit occurs in three areas to the east, north and west of the Imatong Mountains and occupies broad zones within the Raga region west of longitude 26°30' E (HUNTING, 1976). The migmatitic rocks occur between Maridi and Mundiri and southeast of Tambura. Rocks of this group include quartz-feldspar-biotite-garnet gneisses, graphite-sillimanite gneisses and migmatites, in addition to quartzites, schists, marbles, etc. of metasedimentary sequences.

d) Western Sudan

The area was first investigated by the Nile-Congo Divide Syndicate (1900-1925), and by the Anglo-American Corporation, the Messina, Transvaal Development Company Limited (1952), and the Nippon Mining Company (1963-1964). Most of the work was concentrated around the Hofrat En Nahas area, to the southwest of Darfur Province and aimed at the eventually economic exploitation of the copper deposit within that area. The more systematic geological work was carried out by the Geological Survey Department of the Sudan (1956-1973) and HUNTING Geology Group in 1970. The Basement Complex rocks in the area were subdivided, on petrological grounds, into three groups :

3 - the Gneiss Group,
2 - the Quartzite Group,
1 - the Mudstone Group.

These Basement rock groups were intruded by several post-tectonic granites (Younger Granites). The age of these granites, by comparison with similar intrusions in adjacent areas, was estimated at around 550 M.y.. The last phase in the evolution of the Basement Complex was the intrusion of numerous quartz dykes.

1) The Gneiss Group

Most of the area between Jebel Marra and Meidob Hills is underlain by various types of gneisses including biotite gneisses, biotite-muscovite gneisses, grey augen gneisses, quartzo-feldspathic biotite-muscovite gneisses and granitic gneisses which represent early granitic intrusions.

2) The Quartzite Group

This group corresponds to the southern part of the Abyad sheet n° ND 35-J and much of the Taweisha sheet n° ND 35-N. The rocks consist of long quartzite ridges that gave the group its name. The quartzites are of medium to coarse-grained texture with bedding and current bedding structures commonly well-preserved and have a flinty appearance. The commonest type is a feldspathic quartzite intensely brecciated and recemented with jasper, chalcedony and hematite.

Unfortunately, 90 % of the Quartzite Group area are covered by stabilised sand dunes and, therefore, hidden rock types are not known. It is believed however, that they consist largely of gneisses similar to those of the Gneiss Group representing quartzo-feldspathic and pelitic sediments interbedded with non-mineralised quartzites. Similar gneisses occur south of El Fashir and northeast of Nyala.

3) The Mudstone Group

The Mudstone Group occurs as a series of isolated outliers on the Umm Badr sheet n° ND 35-G and Tagabo sheet n° ND 35-F, Kordofan Province. The characteristic rock type of the Mudstone Group is a cleaved, commonly fibrous and silicified, bluish grey mudstone. In the area southeast of the Meidob Hills, sandy mudstones occur with chlorite schists.

In the southwestern part of the southern region, the Basement Complex rocks consist of the following groups :

1 - the oldest rocks are the Gneiss Complex and gneissose Granite Group ;
2 - a group of ferruginous quartzites ;
3 - the Quartzite Schist Group ;
4 - the Migmatite Group (in the cores of major anticlines).

e) Central Sudan

The first information concerning the geology of the central Sudan area was published by Grabban (1906-1909), then Andrew (1948) and later by some geologists from the Geological Survey of the Sudan.

The northern part of the central Sudan was studied by Hottinger and Mc Beath (1960), Geological and Radiometric Reconnaissance Surveys (1978), Strojexport (1975), while the southern part was investigated by the Sudanese-German project (Angermeier and others, 1979).

The Basement Complex in the northern area was classified into the following groups :

1) Early to Late Precambrian

This group is divided into :

a - ortho- and paragneisses and migmatites (Gneiss Group) ;

b - sericite-graphite schists, chlorite schists, muscovite-sericite phyllites, meta-arkoses, slates and metaquartzites, schists (metasedimentary Group).

2) Late Precambrian to Early Paleozoic

It is generally made up of unfoliated younger intrusive complexes including granites, granodiorites, gabbros, syenites, rhyolites. Also of the same age are the quartzo-feldspathic gneisses, biotite augen gneisses and marble bands which were observed in the area, especially west of Wadi el Melik.

The Basement Complex in the southern area (Nuba Mountains area) consists of four units recognised by A.O. Mansour and A. Samuel (1957), J.R. Vail (1973) and Angermeier (1979) :

a - banded granitic and granodioritic gneisses ;
b - micaceous schists, crystalline limestones, ferruginous quartzites and rare metavolcanic rocks ;
c - graphitic schists and siltstones ;
d - low grade metavolcanic rocks.

The gneisses are usually quartzo-feldspathic rocks containing muscovite, hornblende and biotite.

The sedimentary rocks near Talodi and south of Abu Gubeiha have a different degree of metamorphism and tectonic fabrics and may belong to another sequence. They are made up of graphitic schists, siltstones and mud-flake conglomerates with sericite and green mica porphyroblasts (Vail, 1973). Quartz-sericite schists near Rigl el Fula area were reported to contain glaucophane (Mansour and Iskander, 1960). A number of small gabbroic masses showing weak foliation occur throughout the Nuba Mountains area as well as a troctolite observed near Dilling. Serpentinisation and chloritisation in these rocks suggest retrograde metamorphism. Young granitic and syenitic intrusive masses in the basement rocks are common and cover some large areas of rugged relief. Most of these igneous bodies are poorly foliated or not foliated at all, and clearly represent late or post-orogenic emplacements.

f) Northern Sudan

Basement Complex rocks in northern Sudan are exposed along the course of the Nile, from Wadi Halfa to Akasha, Dongola, Merowe, Abu Hamed and Atbara as well as in the region east of the Nile up to the Red Sea Hills. Another area of basement outcrops is in the northwestern part of the country, around Jebel Uweinat, and in the areas southeast of it.

The Nile valley was traversed by Hume (1925, 1934, 1935, 1937) and Whiteman (1971) who gave description of the basement rocks along the Nile. Maley (1970) described the geology around the second cataract to the south of Wadi Halfa, Vail, Dawoud and Ahmed (1973) described that of the third cataract near Kerma.

Jebel Uweinat area was studied by Menchikoff (1927a), Sandford (1935a), Burollet (1963), Pesce (1968), Klerk (1971) and more recently by Khitzsch and List (1979).

The basement rocks along the Nile appear to belong to two main groups :

1 - the oldest group made up of quartzo-feldspathic biotite and hornblende gneisses, quartzites, micaschists, marbles and amphibolite lenses ;

2 - the younger unit predominantly formed of basic volcanic rocks now in the greenschist facies of regional metamorphism, minor gabbroic bodies followed by granitic batholiths and dikes intruding the oldest group. Some of these intrusive rocks post-date the greenschists.

The basement rocks in Jebel Uweinat area include biotite gneisses, leptynites, amphibole-pyroxene gneisses, hornblende-augite-labradorite gneisses, granitic gneisses, hornblende and biotite schists, plus gneisses, quartzites, phyllites, slates and marbles. The basement rocks are intruded by a number of granitic masses and basic and acidic volcanic rocks.

g) Eastern Sudan and Sabaloka inlier

Several investigations and studies were carried out in these areas. The most important works are those of Grabham (1928-30), Delany (1952), Dawoud (1953), Vail (1970), Kabesh (1967), Gindy (1967), Almond (1967, 1971), Whiteman (1970), HUNTING Geology Group (1969) and the Geological and Mineral Resources Department.

In the light of the presently available data, the following three major groups were reported as recognisable groups and are separated by erosional breaks, tectonic and igneous activities :

1 - the oldest group is identified as a group of biotite and hornblende gneisses, grey granodioritic gneisses, migmatites and quartzo-feldspathic gneisses. These rocks, well developed east of the Sabaloka area, are associated with pyroxene-amphibole-garnet granulites ;

2 - the second group of metamorphosed rocks is made up of micaceous and graphitic schists, marbles, quartzites and psammitic gneisses. They represent a sedimentary sequence now in the amphibolite facies of regional metamorphism. A minor occurrence of metamorphosed shales, flaggy sandstones, and quartzites was considered as part of the Sabaloka igneous complex ;

3 - the third group predominantly consists of basic volcanic rocks of basaltic to andesitic composition. They are best developed in the central Butana area also, east and southeast of the Ingessana Hills and in the Gezira plains. These rocks are usually in the greenschist facies of regional metamorphism, and were referred to as Butana Green Series (Delany, 1952b ; Whiteman, 1971a).

