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UNITED NATIONS
DEVELOPMENT PROGRAMME

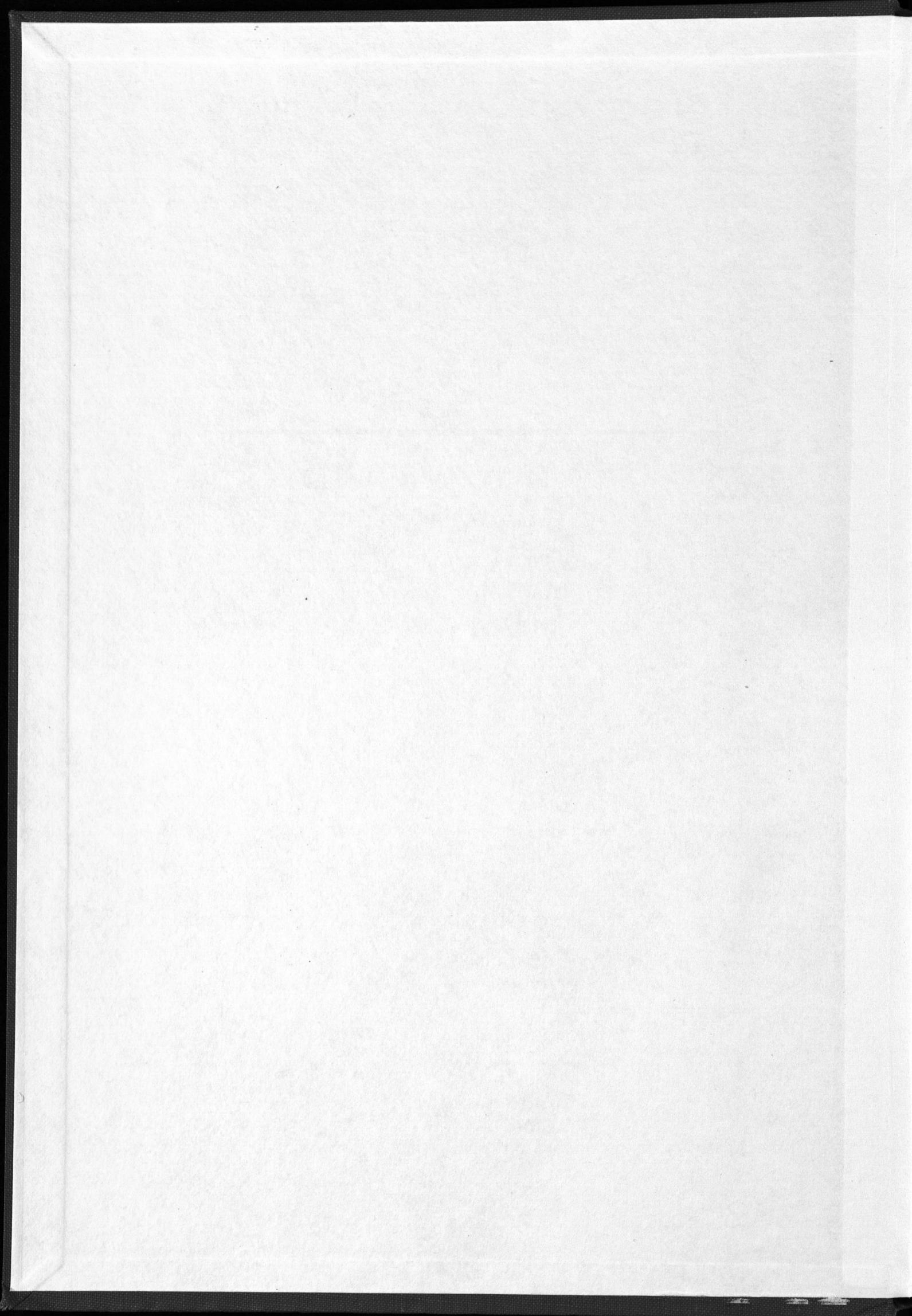
REPUBLIC OF THE SUDAN

MINERAL SURVEY IN THREE SELECTED AREAS
IN
REPUBLIC OF THE SUDAN

PHOTOGEOLOGICAL SURVEY
OF THE WESTERN AREA

HUNTING GEOLOGY AND GEOPHYSICS LTD.

1969



DEPARTMENT OF THE INTERIOR

MINERAL INVESTIGATION SERVICE

PHOTOGEOLOGICAL SURVEY
WESTERN AREA

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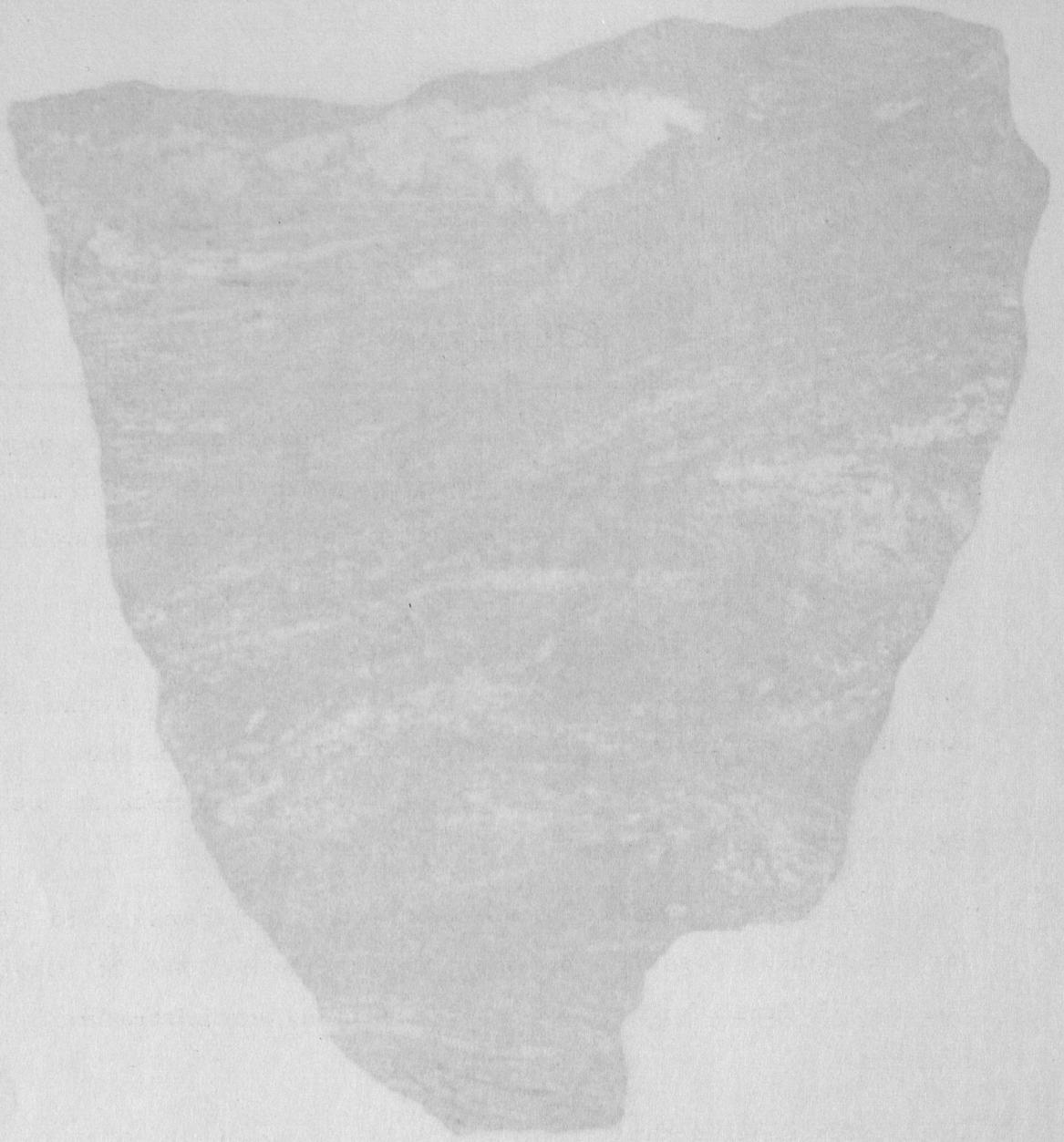
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1:100,000
1:100,000
1:100,000



MIGMATITIC GNEISS - JEBEL MIRI X 2/3

Strongly developed shear surfaces cross specimen horizontally. These cut folded older surfaces of several generations. Segregation into finer mafic and coarser bands of mixed composition is associated with the older surfaces. Coarse lenses of unfoliated quartzo-feldspathic material are enclosed by the foliation.



MIGMATITIC GNEISS - JEBEL MIRI X 23

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Strongly developed shear surfaces cross specimen horizontally.

ACKNOWLEDGEMENTS

We wish to express our thanks and appreciation of the help received from the Geological Survey Department of the Sudan and the United Nations Development Programme during the course of this photogeological survey.

In the Geological Survey our thanks go to the Director, Mr. Abdul Latif Widatalla and the former Director, Mr. Mahmoud Ahmed Abdullah and to the Project Co-Manager, Mr. Ibrahim Mudawi Babiker. To Mohamed Ali Abdel Rahim, geochemist, we express gratitude for hospitality in the field.

Amongst the staff of the United Nations our thanks go to Mr. D. Manson, Assistant Resident Representative, Mr. M. Davies and Mr. G. Small for their assistance on many administrative matters.

Our special thanks go to Mr. A.M. Quennell, the U.N. Project Manager, for helpful discussions and suggestions as the work proceeded.

- 1 -

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ABSTRACT

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The area consists of a Precambrian and Palaeozoic complex with extensive cover of superficial deposits. The nature of these rocks, the evolution of structures and the distribution and control of mineralization are discussed. A suggested outline of the geological history is presented.

Recommendations are made for further investigation in areas considered most favourable for the location of economic mineralization.

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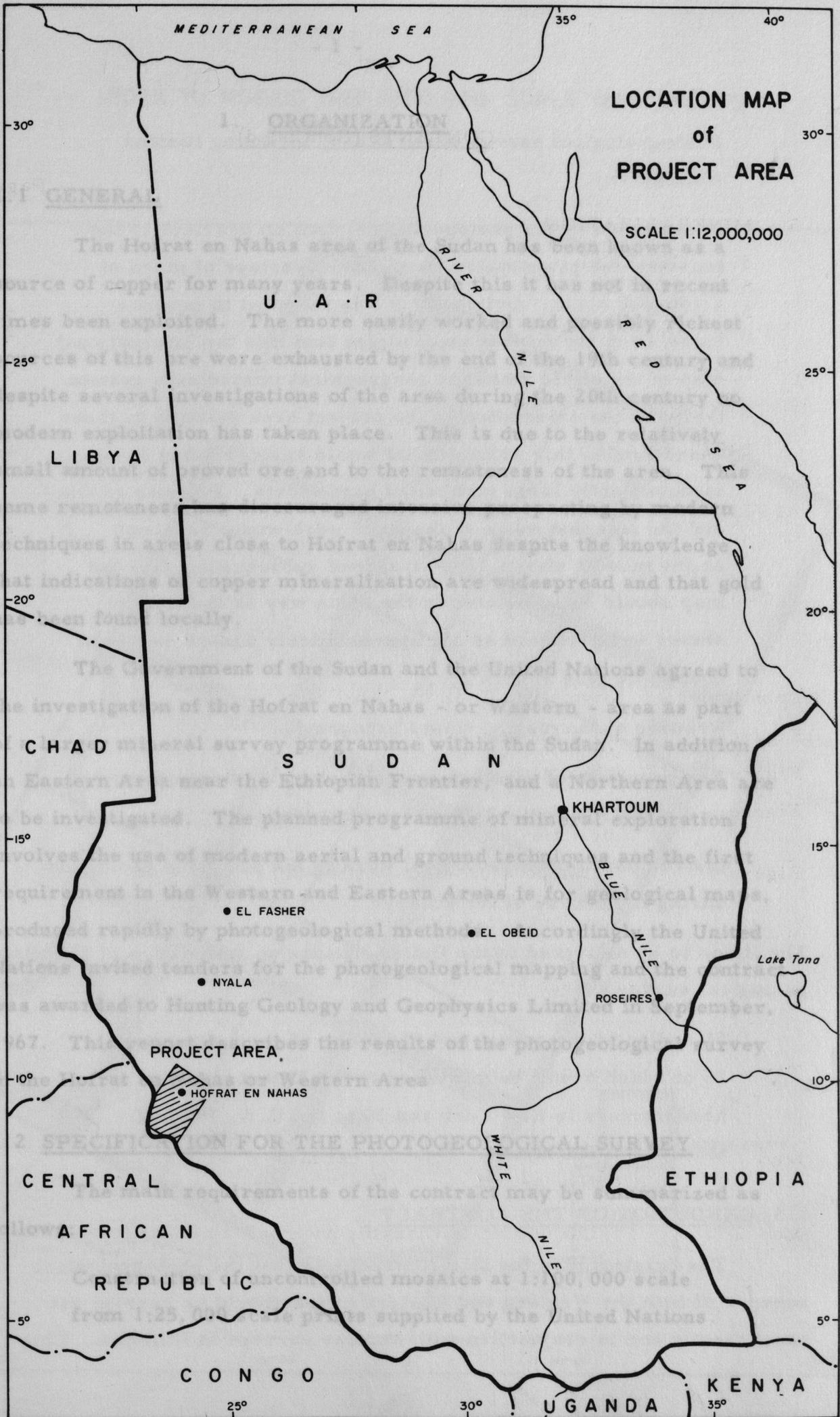
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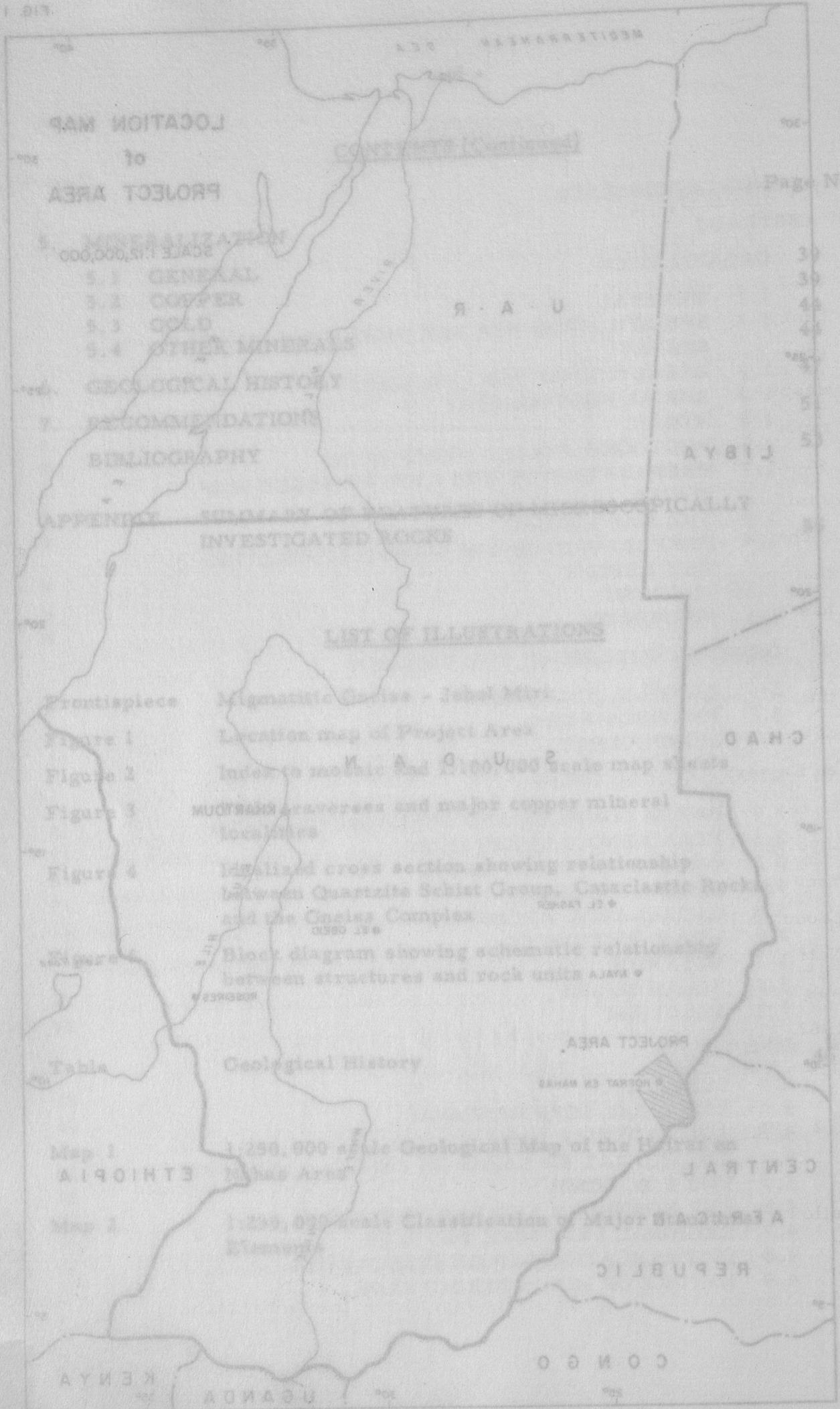
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of
PROJECT AREA

GENERALIZATION
SCALE 1:12,000,000

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ETHIOPIA

PROJECT AREA
HONKAT EN MAREB

CENTRAL
AFRICAN
REPUBLIC

KENYA

UGANDA

CONGO

1. ORGANIZATION

1.1 GENERAL

The Hofrat en Nahas area of the Sudan has been known as a source of copper for many years. Despite this it has not in recent times been exploited. The more easily worked and possibly richest sources of this ore were exhausted by the end of the 19th century and despite several investigations of the area during the 20th century no modern exploitation has taken place. This is due to the relatively small amount of proved ore and to the remoteness of the area. This same remoteness has discouraged intensive prospecting by modern techniques in areas close to Hofrat en Nahas despite the knowledge that indications of copper mineralization are widespread and that gold has been found locally.

