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UNITED NATIONS
DEVELOPMENT PROGRAMME

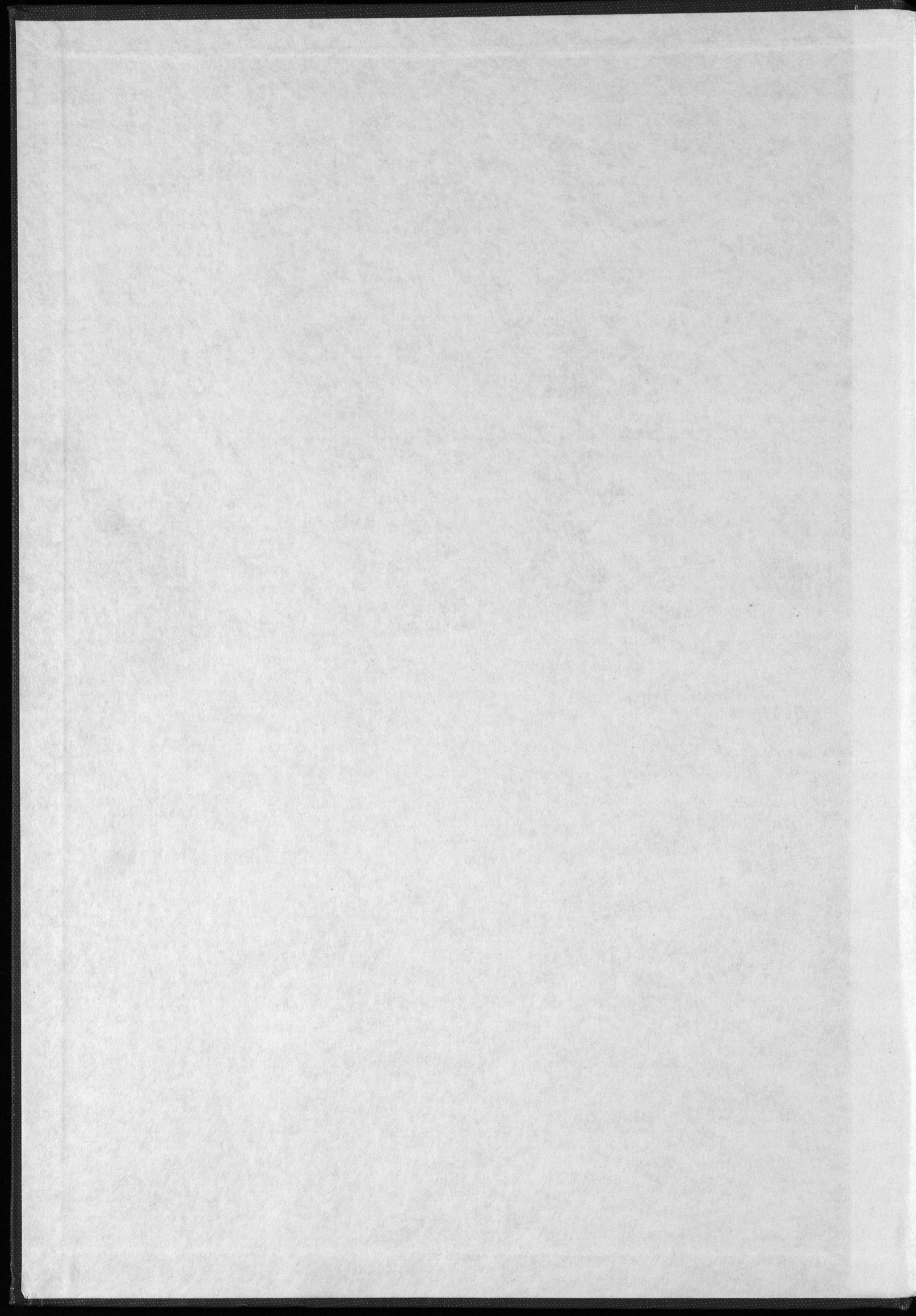
REPUBLIC OF THE SUDAN

MINERAL SURVEY IN THREE SELECTED AREAS
IN
REPUBLIC OF THE SUDAN

PHOTOGEOLOGICAL SURVEY
OF THE EASTERN AREA

HUNTING GEOLOGY AND GEOPHYSICS LTD.
1969

136A



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ACKNOWLEDGEMENTS

ABSTRACT

We gratefully acknowledge the help 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 we are much indebted to the Director, Mr. Abdul Latif Widatalla and to the Project Co-Manager, Mr. Ibrahim Mudawi Babiker.

Amongst the staff of the United Nations our thanks are due to Mr. D. Manson, Assistant Resident Representative and Mr. G.N. Small for their assistance on many administrative and organisational matters.

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

Recommendations are given for further work.

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Mehawi Babiker

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CONTENTS

	Page No.
ACKNOWLEDGEMENTS	1
ABSTRACT	iii
1. ORGANISATION	
1.1 GENERAL	1
1.2 SPECIFICATION OF PHOTOGEOLOGICAL SURVEY	1
1.3 EXECUTION OF THE CONTRACT	2
<p>The results are presented of a photogeological study of the area between Qala en Nahl and the Ingessana Hills, Eastern Sudan, comprising approximately 11,000 sq.km.</p>	
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<p>Recommendations are given for further work.</p>	
3. LITHOLOGICAL UNITS	
3.1 THE GNEISSES	15
3.2 THE METASEDIMENTARY ROCKS	16
3.3 THE SERPENTINITE GROUP	18
3.3.1 Serpentinites	18
3.3.2 Talc-carbonate Rocks	19
3.3.3 Silicified Serpentinite and Birbirite	21
3.4 THE CENTRAL INGESSANA MAFIC COMPLEX AND THE EPIDIORITES OF QALA EN NAHL	22
3.5 THE WAD WADEDA MAFIC COMPLEX	24
3.6 THE GRANITIC ROCKS	26
3.7 THE NUBIAN SANDSTONE	27

ABSTRACT

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CONTENTS

	Page No.
ACKNOWLEDGEMENTS	i
ABSTRACT	iii
1. ORGANISATION	
1.1 GENERAL	1
1.2 SPECIFICATION FOR THE PHOTOGEOLOGICAL SURVEY	1
1.3 EXECUTION OF THE CONTRACT	2
1.4 AERIAL PHOTOGRAPHY	3
1.5 MOSAIC	3
1.6 PHOTOGEOLOGICAL PROCEDURES	3
1.7 PREPARATION OF THE 1:100,000 SCALE MAP SERIES	4
1.8 PREPARATION OF THE SMALL SCALE GEOLOGICAL MAP ACCOMPANYING THIS REPORT	4
1.9 TRAINING	5
1.10 PERSONNEL	5
2. GENERAL OUTLINE OF THE GEOLOGY	
2.1 GENERAL STATEMENT	7
2.2 PREVIOUS WORK	7
2.3 MORPHOLOGY	10
2.3.1 The Qala en Nahl Hills and Surrounding Pediments	10
2.3.2 The Rahad - Dinder - Blue Nile Flood Plains	11
2.3.3 The Ingeessana Hills and Surrounding Pediments	12
3. LITHOLOGICAL UNITS	
3.1 THE GNEISSES	15
3.2 THE METASEDIMENTARY ROCKS	16
3.3 THE SERPENTINITE GROUP	18
3.3.1 Serpentinites	18
3.3.2 Talc-carbonate Rocks	19
3.3.3 Silicified Serpentinite and Birbirite	21
3.4 THE CENTRAL INGESSANA MAFIC COMPLEX AND THE EPIDIORITES OF QALA EN NAHL	22
3.5 THE WAD WADEDA MAFIC COMPLEX	24
3.6 THE GRANITIC ROCKS	26
3.7 THE NUBIAN SANDSTONE	27

CONTENTS (Continued)

	Page No.
3.8 SUPERFICIAL SEDIMENTS	28
3.8.1 Alluvium	28
3.8.2 Undifferentiated Soils	29
3.8.3 Calcrete (Kankar)	29
3.8.4 Valley Gravels	29
4. STRUCTURE	
4.1 GENERAL	31
4.2 THE AREA AROUND QALA EN NAHL	31
4.3 THE INGESSANA HILLS	34
5. MINERALISATION AND ECONOMIC GEOLOGY	
5.1 GENERAL	37
5.2 CHROMITE	37
5.3 ASBESTOS	38
5.4 MAGNESITE	38
5.5 COPPER	38
5.6 HEMATITE	39
5.7 GOLD	39
5.8 BUILDING MATERIAL	39
6. GEOLOGICAL HISTORY	41
7. CONCLUSIONS AND RECOMMENDATIONS	43
BIBLIOGRAPHY	45

APPENDICES

APPENDIX A	SUMMARY OF RESULTS OF UNDERGROUND WORK AT QALA EN NAHL, AFTER RUXTON (1957-b)	49
APPENDIX B	BOREHOLES ILLUSTRATING THE COMPOSITION OF THE NUBIAN SANDSTONE AND OF THE ALLUVIAL FLOOD PLAIN DEPOSITS OF RAHAD, DINDER AND BLUE NILE, AFTER GEOLOGICAL SURVEY DEPARTMENT DATA	51
APPENDIX C	SUMMARY OF THE FEATURES OF MICROSCOPICALLY INVESTIGATED ROCKS	55

CONTENTS (Continued)

LIST OF ILLUSTRATIONS

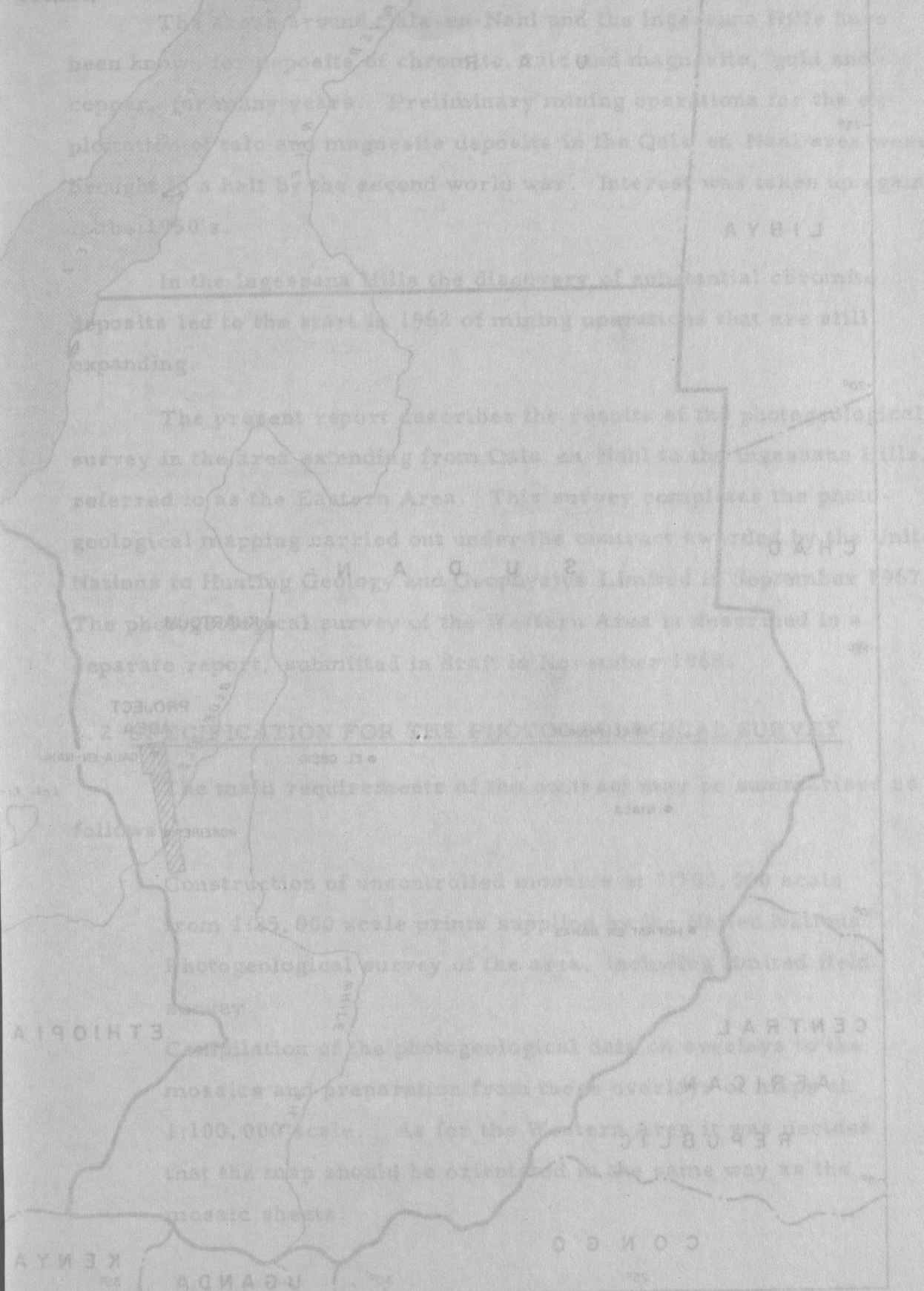
		Facing Page No.
Figure 1	Location map of the Project Area	1
Figure 2	Index to mosaics and 1:100,000 scale map sheets	2
Figure 3	Field traverses	4
Figure 4	Morphological units	10
Table I	Summary of photo characteristics of rock groups	On Page 14
Table II	Geological history	41
Map	1:300,000 scale geological map of the Project Area	

CONTENTS (Continued)

	Page
LIST OF ILLUSTRATIONS	25
1. Photographs of the study area	27
2. Map of the study area	28
3. Map of the study area	29
4. Map of the study area	30
5. Map of the study area	31
6. Map of the study area	32
7. Map of the study area	33
8. Map of the study area	34
9. Map of the study area	35
10. Map of the study area	36
11. Map of the study area	37
12. Map of the study area	38
13. Map of the study area	39
14. Map of the study area	40
15. Map of the study area	41
16. Map of the study area	42
17. Map of the study area	43
18. Map of the study area	44
19. Map of the study area	45
20. Map of the study area	46
21. Map of the study area	47
22. Map of the study area	48
23. Map of the study area	49
24. Map of the study area	50
25. Map of the study area	51
26. Map of the study area	52
27. Map of the study area	53
28. Map of the study area	54
29. Map of the study area	55
30. Map of the study area	56
31. Map of the study area	57
32. Map of the study area	58
33. Map of the study area	59
34. Map of the study area	60
35. Map of the study area	61
36. Map of the study area	62
37. Map of the study area	63
38. Map of the study area	64
39. Map of the study area	65
40. Map of the study area	66
41. Map of the study area	67
42. Map of the study area	68
43. Map of the study area	69
44. Map of the study area	70
45. Map of the study area	71
46. Map of the study area	72
47. Map of the study area	73
48. Map of the study area	74
49. Map of the study area	75
50. Map of the study area	76
51. Map of the study area	77
52. Map of the study area	78
53. Map of the study area	79
54. Map of the study area	80
55. Map of the study area	81
56. Map of the study area	82
57. Map of the study area	83
58. Map of the study area	84
59. Map of the study area	85
60. Map of the study area	86
61. Map of the study area	87
62. Map of the study area	88
63. Map of the study area	89
64. Map of the study area	90
65. Map of the study area	91
66. Map of the study area	92
67. Map of the study area	93
68. Map of the study area	94
69. Map of the study area	95
70. Map of the study area	96
71. Map of the study area	97
72. Map of the study area	98
73. Map of the study area	99
74. Map of the study area	100