Delany (1953) recognised foliated and unfoliated granites. Two intrusive phases of gabbros were also identified in this area. Extrusive basaltic and rhyolitic volcanic rocks are also present in places. The most striking intrusive bodies are the numerous ultrabasic and basic rocks, the most significant of which are those of the Ingessana Hills and Qala En Nahal. These intrusive bodies consist of serpentinised dunite, talc-carbonate schist, peridotite, epidiorite, norite and gabbro.

C - STRUCTURE

The first attempt to show the major bedding-foliation orientation of the Basement Complex exposures on a regional scale was made by Vail and Rex (1970) and by Vail (1972a).

The dominant trends of the tectonic lineaments were clearly recognised, but the different phases of folding and their associated metamorphism and igneous activity have yet to be distinguished.

The metamorphosed Basement Complex rocks are well-banded and show strong mineral orientation in most of the country.

In the Red Sea Hills region, the main lineaments in the northern and northwestern parts show a general N-S trend, while in the central part, between Dungunab and Port Sudan, the main lineaments show a NE-SW trend. In the southern parts, near the Ethiopian boundary, the trends are again N-S.

The lineaments are folded by at least two types of fold systems clearly observed from the aerial photographs. One system represents isoclinal folding with axial planes trending parallel to subparallel in relation to the main trend. The other fold system represents asymmetrical tight folding associated usually with wrench faults. The axes of the two-fold systems are steeply plunging to the southwest in the area west of Derudeib and to the northeast in area west of Port Sudan.

The faults in the Red Sea region are mainly NE-SW and deformed by the later NW-SE wrench faults. The two-fault directions are affected by the latest N-S and E-W fault system.

In the Bayuda desert, three-fold systems were distinguished :

1 - the first fold system is recumbent folding with flat axial planes ;

2 - the second system consists of concentric reclined folds with recumbent limbs and N.NE axes. Thrust and wrench faults are commonly associated with this folding ;

3 - the last fold system is made up of open concentric folds with NW axes accompanied by shearing (strain slip cleavage).

Those main fault systems are recognisable in this area : E.NE-W.SW fault system, N-S fault system, E-W fault system. Some NW-SE faults are observed.

In eastern Sudan, two-foliation trends were observed : the older one strikes N-S and the younger one, NW-SE.

The area to the north and east of the Blue Nile is affected by more than one foliation trend but the dominant foliation strikes NE-SW.

The central and north-central Sudan regions are characterised by at least two phases of fold systems distinguishable in the field : the first fold system is isoclinal with NE-SW foliations and steeply plunging axes. Strike step faults are associated with this folding parallel to the foliation ; the second fold system is made up of asymmetrical tight to close folds with N.NW-S.SE foliation. This foliation is twisted towards the N-S and NE-SW in the northern part of the area and thus is parallel to the first foliation. In the area around Jebel Uweinat, the main foliation strikes E-W.

In the southern and southwestern Sudan, two fold systems were distinguished from the Landsat imagery. The first system shows isoclinal to close folds with NE-SW axial plane surface. Some faults are parallel to this direction. Both structures are folded by the second fold system which has a NW-SE foliation parallel to the Nimule fault direction.

The western part of the Sudan is affected by three tectonic phases : the first phase developed the main foliations of the metamorphic rocks ; the second tectonic phase caused the folding of the foliations around N.NE-S.SW axes ; and both structures were further deformed by the third tectonic phase which folded them with NW-SE to W.NW-E.SE axes.

2 - THE CAMBRIAN

The Cambrian rocks in the Sudan are represented by the Nawa Formation and the Amaki Series.

1) The Nawa Formation (Nw)

This formation is made up of gently dipping sediments including purple to green-coloured mudstones, micaceous and arkosic grits and limestone bands, unconformably overlying the metamorphosed basement rocks. The Nawa Formation is only known from drill hole data in the Er Rahad area and the Khor Abu Habil, situated both in the Kordofan Province. The Nawa Formation strata do not outcrop on the surface, and in all places, are covered by a thick cover of unconsolidated sediments of the Umm Ruwaba Formation, eolian sands and/or alluvia. Field relationships as extrapolated from drill hole data indicate that the Nawa Formation was only preserved in faulted areas. Its proved thickness is 285 m, and no fossils were encountered.

2) The Amaki Series (Am)

This series is represented by small outcrops of sandstones and conglomerates with some limestones and cherts, observed between Abu Hamad and Shereik in the northern Sudan region.

3 - THE CAMBRO-ORDOVICIAN (Ɛ O)

This formation rests with a marked unconformity upon the metamorphosed basement rocks north of Wadi Hawar, near Geneina and around the Uweinat inlier.

It comprises some hundred metres of fluvial continental sediments of basal conglomerates, and sandstones containing tigilite fossils overlain by fine to medium-grained sandstones.

4 - SILURIAN (S)

Umm Ras Beds (a : outcrop ; b : non outcrop)

The sediments of Umm Ras Beds range in thickness from 150 to 250 m and are at least partly marine. Silurian sandstones were recorded in northwest Sudan. Some cross-bedded, fine to coarse-grained friable sandstones with the same fossils were also noted west of the River Nile, between latitudes 20° and 21° N, and in the northwest corner of the Sudan.

In the area south and southeast of Jebel Kisser, the Basement Complex rocks are overlain by a relatively thin sequence of Silurian sandstones with some marine intercalations bearing fossils of the Harlania species and Cruziana acaensis. Similar outcrops were also found west of the River Nile.

Along the Sudanese-Egyptian border, the Silurian strata are characterised by the abundance of Scolithus structures which were found at Karkur Talh (Uweinat, Egyptian side) in association with Harlania.

5 - THE LOWER - UPPER DEVONIAN (D)

Lower and Upper Devonian strata are well developed in Chad and near the western side of the Uweinat basement in Libya. Some outcrops of Devonian to Carboniferous age, made up of sandstones, siltstones and shales, containing mainly continental plant fossils were noted west of Wadi Halfa and to the northwest of Wadi Hawar. At Karkur Murr, south of Uweinat in the Sudanese side, Lower Carboniferous formations directly overly the basement rocks. The basal sediments of Silurian age are missing. The formation is 80 to 90 m thick and contains Precyclostigma near the base which is only known from strata of the Devonian age.

6 - THE DEVONIAN TO CARBONIFEROUS (DC)

These periods are represented by the Karkur Murr and Lake Formations which are made up of crossbedded sandstones, siltstones and shales.

Three formations of Carboniferous sediments were recognised in the northwest corner of the Sudan. The oldest known are the Karkur Murr sandstones formed of conglomerates, siltstones and micaceous sandstones. Plant fossils found in these sediments indicate a Late Devonian to Early Carboniferous age.

The second formation, the Wadi Waddan shales, is made up of about 300 m thick strata of fine sandstones, siltstones and variegated shales.

The upperwest unit is known as the Cima sandstones, i.e. massive quartzitic sandstones, nearly 400 m thick and of probable Lower Carboniferous age.

7 - PERMO-TRIASSIC (PT)

These periods are represented by sandstones, conglomerates and arkosic sandstones interbedded with siltstones and mudstones which were noted east of Jebel Uweinat (northwest Sudan).

8 - JURRASSIC (J)
Gilf Kabir Formation

The Jurrassic period is represented by the Gilf Kabir Formation of interbedded sandstones, siltstones and pebbles. The sandstones show current crossbedding indicating that the material was mainly transported in a north to northwest direction. However, in some places, the direction of the transport appears to have been south to southwest.

The exposed thickness of the Jurrassic to Early Cretaceous deposits does not exceed 150 to 200 m.

9 - CRETACEOUS (N)
Nubian Sandstone Formation

The Nubian Sandstone Formation covers about a third of the surface area of Sudan and continues extensively into Egypt, Libya and Chad.

Nubian Sandstone outcrops are mainly confined to the northern part of the country, but isolated outliers of the main formation are found in the Upper Nile and Bahr el Ghazal Province.

The Nubian Sandstones Formation overlies the Basement Complex rocks over most of its outcrop areas. This formation is dominated by arenaceous and rudaceous beds, although siltstones and mudstones are not uncommon. A rare 15 cm thick lignite horizon was reported near Dongola, gypsum near Shendi. Calcareous and ferruginous horizons are also common, in particular the latter.

Due to the lack of diagnostic fossils or distinctive marker beds, the identification of the Nubian Sandstone Formation depends largely on its lithology. Silicified wood fragments are common in this formation as well as locally silicified trees.

There is a controversy over the Nubian Sandstone Formation correlation, age, origin, stratigraphy, distribution and even over its name.

Edwards (1926) assigned an Early Cretaceous age (Early Maestrichtian) to the Lower Nubian, and the Upper Nubian units (Maastrichtian) were taken to be of Paleocene age. Both Müller and Young (1982) suggested, from the geological study of the paleontologic microfauna analysis, that all the exposed sediments of the Khartoum-Dongola area are of Tertiary age. Some older fossils which may be of Late Jurassic to Cretaceous were found, but appear to have been reworked, i.e. Mesozoic rocks were once exposed on the surface, eroded and redeposited. This also implies that older sediments were most probably burried under the Cainozoic.

