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Summary of Tertiary investigations in western Saudi Arabia, current work by the U.S. Geological Survey and recommended future studies.

by

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SUMMARY OF TERTIARY INVESTIGATIONS IN WESTERN SAUDI ARABIA, CURRENT WORK BY THE U.S. GEOLOGICAL SURVEY, AND RECOMMENDED FUTURE STUDIES

by

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ABSTRACT

In 1936, geologic work related to the Tertiary System in western Saudi Arabia began with a study of the Umm Gerad barite deposit by K. S. Twitchell. In 1944, a study focusing specifically on Tertiary rocks was conducted by Steineke and others near Jiddah. Small-scale mapping of Tertiary sequences began in 1950 in southwestern Saudi Arabia and later in northern Saudi Arabia as part of the Kingdom's early mapping program. These studies were part of a larger program being directed by the Government of Saudi Arabia in connection with mineral resource investigations.

In the mid- to late-1960's, the Bureau de Recherches Geologiques et Minieres discovered mineralized Tertiary rocks at Jabal Dhaylan and began a study, which continues to the present, of both the Tertiary rocks and the mineralization. Following a number of early local studies, in 1973 the U.S. Geological Survey began detailed study of the Tertiary layered rocks along the Red Sea coastal plain south of Jiddah. More recently, Riofinex and Seltrust have been exploring for selected commodities in Tertiary sequences of northwestern Saudi Arabia and the Red Sea coastal plain.

Results of these studies, including work by the Saudi Arabian Directorate General of Mineral Resources and the Saudi government agency preceding it, are summarized in this report. Characteristics of the Tertiary rocks south of lat 23° N. and the Tertiary mineral deposits of western Saudi Arabia are also summarized. Recommendations are made for future geologic studies and mineral assessment of the Tertiary rocks of western Saudi Arabia.

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INTRODUCTION

Geologic investigations bearing on the Tertiary System in western Saudi Arabia (fig. 1) began as early as 1936 when Karl S. Twitchell prospected the Red Sea coastal plain. One objective of this early study, conducted chiefly by the Saudi Arabian Mining Syndicate (SAMS), was to gain some insight into the composition and structure of the rocks of western Saudi Arabia, but the main objective was to examine these rocks for their ore-bearing potential using reconnaissance methods. Of necessity the study was broad in scope, and as many rock types were examined as time permitted without regard to their age or other particular geologic characteristics.

During most of the forties, very little geologic work was attempted in western Saudi Arabia because of World War II.

In 1947, water-resource and geologic studies in the Kingdom were resumed under the auspices of the Ministry of Finance and National Economy, and, until 1954, SAMS continued its mineral exploration in western Saudi Arabia. In 1950, a general program of natural-resource investigations was initiated at the specific request of King Abdulaziz ibn Saud and the U.S. Geological Survey (USGS) began a study of western Arabia that included reconnaissance geologic mapping. This study was conducted under the auspices of the Bureau of Mines and Companies within the Ministry of Finance and National Economy until 1954, when the Bureau was reorganized as the Directorate General of Petroleum and Mineral Affairs. Office and laboratory phases of the program continued, resulting in the publication between 1956 and 1963, in cooperation with the Arabian American Oil Co., of a series of 21 geologic maps of the Kingdom of Saudi Arabia at a scale of 1:500,000 and a geologic map of the Arabian Peninsula at a scale of 1:2,000,000. In 1961, the Directorate General of Mineral Resources (DGMR) was formed within the Ministry of Petroleum and Mineral Resources (MPMR).

The DGMR intensified its mineral resource and geological studies through a series of work agreements or contractual arrangements with the U.S. Geological Survey in 1963, geologists from the Japanese Geological Survey (JGS) in 1964, the French Bureau de Recherches Geologiques et Minieres (BRGM) in 1965, Watts, Griffis, and McQuat (WGM) in 1972, Imperial College in 1975, Riofinex in 1976, Minatome in 1979, and Seltrust in 1981. Studies of the Tertiary System were included in the geologic investigations, and work by most of these organizations continues to the present.

The purpose of this report is to summarize economic and scientific studies of the Tertiary System of western Saudi Arabia and the Red Sea that have been conducted under

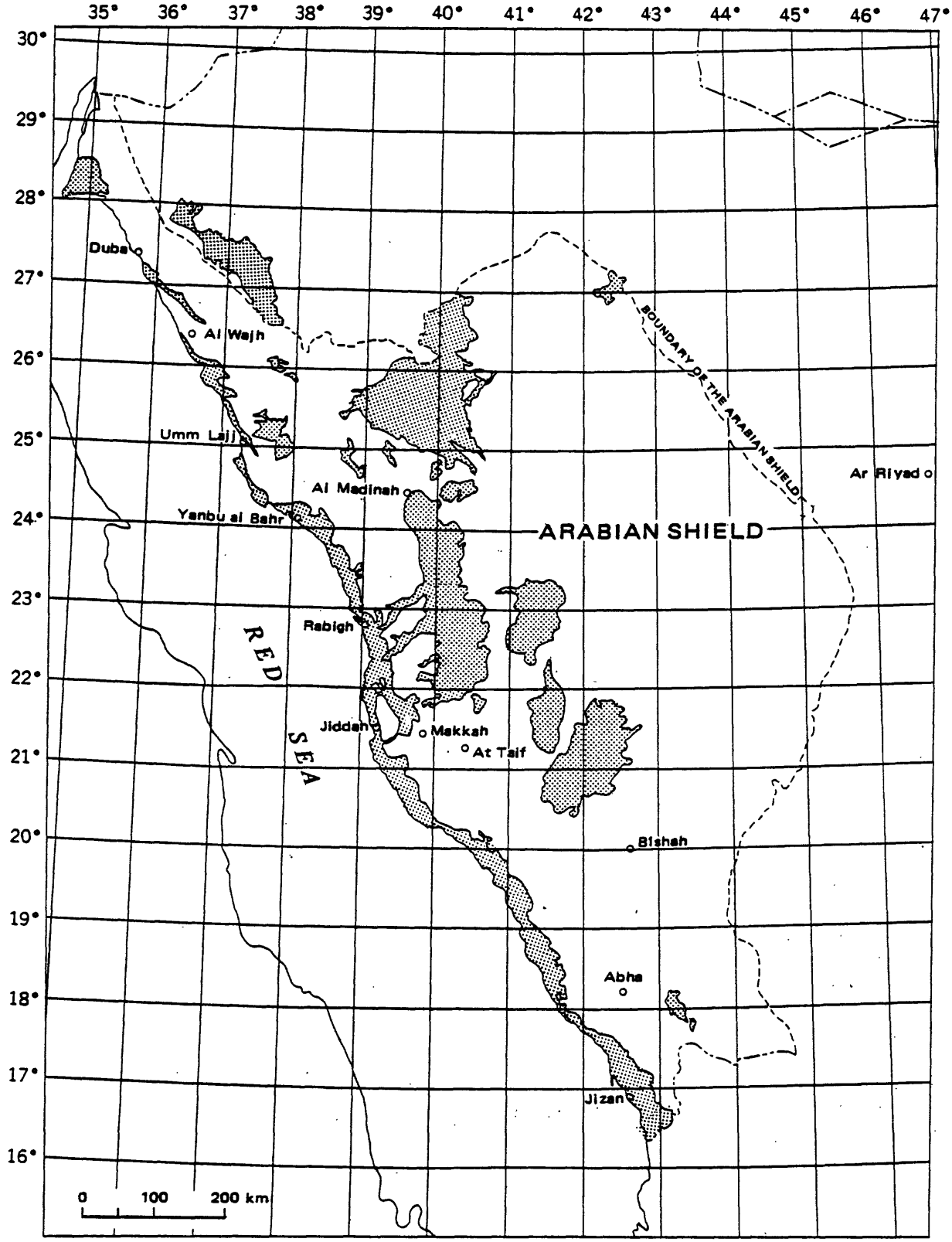

Figure 1.--Index map showing distribution of Cenozoic rocks (stippled pattern) in western Saudi Arabia. Adapted from Riofinex Geological Mission (1977).