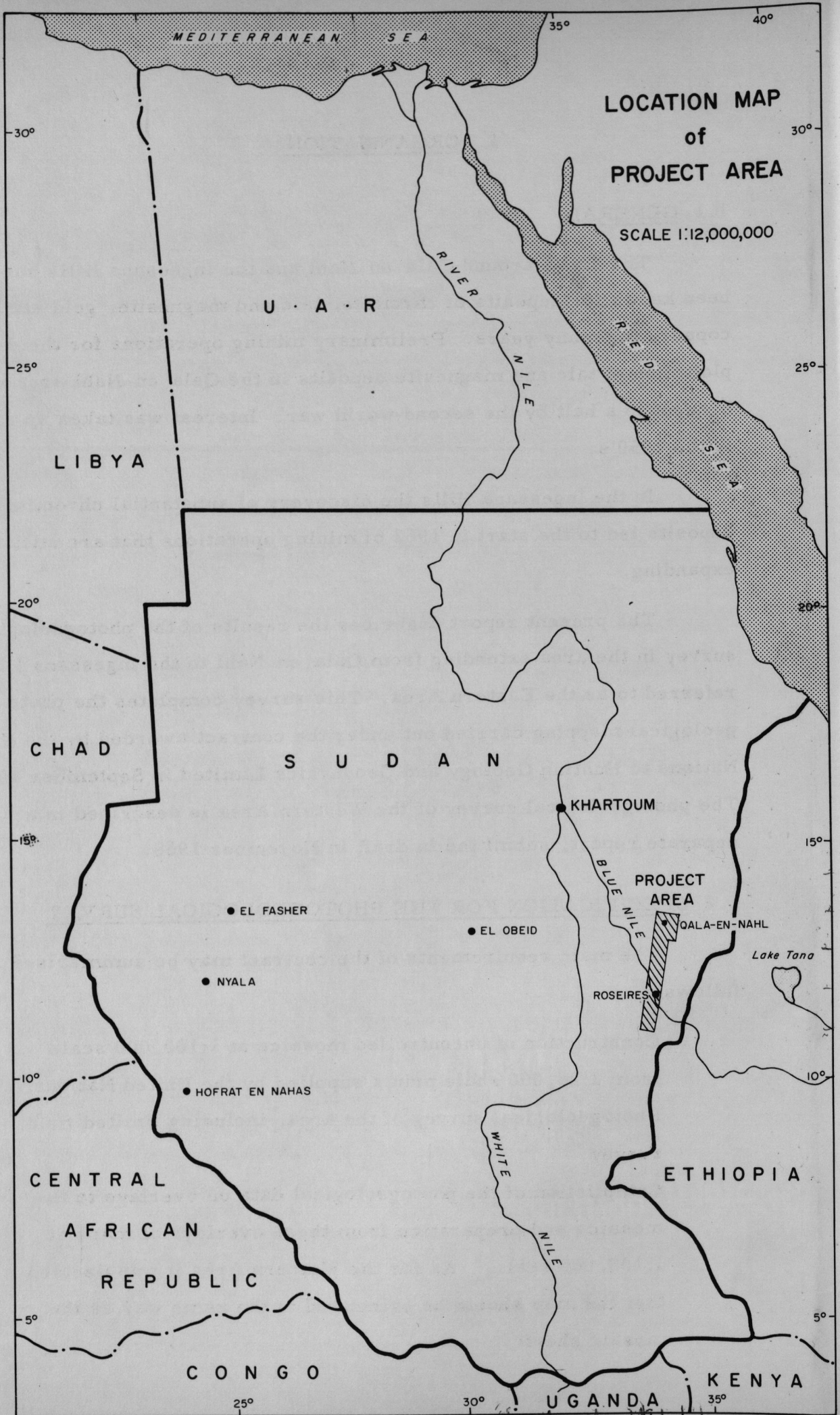
LOCATION MAP
of
PROJECT AREA

GENERAL
SCALE 1:2,000,000



PHOTOLOGICAL SURVEY FOR THE PROJECT

The main requirements of the project are to provide a photographic survey of the area. This survey is being carried out under the supervision of the Geological Survey of the Democratic Republic of Congo. The survey is being carried out in the area extending from the Nile River to the east. The survey is being carried out in the area extending from the Nile River to the east. The survey is being carried out in the area extending from the Nile River to the east.



1. ORGANISATION

1.1 GENERAL

The areas around Qala en Nahl and the Ingessana Hills have been known for deposits of chromite, talc and magnesite, gold and copper, for many years. Preliminary mining operations for the exploitation of talc and magnesite deposits in the Qala en Nahl area were brought to a halt by the second world war. Interest was taken up again in the 1950's.

In the Ingessana Hills the discovery of substantial chromite deposits led to the start in 1962 of mining operations that are still expanding.

The present report describes the results of the photogeological survey in the area extending from Qala en Nahl to the Ingessana Hills, referred to as the Eastern Area. This survey completes the photogeological mapping carried out under the contract awarded by the United Nations to Hunting Geology and Geophysics Limited in September 1967. The photogeological survey of the Western Area is described in a separate report, submitted in draft in November 1968.

1.2 SPECIFICATION FOR THE PHOTOGEOLOGICAL SURVEY

The main requirements of the contract may be summarised 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 area, 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. As for the Western Area it was decided that the map should be orientated in the same way as the mosaic sheets.

Results of a mapping programme of the Geological Survey Department in part of the Eastern Area led the U.N. Project Manager to the decision to exclude an area in the alluvial flood plain between the Blue Nile and the Rahad from the photogeological survey and to extend the northern part of the project area to cover more completely the area of intrusive rocks. It was agreed subsequently to produce the final 1:100,000 maps in three sheets, one of 45 minutes by 30 minutes in the north and two of 45 minutes by 22 minutes in the south (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 this 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 each 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 Area and the Eastern Area should be carried out concurrently and in conjunction with similar surveys in Ethiopia.

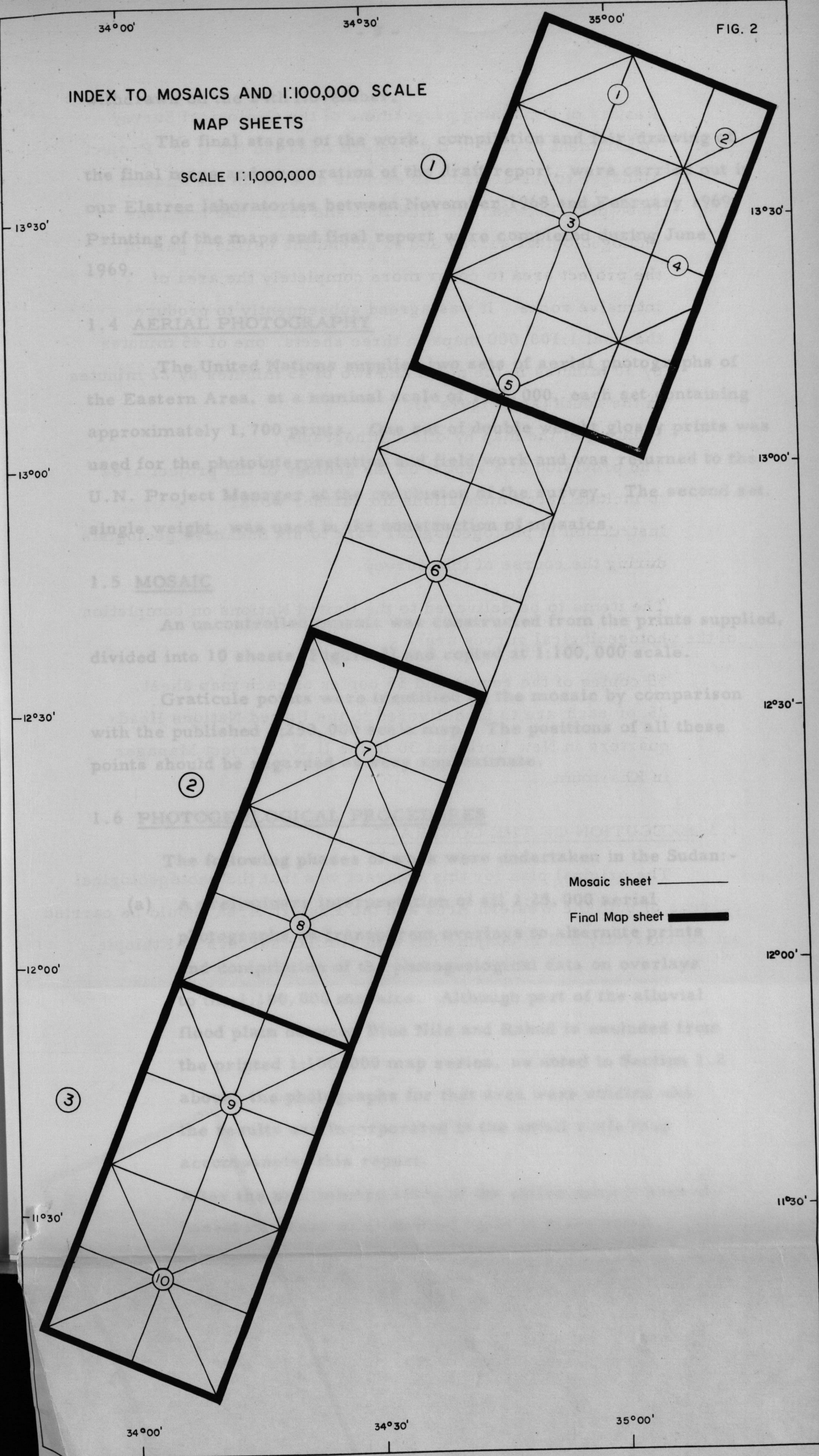
For reasons outlined in the report on the photogeological survey of the Western Area (p. 3) the work in the Eastern Area could not be started before the end of the rainy season.

Construction of the mosaics of the Eastern Area was begun in Elstree in March and completed in May 1968.

The team arrived in Khartoum on the 26th September and was

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

SCALE 1:1,000,000



Mosaic sheet ————
 Final Map sheet ————

The final stages of the work comprising the preparation of the final mosaic and the final report were carried out at our Elstree laboratories between November 1968 and June 1969. Printing of the maps and final report was completed in June 1969.

1.4 AERIAL PHOTOGRAPHY

The United Nations supplied 100 aerial photographs of the Eastern Area, at a nominal scale of 1:100,000, each containing approximately 1,700 prints. A selection of 100 prints was used for the photostereoscopic mosaic and was returned to the U.N. Project Manager at the end of the project. The second set, single weight, was used for the mosaic.

1.5 MOSAIC

An uncontrolled mosaic was prepared from the prints supplied, divided into 10 sheets, each at a scale of 1:100,000.

Graticule points were marked on the mosaic by comparison with the published map. The positions of all these points should be reported in the final report.

1.6 PHOTOGRAPHIC INTERPRETATION

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

(a) Aerial photographs were examined to identify features of interest and to determine their positions on the mosaic.

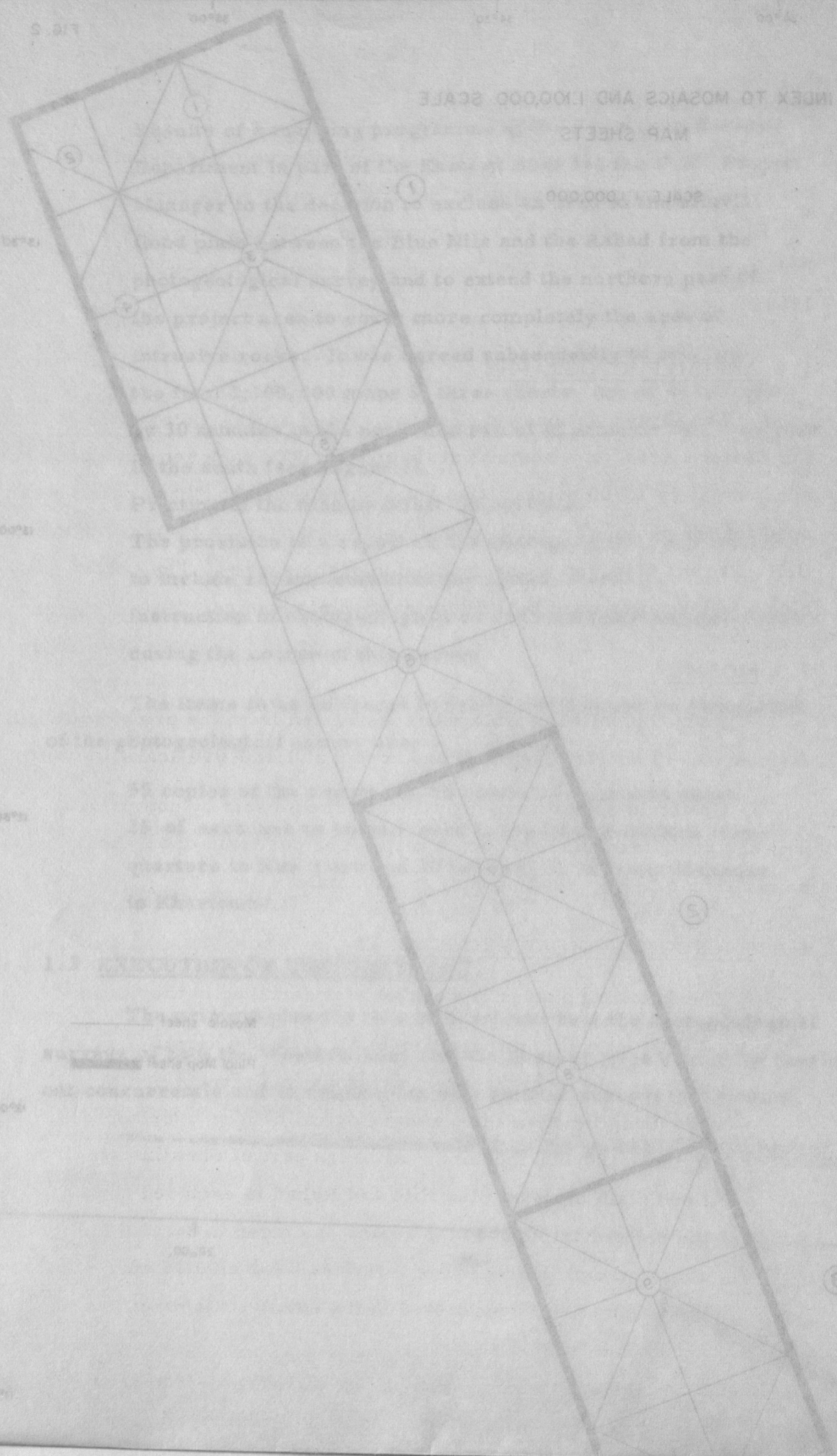
(b) Aerial photographs were examined to determine their positions on the mosaic.

(c) Aerial photographs were examined to determine their positions on the mosaic.

INDEX TO MOSAICS AND 1:100,000 SCALE

MAP SHEETS

SCALE 1:100,000



INDEX TO MOSAICS AND 1:100,000 SCALE

MAP SHEETS

SCALE 1:100,000

MAP SHEETS

SCALE 1:100,000

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MAP SHEETS

SCALE 1:100,000

MAP SHEETS

SCALE 1:100,000

withdrawn on the 24th November.

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 November 1968 and February 1969. Printing of the maps and final report were completed during June 1969.

1.4 AERIAL PHOTOGRAPHY

The United Nations supplied two sets of aerial photographs of the Eastern Area, at a nominal scale of 1:25,000, each set containing approximately 1,700 prints. One set of double weight glossy prints was used for the photointerpretation and field work and was returned to the U.N. Project Manager at the conclusion of the survey. The second set, single weight, was used in the construction of mosaics.

