SO-2

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROJECT REPORT
Somalia Investigation
(IR)SO-2

A PRELIMINARY EVALUATION OF THE NON-FUEL MINERAL POTENTIAL OF SOMALIA

By William Rucker Greenwood
U.S. Geological Survey

U.S. Geological Survey
Open-File Report 82-788

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. (Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.)

1982

CONTENTS

Page

Page

ILLUSTRATIONS

ABSTRACT

Additional exploration in Somalia is warranted for a wide variety of metallic and nonmetallic deposits. In Precambrian rocks, deposit types favorable for exploration include: a banded iron formation; platinum-bearing mafic-ultramafic complexes; tin-bearing quartz veins; phosphorite; stratabound base-metal deposits; uranium associated with Precambrian(?) syenite; apatite, molybdenum, and alumina in alkalic rocks; Jurassic and Cretaceous black shales; possible bedded-barite and massive base- and precious-metal sulfide deposits; vein barite in Tertiary rocks in fault zones; sepiolite and bentonite for drilling muds and other industrial uses; celestite; possible Tertiary zeolite; and uranium deposits.

Several of these deposit types could be jointly developed and integrated into domestic industries; for example, phosphate and gypsum, or bentonite for pelletized iron from the banded iron deposits. Other deposits such as barite and sepiolite are of value because of their proximity to major drilling operations in the Arabian Gulf. Still other deposits, such as alumina and banded iron, might be marketable because of proximity to aluminum and iron-refining industries now being constructed in Saudi Arabia. Some deposits, such as celestite, can be developed with little capital investment; others, such as the iron deposits, would require large capital commitments. Exploration and evaluation for many of these deposits can be accomplished by Somali geologists with a few advisors. Most of the deposits require feasibility studies conducted by teams of economic geologists, extractive metallurgists, and economists. Some marginal deposits could be exploited if cooperative development schemes could be negotiated with governments in nearby countries.

INTRODUCTION

This preliminary evaluation of the non-fuel mineral potential of Somalia was made to summarize available geologic and mineral deposit information and identify favorable targets for exploration.

Somalia occupies a territory of about 638,000 km^2 in the Horn of Africa. It is bordered to the north by the Gulf of Aden, the east by the Indian Ocean and the west and south by Kenya, Ethiopia, and the Territory of the Affars and Issas.

Most of the country consists of a gently southeast dipping plateau, bordered on the north by fault-scarp-bounded mountains near the margin of the Gulf of Aden. The northern mountains are as high as 2,500 m and are drained by north-flowing streams into the Gulf of Aden. The central part of the country is drained by Uadi Nogal, an integrated network of intermittent streams that flow east toward the Indian Ocean. The southern part of the country is drained by two perennial rivers, Uebi Scebeli and Uebi Guida, that flow southeastward to the Indian Ocean. The country is a semi-desert and covered to various degrees by shrubs except for irrigated farmland along the southern rivers and sparse forests in some higher mountains in the north. Rock outcrops generally are well exposed in the northern mountains, but deep soil, eluvial deposits, and dense thorny shrubs cover most of the rocks in the south.

Geologic and mineral deposit studies have been conducted in Somalia chiefly by British and Italian geologists prior to independence in 1960. The principal recent mineral evaluations of the country in English are by Holmes (1954) and the United Nations Development Programme (U.N.D.P.), 1970. Neither of these reports was widely distributed. A major review of mineral deposits of Ethiopia and Somalia by Usoni (1956) is in Italian.

Data on non-fuel mineral deposits of Somalia have been abstracted from available reports and entered into the U.S.G.S. CRIB mineral data computer file by the author. Mineral deposits that merit additional exploration and possible exploitation are identified and compared with economic deposits being developed elsewhere. Exploration techniques are suggested for favorable deposits.

This report is limited to a review of the Somali literature listed in the reference section. Many additional reports are listed by Puri (1961) and discussed by the U.N.D.P. report (1970) but were not available for this evaluation. Additional reports in Italian are referenced by Merla and others (1979) and Usoni (1956) but were not available to the author. The computerized data compilation and this report were made during parts of June, July, and August 1981.

The author gratefully acknowledges helpful discussions with Somali geologists and technicians working with the U.S. Geological Survey Saudi Arabian Mission at Jiddah, Saudi Arabia, and especially Rashid Sametar, geologist, and Omar Nour, driller, whose interest in the development of their country prompted this report. Ahmed M. Behi, former Chief Geologist of the Somali Mineral and Groundwater Survey, was extremely helpful in providing an unpublished report on geochemical exploration of northern Somalia (Behi, 1973). The author also acknowledges the helpful assistance of Greta Orris, U.S. Geological Survey, Denver, who facilitated compilation of the computer file, and A. H. Chidester, U.S. Geological Survey, Reston, for his encouragement in this work. R. B. Hall and R. A. Sheppard, U.S. Geological Survey, Denver, helpfully provided background information on some of the mineral deposit types.

SUMMARY OF GEOLOGY

Somalia is underlain principally by Mesozoic and Tertiary marine and continental-margin sedimentary rocks deposited unconformably on Precambrian metamorphic and igneous rocks. Quaternary and Holocene alluvial and eluvial deposits cover much of the southeastern coastal area. The Precambrian rocks are exposed in the northern block-fault mountains and in a broad uplift in the Bur region, along the Indian Ocean in southern Somalia.

The structure of the region is dominated by the apparently fault-controlled, southwest-trending margin of the Indian Ocean; the rifted and block-faulted, east-northeast trending margin of the Gulf of Aden; and the complexly faulted East African Rift on the west. These structures were formed by major crustal plate movements related to formation of the Indian Ocean, Gulf of Aden, and Red Sea during the Miocene. These tectonic features are characterized by normal faulting and isostatic uplift related to regional extension.

Precambrian

The Precambrian rocks of Somalia are divided by Merla and others (1973) into an older unit, consisting of amphibolite-facies biotite and amphibole gneiss, migmatite, amphibolite, quartzite calc-silicate rock, and marble; and a younger unit, consisting of greenschist facies variegated slate, quartzite, dolomitic marble, and metaconglomerate. Merla and others (1973) map the older unit as forming all Precambrian outcrops in Somalia except for a zone where the younger unit is discontinuously exposed northeast of Erigavo to near Bender Cassion. Merla and others (1979) indicate that this relative chronology is based on comparison with similarly metamorphosed rocks in Ethiopia. Their younger unit generally corresponds to the Inda Ad Series as used in Somalia (Farquharson, 1924; S.O.E.C., 1954; Osman and others, 1976). This two-fold stratigraphy in northern Somalia has been questioned by Greenwood (1960) and Osman and others (1976), who suggest that an unconformity has not been established between the two units.

Bur Region

Precambrian rocks of the Bur Region are divided into four units: (1) biotite gneiss; (2) calc-silicate rocks, marble, and quartzite; (3) mafic intrusive rocks; and (4) biotite monzogranite.

The calc-silicate, marble, and quartzite unit is inferred to unconformably overlie the biotite gneiss unit (U.N.D.P., 1970; Osman and others, 1976). Unit 1 contains subordinate intercalated amphibolite and quartzite. Unit 2 contains subordinate biotite gneiss and varies from predominantly calc-silicate and marble on the east to predominantly quartzite and banded iron formation on the west (Osman and others, 1976). These layered rocks are metamorphosed to amphibolite facies and are tightly to isoclinally folded. The foliation generally strikes northwest except in minor domes and near a forcefully emplaced monzogranite complex east of Dinsor. The foliation generally dips to the northeast but shows many local reversals suggestive of isoclinal folding and widely varying dips in and near the monzogranite complex.

Mafic intrusive rocks form five plutons of moderate size (U.N.D.P., 1970), probably largely composed of gabbro but may also include diorite. The monzogranite is pink to yellow, medium to coarse grained, commonly contains large phenocrysts of microcline and biotite, and locally is devoid of mafic minerals. This unit also contains subordinate aplite, syenogranite, and syenite. The syenogranite and syenite contain appreciable coarse magnetite.

Northern mountains

Precambrian rocks of the northern mountains are divided into four units: (1) A gneissic complex; (2) the Inda ad series; (3) mafic intrusive rocks; and (4) granite to tonalite.

Gneissic complex.--The gneissic complex is reported to consist of a thick basal sequence of gneiss and schist, an overlying sequence of amphibolite and subordinate marble and quartzite, and an upper sequence of greenschist-facies graywacke, shale, and volcanic rocks (Osman and others, 1976). Because the latter two units also are variably intruded by gneissic and migmatitic igneous rocks (Mason, 1962; Gellatly, 1960; Mason and Warden, 1956; and Hunt, 1958, 1960), the separate existence of an underlying gneissic basement is difficult to establish. Evidence of such a basement includes: a structural disconformity of layering in the gneiss to current bedding in overlying graywacke (Gellatly, 1960); granitoid pebbles in graywacke (Gellatly, 1960; and Hunt, 1958); traces to moderate amounts of detrital potassium feldspar with plagioclase in graywacke (Gellatly, 1960; Mason, 1962; Mason and Warden, 1956; and Hunt, 1958, 1960); and rhyolite volcanics interbedded among the layered rocks (Mason and Warden, 1956; and Gellatly, 1960). None of these features is present in Precambrian metasedimentary and metavolcanic rocks of southern Saudi Arabia that were deposited on oceanic crust (Greenwood and others, 1976, 1980).

Metavolcanic rocks are subordinate to metasedimentary rocks in the gneissic complex. These metavolcanic rocks include pillow basalt, mafic tuff, and subordinate rhyodacite to rhyolite. These volcanic rocks were deposited rapidly in marine basins along with graywacke and shale. Abundant metadolerite sills (Hunt, 1960) probably were intruded during deposition.

The amphibolite, marble, and quartzite sequence of Osman and others (1976) occurs as layers and lenses from 2 to 70 m thick within metagraywacke (Gellatly, 1960). The amphibolite probably represents metamorphosed marl. Thick calc-silicate and marble layers occur in biotite schist and hornblende gneiss of probable sedimentary origin in the area north of Hargeisa and Laferug (Mason, 1962). Thin calc-silicate and marble layers are widespread in metagraywacke and biotite schist (Hunt, 1960). Quartzite and marble layers occur separately, in pelitic schist and metagraywacke respectively, in the Adadleh area (Hunt, 1958). Finally in the Berbera-Sheikh area (Hunt, 1960), manganiferous and iron-rich quartzite layers occur in metagraywacke and commonly are associated with hornblende gneiss of metasedimentary origin. Therefore, the amphibolite, marble, and quartzite sequence of Osman and others (1976) probably represents facies variations within a thick metagraywacke, pelitic schist, and metavolcanic unit.

Inda Ad Series.--The Inda Ad Series crops out in a narrow east-northeast trending anticline north and northeast of Erigavo. The unit consists of interbedded graywacke, siltstone, and variegated shale with subordinate quartzite and marble layers as thick as 170 m. This unit is characterized by rapid lateral and vertical facies changes but generally appears to grade from lowermost pebble graywacke, to a graded graywacke-shale unit, to siltstone and shale, and finally to pebble graywacke (Greenwood, 1960; Mason and Warden, 1956). Current ripples occur in siltstone and corrugated bedding and other soft-sediment structures occur in interbedded graywacke and shale (Greenwood, 1960). Graywacke of the unit contains detrital potassium feldspar as well as abundant plagioclase. Pebbles in the graywacke consist of porphyritic felsite, metabasalt, quartzite, marble, shale, and phyllite (Greenwood, 1960). The Inda Ad Series probably represents a transgressive marine fan with an uppermost regressive facies.

The Inda Ad Series is mapped as unconformable on older metavolcanic and metasedimentary rocks in the Heis area (Mason and Warden, 1956). However, the units also may represent different facies but not necessarily units of greatly different age (Greenwood, 1960; see also Osman and others, 1976).

Mafic igneous rocks.--Mafic igneous rocks include gabbro, metagabbro, and minor associated diorite. The gabbro and metagrabbro generally are medium- to coarse-grained, dark gray, and commonly weather to rounded boulders in grus. Some of the mapped plutons are layered. Rhythmically layered gabbro is also described at Moro Tug (lat 10°10′ N.; long 44°44′ E.) by Mason (1962); the map for that report was not available during this compilation. The Moro Tug gabbro contains thin interlayered pyroxenite and anorthosite. At one locality pyroxenite grades into anorthosite in a series of rhythmic layers. Many of these gabbros occur in the cores of close synformal structures defined by foliation in the host metamorphic rocks. In detail, gabbro contacts are discordant.

Granite.--The granite unit includes massive to foliated granitoid rocks shown on available 1:125,000 scale geologic maps as well as lower Paleozoic and Precambrian granites and quartz diorites of Merla and others (1973). The unit consists predominantly of medium- to coarse-grained granodiorite and monzogranite. Biotite commonly exceeds hornblende or is the sole mafic mineral. Rocks of this unit intrude the Inda Ad Series, as well as highly metamorphosed rocks, and probably are late- to post-tectonic plutons. Locally, however, it is difficult to distinguish between this unit and strongly gneissic to migmatitic granitoid rocks not shown separately on the geologic map.

Structure.--Foliation trends generally north to north-northeast in the Inda Ad Series and more highly metamorphosed rocks east of about long 45°30′E. West of that longitude the foliation swings abruptly to east-northeast, east, and west-northwest trends that continue to near the western border of Somalia. At the western border of Somalia the foliation turns to the southwest. All the layered rocks, including the Inda Ad Series, are tightly to isoclinally folded and cleaved to schistose. The more highly metamorphosed rocks show multiple deformation. Strike-slip and thrust faults locally have produced mylonite and phyllonite zones (Gellatly, 1960; Hunt, 1958) nearly parallel to the local structural grain.

Metamorphism.--Regional metamorphism is low greenschist facies, or possibly zeolite facies in the Inda Ad Series. Near intrusives biotite to hornblende hornfels occurs (Greenwood, 1960; Mason and Warden, 1956). From east to west the Inda Ad Series shows a progressive increase in the intensity of folding and metamorphic cleavage. The metavolcanic and metasedimentary rocks in contact with the Inda Ad Series near Mait are metamorphosed to greenschist facies and isoclinally folded. These rocks undergo a rapid westward increase in grade to amphibolite facies and are intruded by migmatite about 15 km to the west of the contact with the Inda Ad Series. Migmatite is the dominant rock in the Heis area (Mason and Warden, 1956).