The Government of the Sudan and the United Nations agreed to the investigation of the Hofrat en Nahas - or Western - area as part of a larger mineral survey programme within the Sudan. In addition an Eastern Area near the Ethiopian Frontier, and a Northern Area are to be investigated. The planned programme of mineral exploration involves the use of modern aerial and ground techniques and the first requirement in the Western and Eastern Areas is for geological maps, produced rapidly by photogeological methods. Accordingly the United Nations invited tenders for the photogeological mapping and the contract was awarded to Hunting Geology and Geophysics Limited in September, 1967. This report describes the results of the photogeological survey in the Hofrat en Nahas or Western Area

1.2 SPECIFICATION FOR THE PHOTOGEOLOGICAL SURVEY

The main requirements of the contract may be summarized as follows:-

Construction of uncontrolled mosaics at 1:100,000 scale
from 1:25,000 scale prints supplied by the United Nations.

Photogeological survey of the areas, including limited field survey.

Compilation of the photogeological data on overlays to the mosaics and preparation from these overlays of maps at 1:100,000 scale. Originally it was intended to produce these as thirty minute quadrangles tied into the International Map of the world standard geographical co-ordinate system. Owing to the orientation of the project area relative to these quadrangles this arrangement would have resulted in an inconveniently large number of part sheets. Because of this and the fact that much of the later work would be based on the mosaic sheets, it was agreed subsequently that the map should be orientated in the same way as the mosaic sheets and produced as six approximately square sheets of equal size (see Figure 2).

Printing of the map by offset lithography.

The provision of a report on the geology of the project area, to include recommendations for further work.

Instruction in photogeological work to six Sudanese geologists during the course of the survey.

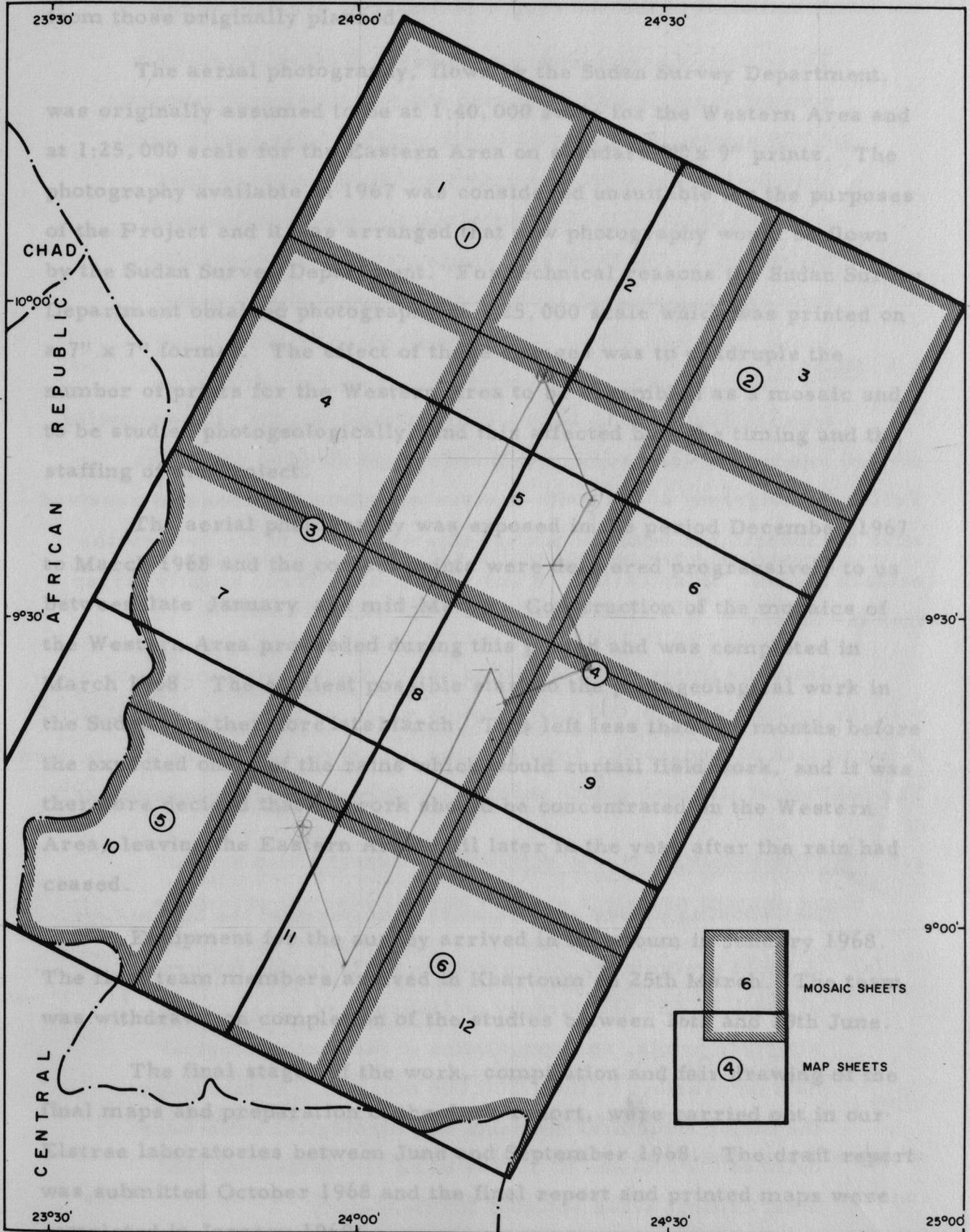
The items to be delivered to the United Nations on completion of the photogeological survey are:-

55 copies of the report and 55 copies of each map sheet, 25 of which are to be delivered to the United Nations headquarters in New York and 30 to the U.N. Project Manager in Khartoum.

1.3 EXECUTION OF THE CONTRACT

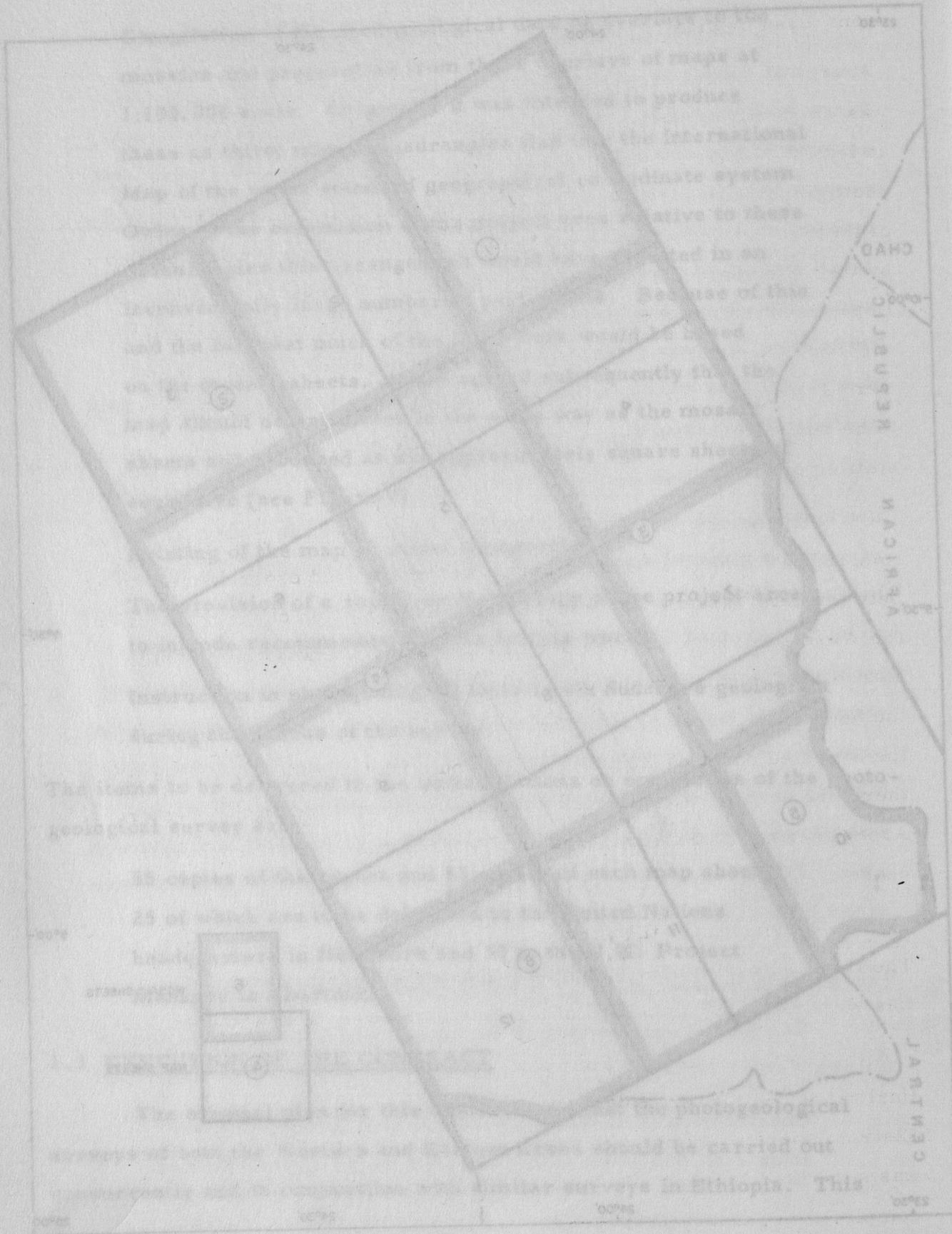
The original plan for this contract was that the photogeological surveys of both the Western and Eastern Areas should be carried out concurrently and in conjunction with similar surveys in Ethiopia. This

INDEX TO MOSAIC AND 1:100,000 SCALE MAP SHEETS



INDEX TO MOSAIC AND 1:100,000 SCALE MAP SHEETS

Geological Survey of Ethiopia, Addis Ababa, 1968



plan had to be changed, first because the aerial photography for the Sudan areas was not available when the survey began in Ethiopia, and second because the scale and format of the aerial photography differed from those originally planned.

The aerial photography, flown by the Sudan Survey Department, was originally assumed to be at 1:40,000 scale for the Western Area and at 1:25,000 scale for the Eastern Area on standard 9" x 9" prints. The photography available in 1967 was considered unsuitable for the purposes of the Project and it was arranged that new photography would be flown by the Sudan Survey Department. For technical reasons the Sudan Survey Department obtained photography at 1:25,000 scale which was printed on a 7" x 7" format. The effect of these changes was to quadruple the number of prints for the Western Area to be assembled as a mosaic and to be studied photogeologically, and this affected both the timing and the staffing of the Project.

The aerial photography was exposed in the period December 1967 to March 1968 and the contact prints were delivered progressively to us between late January and mid-March. Construction of the mosaics of the Western Area proceeded during this period and was completed in March 1968. The earliest possible start to the photogeological work in the Sudan was therefore late March. This left less than two months before the expected onset of the rains which would curtail field work, and it was therefore decided that all work should be concentrated on the Western Area, leaving the Eastern Area until later in the year after the rain had ceased.

Equipment for the survey arrived in Khartoum in January 1968. The first team members arrived in Khartoum on 25th March. The team was withdrawn on completion of the studies between 16th and 19th June.

The final stages of the work, compilation and fair drawing of the final maps and preparation of the draft report, were carried out in our Elstree laboratories between June and September 1968. The draft report was submitted October 1968 and the final report and printed maps were completed in January 1969.

1.4 AERIAL PHOTOGRAPHY

The following materials were supplied by the United Nations at the commencement of this survey:-

Three sets of aerial photographs of the Western Area, at a nominal scale of 1:25,000, each set containing approximately 4,400 prints. Two sets of double weight glossy prints were used for the photo-interpretation and field work and were returned to the U.N. Project Manager at the conclusion of the survey. The third set, single weight - predominantly semi-matt - was used in the construction of the mosaics.

1.5 MOSAIC

An uncontrolled mosaic was constructed from the prints supplied, divided into twelve sheets (Figure 2) and copied at 1:100,000 scale. Further photography of the south-eastern margin of the area was received after the mosaic had been divided and this was added to the four south-eastern sheets. Mosaics 3, 6, 9 and 12 are, therefore, slightly larger than the others.

Graticule points were identified on the mosaic by comparison with the published 1:250,000 map. Points which could not be identified, owing to lack of topographic details on the published map, were interpolated. The position of all these points should be regarded as very approximate.

1.6 PHOTOGEOLOGICAL PROCEDURES

The following phases of work were undertaken in the Sudan:-

- (a) A rapid preliminary interpretation of the major features of the 1:25,000 photography on transparent overlays to alternate prints, and compilation of the photogeological data on overlays to the 1:100,000 mosaics. At this stage the major structural elements and lithological units were outlined. Problems of access were recognized and the most critical areas selected for field study.

(b) Field checking of interpretation by traverses over motorable country. The field work occupied about 20 per cent of the team's time in the Sudan. Traverses undertaken are indicated in Figure 3.

It was essential that field work commence as soon as possible after the team's arrival in Khartoum. This was because the seasonal rains - usually commencing in the Western Area around mid-May - rapidly restrict movement and can completely cut off the area for considerable periods. The Land Rovers with all necessary equipment left Khartoum on 4th April with the Supervising Geologist. The first field party flew to Nyala on 8th April and joined up with the vehicles there before proceeding to Hofrat en Nahas. The second field party flew to Nyala and relieved the first on the 22nd April. They returned to Khartoum by road on the 7th May.

The only motorable tracks within the project area are:-

- (i) Radom - Songo, which originates in Nyala.
- (ii) Radom - Kafia Kingi.
- (iii) Songo - Kafia Kingi.
- (iv) Songo - Bir Ileba and northwards.
- (v) Songo - Hofrat en Nahas - J. Wangara, a track cut especially for this project.

Various cattle tracks are more or less motorable, but elsewhere the vehicles had to force their way through scrub land. The southern part of the area is inaccessible by vehicle owing to the increase in size of gullies which are completely unnegotiable.

In the field the preliminary interpretation of the photography was checked. The attitude of structural features was measured and the lithology of the major rock units examined.

In addition the nature of the mineralization was investigated.

- (c) Detailed re-interpretation of geology in the light of field evidence followed by completion of the 1:100,000 overlays, insertion of symbols and labels. Finally adjacent sheets were edge matched.

1.7 PREPARATION OF THE 1:100,000 SCALE MAP SERIES

The overlays to the 1:100,000 scale mosaics were carefully edge matched and then joined to form a continuous overlay for the whole area. Points of latitude and longitude had already been identified on the mosaics by reference to the published maps and these points were transferred to the overlays. The project boundaries were plotted by reference to these points and similarly transferred. Because the photography extends beyond the defined limits of the project area the north-eastern boundary has been drawn slightly outside the line specified in the contract in order to square off the north-eastern sheets and to include as much photogeological information as possible. The overlay was then divided into six equal sheets (Figure 2).

The final map sheets are, therefore, directly related to the mosaics. This should make them of more value for field work than if they were corrected to fit the cartographic grid.

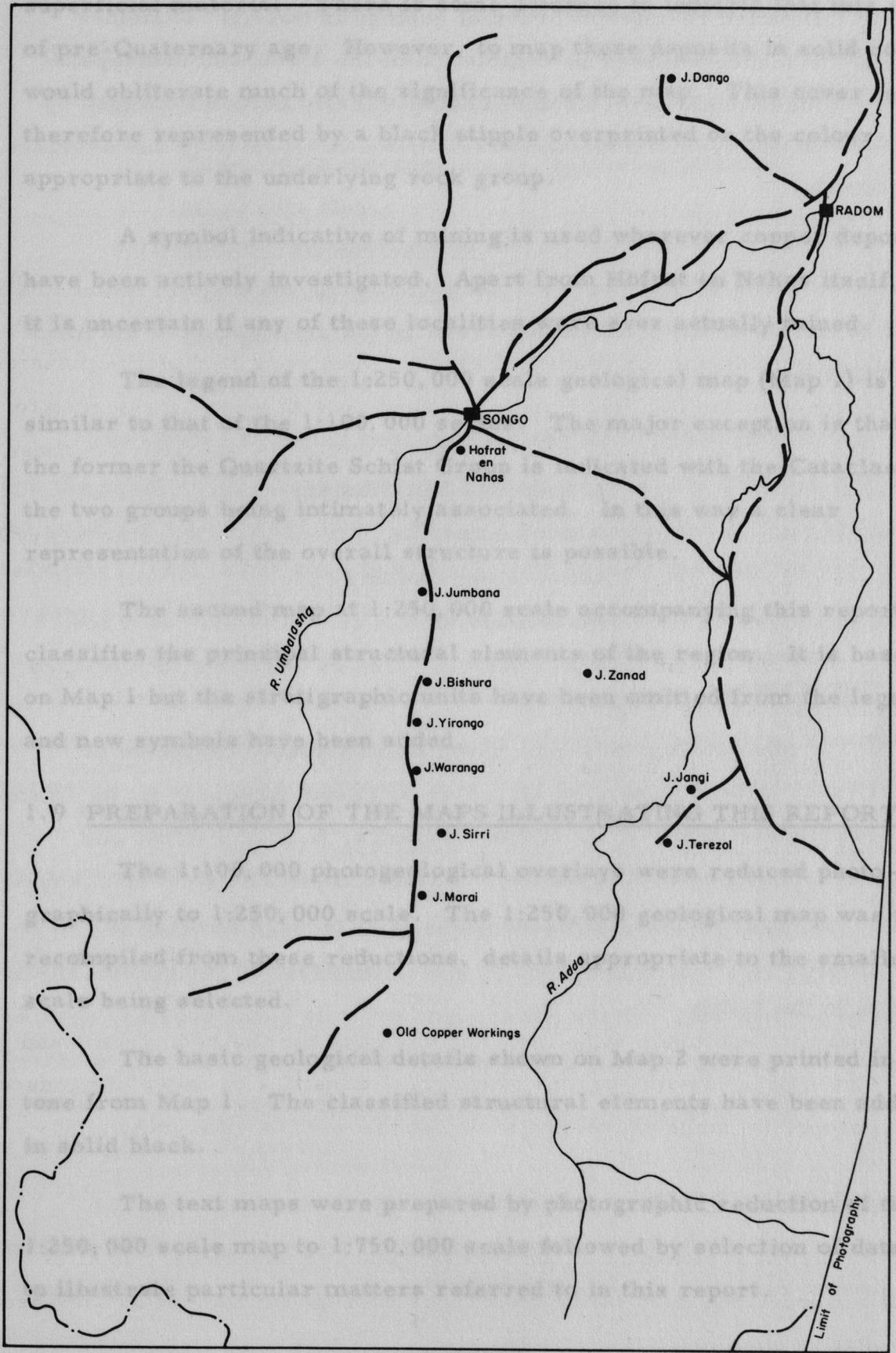
The map sheets were fair drawn and separate plates prepared for each stage in the colour printing. Each sheet required four Astrafoil colour separations: one for the black plate with all line work, lettering, marginal data and black stippling; and one each for the red, yellow and blue plates printed with screens of different densities in order to produce the appropriate range of colours to depict the various rock units.