sponsorship of the Government of Saudi Arabia, including the current investigations being conducted by the USGS, and to recommend a program of future study. Presentation of the studies is organized into four periods based on government- and agency-level administrative events that mark breaks in the chronology of geologic fieldwork in Saudi Arabia. The periods are prior to 1947, 1947-1960, 1961-1972, and 1973-1982. The events defining these periods, together with other events that relate directly to geologic activity in western Saudi Arabia in general and studies of the Tertiary System in particular, are shown in table 1. Publications related to studies of the Red Sea basin not sponsored by the Government of Saudi Arabia generally are not included in this report. Abstracts are also not included. Both these types of publications may be obtained by reference to an earth-science bibliography of the Arabian Peninsula and surrounding area (Gettings and others, 1981). Titles of references presented in the appendices (1-4) summarizing the four periods noted above are abbreviated partly for convenience; complete references are listed at the end of the report.

A detailed review of Red Sea geologic studies through mid-1971 was published by Patrick Skipwith (1973). A companion paper to this present summary discusses the more technical aspects of the Tertiary geology and evolution of the Red Sea (Schmidt and others, 1982).

PREVIOUS INVESTIGATIONS

Prior to 1947

Prior to 1947 very few geologic studies were conducted that specifically related to the Tertiary System (appendix 1). In the late 1800's, Burton (1979) examined Tertiary rocks (Raghama formation) in the Al Bad area. In 1936, Twitchell (Schaffner, 1958a) briefly studied the Umm Gerad barite deposit, and Shaw (1936) prospected in the Rabigh district and presumably evaluated the Umm Gerad barite veins as well. Both Twitchell and Schaffner worked for the Saudi Arabian Mining Syndicate, a private consortium that had been granted a concession for mineral exploration by the Saudi Arabian Government. In 1944, reconnaissance mapping of Tertiary and Quaternary rocks and sediments of the Jiddah-Usfan-Wadi Fatima area was carried out by Max Steineke and E. L. Berg of the Arabian American Oil Company (Aramco) and G. Wadsack of the U.S. Military Mission; the results of this study were not published, but their reconnaissance geologic map is available.

1947-1960

Following World War II, geologic studies were resumed in Saudi Arabia, with emphasis on the Precambrian Shield area (appendix 2).

Although not the principal objective of these studies, the first regional mapping and study of the Tertiary System in western Saudi Arabia began with fieldwork by G. F. Brown and R. O. Jackson along the coastal plain near Jizan. Mapping commenced in 1950 and resulted in publication of the 1:500,000-scale Asir quadrangle (Brown and Jackson, 1959) and the Tihamat ash Sham quadrangle (Brown and Jackson, 1958), which show the Tertiary rocks along the coastal plain from the Yemen border to lat 20° N. The remainder of the maps in the 1:500,000-scale series were published by 1963, and together these maps show the distribution of Tertiary rocks in western Saudi Arabia and along the coastal plain (appendix 2), including depiction of the important Tertiary sections peripheral to Harrat Hadan and the volcanic rocks and laterite in the As Sarat area.

The period between 1947 and 1960 was a formative one in Saudi Arabia for Tertiary geologic studies as well as studies of the older Precambrian rocks. A broad foundation was laid for future detailed work and included: (1) acquisition of third-order vertical and horizontal control and Shoran; (2) aerial photographic surveys that produced a complete set of 1:60,000-scale high-resolution photographs of the whole of the Arabian Shield and coastal plain from which a partial set of 1:100,000-scale photomaps were compiled and an almost complete set of 1:100,000-scale semicontrolled photomosaic bases were produced; (3) a set of 42 geologic and geographic maps at 1:500,000-scale compiled or in progress for the whole of the Kingdom; and (4) three maps, two geographic and one geologic, covering the Arabian Peninsula, adjoining water bodies, and portions of adjacent land areas at scale 1:2,000,000.

Simultaneous with the 1:500,000-scale mapping and compilation work by the USGS and Aramco, other studies were being conducted by the Government of Saudi Arabia. Numerous Tertiary localities were mapped and studied, and some mineralized areas that had been studied previously, such as the Umm Gerad barite area, were reexamined.

Philby (1957), accompanied by R. G. Bogue, U.S. Geological Survey, made observations in the Midian area of northwestern Saudi Arabia but conducted no detailed geologic investigations of Tertiary rocks.

1961-1972

In 1961, the Directorate General of Mineral Resources was established within the Ministry of Petroleum and Mineral Resources, thus formalizing a Saudi government agency whose prime objective was mineral resource investigations. As a

Table 1.--Chronology of geologic and government- and agency-level historical events related significantly to earth-science investigations of the Tertiary System of western Saudi Arabia and the Red Sea

Date	Event
1877	Richard Burton explores Midian; he discovers Tertiary evaporitic rocks near Maqna
1933	K. S. Twitchell explores the geology of Wadi Yanbu and El Furra
1934	The Saudi Arabian Mining Syndicate (SAMS) is constituted and a concession agreement covering 110,000 square miles to explore for mineral resources in western Saudi Arabia is signed by the company and the Government of Saudi Arabia
1936	K. S. Twitchell discovers and briefly documents the Tertiary barite mineralization at Umm Gerad near Rabigh
1939	Compagnie General de Geophysique conducts the first geophysical survey in western Saudi Arabia. The survey was designed to elucidate the structure of the subsurface Tertiary rocks in the area of Jizan
1944	Max Steineke, R. A. Bramkamp, and F. Wadsack map Tertiary rocks near Jiddah (unpublished)
1947	Following World War II, the Saudi Arabian Government (Ministry of Finance and National Economy) resumes geologic exploration in western Saudi Arabia
1948	The Swedish vessel Albatross discovers anomalously high bottom temperatures in the axial trough of the Red Sea
1949	High-altitude photography begins in the Kingdom at 1:60,000 scale; third-order vertical and horizontal control and shoran are established and utilized in compiling the photography
1950	The U.S. Geological Survey is invited by the Saudi Arabian Government to begin mapping and mineral resource investigations in western Saudi Arabia and to prepare, in conjunction with the Arabian American Oil Company (ARAMCO), a set of semicontrolled geographic and geologic maps of the Kingdom and Peninsula at scales of 1:2,000,000 and 1:500,000
1958	The first geologic map of the Kingdom covering the Red Sea margin is published at a scale of 1:500,000, the geologic map of the Tihamat Ash Sham quadrangle (I-216 A)