The layered rocks of the gneissic complex are metamorphosed to the amphibolite facies and are variably intruded by migmatite in the Adadleh (Hunt, 1958), Berbera-Sheikh area (Hunt, 1960), and the area north of Hargeisa and Laferug (Mason, 1962). Amphibolite facies predominates in the Las Dureh area; however, an isolated exposure of these Precambrian rocks in the Jirba Range is metamorphosed to greenschist facies (Gellatly, 1960). Kyanite is reported in the Las Dureh area (Gellatly, 1960) and in the Borama area (Daniels, 1960) indicating Barrovian-style metamorphism for those areas at least. Pyroxene-hornfels facies (also called granulite facies) metamorphism is reported in the Las Dureh area (Gellatly, 1960). Widespread granoblastic textured metasedimentary rocks and diopside-bearing calc-silicate rocks are described by Gellatly as granulite; however, these features can also be formed by amphibolite facies metamorphism.

Phanerozoic

Jurassic Rocks

Jurassic strata unconformably overlie Precambrian rocks in four main outcrop areas: the Bur region of southern Somalia; the Borama-Zeila area of northwest Somalia; the Bihendula area of north central Somalia; and the Ahl Mado region of northeast Somalia. The Jurassic strata differ among these outcrop areas and therefore will be discussed separately.

Borama-Zeila area.--The Jurassic rocks of the Borama area consist of the basal Adigrat Sandstone (3-24 m thick), and the upper Gawan Limestone (about 180 m thick), according to sections of Somaliland Oil Exploration Company (S.O.E.C.), (1954) and nomenclature of Merla and others (1979). These units are shown undivided on the map in this report as shown in Merla and others (1973).

The Adigrat Sandstone rests on Precambrian rocks and predominantly is medium- to coarse-grained quartz sandstone with subordinate feldspar and rare heavy minerals. The unit has trough and planar crossbedding in sets ranging from a few centimeters to as much as 100 m thick. Conglomerate and thin gypsum beds are near the base. Higher in the section siltstone (commonly cross laminated) occurs with sandstone. The unit grades upward into the

Sa Wer limestone and is transgressive from a lower fluvial and marine marginal to an upper shallow marine environment. The rocks probably are about Dogger or upper Liassic-Malm in age in this area (Merla and others, 1979).

The overlying Sa Wer limestone is gradational with Adigrat sandstone and comprises three subunits: (1) basal, distinctly bedded, coarse-grained limestone and sandy marl, massive to micritic light or gray limestone, locally dolomitized, and marly limestone; (2) middle, well-bedded limestone and massive limestone with chert and silicified coralline units; and (3) upper, interbedded calcareous and marly beds; locally contains conglomerate layers with Precambrian crystalline and Jurassic organogenetic limestone pebbles. The lower and middle units are shallow marine facies, locally lagoonal (Merla and others, 1979). The upper unit represents shallow marine to carbonate fan facies and may indicate active depression of the basin. The unit ranges in age from Bathonian-Callovian to early Kimmeridgian (Merla and others, 1979).

The Dagham shale in this area rests on Sa Wer limestone and consists of marly shale, thin porcellaneous limestone to rubbly limestone, and dark mudstone with occasional black carboniferous layers (S.O.E.C., 1954). The unit represents outer marine shelf facies. The unit is of Early and Middle Kimmeridgian age (Merla and others, 1979).

Bihendula area.--The Jurassic rocks of the Bihendula area consist of, in ascending order, the basal Adigrat sandstone (77-219 m thick), Bihen limestone (about 125 m thick), Gahodleh shale (about 103 m thick), Wanderer limestone (about 108 m thick), Daghani shale (about 340 m thick), and Gawan limestone (about 240 m thick), according to S.O.E.C. (1954). These units are shown undivided in this report, as they are in Merla and others (1973).

The Adigrat sandstone rests unconformably on Precambrian rocks. The unit is generally similar to the Adigrat in the Borama-Zeile area except that at the base it consists of interlayered pillow basalt, ash, limestone, and chert (as thick as 24 m). Also, near the top, the sandstone at Bihendula contains common calcareous dolomitic layers that at least in part are a calc-arenite. The lower part of the unit consists of fining-upward clastic cycles about 10-20 m thick that are lens shaped and have erosive bases. Laminar gypsum layers are interbedded with the fine-grained upper parts of these cycles. Near the base of the unit, terrigenous clasts are derived from the east. Near the top of the unit, clasts are derived from the west (Bruni and Fazzouli, 1976). The unit is transgressive from a lower fluvial facies to an upper littoral marine facies. The rocks are pre-Bathonian, based on the age of the overlying Bihen limestone (Merla and others, 1979).

The Bihen limestone consists of distinctly bedded, medium-fine-grained, and locally dolomitized limestones, and subordinate shale, marl, and marly limestone (Merla and others, 1979). The unit represents a clastic-starred lagoonal facies at the base and changes upward to marine marginal with bars and sand banks (Bruni and Fazzouli, 1976). The rocks range in age from Bathonian/Callorian to Callorian/Oxfordian (Abucar, 1977).

The Gahodleh shale consists mainly of limy shale, mudstone, and thin limestone, and includes some kerogenous black calcareous shales and local fibrous gypsum (S.O.E.C., 1954). The unit was deposited on a wide continental shelf (Bruni and Fazzouli, 1976) and is of Oxfordian age (Abucar, 1977).

The Wanderer limestone consists of alternating well-bedded limestone and marly limestone, with thin clayey intercalations (Merla and others, 1979). The unit was deposited in an open marine, upper shelf environment (Bruni and Fazzouli, 1976) and is of Middle to Late Oxfordian and Early Kimmeridgian age (Merla and others, 1979).

The Daghani shale consists of yellow or variegated shale and subordinate marl, with rare calcarenite and thin gypsum layers (Merla and others, 1979). The unit also contains local black calcareous shale and appreciable amounts of thin-bedded and concretionary limestone. The shale is marly and commonly passes laterally into limestone (S.O.E.C., 1954). Deposition occurred in an outer shelf, marine shale environment that underwent repeated transitions to upper shelf carbonate environment and received distal carbonate-fan deposits. The rocks are of Early and Middle Kimmeridgian age (Merla and others, 1979).

The Gawan limestone consists mainly of well-bedded, locally marly limestone with thin shale intercalations (Merla and others, 1979). The rocks are thin bedded (less than 1.25 m thick) and some are porcellaneous. Near Bihendula the upper 60 m contains chert-chalcedony concretions, and the limestone becomes sandy toward the contact with overlying Cretaceous Jesomma sandstone. Elsewhere, as in the Jirba Range, the Gawan is massive and the Cretaceous Jesomma sandstone rests unconformably on a compressed Jurassic section from 150 to 220 m thick and capped by the Wanderer limestone. The lower part of the Gawan was deposited in open-marine, upper shelf facies. The upper Gawan was deposited in marine marginal and lagoonal facies (Merla and others, 1979). The rocks are of Tithonian (S.O.E.C., 1954; Abbate and others, 1974) or Late Kimmeridgian (Abucar, 1977) age.

Erigavo-Candala area.—The Jurassic rocks of the Erigavo-Candala area consist of the basal Adigrat sandstone (40 m to as much as 196 m thick), and an overlying Ahl Medo sequence consisting generally of five subunits and aggregating as much as 600 m in thickness (Merla and others, 1979; S.O.E.C., 1954). These units are shown undivided in this report, as they are in Merla and others (1973).

The Adigrat sandstone rests on Precambrian rocks and generally resembles the Adigrat at Bihendula. The unit grades upward into limestone of the overlying unnamed Jurassic unit. Near Inda Ad, limited data indicate that the clasts were transported from the south (Abucar, 1977). The unit was deposited in fluvial to marine marginal facies. The rocks are possibly of Early Callovian or Early Liassic age (Merla and others, 1979). The transition to overlying limestone appears to have occurred earlier in some areas than others, indicating lateral facies changes in the basin.

The Ahl Medo sequence comprises five subunits: (1) basal fossiliferous limestone, and marly and sandy limestone (from a few meters to 120 m thick); (2) marl, sandstone, and gypsum with subordinate limestone (from 0 to 70 m thick); (3) hard, thick-bedded limestone near Candala, passing westward to marly and sandy limestones west of Bender Cassim and then into sandstone near Laskhoreh (from 50 to 150 m thick); (4) limestone, marly limestone, sandy limestone, and marl (from 25 to 70 m thick); and (5) fine-grained, light-gray, porcellaneous, thin-bedded limestone (from 132 to 200 m). Subunits 4 and 5 are missing under the Cretaceous Tisje formation at Huartino. The Ahl Medo sequence is characterized by widespread and locally abundant terrigenous clasts. The depositional environment changes from shallow marine for subunits 1, 2, and 3 to slightly deeper, carbonate shelf facies for subunits 4 and 5 (Merla and others, 1979). Widespread sandy layers indicate proximity to emergent areas throughout the deposition of the Ahl Medo sequence. The westward transition to sandstone in subunit 3 indicates that emergent conditions probably existed west of Las Khoreh during that time. Drilling shows that Jurassic rocks similar to the Ahl Medo sequence are present about 90-100 km south of Bender Cassiom (Azzaroli and Fois, 1964; Barnes, 1976). The basal unit of the Ahl Medo sequence, similar to that of the underlying Adigrat sandstone, is oldest at Haurtino and becomes younger both to the east and to the west. At Huartino the basal limestone is of Liassic age (S.O.E.C., 1954). Elsewhere the basal limestone is Callovian. The uppermost subunit of the sequence is of Middle and Late Oxfordian and Early Kimmeridgian age (Merla and others, 1979).

Bur Region.—The Jurassic rocks of the Bur Region consist of the basal Hamanlcei formation (from 210 to over 2,000 m thick), Warandab formation (from 400 to 700 m thick), Gabredarre formation (from 350 to 629 m thick), and Garbeharre sandstone (from 100 to 670 m thick) as summarized by Merla and others (1979).

The Hamanlei formation rests unconformably on Precambrian rocks in the Bur Region. To the west in Kenya, the Hamanlei rests on Jurassic Mansa Guda sandstone that appears to correlative with the Adigrat sandstone of northern Somalia. In the subsurface to the east and northeast, the unit rests on Adigrat sandstone (Barnes, 1976). In the type section at Hamanlei in the Ogaden, the unit consists of about 210 m of bedded, generally oolitic and fossiliferous limestone. In southern Somalia, the Hamanlei is light-gray, fossiliferous limestone, oolitic in the lower part (Stefanini, 1925). In the northwestern Ogaden and northern Somalia, the unit consists of back-reef dolomite, oolitic limestone, and anhydrite. Wells at Dudduma, Gira, and Obbia, northwest of Webi Shebeli, indicate a facies transition to dark limestone and marl (Hilal and others, 1977). At Iscia Baidoa the unit is about 850 m thick and contains subunits including: a basal sandstone, shale, limestone, and upper oolitic limestone (Barbieri, 1968). The rocks represent shallow carbonate shelf with locally neritic sandy units, back-reef lagoonal facies, and some deeper carbonate shelf to shale in central Somalia (Merla and others, 1979). The unit ranges in age from Liassic to Callovian or Oxfordian.

The Warandab formation rests conformably on the Hamanlei limestone. At the type locality near Warandab, in the Ogaden, the unit consists of dark laminated shale that has a gypsiferous lower part (about 15 m thick) and is interbedded with marly limestones in the upper part (about 55 m thick). In southern Somalia, the formation consists of yellow, marly, fossiliferous limestone (Barnes, 1976). At Ande Issa in southwestern Somalia, the unit is about 400 m thick and in central Somalia the unit is as thick as 700 m (Hilal and others, 1977). The rocks represent deposition in a neritic environment under tectonically stable conditions (Merla and others, 1979). The unit ranges from Oxfordian or Lusitonian to Kimmeridgian.

The Gabredarre formation rests on the Warandab formation with a sharp transition at the type area at Gabredarre, eastern Ogaden, but with a gradual transition in western Ogaden. In the type area, the unit consists of light-gray, compact limestone with oolitic layers and intercalations of anhydrite and shale. Locally the unit contains arenaceous and marly limestone layers. In southern Somalia, the formation consists of tan to gray, compact, fossiliferous limestone (Barnes, 1976). Although 410 m thick at Gabredarre, wells indicate the unit is 629 m thick at Gubaro and 347 m thick at Obbia (Barnes, 1976). The unit is about 350 m thick in southwestern Somalia. The unit ranges in age from Kimmeridgian to Portlandian (Merla and others, 1979), and represents deposition in a shallow carbonate shelf environment with local transitions to back-reef facies.

The Garbeharre sandstone rests on the Gabredarre formation. The unit consists of a lower member of red crossbedded sandstone with ripple marks, dolomitic limestone, and fossiliferous calcarenite, and an upper member of alternating limestone, and dolomite, sandstone, shale, and anhydrite, and is topped by massive crossbedded sandstone (Barnes, 1976). It ranges from about 100 m thick in southern Somalia to a maximum of 670 m thick in the Mandera-Lugh basin. In the Ogaden, the unit undergoes a lateral facies transition to limestone of upper part of the Gabredarre formation and also to the Main Gypsum formation. The rocks represent deposition in neritic to littoral marine, brackish back reef, and continental facies (Merla and others, 1979). The unit ranges in age from Portlandian or Tithonian to early Cretaceous (Merla and others, 1979).

Cretaceous rocks

Cretaceous rocks generally unconformably overlie Jurassic or Precambrian rocks in the northern mountains and in the Bur Region. The Cretaceous rocks in these two areas differ and are discussed separately.

Northern mountains.—In the western part of the northern mountains, the Cretaceous is represented by the Jesomma sandstone. East of Erigavo the Jesomma grades laterally into the Tisje formation.

The Jesomma sandstone generally consists of sandstone, with subordinate siltstone and conglomerate. The unit contains layers, as thick as a few meters, of red and violet mudstone. The sandstone displays abundant planar and trough crossbedding. The mudstone contains bioturbation structure, concentrations of iron and manganese oxides, and calcretes. Where the sandstone overlies Precambrian rocks, it ranges from 200 to 400 m in thickess. Where the unit overlies Jurassic rocks, it ranges from about 500 to 1,700 m in thickness. In general, the thickest Cretaceous rocks overlie the thickest Jurassic rocks. At Bihendula, the transition is continuous from Jurassic limestone to Cretaceous sandstone. Elsewhere the base is unconformable. The maximum western extent of marine carbonate in the Jesomma is about longitude 46°00 E. in the northern mountains.