The petroleum potential of the Nubian strata is currently undergoing serious investigation.

Five stratigraphic units in the Nubian Sandstone Formation were differentiated in addition to the undetermined pinkish granite basement associated with very hard, bluish to greenish white quartzite exposed to the west (southern Kababish).

All five units show evidence of having been deposited in a dominantly continental environment during the Neogene.

The exposed stratigraphic sequence of the Khartoum-Dongola region as established from field observations, sample analysis and interpretation of enhanced Landsat imagery, is as follows from bottom to top :

<u>Unit 1</u>

This unit is made up of quartz arenite of continental-fluvial origin, varying in colour from light to medium dark grey and brown, becoming yellowish brown in its upper parts. The very top of the unit is white to purplish grey in colour.

Unit 1 is exposed west of the Nile, in the Kababish area south of Wadi el Melik and el Qureinat, southeast of El Zarga - Ed Deiga and west of Gabrat Said. It was dated as of Miocene age, presumably of lowermost Miocene as it conformably overlies the sediments of unit 2.

<u>Unit 2</u>

This unit consists of quartz arenites, including interbedded shales and siltstones in the north, and some arkose and quartzite of continental and mostly fluvial origin in the southeast. The rocks are brown grey to dark-coloured in the west and south, light-coloured in the north and east. They are yellowish to reddish orange everywhere else except in the south. Unit 2 is exposed north of Jebel Abu Inpira, east of Abu Dulu, southeast of Ushar-Ed Deiga, south central part of Wadi el Kasar and Wadi el Melik, south of Umetto-Tarfawi and west of Wadi el Quabo-Dongola. The rocks are dated as of Lower Miocene age.

Unit 3

Unit 3 comprises quartz arenites interbedded with shales, siltstones and locally lithic arkoses. Deposition environment may be of near shore, possibly lacustrine and partly fluvial. Strata are yellowish brown, orange and very light to dark grey in colour.

It is exposed north of Dongola, south of Tarfawi, southwest of Jebel Abyad, northwest of Wadi el Quabo and northwest of Jebel En Nar. The rocks are dated of Middle to Late Miocene.

Unit 4

This unit is formed of dolomites interbedded with shales. The dolomites are overlain by 12 m of shales covered by 5 m of very coarse sandstones which may be the equivalent of Unit 5.

Unit 4 is of lacustrine and possibly brackish origin. White to pinkish white shales are interbedded with greenish light grey coloured shales. It is exposed west of Kababish and northwest of Jebel Abyad. This unit rock is of Late Miocene.

Unit 5

This unit consists of quartz arenites interbedded with conglomerates and sublithic arenites (fluvial). The rocks are dark grey, yellowish, brownish to bluish purplish in colour and are lighter coloured in the north. Unit 5 is exposed north of El Khandag, east of Wadi el Mugaddam and of Abu Dulu, south of Nagashush and west of Jebel Abyad. It is dated as Late Miocene to Early Pleistocene.

The Nubian Sandstone strata in southwestern Egypt reach an average thickness of 1,000 to 2,000 m with an age ranging from Jurassic to Late Cretaceous (E. Khitzsch, 1978). Most of the age determinations are based on plant fossils. The sequence may be divided into six distinctive lithologic units. The three major sandy units were deposited mainly in alluvial plain environments and include channel, flood plain and rare lacustrine or marginal marine facies.

The petroleum potential of Nubian Sandstone strata is being actively investigated at present. Radar images taken during the second U.S. space shuttle mission revealed a hitherto unknown world lying beneath the sands of the Sahara desert. Running over northwest Sudan, the images show a number of former river beds apparently hundreds of miles long, and some of them as wide as the Nile valley, as well as large former lake basins and tectonic fractures. A huge crack was also observed in the earth surface.

Exploration for both oil and water will undoubtedly benefit from this new type of evidence.

10 - MESOZOIC TO TERTIARY (B and Av)

This age group is composed of :

1) Basic volcanics, mainly basalts (B)

They are found in the southeast corner of Kenya-Ethiopia and Sudan common border, as well as in eastern Sudan around Gedaref area, north of Kassala at the Ethiopia-Sudan common border, in western Sudan at Jebel Marra. Some other outcrops are found south and north of Wadi Hawar.

2) Acidic and intermediate volcanics, mainly rhyolites and trachytes (Av)

Small outcrops of this group were noted between the Red Sea Hills and the River Nile as well as between Jebel Marra and Khartoum, and to the east, between Khartoum and the Ethiopian border.

11 - MESOZOIC TO RECENT (Tr)
Red Sea Littoral Group

It is formed of reefal and perireefal complex with associated deposits of clastic sediments, evaporites and fossiliferous limestones.

Andrew (in Tothill, 1943 and unpublished M.Sc.,1943)gave a generally accepted view : the Red Sea was formed in mid-Tertiary, Post-Eocene, probably Oligocene times. According to Andrew no sediments older than Plio-Pleistocene are present along the Red Sea shores of the Sudan. Moreover, by analogy with those of the southern part of the Gulf of Suez in Egypt, younger sediments were found along the coastal strip of the Sudan.

The Plio-Pleistocene beds are made up shelly limestones or coralline shells, marls, clays, grits, conglomerates and gypsum beds. They are partly overlain by thick and very coarse angular river terrace deposits. The characteristic fossils are Pecten vasseli and Laganum depressum with a small variety of lamellibranches and gastropods.

12 - TERTIARY (Hc)
Hudi Chert Formation

The rocks of the Hudi Chert Formation were first found near the Hudi railway station, east of Atbara. They are fossiliferous cherts, usually weathered on the surface (large rounded boulders). They are found in about a dozen of localities in the Northern Province between Shendi and Atbara, usually not far from the Nile or its tributary wadis. Lox (1932-33) described eleven species of fossils in the Hudi Chert : ten of them were non-marine gastropods, only one was a marine fossil.

The chert occurs as irregular ellipsoidal boulders up to about 30 cm diameter and are characteristically yellowish brown, irregularly pitted, and contain fossil shells or casts. The rock is very fine-grained, hard and in parts brecciated. A variety of non-marine fossils found in the chert includes gastropods, pila and pseudoceratodes. The origin of the chert may be due to the silicification of lacustrine deposits.

13 - TERTIARY TO QUATERNARY (GF - UR)

1) Gezira Formation (GF)

The Gezira name refers to the land between the White Nile and Blue Nile. The Gezira Formation consists of unconsolidated clays, silts, sands and gravels. The type-locality of the formation is at Ghubshan village where the formation thickness reaches some 200 feet (70 m). It rests unconformably on the Nubian Sandstone Formation and is overlain by eolian sands and other superficial deposits. Gravelly sand, 30 feet (9 m) thick, occurs at the base of the formation, at Ghubshan. It gradually changes upwards into clayey sand of about 115 feet (35 m) thick, and hard dark clays and silts of 55 feet (17 m) thick, locally known as Gezira clays. Rapid lateral and vertical facies changes are common in the Gezira Formation, which also varies considerably in thickness from place to place. Williams and Adamson (1973) conclude that the Gezira Formation was built up by fast flowing streams carrying coarse detrital material from the south. The Gezira Formation is lithologically in a way similar to and is continuous with the Umm Rawaba Series beds west of the White Nile as seen in the similar deposits of the Upper Nile Province towards Malakal.

East of the Blue Nile and in the drainage basins of the Rahad, El Atshan and Dinder rivers, in the Blue Nile Province, there are similar unconsolidated sediments called "Older alluvium", referred to as the El Atshan Formation which are similar to the Umm Rawaba and Gezira Formations. Although considered to belong to the same broad group of other unconsolidated sands and clays, they were distinguished as alluvia on the geological map prepared by Professor J.R. Vail (1974).

2) Umm Rawaba Formation (UR)

The Umm Rawaba Formation is widely distributed in the central and southern Sudan, almost totally covering the Upper Nile Province and partly the Equatoria, Bahr el Ghazal, Darfur, Kordofan and Blue Nile Provinces. The type-locality for these deposits is located at the Umm Rawaba village, in the Kordofan Province. This formation contains very few fossils and therefore not much can be said about age. It is considered of Quaternary to Tertiary age by Whiteman and as Quaternary by Vail.