1.8 THE MAP LEGEND

The main elements of the stratigraphy are now clear. Earlier work had indicated most of the rock types present but had not established the relative ages.

FIELD TRAVERSES AND MAJOR COPPER MINERAL LOCALITIES

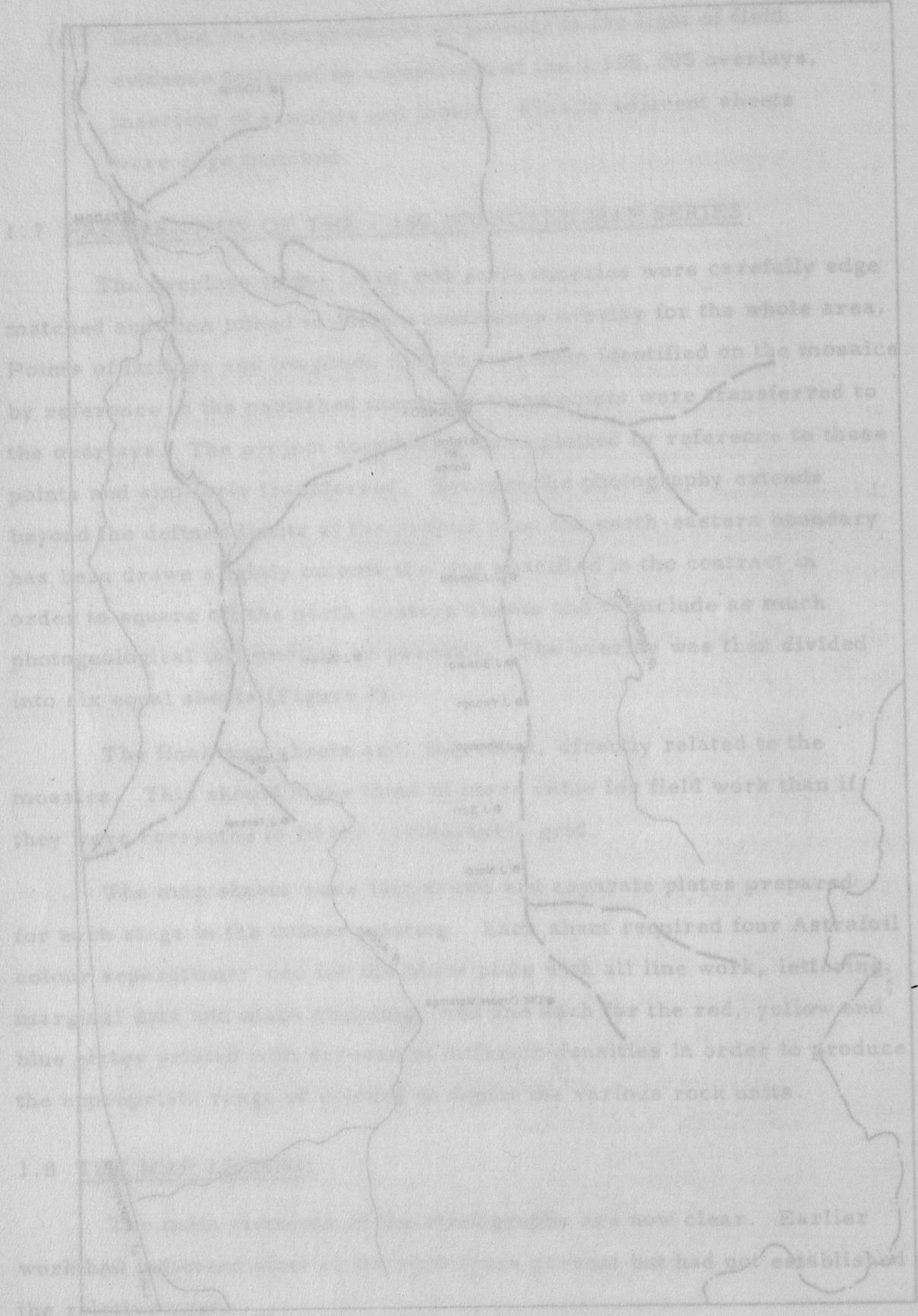
SCALE 1:750,000



TRVERSE -----
INTERNATIONAL BOUNDARY - . - . - .
COPPER MINERAL LOCALITY .

FIELD TRAVERSES AND MAJOR COPPER MINERAL LOCALITIES

Geological Survey of Canada, Ottawa, Ontario, Canada



----- TRAVERSE
 - - - - - INTERNATIONAL BOUNDARY
 ■ COPPER MINERAL LOCALITY

Large areas are covered by laterite, hard pan and other superficial material. There is some evidence to indicate that this is of pre-Quaternary age. However, to map these deposits in solid colour would obliterate much of the significance of the map. This cover is therefore represented by a black stipple overprinted on the colour appropriate to the underlying rock group.

A symbol indicative of mining is used wherever copper deposits have been actively investigated. Apart from Hofrat en Nahas itself, it is uncertain if any of these localities were ever actually mined.

The legend of the 1:250,000 scale geological map (Map 1) is similar to that of the 1:100,000 series. The major exception is that in the former the Quartzite Schist Group is indicated with the Cataclasites, the two groups being intimately associated. In this way a clear representation of the overall structure is possible.

The second map at 1:250,000 scale accompanying this report classifies the principal structural elements of the region. It is based on Map 1 but the stratigraphic units have been omitted from the legend and new symbols have been added.

1.9 PREPARATION OF THE MAPS ILLUSTRATING THIS REPORT

The 1:100,000 photogeological overlays were reduced photographically to 1:250,000 scale. The 1:250,000 geological map was then recompiled from these reductions, details appropriate to the smaller scale being selected.

The basic geological details shown on Map 2 were printed in half-tone from Map 1. The classified structural elements have been added in solid black.

The text maps were prepared by photographic reduction of the 1:250,000 scale map to 1:750,000 scale followed by selection of data to illustrate particular matters referred to in this report.

1.10 TRAINING

The contract required training in photogeological techniques to be given to six Sudanese geologists. This was done by working side by side with the trainees. They examined interpretations produced by the Hunting team and then produced their own interpretation and overlays to mosaics.

The trainees also accompanied the Huntings' field parties. Subsequently two of their number, Mahadi Ahmed and Abdulla Abdel Hadi came to Boreham Wood to see and assist in the preparation of the maps and reports.

The other trainees were:-

Mohammed Said Ahmed

Ahmed Awedalla

Gibril Abdel Halim

Musa Zubeir.

1.11 PERSONNEL

The photogeological team, based on Khartoum, consisted of J.P. Crook, B.Sc., A.M.I.M.M., F.G.S. (Team Leader), H. de Boorder, Doctorat (Amsterdam), A.H. Lloyd-Lawrence, B.Sc., F.G.S. and L.J. Lucarelli, Doctorat (Firenze). These completed a total of 325 man days of operations in the Sudan, of which 71 days were spent in the field. W.A. Willox, B.Sc., M.I.M.M., F.G.S., Supervising Geologist, spent 33 days in the Sudan.

2. GENERAL OUTLINE OF THE GEOLOGY

2.1 GENERAL STATEMENT

The rocks of the Hofrat en Nahas area can be grouped broadly as:

Tertiary/Quaternary cover, including laterites

Migmatite Group

Quartzite Schist Group

Ferruginous Quartzite

Gneissose Granite

Gneiss Complex.

The Gneiss Complex represents a series of much greater age than the other rocks, having passed through at least one tectonic cycle and reaching a gneissose condition before the deposition of the Ferruginous Quartzite. This latter rock in turn appears to bear the imprint of orogeny prior to the deposition of the Quartzite Schist Group. Following the sedimentation of the latter rocks, a period of major orogeny followed during which the Migmatite Group was generated. This orogeny was followed by a long period of erosion. Rocks of the Nubian Sandstone Formation occur to the north and it is possible that thin residuals occur within the area but have not been recognized because of the widespread terraced effect produced by the eroded lateritic cover.

The laterite appears to have developed generally, with the possible exception of areas underlain by the quartzites. Subsequently the area has been tilted at a low angle to the north. This has led to the elevation, dissection and erosion of the laterite to the south and its burial in the north below Quaternary deposits. The age of the laterites is believed to be Oligocene.

Recent volcanic activity is known to the north at Jebel Marra and several hot springs are known in adjacent areas in the Central African Republic. To date no such activity has been recorded in the project area.

The complex of basement rocks has been previously referred to as Precambrian but no radiometric dating has been carried out. There is some evidence (see concluding section) to suggest correlation of the Gneiss Complex with the Dahomeyan of West Africa and of the Quartzite Schist Group with the Togo/Atacorien of that region. The Dahomeyan is recognized as a group of Precambrian gneisses and granites (possibly sediments largely of Birrimian age (c. 2,500 m.y.) with post-Birrimian intrusives) more or less reconstituted during the Cambro-Ordovician by orogeny.

All bearings given in this report are magnetic.

2.2 PREVIOUS WORK

The occurrence of copper in the Hofrat en Nahas area has been known for many years. It is certain that copper was won at least as early as the beginning of the 19th century. Reports indicate that mining was abandoned in 1897 during disturbances prior to the Khalifa's defeat; but it is uncertain whether political or economic reasons were dominant in this abandonment.

Russeger's work (1841-49) in the 1830's indicated that the product of the mine was pure granular copper. Others report the marketing of large rings and cakes of copper, each weighing about twelve pounds. Russeger was unable to obtain samples of the ore but was assured that the native metal was mined. By the turn of the century, the Handbook of the Sudan stated that the ore mined was the carbonate and came from a vein rising two feet above ground level. A similar statement about the vein was made in 1918 by Mr. Burgess-Watson.

One Colonel Sparkes visited the area in 1903. He reported the mine totally abandoned, the population having moved to Kafia Kingi. Samples of ore collected by him showed 14 per cent copper content.

There appears to be inconsistency in the reports to this date. Reports of great quantities of copper mined and of considerable native copper deposits do not rest easily alongside the statement of veins of

carbonate ore rising above ground level. The absence of any significant amount of slag does not support statements of large tonnages of extracted metal. It is also reported that mining was by intensive pitting to depths of 30 to 40 feet - the pits being sunk to intercept the occurrences thus often occurring outside of surface indications of ore. This is a more acceptable report and would presumably indicate that the ore did not contain much native copper. It would also account for the lack of extensive spoilheaps if holes were refilled as further excavations were made.

In 1920 the first systematic investigation was begun by the Nile-Congo Divide Syndicate - a subsidiary of Tanganyika Concessions Ltd. Prospecting for both copper and gold was carried out, the work continuing until the end of 1925. This provided the basis for most of the future work and, in fact, little has been added to it, except for detailed investigation of the Hofrat en Nahas deposits, to the present date. They estimated that about 50,000 tons of lode had been extracted by earlier mining operations.

In 1948 T.D. Guernsey and P.E. Fairbairn spent six weeks in the area and added data from the hills south-west of Hofrat en Nahas. Others visited the area briefly until, in 1957, the Sudanese Geological Survey carried out an extensive investigation of the Hofrat en Nahas mine over three field seasons. They also paid short visits to the area south-west of the mine (Afia and Widatalla, 1961).

In November 1964, the Nippon Mining Co. Ltd., began a survey of the Hofrat en Nahas deposits which lasted until May 1965. Again brief visits were made to the localities to the south-west.

The reports by commercial concerns came to similar conclusions, the Japanese report being most detailed in reaching budget figures indicative of a mine of short life being worked at considerable loss.

2.3 MORPHOLOGY

The area is in the heart of Africa at the watershed between the

Nile (Mediterranean), Congo (Atlantic) and Tchad (internal) drainage systems. Most of the area is within the Nile basin but the north-western portion drains into the Tchad system and parts of the southern margin are drained into the Congo system.

Most of the area is an undulating plain with a general elevation between 600 and 800m with occasional steep sided quartzite ridges rising above 1,000m. The plain is most uniform in the north-west where it is underlain by Quaternary sediments. There is little well formed drainage pattern in this area which is apparently inundated seasonally. Elsewhere the plain is underlain by gneiss with a well developed drainage pattern.

The general elevation tends to rise to the south-west and quartzites, which form isolated ridges generally trending between N-S and NNE-SSW in the north, develop into more continuous features with increase in their maximum height. In the west a large number of sub-parallel quartzite ridges form an area of hill and valley country along the frontier with the Central African Republic.

Two areas of migmatite in the south and south-east form hill complexes of more rounded relief than those produced by the quartzites. Their tops are of fairly uniform height and a slight plateau feature develops in the south-west which is almost entirely covered by laterite.

The lower ground between the hills is also largely covered by laterite. In the south the laterite has been deeply gullied and a terraced topography is common in the valleys. This terracing fades northwards as the elevation decreases.

Drainage within the area is largely controlled by structure. Inspection of the maps clearly indicates the linear pattern of the drainage. Even where streams meander the meander belts show a strong linear pattern over considerable distances. Streams within the major alluvial belts also show a strong rectilinear pattern.

The gradients of the streams are low away from the ridges. In

the north they are very low and wide areas are subjected to seasonal flooding. Some of the smaller streams are characterized by ill defined courses which tend to disappear in local swampy depressions.

This group occupies the bulk of the project area and is almost synonymous with the term "Older Plaines Group" of previous workers. No distinct units can be separated within the complex. The rocks are of varying mineralogy and texture but tend to be unified by their complex tectonic history. The widespread superficial cover, the weathered nature of much of the outcrop in the plains and the general lack of distinctive expression of any one rock type on the photographs, makes it impossible to state with certainty the order of importance of each rock type and its distribution.

The most widespread rock type encountered is quartzo-feldspathic gneiss. There is a considerable range of mica content. Some varieties are mica poor, others are rich in biotite or muscovite - sometimes both micas are present. The rock is usually well foliated and may also show banding on varying scales. Alternate bands may vary both in composition and in texture. Generally mica shows the widest variation in both types of banding.

These gneisses grade locally into more variably foliated types which, in hand specimens, may be called biotite or biotite-muscovite granite. This tendency reaches its fullest expression in the Jebel Simso and Kafia Kingi areas where very thick bands of foliated grey biotitic granite are interbanded with mica poor rocks.

These gneissose granites are medium to coarse grained. They contain megacrysts of potassic feldspar commonly up to three centimetres across. These are commonly concentrated in swarms which are associated with pegmatitic areas. Here the pegmatite usually consists of potassic feldspar, colourless mica books, tourmaline and quartz. As noted below, tourmaline is widespread throughout the project area.

The groundmass of the gneissose granites is distinctly foliated

the north side of the river, which is subject to seasonal flooding. Some of the smaller streams are characterized by the presence of rapids which tend to deposit local swamps. The general appearance of the landscape is

characterized by a general leveling of the land with a few scattered ridges. The terrain is mostly flat, with a few small hills rising in the north. There is little or no forest cover, and the land is mostly open fields. The soil is generally light and sandy, and the vegetation is sparse.

The general appearance of the landscape is similar to that of the north side of the river. The terrain is mostly flat, with a few small hills rising in the north. There is little or no forest cover, and the land is mostly open fields. The soil is generally light and sandy, and the vegetation is sparse.

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3. LITHOLOGICAL UNITS

3.1 GNEISS COMPLEX AND GNEISSOSE GRANITES

This group occupies the bulk of the project area and is almost synonymous with the term "Older Plains Group" of previous workers. No distinct units can be separated within the complex. The rocks are of varying mineralogy and texture but tend to be unified by their complex tectonic history. The widespread superficial cover, the weathered nature of much of the outcrop in the plains and the general lack of distinctive expression of any one rock type on the photographs, makes it impossible to state with certainty the order of importance of each rock type and its distribution.

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The groundmass of the gneissose granites is distinctly foliated

and local segregations into mafic and felsic portions are common. The rock grades into the rest of the Gneiss Complex: east of J. Siomo it passes into fine grained more gneissose rock with gradual disappearance of the potassic feldspar. In this transitional phase minor pegmatitic veins traverse the joints. Movement appears to have occurred along these joints prior to the intrusion of the pegmatites.