At Erigavo, the unit contains three thin fossiliferous carbonate layers. East of Erigavo, carbonate rocks gradually increase to about longitude 47°50 E, where they are predominant over sandstone and the rocks are mapped as Tisje formation. At Erigavo, clastic sediments were transported from the south. The rocks overlying the Precambrian were deposited in a continental fluvial environment. The rocks deposited on the Jurassic range from continental fluvial to marine littoral in the west to dominantly marine littoral in the east. A tropical to subtropical climate is indicated. Active erosion and continuously emergent sources for sand are also indicated. (S.O.E.C., 1954; Merla and others, 1979). The unit ranges from earliest Cretaceous to late Early Cretaceous in age.

The Tisje formation rests unconformably on Precambrian and Jurassic rocks and grades into the Jesomma sandstone to the west. East of long 47°E., the unit is 90 percent carbonate and is continuous with underlying Jurassic limestone. The unit generally consists of massive and bedded limestone, cherty and arenaceous limestone, and marl. To the west, the amount of sandy limestone and sandstone increases. The unit ranges in thickness from 500 to 800 m. The unit represents deposition on a subsiding carbonate shelf with access to emergent lands (Merla and others, 1979; S.O.E.C., 1954). The rocks are Cretaceous and as old as Barremian.

Bur Region.--In the Bur Region, the Cretaceous is represented by the Merehan sandstone, Main Gypsum formation, Mustahil limestone, Ferfer gypsum, Belet Uen Limestone, Transition beds (in subsurface), and the Jesomma sandstone.

The Merehan sandstone rests conformably on the Warendab formation and is in part a lateral facies variation of the Gabredarre and Garbeharre units. The Merehan sandstone is composed of sandstone and siltite, with occasional calcareous, marly, and shaley layers. The unit is about 450 m thick in Somalia (Barbieri, 1968). The facies is marine littoral to deltaic tending toward continental fluvial in the upper part (Merla and others, 1979). The rocks are possibly Kimmeridgian or probably Portlandian to Early Cretaceous in age.

The Main Gypsum formation in some places rests conformably on Merehan sandstone and unconformably on Hamanlei and Warandeb formations. Elsewhere it passes laterally into the Garbeharre sandstone and therefore probably upward into the Merehan sandstone. The Main Gypsum formation consists of thick-bedded crystalline gypsum alternating with limestone, calcarenite, sandstone, and shale. Local thin dolomite beds occur in gypsum. In central and northern Somalia the unit passes into neritic limestone and marl in the subsurface (Azzaroli and Fois, 1964; Barnes, 1976). Deposition was in a lagoonal environment in the south to neritic carbonate-shelf in the north during a regression of the Jurassic sea (Merla and others, 1979). The unit is 200 m thick at the Gabreharre type section, but elsewhere is as thick as 500 m. The rocks are of Portlandian to Early Cretaceous age.

The Mustahil limestone is a facies locally contained within gypsum-rich units. Along Uedi Shebeli the limestone rests conformably on the Main Gypsum formation and is overlain by the Ferfer gypsum in the north and the Belet Uen limestone in the south. The unit consists, at the base, of cream-colored limestone, green gypsiferous marl, and clay, and grades upward to reef limestone and back reef gypsum. The rocks were deposited under marine infra-littoral to lagoonal conditions with frequent variations in water depth (Hilal and others, 1977; Merla and others, 1979). Thickness of the Mustahil ranges from 130 to 300 m. The unit is of Barremian to Cenomanian age (Tavani, 1949) or Albian age (Osman and others, 1976).

The Ferfer gypsum rests conformably on the Mustahil limestone in Somalia (Merla and others, 1979). The map pattern (Merla and others, 1973) suggests that the Ferfer gypsum passes into the Belet Uen limestone to the south along Uedi Shebeli. The Ferfer gypsum consists of gypsum alternating with marl, limestone, and dolomite. The rocks are of Cenomanian age. The facies is lagoonal and evaporite, with large changes in salinity (Merla and others, 1979), and may be back reef. The unit is about 200 m thick at Ferfer.

The Belet Uen limestone in part rests conformably on Ferfer gypsum (Merla and others, 1979) and in part probably passes laterally into the gypsum. The unit generally consists from the base upward of fossil-bearing limestone with gypsum, sandy and cherty limestone with intercalated marl and sandstone, gypsiferous limestone, sandstone, and marl (Merla and others, 1979). It locally contains argillaceous limestone with pyrite and bioclastic material. The limestone thins southward and south of Bulo Burti it is predominantly composed of marl (Osman and others, 1976). The unit is about 145 m thick at the Belet Uen type locality (Merla and others, 1979) and 180-200 m thick in the subsurface at Dusa Mareb (Osman and others, 1976). The Belet Uen limestone represents an infralittoral transition from carbonate to shale facies. The rocks are of Cenomanian to Turonian (Tavani, 1949) and possibly Senonian age (Hilal and others, 1977).

The Transition beds of Osman and others (1976) do not crop out but appear to lie between the Belet Uen limestone and the younger Jesomma sandstone in the subsurface to the northeast at Dusa Mareb. In that area the Transition beds represent a regressive gradation from marine to continental conditions that is missing from the outcrop because of erosion below the transgressive Jesomma sandstone. The Transition beds contain a lower member consisting of gray to black shale, with sparse silt and sand clasts, fossils and fossil debris, pyrite, glauconite, carbonaceous material, and calcareous cement. An upper member consists of gray, cream, and tan, predominantly clastic limestone, most of which contains minor clay, silt, sand, and carbonaceous material. Shale intercalated in the upper part of the upper member is gray and green and contains abundant pyrite, fine carbonaceous material, and occasional lignitic plant material. The aggregate thickness in the Dusa Mareb area is from 300 to 500 m. The transition beds represent a regressive sequence with transition from lower-shelf shale facies to upper-shelf carbonate facies. The unit marks the maximum regression of Cretaceous seas and may grade into the overlying transgressive Jesomma sandstone. The age of the Transition beds is late Cretaceous (Turonian-Danian) (Osman and others, 1976).

The Jesomma sandstone rests unconformably on Cretaceous and Jurassic rocks in southern Somalia and the Ogaden and on Jurassic and Precambrian rocks in northern Somalia. In southern Somalia the unit consists of red or variegated, poorly sorted, crossbedded sandstone. Gypsum layers occur near the base. The unit is 400 m thick at the Jesomma-type section. The unit is of marine-littoral facies at the base in the lower part of Uebi Shebeli. To the northwest near the Ethiopian border, the unit is of continental fluvial facies. The rocks may be Turonian to Senonian, or Senonian to Maestrichtian (Hilal and others, 1977).

Tertiary rocks

Tertiary rocks lie conformably on the Cretaceous Tisje formation in northeastern Somalia and conformably to unconformably on Cretaceous and older rocks elsewhere in the county. The Tertiary units form most of the surface exposures of central and northern Somalia.

Auradu limestone. The Auradu limestone rests conformably on limestone of Cretaceous Tisji formation in northeast Somalia and conformably on Cretaceous Jesomma sandstone elsewhere. The unit consists of massive, gray, biogenic limestone with many calcareous concretions (Merla and others, 1979; Osman and others, 1976). In the subsurface at Dusa Mareb the limestone is dolomitic, interbedded with siltstone and quartz sandstone, and contains an altered basalt flow at the top (Osman and others, 1976). The unit occurs in the subsurface at Gira near Garad (Barnes, 1976). In the subsurface in northeast Somalia, near the Indian Ocean between Hordigo and Bender Beila, the unit grades laterally into shale of the Sagaleh formation that does not crop out (Azzaroli and Fois, 1964). To the south in the subsurface at Marai Ascia near Obbia, the Marai Ascia formation (unit does not outcrop) is transitional between Auradu limestone and shale of the Sagalah formation. The Auradu limestone is known in outcrop as far south as about lat 3°30′ N. (Merla and others, 1979). The type area of the Auradu limestone is near Berbera. The limestone generally ranges from 200 to 400 m in thickness, and has a maximum thickness of 550 m in the Al Maskat Mountains (Merla and others, 1979); (Osman and others, 1976). The rocks were deposited during a Late Cretaceous to early Tertiary marine transgression. Over most of its extent, the unit represents a neritic carbonate-shelf facies which underwent a transition to the slightly deeper-water shale facies in the northeast. It is of Late Cretaceous to early Eocene age (Merla and others, 1979).

Taleh evaporite.—The Taleh evaporite generally conformably overlies the Auradu limestone, but in the Al Maskat Mountains it appears to grade into and be replaced by the Auradu and younger Karkar limestones. The unit consists mainly of well-bedded anhydrite with intercalated dolomite and cherty limestone, and subordinate siltstone and shale. In the subsurface near Bender Beila, the unit is predominantly composed of dolomite, which to the south grades into sandstone, and then to shale at Obbia (Azzaroli and Fois, 1964; Barnes, 1976). The unit has a maximum thickness of 270 m in northern Somalia (Merla and others, 1979) but ranges from a few meters to over 4,600 m thick to the south (Osman and others, 1979). The Rocks were generally deposited in reef and back-reef, lagoonal evaporite environments. The unit has also been described as representing lensing and time-transgressive facies between and commonly partly grading into limestones of the Auradu and Karkar formations (S.O.E.C., 1954). The Taleh evaporite is of early and middle Eocene age (Merla and others, 1979).

Karkar formation.—The Karkar formation generally conformably overlies the Taleh evaporite, but in the Al Maskat Mountains the unit overlies the Auradu limestone. The formation consists of bedded, nodular, and chalky limestone with intercalated compact limestone, paper shale, and dolomitic limestone. Gypsiferous siltstone interbeds occur at the base (Merla and others, 1979; Osman and others, 1976). In the Daban area, east of Berbera, these rocks are replaced by an estuarian facies consisting of variegated sandstone, shale, clay, marl, and sparse, thin, commonly sandy limestone and massive anhydrite. The estuarian facies includes one thin and lenticular lignite bed. The estuarian facies is mapped as Lower Daban series (S.O.E.C., 1954) and is combined with the Karkar formation by Merla and others (1979). Near the Indian Ocean from Cape Guardafuie south to Hordiyo, the Karkar consists of fossiliferous calcarenite alternating with compact limestone (Azzaroli, 1952). The formation is as thick as 400 m in northern Somalia. The rocks are of middle to late Eocene age (Merla and others, 1979; S.O.E.C., 1954).

Marine Oligocene and Miocene rocks.--Marine Oligocene and Miocene rocks occur in a discontinuous belt adjacent to the Gulf of Aden and Indian Ocean. Along the Indian Ocean the Oligocene and Miocene rocks rest conformably or with local slight unconformity on the Karkar formation; along the coast the rocks are mapped as the Hufun group which consists of marl, sandy marl, sandstone, and fossiliferous limestone (Stefanini, 1925). The Hafren group ranges from early Oligocene to Burdigalian in age (Azzaroli, 1958).

Along the Gulf of Aden, the Guban group rests unconformably on the Karkar formation and older rocks. Oligocene age rocks of this unit occur only in a narrow area south of Bosaso and Elaya and consist of coarse reddish sandstone and conglomerate with lenses of fossiliferous marly limestone (Merla and others, 1979). The thickness and regional correlation of this part of the unit are uncertain. Southeast of Berbera, the middle Daban series included in this unit is reported to be of Oligocene age (S.O.E.C., 1954). The middle Daban series consists of, in ascending order, lensing, red-brown to green, earthy and usually sandy silt, with gypsum; green and yellow gypsiferous locally calcareous sandstone, with several thick intercalations of gypsum; green and brown to white, fine- and medium-grained, commonly crossbedded quartz sandstone; brown and green siltstone and sandstone; thin limestone with abundant chert concretions; green and gray shales; and sandstone interbedded with massive limestone. The upper sandstone and limestone are quite thick. The sandstone in this part of the unit becomes coarser upward and is increasingly conglomeratic, clasts consisting mostly of lower Eocene limestone and chert. Near the southern fault boundaries, the unit consists largely of limestone boulder conglomerate and sedimentary breccia.

Early and middle Miocene rocks of this unit are widespread and consist largely of fossiliferous marine marl and coralline limestone of the Dubar limestone (Gregory, 1896). The limestone contains lenses of boulder conglomerate derived from units exposed in the nearby mountains (S.O.E.C., 1954; Merla and others, 1979). These conglomerate clasts include rocks as old as Precambrian. The Miocene rocks generally represent a rapidly aggrading littoral marine and reef environment along an active tectonic boundary of a proto-Gulf of Aden.

This unit also occurs along the coast of the Indian Ocean where it is mapped as Merca series and is composed predominantly of light-gray cryptocrystalline limestone, breccia, and sand. In the Dusa Mareb area near Gal Guduud, the unit rests on weathered basalt and comprises a lower subunit of clayey sandstone and marl with rare intercalated limestone and gypsum, and an upper subunit of limestone caliche and gypsum crust overlying friable clay and marl. The upper subunit locally contains carnotite and ranges from a few meters to as much as 20 m in thickness. The lower subunit is 25-30 m thick.

Scuishuban formation.--The Scuishuban formation is a lagoonal facies equivalent of the Miocene marine rocks. The unit consists of marl, marly sandstone, and subordinate limestone, limestone conglomerate, and gypsum. The rocks are early and possibly middle Miocene age (Merla and others, 1979; Osman and others, 1976).

Upper conglomerate.--The upper conglomerate occurs as coarse boulder conglomerate at the base of fault scarps in northern Somalia. The unit may be Middle and Upper Miocene (Merla and others, 1973).

Tertiary volcanics.--The Tertiary volcanic unit includes rocks in southern Somalia mapped as undifferentiated volcanics of unknown age and/or lithology by Merla and others (1973), but indicated to be Paleocene-Oliogocene-Miocene volcanics of the Askangi group by Kazmin (1972). Kazmin shows these rocks to be alkali olivine basalt and tuffs with rare rhyolite.

Quaternary volcanics.--The Quaternary volcanic unit includes rocks in northwestern Somalia mapped as Miocene to Pleistocene fissural basalt flows with subordinate rhyolite ignimbrite and flows (Merla and others, 1973).

Quaternary basalt.--The Quaternary basalt includes Pleistocene to Holocene flows and a cone west of Berbera (Merla and others, 1973).

Quaternary deposits.--The Quaternary deposits include Pleistocene and Holocene alluvial, eluvial, colluvial, and lacustrine deposits (Merla and others, 1973). The lacustrine deposits are to the northwest of Sidamo in southern Somalia and may contain tuffaceous interbeds.