The sedimentary rocks of the formation consist of unconsolidated sands, locally gravelly, clayey sands and clays. Rapid facies changes are common in the Umm Rawaba Formation. On the basis of X-ray diffraction analysis, the dominant clayey material in the formation is montmorillonite. According to the heavy mineral fraction, the Umm Rawaba formation may be divided into three units (Shafie, 1975) :

lower unit : some 99 m thick, it is characterised by individual grains of epidote. Authigenic minerals are represented by the presence of many limonite grains ;

middle unit : some 149 m thick, it is characterised by abundant epidote, the increased quantity of which forms the bottom of the cross-section ;

upper unit : some 157 m thick, the quantity of the epidote grains (in general) decreases in this unit. The Umm Rawaba Formation is also characterised by the presence of a considerable amount of feldspars which may reach up to 40 % of the light fraction, and ilmenite which reaches up to 77 % of the heavy fraction.

Much of the area overlain by the Umm Rawaba Formation has surface deposits consisting of heavy clays, dark grey to chocolate in colour with kankar nodules. In the Muglad and Umm Rawaba area (Quz), sands directly overlie the clays.

According to oil exploration data from central and southern Sudan, the maximum drilled thickness of the Umm Rawaba Formation is higher than 15,000 feet (about 4,570 m). According to geophysical data the maximum recorded thickness is higher than 27,000 feet (about 8,225 m) in some places.

The Umm Rawaba deposits are thought to have been deposited in a series of land deltas similar to the Gash delta of the Kassala Province, and to the Sudd region of southern Sudan (Berry and Whiteman, 1968).

Some geologists considered the Umm Rawaba deposits as fluviatile and lacustrine. They may not have accumulated in one large and continuous lake extending as far north as the rocky area of Sabaloka, 45 miles north of Khartoum.

According to Shafie (1975), the rocks of the Umm Rawaba Formation are ferruginous and partly lacustrine as shown from the upper unit (206 - 212 m) where 15 forms of diatoms were described as fresh water species in water of very low salinity (0.5 %). The water reservoir of the ancient lake apparently was not large.

Older alluvium deposits of the El Atshan Formation cover the areas east of the Blue Nile and occupy the drainage basin of Rahad, El Atshan and Dinder rivers. They also extend over the Butana plains between the Blue Nile and Atbara river and are generally made up of unconsolidated sands, clays and gravel. They are very much similar to the deposits of the Umm Rawaba and Gezira Formations. Being of older origin, the El Atshan Formation is classified as part of the Umm Rawaba Formation.

According to A.A. El Shafie (1975), a new formation, named Saiyala Formation, located just north of the Umm Rawaba Formation, is recorded in the inhabited region of Umm Sayal and Fadliya. This formation represents the oldest Neogene development and is arbitrarily assigned to the Pliocene. The Saiyal Formation is represented by the redeposition of the crustal surface chemical erosion products of quartz, sand and argillaceous deposits of kaoline composition (X-ray diffractometry analysis). The Saiyal Formation directly overlies slightly weathered metamorphosed Proterozoic rocks of the Basement Complex. The sediments consist of sands and gravels slightly cemented by the kaolinitic clays. Based on the mineralogical analysis, the light fraction contains 98 % quartz and 2 % feldspars. The heavy fraction comprises ilmenite (40-70 %), limonite (20-55 %) and, in lesser degree, rutile (up to 5 %) as an accessory mineral, zircon, hornblende, tourmaline, kyanite, staurolite, epidote, leucoxene, magnetite, chlorite and pyrite.

14 - SUPERFICIAL DEPOSITS

The northern half of the Sudan lies within the Sahara desert, North Africa. It is an extremely arid area characterised by vast expanses of eolian sands which obscure the bed rock and impede travel.

The sands extend over the whole of northern Sudan but are prevailing in the northwestern parts, west of the Nile. The Red Sea Hills and Atmur desert, east of the Nile, have some moving sands but not as much as the areas west of the Nile. Moving sands extend further south to a line running from the borders of Chad and Central African Republic and passing through past Nyala, El Obeid, Kosti, to Kassala and the Ethiopian-Sudanese international border line, at the Red Sea Hills. The southernmost limit of sands is as far south of latitude 04°00' N where fossil and fixed sand dunes are present. These sand dunes are referred to as Qoz in the Kordofan Province, where the annual rainfall exceeds 500 mm/annum.

All the main drainage systems have alluvia which are developed to a greater or lesser extent depending on the age of the drainage system and its environment. This is particularly true for the Nile and its major tributaries. The rich flood plains of the Nile and its major tributaries have been supporting agricultural settlement for thousands of years.

Some of the large rivers, especially those draining well-watered inlands have developed large deltas forming fan-shaped plains. This is particularly true of the Gash river north of Kassala, Dinder, El Rahad, El Atshan and Atbara rivers in the eastern Sudan Region, Wadi El Ku south of El Fasher town in the Darfur Province and Wadi Baraka in Tokar town in the Red Sea Province.

In other areas, in particular on the Umm Rawaba deposits of south-central Sudan, annual flood by the main rivers causes seasonal overflowing and large areas become inundated with the consequent development of swamps and thin alluvium deposits.

According to Whiteman (1971a), Tertiary, Pleistocene and Holocene formations are difficult to separate and correlate because of the scarcity of characteristic fossils and evidences of paleoclimatic data, of exposures and of datable carbonaceous material.

According to El Shafie (1975), the superficial deposits named Rudda Formation are widely distributed in central and southern Sudan. They are named after an inhabited point located west of Bara town in the Kordofan Province. They are composed of various genetic types of sediments of alluvial, eolian and mixed lacustrine origins.

Based on the X-ray refractometry analyses, the clays of the Rudda Formation are dominantly made up of montmorillonite.

According to the mineralogical analysis, the light fractions are characterised by a low amount of feldspar (2-12 %), the remaining amount (88-98 %) being made up of quartz and some micrograined calcite. The heavy fraction consists of ilmenite (43-53 %), limonite (30-40 %) and rutile (2-15 %). Accessory minerals are tourmaline, zircon, epidote, hornblende, etc.

Diatomaceous rocks were found near the bottom of Qoz sand dunes (Andrew, 1946), in the city of Bara, Kordofan Province, and in the central part of the Darfur Province but were not investigated.

Later investigations established the existence of a widespread diatomaceous sediments. A.G. Piromova determined 67 forms and variations of diatoms in situ, as well as individual valves of three species of the ancient redeposited forms.

The Rudda Formation containing diatomaceous forms can be correlated with the deposits of lake Paleo, Chad. In addition to the diatoms, identical remains of fishes, silurids and elephant's teeth are found in both sediments.

The absolute ages of the diatomaceous deposits in both areas were identical.

Various foraminifers were found in the Rudda sediments which, according to V.A. Krasheainkov, could have been windblown. However, the fine sandy material (grain size : 0.25-0.1 mm) in which the foraminifers were found had angular grains and no traces of eolian erosion were observed.

PART II

MINERAL DEPOSITS AND OCCURRENCES

Mineral, and in particular gold, exploitation has been carried out in Sudan and Upper Egypt for more than 4,000 years (Pharaonic times).

The present-day contribution of the mineral wealth to the economy of the country is almost negligible, although much money and effort is put along this line. Gravel, sand, limestone, gypsum and common salt provide the largest and most economically valuable tonnages. Metallic minerals are of less importance. Mineral fluids recently proved to be of major importance and most of the work and money is centred there.

Many geologists have written on the Sudan mineral deposits : Dunn (1911), Imperial Institute (1922), Putzer (1962), Kabesh (1964), Dekun (1965), Whiteman (1971a), Akasha and Abdalla (1972), Widatalla (1973), A.A. Mageed (1980), and many reports are filed at the Geological and Mineral Resources Department. Also individual and private efforts have contributed much to the literature on the Mineral Resources of the Sudan.

In spite of all these efforts, copper, gold, iron, chrome and asbestos were the only mineral deposits thoroughly studied and investigated by the Geological and Mineral Resources Department alone or in cooperation with friendly countries and interested organisations. As a rule only the Red Sea Hills area and Ingessana, Qula En Nahal and Horat En Nahas areas were intensively explored.

Due to the scarcity of available data, classification of the mineral deposits by age or origin was not possible, and therefore they are classified according to their economic value.

1 - GOLD (Au)

Gold production has been known in Sudan since Pharaonic times (some 4,000 years ago). More than 80 gold occurrences were revealed in the northern and northeastern Sudan and about 20 occurrences in the rest of the country (Geological and Mineral Resources reports, Whiteman (1971a), Grabham (1929), Hume (1934) and Vercoutter (1959)). A brief description of the major gold mines is given below :

A - GEBEIT GOLD MINE

Gebeit Gold Mine is one of the oldest (20°03' N, 36°19' E). It lies west of Dungunab Bay and some 280 km northwest of Port Sudan. It is situated in an area of metavolcanic Basement Complex rocks (Nafirdeib Series), intruded by granitic rocks, diorites, granodiorites and cut by numerous fractures.

