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NEW WATER AND PROSPERITY IN THE RED SEA PROVINCE

A SOCIO-ECONOMIC FEASIBILITY AND GEOPHYSICAL EXPLORATION FEASIBILITY PROGRAM

PHASE I REPORT
MARCH 1989

By

BCI GEONETICS, INC.

Prepared for

The Sudanese Company For Water and Economic Development, LTD.
and the United States Agency for International Development
under Grant # 650-0510-G-00-8067

Cover Photo....

This is a satellite image of the Northern portion of the Red Sea Hills. The image has been computer enhanced to show rock type, structures, and drainage patterns. These features are used in the Megawatersheds Exploration model to locate new sources of groundwater for Sudan.

Computer procressing and enhanced image provided for BCI by Dr. Mohamed Sultan, Department of Earth and Planetary Sciences, Washington University, St. Louis, Missouri.

[redacted]

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بسم الله الرحمن الرحيم

مقدمة

التقرير المرفق يلخص بداية عمل مجموعة علمية تنتمي إلى مؤسسة بي سي آي جيونتكس في البحث عن موارد جديدة للمياه الجوفية في محافظة البحر الأحمر في السودان ضمن إطار مشروع تموله هيئة المعونة الأمريكية. ويهمني كجيولوجي عربي هذا العمل أولا لإهتمامي بدعم السودان الشقيق وتنمية موارده الطبيعية لخدمة التنمية الإقتصادية، وثانيا للتعرف على إحتمالات تواجد المياه الجوفية في الصخور النارية في شرق وغرب البحر الأحمر. هذه الصخور كانت في الماضي تعتبر خالية من المياه لقلة المسامية فيها. ولكن إتضح لنا حديثا وبإستخدام وسائل عصر الفضاء المتقدمة أن الشقوق والكسور العظيمة الشأن في هذه الصخور مسامية تسمح بسريان كميات هائلة من المياه تغذى من أمطار على مسافات بعيدة وتكمن في أعماق كبيرة تبعد عن مصادر التلوث والملوحة، ويمكن تنميتها لخدمة الزراعة والصناعة والمشاريع التعدينية ومعيشة الناس.

ولاشك في أن التقدم العلمي في هذا المضمار وخصوصا من خلال هذا البرنامج البحثي سوف تكون له آثار حميدة في المنطقة العربية كلها. لذا يسعدني ويشرفني كمصري تهمه رفعة شأن الوطن العربي أن أشارك علماء المجموعة المذكورة في دراسة المعلومات الفضائية وتفسيرها لإختيار مواقع حفر الآبار التجريبية، لأني أعتقد أن هذا العمل سوف يعود على السودان وأهلها الكرام بكل خير لأن تنمية الموارد المائية هو أساس التنمية الإقتصادية في منطقة الصحراء الشرقية.

فاروق الباز

١٩٨٩/٤/١٢

EXECUTIVE SUMMARY

The Sudanese Company for Water and Economic Development (SUWED) has received a grant from the United States Agency for International Development, in order to establish the feasibility of developing water-dependent economic resources in the Red Sea Province of Sudan, based on the discovery of new groundwater sources. Once feasibility is proven, SUWED principals will invest in business development tied to mining, agriculture and urban industry within the Red Sea Province, which is currently severely curtailed by the scarcity of sustainable water supplies.

The ultimate objective of this feasibility program is to assess the physical and financial viability of project-specific water-related economic development in the Red Sea region. The program is being conducted in four phases and this report represents the findings of the first phase. The Phase I results include preliminary descriptions of 23 economic development sites and 14 favorable zones for water development.

Phase I groundwater investigations support the "Megawatersheds" Exploration Model, described in the SUWED proposal and in this report. There appear to be substantial correlations between mega-shear/fault zones and basin drainage within the Red Sea Province. Prior investigations of the potential water resources within the Red Sea Province have not emphasized either these correlations or their contributions to the potential discovery of major sustainable yields of usable water from bedrock sources.

Phase I economic development results indicate promising economic projects in cement manufacturing, copper/zinc/gold mining operations, agricultural development and municipal water development for industrial and human consumption.

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I. INTRODUCTION

The Sudanese Company for Water and Economic Development (SUWED) has received a grant from the United States Agency for International Development, in order to establish the feasibility of developing water-dependent economic resources in the Red Sea Province of Sudan, based on the discovery of new groundwater sources. Once feasibility is proven, SUWED principals will invest in business development tied to mining, agriculture or urban industry and the discovery of new groundwater supplies within the Red Sea Province.

II. ECONOMIC POTENTIAL OF THE RED SEA REGION -- OVERVIEW

Minerals

The economic potential of the Red Sea Region appears to be quite favorable but hinges on the sustainable availability of usable water.

The development of metallic minerals, including copper, zinc and gold is promising within the western edge of the Red Sea Region. If water can be found for these operations, then it will greatly facilitate the development of these lucrative mineral resources.

Potentially economic sources for the industrial minerals used in manufacturing fertilizer, cement and plaster have also been located within the Red Sea Hills Region. Some of the factory equipment used in processing these materials have already been imported but are not being utilized due to the non-availability of water obtained at a reasonable cost. Priority target areas have been located for further investigation.

Agriculture

In addition to the economic potential of mineral resources, the Red Sea Hills Region contains a potentially profitable agricultural region within the Tokar Delta. Only 40% of the fertile lands within this delta are currently being utilized for agriculture. The many unknown and unpredictable aspects of both surface water and groundwater in the Tokar region hinder the development of profitable businesses based in agriculture.

Municipal/Industrial

There is a great demand for potable fresh water to supply both industry and residents of the City of Port Sudan and other coastal towns. Discovery of water near Port Sudan would not only aid the over-expanding population, but also encourage further expansion of existing businesses.

III. OVERVIEW OF PHASE I WORK

The results of this work are summarized in the text of the report. The scope of work completed in Phase I is described on the accompanying flow chart (Figure #1). Basic inputs included the following:

- Basic Data Review (Bibliography)
- Socioeconomic Study (Appendix 1)
- Hydrogeologic Study (Appendix 2)
- Geologic Study (Appendix 3)

The interpretation and synthesis of these data resulted in the delineation of (a) 14 Priority Target Areas (PTA) for detailed Phase II studies of hydrogeologic nature, (b) 23 socioeconomic sites for Phase II studies on economic development potential, and (c) preliminary critical environmental impact factors of the region, to be further investigated in Phase II.

The 14 PTA's represent the areas most likely to contain sustainable water resources. The hydrogeologic PTA's divided into two categories: Primary Target Areas and Secondary Target Areas. A more detailed ranking of these sites will accompany the Phase II report.

The 23 socioeconomic sites are ranked from one to 23. The ranking was established using a preliminary matrix analysis as described in Appendix 1. In addition, a preliminary hydrogeologic analysis was performed on each of the 23 socioeconomic sites (see Appendix 2). The Phase II report will contain a detailed synthesis of this information resulting in the selection of five high priority areas for groundwater exploration.

IV. DESCRIPTION OF THE MAP SHOWING THE LOCATION OF FAVORABLE ZONES (PTA's)

Accompanying this report, as a folded map in the back pocket, is a map of the Red Sea Project Area. Location of

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NEW WATER AND PROSPERITY IN THE RED SEA PROVINCE

PHASE 1 - GROUNDWATER EXPLORATION

(Primary Target Area & Socio-economic Zone Selection)

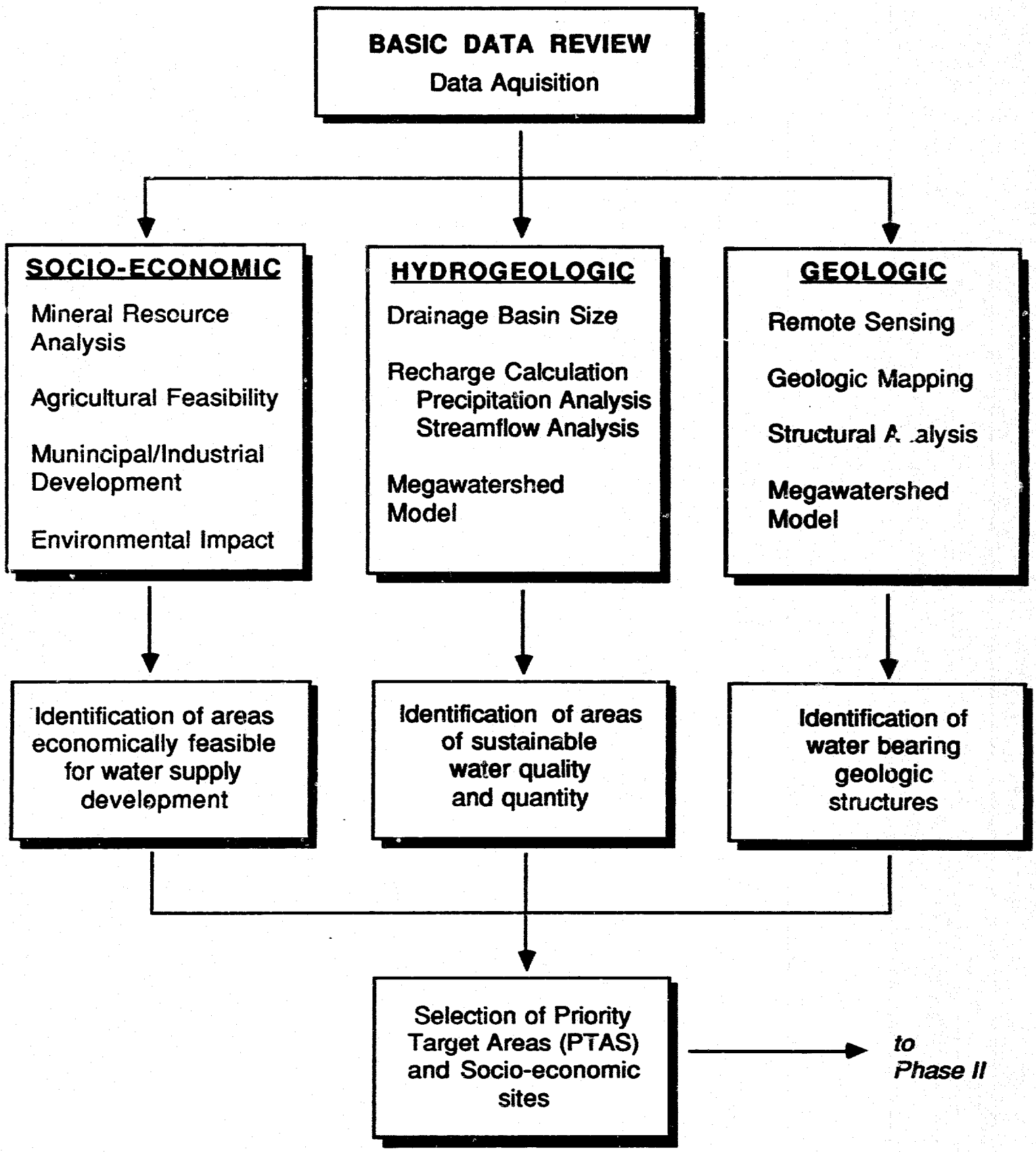


Figure 1

this map within the Sudan is shown on Figure #2. The map shows the location of both Priority Target Areas (Primary and Secondary), and the location of the socioeconomic Target Areas.

The map also shows the location of major mountains, rivers, towns and roads within the project area. The major roads and the Port Sudan-to-Khartoum Railroad) are highlighted and, for reference, a large arrow points to the Town of Port Sudan.

V. SITE SELECTION PROCESS -- RED SEA PROVINCE MEGAWATERSHED EXPLORATION MODEL

The groundwater exploration model applied to the Red Sea study area is termed the "Megawatershed Exploration Model," and is illustrated in Figures 3 through 9. The salient characteristics of the Model are:

1. Large basin/catchment area (Figure 3);

2. Location of complex fracture/fault zones that control shallow drainage and may, themselves, be highly permeable and conductive, and which extend over the entire length of the basin (Figure 4);

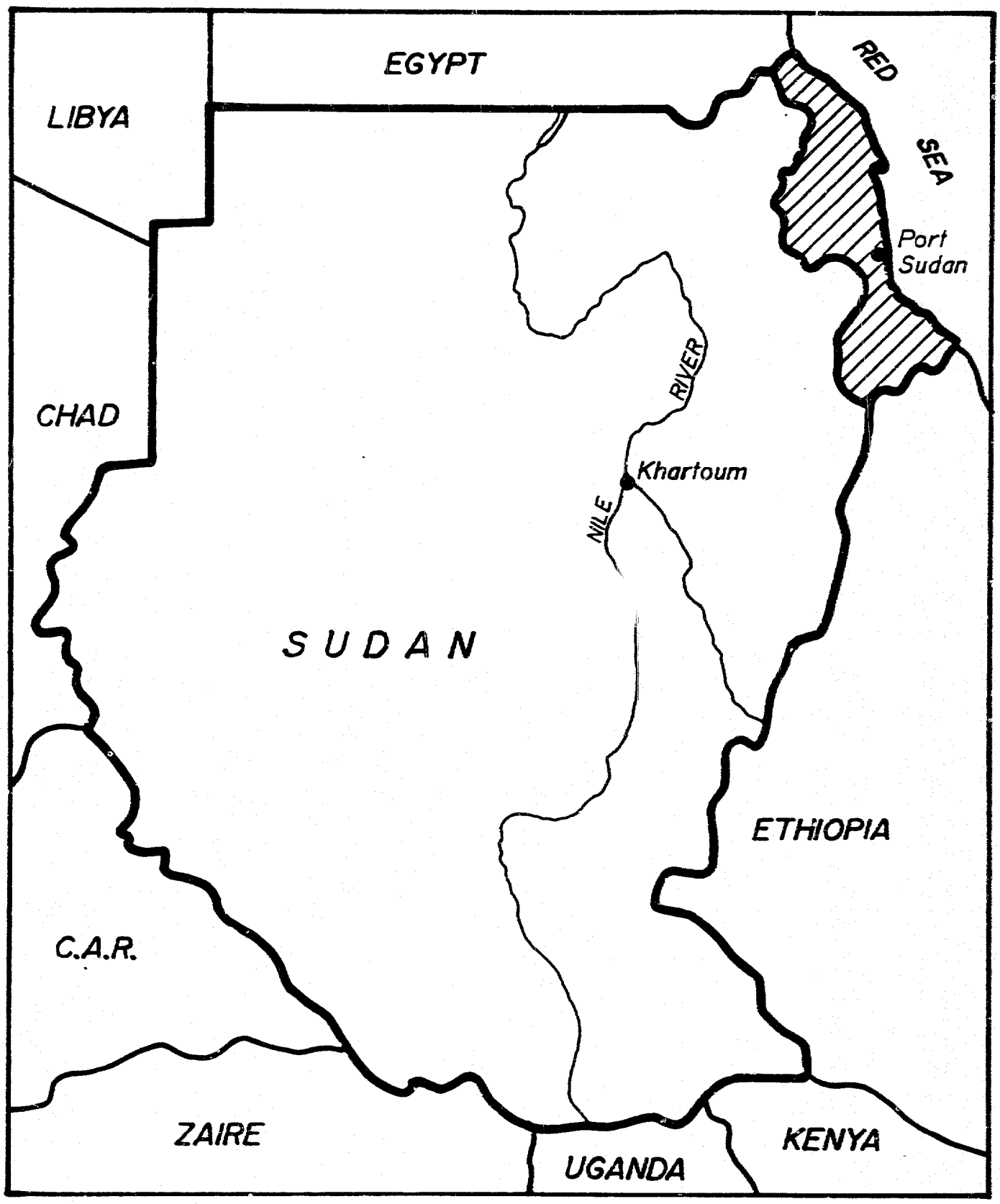
3. Orographic effects on precipitation (Figure 5) with high rainfall in the mountains and lower rainfall on the plains (valleys, coast);

4. The higher mountains, which receive more rainfall, also contain a rectilinear drainage (Figure 7) due to a structural overprinting on the crystalline terrain. This fracture/fault zone overprinting controls the rectilinear drainage and results in greater water transmissivity through pervasive fracture permeability;

5. The higher water transmissivity region of rectilinear drainage feeds into the major fracture/fault zone controlling the location at the center of the basin (Figure 8);

6. This major fracture/fault zone is a complex anastomosing network of faults, fractures, gouge, rock fragments, etc. that varies considerably along its length. The complex, extensive permeable bedrock zone may be, at different places, either

LOCATION OF RED SEA HILLS PROJECT AREA



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confined or in partial hydraulic contact with the overlying sediments, and may create a geometrically intricate aquifer hosting substantial, sustainable, yields of usable water.

The Red Sea Project Area within Sudan contains several areas that fit this "Megawatershed" Exploration Model, especially the Tokar (PTA 5) and Port Sudan (PTA 4) megawatersheds. These areas contain large basins and the basins are dissected by numerous complex shear zones. These shear zones are areas that contain an abundance of fractured bedrock. Both the shear zones and the Tokar and Port Sudan areas are located as shown within Figure 10.

In addition, Figure 10 shows the location of two space shuttle-borne Large Format Camera (LFC) photographs covering the Port Sudan and Tokar areas serving as examples of our target areas. These unique photographs of the region and the overlays that accompany them illustrate the application of our Megawatershed Exploration Model.

The preliminary Megawatershed Exploration Model presented here is generic. The hydrogeologic variations in the Red Sea region which control potential water availability will be analyzed in detail for each given site during Phases II and III.

The Port Sudan and Tokar examples illustrated by the two black and white photographs are areas that contain most of the favorable criteria of our Megawatershed Exploration Model. The region of basin outflow within each of the areas and other PTA's as described below will serve as an area for more detailed analysis in both Phases II and III.

VI. DESCRIPTION OF PRIORITY TARGET AREAS (PTA's)

Following is a brief description of our Groundwater PTAs:

Hydrogeological Primary Target Areas and Secondary Target Areas Listed From North to South in Study Area:

1-PTA: Lat 22.18-22.37, long 35.48-36.08

PTA #1 is centered across a narrow section of the coastal zone containing distal drainage from "Odib" drainage basin to the west. A major NNE trending fault, with Tertiary basalt intrusions along it, is contained