1.5 MOSAIC

An uncontrolled mosaic was constructed from the prints supplied, divided into 10 sheets (Figure 2) and copied at 1:100,000 scale.

Graticule points were identified on the mosaic by comparison with the published 1:250,000 scale map. The positions 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 preliminary interpretation of all 1:25,000 aerial photographs on transparent overlays to alternate prints and compilation of the photogeological data on overlays to the 1:100,000 mosaics. Although part of the alluvial flood plain between Blue Nile and Rahad is excluded from the printed 1:100,000 map series, as noted in Section 1.2 above, the photographs for that area were studied and the results are incorporated in the small scale map accompanying this report.

After the preliminary study of the entire project area the basement areas were studied again in more detail.

- (b) Field checking of interpretation by traverses over motorable country. The field work occupied about 25 per cent of the team's time in the Sudan. Traverses are indicated in Figure 3.

The team left Khartoum on the 24th October for Qala en Nahl, surveyed the surrounding area until the 30th October and traversed the flood plain of Rahad, Dinder and Blue Nile on the 30th and the 31st October. The Ingessana Hills and the country to the north of these hills were investigated between the 31st October and the 7th November. The team returned to Khartoum on the 8th November.

In the Eastern Area there are relatively many motorable roads. In addition several footpaths and cattle tracks are more or less motorable. In the central part of the Ingessana Hills however, there is no access for vehicles. Some vital information was obtained on foot.

In the field the photo-interpretation was checked, structural details were measured, and the lithology of the rock units and the nature of the mineralization were examined.

- (c) Detailed re-examination, in the light of the field evidence, of the photography covering the basement areas, and completion of the 1:100,000 overlays.

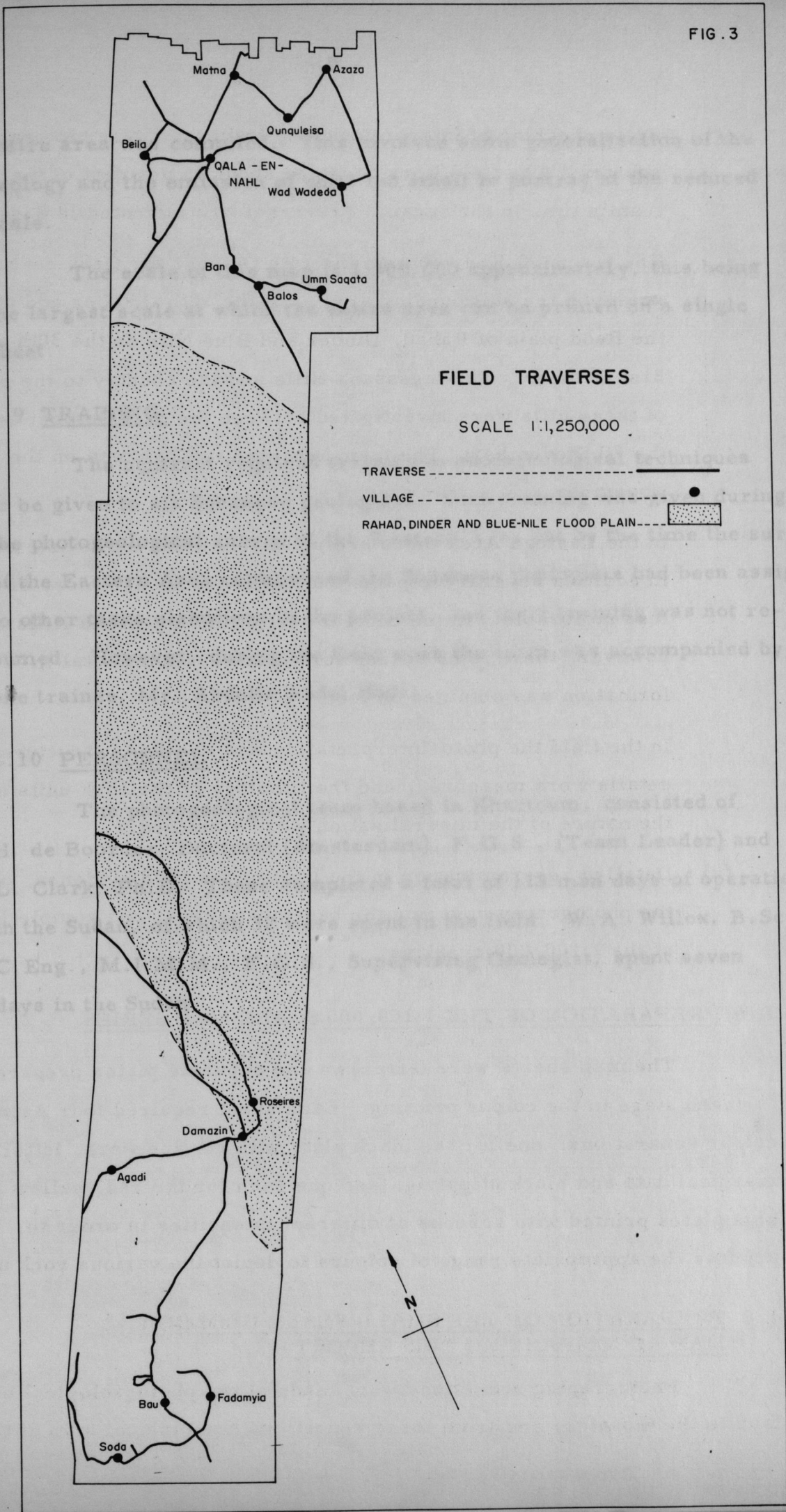
1.7 PREPARATION OF THE 1:100,000 SCALE MAP SERIES

The map sheets were fairdrawn 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 intensities in order to produce the appropriate range of colours to depict the various rock units.

1.8 PREPARATION OF THE SMALL SCALE GEOLOGICAL MAP ACCOMPANYING THIS REPORT

Photographic reductions were made of the photogeological overlays to the mosaics, and from these reductions a geological map of the

FIG. 3



FIELD TRAVERSES

SCALE 1:1,250,000

- TRAVERSE -----
- VILLAGE ----- ●
- RAHAD, DINDER AND BLUE-NILE FLOOD PLAIN ----- [stippled box]



entire area was compiled. This involved some generalisation of the geology and the omission of units too small to portray at the reduced scale.

The scale of this map is 1:300,000 approximately, this being the largest scale at which the entire area can be printed on a single sheet.

1.9 TRAINING

The contract required training in photogeological techniques to be given to six Sudanese geologists. Such training was given during the photogeological survey of the Western Area but by the time the survey of the Eastern Area commenced the Sudanese geologists had been assigned to other tasks elsewhere in the project, and their training was not resumed. However, during the field work the team was accompanied by one trainee, Mr. Abdulla Abdel Hadi.

1.10 PERSONNEL

The photogeological team based in Khartoum, consisted of H. de Boorder, Doctorat (Amsterdam), F.G.S., (Team Leader) and L. Clark, Ph.D. These completed a total of 118 man days of operations in the Sudan, of which 32 were spent in the field. W.A. Willox, B.Sc., C.Eng., M.I.M.M., F.G.S., Supervising Geologist, spent seven days in the Sudan.

2.2 PREVIOUS WORK

The geology and mineralisation of the Omdurman-Nadi district has been intensively investigated in the past thirty years.

entire area was completed. This involved some generalization of the
geology and the character of what you would see in the field at the reduced
scale.

The scale of this map is 1:500,000 approximately. The detail
the largest scale at which the entire area can be printed on a single
sheet.

1.9 TRAINING

The contact parties existing in the geological and topographic
to be given to six separate geologists. Each geologist was given during
the photographic survey of the contact area and of the area the survey
of the contact area would include the contact. Geologists had been assigned
to other areas elsewhere in the field. The photographic survey was not re-
sented. However, during the field work the field was accompanied by
one trainee, Mr. Abdullah Akbar.

1.10 RESEARCH

The photographic team based in Islamabad, consisted of a group
H. de Boer, Doctor (Amsterdam), F.R.S., (Team leader) and
L. Dixon, Ph.D. These completed a total of 15 area days of operations
in the field, of which 11 were spent in the field. W. A. Wilcox, B.Sc.
C. Day, M.I.M.S., F.C.S., (Geological Consultant) spent seven
days in the field.

2. GENERAL OUTLINE OF THE GEOLOGY

2.1 GENERAL STATEMENT

In the area investigated, the alluvial flood plain of the rivers Rahad, Dinder and Blue Nile, which is about 120 km wide, separates two relatively small areas where the Precambrian and possibly in part also Palaeozoic Basement is exposed. Five inselbergs of granite occur in a group between the Blue Nile and the Dinder. It has been found possible to correlate most of the rock types of the area in the north around Qala en Nahl with those in the south in and around the Ingessana Hills.

The following lithological units have been distinguished:

Superficial sediments, of Tertiary and Quaternary age

Nubian sandstone

Granitic rocks

The Wad Wadeda Mafic Complex

The Central Ingessana Mafic Complex and the

Epidiorite of Qala en Nahl

Serpentinite Group

Metasediments

Gneisses

Apart from the Nubian sandstone in the north and the Tertiary and Quaternary sediments these rocks are thought to represent the results of one series of geosynclinal and subsequent orogenic events, although part of the gneisses may be much older. No radiometric dating has been carried out yet. Structural continuity with the Mozambique Belt towards the south is suspected; lithological similarities with the rocks of the South-Eastern Desert in the U. A. R. are often noticeable.

2.2 PREVIOUS WORK

The geology and mineralization of the Qala en Nahl district has been intensively investigated in the past forty years.

In 1929 Captain W. Johnson submitted 96 specimens from the Qala en Nahl area among which G.W. Grabham identified talc schist, talc, periodotite, asbestos and magnesite. Grabham recommended further work in the area. (Letter 68/10299, June 2nd, 1929, in file GS/55/L/G.)

G.W. Grabham produced a sketch map of the geology between Kassala and Mefoza in 1930 (copy in file GS/55/L/G). Qala en Nahl is shown as undifferentiated basement complex. The same year Tanganyika Concessions Limited started work in the Qala en Nahl area. The Sudan Survey Department did a plane table survey of about 1,625 sq.km to help in this work.

During 1931 and 1932 W.H. Tyler of Tanganyika Concessions Limited mapped the area around Qala en Nahl in detail and reconnoitred a much wider area. Tyler's original map on 1:50,000 scale is preserved in file GS/55/L/G. This work has been the basis of all further work in the area.

By the end of 1932 after mineral prospecting (Tyler, 1932; Tyler and Rees, 1934) involving 920 feet of underground working it was concluded that the chromite and asbestos around Qala en Nahl is not present in economic quantities. The underground working comprised four shafts and one adit. The results (from Ruxton, 1957-b) are summarized in Appendix A.

Tyler found occurrences of chromite north of J. Ghanam and at Umm Saqata. He noted asbestos at J. El Fau, Qala en Nahl and Umm Saqata, traces of gold at J. Ghanam and copper at Nafs El Kelb.

After the disappointing results with chromite, Tyler in 1934 examined the talc-magnesite rock. Ten tons were extracted and separated, giving a composition of 46 per cent by weight magnesite, 52 per cent talc and 2 per cent loss. The process was not economic and therefore he examined the entire rock with a view to using it as a refractory (Tyler and Rees, 1934). During 1935 and 1936 500 tons of talc-magnesite were shipped to England. Messrs. General Refractories Limited had

encouraging results making magnesite-chromite and dolomite bricks and in 1937 it was agreed to ship 10,000 tons per annum of talc-magnesite to England. The scheme was dropped in 1938, possibly because of the imminent war.

"A Canadian" dug 13 trenches at Umm Saqata in 1953 looking for chromite (Ruxton, 1957-b, p.31). These showed three lenses of chromite in serpentine with a thin lens of talc-magnesite schist.

The most important post-war work at Qala en Nahl has been done by B.P. Ruxton (1957-b). Late in 1956 he undertook a preliminary re-examination of the area, in particular the talc-magnesite deposits. Ruxton was very enthusiastic about the copper occurrences on J. Nafs El Kelb and J. Salmin in a letter to the Director of the Geological Survey dated 11th December 1956 (in file GS/55/L/G): "All I can say is that I have never witnessed such spectacular mineralization in my life. This is a copper bearing belt, not just odd occurrences." In a later letter of 28th January 1957 Ruxton is less enthusiastic but his specific descriptions of sulphide occurrences are encouraging. In this same letter Ruxton mentions going to Gedaref for an aerial survey of Qala en Nahl but we could not find the results of this survey.

Ruxton summarized all previous work, the results of his reconnaissance and his plans for further work in an interim report 55L/G (in file GS/55/L/G) with an accompanying map of Qala en Nahl on 1:10,000 scale.

Ruxton set out plans for a systematic investigation of the Qala en Nahl talc-magnesite. Asbestos is described from J. El Fau, Qala en Nahl and Umm Saqata, the latter locality being the most promising. He describes the copper locations in the Basal Schists and suggests further investigations.

The results of Ruxton's work on the talc-magnesite rock are summarized in a brief report in 1958 (in file GS/55/L/G). The work proved reserves of 25 million tons of talc-magnesite containing talc 51 ± 2 per cent, magnesite 43 per cent and impurities 6 ± 4 per cent.

A contract of 20,000 tons per annum at minimum price of £6 Sudanese per ton (F.O.B.) should be economic. Sample collection and analyses were incomplete and records of any further work are missing.

Afia and Mohammed (1962) worked at Qala en Nahl in the seasons of 1960-61 and 1961-62, principally on the asbestos occurrences. A report and a map at 1:18,000 scale were produced (Geological Survey Department). Asbestos occurs at Qala en Nahl, J. El Fau and J. Umm Saqata but is most abundant and in better quality at J. El Fau (c.f. Ruxton 1957-b, p.32).

The written history of the Ingessana Hills also commenced with the expeditions of Captain W. Johnson, who collected some samples in 1928. Grabham reported in 1928 on the occurrence of marble south of Damazin. The Damazin rapids in the Blue Nile were investigated by Jones (1954) and by Knill (1962) in connection with the construction of the Roseires Dam. Kabesh (1961) reported on the results of two seasons of geological field work. The chromite deposits discovered in those years (1960 and 1961) are now being exploited at two localities (J. Korba and J. Abu Dom). Recently, prospecting for asbestos has been taken up by the Geological Survey Department.