The gold mineralisation is mainly in the form of auriferous quartz veins of various thicknesses, from a few centimetres to some 3.5 m in width. The alteration zone close to the auriferous quartz veins is mineralised. The auriferous quartz veins strike differently, but they most commonly strike NE-SW and E-W with dip ranging from 60° to 90°. According to the recent interpretation of satellite images, the general trend of the auriferous quartz veins is conformable with that of the lineaments.

Gebeit gold mine was productive up to 1953 and is still worked by the local inhabitants with primitive means. Recently the Geological and Mineral Resources Department together with Minex Company got seriously involved in studies with the intention of re-opening the gold mine, if proved worth it.

B - OYO MINE (21°55' N, 36°07' E)

C - ONIB MINE (21°29' N, 35°20' E)

D - ABERKATEIB (20°41' N, 34°54' E)

E - SERAKOIT (20°10' N, 35°50' E)

These old gold mines are situated in the Red Sea Hills region, in the Basement Complex rocks of the Nafirdeib Series. The gold mineralisation is mainly confined to the auriferous quartz veins and the relatively thin alteration zones close to the quartz veins. The auriferous quartz veins are generally conformable with the regional lineaments striking W.NW, NW, N.NW, NE and E-W (J.R. Vail, 1978).

All these mines were abandoned some time ago, but a serious effort is going on to restudy these mines with the intention of re-opening them if proved of economic value.

Aberkateib gold mine is still being worked on a small scale by private companies.

F - UM NABARDI (21°07' N, 32°47' E)

Some 30 old mines are located east of the railway station (6), along the railway line, between Abu Hammed and Wadi Halfa (Hume, 1934 ; Whiteman, 1971a). The area is composed of the Basement Complex of the Nafirdeib Series. The gold mineralisation is in the form of auriferous quartz veins of thickness ranging from a few centimetres to several metres, and a few hundred metres in length. The mineralisation contains gold, pyrite, arsenopyrite and galena. The strike is generally NE and the dip SE ; other strikes are E-W.

G - DOISHAT (21°23' N, 30°58' E)

Doishat and Dowshet mines lie about 80 km south of Wadi Halfa and near the Kurma temples. They were artisanally operated by individuals between 1904-1960.

The auriferous quartz veins occur within the chlorite-sericite schists which are intruded by granitic and dioritic dykes (Hume, 1934).

H - WADI AMUR

Some six ancient gold workings were noted along Wadi Amur, between the River Nile and the Red Sea Hills. The geological information on the old workings is very limited but they are generally similar to the gold occurrences in the northeastern Sudan. They occur in the Basement Complex rocks of the Nafirdeib Series which are intruded by granitic and granodioritic rocks and show NW and E.NE fracture patterns.

I - ALLUVIAL GOLD OCCURRENCES

About 20 occurrences of alluvial gold were revealed around Kurmuk and Roseries (11° N - 35° E) along the old terraces of the Blue Nile. The local inhabitants using artisanal digging and panning method collect gold grains from pits of 0.5 - 3 m depth. The geology of the area is composed of Basement Complex rocks of amphibolite facies, characterised by N-S and NW fracture pattern (Whiteman, 1971a).

Alluvial gold is also known around Nimule (White Nile), Juba and Kapoeta in the southern Sudan. There the natives also produce gold grains by artisanal panning method.

J - KORDOFAN PROVINCE (Nuba Mountains) (11° N, 30°30' E)

According to Dunn (1911, 1921), Russerger (1938), Mansour and Samuel (1957), Whiteman (1971a) and Vail (1973a), the gold of the Nuba Mountains occurs in small auriferous quartz veins of a few centimetres to 1-2 m in width, striking NW or NE, parallel to the regional strike in that area. Gold is only exploitable where it is concentrated through erosion in the surface soil or gravels.

ORIGIN AND AGE OF GOLD

In northeastern Sudan, the auriferous quartz veins are found within the Basement Complex of the Nafirdeib Series (greenschist facies) and are comparable with faults and joints. The auriferous quartz veins are emplaced in the vicinity of post- to late-tectonic granitic masses. Consequently, the gold mineralisation postdates the last regional metamorphism and predates the younger granitic intrusions. Dekun (1945) recorded auriferous basal conglomerates in the Nubian succession in Egypt, indicating that the probable sources of the gold are the Basement Complex processes. Hence the gold mineralisation may be related to the Archean mineralisation (Vail, 1978).

2 - BERYL (Be)

Beryl was recorded as a minor constituent in the pegmatites of the Bayuda Desert of central Sudan, within the Rahaba Series of the Basement Complex. The Rahaba Series is mainly composed of granitic gneisses, amphibolites and hornblende gneisses. Beryl was also recorded in the pegmatites of the Abu Harik Series biotite-hornblendé gneisses, partly migmatised or granitised, with amphibolites and quartzitic lenses. Beryl crystals vary in size up to 50 cm (Vail, 1971a) for the Rahaba pegmatites, east of Jebel Abu Nahal. The crystals found are whitish to light green in colour and sometimes difficult to recognise.

3 - CHROMITE (Cr)

Chromite is noted in three localities of the Sudan. The ore is found as magmatic concentrations in the form of lenses, veins or disseminations in the basic and ultrabasic rocks of the Basement Complex.

A - INGESSANA HILLS (11°20' N, 34°00' E)

The Ingessana Hills lie some 65 km southwest of the Damazin railway station, in the Blue Nile Province.

The area is composed of basic and ultrabasic rocks emplaced in the metasedimentary rocks of the Basement Complex and intruded by a later granitic mass to the southeast side of Bau (Kabesh, 1961a ; HUNTING Geology and Geophysics, 1969a).

The chromite mineralisation is mainly concentrated in the western side of the Ingessana Hills as lenses, veins, in irregular patches and disseminated deposits in the serpentinites and talc-carbonate rocks of the dunite-peridotite gabbro forming the metamorphosed ultrabasic to basic complex. The lenses and the veins generally strike N.NW with steep dips.

The main deposits of the Ingessana Hills are : Jam Mine, Jebel Abu Dom, Jebel Chicky and Jebel Kurba. Several other small veins and disseminated deposits were recorded. The overall reserves were estimated at some 1,000,000 metric tons (Japanese report, 1980).

An average of 30,000 t per annum of chrome ore was exported over the last ten years by the Sudanese Mining Corporation and the Nile Chromium Corporation.

B - QALA EN NAHAL (13°37'30" N, 34°57'30" E)

Small chromite occurrences were reported east of Qala En Nahal railway station, in the poorly exposed gabbros, serpentinites and talc carbonate rocks as small veins, lenses and disseminated deposits (Tyler, 1932 ; Wilcockson and Tyler, 1933 ; HUNTING Geology and Geophysics, 1969b). At Jebel el Fau, west of the railway station, another small chromite occurrence was noted and a last one in the Jebel Umm Saqatta area, some 40 km south of Qala En Nahal.

C - RED SEA HILLS

Ultrabasic rocks were observed in many localities in the Red Sea Hills and southern Egypt. Chromite mineralisation is quite possible in these localities (Kabesh, 1962c ; Lotfi, 1963a).

However, in the Sol Hamid area (22°12' N, 36°05' E), west of Halaib, serpentinites and gabbros intruded by batholith granites occur as narrow bands with chromite and magnesite mineralisation.

The chromite occurrences were not economically estimated.

4 - COPPER (Cu)

Significant copper deposits were known a long time ago (about 200 years ago) in the Hofrat En Nahas area of southwest Sudan (9°45' N, 24°18' E). Copper occurrences were also reported in different localities of the Red Sea Hills.

A - **HOFRAT EN NAHAS** (9°45' N, 24°18' E)

Hofrat En Nahas copper deposit was exploited by local inhabitants some 200 years ago. Although this deposit was intensively investigated, little is published about it (Nile-Congo Divide Syndicate, 1934 ; Nippon Mining Company, 1965 ; Afia and Widatalla, 1961 ; HUNTING Geology and Geophysics, 1969 ; U.N.D.P., 1972).

The geology of the Hofrat En Nahas area is made up of the metasedimentary and metavolcanic rocks of the Basement Complex. The mineralisation occurs as chalcopyrite, pyrrhotite and pyrite with quartz, calcite and tourmaline as gangue minerals at some 35 m deep. Malachite, azurite, chrysocholla and native copper are the underlying oxidation minerals. Minor torbernite is recorded. Other minerals like molybdenum, cobalt and gold are associated with the mineralisation.

Significant geophysical and geochemical anomalies were found along the mineralised zone extending some 120 km S.SW of Hofrat En Nahas old mine. But the only significant deposit known is that of the Hofrat En Nahas old mine with reserves estimated at 9.5 million metric tons at 4.1 % Cu.

The age and mode of occurrence of the mineralisation has yet to be determined. It is probable that the mineralising solutions came quite late in the evolution history of the Basement Complex (Vail, 1978).