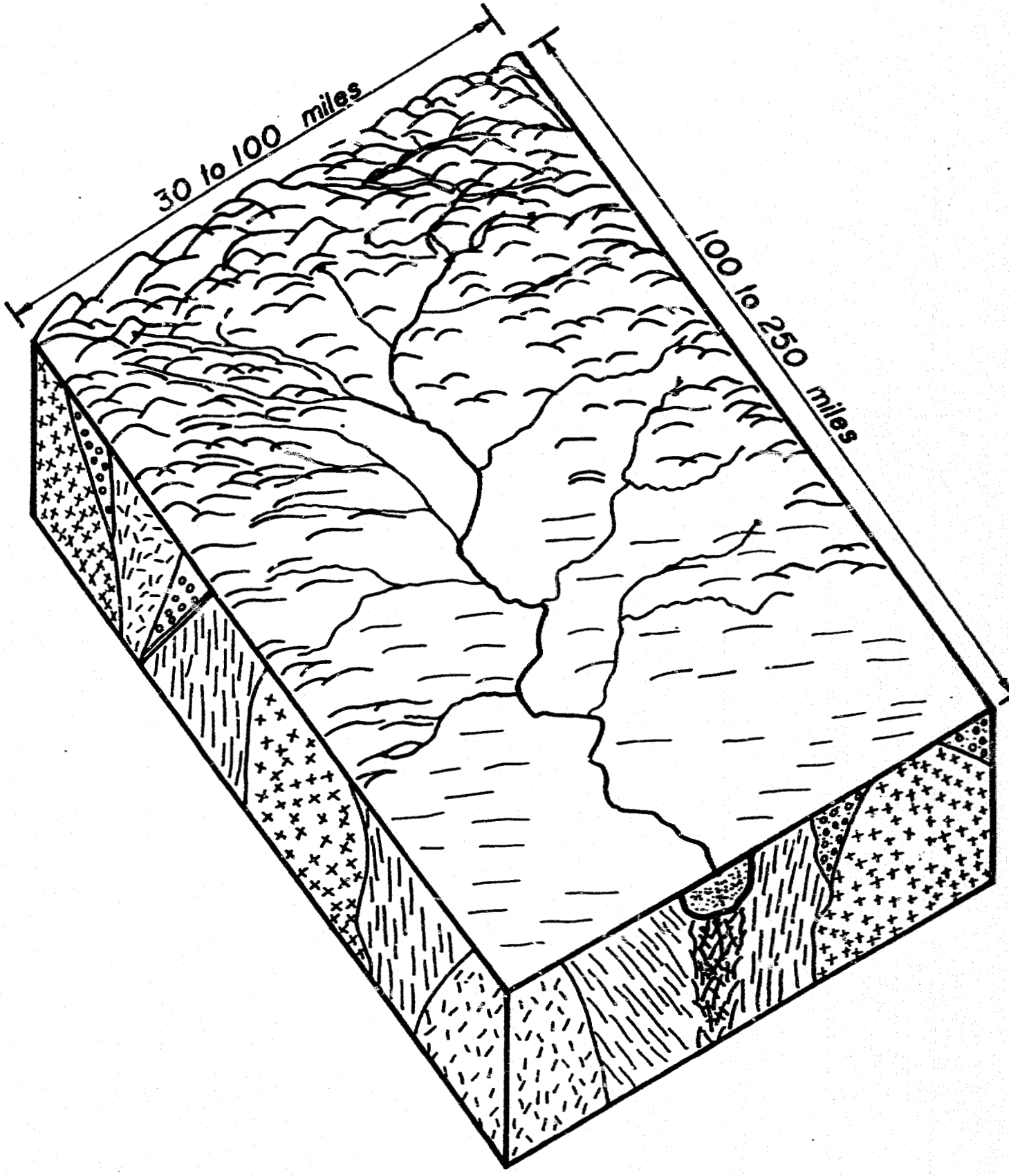


FIGURE 3 **Megawatershed : Exploration Model**

Large basin/Catchment area

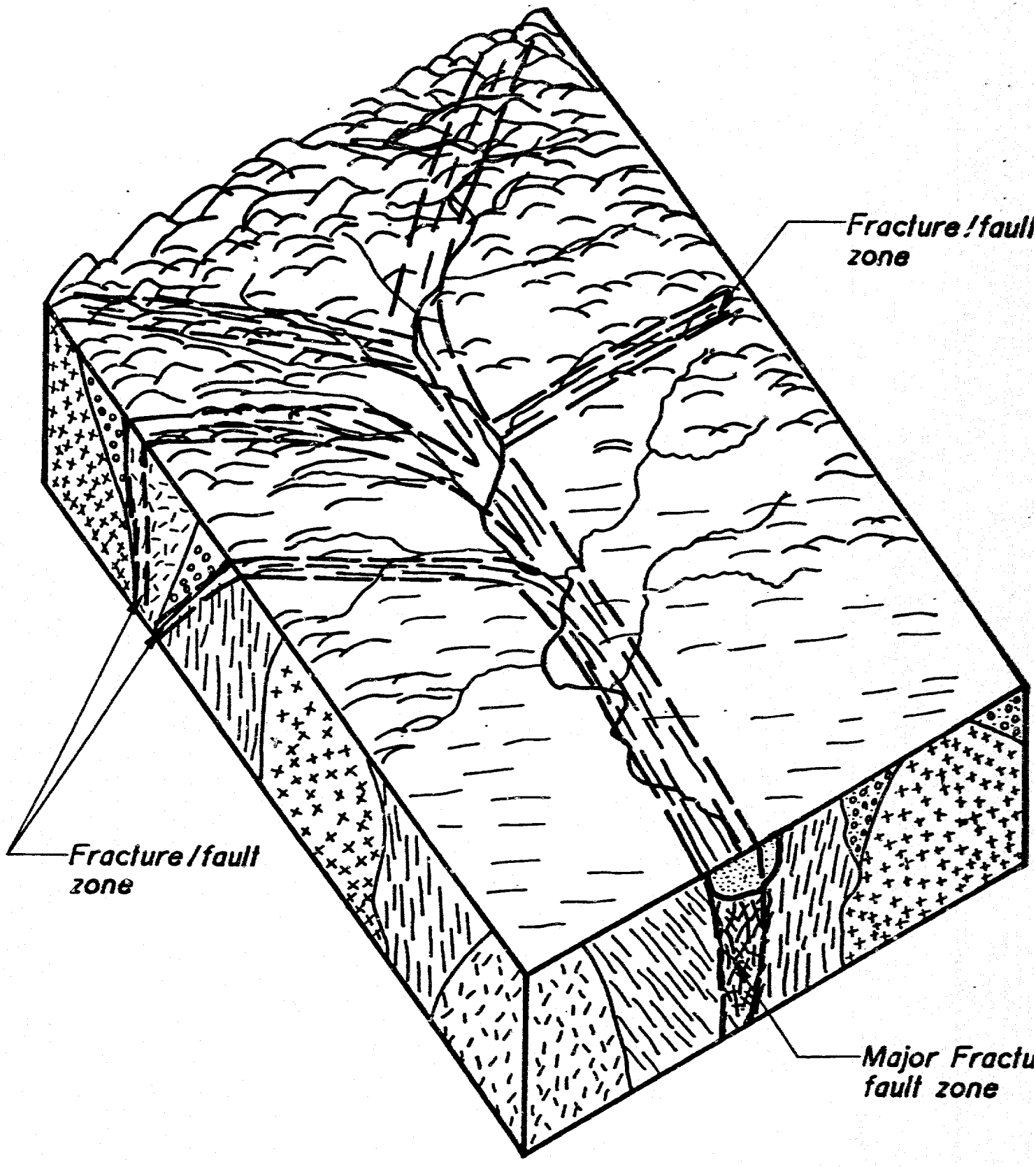


FIGURE 4 **Megawatershed : Exploration Model**

Location of complex fracture/fault zones controlling drainage

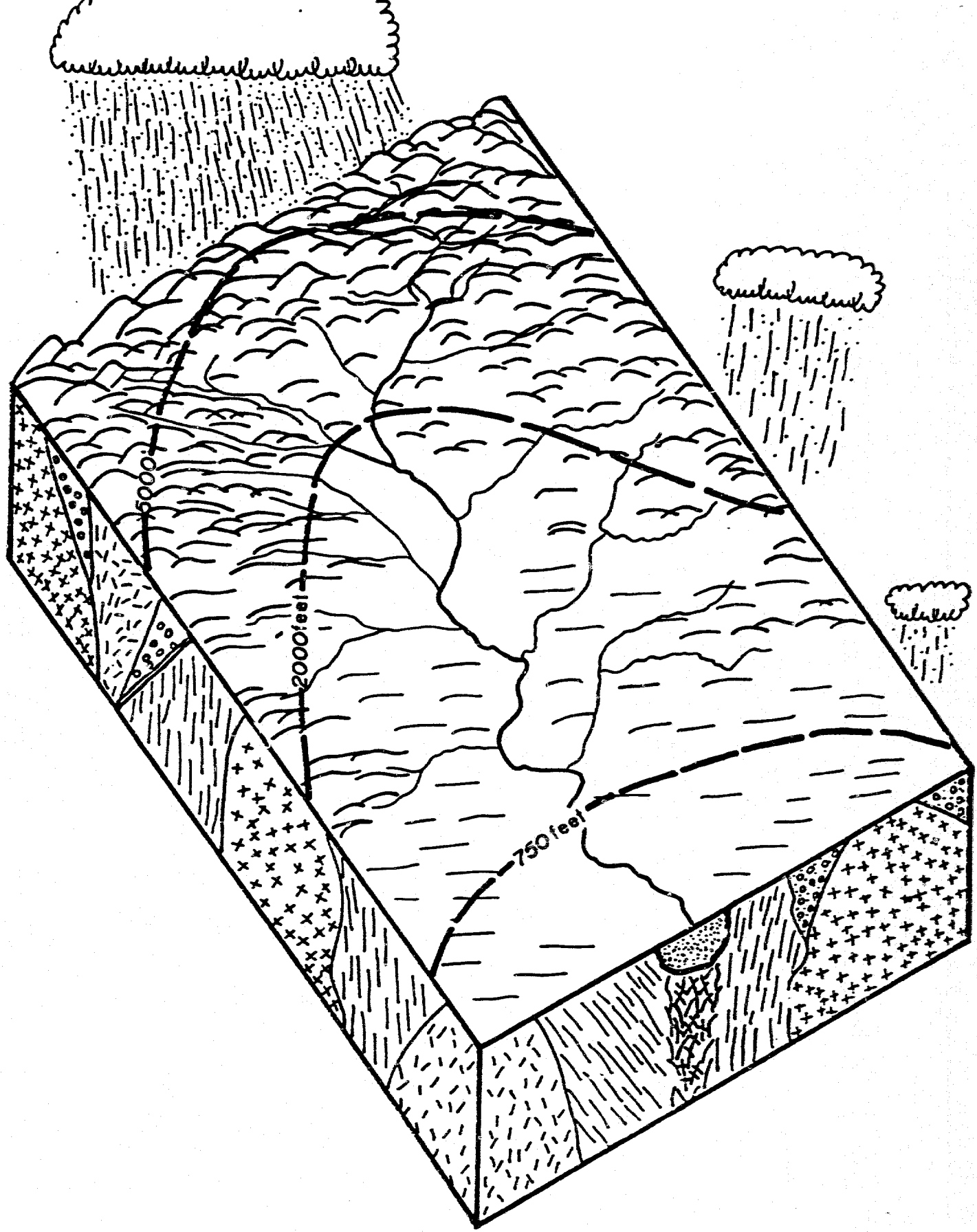


FIGURE 5 **Megawatershed : Exploration Model**

Orographic effects on precipitation
Elevation in feet

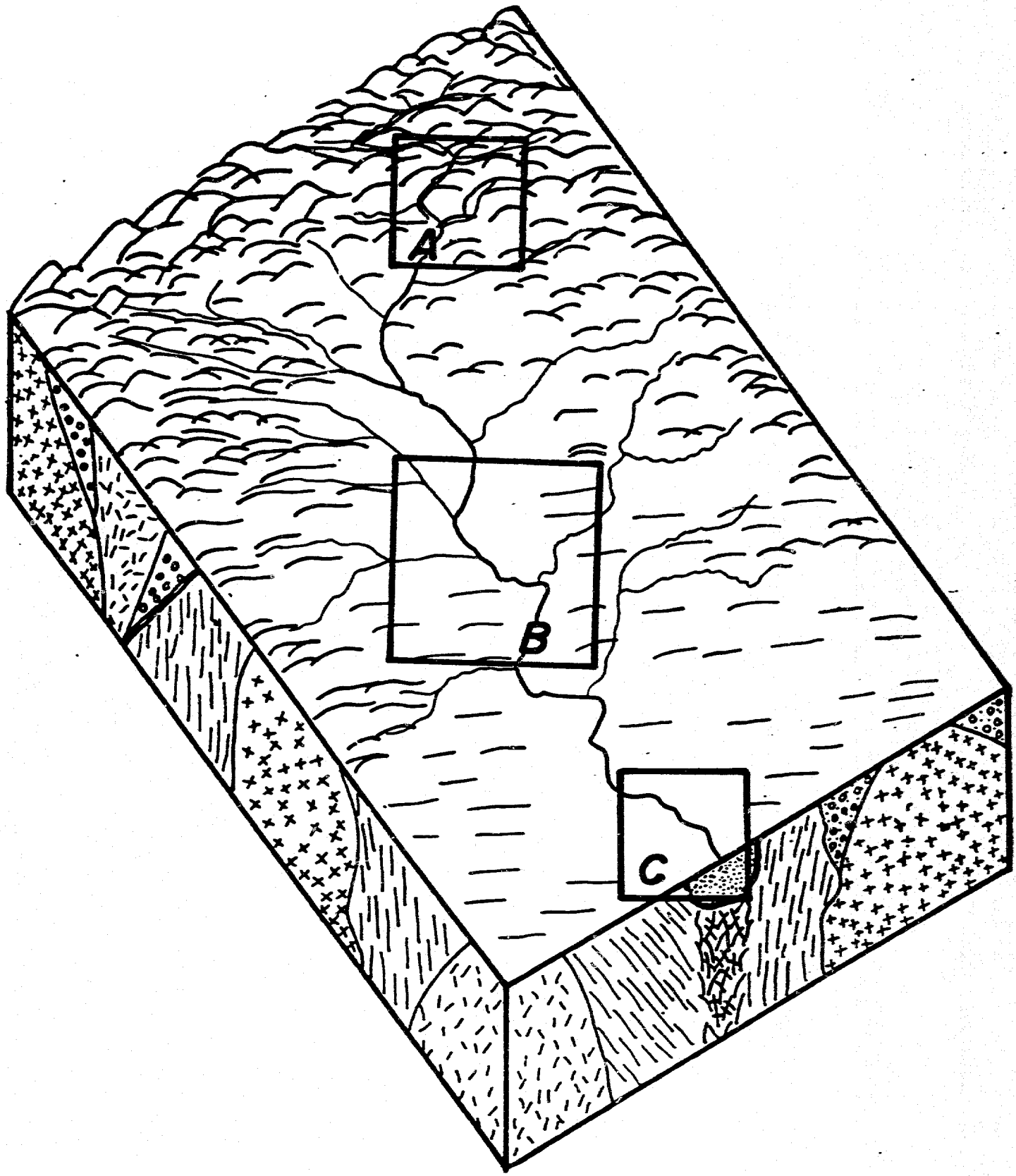


FIGURE 6 **Megawatershed : Exploration Model**

Diagram showing location of close-up views A B & C

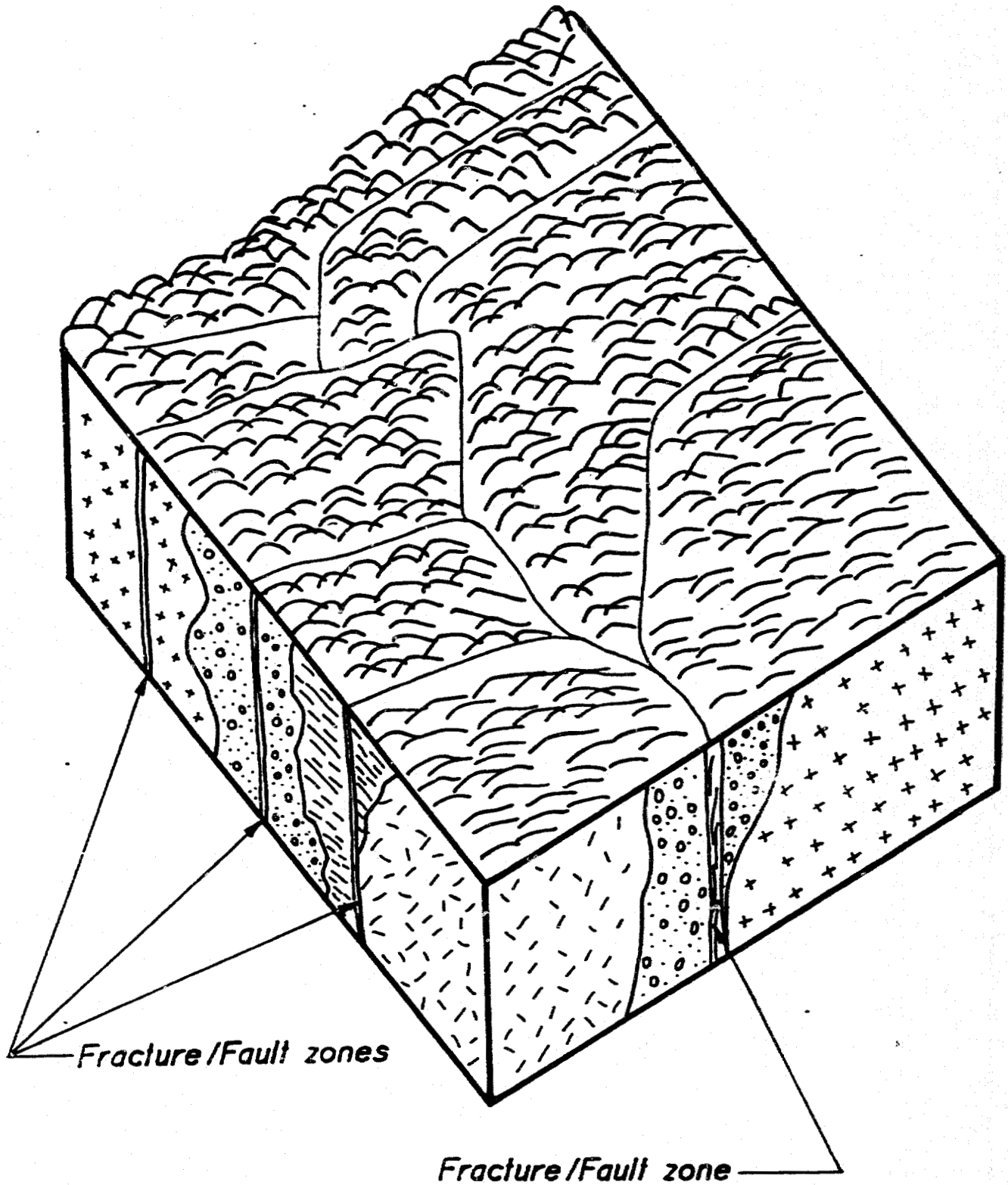


FIGURE 7 **Megawatershed : Exploration Model**

Close-up view area A showing fracture/fault zone controlled rectilinear drainage in the mountains resulting in a greater transmissivity

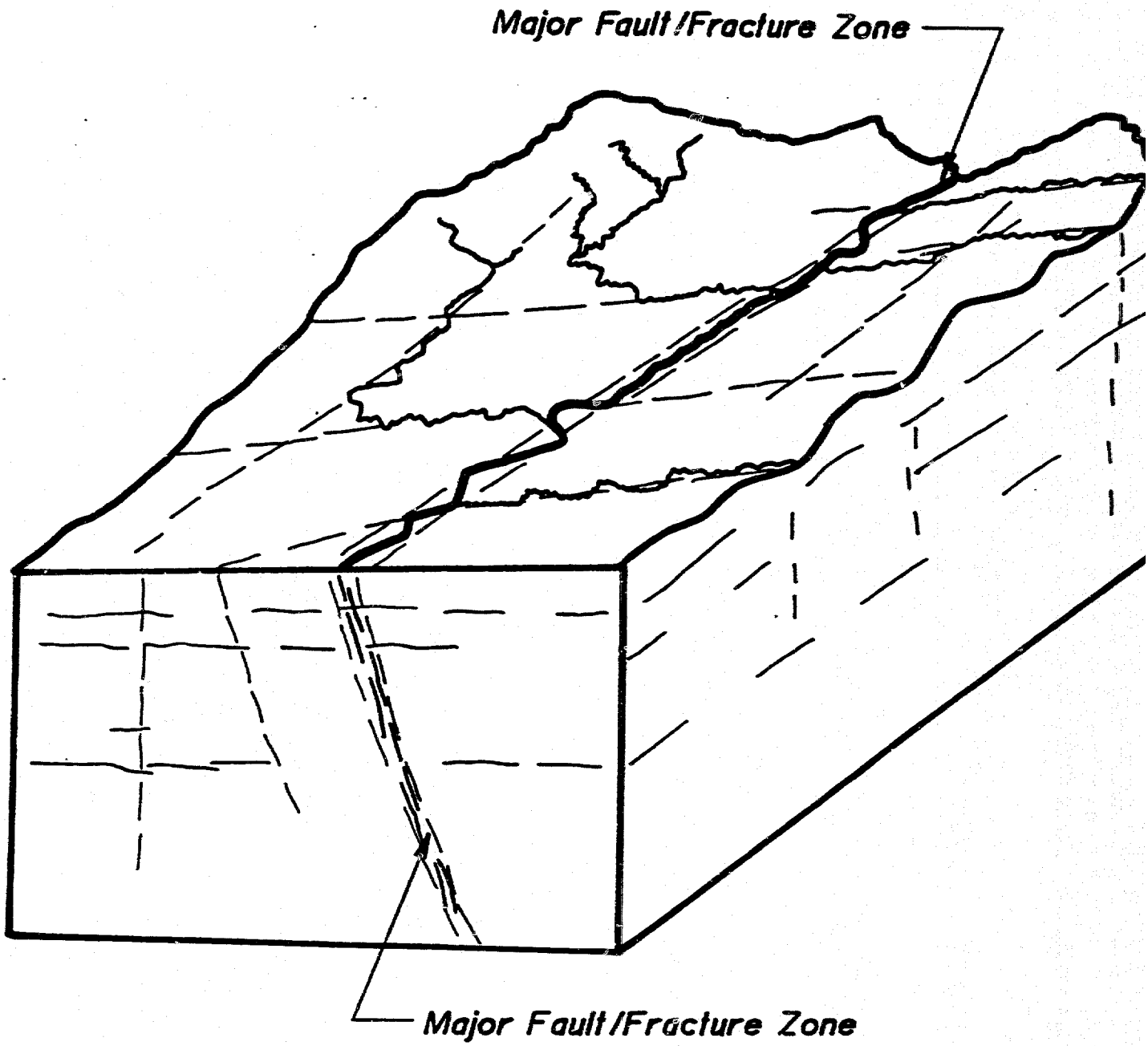


FIGURE 8 **Megawatershed : Exploration Model**

Close-up view area B showing rectilinear drainage feeding major fault/fracture zone

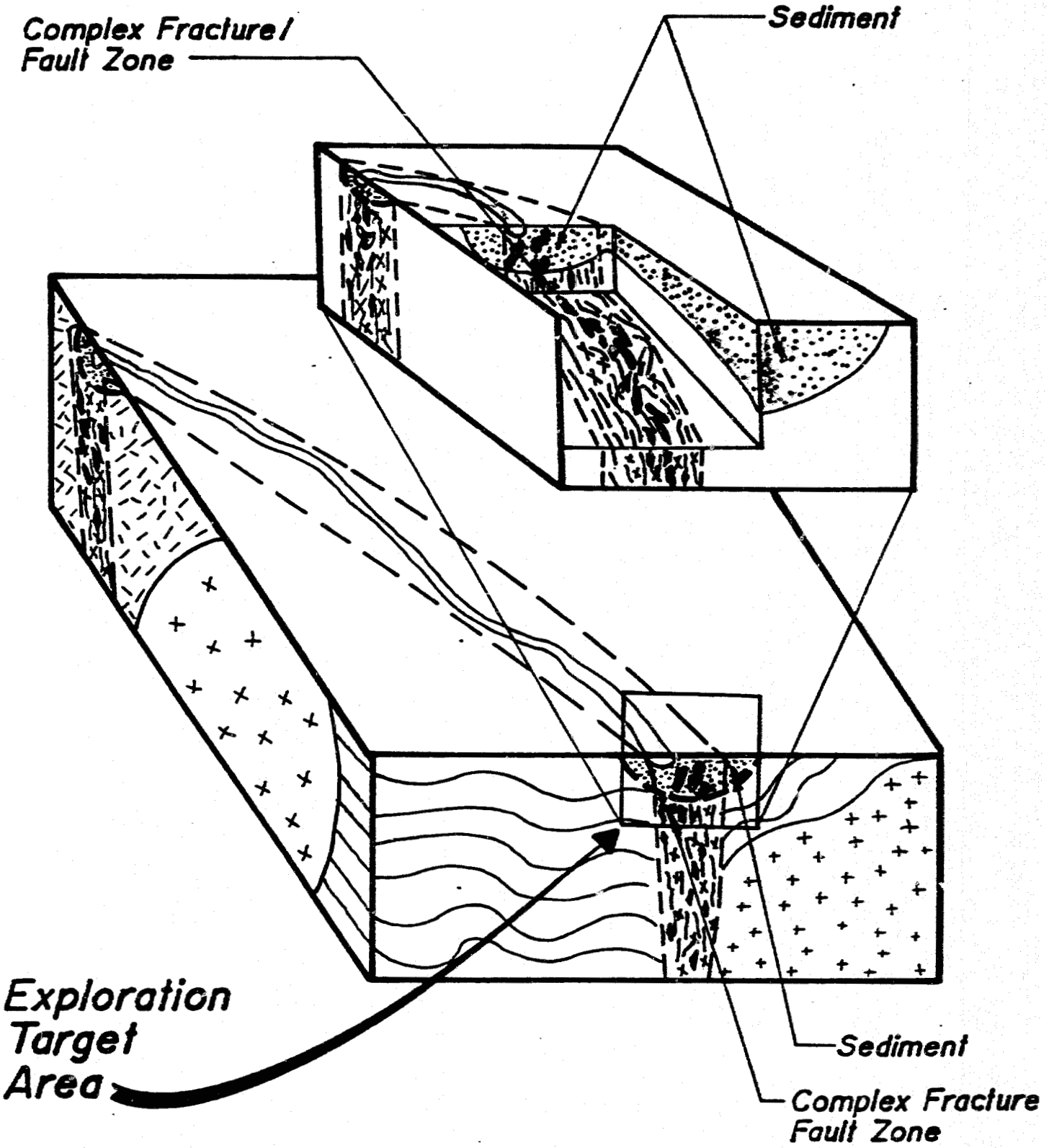


FIGURE 9 **Megawatershed : Exploration Model**

Close-up view area C showing major fault fracture zone acting as the target aquifer with inset showing complex nature of