2.3 MORPHOLOGY

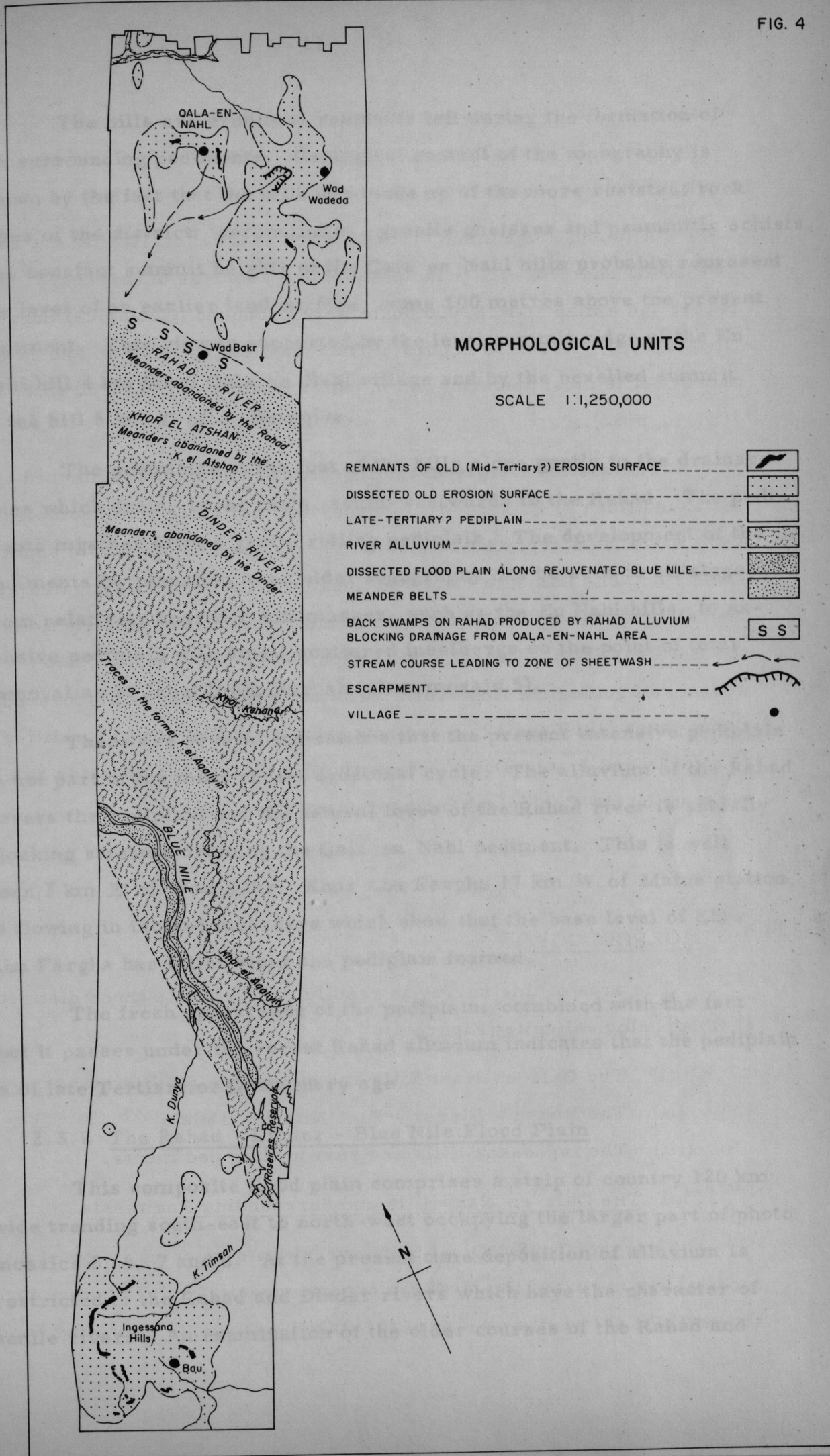
The area of this survey is readily divisible into three distinct geomorphological units (Figure 4).

- (i) The Qala en Nahl Hills and surrounding pediments.
- (ii) The Rahad - Dinder - Blue Nile flood plain.
- (iii) The Ingessana Hills and surrounding pediments.

2.3.1 The Qala en Nahl Hills and Surrounding Pediments

This geomorphological unit covers photo mosaics 1, 2 and 4, most of mosaic 3 and the northern edge of mosaic 5. It is bounded to the south by the northern edge of the Rahad - Dinder - Blue Nile flood plain.

FIG. 4

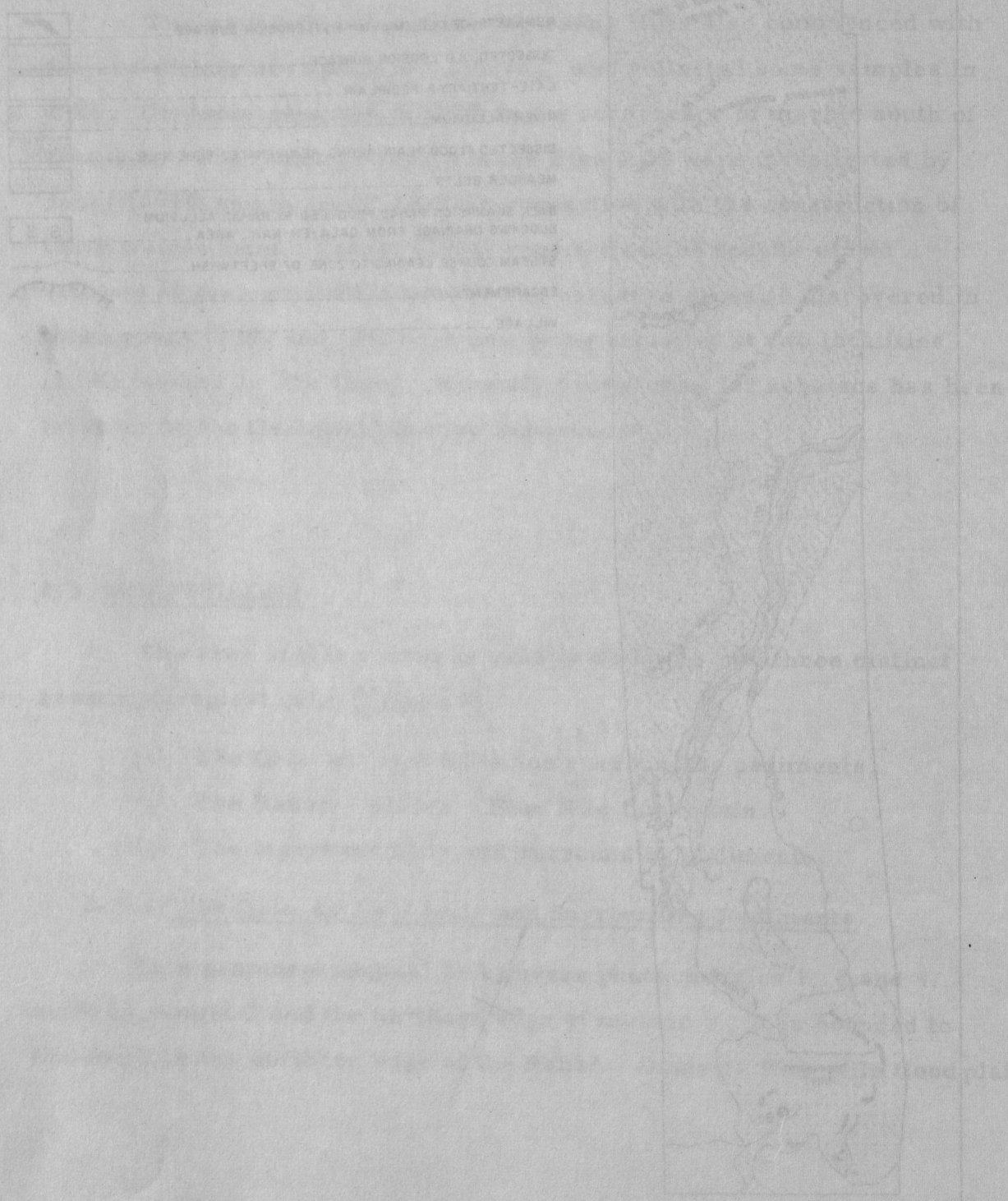


The map shows the distribution of morphological units in the study area. The units are defined as follows:

- Unit 1: ...
- Unit 2: ...
- Unit 3: ...
- Unit 4: ...
- Unit 5: ...
- Unit 6: ...
- Unit 7: ...
- Unit 8: ...
- Unit 9: ...
- Unit 10: ...

The map is a contour map showing the distribution of these units. The units are numbered 1 through 10. The map is oriented with North at the top. The scale is 1:50,000. The map shows the following features:

- Contour lines representing elevation.
- Topographic features such as hills and valleys.
- Boundaries between different morphological units.



The hills are erosional remnants left during the formation of the surrounding pediments. Geological control of the topography is shown by the fact that the hills are made up of the more resistant rock types of the district: serpentinites, granite gneisses and psammitic schists. The constant summit heights of the Qala en Nahl hills probably represent the level of an earlier land surface, some 100 metres above the present pediment. This view is supported by the level summit ridge of the En Nahl hill 4 km SE of Qala en Nahl village and by the bevelled summit of the hill 5 km E. of J. Shanqiya.

The pediments at the foot of the hills slope gently to the drainage lines which drain, in the main, south-westwards to the Rahad. The pediments together form a gently rolling pediplain. The development of the pediments by planation of an older topography can be seen in all stages from relatively uneroded hill masses, such as the En Nahl hills, to extensive pediplain with small scattered inselbergs on the point of total removal, as at Jebel Umm Burush (photomosaic 5).

There are several indications that the present extensive pediplain is not part of the most recent erosional cycle. The alluvium of the Rahad covers the pediplain and the natural levee of the Rahad river is actually blocking streams draining the Qala en Nahl pediment. This is well seen 3 km E. of Wad Bakr. Khor Abu Fargha 17 km W. of Matna station is flowing in incised meanders which show that the base level of Khor Abu Fargha has fallen since the pediplain formed.

The fresh appearance of the pediplain, combined with the fact that it passes under the recent Rahad alluvium indicates that the pediplain is of late Tertiary or Quaternary age.

2.3.2 The Rahad - Dinder - Blue Nile Flood Plain

This composite flood plain comprises a strip of country 120 km wide trending south-east to north-west occupying the larger part of photo mosaics 5, 6, 7 and 8. At the present time deposition of alluvium is restricted to the Rahad and Dinder rivers which have the character of senile rivers. An examination of the older courses of the Rahad and

Dinder suggests that both rivers have migrated several kilometres northwards across the present flood plain surface.

The Blue Nile is incised over 30 m into the flood plain along its southern edge. This river now merely acts as a canal to carry the Ethiopian flood waters through the area. Alluvial deposition is minimal.

Khor Kenana does not carry alluvium into the area. It acts only as a drain for the flood plain between the Dinder and the Blue Nile.

The forms of the various rivers reflect their different functions. The Rahad and Dinder have square cross-section channels incised about 9 m into the alluvium. Their annual floods have built natural levees along part of their courses. The Blue Nile has eroded a deep V-shaped valley through the alluvium to bedrock in places. Consequent streams cutting back into the valley sides have produced a zone of dissected country about 2.5 km wide on either side of the Nile. The Nile has a relatively straight course in contrast to the meander belts of the Rahad and Dinder. Khor Kenana has a meandering course because of the flatness of the flood plain but it is in a shallow V-shaped valley because it is draining and therefore eroding, the alluvium.

The Rahad - Dinder - Blue Nile alluvium is infilling a valley to a depth of over 40 m. The form of this valley is imperfectly known but it trends north-westwards from the Ethiopian border to Dinder station and has obviously formed the main westerly drainage from Ethiopia since the Tertiary. The main line of this valley is interrupted by large strike ridges of resistant strata. The ridge of marbles and foliated granite extending from the Ingessana Hills towards Damazin continues northwards under the alluvium and forms the rapids in the Nile at Roseires. A similar ridge rises through the alluvium to form Jebel Masir (sheet 2, mosaic 7), 80 km north of Roseires.

2.3.3 The Ingessana Hills and Surrounding Pediments

In the area covered by sheet 3 (photomosaics 9 and 10) the serpentinite of the Ingessana Hills stands out as a rugged massif, together with several inselbergs of granite. In the serpentinite massif the isolated

highest summits occur at the same elevation as a dissected plateau in the western part of the massif, presumably representing the same earlier land surface that was observed in the area around Qala-en-Nahl.

The area is mainly drained into the Blue Nile through Khor Timsah and Khor Dunya. Part of the watershed between the Blue Nile and the White Nile is situated in the SW of the area, in the western margin of the serpentinite massif of the Ingessana Hills. Khor Doleib eventually discharges into the White Nile.

The northern pediment of the Ingessana Hills slopes regularly towards the Blue Nile where the drainage lines are generally wider zones, that tend to become temporary swamps where the pediment rises slightly towards the levees of the Blue Nile. In this area the pediment of the Ingessana Hills grades into the alluvial flood plain of the Blue Nile, Dinder and Rahad.

TABLE I

SUMMARY OF PHOTO CHARACTERISTICS OF ROCK GROUPS

ROCK GROUP	TONE	TEXTURE	GEOLOGICAL STRUCTURE	TOPOGRAPHIC EXPRESSION
Gneisses of Ingessana				
Sericite Gneisses	Light to medium	Smooth	Coarse	Subdued; make up lowland and low broad hills.
Biotite Gneisses	Dark	Rough	Finely banded	Medium; forms sharp narrow ridges
Metasedimentary Rocks				
Basal schists of J. Salmin & J. Tahklug	Dark	Rough	Coarse and strong	Strong; makes up rugged hill masses
Basal schists of Umm Quleira, J. Umm Burush & Qala El Baqar	Light	Smooth	Finely banded to absent	Subdued; makes low broad ridges
Metasédiments of Ingessana	Medium	Smooth	Fine	Subdued to medium; chlorite schists generally form negative features
Serpentinites				
Large masses	Dark	Rough	Coarse	Rugged relief
Small hills	Light to very light	Smooth	Absent	Subdued
Talc Carbonate Rocks	Light	Smooth	Finely banded	Subdued; forms depressions in more positive serpentinite
Silicified Serpentinite	Dark	Rough	Birbirite may form dyke-like masses	Rugged relief; forms caps to hill-tops and ridge crests
Epidiorite				
at Qala en Nahl	Very light to light	Smooth but spotted	Subdued or absent	Subdued to medium
in Ingessana Mafic Complex	Light	Smooth but spotted	Well defined in part	Subdued
Wad Wedada Mafic Complex: Meta-Basic Rocks	Light to dark	Medium rough to rough	Well defined	Subdued to medium; rough topography
Granitic Rocks	Very light to medium	Smooth to medium rough	Well defined; mainly joint systems	Pronounced inselberg topography. Massive granites form spectacular joint controlled spires; foliated granites form more subdued inselberg. The Bau granite, in part, forms a subdued basin topography
Nubian Sandstone	Not known	Not known	Reticulate linear pattern in soil may reflect underlying joint pattern	Subdued; soil covered plain

3. LITHOLOGICAL UNITS

3.1 THE GNEISSES

Gneisses are exposed in the bed of the Blue Nile immediately below the Roseires Dam and in the south-western part of the Ingessana Hills, between Kukur and Soda.

On the banks of the Blue Nile and on the islands below the Roseires Dam medium- to coarse-grained leucocratic gneiss bands alternate with bands of fine- to medium-grained biotite gneiss. The bands vary in width from one centimetre to one metre. Occasionally the gneisses become migmatitic due to transition into lensoid and ovoidal masses of coarse-grained granite and granite pegmatite in the axial parts of the major folds. Quartz has often been concentrated in the hinges of the folds. The width of the major folds is of the order of three to five metres. Microfolding is prominent in the bands of biotite gneiss. The strike of the axes of the major folds varies from 030° to 090° . The axes plunge towards the NE and E, in general at angles between 40° and 50° . The outcrops cannot be distinguished on the photographs and the map represents field evidence only.

Along the south-western edge of the Ingessana Hills sericite gneisses and biotite gneisses occur in a synclinorium with a maximum width of about six kilometres east of Kukur, plunging about 20° towards the north.

The sericite gneisses are coarse- to medium-grained leucocratic rocks consisting of sericite, albite-rich plagioclase and quartz with garnet and biotite as minor constituents. Locally they grade into gneisses of granitic composition with potassium-rich feldspar, plagioclase and quartz as major constituents. On two occasions transition into more massive coarse-grained granite was observed.