Table 1.--Chronology of geologic and government- and agency-level historical events related significantly to earth-science investigations of the Tertiary System of western Saudi Arabia and the Red Sea--Continued

Date	Event
1961	The Directorate General of Mineral Resources is established by the Ministry of Petroleum and Mineral Resources
1963	The U.S. Geological Survey is invited by the Ministry of Petroleum and Mineral Resources to begin detailed geologic and mineral resource investigations in western Saudi Arabia
	The first geologic and geographic maps of the Arabian Peninsula at scale 1:2,000,000 are compiled by the U.S. Geological Survey and ARAMCO and published under the joint sponsorship of the Kingdom of Saudi Arabia, Ministry of Petroleum and Mineral Resources, and the U.S. Department of State. These maps illustrate regionally the Cenozoic rocks of western Saudi Arabia
	Systematic oceanographic exploration of the Red Sea hot brines begins with the RRS Discovery and continues with the R.V. Chain, R.V. Meteor, and R.V. Atlantis II
1965	Bedded phosphorite is discovered in the Turayf area of northwestern Saudi Arabia by R. P. Sheldon
1965	The Bureau de Recherches Geologiques et Minieres is invited by the Ministry of Petroleum and Mineral Resources to begin mineral resource investigations in western Saudi Arabia
1973	The U.S. Geological Survey begins a program of systematic study of the Tertiary System in western Saudi Arabia based on mapping of quadrangles along the coastal plain at 1:100,000 scale
1977	The Directorate General of Mineral Resources publishes a volume of collected papers on scientific research of the Red Sea and its margins between 1970-1975
1978	The first seismic deep-refraction profile is conducted across the Arabian Shield and the Red Sea to the Farasan Islands
1981	Seltrust, under a contract with Saudi Arabian Deputy Ministry for Mineral Resources, begins a program to evaluate the potash resources of the Tertiary rocks underlying the Red Sea coastal plain

means of implementing these investigations quickly and systematically, the Ministry of Petroleum and Mineral Resources concluded work agreements with the USGS in 1963, BRGM in 1965, and individual contracts with geologists from the Japanese Geological Survey in 1963, all to undertake detailed geologic mapping and mineral resources studies in western Saudi Arabia. Fieldwork based on broadly constructed programs began immediately afterward.

Thus, between 1961 and 1972 there was a large expansion of activity related to mineral resource and basic geologic studies of the Tertiary System of western Saudi Arabia and in particular the Red Sea coastal area. The Red Sea basin became the focus of worldwide scientific interest because of the rediscovery in 1964 of the hot bottom temperatures and high saline levels in the central part of the Red Sea by Charnock (1964) and Swallow and Crease (1965) on the research vessel RRS Discovery. Because of the potential economic significance of the anomalous metal concentrations in the hot brines of the axial trough of the Red Sea, an understanding of their genesis became important; at the same time the study of ocean basins in general received new attention because of the evolving concepts of sea-floor spreading and plate tectonics.

The sequence of events regarding specific study of the Red Sea demonstrates the importance and value of basic research. Scientific studies of the Red Sea were encouraged by both its unique character as a natural laboratory for the study of young oceans and their genesis and its significance with respect to the East African rift system, the Gulf of Aden, and the immense Tertiary volcanic activity of the Afar triple junction. These studies led to the discovery of the Red Sea metalliferous brine resources. Thus, impetus from the scientific research led to the identification of deposits of potential economic importance, which in turn inspired more research and more exploration.

Numerous significant papers pertaining to the Tertiary System of western Saudi Arabia and the Red Sea emerged between 1961 and 1972. These were published as the result of symposia (Clifford and Gass, 1970; Falcon and others, 1970), as collected works centered on a specific area (Degens and Ross, 1969), or as individual research articles (Al-Shanti, 1966; Berton, 1967, 1968, 1969a and b; Gillmann, 1968; Whiteman 1968, 1970; Girdler, 1969, 1970a, b, c; Bigot, 1970; Bodenlos, 1970; Dadet and others, 1970; Gass, 1970a, b). These and other papers published during the period are shown in appendix 3.

In the course of reconnaissance work for nonmetallic mineral resources along the northern Red Sea coast beginning in 1968, BRGM discovered copper-mineralized rocks of Tertiary age at Jabal Dhaylan (Berton, 1969). This discovery led to a

broader mineral exploration program of the Tertiary rocks of the northern Red Sea coastal plain by BRGM, including mapping, detailed geochemical and geophysical surveys, and drilling at Jabal Dhaylan and other localities from Yanbu al Bahr northward to the vicinity of Haql on the Gulf of Aqaba. These studies continue to the present and have resulted in many papers concerning the Tertiary stratigraphy and structure of the region and have more recently led to a program of phosphate exploration. Publications arising from BRGM's Tertiary studies along the Red Sea margin of Saudi Arabia, including reconnaissance investigations for nonmetallic mineral resources south of Jiddah, are summarized in appendices 3 and 4 or are listed in the cited references of this report.

CURRENT USGS PROGRAM (1973-1982)

Objectives and area of work

The current program of USGS studies related to the Tertiary System of western Saudi Arabia began in late 1973 as a result of 1:100,000-scale mapping along the Red Sea margin (fig. 2). During the mapping program, the area along the coastal plain was observed to contain considerable Tertiary sedimentary, volcanic, and intrusive rocks. As the mapping progressed, it became apparent that the Tertiary sequences required a program of detailed study of a scope beyond that ordinarily devoted to the type of reconnaissance mapping being conducted by the USGS. Thus, in spring of 1974, D. L. Schmidt and R. G. Coleman joined D. G. Hadley in a project designed to study the Tertiary rocks along the Saudi Arabian coastal plain from Jiddah to the Yemen border. The basis of this work was the mapping of the Tertiary rocks by Hadley (1975a, b, 1980, 1981a, b, c, d) and Hadley and Fleck (1980a, b) in the quadrangles shown in figure 2 and previous fieldwork done by Coleman and others (1972, 1977).