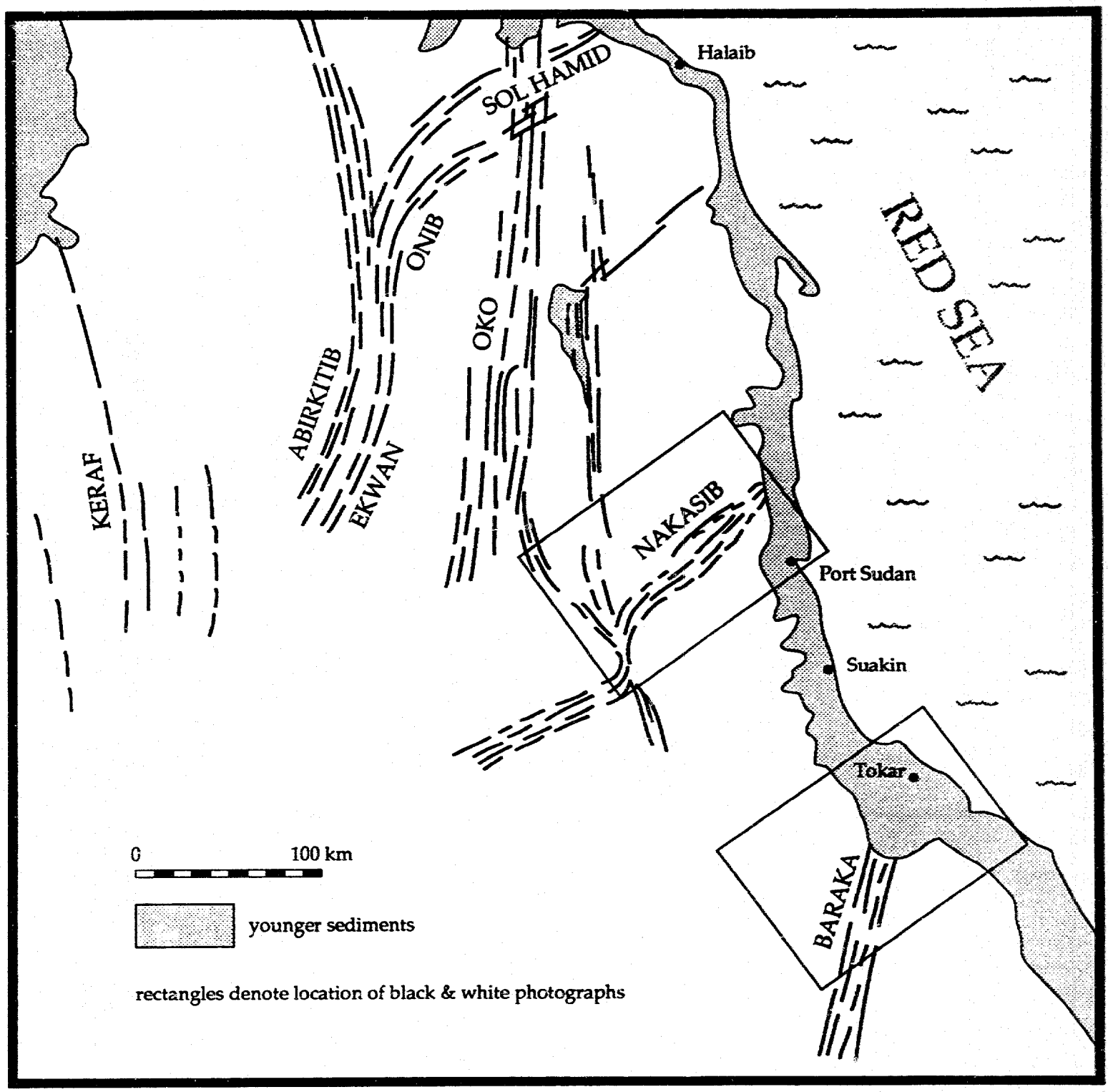
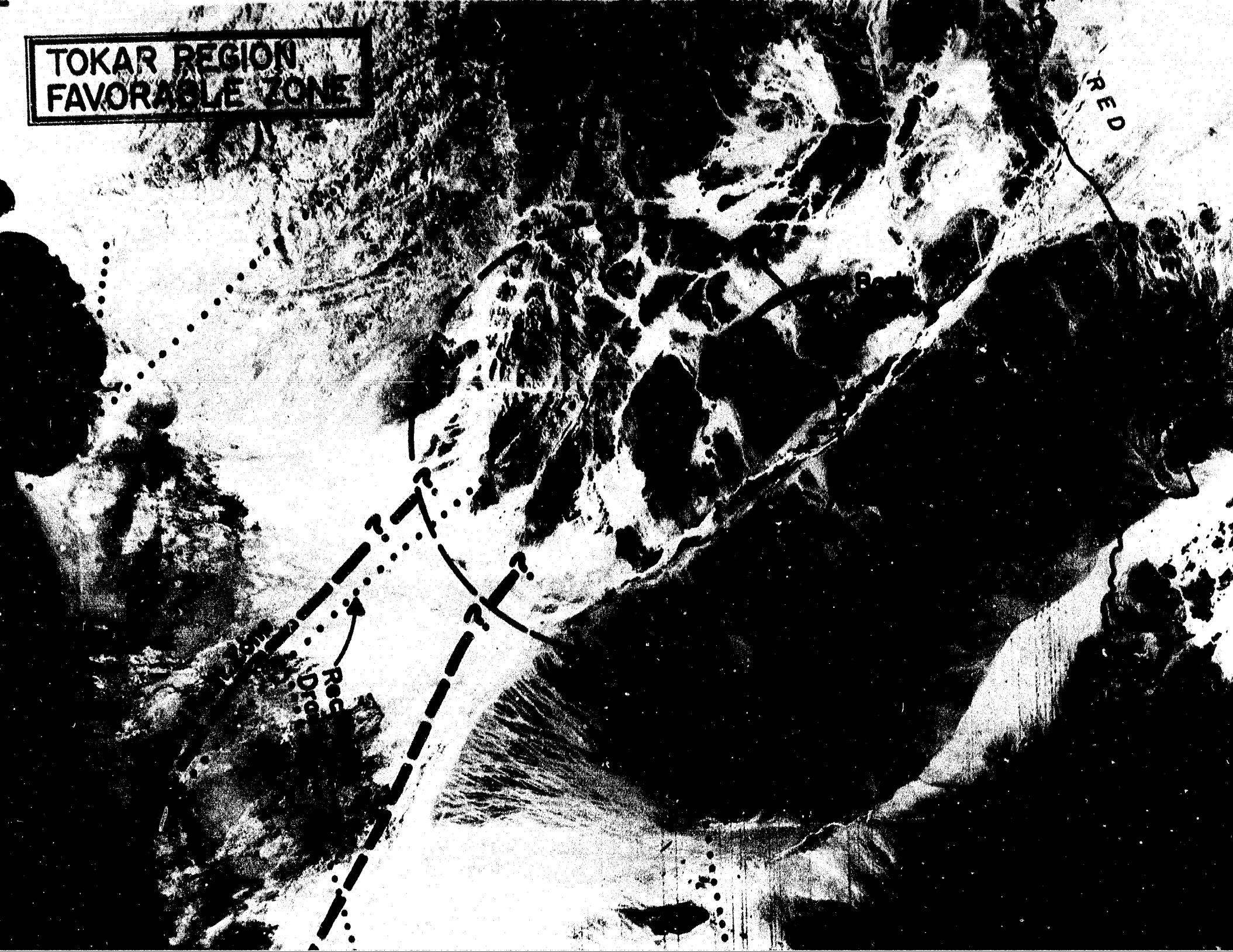


Figure 10 Mega-shear zones in Red Sea Hills area, Sudan

modified from
D.C. Almond, F. Ahmed
and
Sultan, Arvidson, Duncan, Stern, & Kaliouby

Basin
Outflow


TOKAR REGION
FAVORABLE ZONE
RED

within PTA #2. Wadi Diib Odib is superimposed on the fault in the area. Much of the major N-S trending "Odib" stream course drainage within the basin is interpreted to be structurally controlled by the Oko shear zone.

This target area is transsected by the major coastal highway. In addition, Socio-economic target site A is within 60 miles of the target area.

2-PTA: Lat 20.57-21.10, long 36.51-37.06

PTA #2 is centered over the intersection of an 085 degree trending fault, transform type, with a 165 degree trending coast-parallel fault (probable Red Sea Rift master graben). One of the major coast-directed khors is likely to be superimposed on the E-W fault in this area.

This target area is adjacent to Dungunab Bay. The major coastal highway passes through the target area. Socio-economic target site D is centered within PTA #2.

3-PTA: Lat 20.32-20.52, long 35.50-36.15

PTA #3 is situated on the complexly faulted Sasa Graben which contains a sedimentary fill of rocks belonging to the Nubian Formation. The graben faults are structurally controlled by a branch of the Oko Shear Zone (Almong & Ahmed, 1987), a regional crustal shear zone.

The highway from Gabet al Ma adin and Gabet Mine passes through the southeast corner of the PTA. The mine is within 70 miles of this PTA.

4-PTA Lat 19.44-20.02, long 36.58-37.16

PTA #4 is situated over a narrow gap in the Red Sea Hills which is structurally controlled by the Nakaseib Shear Zone. The gap is located 40 miles north of Port Sudan. Khor Adaia is situated within this structural feature. Although no major faults have been mapped within this target area, its proximity to a major crustal suture an to the City of Port Sudan qualifies this zone as a candidate for further exploration.

This PTA is in a favorable location to serve as a potential water supply for Port Sudan. In addition, the major coastal highway passes through this PTA. Socio-economic targets Site J and H are within or directly adjacent to this PTA.

5-PTA: Lat 18.02-18.22, long 37.28-37.48

PTA #5 is situated on the inland reaches of the Tokar Delta. A major fault, which may be structurally controlled by the Baraka Shear Zone, underlies the delta. The presence of Tertiary basalt suggests that this fault was formed or reactivated by Red Sea Rift tectonic activity. The geometry of the feature suggests that it may be a half-graben structure. Superimposed on this fault, at the distal end of a large drainage basin, is Khor Baraka.

This PTA is transsected by the highway from Tokar. S-E target site O, the agricultural district on the Tokar Delta is within and around the PTA. Rainfall is higher in the upper reaches of this basin which suggests a strong potential for adequate recharge to the watershed.

6-PTA: Lat 17.26-17.44, long 37.03-37.22

PTA #6 is located in the upper reaches of the "Baraka" Basin, in Khor Langeb. Here, a system of NNE trending faults with a graben-like geometry, cut Tertiary basalt and acidic volcanic rocks. The secondary permeability of faults and fractures combined with potential primary permeability of volcanics may act as a suitable groundwater reservoir.

This PTA is transsected by the highway from Tokar. The drainage system which is superimposed on these structures may receive suitable recharge due to higher rainfall values in the southern part of the study area. No S-E targets are near this PTA.

7-PTA: Lat 17.08-17.26, long 36.25-36.45

PTA # 7 is centered over a large basin whose drainage takes a right angle turn near the center of the basin. The infiltration may be directed out of the basin along bedrock structures controlling a megawatershed.

S-E target site U and the railroad are east of and within 80 miles of the PTA.

1-STA Lat 22.05-22.10, long 35.52-35.57

STA #1 is positioned over the intersection of a fault (probable rift phase transform origin) with the Wadi Onib and the underlying fabric associated with the Oko Shear zone. Infiltration from the very extensive drainage basin west of the Red Sea Hills may provide ample recharge to this distal area of the basin. Shear zone fabric associated with the Onib shear zone may intersect the Oko shear zone fabric and the brittle transform fault within this STA.

The immediate area is devoid of primary S-E targets, major roads, or major settlements. However, S-E target site A is 40 miles from this STA.

2-STA Lat 21.47-21.53, long 35.59-36.05

STA #2 is also positioned over the intersection of a fault (probable rift phase transform origin) within the Wadi Onib and the underlying fabric associated with the Oko shear zone. Infiltration from the very extensive drainage basin west of the Red Sea Hills may provide ample recharge to this region of the basin.

The immediate area is devoid of primary S-E targets, major roads, or major settlements.

3-STA Lat 21.30-21.39, Long 36.41-36.50

STA #3 is positioned over two major coastal khors that intersect a coast-parallel fault of probable rift phase origin. The fault may be a master graben of the Red Sea rift system. If this structure is recharged with sufficient water from the khors and salt water has not saturated the fault, this feature may provide an economical water supply.

This STA is situated within S-E target Site C. S-E target Site B are adjacent to this STA. The highway south of Fudukwan borders the western side of this STA.

4-STA Lat 20.03-20.08, Long 36.15-36.20

STA #4 is centered over a major E-W trending fault which has a drainage superimposed on it called Khor Hayet.

The immediate area is devoid of primary S-E targets, major roads, or major settlements.

5-STA Lat 19.47-20.00, long 36.07-36.21

STA #5 is centered over an exposure of the Nubian Formation. There is a drainage superimposed over this and it may provide a substantial water supply. The presence of Nubian sediments suggests the presence of some graben-like structure which would act to preserve the sediments from the regional erosion which removed most of the Nubian Formation. The faulting may enhance the possibility for water.

S-E target Site I is located approximately 40 miles east of this STA. A secondary road bisects this STA.

6-STA Lat 18.15-18.45, Long 36.30-36.56

STA #6 is located in a region of intense, complex, regional faulting. The faults may act as intra-basinal transfer conduits for groundwater along megawatersheds. This STA area is large and contains S-E target Site M. In addition, S-E target Site P is adjacent to this STA. The Khartoum-Port Sudan Highway and the railroad transect this STA.

7-STA Lat 18.35-18.45, Long 37.19-37.34

STA #7 is located over the intersections of three faults of major regional extent; one is a coastal-parallel fault of probable rift phase origin, another is a N-S trending fault which crosses several khors, and the third is a NW trending intra-basinal fault.

The immediate area is devoid of primary S-E targets, major roads, or major settlements.

VII. DESCRIPTION OF SOCIOECONOMIC SITES

The following is a brief narrative describing the socioeconomic sites (lettered from North to South on accompanying map) selected for water exploration as described

in the socioeconomic study prepared by Hassabo and Company (Numbers in () refer to numbers in socio economic study. See Appendix 1):

Site A (6): Halaib area: Latitude 22 degrees 13 minutes and longitude 36 degrees 38 minutes a few km. South of Halaib village. Unexplored gypsum deposit.

Also, 30 km. Northwest of Halaib village and about 15 km. West of the share at latitude 22 degrees 14 minutes and longitude 36 degrees 39 minutes is a magnesite deposit which has been partially explored.

Also in this area, between latitudes 22 degrees 5 minutes to 22 degrees 30 minutes and longitudes 36 degrees 12 minutes to 36 degrees 35 minutes are manganese deposits. Ore quality ranges from low to high grades. Small reserves ranging from a few thousand to 26,000 tons. Previously explored and mined.

Site B (17): Fodikwan area: Latitude 21 degrees 44 minutes and longitude 36 degrees 43 minutes. Also nearby at latitude 21 degrees 48 minutes and longitude 36 degrees 43 minutes. Four deposits of iron ore estimated at about four million tons. Fully explored, previously mined. Remote.

Site C (18): Sofaya group: A group of six iron deposits occurring 260 km. Northwest of Port Sudan. Latitudes 21 degrees 25 minutes to 21 degrees 40 minutes and longitudes 36 degrees 21 minutes to 36 degrees 57 minutes.

Site D (12): Shinaab: Latitude 21 degrees 4 minutes and longitude 37 degrees 2 minutes, West of Dungunab Bay. Unexplored gypsum deposit.

(13):* Nabaa: 200 km. Northeast of Abu Hamad town. Remote cluster of gold occurrences not well explored.
*Not within Project area.

Site E (4): Gebeit: Latitude 21 degrees 3.5 minutes and longitude 36 degrees 19 minutes, 256 km. Northwest of Port Sudan and about 70 km. West of the Red Sea coast. Gold deposits under active exploitation between English Minex Co. (Greenwich Resources) and GOS jt. venture. Annual production of one ton of gold with ongoing exploration to increase reserves. They are now treating about 300 MT of rock per day using existing wells in the area, however the amplitude of water is seasonal.

Site F (3): Abir Kateib: Gold mine at latitude 20 degrees 34 minutes 20 seconds, and longitude 34 degrees 55 minutes 40 seconds. Jt. venture between Kenmare and Sudanese Central Desert Mining Company (private sector Sudanese business interests) to develop an old mine in operation for 30 years in a primitive manner. Processing plant to be erected soon to process 28,120 tons of tailings containing average 7.4 gm gold per ton. Further exploration to be carried out along the strike of gold veins. Water for present operation supplied from valley 5 km from mine.

Site G (2): Bir Eit area: Latitude 20 degrees 22 minutes and longitude 36 degrees 53 minutes, about 75 km. North of Port Sudan and 5 km. West of the Red Sea shore. High quality gypsum with proved reserves of 224 million tons. Also, 5 km. from this vicinity in Tobonam lies another unexplored deposit which is currently licensed and used by the Chalk Industry Co. Similarly, 19 km. of Bir Eit is an unexplored but seemingly large gypsum deposit at Saghum.

Site H (8): Marsa Arakaiyai area: Between Latitude 20 degrees to 20 degrees 15 minutes and Longitude 37 degrees 6 minutes to 37 degrees 12 minutes, about 70 km. North of Port Sudan. Huge limestone deposits. A detailed feasibility study was conducted by a joint Sudanese American private venture but was shelved due to lack of water and financing. Potential to revive interest given water.

Site I (15): Wollastonite: Latitude 19 degrees 53 minutes and longitude 36 degrees 31 minutes, 65 km. Northwest of Port Sudan. Wollastonite deposits of high quality estimated at 475,000 MT.

Site J (11): Khor Arbaat: 36 km. North-West of Port Sudan and a few km North of Khor Arbaat, there exists slate of commercial potential. Quality and quantity not tested.

Also in Khor Arbaat, there is potential for agricultural development as there are 49,000 feddans of area with soils suitable for horticultural or crop production. There already exists some attempts at water catchment schemes in the area.

Site K (5): Serakoit area: Just North of Ariab Jt. Venture area. Joint venture between Sudan Mining Co. and Kenmare Co. (Ireland). General prospection works to start for gold.

Site L (7): Ariab area: Latitudes 18 degrees 40 minutes to 18 degrees 44 minutes and longitudes 35 degrees to 35 degrees 36 minutes, about 80 km. North of Musmar Railway Station. About 10 significant deposits discovered with commercial gold and massive sulphides of copper, zinc and silver. Recent new find of higher concentrate gold in area has confirmed commercial viability of site. If groundwater is not found, serious consideration will be given to investing in an alternative supply. This area is currently licensed to the Sudanese-French jt. venture between the State Mining Corporation, BRGM and Total. Hydrogeologists are actively looking for groundwater reserves as an alternative to piping in water from Atbara or Nile River.

Site M (9): Summit area: Latitude 18 degrees 47 minutes and longitude 36 degrees 46 minutes, four km. West of Summit Railway Station. Coloured marble suitable for decorative building use.

Site N (16): Trinkitat: Latitude 18 degrees 30 minutes and longitude 37 degrees 54 minutes, about 192 km. South of Port Sudan and 30 km. North Northeast of Tokar, promising deposit of black sands containing titanium minerals traced for about 25 km. along the coast. Partially explored.

Site O (14): Tokar: The Tokar delta from the Baraka river offers about 250,000 feddans of fertile agricultural land, of which only about 40% is presently cultivated using flood irrigation. If a permanent groundwater supply were found the available soils and infrastructure would permit promising horticultural and crop production.

Site P (10): Tohamyiam area: 10 km. South-West of Tohamyiam Railway station and 2 km. away from the Khartoum-Port Sudan road. White-pink granite.

Site Q: Also in Tohamyiam area, 15 km. South-East of Tohamyiam Railway station is a deposit of good quality quartz suitable for glass. Deposit is leased.

Site R (23): Abu Samr: Latitude 17 degrees 58 minutes and longitude 36 degrees 16 minutes. Zinc, lead, copper, silver ores. Previously explored but abandoned due to difficulty in mining.

Site S (19): Karora group: A group of three iron ore deposits between latitudes 17 degrees 42 minutes to 17

degrees 50 minutes and longitudes 38 degrees 17 minutes to 38 degrees 23 minutes, about 250 km South of Port Sudan. Explored, good potential recovery rate but remote.

Also in this location white and coloured marble occurs in hugs masses. Largely unexplored.

(20):* Maman area: Latitude 16 degrees 20 minutes and Longitude 36 degrees 25 minutes about 60 km. East of Erba Railway Station. White marble suitable for cement production.

* Not located within project area.

(21):* Gadamai: Four km. East of Gadamai Railway Station, green, pink, yellow and white marble suitable for decorative use.

* Not located within project area.

Site T (22): Tehilla: Latitude 17 degrees 44 minutes and longitude 36 degrees 3 minutes, North of Derudeb. Large quantities of white grey marble suitable for decoration. Mainly unexplored.

Site U (1): Derudeb area: Between Latitude 17 degrees 33 minutes and Longitude 26 degrees 14 minutes, 20 km. East of Derudeb railway station. Good quality white marble of 98% calcium carbonate. Detailed geological and topographical mapping carried out. Raw materials suitable for cement industry. Current investment being considered but there is a need to solve water supply problem.

Also, about 22 km. East of Derudeb Railway station, and a few km. East of the marble deposit, it a deposit of quartz.

VIII. ENVIRONMENTAL FACTORS

For purposes of identifying potential environmental impacts associated with water resources development in the Red Sea Hills district, a survey of all available information on soils, vegetation and climatic characteristics, along with a thorough literature review of current environmental problems was made. From these considerations a preliminary list of concerns was drafted, encompassing the range of possible impacts, from trivial to severe. This list was then narrowed on the basis of expected magnitude (quantum changes), extent (area affected), significance, and

sensitivity of the area, in order to focus on impacts of greatest potential concern to the maintenance of environmental integrity throughout the region. the unfavorable impacts identified are generally of a secondary nature, related to projected land use practices resulting from increased water availability, rather than from the introduction of water per se. These are associated primarily with agricultural and mining interests.

(a) It is reasonable to assume that a temporary increase in carrying capacity for both human and livestock populations will result from elevated agricultural productivity, following the development of new irrigation water supplies. The possibility exists, then, that additional population pressures (e.g. increased fuelwood demand, increased pastoralism) will be experienced as an adjunct to agricultural activities, raising concern for increased decertification in outlying areas. On the other hand, where productivity (hence carrying capacity) may be raised to meet existing overpopulations of humans or livestock, a carefully formulated regional integration of pastoral and agricultural activities could stall local decertification. The durability of the landscape to loss of native plant cover, soil compaction, and erosion, or, conversely, its potential for recover, is a function of topographic character and soil physical properties, precipitation and wind regimes, the nature of the local vegetation and intensity of land use. These variables will be studied thoroughly on a site-specific basis in Phase II.

(b) ancillary problems associated with the introduction or intensification of irrigated agriculture in the Red Sea Hills district may be related to increased salinization of soil and salt contamination of shallow groundwater, a common problem in arid-land agriculture throughout the world. Loss of productivity as a result of salinization is well know from other provinces in the Sudan (viz. millet production in the ElObeid area), though this experience has not borne out in all irrigation schemes. The potential for salinization is largely dependent on local conditions, namely soil chemical and physical properties and on the quality of irrigation water with respect to total dissolved solids and Ca:Na rations. It is noteworthy here that the Haplic Yermosols of the Red Sea coast and the Galcaric Fluvisols of the Red Sea Hills and Tokar Delta are saline in nature and may respond unfavorably to irrigation. Land abandonment after 5 years is not an unlikely possibility if irrigation schemes are not

developed in concert with site limitations and groundwater sourcing and cycling realities. This has been the experience elsewhere and poses perhaps the single greatest threat to increased decertification of the area. The potential for salinization problems will be assessed carefully on a site-specific basis in Phase II.

(c) Additional potential impacts of new irrigation schemes involve alteration of soil moisture regimes (including lowering of the water table) with consequent changes in the nature of the vegetation cover, possibly fostering the introduction and spread of non-native weedy plant species. Extensive canal networks may also advance the range of water hyacinth and its attendant disease vectors, the fresh water snails (alternate host to the Schistosomiasis parasite) and mosquitos. The likelihood and significance of these potential impacts must be weighed in light of expected benefits from new water development projects in the Red Sea Hills district, including the health benefits of increasing the quantity of drinking water available to rural inhabitants.

(d) Depending on the status quo of the areas involved, the potential for adverse environmental impact exists in connection with cement manufacturing and the mining of precious metals. For example, gold extraction requires large quantities of water, most of which is lost as waste water (non-recyclable) containing relatively high concentrations of heavy metals. The quantity of water used in gold mining is some 70 times greater than that required for copper ores, for example, and only 7% or so is recirculated water. Of the total new and recirculated water used in the extraction of gold, less than 2% is consumed in the process; the remainder is discharged and highly toxic to humans and other organisms. Attention must be given, therefore, to the use of low-quality process water from natural sources rather than potable water, plus the ability of native soils to absorb and contain the various metal ions in mining waste water. These impacts are dependent, of course, on the current potential productivity of soils in the vicinity of mine sites.

(e) Finally, we are cognizant of the occurrence of 3 endangered animal special elsewhere in Sudan that occupy habitats and vegetation types similar to those found in the Red Sea Hills district, Equus africanus is known to range across the northern Sudan from the Nile to the Red Sea coast, while Gazella leptoceros and Oryx dammah are suspected of

persisting in the semi-desert and desert fringes of N. Darfur. We will remain alert to the possible occurrence of these species in our potential target areas.

IX. PLANS FOR PHASE II

The purpose of Phase II is to narrow the field of 14 water PTA and 23 socioeconomic sites down to five high priority PTAs. This will entail field reconnaissance, detailed photo and satellite imagery analysis, along with a more detailed structural and hydrogeologic analysis of each of the Target Areas. These data will be quantified and combined in a weighted matrix to facilitate a rating and ranking of all the Target Areas.

We will then perform a detailed on-site analysis of the five high priority areas. We anticipate that our detailed work during Phase II will enable us to establish more specific PTA boundaries and thus decrease the size from the existing 5,000 to 10,000 square miles down to 1,000 to 2,000 square miles for each of the five high priority PTA's selected. We then plan to locate two to four smaller, more specific, sites within each of the five high priority PTA's. This will yield a total of 10 to 15 smaller PTA of 100 to 1,000 acres each. These smaller sites will be the focus of our detailed on-site work during Phase III.