Intercalated with the leucocratic gneisses relatively narrow bands (up to 200 m in width) of biotite gneiss are found. They consist of biotite, quartz and some plagioclase (An 15-20 per cent), epidote and sphene.

Pegmatite veins with pink potassium-rich feldspar, quartz and mica cross-cut the gneisses in various directions.

On the photographs the coarse-grained leucocratic gneisses appear subdued, constituting lowlands and low broad elevations; the biotite-gneisses stand out as sharp narrow ridges. The axial zone of the synclinorium is a depression with accumulations of debris from adjacent serpentinites. In the stream beds, however, the gneisses are regularly exposed.

In the Qala en Nahl area minor outcrops of banded gneiss were found at J. Beila and J. Qurein. They are in part migmatitic, Leucocratic bands average 10-20 cm in thickness; mafic bands are generally thinner. Quartz occurs in grains elongated parallel to the foliation. Microperthite is the commonest feldspar but non-perthitic microcline is also abundant. Albite-oligoclase is subordinate; biotite is the only ferromagnesian mineral.

In view of the close association with the foliated granites the gneisses in this area have been included on the maps in the general colour scheme for the granitic rocks (see also Section 3.6).

3.2 THE METASEDIMENTARY ROCKS

Probably the oldest rocks in the area investigated are the meta-sedimentary rocks. Although only constituting relatively small outcrops they provide useful keys to the earlier structural history because they are scattered all over the northern and southern parts of the area investigated.

In view of composition, structural features and metamorphic characteristics they have been given one colour on the maps, with letter symbols to distinguish between the various types on the 1:100,000 scale maps. These rocks include the "Basal Schists" of Tyler (1932) in the north and the psammitic and pelitic rocks of Kabesh (1961) in the south.

Basalt Schists crop out around the base of the Qala en Nahl hills and make up the hills of Umm Quleira, Nafs El Kelb, J. Salmin, J. Takhlug

and a low ridge extending south from J. Ghanam to J. Um Burush and Qala El Baqar. The rock types include pelitic chlorite and graphite schists with subordinate marbles, and psammitic sericite-quartz schists. The commonest rock type exposed is a soft sericitic schist.

The photo characteristics of the Basal Schists vary with the physical character of the rocks. On Jebels Salmin and Takhlug the schists show a dark tone, a rough knobby texture, strong topographic expression and a coarse strong structure; they closely resemble the ultra-basic rocks. The Basal Schists elsewhere on sheet 1 have a light tone, smooth texture, and a subdued topographic expression.

The pronounced relief of Jebels Salmin and Takhlug suggests that the schists on these hills are much more massive and psammitic than elsewhere. Tyler's map (1932) shows a swarm of quartz dykes on Takhlug and these may have helped to enhance the relief.

The extent of the Basal Schists is not known. The coincidence of the schist outcrop with the pediment of the Qala en Nahl hills, and the subdued topography associated with most of the schist outcrops suggest that the Basal Schists may underlie much of the soil covered pediment. The irregular pattern of photo linear features in the superficial deposits in photomosaic 1 west of the railway, in contrast to the rectilinear pattern east of the railway, is explicable if the area is underlain by schists.

In the south, metasediments of about the same range in composition are found to constitute many of the isolated inselbergs around the Ingessana Hills complex proper. They are also found along the foot of the serpentinite ranges in occasional small outcrops in the roads and in the stream courses. The majority of the metasediments are chlorite-quartz-sericite schists. In addition biotite-chlorite-quartz schists, quartz-sericite-graphite schists, quartz-chlorite schists, quartzites, ferruginous quartzites, banded mudstones and marbles occur.

The photo characteristics of the metasedimentary rocks in the Ingessana Hills appear to be more uniform than in the area around Qala en Nahl, probably because the chlorite-quartz-sericite schists constitute

the bulk with only relatively unimportant intercalations of slightly different composition. The hills are generally smooth, with medium-grey tone and a fine structure expressed by more quartzitic bands that are often of slightly darker tone.

The metasediments represent a series of mudstones and impure sandstones with subordinate calcareous and carbonaceous beds. They were deposited under geosynclinal conditions and regionally metamorphosed in the greenschist facies.

The metasedimentary rocks in the Qala en Nahl Ingessana region very much resemble the rocks of the "Southern Assemblage" of geosynclinal sediments found during a previous photogeological survey in the South-Eastern Desert of Egypt (Hunting Geology and Geophysics Ltd., 1967), consisting of greenschists and mudstones together with marbles and localised conglomerates.

3.3 THE SERPENTINITE GROUP

3.3.1 Serpentinites

Serpentinite is found in the northern part of the Eastern Area in several large massifs (up to six km in length and one km in width): J. El Fau, J. Umm Saqata and J. El 'Utash and at Qala en Nahl. In the south serpentinite and the rocks derived from it through various alteration processes, constitute the greater part of the Ingessana Hills. Generally the serpentinite stands out in strong rugged relief, but it is also found to constitute several smooth low hills and hillocks, which made identification on the air photographs during the preliminary interpretation of the photographs sometimes problematic. The serpentinites do not appear to extend very far away from the hills. This is particularly noticeable at Qala en Nahl and around the main massif of the Ingessana Hills where the junction between the hill slopes and pediment is coincident with the contact with the schists.

The serpentinite proper is a hard, fine-grained massive rock, greyish green to dark green in colour. Most of the serpentine occurs as the antigorite variety. It is found together with variable proportions

of talc, chlorite, carbonate and opaque ore. Occasionally pseudomorphs after olivine and pyroxene together with the arrangement of crystals in a much coarser texture suggest that the serpentinite itself was derived from mafic and/or ultramafic rocks. Wilcockson and Tyler (1933) report remnants of olivine in the serpentinite and suggest a dunite as the original rock.

Although some preferred orientation is sometimes observed in thin section little foliation was observed in the field or on the air photographs. Especially the process of silicification of the serpentinites is thought to have blurred much of any foliation and in some areas homogeneous looking birbirite caps completely mask underlying rocks (western part of the Ingessana Hills). The most obvious field character of the serpentinites is their extreme alteration. Exposures of fresh rock are uncommon, the serpentinite usually being weathered to a buff colour. In most exposures the originally massive serpentinite is extensively fractured and jointed in many directions with veins or crusts of magnesite in the fractures. Intensive veining and metasomatism by carbonate is a widespread phenomenon. Mechanical alteration to schist and slate is also common. The fractured nature of the rocks precludes large rocky exposures and most hillsides are largely talus slopes.

The serpentinites are thought to have been emplaced as a number of "alpine-type" masses (see also Chapter 6) into the sediments during the presumably late Precambrian orogeny that terminated the geosynclinal deposition. They were probably emplaced as "cold intrusions" in the manner postulated by Bowen and Tuttle (1949) in which serpentinitization of the ultrabasic rock took place by auto-retrogression synchronously with intrusion. Evidence of intense contact metamorphism was not observed.

3.3.2 Talc-carbonate Rocks

The ultrabasic rocks were subsequently subjected to several periods of tectonic activity and chemical alteration. The most important of these periods of tectonic and chemical activity led to the development of large

masses of talc-magnesite rock within the serpentinite. This tectonism post-dated the initial intrusion, serpentinitization and deformation of the serpentinites but its exact age is unknown.

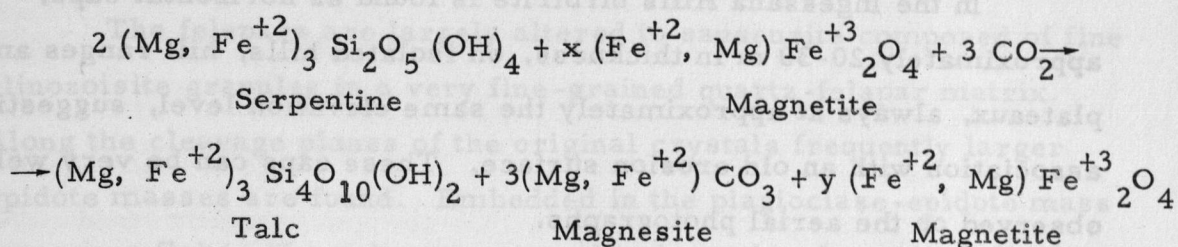
On a small hill 0.3 km E of Qala en Nahl station massive serpentinite is intensively invaded by veining and metasomatic replacement by magnesite. The serpentinite is also cut by a schistosity at right angles to the primary foliation. On the summit the rock has been converted to a pale green slaty schist with remnants of the massive serpentinite remaining in the schist. At the base of the hill the schist is restricted to shear zones about 10 cm wide. Some of these shear zones are mineralized by magnesite and parts of the schist have been converted to talc schist. Similar exposures where the serpentine has been sheared to a slaty schist and permeated by magnesite are widespread. The development of talc may be relatively minor in these exposures.

The largest masses of talc-magnesite rock are on the east end of Jebel El Fau and the south end of the Qala en Nahl mass. These field occurrences of the talc-magnesite rock have been fully described by Wilcockson and Tyler (1933) and Ruxton (1957-b). An accessible exposure of talc-magnesite rock is found on the north side of Jebel El Fau, 2.5 km W. of the railway. The site is marked by a prominent white scar formed by a massive quartz lens 4 metres thick. The rest of this bluff is formed of magnesite cut by a reticulate system of quartz-filled gash veins. The magnesite weathers brown and looks like a marble. The hollows between the bluffs on this hillside mark lines of slabby talc schist.

The talc-magnesite rock can be identified on aerial photographs by its contrast with the serpentinite. The easily weathered rock forms depressions in the ultrabasic mass. The deep weathering leads to thicker soils, lusher vegetation and therefore smooth texture and light tones. Where the talc and magnesite form a banded sequence, as on Jebel El Fau, this is readily seen on aerial photographs.

The talc-carbonate rocks originated by the carbonation of

serpentine. This process has been discussed in detail by Chidester (1962) in connection with talc-bearing rocks from Vermont. The process can be represented approximately by the equation:-



The present workers agree with Chidester (op. cit., p. 128) that the CO₂ comes in solution in connate waters and is independent of a magmatic source. The shearing associated with the development of the talc-magnesite would provide ready access routes for the percolation of the carbonate waters. To require a parent granite beneath every serpentine-talc-magnesite occurrence would require an impossible coincidence, when the number of such occurrences is considered.

3.3.3 Silicified Serpentinite and Birbirite

Silicification is a further chemical alteration process that took place on a large scale in the serpentinites. It produced fine-grained, very hard, brownish red rocks, full of drusy cavities, the walls of which are iron-stained quartz or chalcedony. The ultimate product of this alteration process is very similar to the Ethiopian birbirite (name derived from River Bir-Bir, Wollega, Ethiopia) in which a reticulate veining of silica or silica-limonite is general and in more porous varieties a limonitic boxwork or honeycomb structure is common (Jelenc, 1966; Duparc and Molly, 1928; Hunting Geology and Geophysics Ltd., 1968).

Tyler and Wilcockson (1933) mentioned the occurrence of small outcrops of this rock type in the area around Qala en Nahl. They suggest that siliceous solutions formed quartz veins in open fissures but when the fissures closed the solutions percolated through the solid serpentinite and silicified it, commonly along lines parallel to the regional strike.

Two very prominent lines of dark hard rock forming the crests of the northern half of Jebel El Fau may well be such lines of silicification.

In the Ingessana Hills birbirite is found as horizontal caps, approximately 20-30 m in thickness, on isolated hills, hill ranges and plateaux, always at approximately the same elevation level, suggesting association with an old erosion surface. These caps can be very well observed on the aerial photographs.

Alignment of hills capped by birbirite in the western part of the Ingessana Hills suggests some kind of structural or compositional control of the serpentinite. This is corroborated by the occurrence of similarly aligned pyroxenite bodies mapped previously by Kabesh (1961) in this part of the Ingessana Hills. In the field, however, discontinuities of this magnitude in the serpentinite have not been observed.

3.4 THE CENTRAL INGESSANA MAFIC COMPLEX AND THE EPIDIORITES OF QALA EN NAHL

Within the semi-circular zone of serpentinite in the western part of the Ingessana Hills various mafic rocks are found. Morphologically this central area is much subdued and covered by varying amounts of superficial material, comprising fluvial boulder beds, locally up to 4 m in thickness, fluvial sand and cotton soil. Outcrops are few but the stream courses furnish good opportunities for investigation.

The following rock types have been observed:-

1. Medium-to fine-grained epidiorite.
2. Fine-grained light green occasionally schistose metadolerite.

The Complex is a metamorphosed mixed association of basic igneous rocks.

The epidiorite is very abundant as boulders, cobbles and pebbles in the stream courses draining this area to the east, and it is thought to constitute the greater part of the Central Ingessana Mafic Complex.

In the hand specimen the epidiorite is a coarse- to medium-grained foliated rock. The white feldspar crystals have lost their original outlines but there is still a suggestion of gabbroic texture.

The feldspars are largely altered to saussurite composed of fine clinozoisite granules in a very fine-grained quartz-feldspar matrix. Along the cleavage planes of the original crystals frequently larger epidote masses are found. Embedded in the plagioclase-epidote mass numerous flakes of a pale green to colourless chlorite and needle-like crystals of a colourless amphibole are often observed. The amphibole crystals occasionally occur together in sheaf-like aggregates where they constitute pseudomorphs after pyroxene. The amphibole in turn is commonly replaced by large crystals of the chlorite.

The metadolerite is a hard, massive, medium- to fine-grained, light green rock, for which the name greenstone would be quite appropriate. In some places it was found as sills and dykes, up to 50 cm in width, in the epidiorite. Locally the metadolerite is schistose in narrow shear zones striking 140° , with a dip of 60° to 80° NE.

Within the Central Ingessana Mafic Complex two zones were observed, each approximately one kilometre in width, striking 145° and 160° , standing out as low smooth ridges with a well-defined foliation parallel to the strike of the ridges. They were found to consist of epidiorite only. In the lower terrain in between, the epidiorite occurs together with the metadolerites or greenstones.

Epidiorites also crop out in a group of low hills in the Qala-en-Nahl area. This rock group has been delimited and described in some detail by previous workers, principally Tyler and Wilcockson, as "The Older Grabbros". On aerial photographs the epidiorites here have a very pale tone, and give rise to a low to medium topography. Their texture has a very smooth background with superimposed rough spots. Structural lines are absent or subdued.

The epidiorites are contained within the curve of the Qala en Nahl serpentinite in a similar relationship to that between the Central

Mafic Complex and the main western serpentinite ring in the Ingessana Hills. Wilcockson and Tyler (1933) mention other outcrops associated with the Umm Saqata ultrabasic mass. The epidiorites and serpentinites are believed to belong to the same intrusive sequence.

The epidiorites are very altered foliated rocks. In almost every exposure the rock has been subjected to shearing with the development of a schistosity along discrete planes or through the whole rock. The schistosity varies widely in the intensity of its development. At the Qala en Nahl rubbish dump, 1 km east of the village centre epidiorite is cut into lozenges by schist planes striking 020° dipping 60° ESE and joint planes with a parallel strike but steeper dip.

3.5 THE WAD WADEDA MAFIC COMPLEX

The Wad Wadeda Mafic Complex corresponds to the Qunquleisa Gabbro on Ruxton's 1:250,000 scale compilation map and to the "Newer Intrusions" (altered norites and gabbros) on Tyler's (1932) map. It makes up numerous small hills in the vicinity of Wad Wadeda, the group of low north-north-westerly hills at Er Raqal and the dissected country of Qala et Takarir.

The Complex is a multiple intrusion or a mixed association of basic intrusive and extrusive rocks. The different rocks have been grouped together as a 'complex' because they are related to each other and cannot usefully be subdivided on the scale of the present work.