This project had five main objectives, including an understanding of (1) the distribution of the rocks; (2) the composition of these rocks (geochemical and stratigraphic); (3) their environment of deposition, including the structural and geomorphic character of the proto-Red Sea rift/basin; (4) their economic potential; and (5) the configuration of the continental-oceanic boundary as determined from geophysical studies. Results of the project suggested that the mid-Tertiary layered rocks cropping out on the Red Sea coastal plain held the key to unlocking unresolved problems related to breakup of the Afar triple junction and the Arabian-Nubian craton and development of the subsequent rift into a bona fide Miocene ocean floored by simatic material. Further, the results suggested that (1) the sedimentary rocks and their coeval volcanic rocks were likely hosts for hydrothermal base-metal deposits similar to those along the northern Red Sea coastal plain, such as at Jabal Dhaylan, and to those

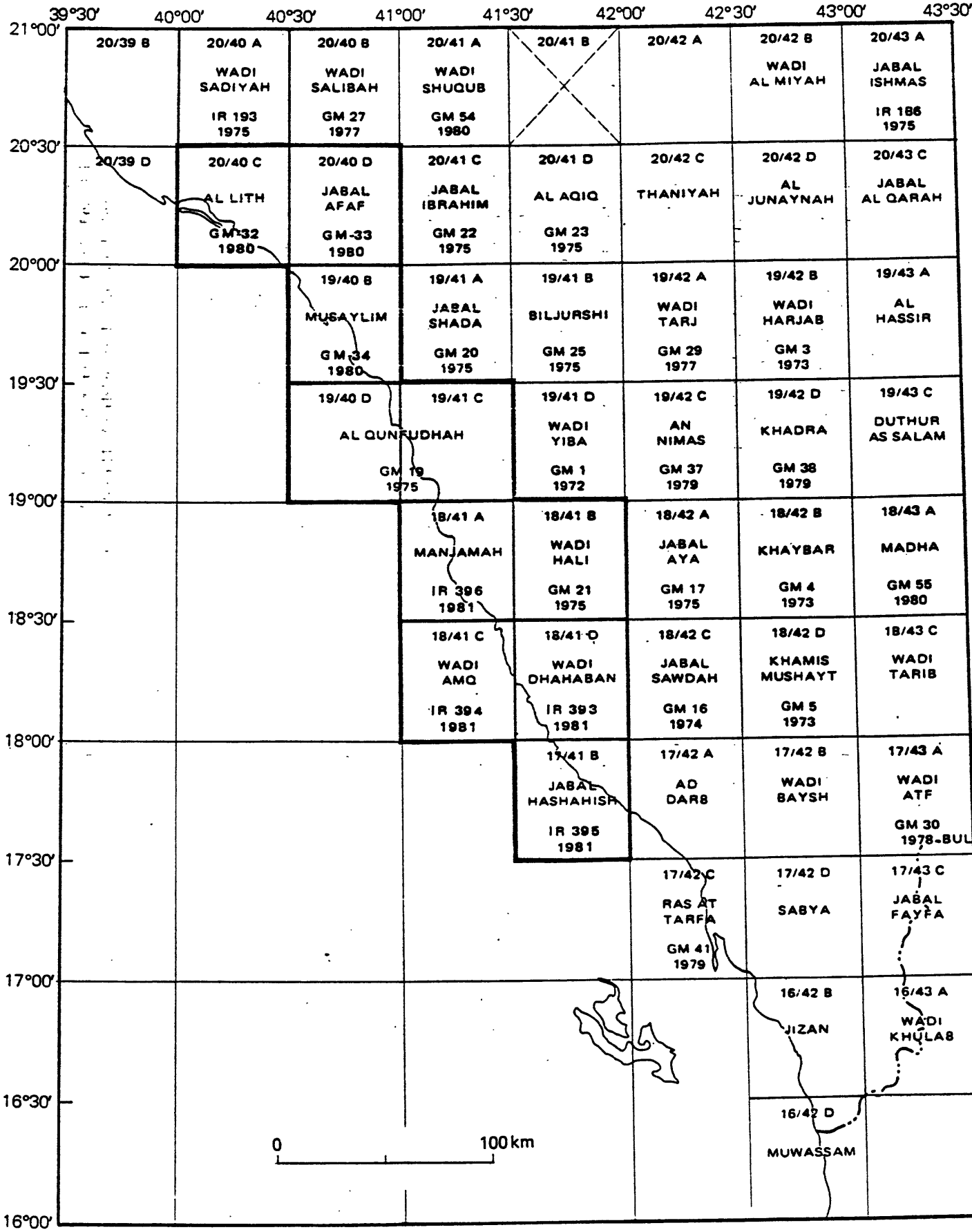

Figure 2.—Map showing quadrangles mapped by the U.S. Geological Survey (heavy outline), on or adjacent to the Red Sea coastal plain, that formed the basis for initiating detailed studies of the Tertiary System in southwestern Saudi Arabia beginning in 1973.

across the Red Sea in Egypt, and (2) the oceanic crust underlying parts of the coastal plain might contain metalliferous deposits similar to those being generated in the axial-trough brine pools today.

In order to gain a complete knowledge of the Tertiary rocks along the coastal plain, the project area was expanded to include a reexamination and mapping of the Tertiary rocks south of Ash Shuqayq and northward from the Al Lith quadrangle to approximately lat 23° N. (figs. 1 and 2). Although the rocks near Jiddah had been mapped previously (Al-Shanti, 1966; Nebert and others, 1974), the Shumaysi formation had never been carefully correlated with the Tertiary succession (Jizan group) to the south. Therefore it was necessary to briefly reexamine the Shumaysi formation and to map and study the rocks in the areas of Jabal Sita (lat 20°55' N.), Jabal Abu Shidad (lat 20°50' N.), and around Harrat Shama (lat 20°40' N.). In addition to studying the older Tertiary rocks (Oligocene to Pliocene), the volcanic rocks of Harrat al Birk and nearby volcanoes such as Jabal Baqarah and Jabal al Haylah were sampled and examined.

Results and conclusions

Published data

During the present phase of Tertiary System studies in Saudi Arabia, from 1973 to the present, numerous significant papers have been published on the Red Sea and its margins. Many of these papers have been published or sponsored by the Directorate General of Mineral Resources. These are tabulated and synoptically summarized in appendix 4 along with other reports published since 1973.

To facilitate our work begun in late 1973, a bibliography of the Red Sea and its margins and rift extensions was prepared and published (Hadley and Schmidt, 1977) in a DGMR volume devoted to Red Sea research between 1970 and 1975 (Hilpert, 1977). Two other papers were published at a later date that are related directly to the work begun in 1973 (appendix 4). One concerns the composition, chemistry, and mode of origin of the ophiolitic rocks of the southern coastal plain between Ad Darb and the Yemen border (Coleman and others, 1979), and the other deals with ultramafic inclusions and host alkali-olivine basalts of Harrat al Birk (Ghent and others, 1980). Finally, one additional paper related to Tertiary studies in western Saudi Arabia, although not to the coastal plain work, deals with the Umm Himar formation near Harrat Hadan and the Paleocene invertebrate faunal assemblage of the Umm Himar lacustrine beds (Madden and others, 1979).

Geologic data

A preliminary paper recently has been completed that deals with the stratigraphy and structural aspects of the Tertiary layered rocks from near Jiddah to the Yemen border (Schmidt and others, 1982). It presents data and interpretation related to fieldwork initiated early in the USGS Tertiary program and to studies carried on in more detail by Schmidt since February 1980.

Tertiary rocks in the area of study range from approximately middle Oligocene to middle Miocene and include the Baid formation (Brown and Jackson, 1959); mafic, felsic, and silicic volcanic rocks formerly described within the Baid (Brown and Jackson, 1959; Gillmann, 1968); a mafic complex identified as the Tihama Asir ophiolite (Coleman and others, 1977, 1979); and the Bathan formation (Hadley and Fleck, 1980a and b). In the course of fieldwork conducted since 1980 we have redefined the Baid formation. Although Brown and Jackson (1959) and Gillman (1968) had mapped and described volcanic flows and tuffs within the Baid formation, we have excluded these rock types and defined the Baid formation as a dominantly sedimentary formation, even though it contains an appreciable quantity of very fine grained waterlaid tuffaceous detritus.