B - RED SEA HILLS COPPER OCCURRENCES

The copper mineralisation of **Tohamiyan** (18°20' N, 36°32' E) occurs in the form of malachite staining in the metavolcanic and metasedimentary rocks of the Nafirdeib Series of the Basement Complex. Geological investigations including drilling were carried out in that area but the reserves were not estimated. The investigations were confined to the shear and fracture zones.

Another copper occurrence, recorded 40 km northwest of Port Sudan at **Khor Arbaat,** is also related to the metavolcanic rocks of the Nafirdeib Series and is concentrated in the shear and fracture zones.

Copper occurrences were also noted in the **Derudeib** (18°40' N, 36°30' E), **Sofaya** (21°18' N, 36°3'30" E) and **Musmar** (18°5' N, 36°7' E) areas. These copper occurrences are all associated with the shear and fracture zones in the metavolcanic and metasedimentary rocks of the Nafirdeib Series.

5 - IRON (Fe)

Some six significant iron ore deposits and several occurrences are known in the Sudan. Most of these deposits were geologically investigated and some evaluated but none of them has been exploited.

Different workers including Dunn and Grabham (1910), Andrew (1952), Afia, Kabesh and Mansour (1956), Whiteman (1971a) and the Geological and Mineral Resources Department geologists have visited these iron ore deposits.

A brief description of some of the iron ore deposits and occurrences is given below :

A - ABU TULU (11°41'30" N, 28°29'30" E)

Jebel Abu Tulu is situated some 30 km east of the El Fula railway station, in the southern Kordofan Province. The mineralisation occurs in the form of two huge bands of hematite with rare magnetite enclosed within compact quartz-sericite schists and metavolcanic rocks of the Basement Complex.

The orebodies are displaced by fracturing. Mansour and Iskander (1960) believed that the mineralisation is of sedimentary origin and hence might continue over a considerable distance. All indicates a replacement origin like the iron ore deposits of the Red Sea Hills.

The ore reserves were estimated at some 35 million metric tons by Mansour (1961) but a later estimation made by the Chinese geologists (1974) gave results of some 81 million metric tons. The ore is of economic value, with 63-65 % Fe, negligible phosphorus and sulphur content and only 5-7 % silica in the form of free quartz.

El Ageed (1974) discovered some iron ore occurrences in the northeast area of the Nuba Mountains, but these were considered as small occurrences of no economic potential.

B - RED SEA IRON ORE DEPOSITS

a. <u>Sofaya iron ore deposits</u> (21°15' N, 36°13' E)

The Sofaya iron ore deposits consist of seven separate localities named Ankur, Ader Aweib, Yaw - Kurar, Nafirdeib, Aguissan, Aklat and Adarein. They are situated some 90 to 120 km from the small harbour of Abu Imama on the Red Sea and 250 km north of Port Sudan.

The ore occurs within the metasedimentary and metavolcanic rocks of the Nafirdeib Series of the Basement Complex, in the form of lenses and dikes as bodies with sharp contacts with the country rocks.

The reserves amount to some 14 million metric tons of high grade ore at 60-63 % Fe content and negligible phosphorus and sulphur content. It is worth mentioning that, although small, these deposits do not require beneficiation and are rich enough to be worked.

b) Fodikwan iron ore deposit (21°42' N, 36°43' E)

Fodikwan mine is located 15 km of Marsa Osif on the Red Sea and 280 km north of Port Sudan. The iron ore occurs within the metasedimentary and metavolcanic rocks of the Nafirdeib Series.

The ore is mainly made up of magnetite altered to hematite, with minor goethite and limonite (Kabesh, Afia and Widatalla, 1958), with more than 60 % Fe and negligible amounts of phosphorus and sulphur. The reserves were estimated at some 4 million metric tons. The ore mineralisation may be related to hydrothermal solutions that occupied the weakly foliated shear zones.

Naakuri and Tikranit are two small iron ore occurrences, about 4 km north of Fodikwan (Kabesh and others, 1958). Grab del Heit iron ore deposit was recently discovered (Anon, 1977). The ore is mainly made up of hematite and the reserves were estimated at some 30 million metric tons with some 35 to 40 % Fe content.

C - JEBEL BARBERI (14°41'30" N, 23°04'30" E)

The iron ore deposit of Jebel Barberi is situated in the northern Darfur Province, not far from the Sudan border with Chad. The ore deposit is mainly made up of specularite and massive hematite emplaced within the granitic gneisses of the Basement Complex (Andrew, 1952) and occupies the weakly foliated zones.

The reserves were not estimated but the analysed samples yielded 63 % Fe, 2 % SiO_2 with no phosphorus nor sulphur.

D - LATERITIC IRON DEPOSITS

Lateritic soil extensively overlies large portions of the Basement Complex of the southern Region, especially the Bahr el Ghazal and Equatoria Provinces (Andrew, 1948; Afia, Kabesh and Mansour, 1966). The iron content of the laterites is generally low, ranging from 15 to 40 % Fe. Nevertheless, they may contain considerable reserves.

E - OOLITIC IRON ORE OCCURRENCES

These occurrences are usually found in the form of thin bands within the most arenaceous Nubian Sandstone Formations. Two thin bands occur on both sides of the Nile near Wadi Halfa. Their Fe content ranges from 37 to 45 % (Kabesh, Afia and Mansour, 1966 ; Whiteman, 1971a).

Similar oolitic iron ore occurrences were found in the Kordofan Province (Kleinserge and Kreysing, 1960 ; Afia, Kabesh and Mansour, 1966). The largest occurrences are located to the southeast of Nahud, at Jebel Howag (12°30' N, 28°55' E). Other occurrences are known from the En Nahud Nubian Sandstone Formation outlier and from the outcrops in the eastern part of the Babanousa basin, near El Fula.

None of these occurrences is presently of economic value.

6 - MAGNESITE (Mg)

Magnesite is known in three localities, namely Ingessana Hills, Qala En Nahal and Haleib.

It usually occurs within serpentinised ultrabasic rocks and hence its geological environment is similar to that of chromite and asbestos.

In the Ingessana Hills, magnesite is found on the eastern margin of the basic intrusive rocks, in the Fadamyia village, and near the Soda village and Gam mine on the western margin. It occurs in the form of pockets, veins and along the shear and fracture zones. It is generally associated with the chromite.

In Qala En Nahal, the magnesite is associated with the serpentinites and talc carbonate schists (Wilcokson and Tyler, 1934). The first estimation of the reserves amounts to 20 million metric tons (Geological Survey of the Sudan, 1958).

The magnesite occurs in veins and lenses west of Halaib (Red Sea Hills) and as surface incrustations on the ultrabasic rocks of the Basement Complex at Sol Hamid. The reserves were estimated at some 450,000 metric tons with 37 % MgO content (Anon, 1972).

7 - MANGANESE (Mn)

Several manganese occurrences are known in the Sudan. Most of them occur in the Red Sea Hills, northern Province, and Upper Nile Province (Kabesh and Afia, 1961 ; Whiteman, 1971a and Geological and Mineral Resources Department reports and files).

None of these occurrences was properly evaluated or exploited, although a few tons were exported by local miners in the late 1950's.

There are two types of manganese occurrences :

i) epigenetic manganese occurrences in the Red Sea Hills. They take the form of vein and fissure fillings in the metamorphosed Basement rocks of the Nafirdeib Series or stockworks cementing the basal conglomerates in the coastal sediments ;

ii) syngenetic manganese occurrences of the Umm Ruwaba Series.

A - RED SEA HILLS

a) Haleib (22°14' N, 36°38' E)

Manganese occurs as small veins occupying faults and shear zones in the conglomerates and sandstone-limestone-evaporite succession. The veins strike E-W, N-S or NW with steep dip, and contain pyrolusite and/or manganite with some quartz, calcite and barite. The ore is of various grade and may reveal up to 50 % Mn.

b) Sinkat area (19°7'30" N, 36°17' E)

Manganese occurs as small psilomelane and pyrolusite veins within the Nafirdeib Series of the Basement Complex, some 65 km northwest of Sinkat. The largest veins are about 2 to 4 m across with Mn content ranging from 47 to 55 %.

c) Tehilla area (18°18' N, 36°30' E)

Manganese was produced in Abu Samar, Alikaleib, Tolik and Wurreiba, close to the Tehilla ring complex, east of the Kassala-Haya railway line.

The ore occurs as small veins within the Nafirdeib Series mainly consisting of metasedimentary and metavolcanic rocks. The ore minerals are chiefly psilomelane, manganite, pyrolusite and rhodochrosite. Galena was also noted in Alikaleib. The Mn content ranges from 7 to 52 % and from 4 to 45 % Fe.

Intensive exploration programmes were recently executed by the Geological and Mineral Resources Department in cooperation with the BRGM to evaluate these deposits.