At J. Cheili granitic gneisses show colour variations, grey, pink and white gneisses cropping out around the base of the hill. Similar variations may be seen around other Jebels (exposure generally improving around these hills, local variation is more easily recognised) e. g. J. Waranga, J. Patapan and J. Dongo. Pegmatitic veins in these rocks show a structural relationship to their host similar to those around J. Siomo.

Locally considerable amounts of sillimanite come in as fibrolite, which together with small biotite flakes and opaque granules, appear to be concentrated in well defined bands. It is suspected that the sillimanite has developed in the aureoles surrounding the main areas of the Migmatite Group but there is too little evidence presently available to confirm this.

More basic rocks develop within the Gneiss Complex. Hornblende bearing gneisses are fairly widespread. These show a range of variation similar to the quartzo-feldspathic rocks described above, and as they become less foliated individual specimens may qualify for the term hornblende syenite. Sphene is a common accessory. Some of these rocks have been referred to as xenoliths by earlier workers, others appear to occur as definite bands of considerable extent but varying thickness. During the present survey individual pieces of hornblendic float have been seen and in previous work basic float has been recorded. However, no intrusions of this nature have been described.

The most basic gneiss seen during the present survey was in the Wadi Miri. Here medium to coarse grained massive garnetiferous amphibolites crop out. The garnet is conspicuous, being of pink colour,

but it forms less than 5 per cent by volume of the rock. The bulk of the rock is made up of hornblende. In thin sections the hornblende is usually greyish to dark brown/green but occasionally more bluish colours appear. The hornblende crystals show a weakly expressed preferred orientation. Quartz and plagioclase (An 15-20) occur in about equal amounts but together form not more than 10 per cent by volume of the rock. The plagioclase does not show compositional zoning. Biotite occurs in minor amounts and in some samples diopside is intergrown with the hornblende.

Similar rocks - those seen being free of garnet - were found south-west of Kafia Kingi. It is uncertain to what extent the mineralogy of those rocks is affected by proximity to the Migmatite Group.

Earlier workers have noted Ca-Mg silicates and some crystalline limestones in the Gneiss Complex in the J. Nyalla, J. Kulu, Khor Kedada area. These are associated with talcose, graphitic and epidotised rocks. During the present survey this facies was not located and it seems clear that it is in fact of minor volumetric importance within the complex.

Various chloritic and epidote schists have been described - especially at Hofrat en Nahas - during previous work. It is thought that these probably belong to the cataclastic gneisses and are noted further in that section.

3.2 FERRUGINOUS QUARTZITES

These rocks are known only in the two areas of J. Gulamara and J. Angbeigi. They form low hills of rounded form both in section and in plan. On the aerial photographs their appearance is dominated by a strong rectilinear joint pattern. Foliation is virtually undetectable on the photographs. The rock units show distinct junctions with the Gneiss Complex.

In the field the rock has a gneissose appearance. It is strongly banded on a fine scale. The banding is textural rather than mineralogical

although there is sometimes a slight concentration of iron oxides in some bands. The bulk of the rock is quartz with iron oxides next in amount. However, it is thought that the oxide content is low: its usual occurrence as concentration in blebs, around which considerable staining haloes form, gives a misleading first impression of its amount. Alternate bands show medium to coarse then fine grained quartz. It is thought that the banding is of sedimentary origin, the iron oxides being original heavy mineral aggregates.

The banding is complexly folded and contorted with at least three periods of folding represented.

The iron oxide blebs often develop rodded form within individual beds.

3.3 QUARTZITE SCHIST GROUP

This group is characterized by a wide range of textures in rocks of essentially uniform mineralogy. The most prominent rock types are quartzite, quartz-schist and sericitic quartz-schist. These form the resistant spines of the long linear, occasionally sinuous, ridges in which this group is represented. Generally even very small occurrences of these rocks are sufficient to produce a marked ridge feature and in some ridges they may be virtually absent although the rocks now forming the ridges - the cataclastic gneisses - testify to the recent erosion of the overlying quartzites. The rocks are generally medium to fine grained although grain size may be difficult to observe in hand specimen.

Possibly of greater volumetric importance than the quartzites, but seldom exposed unless immediately below an overhanging outcrop of the more resistant rock, are the sericitic schists and quartz sericite schists. These are usually much weathered and iron stained. They probably underlie the grass and shrub covered hillside between the bands of quartzite.

Apart from quartz and sericite a very small fraction of other minerals is present. Locally the rocks become feldspathic - some

detrital plagioclase of crystal size similar to the enclosing quartz is fairly common in most rocks, although of very small amount. Grains of heavy minerals, predominantly iron oxides and rutile, mark bedding planes. Again, these are of small amount but are conspicuous as weathering leads to staining haloes around them. Colour banding - equivalent to bedding - and staining along crystal boundaries, helping to define preferred dimensional orientation, are common. A little very fine garnet is detectable in some of the sericitic phases.

Bedding is indicated both by colour banding and by sudden variation in sericite concentrations. The individual plates of mica are commonly oblique to the bedding as they mark axial schistosity.

On the limbs of the isoclinal folds where shearing reaches maximum intensity, quartzites are made over into quartz schists. Individual quartz grains become elongate parallel to the axial schistosity and a mosaic of much flattened, well sutured crystals develops. This results in a flaggy rock with well developed parting planes even in the sericite-poor beds. Generally these are conformable with bedding owing to the isoclinal nature of the folds. Towards the fold closures, where foliation would be expected oblique to bedding, the intensity of shearing has been too low to cause significant dimensional orientation of the quartz. Only the sericite is obviously oblique to bedding.

In some rocks exceptions to the general uniformity of grain size are apparent. Here patches of quartz show a well sutured mass of grains of large size than in the groundmass. These patches have a common boundary with the groundmass and apparently indicate original larger detrital particles that have undergone degradation during cataclasis.

3.4 MIGMATITE GROUP

The rocks of this group form moderately well defined areas in the south-west and south-east of the project area. In the south-west they appear to be continuous with the belt mapped as amphibolite by Delafosse (1960). He notes that some of those rocks have undergone

migmatization and are, in general, very heterogeneous.

Topographically the group is characterized by strong local relief with sharp ridges and complex banding traversing individual hills. These ridges alternate with areas of low relief and are similar in appearance to the bulk of the Gneiss Complex. However, the topographic expression is modified by the widespread distribution of lateritic overburden.

Basically the group represents those parts of the Gneiss Complex occupying the cores of the major antiforms during the last orogeny affecting the area. They have been more or less made over into new rocks by anatexis.

The rocks were observed in the field north of J. Miri. Here the rocks of granitic appearance were found together with inhomogeneous gneisses in which complex microfolds are abundant (see Frontispiece). The granitic rocks are fine to medium grained and massive. They are generally of light pink colour. On close inspection strong foliation may be distinguished due to alternation of diffuse darker and lighter bands. Small garnet crystals are occasionally found.

The pale pink granitic gneiss forms ridges with smooth steep faces that appear as light toned areas on the aerial photographs, due to the reflection of light. Enclosed in these rocks are bands and lenses of inhomogeneous rock of coarse to medium grain size. These enclaves have been observed to attain lengths of 20 m and widths of up to 5 m and study of the photographs indicates that larger units are most probably present.

Almost monomineralic lenses and bands of biotite, feldspar and quartz grade diffusely into one another. These vary in width from one millimetre to several centimetres. They show intense microfolding and shearing and are frequently offset along cross faults. Rapid variation in mineral proportions together with gradual decrease of intensity of foliation cause nebulous domains of granitoid rock within the group.

3.5 CATACLASTIC ROCKS

These rocks have not been mapped separately except where they can be inferred with some certainty. They always show transitional relationships with their parent rocks - the Gneiss Complex. They result from the tight infolding of those rocks with the Quartzite Schist Group. Differential movement between the two groups reaching its maximum along the limbs of isoclinal folds; the cataclasites also reach their most intensive grade of degradation and their thickest development in those zones.

Although much of the Quartzite Schist Group is itself in a more or less cataclastic state it is excluded from the cataclasites shown on the 1:100,000 series. On the 1:250,000 compilation the two groups are mapped as one unit because (a) when they occur together they form units too small to plot individually, and (b) their structural context is so similar that indicating the cataclasites with the quartzites makes for greater clarity of the structural pattern.

The major varieties of cataclasite present are:-

Augen Gneiss

Augen Schist

Mylonite ("Brown Schist" of earlier workers)

Greenschist.

The mylonites are present around the junctions of the Quartzite Schist Group with the Gneiss Complex (Figure 4). The other rocks of this group tend to grade into the mylonites but are more widely distributed. They can be distinguished from the rest of the Gneiss Complex by the presence of abundant foliation traces of post-Quartzite Schist Group age and from those younger rocks by the presence of foliation - more or less faint - of pre-Quartzite Schist Group age.

The augen gneisses are probably the most widespread of the cataclasites but are the most difficult to distinguish as they have no photogeological characteristics sufficiently diagnostic to separate them

from the Gneiss Group. Mineralogically they are similar to the quartzo-feldspathic gneisses except that the feldspars become more generally epidotized and chlorite develops in the groundmass. The feldspar augen have not been observed to reach exceptional size but are sometimes slightly elongate within the foliation. Possibly there is some augen gneiss of earlier age within the gneiss complex.

Texturally the augen gneisses grade into augen schist in which chlorite and epidote become conspicuous. The feldspar tends to be more elongate in these rocks than in the gneisses and streaky banding develops.

The most intensely altered rocks are those referred to in previous reports as "Brown Schists". In hand specimen these show some resemblance to the Ferruginous Quartzites, but closer inspection shows the essentially cataclastic nature of the quartzo-feldspathic constituents, with some sericite and chlorite. This is more or less masked by iron staining. The amount of iron-oxide in the rock is apparently considerable but insufficient to be considered as potential ore. It occurs as blebs and rodded structures which tend to merge with fine foliation trending through them.

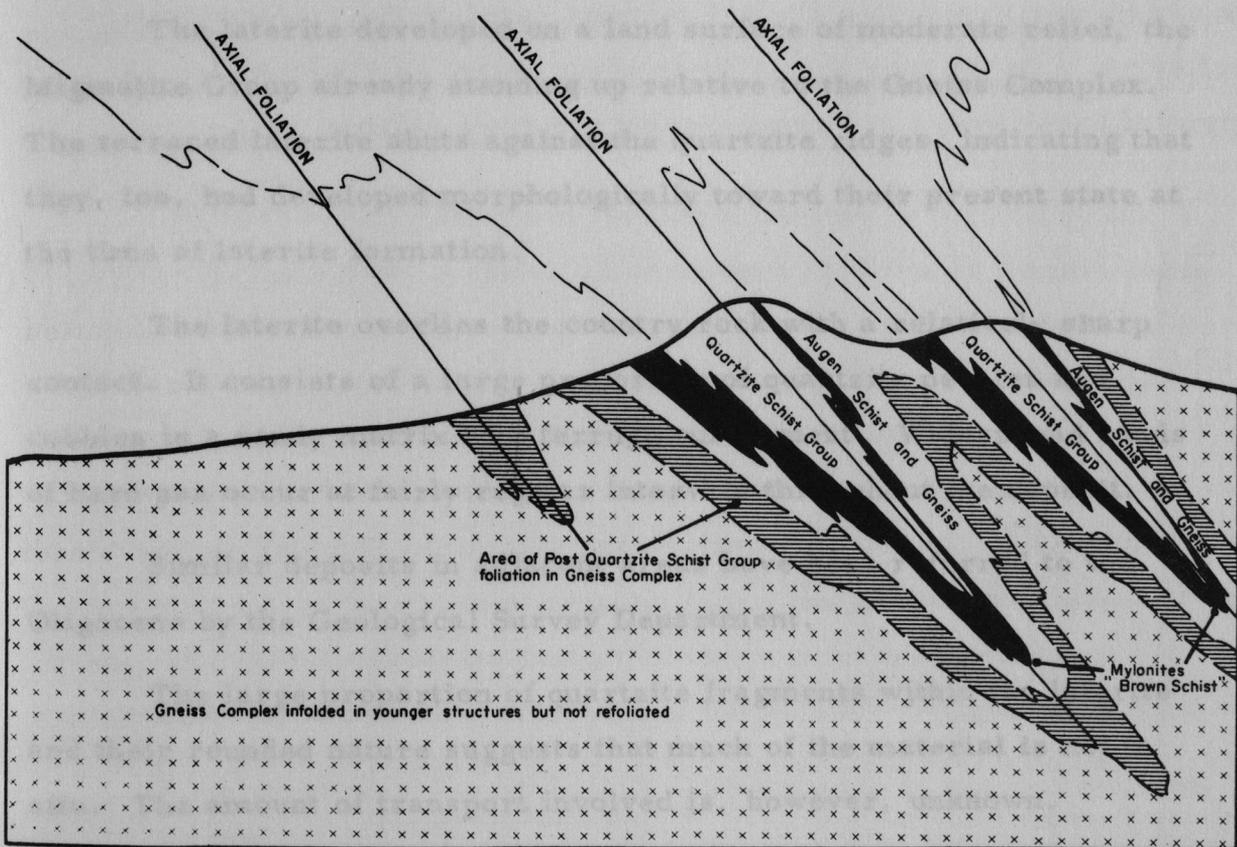
Greenschists have been described at Hofrat en Nahas in association with the copper deposits (Afia and Widatalla, 1961). Chlorite schists have been noted elsewhere. They were not seen in situ during the present survey but from description and examination of samples they appear to be products of retrograde metamorphism - possibly of the more hornblending facies of the Gneiss Complex.

3.6 MINOR INTRUSIVES

The only intrusive rocks recognized that are younger than the Gneiss Complex are pegmatites. These are widespread but their predominant trend is uncertain. They cannot be recognized on aerial photographs except for some isolated occurrences in the north of the project area.

Most of those noted in the field show foliation, although this may

IDEALIZED CROSS-SECTION SHOWING RELATIONSHIP BETWEEN QUARTZITE SCHIST GROUP, CATACLASTIC ROCKS AND THE GNEISS COMPLEX

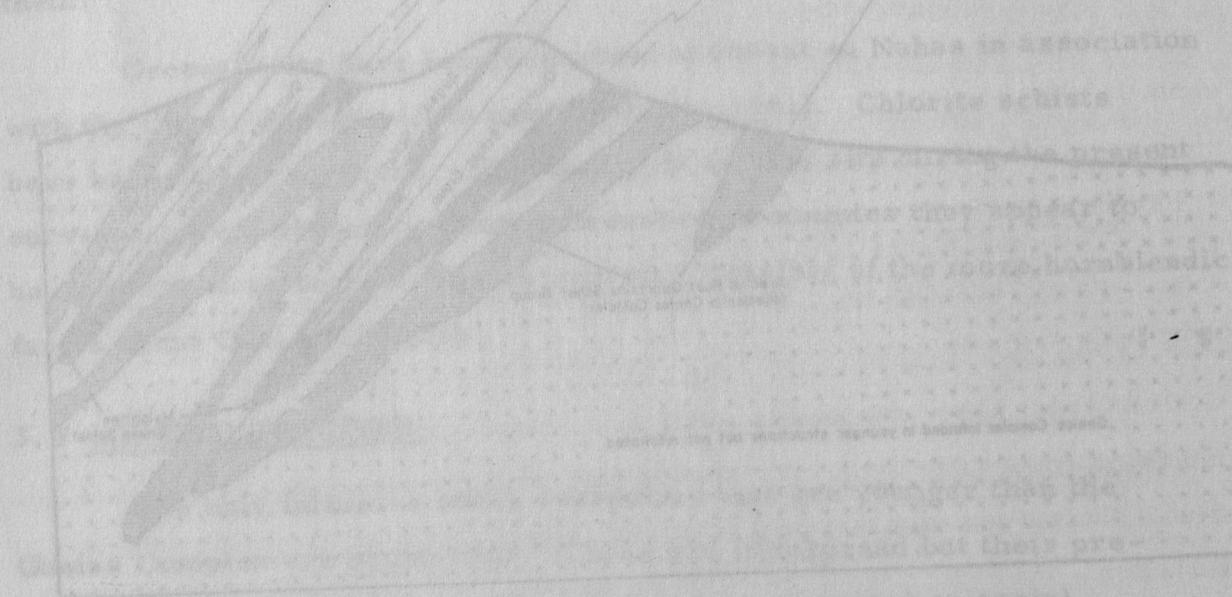


3.6 TONAL SERIES

These rocks form an extension of those mapped in the Central African Republic by Delafosse (1960). They are essentially a thin

IDEALIZED CROSS-SECTION SHOWING RELATIONSHIP BETWEEN QUARTZITE SCHIST GROUP, CATACLASTIC ROCKS AND THE GNEISS COMPLEX

...in this region and along ...
...of about ...
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...at ...
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...The ...
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...through



...in this ...
...this may

be difficult to recognize in such coarse grained rocks. Many show tourmalinization and some copper staining, but this is sporadically distributed and does not appear to have a genetic relationship with the intrusives.

Cassiterite has been reported from some of these intrusives in the east of the project area but this appears to be of very restricted occurrence (Afia and Widatalla, 1961).

3.7 LATERITE

A lateritic deposit developed in the Tertiary over the whole area with the possible exception of the Quartzite Schist Group. It has been partially buried in the north and preserved by younger sediments. In the south it is relatively elevated and is undergoing active erosion.

The laterite developed on a land surface of moderate relief, the Migmatite Group already standing up relative to the Gneiss Complex. The terraced laterite abuts against the quartzite ridges, indicating that they, too, had developed morphologically toward their present state at the time of laterite formation.

The laterite overlies the country rock with a relatively sharp contact. It consists of a large proportion of quartzite pebbles and cobbles in a sandy matrix with ferruginous cement. Widespread bands of hard pan occur at fairly regular intervals throughout the deposit.

Similar deposits in adjacent areas have been referred to the Oligocene by the Geological Survey Department.