CONCLUSIONS

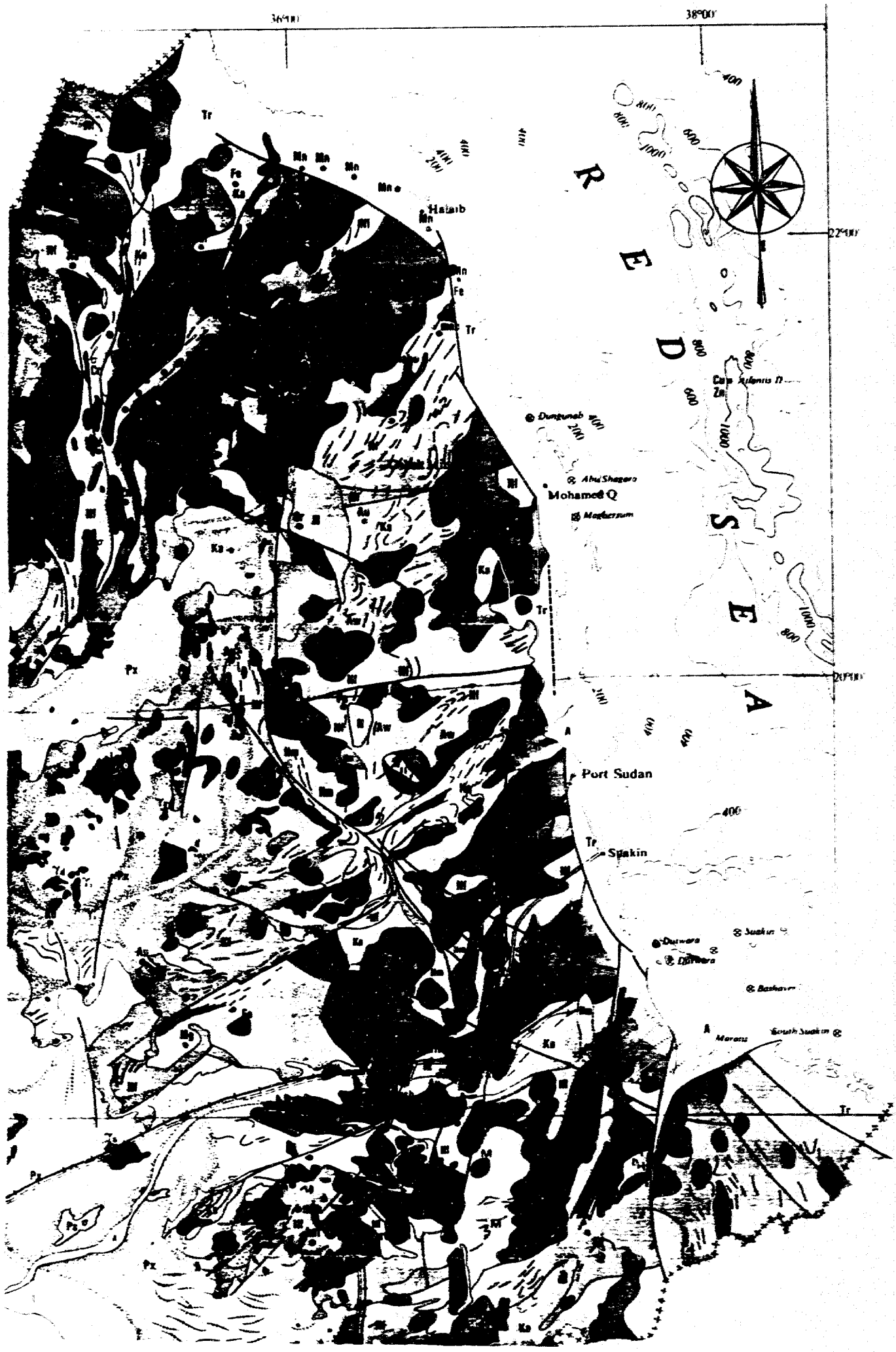
The correlations between mega shear zones, faults, large catchment areas and drainage in the Red Sea Hills region is overwhelming. Prior investigations of the potential water reserves within the Red Sea Hills area have not emphasized these correlations nor their contributions to the discovery of sustainable yields of usable water. The Megawatershed Exploration Model serves as the framework for a scientific analysis of these correlations.

During Phases II and III, we will analyze and evaluate the scientific, economic, and financial feasibility of business uses of potential water reserves within five exploration target areas, which may or may not be selected out of the original PTAs. We will identify and select specific business applications for each site and evaluate the environmental impact of such applications.

The successful demonstration of economic and exploration feasibility during this pilot project will trigger an extended business venture on the part of the parties involved. The results will lead to an increased prosperity for communities in the Red Sea Hills region of Sudan.

Legend for the Geological map for the Red Sea Region of Sudan

Recent	A	Alluviums, wadi fills, terraces, and deltaic deposits
Mesozoic to Recent	Tr	RED SEA LITTORAL GROUP Reefal and perireefal complexes with associated deposits: clastic sediments, evaporites, and fossiliferous limestones.
Mesozoic to Tertiary		Basic Volcanics, mainly basalts a - outcrop, b - non-outcrop Acidic and intermediate volcanics, mainly rhyolites and trachites a - outcrop, b - non-outcrop
Cretaceous		Nubian Formation Continental clastic sediments including sandstones, siltstones, mudstones, and conglomerates
Upper to lower Proterozoic Intrusive rocks		Younger Granites, Mainly stocks, bosses, plugs and ring complexes Syenites, Mainly stocks, bosses, plugs, and ring complexes
		Basic intrusives, Mainly gabbro
		Batholithic Granites, grey granites and pegmatites Granodiorites
		Ultrabasic rocks and serpentinites
Upper Proterozoic Basement Complex Schist group		AWAT SERIES Conglomerates, mudstones, rhyolites, dacites, and andesites HOMOGAR SERIES Acidic and basic volcanic rocks and tuffs NAFIRDEIB SERIES and ODI SERIES Metasediments, acidic and basic metavolcanic rocks
Lower-middle Proterozoic Basement Complex Gneiss group		KASHEBIB SERIES Granitic gneisses, amphibolites, quartzites, and migmatites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APPENDIX 1:

SOCIOECONOMIC STUDY

RED SEA PROVINCE WATER EXPLORATION PROJECT

SOCIO-ECONOMIC FEASIBILITY STUDY

PHASE I

Prepared by Hassabo & Company, Khartoum Sudan
on behalf of:

The Sudanese Company for Water and Economic Development, Ltd.
and the U.S. Agency for International Development
under Grant # 650-0510-G-00-8067

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I. INTRODUCTION

The U.S. Agency for International Development has provided grant funding for a highly innovative joint venture to find and develop "megawatersheds" as an economic resource in the Red Sea Province of Sudan. The joint venture is between a U.S. company, BCI Geonetics Inc., and the Sudanese Company for Water and Economic Development, Ltd, (SUWED). The objective of the project is to assess and demonstrate both the physical and economic viability of private sector water development in the Sudan. The project will be conducted in four phases. This report presents the findings of the first phase of the socio-economic feasibility study.

II. OVERVIEW OF PHASE I WORK

During this phase of socio-economic feasibility work, we conducted a review to ascertain the full range of potential uses of water in the target area given the presumption that water can be found. Our efforts focussed mainly on assessing the inherent physical potential of the target area for water-assisted business development and, inasmuch, did not concentrate on a market analysis at this stage. Once the range of potential business opportunities and corresponding site locations was identified, preliminary criteria were developed and applied to achieve a first round of site rankings. The purpose of the site rankings is to help narrow the scope and prioritize the exploration efforts of the geological team.

III. DEFINITION OF WATER-ASSISTED BUSINESSES

At this stage the broadest possible definition was applied to the concept of a "water-assisted business." The ultimate objective of SUWED is to utilize a newly discovered source of water as a commercial resource. In this respect, it may be that the water itself will be the commercial resource: that ready clients willing to purchase water for whatever reason will be identified. In such a case, the early effort and investment of SUWED would focus on the development and management of the water source itself. On the other hand, it may be that water will be found in an area where no ready client exists, but where there exists the potential to use water to develop inherent agricultural or mineral resources. In this case, SUWED may choose to use the water to develop the promising resources themselves. Alternatively, they may promote the potential of a given site to third parties with an interest in developing in the underlying resource given that the water constraint has been relieved. This definition also gives scope for developing water for consumption purposes, for instance, as an alternative source of municipal water supply.

IV. OVERALL POTENTIAL OF THE RED SEA HILLS PROVINCE

With the parameters outlined above, we began by assessing the agricultural and mineral potential of the province to identify the comparative advantages of the target area. In addition, we held interviews with donor agencies to determine the current status of municipal water development for Port Sudan. Contacts were also made with companies in Port Sudan to elicit

the level of interest in a commercial supply of water for on-going industrial concerns.

A. Mineral Potential

Overall, it appears that the Red Sea Hills Province enjoys a considerable comparative advantage over other areas in and outside of Sudan with respect to mineral resources. The lack of water in abundant quantities has been a severely limiting factor for their development. The area contains numerous raw materials suited to the demands of domestic and export industry, (lime, marble, gypsum, dimensional stones, slate, quartz). It contains base metals suitable for export markets, (copper, lead, zinc), and more than one hundred sites of the noble metal gold have been located in the Province. Annex I presents a detailed review of the mineral potential of the Red Sea Province prepared by a prominent Sudanese geologist, Mr. Adly Abdel Mageed Ahmed.

Interestingly, during the course of our work we found several instances wherein a proposed investment related to mineral development had been carried far into the stages of realization but had ultimately not been completed. For example, there exists in Khartoum North a fully constructed factory held by a public corporation designed to manufacture fertilizer. Given a source of groundwater in the right location, the raw materials for fertilizer and several other chemicals could be developed within the Red Sea Hills province. Similarly, factory equipment has been imported into Sudan, but never erected, for the processing of gypsum into building plaster. We learned of

two cases in which detailed feasibility studies were carried out for the establishment of cement factories. These are not necessarily "dead" projects. In fact we found that considerable interest remains in various quarters to revive or reconsider these investments should the economic picture prove attractive. In most cases the reason cited for delay or discontinuation of these projects was the lack of financing, though this may not tell the whole story. The cost-benefit analysis of most of these investments also had to incorporate development of a costly source of water. For example, the cement factories had to factor in the cost of pumping water over hundreds of kilometers, or desalination of sea water. We have been told that the public corporation intended to import all the raw materials for its fertilizer factory which would have made its operations un-economic. Water-assisted development of lime and other materials required for fertilizer might change that picture.

Aside from domestic industry, considerable scope exists for the direct export of base and noble metals. Gold, manganese and iron ore have all been exported from the Sudan in the past. Currently there are four active mining ventures for base and noble metals, three between the Sudan Mining Corporation and foreign companies, and one between an Irish company and a private Sudanese company. Though prospecting is often a risky venture, the raw potential of the latter mining efforts was deemed to be sufficiently attractive to put aside the water constraint for the time being and conduct extensive explorations. If gold is found

in the promising quantities suspected, it would then become economic go as far as pumping water from the Nile if need be. In such a case, abundant supplies of groundwater would be a welcome alternative. All in all, it is clear that considerable scope exists for utilizing water to develop minerals in the Red Sea Province.

B. Agricultural Potential

A review of the potential for water-assisted agricultural development is presented in Annex II. This was prepared by a Sudanese agricultural economist, Mr. Mohammed Osman Abdel Mageed. Relatively speaking, agricultural potential takes a back seat to mineral potential in the Red Sea Hills Province. The reason for this is not that the Province is devoid of agricultural potential; rather, it holds no particular advantage over other regions within the Sudan. In fact, as much as 27.5 million feddans, or 56% of the total area, is thought to be suitable for crop production, horticulture and livestock grazing. These are located in the middle and southern zones of the province since the northern third is an inhospitable semi-desert environment. Soils suitable to crop and horticultural production tend consistently to be located along seasonal riverbeds (khors and wadis) or in deltas. Aside from the fact that these are often remote or limited in size, the phenomenon of seasonal flooding requires that investments be made in effective control of the water.

Experience with subsistence crops and experiments conducted

on vegetable production in pump-schemes indicate that yields in the Red Sea Hills province are no better than those achieved in the Western regions of Sudan, and worse than those achieved in the mechanized rainfed sector and irrigated sectors. Though the proximity of the nation's seaport is a potential advantage for promoting agricultural exports, this does not outweigh the constraining factors. Given these features, individuals or organizations specializing in agricultural development would likely find that investments in other areas of the country will yield equivalent or higher returns.

One exception in the province is the exceedingly fertile Tokar delta of the Baraka river. The fertile lands of this area are currently only about 40% utilized to the lack of a permanent water supply. Similarly, the lands around the Arbaat fresh water springs are also highly fertile but are constrained due to competing demands for the water. A "megawatershed" found in either of these localities would offer significant agricultural potential. There might be scope for SUWED to promote agriculture outright, or to promote the use of water to the Tokar agricultural corporation or tenants groups through well-defined production relationships.

During Phase II of the socio-economic study we intend to visit with the Regional agricultural officer in Kassala and will explore further into the potential for fruit tree production (particularly citrus and dates) since little data was found on this in Khartoum. Likewise, we will conduct more inquiries on

the potential for and interest in livestock production using fodder crops.

C. Municipal Water Supply

It is an established fact that water is a very scarce and essential commodity for Port Sudan. At the outset of our work it was believed that the World Bank was considering making a sizeable loan to develop the Port Sudan municipal water supply. This was found not to be the case. In fact, such a project has not even been identified for their five-year project pipeline. On the other hand, it was discovered that the Federal Republic of Germany is funding a project to provide drinking water in Port Sudan. Efforts are being made to follow up on the potential role of SUWED in this context.

D. Demand for Water by Existing Businesses

We held interviews with a number of businesses in Port Sudan which require water for their operations, whether for cooling their equipment or otherwise in their production process. We learned that some factories have made special investments (such as in desalination) to assure a reliable water supply, while others are handicapped by its overall lack. We learned of one manufacturer of soft drinks which used to offer a line of mineral water. Many new investments considered for Port Sudan have either been scrapped or have been re-located to Khartoum due to the lack of water. There is little doubt that existing businesses and new investments would have a strong commercial interest in a reliable alternative water supply for the Port

Sudan area.

V. DEVELOPMENT OF PRELIMINARY RANKING CRITERIA

Having assessed the relative physical potential of the Province, it was necessary at this stage to achieve a preliminary ranking of potential target areas for water exploration. For this purpose we developed a few criteria against which each site could be measured. It is important that the screening criteria applied at this stage be clearly understood, so that they may be relaxed or changed to accomodate the wishes of the SUWED founders.

As regards mineral potential, at this stage only those sites known or reasonably suspected to have deposits of significant economic value were selected for inclusion. This excludes, for the time being, numerous sites where there exists potential to find minerals but where extensive geological exploration would still need to be undertaken. Thus for example, numerous sites which have shown evidence of gold were omitted from inclusion at this stage. Depending upon the findings of the geological team, as well as the investment interests and risk tolerance of the Founders Group, the pool of potential sites could certainly be rearranged to give these areas a higher priority for exploration. The mapsincluded in Annex I present the full "universe" of potential mineral deposits as is known at the present time.

Similarly with agriculture, only those areas with a clear comparative advantage were selected for inclusion at this time. In fact, any significant permanent water source found nearby a

fertile valley floor would offer potential for agricultural development.

Other factors favoring the relative ranking of a given site are the following: proximity of the site to established transport infrastructure (railway, road, port); the extent of qualitative and quantitative exploration previously conducted; whether there exists potential for the development of more than one resource at a given location; and whether the raw material or end product has inherent export potential. Along with these, it was felt that primary or secondary client potential was a key benefit of a given site. In particular, a site with "primary" client potential is one at which SUWED would likely find a ready client for water were it to be found. A site with "secondary" client potential is one at which water could be constructively used to develop an underlying resource (eg. fertilizer, cement) and there currently exists an interest on the part of third parties or founding group members to develop that business. On the other hand, where similar resources already exist elsewhere in Sudan unconstrained by a lack of water, this is a possible detractor from a given site.

In developing these criteria it was felt that, in the short run, the Sudanese Company for Water and Economic Development would want to develop a source of cash flow as early as possible. With this established, SUWED could afford to turn further afield to ventures with a higher risk/reward ratio for example. This is the reason why client potential was chosen as a key selection

factor at this stage. In fact, before proceeding far into the next phase of work, feedback will be elicited from the Founders Group members to determine whether there exists a consensus on this point. Also, early during phase II we will examine the legal implications of groundwater development in areas where mining rights have already been leased as this could affect the relative attractiveness of potential clients.

VI. PRESENTATION OF PRELIMINARY SITE SELECTIONS

Table I on the following pages presents twenty-three selected locations along with the factors which affected their preliminary ranking. The geological potential for finding water has in no way been taken into account in making these site selections. It should be remembered that these are only preliminary rankings and that many factors could work to change the selected sites or their relative attraction.

POTENTIAL SITE LOCATION KEY

SITE #	LOCATION	FACTORS AFFECTING RANKING A	B	C	D	E	F	G	H	I	J	K
1	DERUDEB	X		X	X	X	X	X	X			
2	BIR EIT	X		X		X	?		X		X	
3	ABIR KATEIB	X			X		X			X	X	
4	GEBEIT	X			X		X		X		X	
5	SERAKOIT	X			X		X			X		
6	HALAIB	X				X	X		X	X		X
7	ARIAB	X			X		X		X		X	
8	MARSA ARAKAIYAI	X				X	X	X	X			
9	SUMMIT	X		X		X	X	X		X	X	
10	TOHAMYIAM	X		X			X			X		X
11	KHOR ARBAAT	X	X			X	X			X		X
12	SHINAAB	X				X	?			X		
13	NABAA	X				X	X		X			
14	TOKAR		X	X			X				X	
15	WOLLASTONITE	X					X		X			
16	TRINKITAT	X		X			X		X			
17	FODIKWAN	X					X		X			
18	SOFAYA	X					X			X		

KEY TO RANKING FACTORS

Best Available Copy

A Inherent potential of mineral deposit
B Inherent agricultural potential of site
C Relative proximity to transport infrastructure
D Primary client potential (Demand for H20 itself)
E Secondary client potential (Demand for resource or product)
F Raw or end product may have export potential
G Similar deposits elsewhere in Sudan unconstrained by H20
H Detailed site explorations have been conducted
I Qualitative and quantitative exploration not conducted
J Site currently being exploited to some degree

SITE		FACTORS AFFECTING RANKING										
#	LOCATION	A	B	C	D	E	F	G	H	I	J	K
19	KARORA	X					X		X			X
20	MAMAN	X		X			X	X		X		
21	GADAMAI	X		X			X	?		X		
22	TEHILLA	X		X			X	X		X		
23	ABU SAMR	X					X		X			

The following is a brief narrative presentation of the sites selected for water exploration.

1. Derudeb area: Between Latitude 17 degrees 33 minutes and Longitude 26 degrees 14 minutes, 20 km. East of Derudeb railway station. Good quality white marble of 98% calcium carbonate. Detailed geological and topographical mapping carried out. Raw materials suitable for cement industry. Current investment being considered but there is a need to solve water supply problem.

Also, about 22 km. East of Derudeb Railway station, and a few km. East of the marble deposit, is a deposit of quartz.

2. Bir Eit area: Latitude 20 degrees 22 minutes and longitude 36 degrees 53 minutes, about 75 km. North of Port Sudan and 5 km. West of the Red Sea shore. High quality gypsum with proved reserves of 224 million tons. Also, 5 km. from this vicinity in Tobonam lies another unexplored deposit which is currently licensed and used by the Chalk Industry Co. Similarly, 19 km. of Bir Eit is an unexplored but seemingly large gypsum deposit at Saghum.

3. Abir Kateib: Gold mine at latitude 20 degrees 34 minutes 20 seconds, and longitude 34 degrees 55 minutes 40 seconds. Jt. venture between Kenmare and Sudanese Central Desert Mining Company (private sector Sudanese business interests) to develop an old mine in operation for 30 years in a primitive manner. Processing plant to be erected soon to process 28,120 tons of tailings containing average 7.4 gm gold per ton. Further exploration to be carried out along the strike of gold veins. Water for present operation supplied from valley 5 km from mine.

4. Gebeit: Latitude 21 degrees 3.5 minutes and longitude 36 degrees 19 minutes, 256 km. Northwest of Port Sudan and about 70 km. West of the Red Sea coast. Gold deposits under active exploitation between English Minex Co. (Greenwich Resources) and GOS jt. venture. Annual production of one ton of gold with ongoing exploration to increase reserves. They are now treating about 300 MT of rock per day using existing wells in the area, however the amplitude of water is seasonal.

5. Serakoit area: Just North of Ariab Jt. Venture area. Joint venture between Sudan Mining Co. and Kenmare Co. (Ireland). General prospection works to start for gold.

6. Halaib area: Latitude 22 degrees 13 minutes and longitude 36 degrees 38 minutes a few km. South of Halaib village. Unexplored gypsum deposit.

Also, 30 km. Northwest of Halaib village and about 15 km. West of the shore at latitude 22 degrees 14 minutes and longitude 36

degrees 39 minutes is a magnesite deposit which has been partially explored.

Also in this area, between latitudes 22 degrees 5 minutes to 22 degrees 30 minutes and longitudes 36 degrees 12 minutes to 36 degrees 35 minutes are manganese deposits. Ore quality ranges from low to high grades. Small reserves ranging from a few thousand to 26,000 tons. Previously explored and mined.

7. Ariab area: Latitudes 18 degrees 40 minutes to 18 degrees 44 minutes and longitudes 35 degrees to 35 degrees 36 minutes, about 80 km. North of Musmar Railway Station. About 10 significant deposits discovered with commercial gold and massive sulphides of copper, zinc and silver. Recent new find of higher concentrate gold in area has confirmed commercial viability of site. If groundwater is not found, serious consideration will be given to investing in an alternative supply. This area is currently licensed to the Sudanese-French jt. venture between the State Mining Corporation, BRGM and Total. Hydrogeologists are actively looking for groundwater reserves as an alternative to piping in water from Atbara or Nile river.

8. Marsa Arakaiyai area: Between Latitude 20 degrees to 20 degrees 15 minutes and Longitude 37 degrees 6 minutes to 37 degrees 12 minutes, about 70 km. North of Port Sudan. Huge limestone deposits. A detailed feasibility study was conducted by a joint Sudanese American private venture but was shelved due to lack of water and financing. Potential to revive interest given water.

9. Summit area: Latitude 18 degrees 47 minutes and longitude 36 degrees 46 minutes, four km. West of Summit Railway Station. Coloured marble suitable for decorative building use.

10. Tohamyiam area: 10 km. South-West of Tohamyiam Railway station and 2 km. away from the Khartoum-Port Sudan road. White-pink grantite.

Also in Tohamyiam area, 15 km. South-East of Tohamyiam Railway station is a deposit of good quality quartz suitable for glass. Deposit is leased.

11. Khor Arbaat: 36 km. North-West of Port Sudan and a few Km North of Khor Arbaat, there exists slate of commercial potential. Quality and quantity not tested.

Also in Khor Arbaat there is potential for agricultural development as there are 49,000 feddans of area with soils suitable for horticultural or crop production. There already exist some attempts at water catchment schemes in the area.

12. Shinaab: Latitude 21 degrees 4 minutes and longitude 37

degrees 2 minutes, West of Dungunab Bay. Unexplored gypsum deposit.

13. Nabaa: 200 km. Northeast of Abu Hamad town. Remote cluster of gold occurences not well explored.

14. Tokar: The Tokar delta from the Baraka river offers about 250,000 feddans of fertile agricultural land, of which only about 40% is presently cultivated using flood irrigation. If a permanent groundwater supply were found the available soils and infrastructure would permit promising horticultural and crop production.

15. Wollastonite: Latitude 19 degrees 53 minutes and longitude 36 degrees 31 minutes, 65 km. Northwest of Port Sudan. Wollastonite deposits of high quality estimated at 475,000 MT.

16. Trinkitat: Latitude 18 degrees 30 minutes and longitude 37 degrees 54 minutes, about 192 km. South of Port Sudan and 30 km. North Northeast of Tokar, promising deposit of black sands containing titanium minerals traced for about 25 km. along the coast. Partially explored.

17. Fodikwan area: Latitude 21 degrees 44 minutes and longitude 36 degrees 43 minutes. Also nearby at latitude 21 degrees 48 minutes and longitude 36 degrees 43 minutes. Four deposits of iron ore estimated at about four million tons. Fully explored, previously mined. Remote.

18. Sofaya group: A group of six iron deposits occuring 260 km. Northwest of Port Sudan. Latitudes 21 degrees 25 minutes to 21 degrees 40 minutes and longitudes 36 degrees 21 minutes to 36 degrees 57 minutes.

19. Karora group: A group of three iron ore deposits between latitudes 17 degrees 42 minutes to 17 degrees 50 minutes and longitudes 38 degrees 17 minutes to 38 degrees 23 minutes, about 250 km South of Port Sudan. Explored, good potential recovery rate but remote.

Also in this location white and coloured marble occurs in huge masses. Largely unexplored.

20. Maman area: Latitude 16 degrees 20 minutes and Longitude 36 degrees 25 minutes about 60 km. East of Erba Railway Station. White marble suitable for cement production.

21. Gadamai: Four km. East of Gadamai Railway Station, green, pink, yellow and white marble suitable for decorative use.

22. Tehilla: Latitude 17 degrees 44 minutes and longitude 36 degrees 3 minutes, North of Derudeb. Large quantities of white-

grey marble suitable for decoration. Mainly unexplored.

23. Abu Samr: Latitude 17 degrees 58 minutes and longitude 36 degrees 16 minutes. Zinc, lead, copper, silver ores. Previously explored but abandoned due to difficulty in mining.

VII. CONCLUSION

During phase II we will refine our picture of the potential for water-assisted businesses in the Red Sea Hills Province. Feedback from the Founders Group and the geological team will cause us to review our universe of potential exploration sites. Legal aspects affecting underground water development and mining rights will be looked into. Client potential will be followed up on and a preliminary analysis of potential export markets will be conducted. At the conclusion of this phase there appears to be considerable cause for optimism by the Sudanese Company for Water and Economic Development.