Phanerozoic structure

Mesozoic.--A Jurassic marine transgression that covered much of Somalia occurred as the Indian Ocean expanded and Madagascar moved away from the Horn of Africa (Rabinowitz, Coffin, and Falvey, 1982). The rifting away of India was accompanied by horst and graben tectonics and local drape folding along a hinge line or intraplate boundary in southern Arabia. That boundary now separates the Rub al Khali basin in Saudi Arabia from complexly folded and faulted rocks of Yemen and the Hadramaut. During the Jurassic, the boundary was marked by the west-northwest-trending Jawf graben in northern Yemen (USGS-Aramco, 1963; Geukens, 1966; Greenwood and Bleakley, 1967; Brown, 1972). A pre-Red Sea palinspastic reconstruction (Greenwood and Anderson, 1977) shows that this graben extended into the Mekele area in Ethiopia. The Mekele graben is 80 km across and has a downthrow of as much as 2 km (Black and others, 1974). The Jawf graben is about 100 km across and has a downthrow of about 2.5 km. Both grabens contain Jurassic marine limestone and are bounded by Precambrian rocks. Cretaceous rocks unconformably overlie these grabens. These structures may represent failed rifts related to the separation of Madagascar and subsequent tectonic adjustments. Contemporaneous gentle folding on east-northeast-trending axes are suggested by outcrop patterns in southern Arabia near Al Mukalla (USGS-ARAMCO., 1963) and in the northern mountains of Somalia (Merla and others, 1973).

Jurassic folding in northern Somalia is indicated by distribution of Jurassic and Cretaceous rocks overlying the Precambrian as shown in figure 1. The Jurassic zero isopach is shown as a solid line delineating the northern Somalia high. A similar high was located east of Candala and accounts for the lack of Jurassic rocks on Socotra, the Brothers, and Ahd al Kuri Islands, northeast of Cape Guardafui in Somalia. These patterns appear to date from

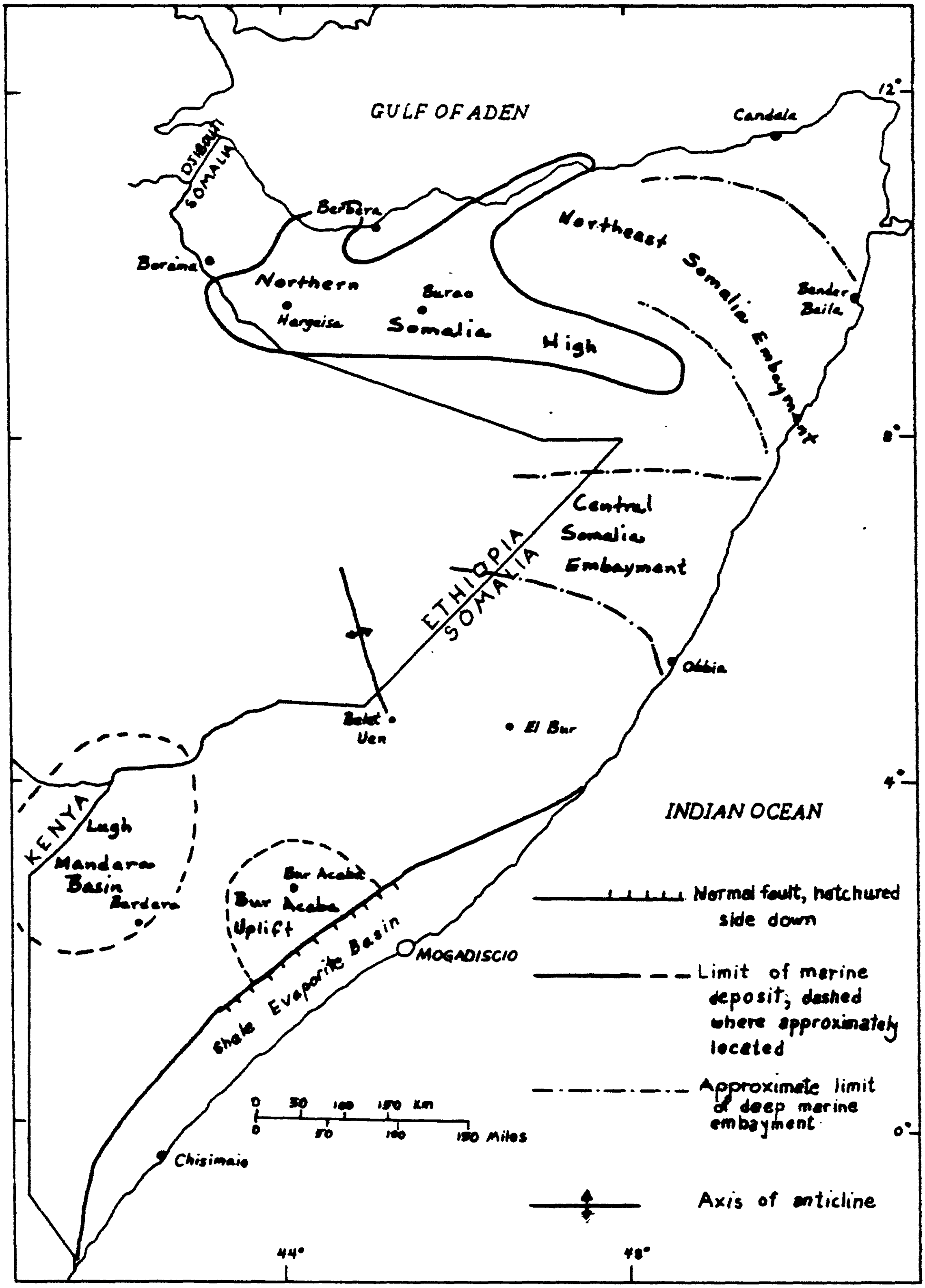

Figure 1. Mesozoic structures in Somalia.

the earliest Jurassic or Triassic, because the basal Adigrat sandstone near Bihendula is thickest near the proposed synclinal axis and thins away from it. The Cretaceous rocks are thickest in the downwarps, indicating that the structures remained active through the Cretaceous. These structures were reactivated in the Miocene during the formation of the Gulf of Aden. The Jurassic-Cretaceous structures locally were strongly asymmetric and steep sided, resulting in rapid pinchout of the deposits such as between Bihendula and Sheikh. This suggests down-to-basin faulting and drape folding that may have been shallow reponses to deeper extensional tectonics. Extensional faulting is also suggested by pillow basalt in the Adigrat sandstone near Bihendula.

The north Somali high was emergent during the Jurassic and Cretaceous and separated marine basins in the Borama-Zeila and Bihendula areas from the main marine deposits of eastern and southern Somalia. The Borama-Zeila and Bihendula basins have partly correlative Jurassic units and were separated only by a narrow high at Bulhar. On the other hand, the Jurassic rocks east of Erigavo are distinctly different from contemporaneous rocks of the Bihendula basin, indicating effective separation of these depositional areas. A Jurassic high in the El Afweina area is suggested by a southern clastic source for the basal Adiguat sandstone near Las Khoreh (Abucar, 1977). An active high in Jurassic and Cretaceous time in the upper Nogal Valley is indicated by a thin section of Cretaceous rocks resting on Precambrian syenite and overlain by basal Tertiary rocks near Gorei (S.O.E.C., 1954; Mason, 1957) and subsurface data (Barnes, 1976). Jurassic emergence in at least part of northern Somalia and Sokotra has been previously suggested by (S.O.E.C., 1954; Stefanini, 1928; Arkell, 1956; Mohr, 1962; Azzaroli and Fois, 1964; Greitzer, 1970; and Merla and others, 1979).

Deep Jurassic embayments formed adjacent to the northern Somalia high (Barnes, 1976). In southern Somalia the Bur Acaba uplift was emergent through most of Mesozoic. The basal Adigrat Sandstone is missing over this structure. Uplift in the Bur Acaba area was related to the formation of the Lugh Mandara basin to the west (Barnes, 1976) and a major shale-evaporite basin to the east (Rabinowitz, Coffin, and Falvey, 1982). This shale-evaporite basin probably formed during rifting and southward movement of Madagascar from the southeastern margin of Somalia to its present position off the coast of Mozambique (Rabinowitz, Coffin, and Falvey, 1982).

Tertiary.--The Mesozoic structures of northern Somalia appear to have been eroded by the end of the Cretaceous and did not have an obvious influence on deposition in the early Eocene. The early Tertiary Auradu marine transgression extended west to Hargeisa (shown as lower Eocene in figure 2), but in southern Somalia is represented only in the subsurface along the Indian Ocean south of the Juba River mouth. The overlying Eocene evaporite and carbonate units broadly represent regressive marine conditions. The present extent of upper Eocene marine limestone (see figure 2) suggests contemporaneous uplift in the Nogal area.

By the Oligocene, the Horn of Africa was slightly emergent with very nearly its present outline and coastline, as indicated by the present distribution of littoral facies Oligocene rocks.

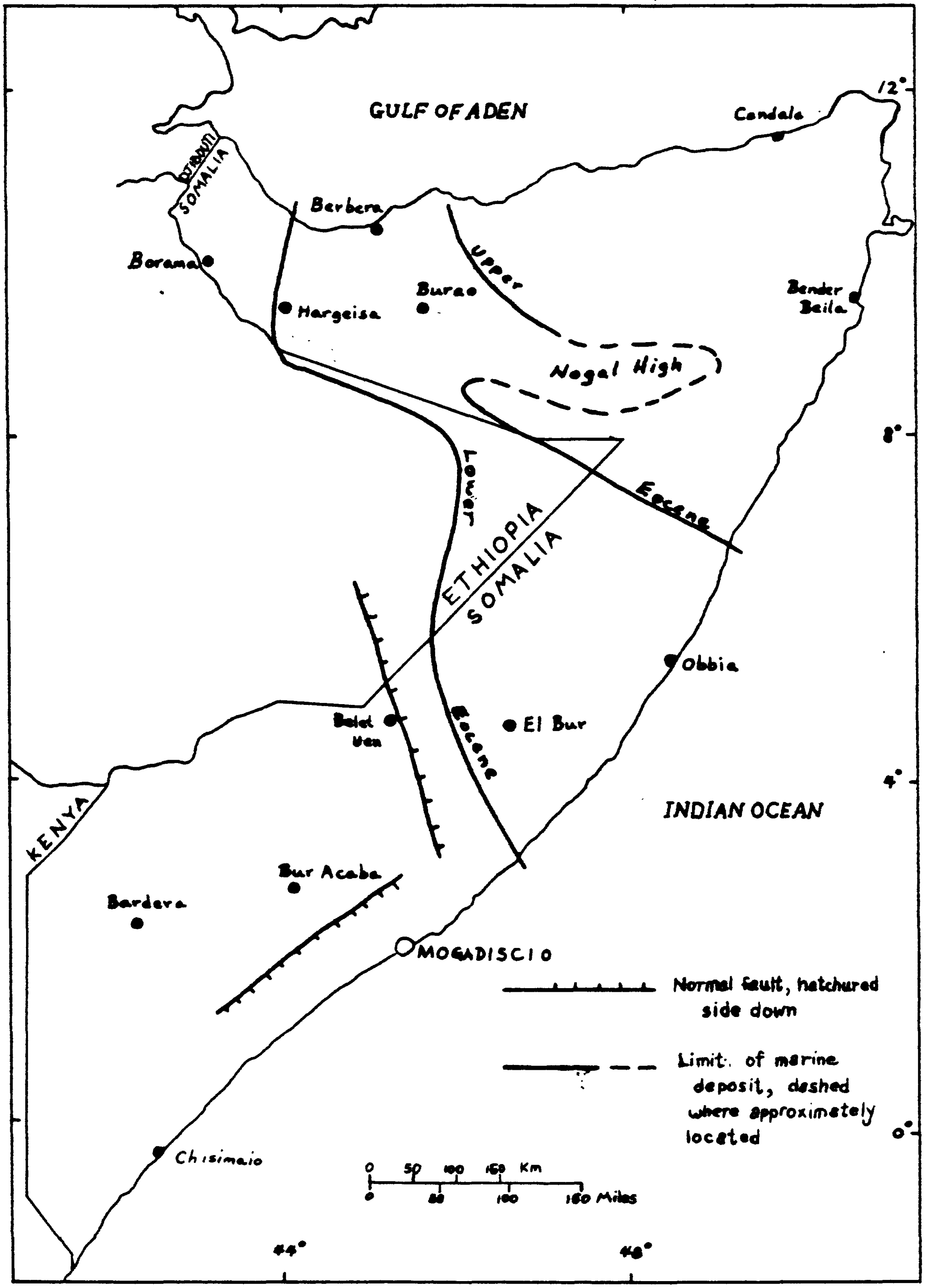

Figure 2. Early Tertiary structures in Somalia

The Miocene rocks reflect major tectonic activity. Near Berbera, the upper part of the Middle Dahan series of late Oligocene or Miocene age is an upward-coarsening unit that consists largely of limestone boulder and sedimentary breccia near the syndepositional faults to the south. To the east the Lower and Middle Dubar limestone contains conglomerate lenses including rocks as old as Precambrian. Contemporaneous lagoonal-facies rocks occur in a major interior graben in the Darror Valley. The Darror lagoonal rocks grade into littoral marine facies rocks to the east near Hordio and into fluvial deposits near syndepositional faults to the north and south. A similar down-faulted or downwarped area may have formed west of Bender Beila where lagoonal Miocene rock occurs. Clearly the Tertiary structural patterns began to form in early Miocene time continuous with marine marginal sedimentary deposition. The northern mountains were uplifted and arched in response to Miocene sea-floor spreading and formation of the Gulf of Aden. This process resulted in complex synthetic and antithetic faults along which sedimentary blocks were rotated away and toward (respectively) from the Gulf of Aden. The faulting has steepened the north limb of the Mesozoic Ahl Mado anticline (figure 3) with the result that Eocene rocks now crop out near sea level. A major southeast-trending down-faulted region extends from near Raz Khanzira to near Bender Beila. This zone forms a major break in the Precambrian exposures. To the southwest the Raz Khanzira-Bender Beila zone is flanked by a broad southeast-trending arch extending from Sheikh to near Eil. This arch has centrally downthrown fault blocks that expose lower Tertiary and Cretaceous rocks.

Southeast-trending faults are related to Red Sea structure and northeast-trending faults to Gulf of Aden structure (S.O.E.C., 1954; Merla and others, 1979). However, the map patterns suggest the structures of both trends are interrelated and contemporaneous responses to crustal extension near a rift triple point.