The age of the Wad Wadeda Mafic Complex is uncertain. It is younger than the early phase of folding because there is little northerly structure in the complex. The foliation and retrogressive metamorphism in the rocks, however, show that it is older than the youngest regional tectonism of the area.

Er Raqal Group. The rocks forming the very low hills on Er Raqal form a unit distinct from the rest of the mafic complex. Structure is not seen in the field but the hills have a strong north-north-westerly trend.

The Er Raqal rocks include various fine-to medium-grained meta-basic rocks, mainly meta-basalts. These rocks are cut by numerous fine leucocratic veins. Thin veins of very fine basic rock cut the basalt but are rare. Their fine grain size indicates that these rocks are lavas but no definite evidence of their extrusive nature has been seen. A small intrusion of quartz porphyry occurs 12 km NW of Wad Wadeda.

The basalts are seen in thin sections to contain large amounts of quartz. The classification of these rocks is dependent on the origin of this quartz; if the quartz is primary then they are quartz andesites or dacites. They are here assumed to be silicified altered basalts.

Ruxton (1957-b, p. 24) reports the presence of acid volcanics, including lavas and agglomerates on Er Raqal. He may have meant the rocks under discussion but this is not certain.

The quartz porphyry at Er Raqal is a fine flinty dark grey rock with quartz and felspar phenocrysts 2 to 3 mm in diameter.

The Wad Wadeda Group: This group of rocks make up the small hills around Wad Wadeda. The hills form a distinct linear feature curving north from the village.

The Wad Wadeda Group comprises a coarse gabbroic rock associated with a finer basic rock similar in appearance to the Er Raqal Group. The finer type may be a sheared equivalent of the coarser or they may represent two intrusions. One fine basic vein has been noted intruded into the coarse rock, but 6 km NW of Wad Wadeda gabbroic rock is seen intruding the finer type. In exposures close to Wad Wadeda the gabbroic rock is extensively altered to poikiloblastic amphibole.

The fine-grained rock from Wad Wadeda (LC 18) is a purplish blue-grey resinous basic rock. Weathering etches out a fine banding. In thin sections this specimen has the appearance of a fine basic granulite with a strong foliation shown by lenses and bands of mafic minerals one to two mm across. The texture is granoblastic with a grain size of 0.2 mm. Mafic minerals (hypersthene, clinopyroxene, hornblende and opaque ore) make up about 20 per cent by volume of the rock. Quartz may be present but it has not been identified with certainty.

Wilcockson and Tyler (1933, p. 316) describe the area of Qala et Takarir as being mainly composed of a normal gabbro composed of basic labradorite and diallagic augite. All specimens from the Wad Wadeda area are of noritic character. The norite and gabbro may be two distinct intrusions or they may represent different mineral phases of the same intrusion.

3.6 THE GRANITIC ROCKS

Granitic rocks occur throughout the area. Distinction is made between the medium-to coarse-grained massive granites and the medium-grained, foliated and gneissose granites to granodiorites.

The foliated and gneissose granites are often observed to be harmoniously related to the regional tectonic framework brought about by the structural features of metasediments and gneisses. Especially in the northern part of the area investigated these granites occur in some wide belts parallel to the regional strike (J. Ban - J. El Agmarr; J. Balos/J. Huweig - J. Kambaros; J. Umm Masan - J. Qurein - J. El Arid - J. Beila).

Towards the south this type of granite is observed only in isolated inselbergs, although immediately N of the Ingessana Hills several inselbergs are found together in a belt which follows, more or less, the trend of the foliation within the granite (J. Kilgu, J. Burgu, J. Bagis and J. Abu Qurein). Almost vertical cross joints are prominent on the photographs but during the field work low-dipping joints were also found to occur abundantly.

A similar phenomenon is found about 80 km N of Roseires where inselbergs, with J. Masir as the most prominent, are found along the arcuate trend of the foliation. At J. Beila in the NW the normally foliated two-mica granite grades into banded gneiss which is locally migmatitic. In view of its association with the granites, this gneiss has not been distinguished in colour from the granite (see also Section 3.1). The gneisses near J. Beila are transected by a reticulate system of massive pink granite veins.

The medium-grained massive granites are usually found in much smaller massifs. An example in the north is that at J. Ban and in the south there is the granite around the village of Bau in the eastern part of the Ingessana Hills. These granites are commonly discordant. Discordant contact relations with the country rocks have been described by Kabesh (1961) for the granite around Bau.

The limited size of the bodies of medium-grained massive granite, the generally weakly expressed foliation and the often disharmonious setting suggest that these were emplaced when regional compressive tectonic forces were much weaker than at the time of emplacement of the more concordant, foliated and gneissose granites. Presumably they have to be considered as post-tectonic granites, emplaced at rather high crustal levels. No evidence of contact metamorphism or mineralisation related to the granites was seen during the field work.

Still younger granite veins occur in the Bau Granite, north of the village striking 090° , and low-dipping sills of fine-grained granite are found intrusive into the gneisses constituting the banks of the Blue Nile (Jones, 1954). The sills have been affected by minor later movements, for they are slightly buckled.

3.7 THE NUBIAN SANDSTONE

Nubian sandstone occurs along the northern edge of the area investigated. Only two exposures of the sandstone are known. In the centre of the village of Azaza a small excavation reveals well-bedded horizontal medium-coarse pink sandstone. Jebel Matna is a low flat hill with prominent edges of sub-horizontal sandstone beds.

The sandstones at J. Matna include coarse friable grits and fine, well cemented quartzites. The general grain size of the coarse sandstone is about one mm but pebbles up to three mm are common. The coarser grains are well rounded whereas the smaller grains are sub-angular. The grit is friable, being cemented only by limonite and clay minerals. The fine sandstone is composed of angular to sub-angular

quartz grains averaging about 0.2 mm in grain size, cemented with silica and accessory limonite with clay minerals. This fine sandstone is banded cream and pink and the broad banding shows sedimentary flame and slump structures.

Borehole records from localities north of Matna show that mudstones are a more important member of the succession than would be estimated from available exposures. Borehole BH 776 at Domat, seven km north of J. Matna (outside the project area) gives a representative section (Appendix B).

The basalt revealed in this borehole has not been seen at the surface. The thinness of the Domat succession suggests that the outcrops at J. Matna and Azaza must represent practically the base of the Nubian sandstone.

3.8 SUPERFICIAL SEDIMENTS

3.8.1 Alluvium

Extensive deposition of alluvium is restricted to the flood plain of the Rahad - Dinder - Blue Nile river system. Khor Abu Fargha, flowing westwards in the extreme north of the area, has a flood plain some two kilometres wide. The numerous khors draining the Qala en Nahl and Ingessana highlands have no large alluvial deposits.

The superficial alluvium of the Rahad and Dinder rivers is mainly dark grey clay-loam commonly called "black-cotton soil". Sandier alluvium occurs in places along the courses of these rivers. The general character of the alluvium changes to the south, adjacent to the Blue Nile where the alluvium is a brownish sandy loam.

The alluvium of the Rahad - Dinder - Blue Nile system has infilled a major valley to a depth of almost 100 m. A complete section through this alluvium is given by the geological log of a borehole at Abu Hasheim on the north bank of the Dinder six km NW of the western project boundary. The logs of BH 1531 and BH 1870 have been abstracted from the borehole files held in the Geological Survey Department, Khartoum (Appendix B).

3.8.2 Undifferentiated Soils

The greater part of the pediplain surrounding the Qala en Nahl and Ingessana hills is covered by an undetermined thickness of dark grey clay-loam. This black cotton soil is mainly a colluvium characteristically developed in areas of impeded drainage. At the foot of the hills the soil commonly becomes browner, sandier and enriched in iron. This is particularly evident in the Ingessana Hills where a deep red loam is developed. The iron for this iron enrichment in the Ingessana Hills probably comes from the weathering and decomposition of the ultrabasic rocks.

3.8.3 Calcrete (Kankar)

Locally deposits of surface limestone, over two metres thick in places, occur along many river courses in the Ingessana Hills.

3.8.4 Valley Gravels

Indurated gravels occur in small patches in the bottom of several valleys in the Ingessana Hills. These gravels are evidently older than the present erosion cycle because they have been cemented into conglomerates and are being eroded by the present streams. Their age is uncertain but is possibly Pleistocene.

4.2 THE AREA STUDIED

The regional strike of the schists in the area studied is northerly, usually within 10° of the north-south line. The marked M-form of Nafe El Khatib, which is characteristic of the schists, suggests that the regional strike is the result of a general folding on a northerly axis.

Field examination shows that the schists in the area studied, a mineral banding, has been observed by the schists in a north-westerly strike; this second foliation however, is not clearly visible on the aerial photographs.

3.8.2 Underdrained Soils
 and Ingersoll hills are covered by an undulating thickness of grey clay-loam. This black cotton soil is mainly of volcanic origin and developed in areas of imbedded drainage. At the foot of the hills the soil commonly becomes browner, sandier and enriched in iron. This is particularly evident in the Ingersoll Hills where a deep red loam is developed. The iron for this iron enrichment in the Ingersoll Hills probably comes from the weathering and decomposition of the igneous rocks.

3.8.3 Calcic (Kankar)
 occur along many river courses in the Ingersoll Hills. These are locally deposited in the form of thin layers over two metres thick in places.

3.8.4 Valley Gravels

Indurated gravels occur in small patches in the bottom of several valleys in the Ingersoll Hills. These gravels are evidently older than the present alluvial material because they have been cemented into concretionary masses. They are composed of quartz, feldspar and mica and are certainly of possible Tertiary origin. They are associated with a certain amount of calcareous material and are also associated with some siliceous material.

The Ingersoll Hills are bounded by the Ingersoll and Dinder rivers. The Ingersoll river is mainly a river of the Ingersoll Hills and is bounded by the Ingersoll Hills. The Dinder river is a river of the Ingersoll Hills and is bounded by the Ingersoll Hills. The Ingersoll Hills are bounded by the Ingersoll and Dinder rivers.

The Ingersoll Hills - Dinder - Blue Nile system has yielded a number of borings to a depth of about 100 m. A complete section through the Ingersoll Hills at el-Dahab is given by the Ingersoll Hills. The Ingersoll Hills are bounded by the Ingersoll and Dinder rivers. The Ingersoll Hills are bounded by the Ingersoll and Dinder rivers. The Ingersoll Hills are bounded by the Ingersoll and Dinder rivers.

4. STRUCTURE

4.1 GENERAL

Previous work was largely confined to prospecting and mapping of the distribution of major rock types. Little was known about the structure. Kabesh's work in the Ingessana Hills was the first step of a more detailed analysis of the structure of the southern part of the present area.

The correlation of rock types across the 120 km wide alluvial flood plains of the Rahad, Dinder and Blue Nile is uncertain, and the correlation of structural phenomena is even more problematical. However, the areas around Qala en Nahl and the Ingessana Hills both contain the elements of two similar foliation trends: one NNW-SSE to NNE-SSW and a younger trend WNW-ESE to NW-SE. On the aerial photographs rarely more than one of these foliation trends is visible in one place. Each of them appears to dominate in areas of varying size. In the field, however, two foliations are occasionally observed in the outcrops of metasediments and gneisses and the north-westerly foliation trend is always found to be younger than the northerly trending system.

A major shear zone is thought to divide the Ingessana Hills into two parts. It is postulated that this shear zone is related to the NNE-SSW shear zone found by Knill (1962) in the Damazin Rapids. Elsewhere, faults are generally of local importance only.

4.2 THE AREA AROUND QALA EN NAHL

The regional strike of the primary foliation in the Basal Schists is northerly, usually between 360° and 020° . At Umm Quleira gentle swings in the strike are shown by the sinusoidal line of hills. The marked M-form of Nafs El Kelb, showing major folding in the schists, suggests that the regional strike is the result of isoclinal folding on northerly axes.

Field examination shows that the primary foliation, a mineral banding, has been affected by refoliation along a north-westerly strike; this second foliation however is not usually visible on the aerial photographs.

At Umm Quleira banding, possibly bedding, in ferruginous quartz-sericite schists strikes at 007° with a steep easterly dip. This primary foliation is cut by a secondary foliation, the vertical axial plane foliation of microfolds and kink lines, striking 147° . The intersection of two foliations of equal strength gives the schist a pronounced lineation and a rodded structure.

It is noticeable that the foliation trends of Jebels Salmin and Takhlug are subparallel to the edges and major foliation trends of the adjacent ultrabasic masses of Umm Saqata and Jebel El'Utash. This could mean that the massive ultrabasic rocks have exerted some controlling structural influence on the schists. A similar relationship may exist between J. Abu Sharana and the southern edge of the Wad Wadedda Mafic Complex. The major foliation in the schists of J. Salmin strikes about 40° , the foliation at J. Takhlug strikes at 140° , and between Jebels Salmin and Takhlug the two foliation trends cross almost at right angles. Structural elements striking 40° are clear on the east end of Takhlug and elements trending 140° are found on the west side of Salmin. On J. Salmin the north-westerly trend definitely appears to be the younger trend.

The serpentinite masses are subparallel to the region foliation trend and show strong photo-linear features that probably represent the primary foliation. The serpentinites have reacted massively to folding and display several small open folds with axes commonly striking about 160° . The topographic expression of these folds gives the serpentinite hills very characteristic 'pot hook' shaped side-ridges. The arcuate forms of J. El Fau and the Qala en Nahl Hills, together with the curve of J. El'Utash and J. Umm Saqata, suggest that these large masses have been folded on northerly axes. J. Umm Saqara is a prominent annular feature on topographic maps and on aerial photographs the southern half of this hill is seen to form a distinct arcuate mass trending at right angles to the regional strike.

Examination in the field shows that the massive serpentinites have been widely affected by a later schistosity produced by shearing associated with metasomatism. The end product of this process is a schistose talc-magnesite rock. Intense refoliation of serpentinite is most clearly seen on J. El Fau. At the east end of J. El Fau massive serpentinites striking about 095° are cut by a zone of schist 500 m wide striking about 025° . The schist is made up of talc-carbonate rock. Similar schist zones can be seen on the photographs of the Qala en Nahl Hills.

The gneissose Beila Granite crops out as a line of inselbergs from Beila to Qurein, in the north-western part of the area, making up a ridge parallel to the regional northerly strike. At Beila the foliation strikes 140° , dipping 20° NE. Towards the south the strike of the foliation is generally $10^{\circ} - 30^{\circ}$ with a dip of 60° NW.

In the area of the villages of Ban and Balos a line of inselbergs - J. Ban, J. Abu Ghureira, J. El Agmarr, J. El Buweida, J. Sherif Miskin, J. Suweibet and J. Balos - make up a conspicuous ring. Massive unfoliated granite is much more abundant than between J. Umm Masan and J. Beila to the west. Because of the absence of outcrops in the centre of this ring it is not possible to decide whether the Ban - El Agmarr - Balos granites represent a ring-shaped intrusion or a massive cylindrical pluton. The internal structure of the generally massive rocks is not sufficiently expressed to warrant a conclusion as to structural continuity from one inselberg to another.

A zone of slightly more foliated granite east of the Ban - El Agmarr - Balos line of inselbergs extends from J. Huweig to J. Shanquia and possibly as far as J. Kambaros to the north, roughly parallel with the schist belt to the east.