MINERAL POTENTIALITIES AND DEVELOPMENT OF MINING INDUSTRY IN THE RED SEA PROVINCE

INTRODUCTION:

Since a principle goal is development of economic mineral sources, the Red Sea Hills Region, has been the main focus of works due to its location and known mineral deposits. The Red Sea Hills Region propably offers as many geological environment for mineralization of different types as any other region of comparable size in the world. The ancient precambrian strata having been intruded by mafic and silicic plutons and locally abundant dykes coupled with metamorphism and later burial by continental sediments, provide an abundance of pre- Cenozoic environments. Fracturing, intrusion and volcanism related to Tertiary rifting caused emplacement of mafic and ultramafic plutons, dykes and volcanoes mainly along N-S trending fracture zones, further mobilizing metallic elements and increases the chances for local concentrations. Although, the regional geology is still relatively unknown, these basic parameters indicate environments favourable for a wide variety of Minerals.

The contribution of the mineral sector to the development of the Red Sea Province can be immeasurable for the whole Sudan. The development of the known mineral deposits and industrial rocks and the discovery of new economic deposits will have a major impact on the industrial growth and consumption. Substantial benefits can accrue to the Red Sea Province from a properly structured and administered mineral industry. In addition to providing foreign exchange earnings, mining activity may produce additional revenue through taxes and royalities, stimulate development of this depressed region, improve the professional and technical skills of nationals.

The principal problems and challenges facing the development of the mineral deposits in the Red Sea Province from their very prospective phase to their promotion to industry is water among other infrastructures.

Future discoveries of major important ores sure to occur, particularly if we consider the relatively large areas which remain virtually unexplored and the progress being made with new exploration techniques and the increasing awareness of the Sudanese to promote exploration in the Red Sea Hills.

INDUSTRIAL MINERALS & ROCKS

The most important available industrial minerals and rocks in the Red Sea Provice which can be used for the manufacturing of building and construction materials as well as the manufacturing of glass, fillers, refractories, fertilizers and chemicals are:-

1. Limestones and Marble

2. Dimensional stones (granite, dolomite, slate).
3. Gypsum
4. Salt
5. Quartz
6. Wollastonite
7. Magnesite
8. Black sands

All these materials are found in sufficient quantities and suitable quality to support any size of industry. Some of them have been investigated in detail to the stage of feasibility studies (limestones and gypsum) and some in semi detail (wollastonite, magnesite and salt). The others were only preliminarily investigated. Finance and water are the main problems facing the evaluation and promotion of the mineral deposits to their industries. If these problems are solved, a wide range of industries based on limestones, marbles, gypsum and salt will immediately start and can gradually lead to the development of the other mineral deposits.

Brief description of the known industrial minerals and rocks occurrences in the Red Sea Provice. (Map No 2).

1. LIMESTONES & MARBLES:

Limestones and marbles (Calcium Carbonate) are used as building stones, in the manufacturing of cement,in the production of lime which has several industrial applications e.g. tanning, fluxing material in metallurgical operations, filler, white wash as well as in the manufacturing of calcium carbide, sodium carbonate and sugar and paper industries. Coloured marbles are used as decorative stones.

All the above industries can well be developed in the Red Sea Province. Abundant limestones are outcropping all along the coastal area of the Red Sea especially North of Port Sudan Town. Of particular interest, are those coralline limestone reefs extending for 16 km from Marsa Arus to Marsa Arakaiyai i.e. between latitudes 20 degrees to 20 degrees 15 minutes and longitudes 37 degrees 6 minutes to 37 degrees 12 minutes, about 70 km North of Port Sudan. This area has been the focus of active studies for the erection of a cement plant during the period 1978-1980. This project which was crowned with a feasibility study is abandoned mainly because of finance and water problems.

Good quality white marbles are located 20 kms East of Derudeb railway station represent the second raw material for cement industry in the Red Sea. Attempts to erect a cement plant on this site are still going on. Problem of water supply has yet to be solved. Coloured marblles, pink, brown, black, grey, white occur at many places. However, only one marble guarry is under limited production.

Apart from the above mentioned localities the limestones and marbles at the other sites in the Red Sea Hills have not received any study. The following is a brief description of the

limestones and marbles.

A. Marsa Arakaiyai Limestones

Location: 70 kms North of Port Sudan Town, at latitude 20 degrees 15 minutes and longitude 37 degrees 12 minutes.

Quality: Average chemical composition

CaO	47.7 - 49.0%	Na2O	0.72-0.65%
MgO	3.1 - 2.4%	K2O	0.11-0.08%
Al2O3	0.96-0.60%	LOI	41.55-42.70%
SiO2	3.86 - 2.90%	S	0.31-0.20%
TiO2	0.10 - 0.10%	Cl	0.61-0.51%
Fe2O	0.49 - 0.35%		

Quantity: Proved reserves at Marsa Arakaiyai 60 million tons. Expected reserves at the immediate vicinity more than 100 millions ton. Expected reserves in the whole area from Marsa Arus to Marsa Arakaiyai exceeds 200 million.

Status Of Exploration: 18 bore holes were drilled, 20 pits were dug , 176 core samples analysed , Topgraphic map 1:25.000 and contour map 1:1000 were prepared, Plant site located. Feasibility study is ready and need to be updated. The project is abandoned for finance and water problems.

Existing Exploration and Mining Rights: The limestones are leased to Sharaf Cement Co., a subsidiary of Sharaf International Khartoum.

Processing Of Raw Materials: The primary raw materials, limestones and clays mixed with water are burnt at high temperature to produce a secondary product, Clinker. Gypsum is then ground with the clinker to produce Portland cement. Gypsum lies about 5 kms West of the proposed site of the plant while good clays occur 17 kms West of it .

Water Requirements: The magnitude of water used in the industry is large. The daily requirements of the cement plant for domestic use and industrial purposes sum up to some 1000 cubic metre per day or 360,000 cubic metre per year.

Khor Eit drainage system may be considered as the most promising water resource. It starts from the hilly ground to the West and drains to the Sea at Marsa Aweitier and Marsa Arakaiyai. It runs for a distance of 50 kms and has a catchment area of approximately 1000 square kms.

Five wells exist upstream and six downstream. The quality of the water is generally good for the domestic use. Near the sea, however, the water is contaminated with the sea water. The potentialities of Khor Eit may be well raised by construction of small dams at constrictions in the Khor. However, detailed Hydrogeological works should be carried out to prove the availability of enough water needed for the plant. Desalination

is also thought of as alternative water supply.

Harbour Situation: The plant site will be at Marsa Arakaiyai, a natural harbour, which is used now by the Navy. It is quite feasible to put it to best use. Any construction will be easy and cheap due to the extension of the competent coral reef for considerable distance in the sea. Building materials including gravels, sands and dimensional stones are abundant in the area. The proposed site is relatively populated and several small villages exists around.

Business Context : Sudan has a vital need for continuely increasing volume of cement. Present facilities are inadequate to supply these needs. Importation of cement is not a solution to Sudan's problem because of shortage of foreign currency. Cement in substantial quantities is required for the development of the basic infrastructures such as harbours, roads, railways, dams, power station, housing plans etc.

From the data available, consumption of cement has been growing considerably. Production of cement at the only two factories in the Sudan, Atbara and Rabak, has proven to have been considerably fallen short of the actual demand. As a result, the country has been restoring to cover part of this shortage by import.

Forecasts of future demand of cement have been the subject of various efforts undertaken by different organizations. It is known that the production from the two plants has never exceeded 250,000 tons/year. The projection of the demand and domestic supply as forecasted by the six years economic plan 1977 - 1983, showed shortage of 500,000 tons of cement would have been atained by 1983. According to this forescast, the shortage of cement in the Sudan will exceed one million tons by 1989.

From the above, it can be concluded that, erection of cement plant at Marsa Arakaiyai of capacity half a milion to one million tons per year will considerably overcome the problem of cement in this country. Not only that, but if a second plant at Derudeb is erected, part of the cement at Marsa Arakaiyai can be exported.

B. White Marbles At Derudeb :

Location: 20 kms East of Derudeb railway station at latitude 17 degrees 33 minutes and longitude 26 degrees 14 minutes.

Quality: Good quality marble of 98% Calcium Carbonate, Magnesium Oxide is trace.

Quantity : Calculated reserves exceed 30 Million Tons.

Status Of Exploration: 10 bore holes were drilled, more than 100 samples analysed geological and topographical mapping carried out. Suitable clays for the industry were tested by pits in the valley lying between the marble deposits and Derudeb railway station.

Exploration Rights: The marble was licenced to the Arab

Cement Co. 1976. Now licensed to few Sudanese Individuals.

This good quality marble at Derudeb can support a cement industry for more than 50 years with annual production of 400,000 tons provide that suitable water supply can be saved. The only water supply comes from the open wells at Khor Derudeb which is not even sufficient enough to supply the domestic use of the town of Derudeb. The iron used as an additive in the industry can be obtained from the small iron deposit to the near South at Gadamai railway station.

Water Supply: Large amount of water is required for the industry. Extensive hydrogeological works should be undertaken to locate good water supply in the adjacent areas. An alternative will be the pumping of water from Atbara River at Qoz Ragab along a pipe line to Ungwatiri railway station then follow the railway line to Derudeb.

C. Coloured Marble For Decoration At Summit:

Location: 4 km South West of Summit Railway Station at latitude 18 degrees 47 minutes and longitude 36 degrees 46 minutes.

Quality: Good quality coloured marbles, white, pink, grey, yellow, brown, suitable for decoration purposes. The Calcium Carbonate content of the coloured marble varies between 75 - 95% with magnesium oxide upto 12%. The white marbles contain upto 99% Calcium Carbonate and traces of Magnesium Oxide .

Quantity: The marble deposits are not explored. They are under limited exploitation since the fifties. Estimated reserves above the surface four milion tons, to a depth of 50 metres 36 million tons and to a depth of 100 metres 97 million tons.

Mining Rights: Part of this marble deposit is licenced to Mr. Omer Abu Amna P.O.Box 1 Gebeit.

Marble is cut as primary raw material into blocks of various sizes. The amount of water needed depends on the scale of Mining. For large scale production large amount of water is needed for the domestic use as well as cooling agent for the drilling and sawing machines.

This marble can find its way to the International markets especially the Gulf Area. If the finance and water problems are solved, large quantities of the marble can be exported. The only source of water in the area is the ground water.

Other Important Marble Localities:

1. Maman area at latitude 16 degrees 20 minutes and longitude 36 degrees 25 minutes. Huge hills of coloured banded marbles good for decoration and almost white pure marble for cement occur. The area is about 60 kms East of Erba railway station. No studies have yet been made. Suitable alluvial clays of the type used in the cement industry are expected to cover the flat area west of these marble deposits. Small high grade iron deposit lies near by. Water supply for the Mining and for the

Industry can either be from local ground water or from River Atbara along a pipe line.

2. Gadamai Coloured Marbles:

Beautifully coloured marbles, green, pink, yellow, white, and page are out-cropping in the flat area about 4 km east of Gadamai railway station. Their qualitative properties and their quantities are not known.

3. Tehilla Marble:

Large quantities of white - grey banded marbles suitable for decoration occur at Tehilla north of Derudeb at latitude 17 degrees 44 minutes and longitude 36 degrees 3 minutes. The quality and the quantity are not known.

4. Karora Marble:

White and coloured marbles occur in huge masses in Karora area in the extreme South of the Red Sea Hills at latitude 17 degrees 40 minutes and longitude 38 degrees 17 minutes. They are not investigated.

All the marbles at the above localities are not licensed.

2. DIMENSIONAL STONES, GRANITE, DOLOMITE AND SLATE:

Dimensional stones are considered by many the premium materials for beauty and durability in institutional and monumental construction. They are also used in flagging, curbing, paving, roofing, slate laboratory furniture and refractory bricks. Granites and white marbles are the preferred stones for monumental use. Slate is used in flagging, roofing, electric switchboard, panels, billiard tables, blackboard, etc. Granites in large quantities are used in curbing and paving because of their superior resistance to abrasion and weathering.

The industry of the dimensional stones is not well known to the Sudanese. Sudan enjoys a wealth of dimesional stones especially in the Red Sea Hills. Because of their blandness of pattern and uniformity of colour, the Sudanese stones can competatively be introduced to the International Markets provide that medium amounts of water are available at the different sites of stones. Water will be mainly used for the domestic purposes as well as for cooling the sawing and cutting machines.

Unfortunately, there is no any effort made to assess the quality and quantity of this stones. Of the promising occurrences, the following are briefly described.

1. The Granites:

Granites are very common in the Red Sea Hills Region. The most interesting commercial occurrence lies about 10 kms South West of Tohamyiam railway station and 2 kms away from Khartoum - Port Sudan road. The Granites are white pink in colour, coarse to medium texture, fresh and make up several moderate to high

hills. They have three wide spaced sets of joints, two vertical and one horizontal. Blocks of up to 3x2x2 cubic metres can be cut. The outcropping reserve are big enough to support any large size of operation.

In order to properly evaluate a potential dimensional stone deposit, one must determine the marketability of the stone, its soundness, its size and shape, the overburden, the distance to the market, the kind of transportation available, the availability of sufficient water, labour, the availability of power and other utilities. Small amount of water is needed if the stones are shipped direct to the market but if the stone are to be prepared at the site i.e. cutting, sawing, shaping, grinding and polishing, large amount of water must be saved.

It is recommended that a general survey and evaluation of all types of granite including what is called Black Granites, i.e. diabases and basalts that lie close to the railway or the asphaltic road or near to the Red Sea Shore should be undertaken. This will flourish the industry of the dimensional stones in the Red Sea Hills and will encourage the Sudanese to invest in this field.

2. Slate:

Commercial slate is defined as a microgranular metamorphic rocks derived from argillaceous sediments and is characterised by excellent parallel cleavage. Slate slabs can be used in roofing, flooring and flagging. Slates are reported to occur at several places in the Red Sea Hills but the promising slate is located about 36 kms North-West of Port Sudan and few kilometers North of Khor Arbaat. Unfortunately, the quality and quantity are not tested to show the suitability of this slate for the building as well as for other industries . It is therefore important to evaluate the slates at this site for their industrial utilization. Medium amount of water will be needed if the slates are to be prepared as finished products at the site. Hydrogeological works should be undertaken to locate ground water resources. The alternative will be the pumping of water along a pipe line from Khor Arbaat few kilometers to the South of the area.

3. Dolomitic Limestones:

Huge deposits of Dolomitic limestones occur as moderate to high series of hills, 70 kms North of Port Sudan. They extend for 20 kms from Bir Eit to J. Saghum along the Red Sea Coast. The Dolomite content varies from 19% to 30% magnesium carbonate. These deposits are not investigated. They are good stones for decoration as well as for dimensional stones.

3. GYPSUM:

The huge gypsum deposits on the coastal area of the Red Sea North of Port Sudan can support wide range of industries for 100 of years. Of the five major occurrences, only Bir Eit deposit, 70 kms North Port Sudan was explored and evaluated in detail. The proved reserves exceed 200 million tons of high quality gypsum. The present annual production does not exceed 25,000

tons which are mainly consumed by the two cement factories at Atbara and Rabak.

A feasibility study on the calcination of gypsum into plasters was completed in 1978 and updated in 1983. The project is based on the calcination of about 42,000 tons of gypsum to produce plaster blocks, wall plaster and plaster cement. Although the factory has been imported in the Sudan, it is not yet erected at its site at Port Sudan.

Gypsum can be utilized in the industry of plasters, plaster board, plaster wall, sulphuric acid etc. Raw gypsum and its manufactured products can find their way to the local and international markets especially in the Gulf Area.

The most important important localities of gypsum are:

1. Khor Eit Gypsum Deposit:
Location: about 75 kms North of Port Sudan and 5 kms West of the Red Sea Shore at latitude 20 degrees 22 minutes a longitude 36 degrees 53 minutes.

Quality: High quality gypsum - the average chemical composition

CaO	32.2%	SiO2	< 2.0%
SO3	45.6%	Fe2O3	0.2%
H2O	18.6%	MnO	0.5%
MgSO4	0.21%	Na2O	0.05%
K2O	0.03%		

Specific gravity - 2.32.

Quantity: Proved reserves to 50 metres depth, 224 million tons .

Status Of Exploration And Mining:
Detailed geological, contour and topographic, drilling of 20 bore holes to depth of 50 metres, 589 samples analysed were completed.

Existing Rights: This area is leased to the Sudanese Mining Corporation and to several individuals.

Processing Of Gypsum: Primary raw gypsum is used as cement retardar and is shipped as lumpy ore to the cement factories or ground raw gypsum as a fertilizer for certain crops such as peanuts and tomatoes which require large amount of soluble calcium. It is used direct rather than a component of mixed fertilizer. Second products of gypsum are manufactured by the process of calcination i.e. burning to get all types of plasters, cement etc. Large amount of water is needed for the different industries of gypsum. Ground water will be the only solution for these industries.

The production of large quantities of plasters from gypsum will definitely solve the problem of the building material in the Sudan especially the severe shortage of cement. The plaster cement is much cheaper than the Portland cement. Further more, the production of plaster wall, plaster board and plaster blocks will produce new style of building materials especially in Port

Sudan and other major towns in the Red Sea Province where the expensive cement bricks are in use now. Again, the different plaster products as well as raw gypsum can be exported to the International Market.

2. Tobonam: Lies 5 kms of Khor Eit Gypsum. The deposit is not explored. It is licensed to the Chalk Industry Co. of Sudan where it is used for the manufacturing of chalk.

3. Saghum: 19 kms North of Khor Eit Gypsum deposit. The gypsum at this locality is not explored and not licensed. It seems to be a big deposit.

4. Shinaab: West of Dungunab Bay at latitude 21 degrees 4 minutes and longitude 37 degrees 2 minutes. The gypsum is not explored and not licensed.

5. Halaib: Few kilometres South of Halaib village at latitude 22 degrees 13 minutes and longitude 36 degrees 38 minutes. The gypsum is not explored and not licensed.

4. SALT:

There are no statistics available about the Sudanese Salt demand and supply. The greater part of salt demand is satisfied with solar salt from the Red Sea Coast. In addition, an unknown quantity of salt is supplied by numerous small scale operations inland which are scattered over many parts of the country and produce more or less pure salt from a variety of sources and for different applications.

The average production and consumption of the Red Sea Salt for the period 1980-86 can be estimated as follows:-

Year	Total Production	Human Consump.	Industrial Consumption	Total Consump.
1980	132,800	72,980	33,420	106,400
1981	137,040	75,310	34,490	109,800
1982	141,440	77,730	35,590	113,320
1983	145,970	80,420	36,730	116,950
1984	150,640	82,780	37,910	120,690
1985	155,460	85,430	39,110	124,550
1986	160,420	88,160	40,370	128,530

(The above figures are in tons per year).

The annual rate of the increase in the total consumption can be assumed as 3.2%. One would therefore expect that the total consumption of the salt in the Sudan will increase in the year 1990 to about 145,790tons. However, the actual total salt consumption of the Sudan cannot be properly estimated unless concise estimation of the unofficial export and import of salt is

known .

Location: Solar salt ponds lie along the Red Sea coast mainly between Port Sudan and Suakin and few in the North of Port Sudan.

Quality: The average chemical composition :

Na	36.13%
Cl	56.6%
K	0.18%
Mn	0.43%
CO2	0.22%
Insol	0.12%
NaCl	91.85% (salt)

The salt is not further washed and purified because of lack of sufficient water.

Existing Rights: The main producers of salt are:

1. Sudan Salt Co.
2. Mustafa Satti & Sons
3. Shams El Din Abdel Karim
4. Prison Dept of Port Sudan.
5. Prison Dept of Suakin.

The average annual consumption of industrial salt is about 40,000 tons. 41.9% of this amount is consumed by the soap industry, 41.3% by bakeries, 9.6% for animal food, 2.4% by tanneries, 2.1% by textile industry, 1.5% for fishing, 0.9% used as fertilizers and 0.3% by canned food and ice factories.

The Red Sea represents an ideal climatic environment for the production of large scale industrial solar salt. The improvement of the present operating salt ponds and construction of additional ponds will put salt as one of the leading economic commodity in the local and international markets. This will successfully be realized if salt is used in the manufacturing of caustic soda, chlorine and soda ash. Furthermore, the prification of the Sudanese salt to more than 98% NaCl will help greatly in its marketability. Large quantity of water will be needed for the above industries of the salt.

5. QUARTZ - Glass Raw Materials.

The glass industry is the major user of many industrial minerals in the manufacturing of its product. Soda-lime-silica glass represents the largest proportion of glass manufactured for commercial use. It is produced by the fluxing and melting of pure silica sands(quartz) in the glass melting furnace together with the soda ash, limestone, dolomite, felspar, gypsum and salt. All these materials are present in the Red Sea Province.

Quartz is very common almost everywhere in the Red Sea Hills and occurs as veins and dykes. Good quality quartz of the type used for the glass industry is at present known to occur at two

localities. The first locality lies about 15km south-east of Tohamyiam railway station. The purity of the quartz reaches upto 99% SiO_2 with iron content of less than 1%. It is not explored in detail but the visual reserves may exceed 2 million tons. The deposit is leased to Mr. Omer Abu Amna. P. O. Box No.1, Gebeit.

The second occurrence of commercial quartz lies about 22km east of Derudeb railway station and only few kilometers east of Derudeb marble deposit. The analysis of the sample taken from the deposit showed a content of 99% SiO_2. This quartz deposit is not explored and not licensed.

Large quantity of water will be needed for the industry of glass. Quartz as raw-material can be exported to the international market.

6. WOLLASTONITE Calcium Silicate.

Wollastonite is an important industrial mineral used as filler in the ceramic, tile, marine wall board, paint, plastics, and refractory liner in steel mills and as a partial replacement for short-fibre asbestos in certain application such as brake lining.

In the Red Sea Hills, important deposits of wollastonite occur 65 km north-west of Port Sudan at latitude 19 degrees 53 minutes and longitude 36 degrees 31 minutes, at Dirbat well.

Quality : High quality of wollastonite of average content of 98% Calcium Silicate.

SiO_2	50.72%
CaO	47.64%
MgO	0.16%
Fe_2O_3&Al_2O_3	1.08%

Quantity: The reserves are estimated at 475,000 MT.

Status of Exploration: Geological and topographical mapping and drilling of two bore holes were completed.

Existing Rights: The deposits are not leased.

Wollastonite is extracted and used as primary ore. Medium quantity of water will be needed for the mining operation. Wollastonite will be mainly mined for export as lumpy or as crushed packed material.

7. MAGNESITE - Magnesium Carbonate

Magnesite is mainly used in the refractory industry, as a basic material for high temperature refractory bricks which are used for the extraction of magnesium metal, in alloys, in chemical industry and in animal feed.

In the Red Sea Hills, magnesite occurs at Khor Ekwan, 30km north-west of Halaib village and about 15 km west of the Red Sea shore at latitude 22degrees 14 minutes and logitude 36degrees 39 minutes.

Quantity: Estimated reserve - 1.6 million MT.

Qualtiy: The average magnesium carbonate content of the magnesite exceeds 80% or about 37% MgO.

Status of Exploration: Magnesite was only explored by surface trenching . No other exploration works has been done.

Existing Rights: The deposit is not licensed.

Processing and Concentration of Magnesite: Magnesite can be used as crude, dead burned or caustic calcined. The dead burned product is a dense weatheredstable granules suitable for use as refractory. For the latter production, crushing, concentration by flotation are needed.

Medium amount of water are needed for the processing of magnesite which should be saved locally. Magnesite can only be utilized for export from Marsa Abu Ramad on the Red Sea.

8. BLACK SANDS:

Promising deposits of black sands containing the titanium minerals ilmenite and rutile together with magnetite and zircon, occur along Trinkitat shore on the Red Sea. It is about 192 kms South of Port Sudan and 30 kms North North East of Tokar, at latitude 18 degrees 30 minutes and longitude 37 degrees 54 minutes. The black sands can be traced for about 25 kms along the coast.

Preliminary investigations were carried out where several tens of shallow auger holes were drilled. The average mineralogical composition of black sands as reflected by the samples is about 70% ilmenite, 2% rutile, 2% zircon, 12% magnetite and 3% garnet.