A major downwarp formed in the middle and late Tertiary along the Indian Ocean. A northeast-trending downwarp extending through Lugn Ganana probably formed in response to uplift of the Bur Region. To the north the Bur uplift appears to be bounded by north-northwest-trending structure extending through Belet Uen. This structure probably is a major tectonic boundary. To the northwest, this structure extends into a major arch of similar trend in the Ogaden (Merla and others, 1979) and then into the rifted Afar depression.

ECONOMIC GEOLOGY

General

Somalia has not been a major producer of minerals in the past. However, the geologic environment and indications of mineralization are favorable for the discovery and development of several types of non-fuel mineral deposits.

Past mineral exploration is discussed and mineral exploration targets are proposed and discussed in outline form to facilitate easy reference.

Mineral resource records

Mineral exploration was conducted by the British Government in the former Somaliland British Protectorate and by Compagnia Mineraria Etispica (COMINA) in Station Somaliland prior to independence in 1960. British geologists

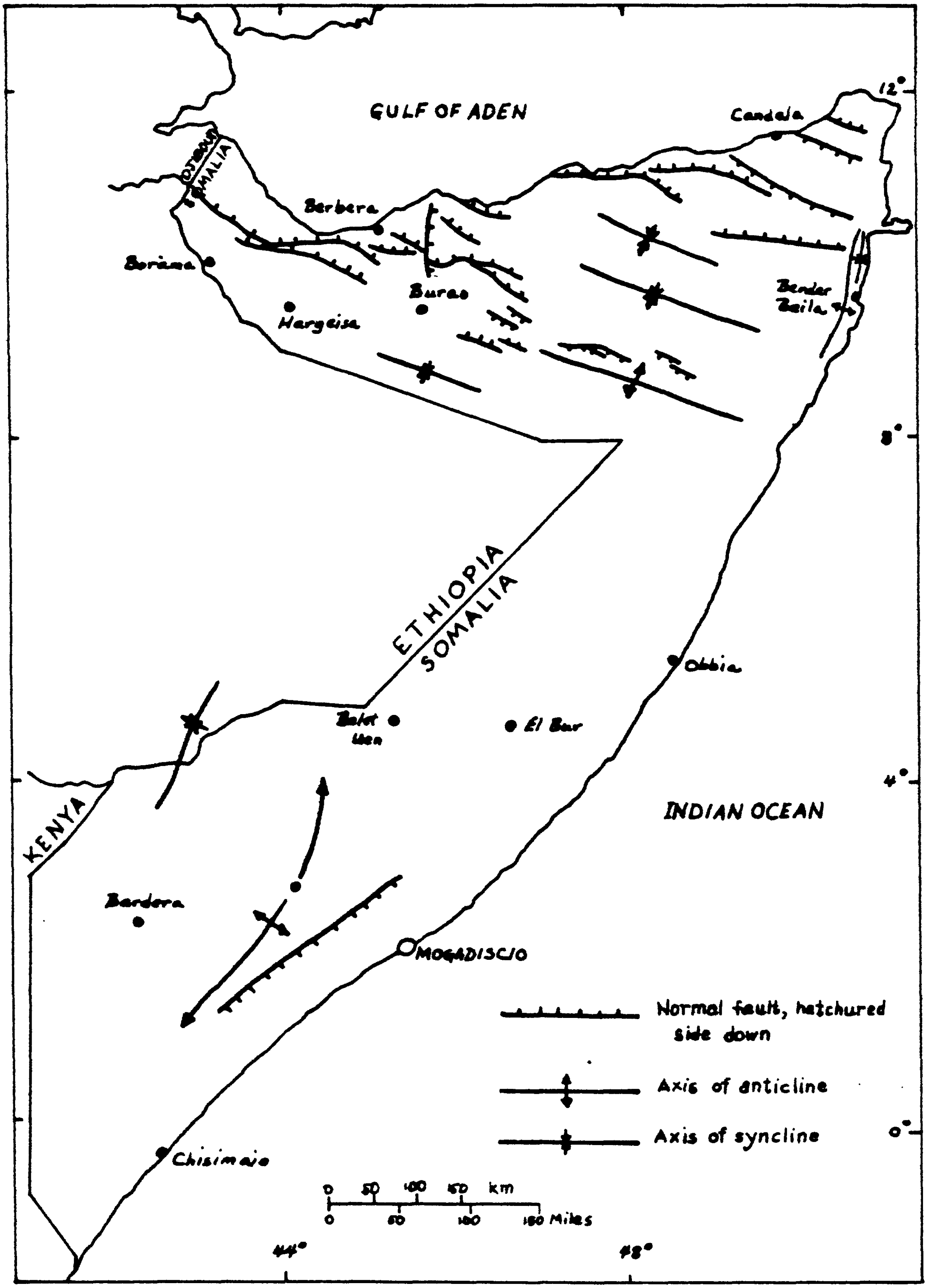

Figure 3. Late Tertiary structures in Somalia

mapped most of the Precambrian rocks of the northern mountains at 1:125,000 scale. Their reports contain brief descriptions of many mineral prospects and occurrences. Following World War II, a U.S. Technical Assistance Mission evaluated the mineral potential of the area of former Italian Somaliland (Holmes, 1954). After independence the U.N.D.P. conducted a mineral evaluation of the entire country (U.N.D.P., 1970).

Mineral occurrence and prospect data from these sources have been entered in the U.S. Geological Survey Computerized Resource Information Bank (CRIB) and are available to the public through General Electric Information Services Company, 401 North Washington Street, Rockville, Md. 20850. A copy of these data is included as Appendix A. Plate 2 shows the location of mines and mineral prospects and occurrences in this file.

Geochemical exploration

A reconnaissance geochemical survey was made of parts of northern Somalia by the Somali Mineral and Groundwater Survey under the guidance of a U.N.D.P. mission. The reconnaissance survey comprised stream-sediment sampling over an area of about 20,000 km^2, with an average sample density of about 1 sample per 2 km^2. The samples were analyzed by atomic absorption methods for Pb, Zn, Cu, Ni, Cr, Mn, and Li (figure 4). This survey revealed 84 geochemically anomalous areas of which ten were selected for more detailed studies (figure 5). Of these, seven were geologically and geochemically studied. Data on these studies comes from an unpublished preliminary report on the survey made by the former Chief Geologist, Ahmed M. Behi (1973).

The seven detailed studies included: Dagah Kureh Cu-Pb-Zn anomaly; Arapsiyo Zn-Cu-Pb-Cr-Ni anomaly; Bawn Zn-Cu-Cr anomaly; Qolujeit Pb-Zn-Cu anomaly; Udan Cu-Ni-Cr anomaly; Sheikh Cu-Cr anomaly; and Satawa-Hog Cu-Cr-Ni-Pb-Zn anomaly. The survey also reported limited information on copper deposits at Seinat and on piezo-quartz.

Dagah Kureh Cu-Pb-Zn anomaly

Detailed studies show that the Dagah Kureh area (lat 9°43′-9°48′ N.; long 43°52′-43°56′ E.) (near Biyo Ase on figure 5) has base- and locally precious-metal-bearing quartz and carbonate veins associated with Precambrian porphyritic granite. Sulfide minerals include chalcopyrite, bornite, sphalerite, galena, arsenopyrite, and pyrite. Quartz, calcite, calc-silicates, dolomite, and barite are the gangue minerals.

A geologic map of the area was made and a geochemical survey was done which included collecting and analyzing soil samples taken on a grid pattern. Seven trenches (300 m, total length) were dug across veins and mineralized areas and a limited drilling program was carried out.

Mineralized veins dip steeply and trend north to north-northeast, transecting the west-northwest strike of the Precambrian country rock. At Biyo Ase the largest vein is about 3 m wide and at least 18 m long. Samples from veins at Biyo Ase contain as much as 22 ppm Au and 38 ppm Ag as well as significant Cu and Pb mineralization. Grab samples from veins in other parts of the area contain as much as 11 percent combined Pb and Zn. Other samples contain as much as 1.2 percent Cu.

Whereas the vein mineralization in the Dagah Kureh area is significant and worth additional exploration, the association with porphyritic granite suggests possibilities of large disseminated (porphyry) copper, molybdenum, and possibly gold deposits. This area is an important exploration target.

Arapsiyo Zn-Cu-Pb-Cr-Ni anomaly

Detailed stream sampling of the Arapsiyo area (lat 9°35′-9°50′ N.; long 43°35′-44°00′ E.) indicates anomalous amounts of Pb, Zn, Cu, Ni, and Cr in Cretaceous Jesomma sandstone and anomalous amounts of Ni, Cr, and Zn in nearby exposures of Precambrian mafic and ultramafic rocks. Geologic mapping and sampling of favorable parts of this area revealed skarn and vein mineralization with primary chalcopyrite, galena, and sphalerite, and gangue minerals of quartz and calcite. Metamorphosed mafic and ultramafic rocks contain as much as 2 percent Ni.

The mafic and ultramafic rocks of this area are good targets for Ni, Cr, and platinum group metals. The anomalies in the overlying fluvial-facies Jesomma sandstone probably represent heavy-mineral concentrations derived from the underlying and nearby Precambrian rocks.

Bawn Zn-Cu-Cr anomaly

Detailed stream-sediment sampling shows that the Bawn area (lat 10°02′-10°15′ N.; long 43°00′-43°20′ E.) has Cu, Zn, and Cr anomalies associated with Jurassic limestone, and Ni, Cr, and Cu anomalies associated with a variety of Precambrian rocks. The Precambrian rocks include mafic plutons and metavolcanic rocks which are reasonable sources for the observed anomalies in those rocks. However, the Jurassic limestone samples, which contain as much as 730 ppm Zn, suggest the possibility of Mesozoic massive sulfide deposits. This possibility is also suggested by anomalous samples from other Jurassic terrains and deserves geologic and geochemical evaluation.

Qolujeit Pb-Zn-Cu anomaly

Detailed stream-sediment and rock geochemical studies indicate anomalous amounts of Pb, Zn, and Cu in Jurassic limestone of the Qolujeit area (about lat 10°11′-10°16′ N.; long 43°05′-43°15′ E.). The limestone is down-faulted within and entirely surrounded by Precambrian rocks. Galena and sphalerite occur in steeply dipping fault zones within the limestone, and also, in several horizons within the limestone. The stratabound minerals occur in vugs, fracture fillings, and as disseminated grains. Chalcopyrite and malachite locally are associated with anglesite, cerussite, and smithsonite.

This area deserves careful geologic and geochemical study for base-metal massive sulfide deposits.

Udan Cu-Ni-Cr anomaly

Detailed soil sampling of a small terrain, 1 km^2, in the Udan area (near lat 10°40′ N.; long 42°54′ E.) revealed Cu, Ni, and Cr anomalies. Mafic and ultramafic rocks in the area may be the source of these anomalies. Chromite cobbles were found in float. Soil samples contain as much as 470 ppm Ni, 600 ppm Cr, and 152 ppm Cu.

The mafic and ultramafic rocks of this area should be mapped and sampled to evaluate their potential for Ni, Cr, and platinum metals.

Sheikh Cu-Cr anomaly

Detailed stream-sediment sampling in the Sheikh area (near lat 10°07'-10°10' N.; long 45°15'-45°24' E.) shows Cr and Cu anomalies: The anomalous area is underlain by a large layered gabbro complex that locally contains pyrite, chalcopyrite, and magnetite concentrations. Dikes of serpentinized dunite also occur. Stream samples contain as much as 2,650 ppm Cr and 90 ppm Cu.

This layered gabbro complex should be mapped and sampled to evaluate its potential for Ni, Cr, and platinum minerals.

Satawa-Hog Ni-Cr-Cu-Pb-Zn anomaly

Detailed stream-sediment sampling shows that the Satawa-Hog area, also called the Qabri-Bahar area, (lat 10°00'-10°10' N.; long 43°30'-44°00' E.) has anomalies of Ni, Cr, Cu, Pb, and Zn.

The Cr and Ni anomalies probably are related to metamorphosed mafic rocks and gabbro in the area.

Chalcopyrite is reported in shear zones and along foliation planes in quartzite and amphibolite shear zones in quartz diorite. This suggests that Cu and possibly Pb and Zn mineralization in this area may represent partially remobilized stratabound massive sulfide deposits of synvolcanic and synsedimentary origin.

The possibly stratiform Cu, Pb, and Zn mineralization and the Ni and Cr associated with mafic rocks should be evaluated.

Exploration targets

I. Precambrian phosphorite
   - A. Possible economic deposits
     - 1. Phosphate for fertilizer
   - B. Favorable geologic units
     - 1. Phosphate-bearing marble in the Modu Mode area, 25 km west of Bur Acaba
   - C. Possible analog deposits
     - 1. Marine phosphatic limestone of middle Miocene age deposited in warm ocean currents along the eastern coast of Florida, Georgia, and North Carolina (Cathcart and Gulbrandsen, 1973).
     - 2. Most favorable environment
       - a. Sediment-starved shallow basins adjacent to contemporaneously rising structural highs.
     - 3. Deposit characteristics--deposits tend to be marginal or subeconomic unless they have been reworked by submarine currents or concentrated by weathering. Most deposits must be beneficiated to provide a useful product.

D. Modu Mode deposit
   1. Precambrian marble with considerable silicate minerals
   2. Averages 24 percent P_2O_5 (U.N.D.P., 1970).
E. Previous recommendations
   1. U.N.D.P. (1970) considered that the grade of the phosphate-bearing marble was too low to be economic.
F. Present recommendations
   1. Additional exploration is justified for phosphate in the Bur area.
   2. The 24 percent P_2O_5 of the marble is similar in grade to phosphate ore in Idaho now being processed for phosphoric acid without beneficiation (Cathcart and Gulbrandsen, 1973; Emigh, 1975). However, the carbonate matrix of the ore would require a calcination process to produce concentrates for phosphate fertilizer as summarized by Emigh (1975). Fertilizer production could use sulfuric acid generated by processing gypsum at Suriah Melableh in northern Somalia.
   3. Phosphate fertilizer needed for agriculture in southern Somalia phosphate is a low-cost, high-volume product and transportation is a large part of the unit cost as delivered in Somalia. Development of local phosphate resources for domestic use could be integrated into a general mining, agricultural, and industrial scheme that would pro-rate part of the development costs for the phosphate industry because of overall economics.
   4. Exploration for additional phosphate-bearing marble should begin by evaluating available aeroradiometric data. Marine phosphates commonly contain 0.01 to 0.02 percent U_3O_8 (Emigh, 1975) and therefore may be associated with aeroradiometric anomalies.
   5. Marble in the vicinity of Modu Mode should be sampled in outcrop and subsurface to evaluate the grade and tonnage of the deposit.
   6. If exploration indicates adequate phosphate tonnage and grade, metallurgical studies should be made to evaluate the feasibility of processing alternatives.