The large proportion of quartzite fragments within the laterite and their rounded nature suggests that much of the material is not in situ. The amount of transport involved is, however, unknown.

3.8 TCHAD SERIES

These rocks form an extension of those mapped in the Central African Republic by Delafosse (1960). They are essentially a thin

blanket of Quaternary sediments through which protrude those older rocks which possess positive relief. Thus, Delafosse found the majority of the inliers to be formed of quartzites, mylonites and granite.

The Tchad Series consists predominantly of argillaceous sands with calcareous and gypsiferous deposits locally. In the project area they pass laterally into unconsolidated deposits mapped as undifferentiated superficial deposits. They were deposited under alluvial, lacustrine and aeolian conditions (Grove and Warren, 1968).

3.9 ALLUVIUM

Wide bands of alluvium occupy the major valleys in the northern half of the project area. In the south and on the major interfluves wide areas are subjected to sheet floods. Some difficulty occurs therefore in satisfactorily mapping alluvial deposits owing to their gradation into colluvium. On the map sheets those areas shown as alluvium are restricted to the very flat deposits within the river valleys.

4. STRUCTURE

4.1 GENERAL

The structural history of the area is complex but capable of interpretation. Five phases of folding have been recognized in which two distinct cycles of tectonism in time can be recognized. The first of these shows axes generally oriented NE-SW to E-W, the second shows axes oriented NNE-SSW. It is the latter of these two cycles which shows the strongest control of regional structure. The former becomes predominant locally but has usually undergone substantial modification.

The major structure produced in the south by the last cycle comprises two major antiforms separated by a synform. These plunge to the north-east and their surface expression becomes less apparent in that direction, the older structures becoming more continuous but much masked by Tertiary/Quaternary deposits.

The core of the western of the two antiforms is formed by the Migmatite Group around J. Miri. The eastern antiform is a more dome-like structure in the south-east of the project area. The two antiforms are separated by a complex synform, the core of which is marked by the Quartzite Schist hills of the Hofrat en Nahas "copper-line", i. e. that line trending SSW from Hofrat en Nahas along which most of the known copper deposits occur. In the western antiform the Migmatite Group retains a fairly constant relationship to the Quartzite Schist Group. The first impression being that there is an uncomplicated stratigraphic and structural relationship between the two groups.

In the south-east the Migmatite Group occurs in varying relationship to the Quartzite Schist Group. In some localities they are separated by a fairly thick belt of the Gneiss Complex; at others they are almost in contact with one another. Along the frontier zone the Quartzite Schist ridges represent part of a complex synform flanking the western antiform.

Faulting which post-dates the last major period of folding produces locally important structures. Besides possible shatter belts, now infilled with alluvium, the most significant belt is the zone of fractures trending approximately E-W from the frontier north of J. Miri, which shows a similar orientation to several of the major belts of alluvium.

Foliation as shown on the 1:100,000 scale map series shows sudden changes in apparent density. This is often unrelated to topographic or vegetation change or to variation in the thickness of overburden. It is thought that a probable explanation is that areas where many foliation traces are visible have had vegetation burnt off within recent years and that vegetation is regrowing at varying rates selectively along the various bands. Different stages in the regrowth have been noted.

The major structural units can be considered under the following headings:-

1. The Jebel Miri Antiform.
2. The Frontier Area.
3. The Hofrat en Nahas or Central Synform.
4. The S.E. Dome.
5. The Northern and Eastern Area.

4.2 THE JEBEL MIRI ANTIFORM

In this structure the bands of rock within the Migmatite Group cut the earlier foliation of the Gneiss Complex but are locally conformable to those trends. A series of tight fold closures of overall anticlinal form occurs between the Umbelasha river and Wadi Miri immediately south of their junction. The major fold of which these structures represent the closure can be traced SSW to the frontier.

To the east of the Wadi Miri a series of ridges - also within the Migmatite Group - trends NNE-SSW. Southwards these ridges appear to merge with the eastern limb of the anticline but any link between the rocks within the project area is masked by lateritic deposits. Northwards

the ridges terminate fairly abruptly. The reasons for this are not clear. Two alternatives of significance appear possible. The first of these is that the rocks are cut off by cross faulting or simply do not reach the present erosion level. The second is that these rocks represent the western limb of a second anticline within the migmatites, the core and eastern limb of which have been displaced by a major structural discontinuity. Such a fracture has been inferred on the 1:250,000 structural map but the area is completely masked by laterite. However, the quartzite ridges of the adjacent portion of the Central Synform also terminate along this line and some tectonic break seems most probable in this area.

Earlier structures within the antiform are not clear. Between individual ridges of migmatitic rock earlier foliation oblique to the major structure is apparent and, more rarely, sufficient traces are decipherable to allow interpretation of some earlier folds. The largest of these is in the north-west of the antiform where a second fold is deformed around a third fold axis.

In general all folds are indicative of plastic deformation and uniform conditions throughout the structure.

4.3 THE FRONTIER AREA

This area shows a complex pattern of Quartzite Schist Group ridges infolded with the Gneiss Complex. The pattern is complicated by zones of cross faulting. The area is essentially synclinal about a fifth fold axis.

On the margin of the J. Miri Antiform a narrow band of Quartzite Schist Group ridges trends NE-SW. They are made up of very tight complex folds with little aggregate plunge. Southwards the strike of these folds becomes increasingly oblique to the margin of the antiform against which they are truncated. In the extreme south-west of the project area this band is joined in an area of complex cross faulting by a broader zone of ridges coming in from the NNE. This latter band

shows similarly complex folding to the former, but the pattern is more open and individual structures show thicker outcrop width. Axial schistosity is equally well developed dipping to the south-east throughout both groups of ridges.

To the north-west the steeper limb swings around to a more easterly trend as the nose of the antiform is approached. The outcrop of the Quartzite Schist Group becomes broken. Isolated hills of these rocks are linked by strong linear features with attitude similar to the axial schistosity but with stronger surface expression as small but sharp depressions. It is probable that these represent strong shear surfaces and that southwards they become oblique to schistosity and are responsible for the truncation of the ridges against the antiform.

To the north the Frontier Area is cut by several zones of cross faults with a general trend around NE-SW, the predominant strike of foliation within the Gneiss Complex. These faults have an element of shear which is in many cases sufficiently strong to be recognized on the aerial photographs. The faults also have the overall effect of down-throwing structures to the north. The result of this is that two blocks of Quartzite Schist Group hills are preserved along the northward extension of the last major fold axis.

Older structures within the gneiss are occasionally very clear in this area (see map sheet 5). Strong fold structures within those rocks are clear, plunging below, and oblique to, the quartzite ridges.

4.4 THE HOFRAT EN NAHAS OR CENTRAL SYNFORM

This area contains the bulk of the copper localities previously recorded. The main features are the long narrow lines of Quartzite Schist/cataclasite ridges which are continuous over much of the area. Although - as elsewhere - the identity of each ridge with a fourth synclinal axis is certain, the nature of the later F5 axis causing the tight flexures in the main ridge lines is uncertain. An interpretation is given on the structural map.

The F5 fold closing from the north-east on J. Waranga is almost certainly synformal. This is indicated by the opposing attitude of the earlier axial surfaces in the closing ridges and by the thickening of the cataclasites in the closure.

The F5 folds south of this are of less certain nature. That immediately south of J. Waranga has its eastern limb virtually continuous with the western limb of the Waranga fold. Within the fold a second group of quartzite/cataclasite ridges shows similar distribution to the ridges of the main limbs of the fold, but is of restricted development. This suggests that this fold is antiform, folding an earlier double synclinal structure. The significance of the juxtaposition of the eastern limb of the southern fold with the closure and western limb of the northern fold is uncertain. A cross fracture separates the two features, but the magnitude of this is not known. However, the overall linearity of the adjacent ridges, their great extent and their constant attitude suggests a strong degree of structural control.

The extent of individual F5 folds is uncertain. Consideration of the distribution of the younger rocks and the rapid disappearance of structures associated with these folds away from the closures indicates that they do not plunge into the basement. It is therefore, assumed that they are most probably of conical, rather than cylindrical form.

Within the Central Synform the gneisses show little refoliation due to post-Quartzite Schist Group tectonism except in the immediate vicinity of the younger rocks. The general NE-SW trend of the older foliation is little broken.

4.5 THE S. E. DOME

Only the north-west quadrant of this structure falls within the project area. The central part is a fairly regular dome, with the traces of fold axes forming a circular pattern. The pattern becomes less regular outwards. A greater proportion of granitic rocks appears within the central portion, although the complex is essentially of migmatitic character.

Sinuuous F5 axes flanking the central position of the dome sharply deform the Quartzite Schist Group and control the distribution of the Migmatite Group. The migmatites are also locally controlled by older structures, hence detailed interpretation of the structure is not possible except on large scale maps.

A shear zone is inferred along the western margin of the dome with the Central Syncline. This causes truncation of the Quartzite Schist mass in that area.

The drainage over that part of the dome which lies within the project area has a sub-radial pattern.

4.6 THE NORTHERN AND EASTERN AREAS

The Eastern Area shows the normal complex foliation pattern in the gneiss. It is difficult to date individual structures by photogeological methods owing to the absence of the Quartzite Schist Group which provides a datum elsewhere.

The overall distribution of gneissose granites in this area suggests that their occurrence is related to F4 axes, e.g. J. Siomo and J. Terezol.

The Northern Area, on the other hand, shows many outliers of the Quartzite Schist Group or the associated cataclasites. This area represents the northern continuation of the Central Synform in which the major antiform axes have almost entirely died out.

The general NE-SW and E-W trend of foliation in the gneisses is strongly and uniformly developed although the thick cover of residual deposits more or less obscures this.

The post-Quartzite Schist Group structures show tight refolding around F5 axes but these appear to be less continuous than those to the south.

Bir Ileba is situated within an area of thick residual deposits which is underlain by a major fracture zone. The conjunction of these

factors probably controls the sub-surface hydrology.

4.7 REGIONAL FRACTURE PATTERN

Major faults and fractures throughout the area are not clearly developed although their presence can be inferred. The majority of major fractures are the sites of topographic depressions infilled by alluvium. The linear nature of these belts or the rectilinear form of drainage within them indicates the occurrence of the fracture zones. In the west and south-west abrupt termination of the quartzite ridges indicates the more important faults.

Older faults are locally in evidence in the Gneiss Complex; these are indicated by foliation patterns interrupted along a linear or slightly arcuate feature of age greater than the post-Quartzite Schist. Folding can be recognized on some photographs, but is not sufficiently developed to be mapped on scales as small as 1:100,000.

The predominant directions among the regional fractures are:-

NE-SW to NNE-SSW

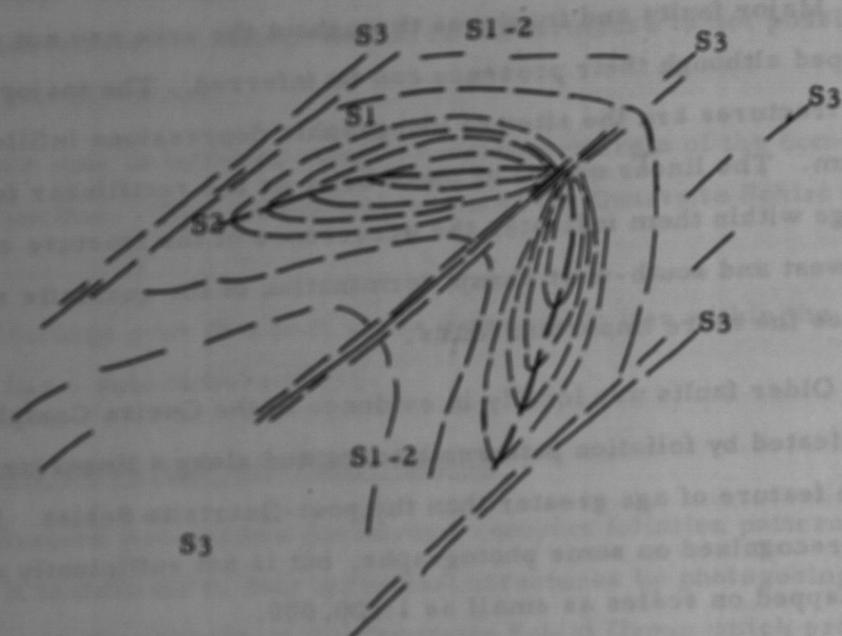
N-S

EW to ESE-WNW.

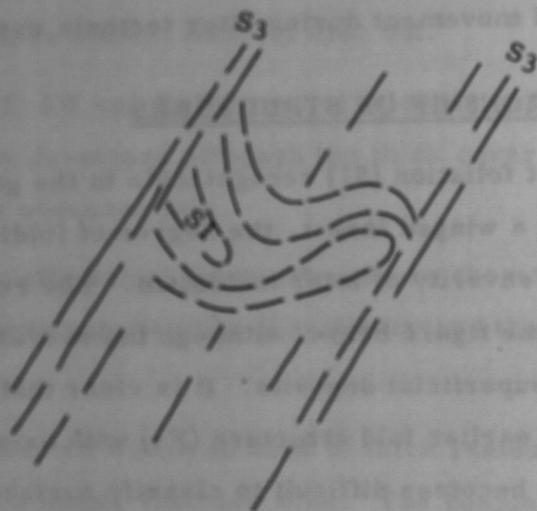
The first of these directions is closely related to the predominant foliation in the Gneiss Complex. This foliation appears to have acted as a locus for lines of movement during later tectonic events.

4.8 INTERRELATIONSHIP OF STRUCTURES

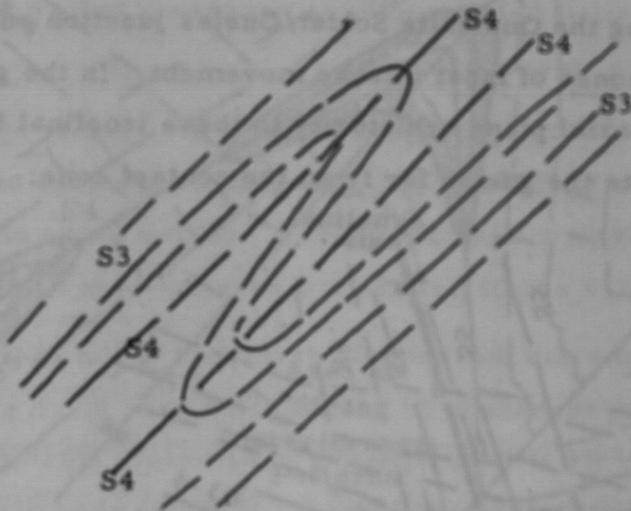
The earliest foliation (S1) recognizable in the gneiss shows a pattern resembling a winged insect, the degree of folding of the wings depending upon the severity of later tectonism. The relationship is usually seen as in the figure below, although the overall pattern is often locally masked by superficial deposits. It is clear that S1 represents surfaces around an earlier fold structure (F1) with axial S2. On the limbs of this fold it becomes difficult to classify surfaces as any S2 foliation becomes coincident with S1.



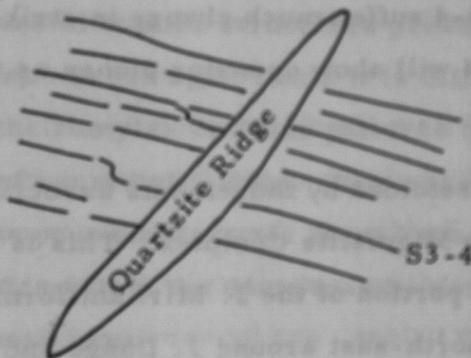
The refolding of F1 is symmetrical around F2 axes and axial foliation S3 is strongly developed. Less regular folds of S1 can occasionally be recognized. These are small in extent, but in general appear on the 1:25,000 photography.