Mapping.--Figure 1 shows the distribution of exposed Tertiary rocks of western Saudi Arabia, including the study area from lat 23° N. south to the Yemen border. Mapping of the Tertiary rocks south of lat 23° N. is complete, except for the area between Jabal Sita and lat 21°15' N. A small amount of detailed mapping may still be required in local areas between Al Qunfudhah and Jabal Sita.

Stratigraphy and lithology.--Detailed stratigraphic sections and geologic columns showing relative age relationships of lithostratigraphic units at 23 localities have been measured and compiled (Schmidt and others, 1982). The stratigraphic age relationships are shown on figure 3.

On the basis of fieldwork from Jabal Sita southward, we have reevaluated the age relationships of the middle Oligocene to middle Miocene succession and have redefined the Baid formation. Previously, the Tihamat Asir complex was considered to be the base of the Tertiary succession in the southern coastal plain and to be approximately coeval with the As Sarat lavas (Coleman and others, 1977, 1979). The Baid formation was described as being deposited unconformably on the Tihamat Asir complex (Gillmann, 1968; Coleman and others, 1977, 1979). We conclude that the Tihamat Asir complex is younger than the Baid formation; field evidence shows that it intrudes both the Baid formation and volcanic rocks equivalent in age to the Baid.

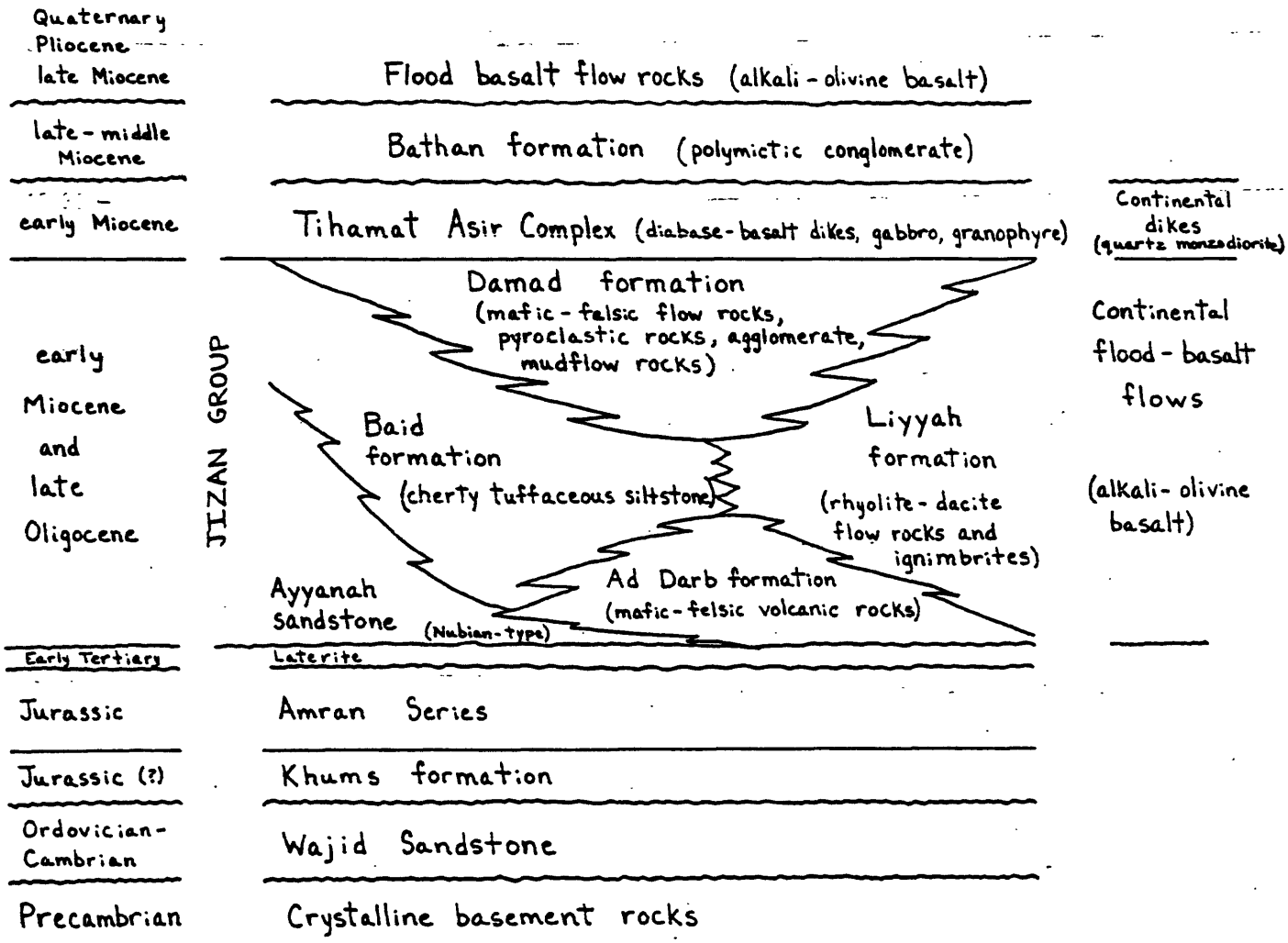

Figure 3.--Schematic stratigraphic section showing the middle Tertiary Jizan group and rock units above and below it within the continental rift of the Red Sea coastal plain, southwestern Saudi Arabia. Dikes and flows (right side of figure) are inland of the continental rift. From Schmidt and others (1982).

Brown and Jackson (1958, 1959) and Gillmann (1968) described the Baid formation as composed of siliceous tuffaceous sedimentary rocks, tuffs, andesite, basalt, and rhyolite. From our studies, we informally name the Tertiary layered rocks (previously known as the Baid formation) the Jizan group, and we define the formations within it in approximate decreasing age as follows: Ayyanah sandstone (equivalent to at least part of the Shumaysi formation in the Jiddah area), Ad Darb formation, Baid formation, Liyyah formation, and Damad formation. It was important to restructure the terminology and rank of these rocks because each formation plays an important role in understanding the rifting of the proto-Red Sea basin, because the newly designated units can be defined with relatively homogenous composition, because each formation is from tens to hundreds of meters thick, and because the formations intertongue. Table 2 lists the stratigraphy of western Saudi Arabia arising from and related to the current studies. Figure 3 schematically illustrates the vertical and lateral stratigraphic association of the formations in the Jizan group.

Economic studies.--A major objective of the current Tertiary work was to establish a sound stratigraphic and structural framework for the exploration of Tertiary ore deposits along the coastal plain south of lat 23° N. To date, exploitable mineralized rocks have not been found in the area, but the base-metal potential of Tertiary rocks of the coastal plain south of Jiddah is being investigated. The studies of some areas, such as at Umm Araj, suggest that further economic studies are required, and these areas are discussed in the last section of this report.

The economic potential of the Tertiary rocks of the Red Sea coastal plain can be divided into water, energy, and nonmetallic and metallic resources. Characteristics of the principal Tertiary metallic and nonmetallic mineral deposits and mineralized areas of western Saudi Arabia and the Red Sea coastal plain are summarized in table 3.