II. Precambrian banded iron formation
   A. Possible economic deposits
      1. Iron ore
      2. Precious-metal byproducts of iron refining
   B. Favorable geologic unit
      1. Precambrian hematite- and magnetite-bearing quartzite of the Bur area, southern Somalia.
   C. Status of exploration
      1. Bur Galan and Daimir prospects--estimated to contain 112 million tons of potentially extractable ore, averaging 36 percent Fe, to a depth of 100 m. Samples of this ore give a marketable concentrate containing 60-67 percent Fe, 0.02 percent P, 1 percent SiO_2, and less than 0.1 percent CaO for an iron recovery of about 80 percent (U.N.D.P., 1970).
      2. Additional prospects--many additional banded iron ore prospects are known from outcrop and aeromagnetic data. Many of these are partly to totally covered by colluvium.
   D. Previous recommendations
      1. Holmes (1954) recommended a systematic regional exploration for iron ore in the Bur area in order to determine if adequate

tonnage could be identified that would justify development. He stressed that the iron deposits generally are not well exposed and large deposits may underlie covered areas. He also noted that low contents of sulphur, phosphorous, and titanium make the ore attractive despite its marginal iron content. The magnetic character of the ore also facilitates beneficiation.

2. The U.N.D.P. (1970) report recommends against further exploration for iron on the grounds that the known tonnages and grade are not economic on the world market and that discovery of significant additional tonnage is unlikely. The report proposes little downward extension of iron deposits because it assumes that the quartzite is underlain by an older crystalline rock at a shallow depth. The report also states that discovery of surficially covered deposits is unlikely because the banded iron formation always forms outcrops.

E. Present recommendations

1. A systematic exploration should be made for additional iron deposits in the Bur area because: (a) Outcrop and geophysical data indicate many unexplored prospects, some of which could be of substantial size; (b) Holmes (1954) probably is correct that iron deposits do not always make prominent outcrops, and large deposits may be buried; and (c) the rocks are tightly folded and moderately to steeply dipping and the ore beds probably have considerable extent in depth; the proposal of a shallow basement of old gneiss is not proven by the available data.
2. Exploration should include: (a) A preliminary stage of review of available geophysical and geologic data to identify favorable zones or target areas; (b) a field reconnaissance of favorable zones using aerial and ground magnetic methods and geologic sampling of outcrop and limited shallow drill holes; and followed by (c) detailed geologic, geochemical, and geophysical studies of the most favorable prospects.
3. Representative samples of iron formation from the region should be analyzed for trace element contents to check for possible concentrations of gold or silver. Manganese deposits may also be associated with the iron formation. Semi-quantitative spectographic and atomic absorption methods are recommended for this evaluation.

F. Additional considerations

1. An iron and steel complex is being constructed near Dhahran, Kingdom of Saudi Arabia. The iron ore for this complex primarily will be imported from Australia. The available iron deposits in western Saudi Arabia require development of new metallurgical techniques before they can be used. Therefore, there will soon be a nearby market should an economic Somali iron ore deposit be proven out. Somalia and Saudi Arabia enjoy friendly relations in the Arab League. Therefore Saudi Arabia might consider a cooperative program to explore and develop Somali iron deposits to feed the Saudi iron and steel complex.

III. Precambrian stratabound base-metal deposits
   A. Possible economic deposits
      1. Copper
      2. Copper and zinc
   B. Favorable geologic units
      1. Inda Ad Series near Tug Zeinat
      2. Metavolcanic rocks of northwestern Somalia
   C. Possible analog deposits
      1. Precambrian stratabound copper deposits of the African Copper Belt (Cox and others, 1973).
      2. Precambrian stratiform copper-zinc deposits in metavolcanic rocks of Saudi Arabia (Roberts and others, 1975; RIOFINEX, 1977).
   D. Status of exploration
      1. Stratabound copper (malachite at the surface) minerals reported in siltstone of the Inda Ad Series at Seinat along Tug Zeinat (lat 11°00' N.; long 43°30' E.). The mudstone is exposed over 8 km in length and is exposed on both limbs of a syncline whose north-trending axis follows Tug Zeinat. The unit probably is a few hundred meters thick (Behi, 1973). No report of exploration is available on this deposit.
      2. Numerous chalcopyrite-sphalerite occurrences are reported in metavolcanic rocks of northwestern Somalia (see CRIB file). However, no systematic exploration for stratiform copper-zinc deposits has been conducted in the area.
   E. Previous recommendations
      1. Stratiform and stratabound deposits have not been previously evaluated in Somalia.
   F. Present recommendations
      1. Stratiform and stratabound copper and zinc deposits in northern Somalia should be explored by use of regional geochemical techniques.
      2. The Inda Ad Series should be geologically mapped and sampled to evaluate the origin, ore controls, and economic potential of the malachite-bearing siltstone unit.
      3. Metavolcanic units of northwestern Somalia should be geologically mapped and sampled to locate felsic volcanic centers favorable for large stratiform copper-zinc deposits.

IV. Precambrian alkalic plutonic rocks
   A. Possible economic deposits
      1. Phosphate for fertilizer
      2. Aluminum ore
      3. Tin, tungsten, molybdenum, beryllium, niobium, uranium
      4. Piezo-quartz
   B. Favorable geologic units
      1. Alkalic plutons in northern Somalia, including syenite, syenogranite, and syenogabbro
      2. Syenite plutons and dike swarms in southern Somalia
   C. Possible analog deposits
      1a. Nepheline syenite and carbonatite of the Kola Peninsula, U.S.S.R. (Emigh, 1975)
      1b. Specialized granite (tin granite) of Tischendorf (1977)

1c. Tin-bearing granite (Elliott, 1980) and peralkalic granite (Stoeser and Elliott, 1979) in the Arabian Shield of Saudi Arabia

1d. Tin-bearing syenite of Nigeria and Sudan (Bowden and Turner, 1974; Almond, 1979).

D. Status of exploration
   1. Cassiterite-bearing quartz veins in the Inda Ad Series
      a. Extensive surface exploration, shallow trenching, shafts, and limited drilling were done at Manja Yihan by Compagnia Mineraria Etiopica (COMINA) just prior to World War II (Holmes, 1954).
      b. Reconnaissance and detailed mapping and sampling of Dalan deposit (Gellatly, 1961) and vicinity (Greenwood, 1960; and Stewart in Greenwood, 1960).
      c. Geochemical reconnaissance of region (Behi, 1973).
   2. Molybdenum-, columbite-, and beryllium-bearing quartz veins and pegmatites in western part of northern mountains.
      a. Surface reconnaissance and limited trenching revealed vein deposits in a broad east-trending area from Bawn to north of Hargeisa (Daniels, 1960).
      b. Limited data suggest that these veins are related to syenite plutons (U.N.D.P., 1970).
      c. Piezoelectric-quartz deposits of high quality and significant size are reported (U.N.D.P., 1970; Kaplan and others, 1977; Behi, 1973).
   3. Uranium and thorium deposits of the Bur Region
      a. Geophysical reconnaissance, surface mapping, and limited drilling and trenching indicate that subeconomic deposits at Alio Ghelle and Yaq Brava are the result of contact metasomatism at contacts wih syenite dike swarms (U.N.D.P., 1970).
      b. Limited data indicate that subsequent exploration and evaluation by mining companies failed to indicate sufficient resources for development (Kaplan and others, 1977)
   4. Nepheline syenite plutons mapped in northern Somalia especially near Darkainle (lat 10°23' N., long 43°16' E.) are potential sources of alumina.

E. Previous recommendations
   1. The U.N.D.P. (1970) called attention to the possible future economic recovery of alumina from nepheline syenite.
   2. The U.N.D.P. (1970) also indicated that molybdenite, galena, and bismuthinite in and near pegmatites associated with syenite in the Buhl area deserve further exploration.
   3. The uranium-thorium deposits were recommended for additional exploration by the U.N.D.P. (1970) and opened to mining concessions.
   4. Piezoelectric-quartz was recommended for develoment by the U.N.D.P. (1970).
   5. The tin deposits were not considered worth additional exploration by Holmes (1954).

F. Present recommendations
   1. Additional exploration of syenogranite, syenite, and nepheline syenite in Somalia is warranted both for possible future exploitation of alumina, fluorine, and phosphate fertilizer, and

because some of the syenite plutons may contain disseminated but economic deposits of thorium, uranium, beryllium, niobium, tin, molybdenum, copper, and bismuth.

2. Exploration and sampling should include known syenite bodies and outcrop zones as well as regions known to contain associated pegmatite swarms.
3. Available aeroradiometric data should be useful in locating apatite-rich syenite bodies
4. Geochemical surveys consisting of chemical analysis of panned concentrates of stream sediments should be made in regions known to contain alkalic or mafic and ultramafic plutons. Sample splits from previous geochemical surveys (Behi, 1973) should be reanalyzed for the metals sought and for tracer elements in order to help plan future surveys.

5. Aeromagnetic data should be used to identify anomalously magnetic areas that may be produced by magnetite-rich alkalic plutons. This technique should be used to determine if tin-bearing veins in northeastern Somalia are related to a shallowly buried tin-rich pluton.
6. Veins of piezo-quartz can be developed by small teams with little capital investment, under the guidance and assistance of a central research and marketing organization.

V. Precambrian mafic and ultramafic rocks
   A. Possible economic deposits
      1. Platinum
      2. Nickel, chromium, and cobalt
      3. Phosphate
   B. Favorable geologic units
      1. Precambrian mafic and ultramafic complexes
      2. Placer deposits derived from mafic and ultramafic rocks
   C. Possible analog deposits
      1a. The Stillwater Complex Montana, U.S.A. (Page and others, 1973, Page and Nockleberg, 1970).
      1b. Mafic rocks and ultramafic rocks in eastern Uganda and Palabora in Africa and Araxa and Jacupiranga in Brazil (Cathcart and Gulbrandsen, 1973).
      1c. Mafic rocks in Virginia and the eastern Adirondack Mountains U.S.A. (Cathcart and Gulbrandsen, 1973).
      2a. Deposit characteristics--Platinum-group metals are associated with nickel, cobalt, and copper sulfide minerals in these layered deposits. In the Stillwater Complex one chromitite layer averages 0.10 oz/ton of platinum metals (Page, 1971); however, the major platinum concentrations occur with sulfide minerals in anorthositic layers.
      2b. Deposit characteristics--Apatite at economically recoverable grades of 15 percent (6 percent P_2O_5) or more occur in carbonatite pipes and plugs associated with nepheline syenite in some ultramafic complexes (Emigh, 1975). Lower, generally subeconomic concentrations of apatite-magnetite or apatite-ilmenite occur as layers in other parts of mafic and ultramafic complexes.

D. Previous recommendations
    1. No systematic evaluation has been made of the platinum potential of Somalia. The U.N.D.P. (1970) did not discuss platinum.
    2. Traces of platinum are reported from Precambrian mafic-ultramafic plutons in northern Somalia.
    3. No evaluation has been made of the phosphate potential of mafic and ultramafic plutons of Somalia.

E. Present recommendations
    1. Late Proterozoic rifting and sea-floor spreading resulted in deposition of basaltic rocks emplacement of layered mafic and ultramfic complex in northern Somalia (Kroner, 1979; Kazmin, 1976). This tectonic environment is favorable for concentration of platinum, and deposition in layered complexes. Regional exploration for platinum lode and placer deposits is warranted by this tectonic environment.
    2. Aeromagnetic data should be evaluated to locate high magnetic zones possibly indicating mafic and ultramafic complexes.
    3. Geochemical surveys consisting of chemical analysis of pan concentrated stream sediments should explore for chromium concentrations possibly indicating chromitite deposits in mafic and ultramafic complexes.
    4. Known and discovered layered complexes should be systematically mapped and sampled to evaluate their platinum potential. Platinum analyses are expensive and probably should be made chiefly on sulfide-rich layers in banded anorthositic layered assemblages.
    5. Carbonatite associated with ultramafic complexes deserves evaluation for phosphate potential as well as a source for rare-earths, niobium, and other metals.

VI. Phanerozoic black shale environment

A. Possible economic deposits
    1. Black bedded barite
    2. Base- and precious-metal-bearing massive sulfides

B. Favorable geologic unit
    1. Jurassic and Cretaceous black shales--parts of Gahodleh Shale, Warandof Shale, and Daghani Shale in northern Somalia; parts of Warandof Formation and Transitional Series in southern and central Somalia.

C. Possible analog deposits
    1. Selwyn Basin in southeastern Yukon and adjacent Northwest Territories, Canada--black bedded barite and associated stratiform massive sulfide deposits of lead, zinc, and silver (Brobst, 1980).
    2. Transitional zones between anoxic black shale and shelf-carbonate rocks where reefs developed.
    3. Size--a few inches to 50 feet thick barite and (or) massive sulfide layers within mineralized zones as thick as 150 feet Extend thousands of feet along strike and may underlie many acres. Possible large tonnages of ore.

D. Resemblance to Selwyn Basin deposits
    1. Thick section of black shale
    2. Pyritic, glauconitic, and carbonaceous
    3. Chert

4. Transitional to shelf-carbonate rocks to west
5. Fluctuating shelf-anoxic shale boundary produces many possible sites for mineralization.

E. Additional factors
1. Coeval evaporite deposits up-dip to west and underlying and overlying evaporites probably contributed saline connate waters that could have facilitated migration and concentration of metals within the shale or in associated carbonate rocks.

F. Target localization
1. The Daghani Shale of northern Somalia appears to offer the best prospects for exploration.
   a. Black shales are more widely exposed than in southern Somalia.
   b. Greater local relief in northern Somalia produces better outcrops or subcrops of shale for surface sampling and description.
   c. The greater local relief also produces well-integrated drainages that facilitate geochemical prospecting using stream-sediment techniques.
   d. Apparently coeval uplift of the Erigavo high was accompanied by some basaltic volcanism and may have localized hydrothermal solutions of volcanigenic origin.

G. Preliminary recommendations for exploration
1. Conduct semi-detailed geochemical sampling of Daghani shale outcrops and stream drainages in black shale areas.
   a. Analyze shale and sediments for Ba, Sr, Pb, Zn, Mn, Ag by semiquantitative spectrographic techniques.
   b. Collect pyrite from black shale outcrops and analyze for same suite of metals.
2. Analyze, by the same technique, samples taken at 100 ft intervals from all available drill cores of black shale from Somalia.