4.3 THE INGESSANA HILLS

On the photographs the serpentinites constituting the backbone of the Ingessana Hills show little foliation. In the field no foliation has been observed. The metasedimentary rocks and the gneisses around the serpentinite massif reflect two major fold trends. In the east and north-east fold axes and schistosity strike between N-S and NE-SW. In the east the edge of the serpentinite is concordant with this trend, but in the north-east the schistosity planes in the surrounding chlorite schists are parallel or subparallel to it only within a very narrow zone (up to about 100 m) along the contact with the serpentinite. Similarly, north-west and west of the serpentinite massif a WNW-ESE schistosity trend (J. Podra, J. Golak, J. Morong and J. Gonak) appears to adapt itself to the edge of the serpentinite massif, to more easterly directions in the marble and greenschists along the foot of J. Jegu in the north, and to southerly directions in the gneisses E and SE of Kukur.

Between Kukur and J. Podra, however, some outcrops of gneiss along the serpentinite contact have a foliation strike almost perpendicular to the contact with the serpentinite and in this area the serpentinite shows foliation parallel to that in the adjacent gneiss. The foliation appears continuous towards the SE with the foliation observed in the epidiorites of the Central Ingessana Mafic Complex.

The southern contact of the serpentinite with the metasediments is concordant with the schistosity, although further away from the edge of the main massif the schistosity is again NNE-SSW (schist outcrops along the road from Bau to Kurmuk).

The size of the serpentinite massif as a whole (about 35 km in diameter), the apparent vagueness of internal preferred orientation of mineral constituents, and the contact relations with the surrounding rocks mentioned above, indicate a discordant relationship with the regional tectonic framework.

The serpentinite backbone of the Ingessana Hills can be divided into two parts, the western half surrounding the Central Ingessana Mafic Complex of epidiorites, and metadolerites, the eastern half surrounding the Bau Granite which is younger than the serpentinite (see p. 27). The two parts are lithologically continuous in the south, east of J. Abu Dom. The foliation in this area is not continuous, however.

Here, two belts of serpentinite merge into a zone striking 030° with pronounced foliation that also affects epidiorites of the Central Ingessana Mafic Complex and further to the north east the greenschists around the junction of the road from Bau to Damazin and the northern road to Fadamiya. In the latter area two schistose belts in the greenschists merge towards the south west into the 030° zone mentioned above, one from the north west, presumably continuous with the foliation in the northern part of the Central Mafic Complex and the other from the north east. It is thought that the zone with strongly expressed 030° foliation is a shear zone constituting a structural discontinuity between the eastern and western halves of the Ingessana Hills. Its direction, sub-parallel to the general strike of the NE-SW trending regional fold system, and the occurrence of a NE-SW shear zone in the gneisses of the Damazin rapids, 70 km to the north east along the strike, appear to reflect a fundamentally important structure.

Possibly this shear zone was involved in the emplacement of the serpentinite, although its main activity as expressed by the present rocks was after or during the second folding.

The arcuate attitude of the serpentinite belt in the western Ingessana Hills probably reflects the influence of folding along NW-SE to WNW-ESE axes. The two bands of epidiorite in the Central Mafic Complex, which are interpreted as the limbs of a major NW-SE fold, would corroborate this. This fold in later stages has been cut by the 030° shear zone that separates the western part of the Ingessana Hills from the eastern part, where it has been obliterated by the intrusion of the Bau Granite.

The internal structure of the serpentinite provides some supporting

evidence for this assumption. Some foliation trends in the north west of the serpentinite massif, in the area between Kukur and J. Podra are perpendicular to the edge of the serpentinite and parallel to the schistosity in the schists of the J. Podra group of hills and in the gneisses at the latitude of Kukur. These foliation trends probably reflect schistosity in the axial zone of the fold, continuous with the foliation in the rocks of the Central Ingessana Mafic Complex.

In the eastern part of the Ingessana Hills evidence of folding along NW-SE axes is almost absent. Only in the southern part of the serpentinite mass, just north of the road from Soda to Bau, is the foliation unconformable to the contact. Its NW-SE strike would be compatible with a NW-SE fold limb. East of the major shear zone the fold system is clearly one along dominant NE-SW to NNE-SSW axes. The oval outline of this part of the Ingessana Serpentinite could quite well represent a dome resulting from folding along NW-SE and about NE-SW axes, providing a locus for the later emplacement of the Bau Granite.

The youngest intrusions in the southern part of the area investigated, fine-grained granite veins in the gneisses of the banks of the Blue Nile, were affected by minor vertical movements that caused a slight buckling of the low-dipping veins.

5. MINERALISATION AND ECONOMIC GEOLOGY

5.1 GENERAL

The potentially economic rocks and minerals can be divided into those associated with the ultramafic rocks - chromite, asbestos and talc-carbonate rock - and those independent of the ultramafic rocks, of which chalcopyrite is the most important.

5.2 CHROMITE

Chromite occurs in all the serpentinite masses but it has been found in economic quantities in only two localities in the Ingessana Hills: at J. Abu Dom and at J. Korba where it is now being mined. The chromite occurs in lenses and veins in the serpentinite.

The largest mass encountered by Tyler in his extensive investigations at Qala en Nahl (see p. 8) was estimated at 30 tons. In view of Tyler's work it is unlikely that economic deposits of chromite occur at Qala en Nahl. Exploration on J. El Fau and J. Umm Saqata have been more superficial. It is possible that economic deposits occur in the latter two localities.

The excavations on the slope of J. Abu Dom in the Ingessana Hills are in a chromite vein, striking 190° dipping 40° W and varying in width from 1.5 to about 3 metres. It is a solid mass of chromite crystals with very little gangue material.

In some places the serpentinite is schistose, the schistosity striking about N-S and dipping between 40° and 60° to the west. The chromite body is known to extend for about 4 km along its strike to the north. Control of the ore bodies by the schistosity appears highly likely in this part of the Ingessana Hills.

The present production is about 20,000 tons per year but this could easily be increased if desired. Exploitation is both opencast and by adit. The country rock is serpentinite transected by numerous carbonate veins and veinlets containing variable amounts of chromite crystals.

A smaller operation is carried out at J. Korba near Soda. Various other chromite deposits have been mapped by Kabesh (1961).

5.3 ASBESTOS

Asbestos also occurs in all the ultramafic masses but has not yet been proved in economic quantities. Intensive prospecting has been carried out in the Qala en Nahl hills but the results were disappointing. At present a prospecting campaign is being conducted in the Ingessana Hills.

Ruxton (1957-b) found Umm Saqata promising. He located a good fibre bearing zone 500 m long and up to 50 m wide. He also reported a zone 300 m long and up to 50 m wide on Qala en Nahl. The quality of the fibre is commonly impaired by silicification. (Afia and Mohammed (1962) found good results on J. El Fau).

Some asbestos of cross fibre type was observed in the Ingessana Hills during the present survey. It has been suggested (in discussion with United Nations staff) that a relationship may exist between the Bau Granite and the origin of the asbestos in a contact aureole in the surrounding serpentinite. However, the scattering of presently known asbestos occurrences in the Ingessana Hills does not support this theory.

5.4 MAGNESITE

Talc-magnesite rock at Qala en Nahl has been fully investigated from the point of view of mining, marketing and industrial use in the 1930's by Tyler and Rees. A very rough estimate by Ruxton (1958) gives reserves of 25 million tons.

Magnesite occurs in the Ingessana Hills as pockets, lenses and also as veins and vugs transecting the serpentinite. Kabesh (1961) shows several localities where magnesite is of economic importance.

5.5 COPPER

Malachite staining and primary chalcopyrite have been noted by Tyler and Rees over a wide area in the Basal Schists of Nafs el Kelb

and J. Salmin. The copper mineralisation is associated with regional injection of quartz veins.

This copper mineralisation is probably of the disseminated sub-economic type noted in metasediments in many parts of eastern Africa. There is a possibility however, that a local concentration of copper may reach economic grade.

5.6 HEMATITE

Kabesh (1961) reports a minor occurrence of oolitic hematite near the village of Fadamiya, in the eastern part of the Ingessana Hills where it is intercalated in the metasedimentary sequence. This author gives an estimate of 10,000 tons of ore reserves.

5.7 GOLD

Tyler noted traces of gold near J. Ghanam ESE of the village of Balos.

5.8 PLATINUM

The serpentinite in Ingessana has been silicified, leading to the formation of birbirite caps on some hills. In Ethiopia, platinum is found in such birbirites and by analogy there would appear to be some prospect of finding platinum in Ingessana. It has not however been reported previously.

5.9 BUILDING MATERIAL

The granite inselbergs will be an important source of road metal in the event of a road system being built in the area. These rocks already provide freestone for the better quality houses in the district and this usage could spread.

Marble from a quarry along the Blue Nile is being used in the construction of a power station near the Roseires dam. Several other outcrops could be used for road construction in the Ingessana Hills if necessary.

TABLE II
GEOLOGICAL HISTORY

AGE	MAJOR EVENTS	FORMATION	TECTONISM	MINERALISATION	REMARKS	EXAMPLARY LOCALITIES FOR GRANITIC ROCKS
TERTIARY/ QUATERNARY		Formation of present pediments and deposition of the clay, sand, gravel and boulder beds of the flood plain of Rahad, Dinder and Blue Nile				
MESOZOIC		EROSION NUBIAN SANDSTONE EROSION				
? PALAEOZOIC		YOUNGER GRANITES MAFIC ROCKS OF THE WAD WADEDA COMPLEX	LOCAL SHEARING ALONG NNE-SSW ZONES	Silicification of Serpentinites and development of BIRBIRITE ? COPPER SULPHIDES? ASBESTOS DEVELOPMENT OF TALC-CARBONATE ROCKS	Multiple intrusion of gabbro-norite-(diorite)-basalt-dolerite	Dikes at J. BEILA, DAMAZIN BAU J. BAN, AZAZA, QUNQULEISA, BAU
LATE PRECAMBRIAN		OLDER GRANITES TO GRANODIORITES WITH ASSOCIATED PEGMATITES GNEISSES	OPEN FOLDING ALONG NW-SE AXES	(The age relations of these minerals and the geological formations are uncertain)		BAN-BALOS granites and granodiorites Foliated granites of J. KILGU, J. BURGU, J. BAGIS, J. ABU QUREIN, J. AGADI, J. MASIF
		SERPENTINITES AND MAFIC ROCKS OF THE CENTRAL INGESSANA COMPLEX AND AROUND QALA EN NAHL	ISOCLINAL FOLDING ALONG NE-SW AXES	CHROMITE		
		PELITIC AND PSAMMITIC SEDIMENTS		HEMATITE	Emplacement of ultramafic rocks probably associated with deep-reaching shear zones. Serpentinization of peridotites and dunites before and during emplacement	
	TECTONISM, REGIONAL METAMORPHISM AND PLUTONISM					
	GEOSYNCLINAL DEVELOPMENT					

6. GEOLOGICAL HISTORY

Metasedimentary rocks representing original pelitic and psammitic deposits, reflect the infill of a geosynclinal buckle. The original basement has not been recognized. Radiometric age determinations have not yet been carried out for rocks of the presently investigated area. However, it is suggested that in view of lithological similarities the rocks in the area investigated can be correlated with rock assemblages in S.E. Egypt (Hunting Geology and Geophysics Ltd., 1967). Continuity with rocks in the Red Sea Hills as suggested by Ruxton (1956-a) together with the observed NNE to NE trend in the distribution of lithological units would support this correlation. This would place the initiation of the geosyncline at about 1,000 million years ago (El Shazly, 1966).

Towards the end of geosynclinal sedimentation ultramafic rocks, now represented by the chromite-bearing serpentinites, were emplaced presumably along deep reaching shear zones as "cold" intrusions. They were associated with gabbroic rocks, the present epidiorites. It is thought that the serpentinites are original alpine-type peridotites and dunites; the metamorphic and tectonic conditions of intrusion of such rocks have been exhaustively discussed by many authors (e.g. Bowen and Tuttle, 1949; Hess, 1955; de Roever, 1957; and Miyashiro, 1966). Recently a review was presented by Wyllie (1967).

A phase of folding along N - S to NNE-SSW axes seen in the schists, subparallel to the geosynclinal axis defined the beginning of orogenic tectonism. Regional metamorphism under conditions of the greenschist facies and locally also of the amphibolite facies was connected with subsequent stages of plutonism.

A second phase of folding, along approximately NW-SE axes, presumably during the emplacement of the older granites and granodiorites, has affected extensive parts of the area. Local migmatization and the formation of gneisses are thought to be related to the earlier stages of granite emplacement.

The intrusion of the members of the Wad Wadeda Mafic Complex took place probably before or during the second fold phase. No trace of the first phases have been observed in these rocks. Metamorphic alterations are much less than in the mafic rocks around the village of Qala en Nahl and in the Central Complex of the Ingessana Hills.

A phase of shearing with north-north-easterly strike appears to conclude the major tectonic events in the Basement. Probably in this stage the talc-carbonate rocks originated from the serpentinites.

Younger massive granites were emplaced as stocks and dykes when the orogenic compressive forces gradually decreased in strength. The silicification of the serpentinites took place after the formation of talc-carbonate rocks and is possibly also related to this late orogenic to post-orogenic stage.

The later history of the area comprises a long period of erosion before the deposition and subsequent erosion of the Nubian sandstone, the deposition of the sediments in the alluvial flood plains of the Rahad, Dinder and Blue Nile and the formation of the present pediments north and south of this flood plain.

7. CONCLUSIONS AND RECOMMENDATIONS

It is clear from the photogeological studies and from previously available data that the central part of the Eastern Area is occupied by a very thick accumulation of alluvium and is unlikely to be of interest for mineral exploration.

The zones of interest are almost entirely confined to the extremities of the area, around Qala en Nahl and the Ingessana Hills. In these areas the distribution of rock types and the general structure are reasonably clear, but the airborne geophysical survey will no doubt add useful information, particularly in those areas of thin, continuous soil cover.

Sedimentary iron ore occurs at Fadamiya in the Ingessana Hills. The estimated reserves are negligible and it is considered unlikely that economic deposits occur in this region.

Traces of gold have been found near J. Ghanam and a localised programme of panning stream sediments in the J. Ghanam area should be undertaken. However there is no other evidence to warrant a search for gold. Similarly, a regional search for platinum is not warranted but a local investigation of the birbirites should be undertaken.

The only mineral currently being mined in this area is the chromite at J. Abu Dom and J. Korba. It appears that the mine at J. Abu Dom is capable of a considerable increase in output and further deposits may be found in the area. Expansion of the chromite mining would necessitate an increase in the present capacity of the railway to carry one to Port Sudan.

It is recommended that exploration for chromite should begin with work in the area around J. Abu Dom and J. Korba, involving detailed geological mapping and conventional prospecting. This primary detailed work could later be extended into a regional survey for chromite. In view of Tyler's detailed work at Qala en Nahl further work in the En Nahl hills is considered unjustified and it is recommended that these hills be omitted from the regional survey. Geochemical prospecting of stream sediments could be a useful tool in this regional survey. Geophysical work may also be useful, particularly gravimetric and magnetic

techniques, but the interpretation of results will be extremely difficult in the areas of mountainous terrain and complex geology.

The potentially economic talc-magnesite deposits are well known and further field work at present is not warranted. Market research should be started, using available data, to ascertain whether there is a market for the material. On the basis of this study it can be decided whether detailed, pre-exploitation investigations are justified.

Asbestos has been widely prospected but there is no definite information as to whether the deposits are economic or not. It is recommended that work presently in hand in Ingessana be followed by a detailed re-examination of locations previously described from Qala en Nahl, Umm Saqata and J. El Fau.

Copper mineralisation occurs in the basal schists at Nafs el Kelb and J. Salmin. It is recommended that the Basal Schists of this area be investigated for copper by a regional stream sediment survey. Target areas detected by this survey could be further investigated by detailed geological mapping and appropriate geophysical techniques, electromagnetic, self-potential or induced polarization.