The water resource potential has not been pursued but is obviously related to the geologic studies. Energy resources include oil, gas, geothermal, and uranium. The oil and gas potential has been studied by private enterprise, and the geothermal potential is currently being studied by BRGM. The high geothermal crustal gradient at the continental-oceanic margin of the Red Sea enhances the geothermal potential but discourages oil potential. A gas potential is distinctly favorable for the long-term future. For various reasons, the uranium potential is low.

Nonmetallic resources include cement raw materials, gypsum, potassium and sodium salts, clays, barite, phosphorite, and sulfur, and these have been examined in the past. Currently most important are the cement raw materials limestone, clay, pozzolan, gypsum, silica, and iron for the Jizan cement plant and for future plants. The Jizan plant is situated at a large limestone deposit but requires the other raw materials. The raw materials found in the Tertiary rocks have been evaluated by USGS and others for this immediate need (appendices 3 and 4).

Gypsum and potassium and sodium salts are in sediments overlying the Jizan group; their availability is structually controlled, and the search for concealed deposits depends on structural and geophysical data acquisition and interpretation. Bentonite is a potential resource in the abundant pyroclastic deposits of the Jizan group volcanic rocks; it is formed by hydrothermal alteration, a process which was widespread in the coastal plain. Kaolinitic and ceramic clay resources are not promising, on the basis of existing studies. Barite is a resource in the central coastal plain, and one small, poorly exposed occurrence in the southern coastal plain suggests that barite deposits may be more widespread. Barite is a resource in itself but also may be a pathfinder mineral in the search for underlying base-metal deposits.

Low-grade alumina and iron oxide deposits are known resources in the Tertiary section, but higher grade, larger volume deposits have not been identified. Potential, low-grade alumina ores have been described by the BRGM in the As Sarat area, where associated lateritic iron ore deposits have been known for some time. The same lateritic deposits have been found in small volume on the coastal plain, and larger deposits may exist.

Oolitic iron beds in the Shumaysi formation may be related to the leaching of iron over broad areas of deeply weathered Precambrian rocks during a humid climate; however, deposition of the beds in a lacustrine environment is a distinct possibility as well (Lemoalle and Dupont, 1976). Hence, paleoclimate concepts, erosional history, and stratigraphy are important factors in the search for these iron deposits, whether they be in situ, mechanically concentrated, or chemically or biogenically precipitated deposits. Bauxite deposits do not seem to have much potential.

In theory certain metallic deposits are likely to be found in extensional tectonic environments and particularly in continental-rift volcanic deposits. The hydrothermal alteration of the Jizan group rift-volcanic rocks (Taylor and Coleman, 1977) probably resulted in part from volcanic deuteric alteration but also very likely resulted from subsequent convective hydrothermal circulation. Under these conditions, base-metal deposits may have formed within the rift

Table 2.--Stratigraphy, composition, and other geologic characteristics of Cenozoic and older rocks of the Red Sea coastal plain of Saudi Arabia south of lat 23° N. and other parts of western Saudi Arabia structurally affected during evolution of the Red Sea basin

Era and System		Epoch	Unit		Symbol	Lithologic composition	Thickness (meters)	Radiometric age (mega-annum)	Fossil assemblage
CENOZOIC	QUATERNARY	HOLOCENE AND PLEISTOCENE	Surficial deposits		Qu	Terrace conglomerate and gravel, sand and silt; wadi gravel, sand, and silt; eolian sand and silt plains, dunes, and linear ridges; pediment gravel and sand; sabkhah saline silt and sand; coastal calcareous sand	30	---	---
			Basalt		Qb	Alkali-olivine basalt, pyroclastic material	15	0-2	---
			Coral reef deposits		Qr	Coral, coral debris, vertebrate shells and debris	3±1	0.040+	---
			Basalt		QTb	Alkali olivine basalt	30-400	0-13	---
	TERTIARY	PLIOCENE MIOCENE AND OLIGOCENE	Raghama formation		Tr	Conglomerate, sandstone, claystone, limestone, dolomite, siltstone, gypsum, anhydrite, breccia, and basalt	2,000-5,000	---	Unidentified vertebrate material, pelecypods, gastropods, fish scales and teeth, ostracods, wood, echinoids, and foraminifera[1]
			Bathan formation		Tc	Polymictic conglomerate with clasts as long as 2.5 m, sandstone	200	---	---
			Continental dikes		Tcd	Gabbro, quartz gabbro, quartz monzogabbro, monzogabbro, quartz monzonite, monzonite	500	18-42 (average 22)[2]	---
			Tihamat Asir complex		Tta	Gabbro and granophyre plutons, diabase and basalt dikes and sills	?	18-24	---
			JIZAN GROUP	Damad formation	Tjd	Tuffs, flow rocks, agglomerate, and volcanic breccia of basaltic, trachytic, and andesitic composition	1,500	---	---
				Liyyah formation	Tjl	Flow rocks, ignimbrites, tuffs, and volcanic breccia of rhyolitic and dacitic composition	500	---	
				Baid formation	Tjb	Siliceous and tuffaceous siltstone, claystone, and shale	300	---	Freshwater fish; Cyprinid-Barbus; Cichlid-Tilapia, vertebrates, gastropods, pelecypods, ostracods: leaves[3]

			Ad Darb formation	Tja	Flow rocks, tuffs, agglomerate, and volcanic breccia of basaltic, trachytic, and andesitic composition	800	---	
			Ayyanah sandstone	Tjy	Quartz-pebble conglomerate,	42	---	Vertebrates[4]
			As Sarat and Harrat Hadan basalt	Tb	Alkali basalt, alkali-olivine basalt, trachyte	580	24-29 (As Sarat)[2]	--- ---
		EOCENE	Shumaysi formation	Ts	Pebbly sandstone, sandstone, shale, limestone, andesitic basalt, basaltic tuff, oolitic ironstone, chert, and siltstone	Ts-600	---	Mollusks, gastropods, fossil wood, pollen[5]
			Laterite	Tl	Kaolinite, goethite, quartz, illite, calcite, alunite, hematite	36	---	---
		PALEOCENE	Usfan formation	Tu	Limestone, sandstone, conglomerate	100?	42,55[2]	Mollusks[6]
			Umm Himar formation	Tuh	Shale, sandstone, mudstone, phosphatic clay, ironstone, dolomitic limestone, chert	22	---	Vertebrates: sharks, rays, lungfish, catfish, turtles, crocodilians[7]
MESOZOIC	JURASSIC		Amran Formation	Ja	Conglomerate, shale, limestone, gypsum	320	---	Vertebrates, teeth, corals, mollusks, echinoids, gastropods, plant debris, stromatopores[8]
PALEOZOIC	CAMBRIAN AND ORDOVICIAN		Khums Formation	Jk	Conglomerate, sandstone, clay shale, shale	150	---	Plant fossils[9]
			Wajid Sandstone	Oθw	Quartz-pebble conglomerate sandstone, shale, siltstone, hematitic sandstone	950	---	Spores[10]
PRECAMBRIAN			Crystalline basement	Pθ	Volcanic and sedimentary rocks and metamorphic-equivalent rocks (gneisses, schists, granulites, and so forth); mafic, intermediate, and felsic intrusive rocks	---	---	Blue-green alga Obruchevella parva; conical stromatolites, Conophyton[11]

1/ Bigot and Alabouvette (1976), Vazquez-Lopez and Motti (1981).
2/ Aldrich and others (1978), Brown (1970, 1972), Gettings and Stoeser (1981).
3/ Brown (1970), Gillmann (1968), Schmidt and others (1982).
4/ Schmidt and others (1982).
5/ Al-Shanti (1966), Brown (1970), Moltzer and Binda (1981), Schmidt and others (1982).
6/ Brown (1970), Karpoff (1957).
7/ Madden and others (1979).
8/ Geukens (1966), Schmidt and others (1982).
9/ Geukens (1966).
10/ Brown (1970), Hadley and Schmidt (1975b), D. O. Hemer (written commun., 1974), Powers and others (1966).
11/ Cloud and others (1979).