VII. Phanerozoic evaporite environment

A. Possible economic deposits
1. Gypsum
2. Celestite
3. Fullers earth
4. Zeolite

B. Favorable geologic units
1. Main Gypsum Formation
2. Ferfer Gypsum
3. Taleh Evaporites

C. Status of exploration
1. Gypsum
   a. Suriah Malableh, 15 km southeast of Berbera: This deposit occurs in a down-faulted block of Taleh Evaporites and consists of massive fine-grained gypsum interbedded with subordinate marl beds and overlain by limestone. The gypsum contains veinlets and pockets of anhydrite. This deposit is variously estimated to contain 5 million tons of rock with greater than 80 percent gypsum (U.N.D.P., 1970) and 7 million tons of gypsum (Kaplen and others, 1977). A pilot plant to test use of the gypsum as a domestic building

material was to be begin at Suria Malableh in mid-1977 as a joint venture with the Democratic Peoples Republic of Korea. Future development could also include manufacture and sulphuric acid for use in fertilizer and possible processing of Somali uranium ore.

b. Other gypsum deposits: Somalia has several widespread and thick gypsum deposits. However, the deposits at Suria Malableh have the best access and ample reserves to supply domestic needs and possible export opportunities.

2. Celestite

a. Celestite ($SrSO_4$) has been reported from the Taleh Evaporites in the vicinity of Gabile in northern Somalia. The celestite is widespread in a yellow shale within the evaporite unit. The thickness of the celestite zone was not determined. Two samples contained about 55 percent SrO, nil BaO, 0.5 percent CaO, 0.3 to 1.0 percent SiO_2, 0.1 to 0.3 percent Fe_2O_3, 0.2 to 0.3 percent MgO, and 42.7 to 43.5 percent SO_3 (Farquharson, 1924). This deposit resembles celestite-bearing parts of the Kauper marl formation in the vicinity of Yate, near Bristol England. The English deposit is mined by stripping and excavation using front-end loaders, hand-picking of celestite lumps, and transportation to a wash plant for removal of clay and for sizing. This process results in a product containing 90-95 percent $SrSO_4$ (Fulton, 1975).

3. Fullers earth

a. Sepiolite (Meerschaum) in the Taleh Evaporite near El Bur in southern Somalia has been mined in small quantities by hand methods, primarily for artifact manufacture and to a lesser extent for pipe carving. Sepiolite exports were valued at about $20,000 in 1974 (U.S.B.M., 1976).

The sepiolite is exposed over 9 km^2, in a zone 6 km long north-south, and 1.5 km wide east-west. One section consists of about 13 m of well-bedded monolithic sepiolite overlying sandy clay, about 4 m of porous sepiolite, and about 8 m of sepiolite with carbonate interbeds. The sepiolite-carbonate unit is overlain by dolomitic limestone. Dolomitic limestone also underlies the sandy clay below the sepiolite. Gypsum lenses locally occur within the sepiolite. The unit near El Bur is estimated to consist of about 79 percent sepiolite in which evaporite minerals, mainly halite, are the chief impurities.

b. Bentonite near Bayal Well, about 33 km southeast of Berbera in northern Somalia (Farquharson, 1924). This deposit appears to consist of fairly pure bentonite but is of unknown size. The deposit probably is of Miocene-Pliocene age and may have formed by alteration of volcanic ash.

4. Zeolite

a. No deposits of zeolite are reported although they might be expected in association with the bentonite reported in northern Somalia.

D. Previous recommendations

1. Gypsum: The Suriah Malableh deposit was recommended for additional exploration and sampling (U.N.D.P., 1970).
2. Celestite: Celestite deposits have not been discussed in recent mineral evaluations of Somalia.
3. Fullers earth: The sepiolite deposit near El Bur is reported to be unfit for pipe manufacture but suitable for carving into curios and for industrial purposes such as fire bricks (U.N.D.P., 1970). Holmes (1954) recommends the exploration of the El Bur sepiolite for possible industrial uses including machined ceramics and in heat insulation.

   The bentonite deposits have not been discussed in recent mineral evaluations of Somalia.
4. Zeolite: Possible zeolite deposits have not been discussed in mineral evaluations of Somalia.

E. Present recommendations

1. Gypsum: The Suriah Malableh deposit should be developed for domestic construction materials and investigated for possible manufacture of sulphuric acid as a part of a fertilizer industry.
2. Celestite: Celestite near Gabile should be explored to determine the grade and extent of this strontium mineral. The reported association with yellow shale indicates that regional exploration could be confined to examination and geochemical analyses of that unit.

   If the grade and extent warrant, the celestite might be mined by simple, low-capital methods adapted from those used on the Yate deposit in England. Oxen might be used to pull small scrapers, reducing the need for some motorized equipment. Hand cobbing of celestite lumps might achieve the desired ore grade without requiring the expense of milling equipment. Such development could be conducted by many small teams supervised by a central authority that handled transportation and marketing of the ore.
3. Fullers earth: The sepiolite deposit near El Bur should be explored for possible use in the petroleum industry as a drilling mud and in refining processes. It also could provide a carrier for agricultural chemicals such as insecticides, herbicides, fertilizer, etc. A large additional market exists for abundant pellets in industry and in animal litter. The use of sepiolite in drilling muds is expanding because the clay is not significantly affected by electrolytes or temperature. It therefore is increasingly being used to replace bentonite for saltwater drilling and in geothermal drilling. Sepiolite has better filtration and other properties than does attapulgite, now commonly used as a bentonite replacement in salt water drilling (Joseph, 1978).

   The El Bur sepiolite is poorly known and should be explored by drilling in outcrop areas, along strike to the north and south and to the west. The potential tonnage of the deposit is large and may be greatly increased by exploratory drilling in covered areas. The grade and other characteristics of the deposit can also be determined by the drilling.

The geologic environment of the sepiolite appears to be a restricted marine bay, lagoon, or sabkah. Dolomite and sepiolite probably directly precipitated from highly saline water, and gypsum and halite also were precipitated locally. Various amounts of quartz sand and detrital clay were also deposited as impurities and mark bedding surfaces. High contents of Si and Al in the seawater may result in part from evaporation and in part from intermittent Si- and Al-rich alkaline streams draining emergent and deeply weathered feldspathic rocks to the west. Thus, the El Bur area may represent an Eocene infra-tidal restricted basin recharged in part by tide and by intermittent alkaline streams.

Geologic studies should be made to ascertain the origin of this deposit and help to determine whether geologic conditions are favorable for other sepiolite deposits in the Taleh Evaporite. Sepiolite deposits resulting from co-precipitation with dolomitic limestone also occur in southern Nevada (Papke, 1972). Experimental studies by Wollast, Mackenzie, and Bricker (1968) and saturation diagrams by Helgeson, Garrels, and Mackenzie (1969), cited by Papke, support the proposed direct precipitation of sepiolite from alkaline saline solutions.

Sepiolite is now being produced in conjunction with bentonite, saponite, and dolomite at Sinya, Amboseli, Tanzaniya by Tanganyika Meerschaum Corporation. The bentonite is processed at Sinya for use in drilling muds, whereas the sepiolite is processed primarily for industrial absorbants and pet litter (Joseph, 1978).

In northern Somalia, the bentonite near Bayal Well should be mapped and sampled to evaluate the deposit for use in drilling muds and also for possible use in pelletizing Somali iron ore.

4. Zeolite: Regional reconnaissance of Tertiary clay deposits, especially known bentonite deposits, should be made to explore for zeolite for industrial use. Zeolite could also be used in domestic agriculture to stabilize alkaline and salt-rich soils along the rivers in southern Somalia. Quaternary lacustrine deposits in southwestern Somalia probably are alkaline, may contain ash beds, and this may be favorable for zeolite formation.

VIII. Tertiary barite-fluorite-galena veins
- A. Possible economic deposits
  1. Barite for drilling mud
  2. Fluorite, lead, and silver byproducts
- B. Favorable geologic environment
  1. Tertiary fault zones in northern Somalia associated with Miocene sea-floor spreading in the Gulf of Aden

C. Nearly analog deposits
   1. Egyptian barite vein in Tertiary faults at Elba near the Red Sea Coast (Joseph, 1978).
   2. Saudi Arabian barite veins associated with Tertiary faults near Raleigh and at Jabal Daylan along the Red Sea (Brobst, 1966; Al Shanti, 1970; Dadet, 1970; Bigot (1970, 1973).
   3. Yemen barite veins(?) said to be abundant in Wadi al Ghabar (14°13' N. lat; 48°48' E. long) near the Gulf of Aden (Greenwood and Bleackley, 1967).

D. Characteristics of vein barite deposits
   1. Veins and cavity-filling barite deposits commonly show large variations from a few meters in thickness to a few centimeters, and grade from several meters to hundreds of meters in length within deposits and within districts. Contacts with wallrock generally are sharp and do not show large-scale replacement. Rich barite deposits also occur in collapse and sink structures. Barite vein and cavity-filling deposits commonly have associated base and precious-metal minerals which might be extracted as byproducts of barite production or may be the principally mined product. These deposits locally have obvious association with igneous activity. Elsewhere the veins appear to be the result of regional hydrothermal systems only, involving meteoric water (Brobst, 1973).

E. Description of Somali barite vein deposits
   1. Somali barite veins occur in faults and shear zones cutting Precambrian, Mesozoic, and early Cenozoic rocks in a zone that extends as much as 30 km inland from the Gulf of Aden coast. In the east near Candala, barite is associated with southeast-trending faults that cut rocks as young as the lower to middle(?) Miocene Dubar Limestone and Scusciuban Formation, and appear to be associated with the formation of the lower Miocene to Pleistocene(?) "upper conglomerates" of the upper Dahan series (Holmes, 1954; Merla and others, 1973). To the west near Berbera, barite-galena veins occupy faults of east-west and northeast trend that cut Precambrian and younger rocks. Because lead from galena in these western deposits was dated at about 900 m.y. and no barite-galena mineralization was discovered in Mesozoic limestones within the faults, the deposits were interpreted as being of pre-Mesozoic age and the faults as being reactivated in Cenozoic time (U.N.D.P., 1970). However, the lead age on galena probably indicates the time at which the lead was emplaced in the crust, and need not indicate the age of the deposit, which could be much younger. In addition, barite deposits commonly do not form by replacement and therefore the lack of barite-galena veins in nearby Mesozoic limestone does not establish a pre-Mesozoic age for the deposit. Probably all the barite-galena veins along the Gulf of Aden coast formed in late Oligocene and Miocene time.
   2. Associated minerals in Somali barite veins range from galena and hematite in the east near Candala to galena, chalcopyrite, quartz, and fluorite near Berbera.

F. Previous recommendations

1. Holmes (1954) recommended additional exploration of the vein barite potential of northern Somalia, especially considering the growing need for barite for drilling oil wells in the region.
2. The U.N.D.P. (1970) showed interest in base- and precious-metal mineralization but not in barite. Because the U.N.D.P. interpreted the mineralization to be pre-Mesozoic, they recommended that exploration be restricted to Precambrian rocks.

G. Present recommendations

1. The entire Horn of Africa is prospective for Oligocene-Miocene barite deposits and associated metallic minerals.
2. Miocene fault zones are the major ore control and should be explored for barite veins wherever they are indicated. Such structures include the major graben in the Darror Valley, and probably the major uplift in the Nogal Valley. Faults associated with the Nogal uplift (figs. 2,3) extend to within 70 km of the coast of the Indian Ocean to the southeast and are mapped discontinuously into the Afar Rift to the northwest. Folds associated with these faults are interpreted as resulting from leaching of Taleh Evaporite (Barnes, 1976). Cavities formed by such leaching might be sites for large barite-galena deposits.
3. Miocene sedimentary rocks near contemporary faults should be explored for possible bedded deposits of barite, fluorite, and base and precious metals. Such deposits may be surface expressions of metal-rich hot springs rising along the active faults. These sedimentary rocks include upper Daban Series, Dubar Limestone, part of the Hufun Series, part of the middle Daban Series and Scuscuiban Formation. Pebbles of igneous origin occur at several horizons in the middle and upper Daban Series (Macfayden, 1933) and boulder conglomerates interfinger with reefoid limestones of the upper Daban (S.O.E.C., 1954) or Dubar Limestone (Merla and others, 1979), thus indicating the post- and syntectonic nature of these units.
4. Exploration should include: (a) an initial review of available geological and geophysical data and LANDSAT images to identify Miocene structures and distribution of Miocene sedimentary deposits, (b) reconnaissance geologic mapping and sampling of identified prospective areas, and (c) stream-sediment sampling and geochemical analysis in prospective areas and in covered areas on strike with mapped Miocene faults. The nonmagnetic fraction of panned-concentrated stream-sediment samples probably would be a good medium for geochemical prospecting; however, control studies involving several geochemical sample types should be made in areas of known barite-galena mineralization to select the best exploration method.
5. Regional zonation of mineralization associated with barite deposits should be studied to identify possible buried base- and precious-metal targets. As an example, the quartz-fluorite-barite veins associated with galena and chalcopyrite in Precambrian rocks near Berbera may represent more deeply

eroded deposits than do barite veins associated with galena and hematite in Mesozoic and Eocene rocks near Candala.

IX. Tertiary carnotite deposits
   A. Possible economic deposits
      1. Uranium
   B. Favorable geologic units
      1. Calcareous caliche in Miocene Merce Series near Dusa Mareb (lat 5°22'N.; long 46°12'E.)
   C. Status of exploration
      1. Little is known of these deposits. Osman and others (1976) indicate that the mineralized unit ranges from a few meters to 20 m in thickness and has variable amounts of carnotite.
   D. Previous recommendations
      1. This deposit type has not been previously evaluated in Somalia.
   E. Present recommendations
      1. The carnotite-bearing caliche at Dusa Mareb should be geologically mapped and sampled to determine origin, ore controls, and economic potential.
      2. Well logs from the region should be studied to determine if radioactive strata are indicated. Cores of the Miocene rocks should be checked for high radioactivity.

REFERENCES

Abbate, E., Ficcarelli, G., Pirini Radrizzani, C., Salvietti, A., Torre, D., and Turi, A., 1974, Jurassic sequences from the Somali coast of the Gulf of Aden: Rivista Italiana di Paleontologia e Stratigrafia, v. 80, p. 409-478.

Abucar, M. H., 1977, Stratigrafia di alcune serie sedimentarie mesozoiche delle costa somala del Golfo di Aden: Italy, Florence University, Geological Institute, Unpublished thesis.