B - BERBER AREA (18°10' N, 34°02' E)

Manganese ore occurs as small veins within the Basement Complex rocks which are mainly made up of gneisses and chlorite-sericite schists. The main ore minerals are psilomelane and pyrolusite. Some manganese ore was produced by local miners and partly exported. The Mn content of the occurrences ranges from 25 to 45 %.

C - UPPER NILE PROVINCE

Manganese was reported in Paloich (10°27' N, 32°22' E) and Wabnit (9°28' N, 32°00' E), in samples from drilled water boreholes, 50-150 m below the surface (G. Andrews). The ore occurs in thin bands within the unconsolidated sediments of the Umm Ruwaba Series. The Mn content ranges from 6 to 32 %. No further geological investigation was carried out. These occurrences, of sedimentary origin, may be extensive.

8 - MOLYBDENUM (Mo)

A molybdenum occurrence was reported in a locality some 25 km northeast of Haya junction, in the Red Sea Province. The ore is present in small veins and seems to be of low economic potential. Molybdenum was also noted in the Sabaloka area, north of Khartoum (Almond, 1967).

9 - LEAD-ZINC (Pb and Zn)

The Kutum lead-zinc deposit (14°14' N, 24°28' E) in the Darfur Province, and Tohamiyam (17°53' N, 36°17' E) in the Red Sea Province are the two main lead-zinc deposits known in the Sudan.

In the Kutum deposit, the ore occurs in small veins of about 40-50 cm wide and extends over several hundred metres within the gneisses and schists of the Basement Complex (Abdel Wahab and Afia, 1966 ; Abdel Wahab, 1968). The main ore minerals reported are galena, sphalerite and pyrite with minor arsenopyrite, marcasite and chalcopyrite. The shallow oxidation zone minerals observed are limonite, cerussite. Anglesite is also noted.

According to Afia and Abdel Wahab (1966), the origin of the mineralisation derives from hydrothermal solutions, possibly emanating from the nearby granites to the south and found their way along old shear zones and fractures.

In the Red Sea Hills, a Pb-Zn deposit was found in **Alikaleib,** east of the Tohamiyam railway station. The mineralisation occurs in small veins within the metasediments and metavolcanic rocks of the Basement Complex. Intensive exploration programmes are currently underway to assess these deposits.

10 - SULPHUR (S)

Sulphur is known in Jebel Marra in the northern Darfur Province, as thin incrustations overlying the Tertiary volcanics of Jebel Marra. Very little geological investigations have ever been carried out in that area. No information is available on the quantity of the reserves or quality of the occurrence.

11 - TIN (Sn) AND TUNGSTEN (wolframite, W)

Two types of tungsten occurrences were known in the Sudan.

In Gash Amir, Red Sea Hills, west of Halaib (22°14', 36°04' E), the ore occurs in quartz veins of hydrothermal origin filling fissures and containing cassiterite and rare wolframite (Said, 1962) with tourmaline, topaz and fluorite. The reserves are yet to be estimated, but exploration is underway in that area.

Wolframite is present in the Gash Amir area and scheelite west of Suakin (Mohamed, 1962).

Tungsten mineralisation was recently discovered **in Jebel Eyob** (southern Red Sea Hills), near the Tohamyian railway station. The reserves have yet to be calculated but serious exploration programmes are underway by the Geological and Mineral Resources Department and the BRGM.

In Sabaloka area, north of Khartoum, tin-tungsten mineralisation occurs west of the Abu Dom village, on the west bank of the Nile (16° 19' N, 32° 37' E).

The mineralisation takes the form of stockwork and greisen in microgranite and also as mineralised joints and fractures in the granitic gneisses of the Basement Complex. The ore minerals are mainly cassiterite and wolframite with minor amounts of scheelite, molybdenite, galena and calcite.

The type of tin-tungsten mineralisation in young granites is comparable to that of Jos Plateau in northern Nigeria.

It should be mentioned here that the mineralisation symbol is misplaced on the map as it occurs within the Basement Complex rocks and not the Nubian Sandstone formation.

More than 100 ring structures of young granites are found in the different parts of the Sudan. Consequently, the possibility of finding more such mineralisation occurrences of possible economic value is rather good.

12 - ASBESTOS (ami)

Asbestos occurrences were found in the metamorphosed ultrabasic masses of Ingessana, Qala En Nahal, and Sol Hamid in northern Red Sea Hills.

A - INGESSANA HILLS

Four main asbestos occurrences were investigated. They are all of the chrysotile-asbestos type within serpentinised rocks and occur in generally N.NE zones.

The studies and investigations carried out on these occurrences proved that they are sizeable enough to be considered as small deposits. The following table gives the total ore tonnage and the grade for each locality :

Name of locality	Type of asbestos	Tonnage	Fibre content (%)
Fadamiya (12°21' N, 34°10' E)			
Gasbel	chrysotile	2,650,000	2.02
Dufur	chrysotile	2,000,000	3.0
Byol	chrysotile	2,000,000	10.0
Kukur (11°24' N, 33°56' E)	chrysotile	4,000,000	1.94

B - QALA EN NAHAL

Chrysotile-asbestos occurs within serpentinite rocks in four localities of the Qala En Nahal Hills area : Fau Hill, En Nahal Hill, Utash Hill and Umm Sagata Hill. Fau, Umm Sagata and Utash Hills form the three largest occurrences. Utash and Umm Sagata received all attention and were approximately estimated as shown in the table below. However, further detailed studies are necessary for the re-assessment of the deposits.

Name of locality	Type of asbestos	Tonnage	Fibre content (%)
Utash	chrysotile	3,500,000	1.73
Umm Sagata	chrysotile	550,000	1.77

C - RED SEA HILLS

Very little is known about the asbestos occurrence of the Sol Hamid area. Small chrysotile veins were found within the serpentinite rocks of the Sol Hamid ultrabasic masses.

13 - BARITE (bar)

Barite was noted in more than seven localities, and most of these occurrences are situated in the Red Sea Hills. Only a few of these occurrences were geologically investigated. However, the Egyptian have been extracting the barite-manganese veins of Ankaldet on a very small scale, about 60 km north of Halaib for the last fifteen years. Barite occurs (21°55' N, 35°40' E) some 125 km west of the Halaib, as small veins within the Nafirdeib Series in the Abu Samar and Alikaleib areas. These occurrences are being investigated at the moment. Small barite lenses were reported in scattered localities within the Sofaya ring dyke complex, where the barite veins are confined to fracture zones. Barite was also seen west of the railway line, between the Derudeib and Tehilla railway stations.

14 - KYANITE (cya)

Jebel Gerain (17°53' N, 33°35' E), about 60 km northwest of Atbara, is a kyanite concentration within Basement Complex rocks which are made up of biotite gneiss, amphibolite-garnet-hornblende gneiss and muscovite gneiss. The reserves were estimated at some 275,000 metric tons of high grade ore.

It should be noted that the kyanite symbol is misplaced on the map. It is set in the Nubian Sandstone Formation and should have been set in the gneiss group of the Rahaba Series instead.

15 - FLUORITE (flu)

Fluorite mineralisation occurs at Jebel Semeih and Jebel Dambeir (12°44' N, 30°50' E) in the Kordofan Province, as small veins and fracture filling, etc., striking NE within the undifferentiated Basement Complex rocks. No detailed geological investigation was carried out on this mineralisation.

Another occurrence was reported northeast of Dilling (12°00' N, 30°00' E).

16 - GRAPHITE (gra)

Graphite was reported in several localities in the Sudan. Only few of them were generally examined and no reserve estimation was carried out.

Occurrences which are considered of some importance are as follows :

- 20 km west of Shereik, in the northern Region (18°15' N, 33°45' E) ;
- west of Jebel Marra, in Darfur Province (14°10' N, 28°00' E) ;
- around Wau town, in the southern Region (7°50' N, 28°00' E) ;
- south of Marridi, in the southern Region (5°00' N, 28°30' E) and south of Wau (5°00' N, 28°00' E) ;
- south of Torit (4°15' N, 32°40' E).

17 - GYPSUM (gyp)

The main gypsum deposits occur along the Red Sea coastal plain, north of Port Sudan. They are mainly associated with the Dungunab Formation of Miocene age.

Bir Eit gypsum deposit, which is the largest, is located (20°10' N, 37°10' E) 60 km north of Port Sudan. Its ore reserves were estimated at some 220 ± 30 million metric tons (category B) and 410 ± 30 million metric tons (category C) (Adly, 1979) with more than 95 % $CaSO_4H_2O$.

Other gypsum deposits occur between Bir Eit and Halaib area, including Jebel Tabanum, Saghum, Musa Shidab and Halaib.

Limited quantities of gypsum are locally produced for domestic use in cement and chalk industries.