The reserves of ilmenite rutile and zircon in the studied sector of the area are estimated as follows:

Ilmenite	titanium oxide	600,000 tons
Rutile	titanium oxide	45,000 tons
Zircon	zirconium oxide	110,000 tons

This metals have significant industrial application in the manufacturing of steel, aircraft, pigments etc. Zircon is used as a abrasive material. The black sands are first to be separated from the mixed white sands followed by the separation and concentration of the individual components. All these operations can be carried out at the site of the deposit. Large quantities of fresh water will be needed. The finish products should be packed for export to the international markets.

IRON AND BASE METALS ORE DEPOSITS

The iron and base metals ore deposits recorded up to date in the Red Sea Hills Region are:

1. Iron
2. Mangnese
3. Chromium
4. Tungsten
5. Copper - zinc - lead

1. The Iron Deposits

About 20 iron ore occurrences have been known in the region of the Red Sea Hills. Of these deposits, only one mine had been exploited and some 90,000 tons of high grade ore were exported to Yugoslavia since 1964. The mine was closed down in 1967 because of the Middle East war. Because most of the iron deposits lie close to each other, they grouped into three groups, i.e. the Fodikwan, Sofaya and Karora groups. All the iron deposits are of small size ranging from few hundreds of tons to about 7 million tons and of low to high grade quality and most of them occur in remote areas with no infrastructure facilities.

THE FODIKWAN GROUP:

This group comprises four deposits namely, Fodikwan, Naakuri,Peak, and Tikranit.

Location: Fodikwan: 282km north of Port Sudan and 15 km west of Marsa Osief on the Red Sea at latitude 21 degrees 44 minutes and longitude 36 degrees 43 minutes.

Naakuri: At latitude 21 degrees 46 minutes and longitude 36 degrees 43 minutes 30 seconds, about 0.8km north of Fodikwan.

Peak: o.8km north of Naakuri.

Tikranit: 2km west of Naakuri.

QUALITY: The average chemical composition of this group:

Fe	55-60%
$SiO_2+Al_2O_3$	7.8-11.6%
Mn	5.0-6.5%
Ti	3%
P	0.01-1.03%
S	0.16-0.7%

Naakuri ore is of lower grade, 38% Fe

QUANTITY: About four million tons.

Status Of Exploration & Mining : The deposits have been studied in considerable detail by trenching drilling. Mining started in

1964 and abandoned in 1967. 90,000 tons were exported to Yugoslavia .

Mining Right: This group of iron deposits are licensed to the Fodikwan Co. Ltd.

Mining & Processing: The high grade ore is mined directly as lumpy ore and the low grade ores have to be concentrated locally by magnetic separation. Large amount of water are required and should be saved at the sites.

THE SOFAYA GROUP:

Sofaya group of six iron deposits occur to the South West of Fodikwan group, about 260 kms North West of Port Sudan. The distance between the deposits and Marsa Abu Imamaa on the Red Sea Coast varies from 60 to 120 kms. They lie at latitudes 21 degrees 25 minutes & 21 degrees 40 minutes and longitudes 36 degrees 21 minutes & 36 degrees 57 minutes .

Quality and Quantity:

Deposit	Quantity	Quality
Ankur	7.9 MT	51.1% Fe
Aderaweib	1.2 "	45.1% Fe
Yaukurar	4.1 "	41.0% Fe
Aquissan	0.22 MT	48.7% Fe
Mafdeib	0.088 MT	42.0% Fe
Adareim	0.446 MT	56.7% Fe

All the above deposits were explored in detail (geological, geophysical, topographical, drilling and trenching).

No infrastructures exist in the area to help in the exploitation of these deposit. Most of the ores are to be upgraded by concentration where large amount of water will be needed. The Sofaya iron deposits are not licensed.

KARORA GROUP:

This is a group of three deposits lie near the Fronteir with Ethiopia, about 250 kms South of Port Sudan, between latitudes 17 degrees 42 minutes & 17 degrees 50 minutes and longitudes 38 degrees 17 minutes & 38 degrees 23 minutes.

Quality & Quantity:

Locality 1: reserves 6.5 MT with 41% Fe
Locality 2&3: reserves 10 MT with 40% Fe

The results of beneficiation tests carried out in a 20 kg composite sample prepared from cores of 10 bore holes at locality no. 1 may be summarized as follows:

- The ore can be easily upgraded by crushing to minus 65 mesh then magnetic separation.
- A concentrate of high iron content (+60%) can be obtained

with an iron recovery rate of 95% or more.

- An ore with an average content of 40% can be concentrated with an iron recovery rate of 55%.
- Impurities such as phosphorus and sulphur can be eliminated with the tailings at minus 65 mesh.

Status of Exploration:

Detailed exploration works including geological , geophysical , topographical, trenching and drilling have been completed in Karora area except that no drilling has been undertaken at locality 3 as it is unaccessible. Therefore their estimated reserves are geological and not mining reserves.

The deposits are not licensed. Large amount of water will be required for the beneficiation process. The concentrated ores can be exported to the steel factories in the Gulf Area.

Other Iron Deposit Occurrences:

Of the other iron deposits which could be of economic value but has not been explored is that one at Khor Tenabari at latitude 17 degrees 6 minutes and longitude 36 degrees 30 minutes. Three outcrops of the deposit have been found. The most significant is the one forming a hill which rises 200 metres above the valley level with a lenght of not less than 200 metres and a width of 150 metres. The analysis of the few collected samples showed an iron content of 50 - 60% .
An access across low hilly area of 20 kms long from Kassala - Derudeb road will greatly assist in the exploration and evaluation of this deposit. Further more the availability of large amount of water at this place will be of vital importance. All the other occurrences of iron are not of significant value.

2. MANGANESE DEPOSITS

Manganese is principally used in the ferous metallurgical industry to produce manganese metal, ferromanganese alloys and steel ingot and casting. It is also used in the preparation of numerous manganese chemicals, in dry cell manufacturing in welding rod coating etc.

More than twenty manganese deposits were located around Haliab village about 320 kms North of Port Sudan. The manganese mining industry started towards the end of 1955 by few companies and individuals and it diminshed drastically during 1957 due to the lack of necessary technical knowledge among the miners themselves.

Detailed systematic investigations including geological & geophysical surveys, trenching and drilling were carried out during 1976-1978 at selected localities. The most important manganese localities lie between latitudes 22 degrees 5 minutes & 22 degrees 30 minutes and longitudes 36 degrees 12 minutes & 36 degrees 35 minutes.

The quality of the ore ranges from the low grade 20% MnO to the high grade of 60% MnO with less than 1% sulphur and phosphorus. The reserves are small ranging from few thousand tons to 26,000 tons.

About 7,000 tons had been mined during the late fifties and the production is abandoned since that time. There are no exploration and mining rights exist for the all manganese deposits.

The Coastal Area of Halaib is very prospective for possible economic deposit of manganese. It is recommended that extensive exploration should be undertaken for possible location of large buried bodies of manganese which may be present along fault lines. Large quantities of water will be required for the upgrading and processing of manganese ores for export.

3. CHROMITE DEPOSITS

Chromium metal has a wide range of uses in three primary consumer groups. In the metallurgical industry, its principle use is in stainless steel, in ferralloys and in superalloys. For the refractory industry , chromite is used to make refractory bricks, to line metallurgical furnaces. The chemical industries consume chromite for the manufacturing of chromates, chromic acid and pigments. Sodium and potassium chromate and bichromate are the materials from which a wide range of chromium chemicals are made.

No economic chromite deposits have as yet been found in the Red Sea Hills , however, two occurrences have been reported. The first one is a small deposit at Sol Hamid at latitude 22 degrees 12 minutes and longitude 36 degrees 5 minutes at a distance of 35 kms North West of Halaib village. Detailed geological had been carried out but the occurrence was described as of no economic valley and no further works were recommended.

The second occurrence lies at latitude 21 degrees 30 minutes & 21 degrees 36 minutes and longitude 35 degrees.

Detailed geological survey and trenching were carried out. The most important chromite bearing horizon extends discontinuously over a distance of 10 kms. Nine chromite bodies have been located. They vary in length from 1.8 to 35 metres and it width 0.5 to 5 metres. One body extends for 250 metres and a width of 2 to 5 metres. The average chromium oxide content varies from 12.7 to 47.2%, FeO 9.26-17% Al2O3 7.0 -9.87%, MgO 16-32% and SiO2 5.33-27.5%. The content of chromium oxide in the main body is 40%

It is reported that the analytical results on the chromite concentrates are satisfactory and seem to place these concentrates in a category of good quality.

If the exploration works reveal large reserves of chromite at this area, ample amounts of water will be required to concentrate the ores by flotation for export. The chromite at this area is not licenses.

4. TUNGSTEN

The primary use of tungsten in the form of tungsten carbide is as cutting and wear-resistant material. It is also used in the manufacturing of especial steel, mill product, welding and hard facing rods, chemicals and ceramics.

At present, two occurrences of tungsten are known in the Red Sea Hills. The first one is at J. Gash Amir 30 kms, North West

of Halaib village at latitude 22 degrees 15 minutes and longitude 36 degrees 7 minutes. It is found in quartz veins intruding the granite as well as impregnating the country rock adjacent to the veins.

Apart from the geological mapping, no exploration works have been carried out. The tungsten content of the richest veins ranges from 28.1% to 33% and that of the adjacent country rock is about 0.08%. The main tungsten mineral is Hubnerite having a chemical composition of 48.7% tungsten and 48.2% manganese. Its measured specific gravity is 6.956. The reserves are not known.

The second occurrence was discovered in 1978 and was surveyed in detail by the Sudanese-French Joint Venture. It lies in J. Eyob about 20 kms East of Imasa railway station at latitude 17 degrees 52 minutes and longitude 36 degrees 19 minutes. Detailed geological mapping, drilling, trenching and pitting have been undertaken. Tungsten occurs as Hubnerite in the quartz veins and as fine grained Scheelite (Calcium Tungstate) in the greisen parts of the granitic country rock. The total estimated reserves amount to 1.5 MT containing an average of 0.12% tungstate (WO3). It is believe that if hand sorting is to be applied, this will upgrade the tungsten content to 0.92%. Upgrading by flotation will require large amount of water. The area is not licensed.

5. THE BASE METALS: COPPER - ZINC - LEAD

Copper mineralization is a common phenomenon at many places in the Red Sea Hills region. The majority of these occurrences may be described as insignificant. However, potential copper ores occur together with zinc, lead, silver and gold at two localities.

The first locality, Abu Samr, lies about 25 kms East of the railway line and 15 kms North East of J. Eyob tungsten deposit at latitude 17 degrees 58 minutes and longitude 36 degrees 16 minutes. Detailed exploration works including geological, geophysical, trenching and drilling were carried out. The estimated reserves amount to 2.5 MT containing an average of 7.3% Zinc, 2.1 % lead, 0.6% copper, 115 gram per ton silver and some gold.

It is said that the deposit is difficult to mine and the activity of the Joint Venture is abandoned. The area is not licensed.

The second locality, Ariab, is of commercial interest. It lies about 80 kms North of Musmar railway station. The area is bound by latitudes 18 degrees 40 minutes & 18 degrees 44 minutes and longitudes 35 degrees 16 minutes & 35 degrees 36 minutes.

About 10 significant deposits were discovered with commercial gold in their upper 60 metres gossanic covers and massive sulphides of copper, zinc and silver, 100 metres beneath them. Extensive exploration works (geological, geophysical, topographical, trenching and drilling) are going on since 1981. Based on the few bore holes drilled down to a depth of more than 100 metres, reserves of more than 10 MT of ore , are estimated containing and average of 2.5 % copper, 3% zinc, and more than 10 grams per ton silver with some gold.

The area is licensed to the Sudanese - French Joint Venture Project. Water in very large amount is needed for the mining and benficiation processing of these ores. The local groundwater is too small to support this large scale industry. It is planned by the project to pump the Nile Water along a pipe system for a distance of not less than 170 kms. If eventually the ores are proved to be economically exploitable, their main bulk will be for export.

THE NOBLE METALS

GOLD & SILVER:

Gold has been worked in the Red Sea Hills from a very early period. The Egyptians of the middle and new Empires, perhaps about 2000 years B.C and 1400 B.C sent expeditions to the country between the Nile and the Red Sea and these were followed in later times by Arab leaders. During the early years of last century, gold was one of the things which attracted attention to the Sudan and an important expedition lead by Ibrahim Basha reached the confines of the Beni Shangul region in the valley of the Blue Nile. The country was closed to prospecters during the Mahdi revolution.

From 1900-1950, some of the old mines were extensively exploited by English Companies and individuals. Several tens of tons of gold had been extracted from some of the mines, Umm Nabardi at latitude 20 degrees 7 minutes & longitude 30 degrees 44 minutes, Gebeit at latitude 21 degrees 3 1/2 minutes and longitude 36 degrees 19 minutes, Onib at latitude 21 degrees 29 minutes and logitude 35 degrees 16 minutes, Oyo at latitude 21 degrees 55 minutes and longitudes 36 degrees 7 minutes and Uar mine at latitude 21 degrees 42 minutes and longitude 35 degrees 8 minutes. After 1950, the activities on gold mining have been greatly declined.

The results of the extensive geological and mineral exploration works carried out by the Sudan Government through the technical assistance of the Soveit Union during 1970-1976 have encouraged International Mining Companies to rush back for gold in the Red Sea Hills. Further more , the recent highly especialised remote sensing techniques have indicated that the Red Sea Hills still enjoy great potentials of gold which have yet to be well explored, evaluated and developed for production.

Present Activities On Gold Mining:

A- Sudan - Minex gold venture at Gebeit

Gebeit gold mine lies about 256 kms North West of Port-Sudan and about 70 kms West of the Red Sea , at latitude 21 degrees 3 1/2 minutes and longitude 36 degrees 19 minutes. A Joint Venture Agreement was signed in 1982 by the Sudan Government and the English Minex Company (a subsidiary of Greenwich Resources London) . The Sudan Government holds 51% of the shares and Minex 49%. The detailed exploration works including geological and topographical mapping, trenching and extensive drilling started early 198o where reserves of 2o7,ooo tons of

ores containing an average of 19 gram per ton gold were assessed. In November 1987, commercial production started at an annuall rate of production of one ton of gold. Exploration to increase the reserves is positively progressing.

Gold is extracted and concentrated by the cyanide leaching process. Water is supplied from local ground resource at the mine site. It is to be mentioned here that the amount of water used in the gold processing is very variable, depending on the fineness of crushing and the physical condition of the ore. Three to ten times as much water as ore may be required. Coarse grinding or the grinding of oxidised ore, consumes more water than fine grinding.

Gebeit gold mine area is licensed to the Sudan-Minix Joint Venture Project. The Sudanese Mining Corporation, P.o.box: 1034 Khartoum represents the Sudan Government in this project.

B- Sudan - French Gold Venture At Ariab:

Ariab gold deposits lie about 80 kms North of Musmar railway station and about 170 kms eat of the Nile, at latitudes 18 degrees 40 minutes & 18 degrees 44 minutes and longitudes 35 degrees 16 minutes & 35 degrees 36 minutes. Ten gold deposits were discovered in an area of 25 x 25 square kms. A Joint Venture Agreement was signed between the Sudan Government (60%) and the French BRGM and Total Mineral Co. (40%) in 1982 for the exploration and exploitation of gold at this area.

Extensive exploration and development works are being carried out since 1982 including geological, topographical, geophysical, geochemical, trenching and drilling. A total of more than 4 Million Tons of ores containing an average of 7 gram per ton gold are expected to occur. Experimental production of gold by heap leaching process from one site started a year ago while the extensive exploration to develop the other gold deposits is going on.

Local groundwater is only sufficient to process 300 kg of gold per year. For this reason and as it is planned to extract 2-4 tons of gold annually, water has to be pumped along a 170 kms long pipe line system from the Nile.

Ariab area is licensed to the Sudanese Mining Corporation on behalf of the Joint Venture.

C. Sudan - Kenmare Co. (Ireland) New Joint Venture In Serakoit Area.

Head of an agreement leading to a Joint Venture was signed in 1987 between the Sudan government (60%) and the Irish Kenmare Co. (40%) in Serakoit area just North of the Sudan-French Joint Venture area of Ariab. Subject to the signing of the final Agreement, Kenmare will start general prospection works and if successfully locate promising deposits, detailed exploration will be carried out to develop the commercial discoveries to production.

Hydrogeological research for water should be undertaken to locate ample quantities of water that will be required for the processing of gold.

A general prospecting licence will be issued for the Joint

Venture. The Sudanese Mining Corp. will represent the Sudan government.

D. Kenmare Resources Plc - Central Desert Mining Co. Gold Venture At Abir-Kateib.

Kenmare also signed a Joint Venture Agreement with the Sudanese Central Desert Mining Co. (1987) on share basis of 49% and 51% respectively to develop and extract gold from Abir-Kateib gold mine. The mine is about 250 kms North West of Port Sudan at latitude 20 degrees 34 minutes 20 seconds and longitude 34 degrees 55 minutes 40 seconds. The mine is operating since 30 years ago in a very primitive way and with limited production. Kenmare has undertaken a comperhensive sampling programme over the tailing deposit and the underground working. A processing plant has been purchased and will be erected soon at the site first to process the 28,120 Tons of tailings containing an average of 7.4 gm/ton gold where Kenmare expect to produce approximately 5000 ounces of gold. Further exploration of the vein systems will be carried out in order to evaluate the reserves. Further exploration by systematic drilling will be carried out along the strike of the gold veins and at depth beyond the existing workings. The average content of gold as calculated from the actual production is 10.7 gm/ton but the reserves are not known.

Large quantities of water are required from the local ground sources. Water for the present operation is supplied from the valley 5 kms away from the mine.

The mine is licensed to the Central Desert Mining Co. since 1953.

Other Prospective Areas For Gold:

The whole area between the Nile and the Red Sea Shore should be subject to extensive prospection. As it can be seen from the attached map, more than 100 gold sites have been located in this area. Of particular importance, are the cluster of gold occurrences at Nabaa, 200 kms North East of Abu Hamad town. The Southern part of the Red Sea has never been well prospected for gold where good environments exist for gold occurrences.

Groundwater supply is obviously a determining factor for any future mining operation. Availability of groundwater in ample quantities will definitely encourage more international as well as local companies to explore and develop all the gold deposits in this promising area. This will be of great economic benefit for the Sudan economic.

Silver:

Silver is found as a byproduct with gold and the massive sulphide. The most important localities are at Abu Samr and Ariab areas.mentioned above together with the copper - zinc - lead.

OIL AND GAS

The Red Sea is the most prospective area for hydrocarbons in the Sudan. Extensive exploration for oil started in the early

seventies. Chevron Oil Co. of Sudan was granted a large concession area over the Southern off-shore area of the Red Sea. The company carried out extensive seismic survey which resulted in the delineation of good structural basins. The first well was drilled 10 kms off-shore in the extreme South of the concession area. Natural gas was only discovered. The second well was drilled South of Suakin, 40 kms off-shore. The well produced about 7 million cubic feet of gas and 1158 standard barrel of condensates per day.

In 1985, the World Bank financed a promotion project for oil sector in the Sudan were Robertson Research International as consultants compiled all available data on the Red Sea and came up with new interpretation of the prospectivity of the Red Sea for oil and gas. Suakin structure is promoted to be a significant prospect that deserves further attention. As result of this the Government of the Sudan has signed a Production Sharing Agreement with PANOCO, a company from Switherland, to explore and develop the oil and gas at this locality if found in commercial quantities.

Adly Abdel Mageed Ahmed
Geologist

REVIEW OF POTENTIAL FOR WATER - DEPENDENT AGRICULTURAL DEVELOPMENT IN RED SEA PROVINCE

- Total area of Red Sea province is 212,490 sq. kilo, and this amounts to approx. 50 millions feddans. The province area represents 62% of the total area of the eastern region of sudan.
- Total area suitable for agricultural crop production, horticultural production and livestock grazing, amounts to approx. 27.5 million feddans and this figure is about 56% of the total area. Approximately 44% is desert and mountainous areas with high salinity along the Red Sea Coast
- Total area suitable for agricultural production (crops and horticultural products) amounts to 8 million feddans (AOAD report, April 1983), this figure includes all suitable land in the valleys and Tokar Delta.
- Three factors need more and serious attention if agricultural land is to be utilized effectively:-
  1. Land is owned by tribes and means should be developed to convince the people to accept the investment opportunities either through renting of land or compansation in addition to emphasizing work opportunities, satisfaction of needs and higher level of living.
  2. Effective control of rain and flood on the valleys.
  3. utilizing underground water
- The climate of the province indicates the urgent need for water as a development tool. The province can be divided into 3 cliamtice zones.

  1. THE NORTHERN ZONE:
     This includes the semi-desert area that stretches along the Red Sea. It is characterized by scanty rains that amount to 75 mm, and hence has a poor vegetation cover.
  2. THE MIDDLE ZONE:
     This is characterized by rains of 200-300 mm and a good vegetation cover.
  3. THE SOUTHERN ZONE:
     This is characterized by rains more than 300 mm. The vegetation cover is denser than the Middle Zone.
     The most suitable agricultural land lies in the Middle zone and southern zone.
     The maximum temperature is 26 degree in January and starts to rise up to 40 degrees in July. The province is also characterized by two peaks of rainfall : winter and summer rains with an annual average of 200 mm.
     The relative humidity is maximum during the months of June - August (17 mm) and drops to (8 mm) during October February.

- IRRIGATION SYSTEMS:
  3 Irrigation Systems:
  - By Rain (Traditional and mechanized rain farming is

practiced).
- By Flood (In Tokar Delta).
- By Pumps (In some valleys for horticultural Development but still limited at this point of time).

- Attempts to utilize rain waters by building dams and heaps of sands to spread water proved to be not effective mainly due lack of high technology (Table 1 below):

Site	Total Land Available (Feddans)	Utilized Area (Feddans)
Khour Arab	55000	1200
Adrous	10000	700
Houshiri	1000	500
Makaban	3500	750
Arbat	50000	1440
Nubieen	--	500

- SOIL
  3 types of soils:
  - Clay and Sandy
  - Sandy
  - Mountainous

  (See table 2 for sites proposed for agricultural production).

- AGRICULTURAL PRODUCTION
  Tokar Agricultural Scheme

It was established as a livelihood scheme for statement of the Nomadic tribes in the area by providence of sorghum (Dura) crop which is used as the main food crop by the people and cotton crop is cultivated for export. The Delta is a triangular in shape stretching from South to North for about 45 kilometers. It lies between longitudes 37,39 and latitudes 75 North of the equator. It is a result of a big khour (valley) called Baraka coming from Eritrea. The Delta is very fertile land. Its total area is 406000 feddans but the land suitable for agricultural production is estimated to be approx. 250,000 feddans. The land of the Delta is owned by the tribes around the Delta and about 60 % of the land is not utilized for production because of the problem of water. Agriculture in the Delta depends on flood irrigation. At best only 40% of the suitable land is utilized. The Delta can be divided into 3 areas:-

1. Mid-Delta (The most fertile land)
2. Eastern Delta (less fertile than mid-delta and with some sandy areas).
3. Western Delta (for long time not irrigated by the floods and also large areas are of sandy soil. Generally

the soil is characterized as sandy clay loam or loam soil and it is composed of 44.5% sand and 55.5% clay (University of Khartoum, Faculty of Agriculture soil survey, 1981). Cropping in the Delta scheme follows a rotational system where cotton is allotted 80% of the land and Dura/Dukhan 20% of the farmer land (total land under cultivation amounts on average to 80000 feddans). Vegetables are also grown in October and their production cycle goes up to Mayaba (200 feddan). Cotton crop is planted during September,picking starts in mid February and continues up to May.

- AGRICULTURAL CROPS IN THE PROVINCE:
  - Cotton (Acala and Barakart long staple. This crop is grown in Tokar agricultural scheme).
  - Durra (Sorghum)} These two crops are
  - Dukhan (millet)} grown by traditional agriculture mechanized rain-fed farming and Tokar scheme where flood irrigation is practiced. The average yield is higher than in Western Sudan. (See Tables 3-4-5 and 6).
  - Horse Beans 83/84 yield was 200 kg/feddan and in irrigated areas yield was 529 kg/feddan.
  - Cow Peas 83/84 yield was 655 kg/feddan and in irrigated areas was 771 kg/feddan.
  - Harricot Beans } All these are grown on the pump
  - Lupinest Termis} schemes by private farms. The famous
  - Peas } area is ODROUS valley. Their yield
  - Garlic } is considered reasonable if compared } with Northern province or Kassala } province. No reliable data is found.

- EXPERIMENTED CROPS:
  - Groundnut
  - Soya Beans
  - Fodder

  These were suggested by Arab Organization for Agricultural Development (April 1983).