Table 3.--Characteristics of principal Tertiary mineral deposits and mineralized areas of western Saudi Arabia and the Red Sea coastal plain

Name	Location and map sheet number	Type of deposit	Host rocks	Structural setting	Ore and associated minerals	Type of genesis	Principal sources of data	Ore resources/ reserves and grade
Umm Gerad (Rabigh) barite deposit	About 21 km northeast of Rabigh, centered at about lat 22°55' N., long 39°9' E. (22/39A)	Vein	Precambrian granodiorite	Barite veins filled northwest-trending fractures of Tertiary age parallel to the trend of the Red Sea and controlled by Tertiary rifting of the Red Sea basin	Barite, chalcopyrite, galena, jasper, quartz, calcite	Hydrothermal	Al-Shanti, (1970); Schaffner, (1958a), Brobst, (1965a), (Roberts and others, 1975)	1,000,000 tons of barite to a depth of 30 m averaging greater than 90 percent $BaSO_4$
Shumaysi iron ore	Outcrops north and south of Wadi Fatimah about 40 km east of Jiddah (21/39B, D)	Sedimentary, oolitic	Eocene to Miocene Shumaysi formation	Folded sedimentary rocks striking generally parallel to the Red Sea trend; the rocks are in a graben and horst block setting; the basal Shumaysi rests unconformably on Precambrian basement	Goethite, hematite, hydrohemstite; quartz, apatite, gypsum, siderite, anhydrite, clay, feldspar, aluminum gels	Primary sedimentation of goethetic oolites in a relatively low energy freshwater, probably deltaic and lacustrine, environment (James, 1966; Lemoalle and Dupont, 1976)	Al-Shanti, (1966), Internationale Planungs- und Consulting G.m.b.H. (1963b), Moltzer and Binda (1981)	50 million tons of iron ore ranging from 46-48 percent iron
Maqna massif base metal mineralization (Jabals Hamdza, Musayr, Tayran, Faya, and Amrah)	Vicinity of Maqna and Al Bad, (28/34B, 28/35A, 28/34D, 28/35D)	Vein; filled fractures and brecciated zones; stockwork filling	Limestone, dolomite, gypsum, and anhydrite of the Raghama formation of Miocene age and Precambrian basement rocks	Folded, faulted, and fractured sedimentary rocks of the Raghama formation and Precambrian basement	Barite, galena, coronadite-cesarolite group minerals; ankerite, sphalerite, pyrite, chalcopyrite	Primary sedimentation from supersaturated marine water; secondary deposition in fractures of Precambrian and Tertiary rocks by remobilized solutions	Vazquez-Lopez and Motti (1981), Bokhari (1981), Bigot and Alabouvette (1976), Lhegu (1981).	No data

Table 3.--Characteristics of principal Tertiary mineral deposits and mineralized areas of western Saudi Arabia and the Red Sea coastal plain--Continued

Name	Location and map sheet number	Type of deposit	Host rocks	Structural setting	Ore and associated minerals	Type of genesis	Principal sources of data	Ore resources/ reserves and grade
Maqna massif gypsum	Maqna-Al Bad area, northwest Saudi Arabia (28/43B, 28/35A, 28/34D, 28/35C)	Sedimentary (bedded)	Raghama formation of Miocene age	Folded and faulted sedimentary rocks of the Raghama formation deformed during the late Miocene to Quaternary by tectonics associated with structural development of the Red Sea and Gulf of Aqaba rifts	Gypsum; anhydrite, apatite, glauconite, quartz, celestite, halite barite, kaolinite, and illite	Primary shallow marine deposition	Le Nindre (1981), Vazquez-Lopez and Motti (1981), Bigot and Alabouvette (1976), Bokhari (1981), Remond and Teixido (1980)	No quantitative data available on the amount of gypsum present in the area, but reserves are estimated to be high; the economic potential is highly favorable for gypsum extraction. The gypsum ranges from 200 to 300 m thick
Jabel Dhaylan North lead-zinc deposit	Jabal Dhaylan, about lat 25°35' N., long 37°05'-15' E. (25/37A)	Secondary replacement of strata-bound and fracture-controlled zones	Limestone, marl, and arkoae of the lower red series (Ra_1) and Jabal Dhaylan series (Ra_2) of the Raghama formation	Moderately deformed sedimentary strata controlled by horst and graben style tectonics	Galena, cerussite, chrysocolla, malachite, wad, pyrolusite, smithaonite, hemimorphite, hydrozincite, barite, calcite, and quartz	Secondary replacement	Dadet and others (1970), Roberts and others (1975), Bigot and Alabouvette (1976), Vazquez-Lopez and Motti (1981)	300,000 tons: 4.9 percent zinc and 1.39 percent lead; these are total figures for the whole of Jabal Dhaylan
Jabal Dhaylan South lead-zinc deposit	Jabal Dhaylan, about lat 25°35' N., long 37°05'-15' E. (25/37A)	Secondary replacement of strata-bound and fracture-controlled zones	Limestone, marl, and arkose of the lower red series (Ra_1) and Jsbal Dhaylsn series (Ra_2) of the Raghama formation. The lower red series is of Oligocene(?) to Miocene age and the Jabal Dhaylan series is Miocene	Moderately deformed sedimentary strata controlled by horst and grsben style tectonics	Galena, cerussite, chryscolla, malachite, smithsonite, hemimorphite, hydrozincite, wad, pyrolusite, psilomelane, calcite, and quartz	Secondary replacement	Dsdet and others (1970), Roberts and others (1975), Bigot and Alabouvette (1976), Vazquez-Lopez and Motti (1981)	See above
Wadi Hayr to Wadi Amk lead-zinc depoaits	Red Sea coastal plain region north northwest of Umm Lajj between approximately lat 25°15' and 25°35' N. (25/37A, C)	Replacement; deposition of bese metals in fractures and breccisted limeatone	Limestone of the Jabal Dhaylan series (Ra_2), Raghama formation	Deformed Tertiary sedimentary rocks in a horst and graben tectonic environment, marginal to the Red Sea basin	Galena, hemalite, quartz, pyrolusite	Secondary replacement	Bigot and Alabouvette (1976), Vazquez-Lopez and Motti (1981)	No data published