BIBLIOGRAPHY

- AFIA, M.S., and
MOHAMMED, O.M. (1962) Qala en Nahl asbestos. Report
Geological Survey Department of the
Sudan. (Typescript in Mr. O.M. Mohammed's
office, map in Drawing Office).
- BOWEN, N.L., and
TUTTLE, O.F. (1949) The system $MgO-SiO_2-H_2O$.
Geol. Soc. Ass. Bull., 60: 439-460.
- CHIDESTER, A.H. (1962) Petrology and geochemistry of selected
talc-bearing ultramafic rocks and
adjacent country rocks in north-central
Vermont. U.S.G.S, Prof. Pap., 345,
207 pp.
- DE ROEVER, W.P. (1957) Sind die alpinotypen Peridotitmassen
vielleicht tektonisch verfrachtete
Bruchstücke der Peridotitschale?
Geol. Rundschau, 46: 137-146.
- DUPARC, L., and MOLLY, E. (1928) Les gisements platinifères du Birbir
(Abessynie). Bull. Suisse Min. Petr.
Zürich.
- EL SHAZLY, E.M. (1966) Structural development of Egypt,
U.A.R. Proc. 4th Ann. Meeting Geol.
Soc., Egypt.
- GRABHAM, G.W. (1929) Letter 68/10299 to Captain W. Johnson.
in file GS/55/L/G of the Geological
Survey Department of the Sudan.
- HESS, H.H. (1955) Serpentine, orogeny and epeirogeny.
Geol. Soc. Am., Spec. Pap., 62: 391-408.

HUNTING GEOLOGY AND
GEOPHYSICS LTD. (1967)

Assessment of the mineral potential
of the Asswan Region, United Arab
Republic. A Photogeological Survey,
United Nations Development Programme -
United Arab Republic Regional Planning
of Asswan, 138 pp.

HUNTING GEOLOGY AND
GEOPHYSICS LTD. (1968a)

Mineral survey in two selected areas
in Ethiopia. Draft report on photo-
geological survey of part of the Wollega
area, Ethiopia. United Nations Develop-
ment Programme - Imperial Ethiopian
Government, 67 pp.

HUNTING GEOLOGY AND
GEOPHYSICS LTD. (1968b)

Mineral survey in three selected areas
in Sudan. Draft report on photogeological
survey of the Western Area. United
Nations Development Programme -
Republic of the Sudan, 58 pp.

JELENC, D. (1966)

Mineral Resources of Ethiopia.
Ministry of Mines, Addis Ababa.

JONES, F. (1954)

The geology of the Damazin area.
In: Sir Alexander Gibb and Partners,
Roseires Dam Project Report.

KABESH, M.L. (1961)

The geology and economic minerals
and rocks of the Ingessana Hills.
Ministry of Mineral Resources,
Geological Survey Department,
Republic of the Sudan, 61 pp.

KNILL, J.L. (1962)

The geology of the Roseires Dam site.
Ministry of Irrigation and Hydro-Electric
Power. The Republic of the Sudan.

- MIYASHIRO, A. (1966) Some aspects of peridotites in orogenic belts. Jap. J. Geol. Geogr., 37 (1): 45-61.
- RUXTON, B.P. (1956-a) The major rock groups of the Northern Red Sea Hills, Sudan. Geol. Mag., 93 (4): 314-330.
- RUXTON, B.P. (1956-b) Letter to Director of Geological Survey. In file GS/55/L/G of the Geological Survey Department of the Sudan.
- RUXTON, B.P. (1957-a) Letter to Director of Geological Survey. In file GS/55/L/G of the Geological Survey Department of the Sudan.
- RUXTON, B.P. (1957-b) The geology and mineral resources of the area around Qala en Nahl. Unpubl. Interim Report Geological Survey Sudan 55L/G. In file GS/55/L/G. Map in Drawing Office.
- RUXTON, B.P. (1958) The talc-magnesite deposits of Qala en Nahl. In file GS/55/L/G of the Geological Survey Department of the Sudan.
- THAYER, T.P. (1966) Serpentinization considered as a constant volume metasomatic process. Am. Min., 51: 685-710.
- TYLER, W.H. (1932-a) Chromite in the Sudan. Mining. Mag., 48, p.83.
- TYLER, W.H. (1932-b) Geological map of Qala en Nahl, scale 1: 50,000. In file GS/55/L/G of the Geological Survey Department of the Sudan.

- TYLER, W.H., and REES, W.J. (1934) An investigation into the commercial utility of a deposit of magnesite - bearing rocks in the Anglo-Egyptian Sudan. Trans. Ceram. Soc., 33: 104-127.
- WILCOCKSON, W.A., and TYLER, W.H. (1933) On an area of ultrabasic rocks in the Kassala Province of the Anglo-Egyptian Sudan. Geol. Mag. 70: 305-321.
- WYLLIE, P.J., Ed (1967) Ultramafic and related rocks. Wiley, 464 pp.
- RUXTON, B.P. (1957) The tectonics and mineral resources of the area around Gata en-Nahil, Sudan. Intern. Geol. Rev. 5: 1-10.
- RUXTON, B.P. (1958) The tectonics and mineral resources of the area around Gata en-Nahil, Sudan. Geol. Mag. 75: 1-10.
- THAYER, T.P. (1960) Serpentinization considered as a constant volume metamorphic process. Am. Min. 45: 685-710.
- TYLER, W.H. (1932) Granite in the Sudan. Mining Mag. 13: 1-10.
- TYLER, W.H. (1933) Geological map of Gata en-Nahil, scale 1:50,000. In the CS/55/L/G of the Geological Survey Department of the Sudan.

APPENDIX A

SUMMARY OF RESULTS OF UNDERGROUND WORK

AT QALA-EN-NAHL AFTER RUXTON (1957-b)

Shaft 1

Chromite vein in serpentine and talc-carbonate rock. The chromite died out at 27 feet. The shaft was continued to 87 feet, then a 110 feet adit was driven at this level with no result.

Shaft 2

In serpentine to 70 feet with a 160 feet drive at 51 feet level. Chromite lens from 1 to 20 inches wide was located in the drive and followed to 70 feet. Tyler estimated 30 tons.

Shaft 3

Talc-magnesite schist to 92 feet with chromite from 27 to 32 feet and again at 51 to 58 feet. A 160 feet drive was made at 67 feet. Chromite lenses ranged to 27 inches in width and the ore averaged 42 per cent Cr_2O_3 .

Shaft 4

55 feet in talc-carbonate rock and serpentinite.

Adit 1

190 feet at 295° in talc-magnesite schist near its contact with serpentine. No chromite.

APPENDIX A

STATEMENT OF RESULTS OF UNDERGROUND WORK

SHAFT NO. 1 - MAIN SHAFT (SEE FIG. 1)

Shaft 1

Shaft 1 was driven to a depth of 110 feet with no results. Chromite lens from 1 to 20 inches wide was located in the drive and followed to 70 feet. Tyler estimated 30 tons.

Shaft 2

Shaft 2 was driven to a depth of 70 feet with a 100 foot drive at 51 feet level. Chromite lens from 1 to 20 inches wide was located in the drive and followed to 70 feet. Tyler estimated 30 tons.

Shaft 3

Shaft 3 was driven to a depth of 32 feet and again at 51 to 58 feet. A 100 foot drive was made at 67 feet. Chromite lenses ranged to 27 inches in width and the ore averaged 45 per cent Cr₂O₃.

Shaft 4

Shaft 4 was driven to a depth of 35 feet in talc-carbonate rock and serpeninites.

Adit 1

Adit 1 was driven to a depth of 190 feet at 295 feet magnetic contact near its contact with serpeninites. No chromite was located.

APPENDIX B

BOREHOLES ILLUSTRATING THE COMPOSITION OF THE
NUBIAN SANDSTONE AND OF THE ALLUVIAL FLOOD
PLAIN DEPOSITS OF RAHAD, DINDER AND BLUE NILE
AFTER GEOLOGICAL SURVEY DEPARTMENT DATA

B.H. 776 DOMAT

7 km N of J. Matna

Depth in Feet

0 - 5	Rotted ironstained medium - to coarse-grained feldspathic sandstone.
5 - 10	Illsorted fine and medium-grained sandstone, clayey matrix.
10 - 15	Pale purple silty mudstone with sand
15 - 20	Pale purple fine-grained sandstone with silty clay matrix.
20 - 25	Pale buff fine-grained sandstone with silty clay matrix
25 - 85	Pale purple silty mudstone with sand
85 - 90	Pale purple silty mudstone with small pebbles
90 - 100	Purple and grey siltstone
100 - 105	Fine-grained sandstone with few coarse grains
110 - 115	Medium-grained sandstone
115 - 120	Medium-grained sandstone with pink clayey matrix
120 - 125	Pale purple sandy siltstone
125 - 135	Dark grey purple siltstone
135 - 140	Brittle sandstone
140 - 165	Green decayed basaltic tuff
165 - 205	Basement complex, psammitic hornfels

ABU HASHEIM B.H. 1531

6 km NW of western project boundary on the northern
bank of the River Dinder

Depth in Feet

0 - 10	Yellowish illsorted loose sand with quartz pebbles
10 - 35	Fine - to medium-grained loose reddish sand, non-calcareous
35 - 45	Brownish sand with quartz pebbles, non-calcareous
45 - 55	Gravels, pebbles 0.5-1.5 cm in diameter
55 - 60	Fine - to medium-grained light yellow loose sand, non-calcareous
60 - 75	Reddish sandy clay with iron oxide, non-calcareous
75 - 85	Fine - to medium-grained light red, loose sand with gravels
85 - 95	Reddish clayey sand, non-calcareous
95 - 130	Fine - to medium-grained brownish sand with quartz pebbles, non-calcareous
130 - 140	Reddish sandy clay with some gravel, non-calcareous
140 - 175	Fine - to medium-grained yellowish loose sand with quartz pebbles, non-calcareous
175 - 205	Reddish, illsorted fine - to medium-grained loose sand, non-calcareous
205 - 295	Illsorted loose pinkish yellow sand with quartz pebbles
295 - 315	Weathered basement gneisses

A section richer in clay material, and more typical of the alluvium as a whole, is represented by the geological log of a borehole in photo-mosaic 6 at Nur el Galil on the north bank of the Dinder about 20 km east of Abu Hasheim.

NUR EL GALIL B.H. 1870

Depth in Feet

0 - 50	Superficial black cotton soil formed mainly of very compact clay containing kankar nodules
50 - 65	Brown to light brown, very compact clay with white kankar nodules
65 - 70	Very dark compact clay with kankar
70 - 75	Very fine-grained sand with pebbles cemented by carbonaceous material
75 - 80	Yellowish fine-grained sand to gravel cemented by carbonaceous and calcareous material
80 - 90	Silty clay mixed with carbonate
90 - 100	Brownish clay with kankar
100 - 105	Very fine-grained sand cemented with carbonate and kankar nodules
105 - 115	Very compact brownish clay with kankar

APPENDIX C

SUMMARY OF THE FEATURES OF REPRESENTATIVE NUR EL GALIL B.H. 1870

Map Sheet No. 1

1

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* See end of table for key

APPENDIX C

SUMMARY OF THE FEATURES OF REPRESENTATIVE MICROSCOPICALLY INVESTIGATED ROCKS

Map Sheet No.	Sample No.	Name	Mineralogical Constituents*	Texture and Remarks
1	LC 8	Granodiorite	pl(An20-28) -qtz -kfs -hbl -bi -ms -op	medium - to coarse-grained, hypidiomorphic
1	LC 18	Granulite	hyp -hbl -op -pl(An55-60)	fine-grained, banded
1	LC 21	Meta-norite	trem -hyp -aug -pl(An75-85) -op	coarse - to medium-grained, poikiloblasts of amphibole
1	LC 32	Sericite-quartz schist	ser -qtz -op	fine - to medium-grained; strongly schistose; two foliation directions; schistosity interrupted by iron-rich knots possibly constituting pseudomorphs after garnet or staurolite
1	LC 54	Talc schist	tlc -chl -act -op	fine - to medium-grained schistose; talc poikiloblastic
1	LC 57	Gneissose granite	qtz -pl(An10-15) -kfs -op	medium - to coarse-grained; granoblastic; gneissose
1	LC 59	Granodiorite	qtz -mi -pl(An15-20) -bi -op -ser -zc -ap	medium - to coarse-grained, hypidiomorphic porphyritic
1	LC 62	Serpentine	ant -chl -mg -carb	fine-grained, schistose
1	LC 74	Meta-gabbro	fs(sauss) -trem -chl	coarse-grained, granoblastic, slightly schistose in places
3	B 12	Granitic gneiss	qtz -kfs -pl(An5-10) -ser -op -ap	medium - to fine-grained, banded

* See end of table for key.

Map Sheet No.	Sample No.	Name	Mineralogical Constituents	Texture and Remarks
3	B 26	Serpentinite	ant-chl-op-carb	fine-grained, fibrous
3	B 57	Quartz-sericite-graphite schist	qtz-ser-gp-chl-op	fine-grained, slightly banded, schistose
3	B 59	Silicified serpentinite	ant-qtz-ser-chl-op	massive, fine-grained; boxwork texture brought out by iron-stained quartz stringers
3	B 77	Epidiorite	chl-pl(sauss)-ep-act-carb-op	medium - to fine-grained massive, granoblastic
3	B 73	Serpentinite	ant-chl-op-carb	fine-grained, slightly schistose

KEY

amph	=	amphibole	hyp	=	hypersthene
act	=	actinolite	kfs	=	potassium feldspar
(An5-15)	=	anorthite content	mi	=	microcline
ant	=	antigorite	mg	=	magnetite
ap	=	apatite	ms	=	muscovite
aug	=	augite	op	=	opaque ore
bi	=	biotite	pl	=	plagioclase
carb	=	carbonate	qtz	=	quartz
chl	=	chlorite	sauss	=	saussuritized
ep	=	epidote	ser	=	sericite
fs	=	feldspar	tlc	=	talc
gp	=	graphite	trem	=	tremolite
hbl	=	hornblende	zr	=	zircon

THE UNIVERSITY OF CHICAGO
DEPARTMENT OF THE HISTORY OF ARTS
AND ARCHITECTURE IN HILL SELECTED AREAS

ARCHITECTURAL MAP

UNIVERSITY OF CHICAGO
CENTRAL HILLS

1928-1929

BY THE ARCHITECTURAL DEPARTMENT

UNIVERSITY OF CHICAGO
PRESS

Map Sheet No.	Section No.	Form	Mineralogical Constituents	Remarks
1	1-14	Diagenetic	central ep-crys	
2	2-15			
3	3-16			
4	4-17	Diagenetic	at-planned ep and carb-ep	
5	5-18	Diagenetic	sub-ent ep-seam	

KEY

amph	amphibole	amph	amphibole
act	actinolite	act	actinolite
(An5-10)	amphibole content	pl	plagioclase
an	anorthite	qtz	quartz
ap	apatite	causs	calcium silicate
aug	augite	act	actinolite
bl	biotite	tal	talc
crth	crtholite	trms	trondhjemite
clst	chlorite	sc	sericite
ep	epidote		
fs	ferrosilite		
gr	garnet		
hbl	hornblende		

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

GEOLOGICAL MAP
of the
AREA BETWEEN QALA EN NAHL
AND THE INGESSANA HILLS
EASTERN SUDAN

by

HUNTING GEOLOGY AND GEOPHYSICS LTD

SCALE 1:300,000 (approximately)