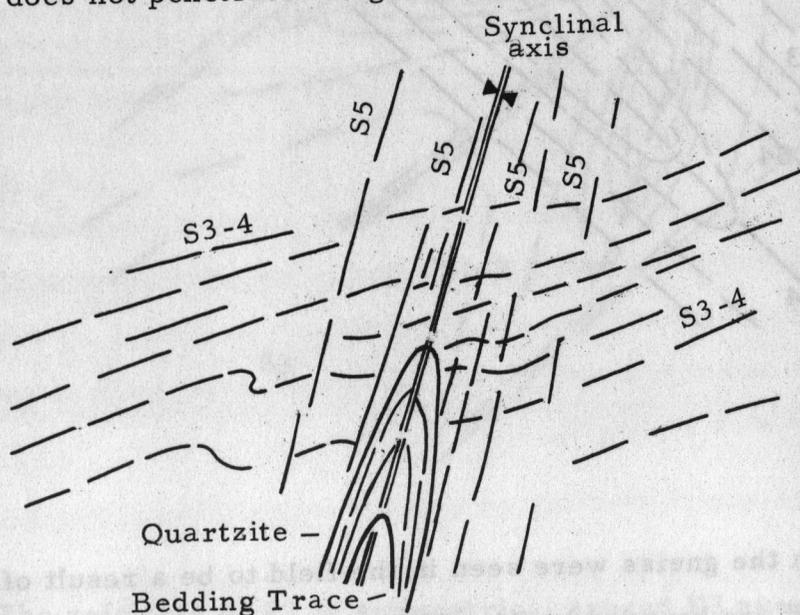
S3 has been refolded isoclinally, but it is not possible to differentiate S4 from S3 (axial schistosity of F3) except in closures of S3:-



Mullions in the gneiss were seen in the field to be a result of the refolding of S3 and are bounded by S4. S3 and S4 predate the deposition of the Quartz Schist Group. The relationship between them and the Quartz Schist Group is often very clearly seen:-

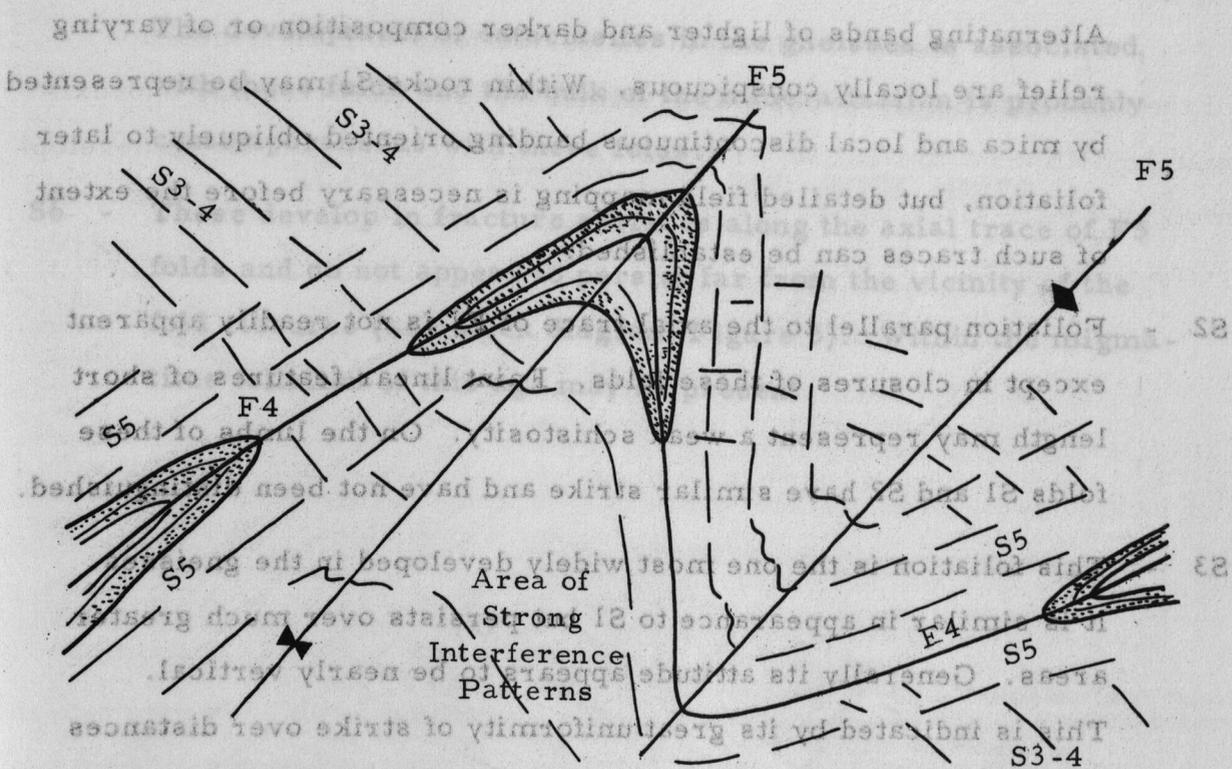


The first phase of folding in the period following the deposition of the Quartzite Schist Group was isoclinal on axes (F4) trending approximately NNE-SSW to NE-SW. This folding was accompanied by the development of cataclasites along the Quartzite Schist/Gneiss junction and by recrystallization in the zones of most intense movement. In the gneiss surface S5 developed as axial plane schistosity to these isoclinal folds but this does not penetrate the gneiss far from the contact zone:-



Within the sediments this surface is very well developed and more or less obliterates bedding. S3-4 are not much deflected by these axes, this is due to their vertical attitude. Only where shallow dips occur or S5 itself has low dips will S3-4 suffer much change in strike although linear structures within S3-4 will show opposing plunge as they cross F4 axes.

Axes (F4) have been refolded by movements associated with the late stage development of the Migmatite Complex. This is most clearly recognizable in the northern portion of the J. Miri antiform, but similar patterns can be seen in the north-east around J. Dongo and in most of the areas where complex ridge patterns occur in the quartzites:-



(Quartzite Schist Group shaded)

Axial foliation (S6) associated with F5 appears restricted to strong fracture lines along the axial trace but is only clearly recognizable in the closures of the folds; elsewhere it becomes difficult to distinguish from S5.

Within the Migmatite Complex the dominant surfaces appear to be controlled by S5 and these are clearly folded by F5. However, there are frequent traces of earlier structures preserved within these folds (see Frontispiece). In the S.E. Dome it is difficult to identify individual trends owing to the complex circular patterns of deformation and the varying amount of recrystallization. It is suggested that the development of the dome is the youngest tectonic event associated with the folding and that small folds within the dome may be younger than F5 as they locally distort those axes.

4.9 NATURE OF MINOR STRUCTURES

S1 - Where S1 has been identified on photographs it appears to be the result of strong compositional layering on a macroscopic scale.

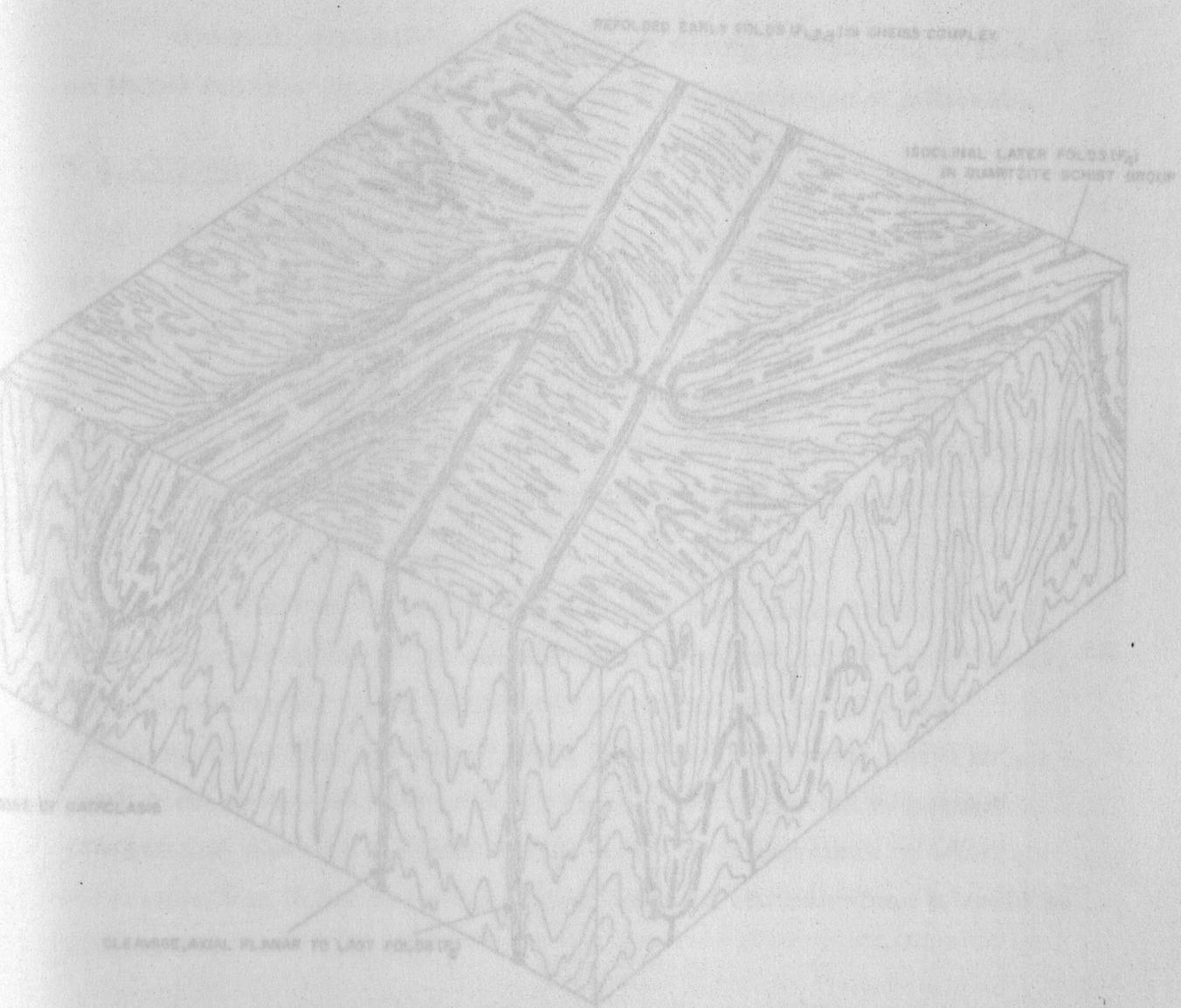
Alternating bands of lighter and darker composition or of varying relief are locally conspicuous. Within rocks S1 may be represented by mica and local discontinuous banding oriented obliquely to later foliation, but detailed field mapping is necessary before the extent of such traces can be established.

- S2 - Foliation parallel to the axial trace of F1 is not readily apparent except in closures of these folds. Faint linear features of short length may represent a weak schistosity. On the limbs of these folds S1 and S2 have similar strike and have not been distinguished.
- S3 - This foliation is the one most widely developed in the gneisses. It is similar in appearance to S1 but persists over much greater areas. Generally its attitude appears to be nearly vertical. This is indicated by its great uniformity of strike over distances of several kilometres and its trace being little deflected by topographic features, fractures or later tectonics. Similarly, its nature indicates that this foliation persists to considerable depth.
- S4 - Occasional sharp sigmoidal flexures in S3 show axial foliation S4. This appears to be a locally developed schistosity, but again it is difficult to judge its extent as away from the closures it merges with S3. Mullions are produced by the tight folding of foliation S3 intersected by S4.
- S5 - This surface is generally apparent in the quartzites and continues along strike for great distances in the gneiss, often linking the quartzite outliers. Within the Quartzite Schist Group it intersects bedding in the fold closures but is more or less parallel to it on the fold limbs. Bedding in the quartzites is usually recognizable by faint colour banding, almost certainly due to varying concentrations of iron oxides, and by varying concentration in bands of sericite. The latter do not invariably indicate bedding as shear along some axial schistosity surfaces produces local concentrations of sericite oblique to bedding traces. Strong mullioning develops in the quartzites with plunge similar to F4 axes.

The development of cataclasites in the gneisses is associated with these folds and the bulk of the mineralization is probably contemporaneous with these folds.

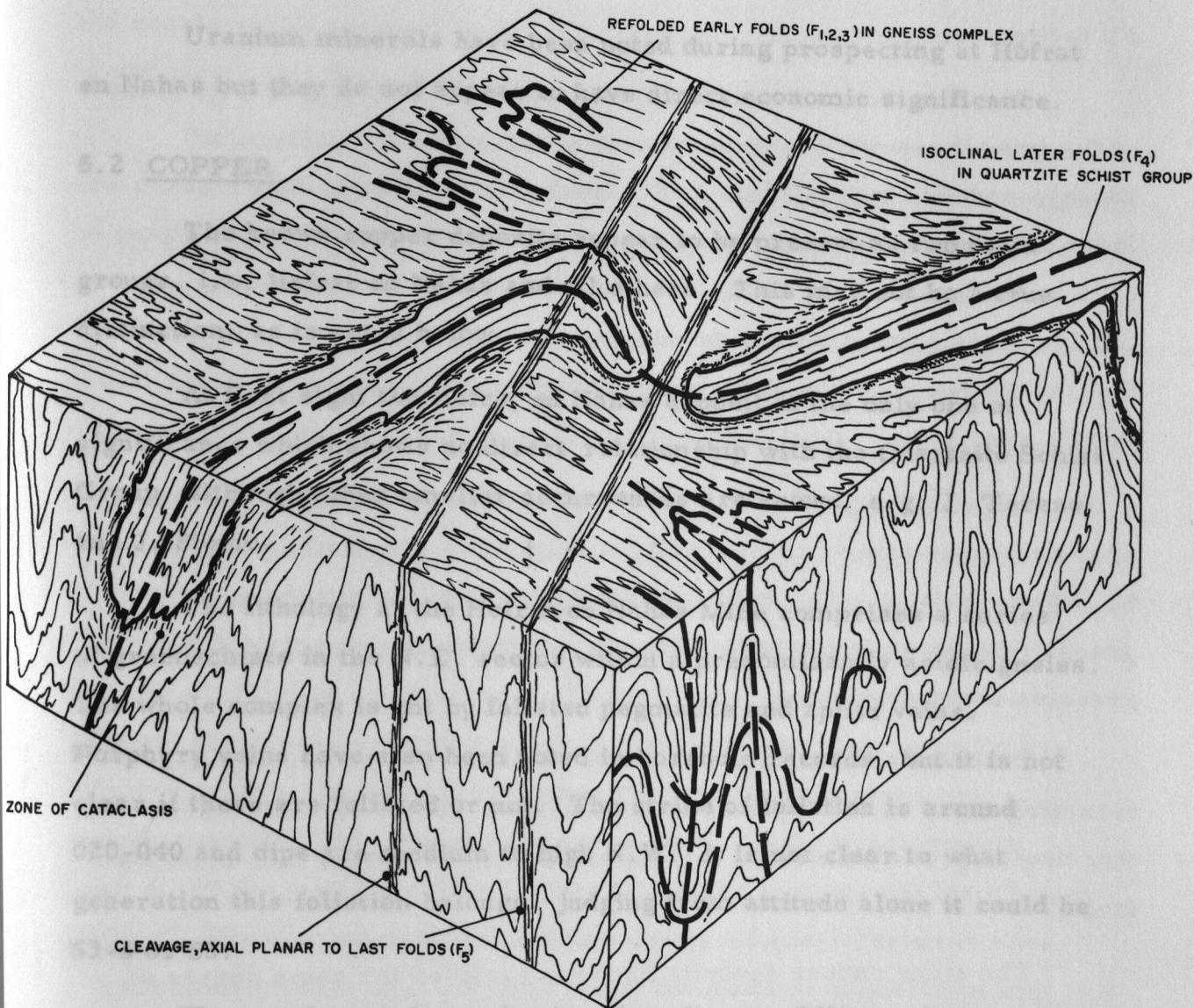
BETWEEN STRUCTURES AND ROCK UNITS

- S6 - These develop in fracture surfaces along the axial trace of F5 folds and do not appear to persist far from the vicinity of the fold closures (see block diagram Figure 5). Within the migmatites foliation of this age may be present.



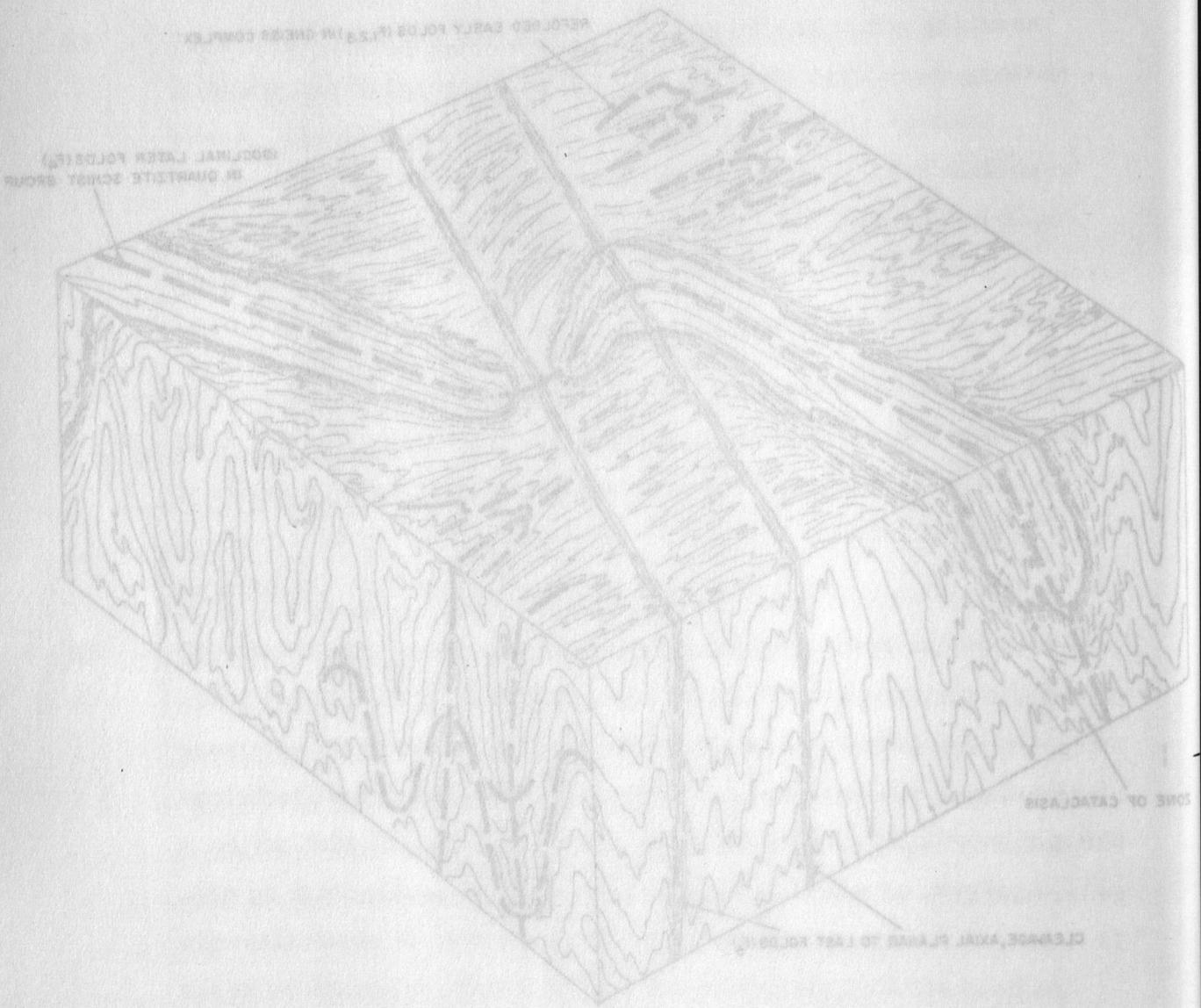
- The development of cataclasis in the gneisses is associated with these folds and the bulk of the mineralization is probably related to these folds. These folds, however, do not appear to persist far from the vicinity of the folds and do not appear to persist far from the vicinity of the folds.
- 22 - These develop in fracture surfaces along the axial trace of F2. These develop in fracture surfaces along the axial trace of F2. These develop in fracture surfaces along the axial trace of F2.
- 23 - Within the migmatite zone (see block diagram Figure 2). Within the migmatite zone (see block diagram Figure 2). Within the migmatite zone (see block diagram Figure 2).
- 24 - This foliation is developed in the gneisses. This foliation is developed in the gneisses. This foliation is developed in the gneisses.
- 25 - Occasional sharp sigmoidal features in F3 show axial foliation. Occasional sharp sigmoidal features in F3 show axial foliation. Occasional sharp sigmoidal features in F3 show axial foliation.
- 26 - This surface is generally parallel to the quartzites and continues along strike for great distances in the gneisses, often linking the quartzite outcrops. This surface is generally parallel to the quartzites and continues along strike for great distances in the gneisses, often linking the quartzite outcrops.
- 27 - Bedding in the quartzites is usually recognizable by faint color banding, which is certainly due to varying concentrations of iron oxides. Bedding in the quartzites is usually recognizable by faint color banding, which is certainly due to varying concentrations of iron oxides.
- 28 - The lower beds invariably indicate bedding as seen along some axial foliations produced local concentrations of iron oxides to weathering traces. Strong mullioning develops in the quartzites with plunge similar to F4 axes.