18 - KAOLIN (kal)

Three kaolin occurrences were reported around Derudeib (17°15' N, 36°30' E). The kaolinisation is rather shallow and associated with the granite and acidic volcanics of the Nafirdeib Series.

The reserves at Shagoneen, the most important of the three occurrences, was estimated at some 36,000 metric tons of high grade ore.

19 - MARBLE (mab)

Marble belonging to the Basement Complex metasedimentary rocks is found in many different parts of Sudan. It is quarried for use in cement industry, as decoration slabs and building stone, and for production of burnt lime.

The basement marbles west of the Nile (17°45' N, 34°10' E) are quarried for the Atbara cement factory. They occur as bands within the calc-silicate metasedimentary rocks and gneisses. The bands extend along the strike for tens of kilometres and may reach up to 200 m across. Hence the reserves are enormous (Vail, 1971a).

The marble deposit of **Nyeifer Rugaig** (12°30' N, 33°30' E) is situated some 60 km south of Kosti. The deposit lies within the calc-silicate metasedimentary rocks and gneisses that were affected by folding and intruded by aplite and granite intrusions. It consists of calcitic and dolomitic marbles. Marble bands were also reported between Sennar and Kosti at Jebel Sagadi and Jebel Dud.

Marble for cement industry is found near **Kapoeta** (4°30' N, 33°45' E), within the gneiss group of the Basement Complex rocks. Considerable quantities of good quality marble were found there.

Some 20 km east of the **Derudeib** railway station (16°40' N, 36°40' E), a large marble deposit was investigated for suitability in cement industry. It occurs as part of the banded metasedimentary layers within the Nafirdeib Series (Adly, 1979).

Fairly sizeable deposits of decorative marble are located west of the **Summit** railway station (18°40' N, 36°55' E), within the Nafirdeib metasedimentary volcanic sequence (Adly, 1979). Several marble occurrences were found in the Red Sea Hills region, e.g., Maman and Gadami.

Marble is currently quarried in the **Butana** area, northeast of Gadarif town and used for ornamental purposes. It is cut and polished by a private company in Omdurman. Marble occurrences were also noted near Shereik (northern Province), Nuba Mountains (Vail, 1973a), Ingessana Hills and Butana (Delany, 1952a), Red Sea Hills (Gass, 1955) and in the Darfur Province.

Huge marble reserves are expected to be found in the Sudan but, unfortunately, they have not been extensively investigated. These marble deposits represent enormous potential sources of raw material for cement industry, burnt lime industry, ornamental and building stones.

20 - MICA (mic)

Muscovite mica occurs west of the Nile near Shereik in the northern Province. It lies within the Rahaba Series of the Basement Complex (granitic gneisses, hornblende and amphibolite gneisses). The deposit was investigated by Kabesh (1959, 1960, 1962b, 1962d), Geological and Mineral Resources Department, U.N.D.P. and Vail (1971a).

Mica is found as books up to 1/2 m in diameter and associated with quartz, feldspar, tourmaline, aplite and beryl.

The mica is extracted for export by the Sudanese Mining Corporation but complementary detailed study of the geological controls of the mineralisation will enhance successful exploitation of the deposit. Also mica occurrences were reported southeast of Demazin (11°10' N, 34°25' E) and in the southern Region (4°25' N, 31°15' E).

It should be noted that some of the mica symbols on the map are misplaced in the Nubian Sandstone Formation.

21-TALC (tal)

Talc was reported in the Ingessana Hills, Qala En Nahal and Sol Hamid in the Red Sea Hills, plus smaller other occurrences in different parts of the Sudan, mostly associated with metamorphosed ultrabasic intrusive rocks. No geological investigations were ever carried out in these occurrences.

Talc also occurs in the southern Region (4°00' N, 32°00' E).

22 - WOLLASTONITE (wol)

Wollastonite was recorded as the major skarn mineralisation within calc-silicate rocks of the Kashebib Series which are intruded by granitic and granodioritic rocks at the Dirbat well, central Red Sea Hills (19°53' N, 36°31' E) (Kabesh and Afia, 1959 ; Lotfi, 1963a).

More than seventy small lens-shaped bodies were reported in the Dirbat well occurrences. The reserves were estimated at some 360,000 metric tons with 70 % wollastonite.

Wollastonite was also noted southwest of Shereik in the northern Province.

23 - OTHER MINERAL OCCURRENCES

Common salts, vermiculite, natron, radioactive minerals (uranium), crushed stones from granites, basalts, syenites, etc. were reported in different parts of the Sudan.

Although several investigations were carried on some these minerals, the available information does not give a detailed idea about their quantity, quality or economic potential.

24 - RED SEA HOT BRINES

Sulphide minerals and precious metal concentrations were recently discovered in the Red Sea deep, at depths of over 2,000 to 3,000 m, almost halfway between the Sudanese and Saudi international water. The Saudi-Sudanese Red Sea Joint Commission, in cooperation with the BRGM, carried out intensive exploration programmes in the Atlantis II deep area and the element reserves of the brine were estimated at some 2,000,000 metric tons of zinc, 500,000 metric tons of copper, 4,000 metric tons of silver and 80 metric tons of gold, with traces of cobalt, nickel, tin and arsenic.

Other hot brine deeps such as Chain were discovered and others were examined, but the detailed studies were confined to Atlantis II area.

25 - UNDERGROUND WATER

The Nubian Sandstone Formation, Umm Ruwaba Formation, Gezira Formation and alluvial detrital deposits, khor or wadi fill deposits and the wind blown sands make up the main aquifers in the Sudan.

The arenaceous bands of the Nubian Sandstone Formation constitute the best aquifers. The saturated zones vary in depth between 10 m near the Nile to 170 m in the Kordofan region (Rodis and Iskander, 1963 ; Rodis, Hassan and Wahdan, 1964 ; Kheiralla, 1967). The recharge comes from the Nile and its tributaries as well as the seasonal streams that flow across the Nubian Sandstone Formation and the rainfall, especially in the southern parts where the precipitations are the heaviest.

The Umm Ruwaba Formation is mainly made up of poorly sorted and unconsolidated clays, silts, sands and gravels. It covers much of the central parts of the Sudan and the White Nile basin. Its thickness ranges from a few metres to 500 m. The underground flow is possibly restricted by the lithology variation and therefore the water is saline in places and generally not as good as that of the Nubian Sandstone Formation.

The recharge of the Quaternary aquifers is mainly from rainfall. In places, near the Nile and its tributaries, the recharge is by seepage from the river. This is quite obvious in the Gezira Formation where the aquifer depth falls sharply when moving away from the Nile (Abdel Salam, 1966 ; El Boushi, 1972).

Wadi fills, delta alluvia and eolian sands form an important groundwater source in many parts of the Sudan. The heterogeneous nature and variable thicknesses of these deposits affect the capacity and quality of the aquifers.

Khor Arbaat, north of Port Sudan is the main fresh water supplier for the Port Sudan town. Its recharge is provided only by rainfall. Khor Hadikwan, Bir Eit and Salalat (60 km north of Port Sudan) also form important sources of fresh water in this part of the country.

El Gash river with some 75 m thickness of gravel and sands provides considerable amounts of fresh water for most of the Kassala Province. Its only recharge is from rainfall from the highlands of Ethiopia and Asmara (Saad, 1969, 1972).

In the Darfur region, Wadi Azom near Zalingei, Wadi El Ku near El Fashir, Wadi Bulbul and Wadi Nyala are the main groundwater resources during the dry season. The fresh water is supplied from shallow hand dug wells that may be only a few metres in depth in these wadis.

Other wadis such as Khor Abu Habil in the Kordofan Province, Wadi Mugadam in northern Kordofan and northern Province and Wadi Hawar form the main groundwater resources during the dry season in these parts of the country.

26 - PETROLEUM PROSPECTS IN THE SUDAN

The first licences for oil and gas exploration in the Sudan were granted in 1959 in the Red Sea coastal area, and in 1974 in central and southern Sudan. Several other companies have applied for licences and some are now negotiating for new concessions while others are interested in exploring new areas.

Several wells have been drilled along the Red Sea coastal plain and offshore as well as in central and southern Sudan. Many prospects are clearly promising and the results are encouraging.

Licences and proposed areas for oil exploration cover more than 50 % of the sedimentary area surface of the Sudan. Many areas are potentially oil and/or gas field areas.

Deep buried sedimentary basins which may contain oil were revealed beneath the Quaternary cover, in the rift valley sedimentary fill, in southern and central Sudan. These formations are thick. Therefore the prospects for oil in commercial quantities are high.

Surface geological work, seismic, gravimetric and magnetometric surveys are being carried out in central and northern Sudan.

However, the greater parts of the Sudan sedimentary areas are occupied by formations that are usually considered to be suitable petroleum source rocks.

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