- OTHER CROPS THAT COULD BE SUCCESSFUL AND TO BE EXPERIMENTED-
  - Castor (successful in Gash Delta in Kassala province and can be experimented with high probability of success, (see Table 3 for yields in Kassala province).
  - Gum Arabic (especially in the Northern zone: semi - desert)
  - Sesame in the clay soils of the Southern and mid - zones.
  - Wheat (for an idea of yield sea table 3 for Kassala province).
  - Sugar cane (but this requires much water).

- HORTICULTURAL PRODUCTION

  The existing farms under pumps and flood irrigation provide

about 20% of the need of the province. Vegetables and fruits are provided to the population mainly from Kassala and Khartoum provinces.

- Vegetables Utilizing Flood Irrigation Proved Successful Yield:

	Red Sea Province Yield/Feddans	Kassala Yeild Feddans
Vegetables:		
1. Okra	2	6
2. Egg Plant	3	6
3. Green Pepper	1.5	5
4. Water Melon	4	-
5. Cantaloupe	-	-
6. Snake-cucumber	10	5
7. Cucumber	4	5
8. Rocket	1	5
9. Tomatoes	2 - 2.5	7 - 10
10. Hot Pepper	-	-
11. Onion	1 - 1.5	5 - 6
12. Potatoes	1 - 8 (big variation)	-
13. Beets	-	-
14. Carrot	-	-
Fruits :		
1. Lemon	-	-
2. Grapefruit	-	7
3. Orange	-	3-5
4. Mandarin	-	2-3
5. Mango	-	4
6. Gaffe	-	5
7. Bananas	-	10

8. Grapes (7 types were experimented in Erkwiet - experiments) and the expectation was that it could also be successful in all places with the same elevation like Sinkat area and Odorous valley). The source of information is regional office of the Ministry of Agriculture in Red Sea Province - report 1976 at Ministry of Agriculture library. No yield estimates were shown in the report.

- Existing schemes established by central and regional governments for agricultural development are shown in Table 7. They are really constrained by water availability.

- LIVESTOCK PRODUCTION:
The province has livestock but if ranked with other provinces it will come at the end of the list (see Table 8). This may be for the following reasons:
  - Inadequacy of water for livestock.
  - Shortage of fodder and poverty of grazing land at

the existing state of the Arts.

A strong statement about the future prospect of the Eastern region of Sudan including Red Sea province with respect to livestock development is FAO report on April 1973 and I quote:-

"Considerable scope exists for irrigated fodder production in the eastern region mainly in Gezira. The large expansion of irrigated fodder production depends upon availability of year round water. At present, this is practiced on a relatively small scale in the Blue Nile, Khartoum and Kassala provinces. The expansion of fodder production in fact will play the major role in developing specialized lines of livestock enterprises in the east. The future dairy industry which mainly aims at providing milk for urban consumption and a large part of the fattening operations which will use the feeder stock coming from the west, are possible if the fodder development is realized. There are suitable areas in the west and east for integrating cattle, sheep ranching with sorghum or groundnut enterprises, particularly in the east with mechanized sorghum and in the west with groundnut schemes. If this untapped potential is developed it would provide substantial increases in meat production and in its quality. It may also be possible to undertake rainfed forage production in relatively higher rainfall areas which can be utilized by grazing. In another area, the animal feed industry will be an essential part of the modern livestock production system in future. The future poultry and dairy industry will largely depend on concentrate feed".

- POULTRY FARMS:

A report of the regional office of the Ministry of Agriculture (1976) pointed out to the felt weed for chicken and eggs and for the attention of families for this issue. The evidence for this tendencies was reflected in one statement of the report where the reporter mentioned that the government had approved the establishment of 3 farms in 3 areas of Sinkat, Saloom and Tokar. Nothing was mentioned in other reports about the execution of these farms or their failure or success.

- RANKING OF ACTIVITIES:

1. Field crops and horticultural crops (medium requirements of water for crops high requirement for hort. crops).
2. Fodder crop (medium requirements for water).
3. Meat and Dairy Industry (medium requirements for water).
4. Poultry farms (low requirements for water).

Mohammed Osman A/Mageed
Khartoum, Sudan.
February 1st, 1989.

APPENDIX 2:

HYDROGEOLOGIC STUDY

PRELIMINARY SUMMARY OF THE HYDROGEOLOGY OF PRINCIPAL AND SECONDARY TARGET AREAS

RED SEA HILLS PROJECT
SUDAN

The hydrogeological descriptions are based on information from various reports and from topographic and geological maps. The principal data reference is the BGR Report of 1989 - (Sudanese German Exploration Project).

INTRODUCTION

The Red Sea Hills region may be considered to have three major morphological zones: coastal plains, mountain ranges, and inland plateaux. The variation of rainfall and topographic catchment configuration serve to provide each of the fourteen (14) target areas with different hydrogeological characteristics. There are three major aquifer types in the region, wadi and alluvial fill, coastal deltaic and alluvial sediments, and fractured bedrock. The small outcrop and elevation of sedimentary Nubian Formations indicate that in this region they have little hydrogeological significance.

From the data reviewed, it is clear that recharge concentrated in wadi systems represents the major groundwater source for past and current aquifer exploitation. Coastal deltaic systems where continental and marine facies interdigitate are seen to have considerable potential but with water quality being a problem. The current extraction of 1500 gallons per minute (0.13 m^3/sec) from Khor Arbart indicates the great potential of wadis emanating from even very arid areas.

The potential of fractured bedrock aquifer systems does not appear to have been adequately investigated. While recognizing the important hydrogeological connection between wadi concentration of water and fractured bedrock recharge, little investigation and no drilling has been reported for targets defined principally on the basis of bedrock structure and fracture systems. The descriptions which follow indicate the importance of further detailed investigation of the potential of bedrock aquifers and of the possibility of recharge and transmission from beyond topographically defined catchments.

TABLE OF HYDROLOGICAL INDICES PRIMARY TARGETS

Project Zone Number		1P	2P	3P	4P	5P	6P	7P
Zone Number		Odib	Dunguneb	Oko	Pt.Sudan	Tokar	Tamhi	Tishelli
Target Zone Map Sheet Number		NF 36-8	NF 37-9	NF 37-9	NF 37-13	NE 37-1	NE 37-5	NE 37-5
Area of Topographic catchment	Km2	35970	1550	14970	4420	60640	14840	9680
% of catchment with low runoff	%	40	4	15	5	8	19	19
Ann aver. precip for catchment	mm	45	40	50	90	250	150	150
annual average precip maximum	mm	80	60	80	100	470	200	200
annual average precip minimum	mm	-40	-40	40	40	70	80	80
annual surface discharge rate average	m3 sec	0.57	0.12	0.69	0.34	7.9	1.3	1.3
Surface discharge rate 8/10 yrs (low)	m3 sec	0.28	0.06	0.34	0.14	5.07	0.69	0.69
Surface discharge rate 2/10 yrs (high)	m3 sec	1.01	0.22	1.1	0.82	11.7	2.2	2.2
Surface dischr rate calc as 1% of m.a.p.	m3 sec	0.51	0.02	0.24	0.13	4.8	0.71	0.46

TABLE OF HYDROLOGICAL INDICES SECONDARY TARGETS

Project Zone Number Zone Number		1S Diib	2S Addrib	3S Hebikwan	4S Salala	5S Agwitiri	6S Haya	7S Sitarab
Target Zone Map Sheet Number		NF 37-5	NF 37-9	NF 36-16	NE 37-1	NE 37-5	NE 37-9	NE 37-9
Area of Topographic catchment	Km2	34500	32805	810	2170	730	2800	1100
% of catchment with low runoff	%	40	40	0	nc	nc	40	nc
Ann aver. precip for catchment	mm	45	45	40	60	60	80	100
annual average precip maximum	mm	80	80	40	50	50	7100	100
annual average precip minimum	mm	-40	-40	-40	80	80	60	100
annual surface discharge rate average	m3 sec	0.5	0.5	0.057	0.25	0.25	0.34	nc
Surface discharge rate 8/10 yrs (low)	m3 sec	0.25	0.25	0.028	0.12	0.12	0.14	nc
Surface discharge rate 2/10 yrs (high)	m3 sec	1	1	0.095	0.41	0.41	0.82	nc
Surface dischr rate calc as 1% of m.a.p.	m3 sec	0.49	0.46	0.01	0.04	0.01	0.07	0.03

nc (Not Calculated)

PRINCIPAL TARGET AREAS

Project Zone Number 1P Obib Map NF 37-5

Large catchment area of 36,000 km² contributing to target zone.

Climatic classification, True Desert, with seasonal precipitation in the northern part, August - November. Very low average precipitation of 45 mm/year. Rainfall events of high spatial and temporal variability. Effective recharge to groundwater only associated with infrequent high intensity, short duration events.

Based on average surface discharge calculations of 0.57 m(3)sec the aquifer recharge potential to this target zone is good, although only a proportion of the discharge is likely to produce aquifer recharge. The catchment has 40 percent of its area with low runoff potential. The gradient of the principal stream axis is 1/590.

The orientation of the major Wadi Diib-Odib drainage channel from south to north appears structurally controlled. The large alluvial fan deposited northeast of the river's exit from the mountains indicates considerable deposition (coastline configuration is affected). That there is no definable channel to the sea confirms the surface water recharge potential of the project target zone.

Hydrogeological potential is likely to be related to two aquifer systems: alluvial and deltaic deposits and bedrock fracture systems. The aquifer systems will exhibit different hydrodynamic and hydrochemical properties. There is likely to be interstitial salts associated with the deltaic sediments because of evaporation concentration of recharge and because of Pleistocene inundation of the coastal zones. The dispersal of salts from the saturated zone will depend on the quality of recharge water and its rate of movement. there is likely to be vertical variation of quality and of yield associated with the complexes of lithostratigraphy in the coastal zone.

It is possible that groundwater movement through bedrock fractures will be more dynamic and, if recharged from flood events, will be of a better quality than from the unconsolidated coastal formations. Drilling target zones will probably be most effective inland of the major delta area.

Project Zone Number 2P Dungunab Map NF 37-9

Catchment area of 1550 Km^2 contributing to target zone.

Climatic classification of True Desert with precipitation events most likely between August and November. Average precipitation of 40 mm year. Rainfall events of high spatial and temporal variability.

Average maximum recharge potential to target zone is a proportion of the mean discharge of 0.12 m^3/sec. Only the lowest part of the catchment has low runoff potential. Gradient of principal stream axis is high at 1/126. Discharge calculation of 0.22 m^3/sec in wet years indicates high runoff potential.

Target zone aquifers of two types related to basement fractures and to overlying alluvial and deltaic sediments.

Major recharge is most likely related to topographic control with concentrated infiltration as streams traverse zone of coastal sediments. The intersection of two presumed fracture systems, eastwest and northwest, likely to be most effective target. Drilling to intersect bedrock fractures in aquifer systems of secondary permeability is recommended. Shallow alluvial aquifers could be variable in hydrochemical characteristics depending on presence of evaporites and the lithological controls of flow dynamics. The rapid runoff likely from a steep catchment zone could result in better quality recharge water than from areas where there is more time for concentration of salts to occur.

The extrusive rocks within the bedrock complex could provide for additional storage of groundwater. Their intersection by fracture systems could be a component of target definition.

The target zone has been submerged beneath the sea on many occasions in the last 100,000 years. The existence of saline connate water is a real possibility unless aquifer hydrodynamics have resulted in flushing of interstitial salts.

Project Zone Number 3P Oko Map NF 36-16

The catchment area above the target zone is 15,000 km^2. Zone 3P is part of the same catchment system as 1P, 1S, and 2S, the Obib system.

The climatic classification is True Desert with no definite season of rainfall. The average annual precipitation is 50 mm with slightly more received in the south. Precipitation events are most infrequent and random in both occurrence and magnitude.

The average surface water discharge at this zone is calculated as 0.69 m^3/sec. the calculation is based on total runoff, much of which occurs as high magnitude, low frequency, flash floods. The target zone is at the junction of two wadi systems. the stream course gradients in the target area are 1 in 600, a low gradient, which provides for recharge potential if alluvial layers greater than 3 meters overlie permeable fracture systems in bedrock.

Apart from the possibility of primary permeability in sandstone lithologies in the Nubian Formation, the aquifer potential is in fractures of the bedrock. The Nubian Formations appear to be at an elevation too high to be saturated. If the valley alluvials are of an adequate depth, then a shallow aquifer potential could exist at the target zone. Wadi Oko appears to follow a north-south trending zone of probable fracture and initial drilling targets should be at the intersection of fault systems.

The dynamics of flow within any fracture system will be important in determining quality of associated groundwater. Unless fracture systems have suitable topographic orientation, they are more likely to bear high salinity water and be less permeable. Fractures intersecting gneiss or Nubian Formations should be favored in drilling target definition.

Project Zone Number 4P Port Sudan Map NE 37-1

The project zone is north of Port Sudan. The catchment area contributing to the zone is 4400 km^2. The characteristics are broadly similar to those of Zone 2P.

The climatic classification is Semi Desert with a precipitation season of July and August -- October to February for the target zone, and a precipitation season of the main catchment area from July to September.

Average annual surface discharge to the target zone is calculated as 0.34 m^3/sec. The high catchment gradient of 1/182 and the high runoff potential of 95 percent suggests effective recharge to the target zone, probably with water of a reasonable quality.

The characteristics listed for 2P are applicable to the aquifer potential of this zone.

Project Zone Number 5P Tokar Map NE 37-5

The topographic catchment area of the Tokar target zone is over 60,000 km².

The climatic classification of the lower portion of the catchment is Semi Desert with the rainfall season from July and August, and October to February. the upper southern portion of the catchment in Ethiopia is semi-arid to arid with a precipitation maximum between April and September.

The average precipitation for the catchment is 250 mm with variations between an average maximum of 470 at Asmara and an average minimum of 70 mm at Tokar.

The average surface water discharge at the target zone is calculated as 7.9 m³/sec. The main stream of the catchment is reported to be perennial in places and it is likely that the combined discharge of rivers in the Baraka system provide considerable groundwater recharge to the alluvial sediments of the target zone. The low runoff area of the Baraka system is estimated as 8 percent and the valley fill of the lower porion of the Baraka is likely to be permanently saturated.

The alluvial fan and deltaic sediments northwest of the main coastal fault contain sediments of varying lithologies with a shallow groundwater system. The reports of water chemistry from the delta indicate high salinity in places. The comments made with reference to Zone 2P apply to the target zone.

Bedrock fractures at, or west of the major fault line are likely to produce waters unaffected by possible residual formation salts. The presence of extrusive rocks, fracture systems, and high recharge potential from the Baraka could provide a basis for defining target zones for drilling.

Project Zone Number 6P Tamhi Map NE 37-9

The catchment of the target area is 14,800 km² and forms part of the Baraka system which discharges at the Tokar Delta.

The climatic classification of the catchment area is Semi Desert with the rainfall season between July and September.

The average annual precipitation for the catchment is 150 mm. The principal drainage system is Khor Langeb.

An estimation of stream discharge is 1.3 m^3/sec with considerable variation related to flash floods and prolonged rainless periods. The catchment has 20% of its area with low runoff potential and the recharge characteristics are likely to be similar for those described in area 3P (Oko). The target area has a low gradient of 1/350 characteristic for the catchment as a whole. The anastomising nature of the stream suggests the presence of a considerable extent of alluvial sediment in the wadi floor.

An orientation of a fracture zone northeast, similar to that of the river system could provide potential for both recharge and dynamic flow conditions (see 3P).

Project Zone 7P Tishelli Map NE 37-9

Catchment area of 9500 km^2 contributing to the target zone. The Khor Langeb river system contributes to the Baraka discharge at the Tokar delta (5P). The target area, 7P, is upstream from 6P (Tamhi).

The climatic characterization and the recharge potential are similar to those described for Zone 6P.

The structural aspects of this zone could be a major influence on hydrogeological potential. A dominant northeast trending fault boundary influences the river course and intersects with north-south oriented structures. The juxtaposition of basalts within the tectonic framework could be important in terms of storage of ground water. Southwest of the target area within the catchment is a flat zone with a low surface runoff potential. The zone may serve as an area of water concentration to facilitate recharge, but there is a chance that evaporation may produce saline concentrations.

Secondary Target Areas

Project Zone number 1S Diib Map NF 36-8

A catchment area of 34500 km(2) contributes to the target zone. Climatic classification is True Desert with precipitation in the north, August to November.

The catchment discharge claculations are as for area 1P and the target zone is only 40 km south of the Obib delta area.

The Wadi discharge is concentrated at the target area and the channel orientation parallels that of Oko shear zone.

Despite the great aridity of the catchment system dry weather discharge calculations of 0.25 m(3)/sec give an index of considerable recharge potential, provided the saturated wadi floor is in hydraulic contact with interconnected fracture systems (See description of 1P)

Project Zone number 2S Addrib Map NF 37-9

Target zone 2S is 40 km up stream from 1S and has a contributing catchment area of 32800 km(2).

Characteristics of discharge and recharge are as described for 1S (Diib).

The area of target zone 2S is structurally more complex than at 1S and hence perhaps of greater potential. Apparent east-west and northeast-southwest lineations (faults) traverse the wadi.

Project Zone Number 3S Hebikwan Map NF 37-9

Area of topographic catchment is 810 km(2)

Climatic classification is True Desert with seasonal precipitation August to November. Mean annual rainfall is very low at 40 mm.

The gradient of the catchment is steep at 1:65 and the catchment above the coastal zone is all of a high runoff characteristic. The runoff discharge is high in relation to the low rainfall, an indication that runoff is rapid and hence evaporation losses less. The quality of recharge water to the coastal alluvial sediments is likely to be of resonable quality.

The target area is assumed to be at the outlet of Khar Hebikwan but recharge potential also exists from Khor Tahamid to the south.

The major structural component is the NS fault of assumed Red Sea Rift phase origin. Of much greater hydrogeological interest are the NE trending faults paralled by river courses such as Khor Tahamid.

Project Zone Number 4S Salala Map NF 37-13

Catchment area is 2170 km(2) and the target zone is the junction of Wadi Haieit and Khar Agwitiri. Both are tributaries of Wadi Odib and zones 4S and 5S are part of the same catchment system as 1P, 2S and 3S.

The climatic classification is True Desert with an average precipitation of 60mm per year. Principal rainfall contribution will be from the eastern tributaries of Wadi Haieit.

The EW fault probably influences the orientation of Wadi Haieit and if intersected at the target zone by a NS fault could present a bedrock well drilling target. At a relatively short distance from the mountains the wadi in the target zone is likely to be permanently saturated (if the sediments are thick). Groundwater associated with wadi sediments more distant from the mountain recharge areas is likely to be more saline because of evaportion.

Project zone number 5S Agwitiri NE 37-1

Most of the description for 4S applies to Agwitiri.

The catchment area is 730 km(2) and rainfall inputs are likely to be less than for those at Wadi Haieit.

Project zone number 6S Haiya NE 37-5

Area of catchment 2800 km(2). The only one of the 16 target areas which is part of the Nile drainage system.

Climatic classification, west, True Desert, east, Semi-Desert. Average precipitation of 60 mm with greater probability of rain between July and September.

The complex structure suggest potential for bedrock aquifer systems. Recharge could be saline because of high evaporation, but with 40% of the catchment producing low runoff there is recharge potential from sediments to bedrock fractures.

Project zone number 7S Sitarab Map NE 37-5

The catchment area is 1100 km (2) and the target area is assumed to include the catchments of Khor Ashat and Khor Sitarab.

Climatic classification is Semi Desert with rainfall seasons July, August and October-February. Average rainfall 100mm.

The catchment gradients are very steep at 1/55 and the recharge characteristics are similar to those described fo 3S and 2P.

The target zone is at the area of intersection of 3 faults and conditions for a productive bedrock well may occur. The definition of the fault sysyems requires further work but coupled with the rapid runoff of probably better quality water, recharge to fracture systems is feasible.

RED SEA HILLS PROJECT -- ECONOMIC TARGETS

DENTIFI-CATION	NAME	PRIORITY RANKING	MAP SHEET	DESCRIPTI REFERENCE
A1	Halaib (gypsum)	6a	NF 37-5	ETA
A2	Halaib (magnesite)	6b	NF 37-5	ETA
A3	Halaib (manganese)	6c	NF 37-5	ETA
B1	Fodikwan (iron ore)	17a	NF 37-9	3S
B2	Fodikwan (iron ore)	17b	NF 37-9	3S
C	Sofaya (6 iron deposits)	18	NF 37-9	3S
D	Shinaab (gypsum)	12	NF 37-9	2P
E	Giebeit (gold)	4	NF 37-9	ETE
F	Abir Kateib (gold)	3	NF 36-16	ETF
G	Bir Eit (gypsum)	2	NF 37-13	ETG
H	Marsa Arakaiyai (limestone)	8	NF 37-13	ETH(4P)
I	Tilkwan (wollastonite)	15	NE 37-1	ETI
J	Khor Arbaat (slate) (crops)	11	NE 37-1	4P
K	Serakoit (gold)	5	NE 36-8	ETK
L	Ariab (gold & Suplphides)	7	NE 36-8	ETL
M	Summit (decorative marble)	9	NE 37-5	ETM
N	Trinkitat (titanium sands)	16	NE 37-6	5P
O	Tokar (crops)	14	NE 37-5	5P
P	Tohamyiam (decorative granite)	10a	NE 37-5	6S
Q	Tohamyian (quartz (glass))	10b	NE 37-5	6S
R	Abu Samir (zinc lead copper)	23	NE 37-9	ETR
S	Karora (oron ore)	19	NE 37-10	ETS
T	Tehilla (decorative marble)	22	NE 37-9	ETT
U	Derudeb (marble cement)	1	NE 37-9	ETU
V	Gadauri (decorative marble)	21	NE 37-9	ETV
	Maman (marble cement	20	S OF MAP	
	Nabaa (gold)	13	W OF MAP	

Best Available Copy

DESCRIPTIONS OF ECONOMIC TARGETS (ET) NOT INCLUDED IN PRIMARY TARGET AND SECONDARY TARGET DESCRIPTIONS

Economic Targets	6	4	3	2	8	15	5	7	9	23	19	22	1	21
	A	E	F	G	H	I	K	L	M	R	S	T	U	V

ETA 1 2 3 -- priority 6a6b6c Halaib — Map NF 37-5

Wadi Serimatai drains to Red Sea north of Halaib. All 3 ET areas are in the climatic zone of True Desert. Precipitation average is 40mm. annual 8/10 year minimum 10 mm and average 2/10 years maximum is 60mm.

Discharge calculations for Wadi Serimtai are, average 0.031 m(3) sec. dry 0.016 m(3)/sec and wet years 0.063 m(3)/sec.

Catchment area is 380 km(2) with 10% of the area classified as low surface runoff. Runoff is likely to be rapid and could give good quality recharge.

Wadi Serimtai is close to target A2, 30 km from A1 and bisects target zone A3.

Groundwater development could be feasible.

ETE -- Priority 4 Giebiet — Map NF 37-9

Target is 600m above sea level at upper portion of a minor tributary of Wadi Giebiet. The target is at the interfluve of north drainage and south west drainage channel systems.

Climate zone is True Desert with average annual rainfall of 45mm (dry years 25) (wet years 75). No obvious local potential for groundwater development.

ETF -- Priority 3 Abir Kateib — Map NF 36-12

Target area 750m above sea level. Closest Wadi is Khor Abu Dueim, a Nile tributary. Area is True Desert with average precipitation of less than 40mm year. Gradients i target area are low, 1:600 and extensive flat sabkha areas occur to the west between 600 and 650m. Possible potential for low quality water but not at high sustainable yields.

ETG -- Priority 2 Bir Eit — Map NF 37-13

Exact position of target site not clear from economic target information. The short east flowing Khor Hadadar is not likely to produce recharge of a magnitude adequate for aquifer potential in the coastal sediments.

Average annual precipitation is 50mm. Potential for groundwater is more favorable at Khor Eit to the south of ETG. (described ETH)

ETH -- Priority 8 Marsa Arakaiyai Map NF 37-13

(See also, description 4P). Target zone is traversed by Khor Eira (Khor Garar from mountains) with a catchment area of 700 km(2). Gradients are steep with a high runoff potential. Average annual rainfall is 60mm (30mm dry) (90mm wet). Discharge calculations for Wadi Eira are average 0.19m(3)/sec, dry 0.06m(3)/sec and wet 0.28m(3)/sec. The description of 4P indicates the likely conditions influencing groundwater potential in the eastern margins of the Red Sea Hills.