**BLOCK DIAGRAM SHOWING SCHEMATIC RELATIONSHIP
BETWEEN STRUCTURES AND ROCK UNITS**



The ore deposit is predominantly a fissure-filling vein type which is concentrated along the gneiss/greenschist junction. Earlier workers have classified the ore into two groups - breccias with

BLOCK DIAGRAM SHOWING SCHEMATIC RELATIONSHIP
BETWEEN STRUCTURES AND ROCK UNITS



5. MINERALIZATION

5.1 GENERAL

Mineralization within the area is chiefly of interest owing to the record of copper deposits. Gold and tin have also been noted as have two groups of iron minerals, one associated with the copper, the other with the laterite. Alluvial diamond deposits are worked in the nearby Central African Republic. None have been found in the Sudan but they may occur within the project area.

Uranium minerals have been noted during prospecting at Hofrat en Nahas but they do not appear to have direct economic significance.

5.2 COPPER

The known copper deposits appear to be present as two main groups, i. e. Hofrat en Nahas and all others. This may not be a true distinction, as is noted below.

At first sight the Hofrat en Nahas deposit is the only one of significance which shows no direct relationship with the Quartzite Schist Group, although other smaller occurrences are known, e. g. J. Terezol and J. Siomo.

The lithology at the Hofrat en Nahas Mine comprises a series of greenschists in the N.E. sector within a predominantly acidic gneiss. The whole complex is cut by foliated pegmatite and aplite veins. Porphyry veins have also been noted in borehole records, but it is not clear if these are foliated or not. The strike of foliation is around 020-040 and dips are medium to high N.W. It is not clear to what generation this foliation belongs; judging from attitude alone it could be S3-4 or S5.

The ore deposit is predominantly a fissure-filling vein type which is concentrated along the gneiss/greenschist junction. Earlier workers have classified the ore into two groups - breccia with

chalcopyrite or cupriferous pyrite and an impregnated network of lower grade. The ore is oxidised to depths of 50m. Malachite, chrysocolla and some native copper predominate. At a depth of between 50m and 70m secondary enrichment occurs. Below this is primary ore associated with molybdenite. The Nippon Mining Co. Ltd. (op.cit) calculated the sulphide ore reserve at 765,764 tons with a copper content of 49,871 tons.

The country rock is kaolinised, silicified and chloritized. It is not clear how far these alteration products are directly the result of mineralizing agencies or how far they are the result of events of F4 and F5 tectonism.

The Nile Congo Divide Syndicate (op.cit) stated that on both sides of the mine there are quartzite haematite lodes similar to those at Bishura and Waranga to the S.S.W. On the aerial photographs these lodes could not be located, nor - save for float - could such rocks be seen in the field. If the observation and correlation are correct - and the Syndicate's observations were generally well founded - it suggests that the Hofrat en Nahas Mine is located in an antiform area between two F4 synclines.

Higham, of the Nile Congo Divide Syndicate, regarded the mine area as representing a trough fault, subsequently diagonally traversed by further faulting. The Syndicate geologists also concluded that in general, increase in intensity of faulting could be correlated with increasing richness of ore.

It seems probable that the faults noted during the drilling and trenching acted as the locus of mineralization. It also seems possible that they represent surfaces related to S4-5 and S6 rather than discrete faults.

The other copper deposits have not received the same degree of attention as those at Hofrat en Nahas. The work has been almost entirely confined to brief visits with limited amounts of pitting and trenching. More rarely drilling has been undertaken. This has led to classification

of these deposits at separate localities, e. g. "the Waranga deposit", "the Bishura deposit" etc. During the present survey it was concluded that mineralization was virtually continuous throughout the S5-S6 surfaces of the Central Synform and the Northern and Eastern Area. Deposits on bedding surfaces of the Quartzite Schist Group were also common in these areas. None of these deposits appeared to be of any size - many were confined to faint staining of the S-surfaces.

The mineralization is often associated with intense tourmalinization of the pegmatites, cataclasites and thin bands of the quartzite and quartz schist adjacent to the cataclasites. Specularite commonly accompanies this mineralization.

Within these localities it has been noted by earlier workers that ore occurrences conform to the strike and dip. This observation should be qualified in that the ore conforms to strike and dip of any structural or lithological surface in which it occurs. Most of the mineralization occurs at change in lithology but as structural surfaces in the Quartzite Schist Group markedly diverge from bedding only in fold closures, in most localities mineralization conforms to all surfaces.

Much of the "vein" quartz in the hill crests - e. g. Waranga - noted during earlier work is now believed to be the sheared remnants of synclinal closures of the Quartzite Schist Group. The presence of "Brown Schists" - cataclasites - around these "veins" lends support to their interpretation as synclines. These "veins" appear also to keep a constant structural position similar to that in which closures of F4 are inferred. Thus, Gurnsey (1948) notes that the tourmalinized and granular quartz, with subordinate specularite, diverges northwards from J. Waranga and that these zones follow the structure of the "Brown Schists". He also notes that these tourmalinized zones "seem to have a distinct affinity for the "volcanic" (i. e. tourmalinized quartzite and quartz schist) members", and that copper mineralization at Bushura, Zanad and Waranga is restricted to these "volcanics".

"Calcareous quartzites" described in the mineralized zones by earlier workers appear to be epidotized mylonites derived from the Gneiss Complex and subsequently weathered.

The Nile Congo Divide Syndicate noted that the central lode at Waranga is closely associated with granitic intrusion. This conclusion is almost certainly wrong. The lodes are apparently invariably infolded with the granitic gneiss.

Traces of copper mineralization in the Kafia Kingi, J. Siomo and J. Terezol areas have been noted in the granitic gneiss and gneissose granites. Similar traces have also been recorded in nearby pegmatites. These traces are invariably accompanied by tourmalinization. It is thought that this mineralization is also associated with synclinal F4 axes which until recently preserved outliers of the Quartzite Schist Group, but that these have now been almost entirely eroded. Stages at which some Quartzite Schist Group remain have been noted at J. Cheili and in the cataclasites of the hills north and north-west of Songo.

Although suggestions and conclusions on the structural control of mineralization can be advanced, hypotheses relating to the source of mineralization and the possibilities of large economic deposits occurring remain nebulous. The following points are of significance in summarizing the position:-

- (a) Post-tectonic intrusives appear to be absent, with the dubious exception of some thin veins described in borehole logs from Hofrat en Nahas.
- (b) Although pegmatites - more or less foliated - are locally the host rock of copper mineralization the association is spasmodic and no causal relationship can be inferred.
- (c) The genesis of the Migmatite Complex is associated in time with the generation of F4 and F5 folds.
- (d) Mineralization is noted almost exclusively adjacent to F4 axes and where there is no obvious relationship apparent

there are some indications of the past occurrence of these axes (e. g. Hofrat en Nahas, J. Siomo).

- (e) The absence of records of copper occurrences outside the Central Synform except for the localities of the Northern and Eastern Area, suggests that the source of mineralization occurs between the two areas of migmatite presently exposed.
- (f) The most continuous traces of mineralization are along the Hofrat en Nahas - Waranga hill line, but the occurrence of mineralization along F4 axes away from this line indicates that this continuity of mineralization is due in turn to the continuity of F4 axes. There is no evidence of other control of mineralization along the hill line.
- (g) The regional fracture pattern has no recognizable relationship to copper mineralization, although the fact that the richest known deposit (Hofrat en Nahas) is near the intersection of an inferred fracture belt with a line of major F4 axes may be of significance.

The hypothesis that emerges as most probable on the present evidence is that the mineralization occurred during the last major period of tectonism. The mineralizing agencies reached their most active state during the development of F4 folds. Their upward progress was barred by a then extensive cover of siliceous sediments which they could only penetrate through the developing S-surfaces. Cataclasites below these sediments provided a more easily penetratable environment, hence concentration occurred along the junction of these units. After the mineralization further folding determined the distribution of these deposits. Since that time erosion has greatly reduced their extent.

This hypothesis does not of itself indicate the possibility of further favourable conditions for concentration of mineralization locally within the Gneiss Complex. It is possible that the mineralizing agencies

derived the copper from a pre-existing deposit at depth which may still exist. It is also possible that country rock more favourable to mineralization occurs within the Gneiss Complex (e.g. the limestones and marbles) but is at present unexposed.

5.3 GOLD

Alluvial gold has been won in small amounts. The Nile Congo Divide Syndicate actively prospected for the metal with unfavourable results. They concluded that much of the gold in the streams had been derived from the disintegration of small quartz bodies and stringers which contain very little gold in themselves but that the alluvium had concentrated the gold over a long period.

Some of the localities they examined are outside the area of the present photogeological study but are noted as they are of general interest.

Ferruginous quartz reefs were examined at Kafia Kingi and to the east of the village. Tourmalinized ferruginous quartzite was found in the Yakka Hills, Kiki Hills, Abulenda-Lyi and the Ringi Hills. Alluvial gold was found in the Khor Lilli at Boro but the most promising gravels were in the Ibba River near the Yambio-Tong road crossing where up to 120 colours per pan were obtained.

The tourmalinization of the vein quartz appears similar to that associated with the copper mineralization and may indicate contemporaneity of the two types of mineralization, in which case the distribution of gold may be greater than hitherto indicated.

5.4 OTHER MINERALS

Tin lodes were reported by a Mr. Lane in 1914. That gentleman had experience of tin occurrence in Malaya and thought he recognized similar deposits "15 miles west of Kafia Kingi" (Affia and Widatalla, 1961). This has not been located by any other workers and no other indications of tin have been reported.

GEOLOGICAL HISTORY

Iron occurs in vast amounts in the iron-pan and iron cemented

gravels but is nowhere of sufficient grade to warrant classification as ore. Iron minerals associated with the copper mineralization are of small volume.

| | | |
|--|---|--|
| <p>Final emplacement of magnetites SE Dome NE-SW, NW-SE NNE-SSW F5 folds S6 surfaces</p> <p>Mineralization NE-SW, NW-SE NNE-SSW F4 folds S5 surfaces</p> <p>Development of magnetite and cataclastic begins</p> | <p>Mixed argillaceous and arenaceous deposits with local gravels argillaceous and calcareous deposits</p> <p>Sandy and pebbly residual deposits with ferruginous cement</p> | <p>ALUVIUM QUATERNARY TCHAD SERIES TERTIARY LATERITE</p> |
| <p>MESOZOIC EROSION</p> | | |
| <p>SECOND OROGENIC CYCLE</p> <p>Final emplacement of magnetites SE Dome NE-SW, NW-SE NNE-SSW F5 folds S6 surfaces</p> <p>Mineralization NE-SW, NW-SE NNE-SSW F4 folds S5 surfaces</p> <p>Development of magnetite and cataclastic begins</p> | <p>MIGMATITE GROUP QUARTZITE SCHIST GROUP Rudites Arenites Argillites</p> | <p>QUATERNARY TERTIARY MESOZOIC EROSION</p> |
| <p>FIRST OROGENIC CYCLE</p> <p>Metamorphism</p> <p>Quartzites with marble Gneiss S1-S2 surfaces F1 folds</p> <p>Syntectonic granite S3-S4 surfaces F2-F3 folds E-W axes</p> <p>Post-tectonic granite S5-S6 surfaces F4-F5 folds E-W axes</p> | <p>IRON RICH ARENITE EROSION FERRUGINOUS QUARTZITE</p> | <p>QUATERNARY TERTIARY MESOZOIC EROSION MESOZOIC EROSION</p> |

TABLE 1

GEOLOGICAL HISTORY

| AGE | FORMATION | SEDIMENTS | PLUTONISM AND TECTONISM |
|--------------------------------------|--|---|---|
| QUATERNARY | ALLUVIUM | | |
| TERTIARY | TCHAD SERIES | Mixed argillaceous and arenaceous deposits with local gravels gypsiferous and calcareous deposits | |
| | LATERITE | Sandy and pebbly residual deposits with ferruginous cement | |
| E R O S I O N | | | |
| MESOZOIC | Nubian sandstone possibly extended over Project Area | | |
| E R O S I O N | | | |
| ? P A L A E O Z O I C | MIGMATITE GROUP | | Final emplacement of migmatites SE Dome NE-SW, NNE-SSW axes F5 folds S6 surfaces Mineralization NE-SW, NNE-SSW axes F4 folds S5 surfaces Development of migmatite and cataclasite begins |
| | QUARTZITE SCHIST GROUP | Rudites Arenites Argillites | S E C O N D O R O G E N I C C Y C L E |
| E R O S I O N | | | |
| P R E C A M B R I A N | FERRUGINOUS QUARTZITE | Iron rich arenite | |
| | GNEISS COMPLEX | E R O S I O N | Pegmatite |
| Syntectonic granite | | Post-tectonic granite E-W axes F2 F3 folds S3-S4 surfaces ? | F I R S T O R O G E N I C C Y C L E |
| Arenite and argillite with limestone | Gneiss with marble Metamorphism | F1 folds S1-S2 surfaces | |

REGIONAL FRACTURE PATTERN DEVELOPS ALONG PRE-ESTABLISHED LINES OF WEAKNESS

S E C O N D O R O G E N I C C Y C L E

F I R S T O R O G E N I C C Y C L E

6. GEOLOGICAL HISTORY

The earliest phase of the geological history known is the evolution and destruction of a Precambrian geosyncline. The oldest rocks represented are thought to be the sediments within the Gneiss Complex. The limestones and those gneisses which show S1 traces are clearly older than the less foliated gneissose granites and granitic gneisses. Although the relevant rock units cannot be delineated it is reasonably clear that the early sediments were folded and metamorphosed prior to the intrusion of the youngest granitic rocks. It is suspected that two distinct groups of granitic rocks are present. The younger are gneissose granites and the older a series of strongly foliated biotite gneisses partly representing syntectonic granites and partly representing granitised sediments. The latter are those biotite gneisses showing most variation in the mineralogy of the banding and rapid textural differences.

At a late stage in the history of the geosyncline, strong nearly vertical isoclinal folds trending E-W developed. The gneissose granites noted above may be younger than those movements, or - less probably - may represent lightly foliated residuals of much larger granite masses. In this context it is interesting to note on the 1:100,000 map that the density of foliation around the gneissose granite is generally less than in the Gneiss Complex. These areas of little foliation may represent the extent of the younger granitic rocks.

A period of pegmatitic intrusion is the last plutonic event during the evolution of the Gneiss Complex.

Ferruginous arenaceous sediments were deposited upon the already folded basement and were then infolded with the basement. The age relationship between these sediments and the pegmatites and granites is not known. The sediments are probably younger. The movement which folded the sediments in the basement are younger than F3-4 but appear to be older than the post-Quartzite Schist surfaces. No

distinct surface that can be labelled has been recognized linking these sediments with the structures in the Gneiss Complex.

The geological history after these events is much clearer. Sedimentation of arenites, argillites and rarer rudites was general over the Gneiss Complex which by then had been deeply eroded. The subsequent tectonic events reduced those sediments to nearly uniform quartzites and sericitic schists in which only occasional "ghosts" of larger fragments can be recognized. For this reason the conditions of sedimentation cannot be clearly recognized. Traces of current bedding in the arenites, the presence of detrital feldspar and the absence of volcanic deposits suggest that local conditions were deltaic or basinal in type rather than truly geosynclinal.

Intense isoclinal folding on NE-SW to NNE-SSW axes followed this sedimentation. The axial planes were probably nearly vertical and show amplitude greatly exceeding fold length. New structures produced by these folds fade rapidly into the gneiss across the strike of the folds but appear to persist in depth. Minor structures along the contact between the Quartzite Schist Group and the gneisses show folds whose amplitude exceeds fold width by a factor of ten or more. This type of folding caused great differential movement between the two groups of rock. Thick zones of cataclasites developed.