Almond, D. C., 1979, Younger granite complexes of Sudan, in Tahoun, S. A., ed., Evolution and mineralization of the Arabian-Nubian Shield: Jiddah, Institute of Applied Geology, v. 1, p. 151-164.

Al Shanti, A. M. S., 1970, Rabigh barite deposits, in Mineral Resources Research 1968-69: Saudi Arabian Dir. Gen. Mineral Resources, p. 51-57.

Arkell, W. J., 1956, Jurassic geology of the World: London, Oliver and Boyd, 806 p.

Azzaroli, A., 1952, I macroforaminiferi della serie del Carcar (Eocene medio e superiore) in Somalia, e la loro distribuzione stratigrafica: Paleont. Italica, v. 47, p. 99-131.

Azzaroli, A., 1958, L'Oligocene e il Miocene della Somalia, stratigrafia, tettonica, peleontologia (macroforaniniferi, coralli, molluschi): Paleont. Italica, v. 52, p. 1-142.

Azzaroli, A., Fois, V., 1964, Geological outlines of the northern end of the Horn of Africa: 22nd International Geol. Congress, New Delhi, Proceedings, v. 4, p. 293-314.

Barbieri, F., 1968, Jurassic microfacies in western Somalia: Rivista Italiana di Paleontologia e Straigrafia, v. 74, p. 805-826.

Barnes, S. V., 1976, Geology and oil prospects of Somalia, East Africa: American Association of Petroleum Geologists Bulletin, v. 60, no. 3, p. 389-413.

Behi, A. M., 1973, Geochemical and geological investigations for base metals and metallic minerals in northern Somalia (Phase II and III): Unpublished manuscript, 65 p.

Bigot, M., 1970, Summary of drilling and stratigraphic geology at Jobal Dhaylan: French Bur. Recherches Géol. Minières Open-File Report 70-10, 26 p.

_____ 1973, Geology and mineral exploration of the Jabal Dhaylan quadrangle: French Bur. Recherches Géol. Minières Open-File Report 73-17, 47 p.

Black, R., Morton, W. H., and Hailu, T., 1974, Early structures around the Afar triple junction: Nature, v. 248, p. 496-497.

Bowden, P., and Turner, D. C., 1974, Peralkaline and associated ring-complexes in the Nigirian-Niger Province, West Africa, in Sorenson, H., ed., The alkaline rocks: London, Wiley, p. 330-351.

Brobst, D. A., 1966, Anomalous metal concentrations in jasperoid from hypogene barite veins near Rabign, Kingdom of Saudi Arabia: U.S. Geological Survey Professional Paper 550-C, p. C187-C189.

_____1973, Barite, in United States mineral resources, D. A. Brobst and W. P. Pratt, (eds.): U.S. Geological Survey Professional Paper 820, p. 75-84.

_____1980, Barite resources in their geologic framework, in Proceedings of minerals and chemicals in Drilling Meds--The 80's and beyond: Industrial Minerals Meeting, Houston, Texas, September 11-12, 1980, p. 30-39.

Brown, G. F., 1972, Tectonic map of the Arabian Peninsula: Saudi Arabian Dir. Gen. Mineral Resources Arabian Peninsula Map AP-2, scale 1:4,000,000.

Bruni, P., and Fazzouli, M., 1976, Sedimentological observations on Jurassic and Cretaceous sequences from northern Somalia: Geol. Soc. Italia Boll. 95, p. 1571-1588.

Cathcart, J. B., and Gulbrandsen, R. A., 1973, Phosphate deposits, in Brobst, D. A., and Pratt, W. P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 515-526.

Cox, D. P., Schmidt, R. G., Vine, J. D., Kirkemo, Harold, Tourtelot, E. B., and Fleischer, Michael, 1973, Copper, in United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 163-190.

Dadet, P., 1970, Zinc, lead, and copper in Cenozoic sediments of Jabal Dhaylan: Ch. 1-4, in Second annual report: French Bur. Recherches Géol. Minières Open-File Report 70-1, 12 p.

Daniels, J. L., 1960, Minerals and rocks of Hargeise and Borama districts: Somaliland British Protectorate Geological Survey Mineral Resources Pamphlet no. 3, 25 p.

Deans, T., 1968, Exploration for apatite deposits associated with carbonatites and pyroxenites, in Proceedings of the seminar on sources of mineral raw materials for the fertilizer industry in Asia and the Far East: United Nations Mineral Resources Development Series, no. 32, p. 109-119.

Elliott, J. E., in press, The tin-bearing granite of Jabal al Gabarra in the southern Arabian Shield, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry of Mineral Resources Bulletin.

Emigh, G. D., 1975, Phosphate rock, in Leford, S. J., ed., Industrial minerals and rocks (4th ed.): American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., Baltimore, p. 935-962.

Farquharson, R. A., 1924, First report on the geology and mineral resources of British Somaliland: London, Waterlow and Sons, Ltd., 53 p.

Fulton, R. B., III, 1975, Strontium, in Leford, S. J., ed., Industrial minerals and rocks (4th ed.): American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., Baltimore, p. 1099-1102.

Gellatly, D. C., 1960, Geology of the Las Dureh area, Burao district: Somalia Geological Survey Report no. 6, 40 p.

Gellatly, D. C., 1961, The cassiterite deposits of Dalan, near Elayu, Erigavo district: Somalia Geological Survey Report DCG-12, 19 p.

Geukens, F., 1966, Geology of the Arabian Peninsula--Yemen: U.S. Geological Survey Professional Paper 560-B, 23 p.

Greenwood, J. E. G. W., 1960, Geology of the Las Kboreh-Elayu area, Erigavo district: Somaliland British Protectorate Geological Survey Report, no. 3, 36 p.

Greenwood, J. E. G. W., and Bleackley, D., 1967, Geology of the Arabian Peninsula--Aden Protectorate: U.S. Geological Survey Professional Paper 560-C, 90 p.

Greenwood, W. R., and Anderson, R. E., 1977, Palinspastic map of the Red Sea prior to Miocene sea-floor spreading, in Red Sea Research: Saudi Arabian Directorate General Mineral Resources Bulletin no. 22, p. Q1-Q6.

Greenwood, W. R., Anderson, R. E., Fleck, R. J., and Roberts, R. J., 1980, Precambrian geologic history and plate tectonic evaluation of the Arabian Shield: Saudi Arabian Directorate General Mineral Resources Bulletin no. 24, 35 p.

Greenwood, W. R., Hadley, D. G., Anderson, R. E., Fleck, R. J., and Schmidt, D. L., 1976, Late Proterozoic cratonization in southwestern Saudi Arabia: Royal Society London Philosophical Transactions, A, v. 280, p. 517-527.

Gregory, J. W., 1896, Note on the geology of Somaliland: Geological Magazine, v. 4, p. 289-294.

Gretzer, Y., 1970, Stratigraphy, hydrogeology and Jurassic ammonites of the Hauar and Diredawa area, Ethiopia: Tel Aviv, Hebrew University, Ph. D. thesis, 184 p.

Helgeson, H. C., Garrels, R. M., and Mackenzie, F. T., 1969, Evaluation of irreversible reactions in geochemical processes involving minerals and aqueous solutions - II. Applications: Geochimica et Cosmochimica Acta, v. 33, p. 455-481.

Hilal, A. F., Pavan, G., and Robba, E., 1977, Gedogia stratigrafica della Somalia, in Quaderni di Geologic della Somalia: Univ. Naz. della Somalia, Fac. di Geol., Mogadiscio, p. 19-50.

Holmes, R. J., 1954, A reconnaissance survey of the mineral resources of Somalia (former Italian Somaliland): U.S. Technical Assistance Mission Report T.A. 45-125, 83 p.

Hunt, J. A., 1951, A general survey of the Somaliland Protectorate, 1944-1950: London, Crown Agents, 203 p.

_____1958, Geology of the Adadleh area, Hargeisa and Berbera districts: Somaliland British Protectorate Geological Survey Report no. 2, 16 p.

_____1960, Geology of the Berbera-Sheikh area, Berbera and Burao districts: Somaliland British Protectorate Geological Survey Report no. 4, 27 p.

Joseph, J. H., 1978, Bentonite, sepiolite, and attapulgite, in Raw materials for oilwell drilling, 1978: Metal Bulletin Ltd., London, p. 51-73.

Kaplan, Irving, Dobert, M. K., McLaughlin, J. L., Maruin, Barbara, Roth, H. M., and Whitaker, D. P., 1977, Area handbook for Somalia: Washington, D.C., American University, Foreign Studies Division, 392 p.

Kazmin, V., 1972, Geological map of Ethiopia: Geological Survey of Ethiopia, scale 1:2,000,000.

Kazmin, V., 1976, Ophiolites in the Ethiopian basement: Ethiopian Institute of Geological Surveys Note no. 35, 16 p.

Kröner, A., 1979, Pan-African mobile belts as evidence for a transitional tectonic regime from intraplate orogeny to plate margin orogeny, in Tahoun, S. A., ed., Evolution and mineralization of the Arabian-Nubian Shield: Oxford, Pergamon Press, v. 1, p. 21-37.

Macfayden, W. A., 1933, The geology of British Somaliland, Part I, Geology and Paleontology: London, Crown Agents, 87 p.

Macfayden, W. A., 1952, Water supply and geology of parts of British Somaliland: Somaliland British Protectorate Geological Survey Report, 184 p.

Mason, J. E., 1957, An isolated occurrence of igneous rocks at Gorei in the Las Anod district of the Somaliland Protectorate: Geological Magazine, v. 94, p. 498-502.

Mason, J. E., 1962, Geology of the area north of Hargeisa and laferug, Hargeisa and Berbera districts: Somalia Geological Survey Report no. 7, 33 p.

Mason, J. E., and Warden, A. J., 1956, The geology of the Heis-Mait-Waqderia area, Erigavo district: Somaliland British Pectectorate Geological Survey Report no. 1, 23 p.

Merla, Giovanni, Abbate, Ernesto, Canuti, Raola, Sagri, Mario, and Tecconi, Paolo, 1973, Geological map of Ethiopia and Somalia: Consiglio Nagionale delle Richerche, Rome, scale 1:2,000,000.

Merla, Giovanni, Abbate, Ernesto, Azzaroli, Augusto, Bruni, Piero, Canuti, Paolo, Fazzouli, Milvio, Sagui, Mario, and Tecconi, Paolo, 1979, A geological map of Ethiopia and Somalia and comment with a map of major landforms: London, Pergamon Press Ltd., 95 p.

Mohr, P. A., 1962, The geology of Ethiopia: Univ. Coll. of Addis Ababa Press, 268 p.

Osman, A. S., Farag, H. A., and Abdi, M. S., 1976, Geology of Somalia: Somali Democratic Republic Ministry of Mineral and Water Resources Report, 23 p.

Page, N. J, 1971, Sulfide minerals in the G and H chromite zones in the Stillwater Complex, Montana: U.S. Geological Survey Professional Paper 694, 20 p.

Page, N. J, Clark, A. L., Desborough, G. A., and Parker, R. L., 1973, Platinum-group metals, in Brobst, D. A., and Pratt, W. P., eds., United States mineral resourcees: U.S. Geological Survey Professional Paper 820, p. 537-545.

Page, N. J, and Nockleberg, W. J., 1970, Preliminary geologic map of the Stillwater Complex, Montana: U.S. Geological Survey Open-File Report.

Papke, K. G., 1972, A sepiolite-rich playa deposit in southern Nevada: Clays and clay minerals, v. 20, p. 211-215.

Patterson, S. H., and Dyni, J. R., Aluminum and bauxite, in United States mineral resources, D. A. Brobst and W. P. Pratt (eds.): U.S. Geological Survey Professional Paper 820, p. 35-43.

Puri, R. K., 1961, Bibliography relating to geology, mineral resources, paleontology, etc., of Somali Republic: Somali Geological Survey Report RKP-1, 13 p.

Rabinowitz, P. D., Coffin, M. F., and Falvey, David, 1982, Salt diapirs bordering the continental margin of northern Kenya and southern Somalia: Science, v. 215, p. 663-665.

Riofinex Geological Mission, 1977, A preliminary review of mineral opportunities in Saudi Arabia: Riofinex Geological Mission Report RF-1977-1, 186 p.

Roberts, R. J., Greenwood, W. R., Worl, R. G., Dodge, F. C., and Kiilsgaard, T. H., 1975, Mineral deposits in western Saudi Arabia: U.S. Geological Survey Open-File Report 75-654, 60 p.

Somaliland Oil Exploration Company (S.O.E.C.), 1954, A geological reconnaissance of the sedimentary deposits of the protectorate of British Somaliland: London, Crown Agents, 41 p.

Stefanini, G., 1925, Description of fossils from south Arabia and British Somaliland, in The geography and geology of Makalla (O. H. Little, ed.): Egypt Geological Survey, p. 143-250.

_____1928, Molluschi e brachiopodi Callovani del Caracorum: Spedizione ital. De Filippi all'Himalaia, Caracorum e Turkestan cinese (1913-1914): Zanichelli, Bologna, Ser. 2, v. 6, p. 1-60.

Stoeser, D. B., and Elliott, J. E., 1979, Post-orogenic peralkaline and calc-alkaline granites and associated mineralization of the Arabian Shield, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 79-1323, 42 p.

Tavani, G., 1949, Fauna melacologica della Somalia e dell'Ogaden, Paleont. Italica, v. 45, p. 83-154.

Tischendorf, G., 1977, Geochemical and petrographic characteristics of silicic magmatic rocks associated with rare-element mineralization, in Metallization associated with acid magmatism: Czechoslovakia Geological Survey, Prague, v. 2, p. 41-96.

United Nations Development Programme (U.N.D.P.), 1970, Mineral and groundwater survey--Somalia: United Nations Report, 133 p.

U.S. Bureau of Mines, 1976, Mineral industries of Africa: U.S. Bureau of Mines, 115 p.

U.S. Geological Survey--Arabian American Oil Company (USGS-ARAMCO), 1963, Geologic map of the Arabian Peninsula: U.S. Geological Survey Miscellaneous Geological Investigations Map I-270-A, scale 1:2,000,000.

Usoni, Luigi, 1956, Risonse minerarie dell'Africa Orientale; Eritrea, Ethiopia, Somalia: Jaudi Supi, Rome, 553.

Wollast, R., Mackenzie, F. T., and Bricker, 1968, Experimental precipitation and genesis of sepiolite at earth-surface conditions: American Mineralogist, v. 53, p. 1645-1662.