Groundwater development could be feasible.

ETI -- Priority 15 Tilkwan Map NE 37-1

Target is at 800m above sea level close to a minor tributary of the Haieil which is part of the Odib system. South of the target is a 25km straight low gradient water course and at the site of Bir Hamikwab well there may exist small potential for a bedrock fracture groundwater source.

Average rainfall is 80mm per year.

ETK -- Priority 5 Serakoit Map NE 36-8
ETL -- Priority 7 Ariab Map NE 36-8

The target areas are 600m above sea level between the Hoshib (north) and Abu Kurum (south) Khors of the Nile drainage system. The area is classified as True Desert and receives an average of less than 40mm of rain per year. Gradients are low at 1:330 and there is evidence of extensive wadi fill. There could be a small potential for low quality water if there is an adequate thickness of sediments.

TEM -- Priority 9 Summit Map NE 37-5

Target area is at 1000m at the interfluve between Red Sea and Nile drainage. (Close to town of Sinkat). There is no immediate evidence of potential for either recharge or storage of groundwater. Average annual precipitation is 100mm. Southern stream tributaries drain to area described in 6S.

ETR -- Priority 23 Abu Samir Map NE 37-9

Target 750m above sea level at confluence of Khor Imasa and Khor Telegal. Low gradient 1:300. Low rainfall, average of 70mm. Groundwater potential low unless bedrock fracture systems occurring. Quality of water probably saline.

ETS -- Priority 19 Karora Map NE 37-10

Topographic map of target area not available. Average rainfall of 300mm could provide recharge.

ETS T -- Priority 22 Tehilla Map NE 37-9

Target at altitude of 700m, all surface drainage away from target and potential for recharge is poor. Groundwater potential not probable.

ETS U -- Priority 1 Derudeb Map NE 37-9

Target at altitude of 600m. Small catchment area of 150 km(2). Annual rainfall average of 70mm. Recharge and storage potential low.

ETS V -- Priority 21 Gadauri Map NE 37-9

Target location not precisely defined but assumed to be close to Khor Gadamai at an altitude of 500m above sea level. Annual average precipitation of 100mm. No obvious evidence for recharge and storage. Catchment area approximately 250km(2).

APPENDIX 3

GEOLOGIC STUDY

Criteria for the Selection of Groundwater Exploration Areas in the Red Sea Hills Region of the Sudan:

The phase one investigation of groundwater resources in the Red Sea Hills, Sudan resulted in the selection of fourteen preliminary exploration areas targeted for a further analysis. Due to the preliminary nature of the sites selected, future feasibility criteria may alter their location or preclude their use entirely.

The first effort toward selection of exploration areas was a comprehensive review of available geologic literature, in order to gain an overview of the geologic and tectonic history of the region. Next, the Geological Map of the Sudan, printed in 1981, was enlarged to a scale of 1 : 1,000,000 and used in conjunction with a topographic map (scale 1 : 1,000,000) to evaluate the geology and geomorphology of the major drainage basins in the region. The trends of major faults and shear zones from the geological map were also evaluated with respect to the orientation of drainage systems.

Regional bedrock fracture systems on the geologic map were located. Each was evaluated for its potential to yield high quantities of groundwater. Specific exploration areas located along favorable fracture systems were selected using the following guidelines.

1) Larger drainage basins should be considered as more productive exploration areas due to greater recharge potential (especially in the northern areas of the region).
2) Larger fracture systems (especially those enhanced by wall rock solution) may provide regional subsurface channelways through which water can migrate over great distances. The intersection of two major fracture systems may provide additional water yield. The contribution of groundwater, within subsurface fracture zones under confined conditions, from surrounding basins may be significant.
3) The superposition of major drainage systems over large fault/fracture zones provide a means of recharging the fractured systems.
4) Lithologic units with high primary and/or secondary permeability which are cut by major faults and are hydraulically connected with a large drainage system may provide significant groundwater storage capacity.
5) The distal end of large basins may contain the maximum amount of available groundwater. Areas where the distal end of large drainage basins are topographically confined will reduce the size of the exploration area.

Fourteen groundwater exploration areas were selected using the above criteria. These areas were further classified as primary or secondary exploration areas depending on their groundwater potential. The bedrock lithology, structure, and drainage characteristics of each area are described in part one of this appendix. The exploration areas are contained on the accompanying topographic base exploration area map. Part two of this appendix contains a tectono-stratigraphic table and accompanying text which briefly outlines the geologic history of the region. A geological map and legend of the Red Sea Hills region of the Sudan, from the Geological Map of the Sudan is included for reference.

Appendix 3: Geologic Study

Part 1

Geologic Descriptions of Favorable Zones for Groundwater Exploration in the Red Sea Hills, Sudan

Geologic Descriptions of Favorable Zones for Groundwater Exploration in the Red Sea Hills, Sudan

Lithologic and structural information for this summary was extracted from The Geological Map of the Sudan, a geologic map of the Red Sea Hills compiled by G.R.A.S.S., and a structural geologic map of the Red Sea Hills compiled by Falkov.

All exploration areas are classified as primary or secondary depending on their relative potential to produce high yields of groundwater. These areas are numbered from north to south. These descriptions are depicted on Plate 1 of this appendix.

Primary exploration area #1

This area is not mapped by the larger scale geologic maps. The bedrock lithology is taken from the Geological Map of Sudan.

Bedrock lithology (oldest to youngest):
1) Kashebib Series gneisses
2) Nafirdeib series metavolcanics and metasediments
3) gabbroic intrusions
4) Mesozoic-Tertiary basalts.
5) Tertiary coastal sediments
6) Quaternary alluvial wadi fills and fan deposits.

Structure:
A major fault mapped as the Oko shear zone is interpreted to underlie the
Wadi Oko-Wadi diib Odib drainage system. The area is centered over the distal end of this fault and drainage system.

Drainage:
Wadi Oko-Wadi diib Odib drainage system

Primary exploration area #2

Bedrock lithology (oldest to youngest):
1) grey and pink biotite granite
2) amphibolitic granites and gneiss
3) Nafirdeib series metavolcanics and metasediments

4) Acidic lavas
5) Tertiary-Quaternary coastal sediments

Structure:
A large E-W trending fault juxtaposes the grey and pink granites with Nafirdeib series metavolcanics and metasediments west of the area. The Falkov map has this fault as a major structural boundary between large blocks. This fault is mapped through the exploration area. Khor Gomatyawa may overlie the large E-W trending fault. The roadway from Mohommad Qol to Gabet al Ma adin also follows the fault and the khor. A large coast-parallel fault intersects the E-W trending fault within the area.

Drainage:
Khor Gomatyawa

Primary exploration area #3

Bedrock Lithology:
1) Kashebib Series grey granites and gneiss
2) foliated gabbroic rocks
3) Nafirdeib Series metasediments and metavolcanics
4) batholithic granites
5) post tectonic granites
6) Nubian Formation sediments
7) Quaternary alluvium and wadi fills

Structure:
This structurally complex area contains a very extensive N-S trending fault (likely associated with the Oko shear zone) mapped beneath Wadi Oko. The wadi and the fault are situated in the western part of the area. The central end east portions of the area contain fault bounded remnants of the Nubian Formation. A NW trending fault bounds the west side of the Nubian Formation sediments and may underlie Khor Tuthi. A N-S fault bounds the eastern side of the Nubian Formation sediments and another may underlie Khor Hume.

Drainage:
Wadi Oko, Khor Tuthi, Khor Hume

Primary exploration area #4

Bedrock lithology:
1) amphibolitic gneisses, west central part of the area
2) foliated gabbroic rocks, SE corner of the area
3) Nafirdeib Series metasediments and metavolcanics
4) post orogenic acidic lavas and tuffs
5) post orogenic granites
6) Nubian Formation (sparse)
7) Tertiary coastal sediments
8) Quaternary alluvium, wadi fills and fan deposits

Structure:
A NE trending structural grain is especially dominant as foliation in the Nafirdeib Series. This structural grain may also be ductile fabric associated with the Nakasib shear zone. Khor Adaia follows this trend and in some areas shows evidence of structural control. The Falkov map has a major fault block boundary through this area.

Drainage:
Khor Adaia

Primary exploration area #5

Bedrock Lithology:
1) Kashebib Series biotite gneiss, SE corner
2) Nafirdeib Series metasediments and metavolcanics, SE corner
3) Tertiary acidic volcanics and basalts, SE corner
4) Tertiary-Quaternary deltaic deposits, alluvium, and wadi fills of the Tokar Delta, occupy most of the area

Structure:
A large N-S trending fault mapped on the Geol. Map of Sudan and the Falkov map bounds the western edge of the Tokar delta. Several NE trending uncertain faults are mapped within the delta. The fault may be associated with the Baraka shear zone. Inland of the delta the shear zone related structure may have controlled the intrusion of the Tertiary volcanics and basalts. The orientation of the drainage systems of Khor Baraka and Khor Langeb also show evidence of structural control.

Drainage:
Khor Baraka and Khor Langeb

Primary exploration area #6

Bedrock Lithology:
1) Kashebib Series grey granites
2) Nafirdeib metasediments and metavolcanics
3) gabbroic intrusives
4) Tertiary acidic volcanics and basalts
5) Quaternary alluvium and khor fills

Structure:
Several closely spaced NE trending faults cut the Tertiary acidic volcanics and basalts. An uncertain NE trending fault is mapped under Khor Langeb.
The Falkov map contains a N-S trending fault which cuts all lithology in the area.

Drainage:
Khor Langeb and its tributaries

Primary exploration area #7

Bedrock lithology:
1) Nafirdeib metasediments and metavolcanics
2) batholithic granites and granosyenites
3) post orogenic acidic lavas
4) basalts, trachites, and basonites
5) Nubian Formation
6) Quaternary alluvium and khor fills

Structure:
A NE trending fault is interpreted to underlie Khor Langeb within the area. On the Falkov map this same feature is mapped as a major fault block boundary which juxtaposes basalts with Nafirdeib series rocks. The fault may have controlled the extrusion of the basalts. Nubian Formation sediments skirt the basalts.

Drainage:
Khor Langeb and Khor Kinabanuideb

Secondary exploration area #1 (Mapped on the Geol map of Sudan only)

Bedrock Lithology (oldest to youngest):
1) Kashebib series granitic gneiss
2) Nafirdeib series metavolcanics and metasediments
3) batholithic granites
4) basic intrusives (gabbroic)
5) Tertiary-Quaternary coastal sediments.

Structure:
NNE tending fault associated with Wadi Odib.

Drainage:
Wadi Oko-Wadi diib Odib

This area is centered over Wadi Odib and the underlying fault or shear zone (Oko shear zone) which is mapped as an extensive crustal deformational feature. The geology is mapped on a regional scale on the Geological Map of the Sudan. Most of the target area is bedrock which is covered by the wadi alluvium.

Secondary exploration area #2

Bedrock Lithology (oldest to youngest):
1) gabbroic gneiss occupies the southern part of the area
2) Nafirdeib series metasediments and metavolcanics in the NE of the area
3) batholithic granites in the NE of the area
4) quaternary alluvium

Structure:
The exploration area is transected by two mapped uncertain E-W trending faults and is bisected by an E-W trending quaternary alluvium deposit associated with the intersection of Wadi Addi ib (Onib) and Khor Shindeb. In this area Wadi Addi ib takes a right stepping jog and may be structurally controlled by the E-W system of faults. The faults also may control the E-W drainage orientation of Khor Shindeb.

Drainage:
Wadi Addib (Odib) and its tributary Khor Shindeb.

Secondary exploration area #3

Bedrock Lithology (oldest to youngest):
1) Nafirdeib series metasediments and metavolcanics bounds the western side of the area
2) Nubian Formation sediments may fill thin down-dropped blocks between a system of NE trending faults
3) Coastal sediments and quaternary khor fills

Structure:
The area is traversed by several short NE trending faults which cut the Nubian strata. A large coast-parallel uncertain fault of probable Red Sea rift phase origin also traverses the area. The Falkov map places a major ENE trending block fault in this area which intersects a major coast-parallel fault.

Drainage:
The major water-course in the area is Khor Haiet and Khor Hebikwan

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Secondary exploration area #4

Bedrock lithology:
1) Awat series sediments on the western edge of the area.
2) Quaternary sediments over post orogenic granite underlies most of the area

Structure:
An extensive E-W trending fault is mapped in this area and may underlie and structurally control the drainage of Khor Haiet.

Drainage:
Khor Haiet

Secondary exploration area #5

Bedrock Lithology:
1) Nafirdeib series metasediments and metavolcanics surround and probably underlie most of the region
2) Red granite intrusions of diorite and some amphibolitic intrusions
3) Acidic lavas in a small central zone
4) Nubian sediments overlie bedrock in the eastern part of the area

Structure:
This area is bisected by an E-W trending fault which may underlie and structurally control a major tributary to Wadi Oko. A NW trending fault is mapped in the SW corner of the area.

Drainage:
Large tributary to Wadi Oko

Secondary exploration area #6

Bedrock Lithology:
1) Kashebib Series amphibolitic gneisses and foliated gabbros
2) Nafirdeib Series metasediments and metavolcanics
3) chloritic schists
4) batholithic granites
5) Awat Series sediments
6) acidic granites and biotite granites
7) quaternary khor fills

Structure:
This large area is structurally and lithologically complex. On the Geological Map of Sudan the area is complexly faulted with many fault intersections and offsets. several NNE and NNW inferred faults (G.R.A.S.S. map) occupy and possibly control the drainage basins in the area.

Drainage:
Proximal end of a large Nile River directed wadi/khor drainage system. The Khartoum-Port Sudan roadway and the railroad follow the drainage system.

Bedrock Lithology:
1) Kashebib Series grey granitic gneiss (G.R.A.S.S.) of batholithic granites (Falkov) underlie the SE half of the area
2) Tertiary-Quaternary coastal sediments overlie basement on the NE half of the area

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Secondary exploration area #7

Structure:
The gneissic (granitic) bodies are cut by a series of NE trending uncertain faults. The Falkov map contains a major fault block boundary, down on the east, and a major coast-parallel fault which intersect within the area.

Drainage:
Small coast-directed khors

Appendix 3: Geologic Study

Part 2

Tectono-Stratigraphic History for the Red Sea Hills, Sudan with Geologic Map

Tectono-Stratigraphic Collumn for the Red Sea Hills, Sudan

Periods	Age (m.y.)	Lithology	Tectonic events
Quaternary	2-0 m.y.	Alluvium, wadi fills, deltaic deposits	
Tertiary	65-2 m.y.	Reef deposits, clastic sediments, evaporites, acidic and basic volcanics, basalt flows	Red Sea Rifting, Rift propagates NW. Saudi-Arabian plate moves NNE
Late Cretaceous	97-66 m.y	Erosion of Nubian sediments from uplifted blocks	Continued uplift and erosion
Cretaceous	144-66 m.y.	Nubian Formation, fluvatile sandstones,siltstones, mudstones, and conglomerates	Uplift with crustal thinning as a precusor to Red Sea rifting
Late Jurassic mid Cretaceous	163-100 m.y.	Acidic volcanics and basaltic flows	Break-up of Pangea
Permo-Triassic	286-208 m.y.	Anorogenic intrusives and intermediate volcanics	Epeirogenic uplift and crustal thinning
Mid-Carboniferous	333-300 m.y.		Collision of Gondwana with Europe
Cambrian to Carboniferous	570-300 m.y.	Deposition of continental and marine clastics into the large grabens	Formation of large 150° grabens with erosion from shoulders and marine transgressions
Cambrian	570-505 m.y	Deposition of continental clastics	Pull apart basins form due to shearing on 70° faults. Then formation of NNW trending grabens
Proterozoic Eon	2500-570 m.y.		
	700-600 m.y.	Awat Series: conglomerates, mudstones,andesites, rhyolites, and tuffs	Uplift and erosion with mild volcanism
	715-630 m.y.		Island arc collisions form the eastern part of the Nubian Shield

	Age (m.y.)	Lithology	Tectonic events
Proterozoic Eon cont.	650 m.y. +-	Formation of the African continental land mass	Pan-African event
	800-720 m.y.	Injection granites forming the Serikoit batholith.Intrusions from gabbro through alkaline granite	
		Unconformity:	
	900-800 m.y.		Two major arcs collide to form the Nakasib Shear Zone
	980 m.y.+-	Homogar Series: meta-volcanic complex	
		Unconformity:	
	1193 m.y. age of meta-morphism?	Nafirdeib and Odi Series: Meta-sedimentary rocks metamorphosed to greenschist facies.Basic to intermediate volcanics, schists, marbles, and quartzites	Rocks of island arc affinity
	1950 m.y. +-	Kashebib series: granite gneiss complex with quartzites	Ancient crystalline basement rocks of the eastern protero-African continent

Tectono-Stratigraphic History for the Red Sea Hills, Sudan

Quaternary: 2 m.y.

Tectonic events:

Weathering and erosion of Red Sea Hills with clastic deposition into numerous wadis and khors. Deltaic deposits mantle the coastal Tertiary sediments where major drainage systems intersect the coast.

Lithology:

Tertiary-Quaternary Coastal sediments:
Pliocene-early Pleistocene; Intense faulting in coastal Red Sea sediments associated with continued uplift of the rift shoulders. Troughs received sedimentation and horsts hosted reefs.
Post Miocene; Intense rift-border uplift and deposition of thick clastic sequence.
Miocene; Marine transgression from the north (to 22°N lat.).
Oligocene; Clastics deposited during a highly erosional tectonic regime associated with rifting related uplift. Clast angularity indicates a short transport distance.

Tertiary: 65 m.y.

Lithology:

A significant period of volcanic activity occurred during the Tertiary which resulted in widely distributed alkaline basalt flows, plugs, and volcanic centers. Related dike and sill swarms mainly trend N-S and E-W. These events are related to crustal thinning and the onset of Red Sea rifting. Erosion from the rift shoulders resulted in a clastic and evaporite sequence with reef deposits.

Tectonic events:

Red Sea Rifting: A NW directed maximum compressive stress reactivated the N-S pre-existing Precambrian sutures in NE Sudan, Saudi Arabia, and Egypt with the onset of Red Sea Rifting. The Red Sea Rift progressed with approx. 105 km of sinistral motion on the

Dead Sea-Gulf of Aqaba Fault. The rift margin sustained uplift while associated fault block subsidence occurred within the rift. Erosion from the Red Sea Hills escarpment resulted in sedimentation on the coastal regions of the Red Sea.

Late Cretaceous: 100 m.y.

Tectonic events:

Uplift of S. Egypt and NE. Sudan associated with crustal thinning (beginning of the Red Sea Rift) caused extensive erosion of the Nubian Formation from the uplifted areas.

Late Jurassic to mid Cretaceous: 150-100 m.y.

Lithology:

Cretaceous Nubian Formation: Continental clastics of Sandstone, siltstone, mudstone, and conglomerates were deposited over most of northern Sudan.

Tectonic events:

The disintegration of Pangea with continued epeirogenic crustal warping resulted in mild crustal deformation, dominated by vertical tectonics, with sparse volcanism in the Red Sea Hills. Volcanic activity consisted mainly of acidic volcanics and some basalt flows.

Permo-Triassic: 260-220 m.y.

Lithology:

Mesozoic anorogenic intrusives: A N-S aligned group of anorogenic alkaline plutons intruded the country rock along the Precambrian Oko shear structure (possibly Pan-African). They are composed of alkali syenites, alkali amphiboles, barkevikite, biotite, and aegirine-augite. Ages for two groups are: 235-220, 173-130

Tectonic events:

Gentle epeirogenic crustal warping which occurred along pre-existing ENE trending faults resulted in the removal of Paleozoic stratigraphy from uplifted blocks to expose Precambrian basement.

Mid-Carboniferous: 320 m.y.

Tectonic events:

The collision of Gondwana (the African shields) with Europe (forming Pangea) resulted in the reactivation of pre-existing faults, especially the 070° trending fabric element, in NE Sudan. Thermal activity related to this collision caused the uplift and magmatism which extended through the early Mesozoic as a precursor to the Red Sea rifting.

Cambrian to Carboniferous: 570-300 m.y.

Tectonic Events:

Graben formation, strong during the Cambrian, began to subside by the Sulurian. Several marine transgressions, southward into the large gabens, (None east of uweinat-Howar uplift of western Sudan) resulted in pervasive sedimentation into the grabens. Transgressions continued into the Carboniferous.

Cambrian: 570 m.y.

Tectonic Events:

Early Cambrian pull apart basins formed along pre-existing 070° trending dextral shear faults during the latest phases of Pan-African tectonics in northeastern Sudan.
Then, in the mid-Cambrian, NNW tending grabens were superimposed on the pull-apart basins resulting in a complex system of NNW trending grabens. Sedimentation into the grabens followed as a result of epeirogenic forces in the Pan-African crust.

Proterozoic 570-2,500 m.y.

Awat Series: Weakly metamorphosed sedimentary-volcanic units 600 m.y.

Lithology: The Awat Series is composed of conglomerates, mudstones, andesites, rhyolites, trachyrhyolites and tuffs. The generally flat lying, undeformed unit is 1-2 km thick. The Awat series is cut by post-orogenic basic and alkali intrusions. This sequence was deposited during periods of uplift and erosion accompanied by mild volcanism in the latest Precambrian.

Tectonic events:

630-715 m.y. Island arcs accreted, in a series of collisions, to form eastern part of Nubian Shield.

Pan-African event 650 m.y. Several microplates converged to form the African continental land mass. Meta volcanic/ meta-sedimentary/ ophiolitic/volcanic rocks of the Nubian shield accreted, as island arcs, onto the E. Saharan craton

A complex structural fault fabric developed during Pan-African event:
-Formation of trans-African lineament trending 070° and similar trending structural grain across northeastern Sudan.
-N to ENE trending structural fabric consisting of foliation and fold axes.
-150° trending faulting.

720 m.y. +- Sinistral shearing along N-S Oko shear zone, within the Serikoit Batholith, resulted in an offset to the Nakasib zone. The Nakasib sustained some component of dextral motion during the tectonism.

Proterozoic intrusive rocks: 720-800 m.y.

Lithology: Injection Granites formed batholiths which are elongated N-S. The granites are composed of Quartz, oligoclase, orthoclase, green hornblende, and biotite. The units are medium grained, well jointed, and often have lineated contacts.

Individual intrusions range from gabbro through alkaline granite. Some older units are strongly gneissose, this deformation occurring during syn-tectonic batholith emplacement. 720-800 m.y.

Tectonic Events:
800-900 m.y. Two major island arcs collide along a subduction zone to form the Nakasib shear zone. Later shearing dismembers the ophiolite sequence.
950 m.y. Volcanic arcs begin to grow to maturity

Homogar Series: Metavolcanic rocks, 980 m.y.

Lithology: The metavolcanic complex comprising the basic to acidic effusive rocks of the Homogar Series are confined to the boundaries of the major tectonic blocks?. The series is greater than 1000 m thick. The rocks are weakly deformed with gentle folds. Dips to fold limbs range from 20° to 30°

Unconformity:

Nafirdeib & Odi Series: metasedimentary rocks 1193 m.y. (age of metamorphism?)

Lithology: The metasedimentary volcanic rocks of the Nafirdeib and Odi Series are of greenschist facies with basic and ultrabasic intrusions, and calc-alkali batholith granitoids. The Nafirdeib Series is mainly composed of basic to intermediate altered effusive rocks and tuffs with intercalating silicious schists, marbles, and greywackes. In the upper part of the series, sedimentary rocks are more common with intercalations of tuffs and effusive greenstone altered rocks. The Odi Series is composed of a variety of metamorphic schists, marbles, quartzites, with rare intercalations of amphibolites and greenstone effusive rocks. Both series are cut by intrusions of ultramafic gabbro, diorite, and batholithic granite complex rocks. Odi series is much more intensely deformed and contains tight isoclinal to overturned westward verging folds.

Tectonic events: Some view this series to represent cover over the Kashebib basement series. Thus, basement rocks are believed to underlie most of the meta-sedimentary units. However, the gneissose and meta-sedimentary rocks have also been found to be of similar age. The meta-sediments are interpreted to be of island arc affinity.

Inferred unconformity:

Kashebib series: Granitic complex, 1950 m.y.

Lithology: A granite gneiss complex including rocks of amphibolite facies metamorphism and consisting of granite gneisses, crystalline schists, quartzites, migmatites, and some associated anatectic granites. Folding in the Series consists of tight to isoclinal eastward verging folds.

Tectonic events: This series may be ancient crystalline basement rock and part of the eastern margin of a protero-African micro-continent.