During this phase of folding (F4) the metamorphism within the sediments and at the contacts with the gneiss was predominantly dynamic and this state also applied to the adjacent portions of the gneiss where augen gneiss developed. At lower levels within the gneiss thermal effects predominated with sillimanite and garnet forming in the highest grade of metamorphism around the developing Migmatite Group. Metasomatic activity mobilized copper and iron - either as a primary cycle of mineralization or, by remobilizing existing deposits, as a secondary cycle. Extensive tourmalinization accompanied this mineralization. The main zone of mineralization appears to have been confined between the developing major (F5) anticlinal axes along which

the Migmatite antiforms were located. The minerals were deposited at the base of the relatively impermeable capping of younger sediments which had reached the state of quartzites and schists. "Brown Schists" were formed by ferruginous deposits in the cataclasites.

As the intensity of tectonic activity increased more deep-seated folds developed. The axes of these F5 folds were sufficiently oblique to F4 axes to refold them sharply where the axes intersected. This stage of tectonism coincides with the maximum mobility of the migmatites, the last phase of which appears to cause the development of doming in the south-east of the project area. This doming distorts fold axes of all known groups.

At high structural levels within these F5 folds some sliding - possibly nappe structures - developed. This is seen in the overturned and truncated S4 folds on the western margin of the J. Miri antiform.

A regional fracture pattern was established in association with the last phase of tectonism. In the frontier area cross-faults with a considerable shear component post-date F4 axes, but are older than the F5 J. Miri Antiform. Their trend is controlled by the strike of S3-S4 surfaces within the Gneiss Complex. A similar set of fractures undoubtedly younger than F5 exists, and in areas away from the J. Miri Antiform all these fractures appear to be contemporaneous and continuous. Hence, the evolution of these fractures is obviously extensive in time.

A period of erosion followed this second orogenic cycle. No deposits associated with the Nubian Sandstone are known in this area although they are known to the north-west of the project area. Their former extension within the area is suggested by the degree of peneplanation of the area.

Following a further period of erosion in which any Mesozoic sediments were removed, laterites of Oligocene age formed. It is possible that thin remnants of Mesozoic sediments are buried beneath

the laterite but no rocks of this nature have as yet been identified. The area was then tilted to the north and the north-western section buried beneath Quaternary continental deposits. Generally low gradients, and high rate of evaporation led to much internal drainage with consequent calcareous and gypsiferous deposits.

Warm springs in the adjacent portion of the Central African Republic and the occurrence of the dormant volcano of Jebel Marra to the north testify to recent volcanic activity in the general area.

The age of the Gneiss Group, the Quartzite Schist Group and the different orogenies noted remains conjectural. That the latter is much younger than the former is clear from the structural evidence, and the suggestion (Delafosse, 1960) of the latter's age as ?Palaeozoic in the Central African Republic is followed in the map legend accompanying this report. More extensive mapping programmes and radiometric dating would tie in the events with others known in Africa. If radiometric dating is possible it is suggested that the migmatites and the J. Siomo gneissose granite would provide useful data. Selecting samples in the Gneiss Complex to give reliable dates as to their original age will be difficult owing to the extent of younger tectonic activity. In the meantime, it is interesting to speculate on the apparent identity of the Quartzite Schist Group with the Togo/Atacorien of West Africa. This similarity is evident both in points of detail and in the relationship of both groups of rock with their basement of gneisses. In West Africa the gneiss complex is referred to as Dahomeyan which is believed to be a complex of Birrimian sediments with post-Birrimian granites, largely reconstituted during orogeny of Caledonian age.

In this correlation the Ferruginous Quartzites would appear to have a position similar to the Tarkwaian of West Africa which is noted for its auriferous conglomerates.

7. RECOMMENDATIONS

Known mineralization of possible economic significance is restricted to copper. Gold is not known to be of near economic significance but if the recommendations made below were followed any trace of gold of significance should be located and if tin or diamonds occur in more than isolated grains, they too should be located.

The airborne magnetometer survey should provide considerable data of use in interpreting the structure. Little direct information as to probable areas of mineralization is anticipated although any anomalous patterns revealed at Hofrat en Nahas could be of interest if they recur elsewhere. The occurrence of uranium minerals at the mine (Afia and Widatalla, 1961) indicates that radiometric surveys could be of use, although it seems probable that there is sufficient soil and lateritic cover to mask most anomalies of this nature.

Further work would be most productive if aimed at specific targets. Those suggested are:-

1. Examination of alluvium throughout the project area by concentration of heavy minerals and geochemical sampling. The examination of heavy minerals within the drainage at regular intervals would appear to be the most direct method of delimiting areas of mineralization. The distribution and concentration of tourmaline might be established as a guide to the main areas of copper mineralization. The concentration of tourmaline observed in pegmatites also indicates that any major pegmatite deposits would be similarly located. Any gold, tin and diamond occurrence of significance would also become apparent during this survey. The heavy mineral sampling could be combined with geochemical sampling within the drainage. Orientation surveys would be the first requirement to determine which elements should be analysed. It seems fairly certain that no difficulty

would be encountered in sampling the main drainage directly for copper. In the upper stretches of drainage the large proportions of laterite in the channels would add a complicating factor to interpretation. The extensive laterite cover would render soil sampling very difficult to achieve and of uncertain value.

However, sampling of the Quartzite Schist Group margins, which are relatively free of laterite, would be of importance and should lead to the definition of areas of greater copper enrichment. Sampling at 1 km intervals as a first stage appears to be practicable.

2. Examination of the Gneiss Complex - cataclasite - Quartzite Schist Group junctions in the area of the Central Synform and Northern Area. The Hofrat en Nahas mine is included in this group of targets.

In areas of high copper values revealed by the geochemical survey, Induced Polarisation geophysical surveys would be a valuable method of search. In the areas of the Quartzite Schist Group this should be combined with the detailed outcrop mapping as there is sufficient outcrop for direct search to be of value. Similar methods at the Hofrat en Nahas mine, J. Waranga and J. Yirongo would appear to be of first importance.

3. Examination of pegmatites in the same area by traversing.
4. Examination of the area noted as containing marble on the eastern flank of the J. Miri antiform. These areas should be examined as similar rocks often form good hosts for mineralization. Here they appear to be very poorly exposed. Besides direct outcrop examination, it appears desirable to attempt to delimit the extent of the marbles under the superficial cover by ground magnetometer traverses which may show them up as non-magnetic bodies within the biotite gneisses.

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SUMMARY OF FEATURES OF MICROSCOPICALLY INVESTIGATED ROCKS

| Sheet No. | Sample No. | Rock Name | Mineralogical Constituents* | Texture and Remarks |
|-----------|------------|---------------------------------------|---|--|
| 3 | B 7 | Porphyritic hornblende-quartz syenite | kfs-pl(ab)-amph-qtz-bi-sph-zc -op-chl | medium to coarse-grained; hypidiomorphic |
| 3 | B 8 | Tourmalinized breccia | tm-qtz-ser-op | ovoids of strained quartz granules in matrix of fine-grained tourmaline |
| 3 | B 10 | Granitic gneiss | kfs-pl(An5-15)-qtz-bi- ms-chl-ser | fine to medium-grained; schistose |
| 3 | B 11 | Sillimanite-quartz gneiss | qtz-sill-bi-op-zc-tm | fine to medium-grained; schistose |
| 3 | B 13 | Garnet-hornblende-quartz schist | qtz-kfs-gt-hbl-bi-chl- op | fine-grained schistose |
| 3 | B 14 | Granitic gneiss | qtz-kfs-pl(An5-15)-bi- ms-chl-op | fine to medium-grained; massive, schistose |
| 5 | B 18 | Granitic gneiss | qtz-mi-pl(An20)-bi- hbl-gt-ap-zc-tm-op | fine to medium-grained; finely laminated |
| 5 | B 21 | Quartzite | qtz-(op)-(ser) | fine to medium-grained; strongly sheared; larger ragged ovoids of quartz granules in a groundmass of fine-grained quartz |
| 5 | B 22 | Garnet amphibolite | hbl-gt-pl(An15-20)- qtz-bi-chl | medium to coarse-grained; slightly foliated |

* See end of table key.

| Sheet No. | Sample No. | Rock Name | Mineralogical Constituents | Texture and Remarks |
|-----------|------------|--------------------------|--|---|
| 5 | B 25 | Garnet amphibolite | hbl-gt-pl(An15-20)-diops-qtz-bi-chl-op-ser | medium to coarse-grained; slightly foliated |
| 4 | B 26 | Tourmaline granite | kfs-pl-(An5-10)-qtz-tm-bi-ms-ap | medium to coarse-grained; prophyritic (kfs); slightly foliated |
| 4 | B 31 | Granitic gneiss | kfs-pl(An5-10)-qtz-bi-ms-chl | fine to medium-grained; gneissose |
| 4 | B 33 | Granitic gneiss | qtz-kfs-pl(An5-10)-bi-ms-chl-op | fine to medium-grained; strongly gneissose |
| 4 | B 39 | Hornblende-quartz schist | hbl-qtz-pl(An25-30)-diops-op | fine to medium grained; schistose |
| 1 | J 4 | Quartzite | qtz-lim | medium to fine-grained; strongly foliated; quartz grains strongly ragged; limonitic material along grain boundaries |
| 4 | J 6 | Tourmaline granite | qtz-kfs-pl-(An5-10)-tm-ms | medium to coarse-grained; foliated |
| 3 | J 12 | Quartzite | qtz-op-chl | fine to medium-grained; ragged quartz grains strongly drawn out |
| 4 | J 23 | Tourmaline granite | mi-pl(An5-10)-qtz-ms-tm | medium to coarse-grained; compositional zoning in plagioclase |

SUMMARY OF LEVELS OF MICROSCOPICALLY INVESTIGATED ROCKS
 ВЪВЕДИХ

| Sheet No. | Sample No. | Rock Name | Mineralogical Constituents | Texture and Remarks |
|-----------|------------|---------------------|-----------------------------------|--|
| 2 | J 26 | Quartzite | qtz-ser | medium to fine-grained; strongly sheared; ragged grain boundaries |
| 4 | J 27 | Granitic gneiss | qtz-mi-pl(An5-10)-bi | fine to medium-grained; gneissose |
| 2 | J 28 | Quartzite | qtz-ser-tm-zc | fine to medium-grained; strongly sheared |
| 2 | L 1 | Quartzite | qtz-ser-lim | fine to medium-grained; strongly sheared |
| 3 | L 2 | Cataclastic granite | qtz-mi-pl(An5-10)-ser-tm-op | medium to coarse-grained; relics of compositional zoning in plagioclase quartz slightly granulated; occasionally broken twin lamellae in plagioclase |
| 3 | L 3 | Cataclastic granite | qtz-mi-pl(An5-10)-ser-op | medium to fine-grained; twin lamellae in plagioclase broken and twisted; microcline shows strongly braided perthitic intergrowth with plagioclase |
| 3 | L 4 | Hornblende hornfels | hbl-pl-(An10-15)-mi-qtz-ep-sph-ap | fine to medium-grained; slightly schistose |
| 3 | L 5 | Quartzite | qtz-pl-(An5-10)-ser | fine to medium-grained; quartz partly recrystallized into larger crystals |

| Sheet No. | Sample No. | Rock Name | Mineralogical Constituents | Texture and Remarks |
|-----------|------------|-------------------------|-----------------------------|---|
| 3 | L 6 | Cataclastic granite | qtz-mi-pl(An5-15)-ms-chl-op | medium-grained; broken twin lamellae; granulated quartz |
| 3 | L 7 | Quartz-albite schist | qtz-ab-ms-ep | medium to fine-grained; weakly schistose |
| 3 | L 8 | Quartz-muscovite schist | qtz-ms-chl-mi-op-zc | fine to medium-grained; schistose |
| 3 | L10 | Quartzite | qtz-ms-op | fine to medium-grained; strongly sheared |
| 3 | L 20 | Quartzite | qtz-ms-op | fine to medium-grained; strongly sheared |

KEY

| | | | | | |
|---------------|---|-----------------|------|---|--------------------|
| ab | = | albite (An 10%) | kfs | = | potassium feldspar |
| amph (An5-15) | = | amphibole | lim | = | Fe-oxides |
| ap | = | apatite | mi | = | microcline |
| aug | = | augite | ms | = | muscovite |
| bi | = | biotite | op | = | opaque ore |
| chl | = | chlorite | pl | = | plagioclase |
| diops | = | diopside | qtz | = | quartz |
| ep | = | epidote | ser | = | sericite |
| gt | = | garnet | sill | = | sillimanite |
| hbl | = | hornblende | sph | = | sphene |
| | | | tm | = | tourmaline |
| | | | zc | = | zircon |

UNITED NATIONS DEVELOPMENT PROGRAMME
REPUBLIC OF THE SUDAN
MINERAL SURVEY IN THREE SELECTED AREAS

GEOLOGICAL MAP

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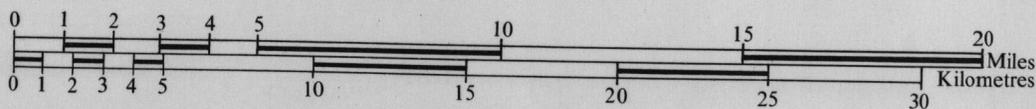
HOFRAT EN NAHAS AREA

WESTERN SUDAN

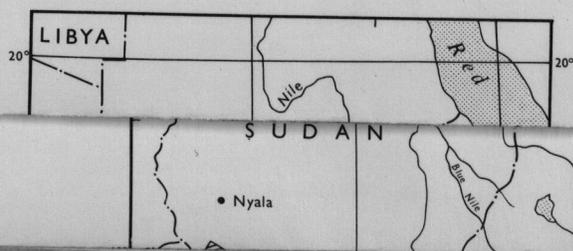
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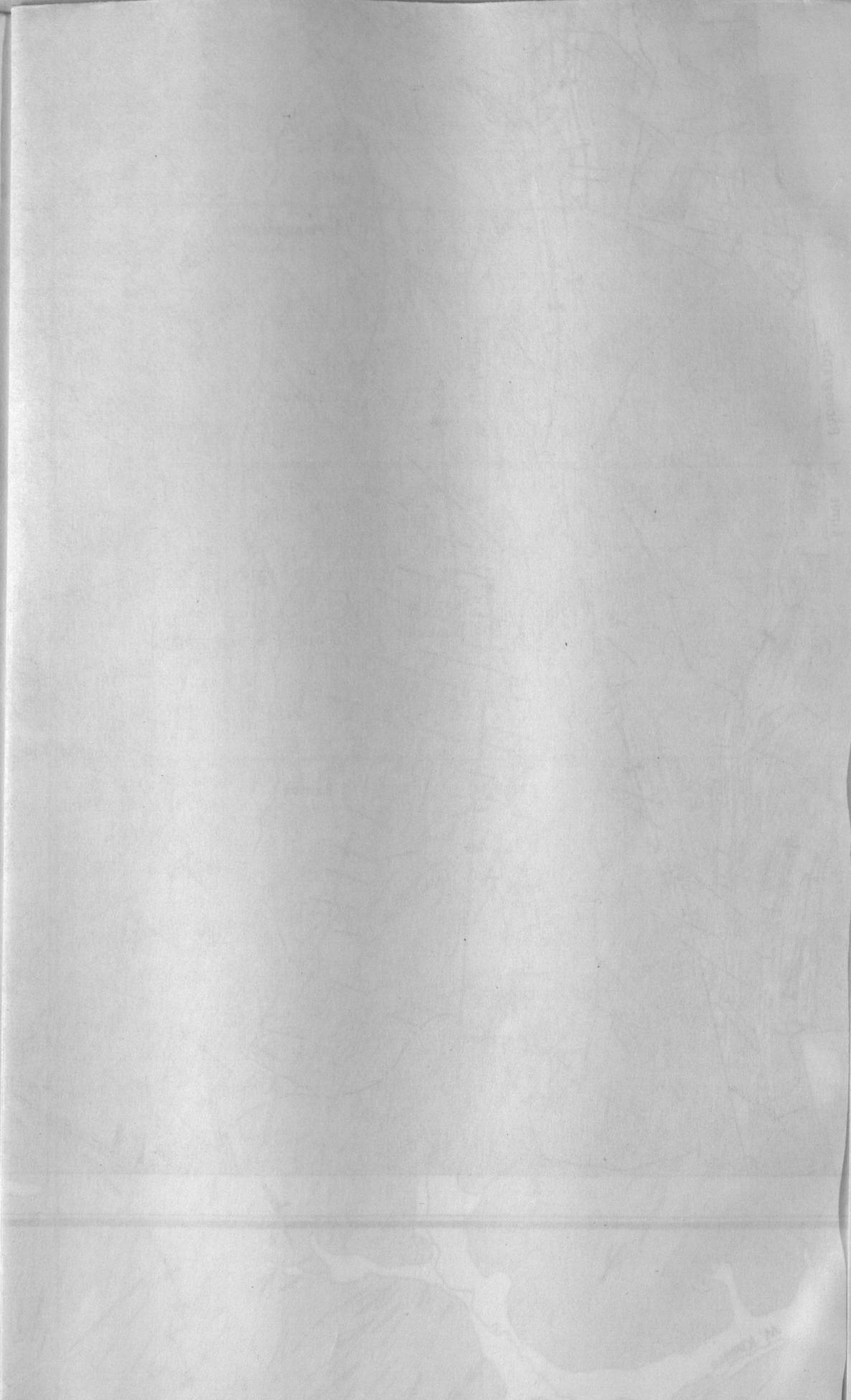
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MINERAL SURVEY IN THREE SELECTED AREAS

CLASSIFICATION OF MAJOR STRUCTURAL ELEMENTS

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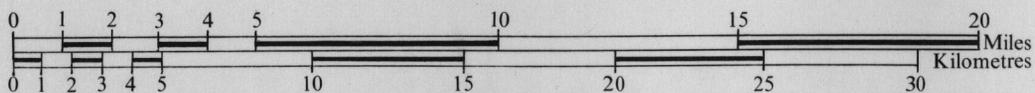
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