Table 3.--Characteristics of principal Tertiary mineral deposits and mineralized areas of western Saudi Arabia and the Red Sea coastal plain--Continued

Name	Location and map sheet number	Type of deposit	Host rocks	Structural setting	Ore and associated minerals	Type of genesis	Principal sources of data	Ore resources/ reserves and grade
Azlam trough bedded phosphate	A northwest-trending zone between Wadi Rabigh and Wadi Bahar, between lat 26°32' and 27°10' N., long 35°45' and 36°40' E. (27/35D, 27/36C, 26/36A, B)	Sedimentary	Cretaceous through Miocene clastic, calcareous, and argilliceous rocks assigned to the Azlam and Raghama(?) formations by Davies (1981)	Graben	The principal ore is phosphatic material in the form of bone fragments and is assumed to be apatite	Sedimentary	Bigot and Alabouvette (1976), Alabouvette and others (1979), Alabouvette and others (1981), Vazquez-Lopez and Motti (1981)	No data
Yanbu al Bahr area lead-zinc deposits	Tertiary exposures 15-30 km north of Yanbu al Bahr between approximate-lat 24°10' and 24°25' N., long 37°35' and 38°15' E. (24/37D, 24/38C)	Secondary replacement of fracture zones; stockwork	Conglomerate, sandstone, and limestone of the Jabal Dhaylan series, unit Ra_2	Deformed sedimentary rocks of the Raghama formation controlled by horst and graben tectonics	Galena, cerussite, vanadinite, and barite	Secondary replacement	Bigot and Alabouvette (1976), Vazquez-Lopez and Motti (1981)	Reserves or resources not published; grades of elements are: 1-12 percent lead; 0.5-13.5 percent zinc; 4 percent barium; 1.1 g/t silver
Al Wajh area Lead-zinc deposits	Coastal Tertiary Raghama formation exposures in a linear belt between Al Humayrah and Wadi Thalbah, lat 26°5'to 26°40' N., long 36°15' to 36°40' E. (26/36A, C, D)	Secondary replacement of fracture zones(?)	Limestone of the Jabal Dhaylan series, Ra_2 (?)	Deformed Raghama formation resting unconformably on Precambrian basement rocks	Galena, zinc and manganese oxides	Secondary replacement		No published resources; lead and zinc are generally less than 1 percent

Table 3.--Characteristics of principal Tertiary mineral deposits and mineralized areas of western Saudi Arabia and the Red Sea coastal plain--Continued

Name	Location and map sheet number	Type of deposit	Host rocks	Structural setting	Ore and associated minerals	Type of genesis	Principal sources of data	Ore resources/ reserves and grade
Jizan salt dome deposit	Jizan, lat 16°52' N., long 42°33' E. (16/42B)	Sedimentary	Upper Miocene Evaporate Series intrudes clastic sediments of Pliocene(?) Continental Series (Gillmann, 1968)	Salt has risen diapirically through overlying Tertiary sedimentary rocks forming a domal structure	Halite	Primary salt deposition	Baltes (1956), Herness (1964), Mideast Industriee, Ltd. (1966)	30 million tons within 40 m of the surface; contains 96 percent NaCl
Yanbu-Umm Lajj gypsum	Near Sharm Mahar lat 24°40' N., long 37°18' E., and Marsa Maqbarah lat 24°26' N., long 37°27' E. (24/37A, C)	Sedimentary	Raghama formation	Deformed sedimentary rocks controlled by horst and graben tectonics	Gypsum	Primary deposition in a shallow-marine evaporite basin	Al-Shanti and Sultan (1966), Alabouvette and Pellaton (1975), Alabouvette (1976), Laurent and others (1978)	300 million tons of gypsum suitable for plaster manufacture
As Sarat laterite	As Sarat Mountains between lat 17°30' and 18°20' N. (17/43A, 18/43C)	In situ soil (layered)	Surface deposit resting on Precambrian basement rocks and Wajid Sandstone; the laterite lies beneath As Sarat basalt dated at 29 Ma	Eroded and uplifted Asir plateau	Kaolinite, quartz, goethite, illite, calcite, alunite	Subaerial weathering in a warm to hot, humid climate; low relief prevailed in the area, probably near sea level	Overstreet and others (1977), Anderson (1979), Odent and Al Habshi (1981)	35 million m^3 of material containing more than 21 percent alumina
Jabal Sita barite	10 km south-southeast of Jabal Sita, lat 20°53' N., long 39°42' E.(20/39B)	Vein	Sandstone of the Shumaysi formation(?) or Ayyanah sandstone(?)	Block-faulted and folded Tertiary sedimentary rocks located at the boundary of the Precambrian basement-Red Sea basin rift	Barite	Hydrothermal	J. S. Pallister and D. L. Schmidt, (oral comm., 1982)	Known exposure small
Masliyah magnetite	Jabal Hathah, 8 km east of Masliyah, (17/42 D)	Magmatic layers(?) and lenses	Precambrian basement	Intrusion of Tihamat Asir gabbro at boundary of Precambrian basement and Red Sea basin rift	Magnetite	Magmatic	Bhutta (1962)	Indicated reserves 60,000 tons magnetite
Al Kura gypsum	Al Harrah, Al Kura 34 km north of Jiddah	Chemical, sedimentary	Raghama formation(?)	Sedimentary rocks deposited at margin of Red Sea	Gypsum	Primary deposit in shallow-marine evaporite basin	Morris (1975)	Small production of 20-30 ton/day for Jiddah cement plant

volcanic pile and in overlying sediments, particularly in overlying limestones such as at Jabal Dhaylan or in an adjacent geologic setting such as at Umm Araj.

Several active hot springs, as well as some ancient hot spring deposits, have been found in the southern coastal plain. These attest to the presence of hydrothermal activity in the coastal plain, and study of these deposits may indicate ore deposits at depth. Iron oxides and manganese oxides in some of these spring deposits are readily observed, but trace element contents are not known.

Highly siliceous pyritic volcanic flow and eruptive conduit rocks containing slightly anomalous amounts of silver crop out at several localities on the coastal plain (Jabal Sita, Musaylim, and near Ad Darb). These occurrences suggest that rhyolitic magma within the continental rift intercepted massive sulfide deposits at depth either in the Tertiary volcanic pile itself or in the underlying Precambrian basement. Hypabyssal granitic outcrops indicate a potential porphyry molybdenite association, the possibility of which is being examined further. A small magnetite deposit has been found in association with the Tertiary layered gabbros, and larger deposits might be expected. A lack of known ultramafic components in these exposed layered gabbros discourages the search for chromium or platinum group metals.

The metalliferous muds of the Red Sea mid-oceanic trench form a favorable deposit that is outside our realm of study. However, older similar metalliferous muds may have also formed, and, because oceanic crust underlies the coastal plain in places, such ancient metal deposits may be present. Such deposits may be too deeply buried to be exploitable, but the possibility of their being reworked and some metals redeposited in more favorable positions should be considered. Zinc, copper, lead, iron, and possibly precious metals may be expected.

Summary

Conclusions drawn from this work to date are presented below in outline form. Some items are not specific conclusions arising from this work but are included in order to present a cohesive account of the evolution of the Red Sea basin. Results and conclusions generated by the current Tertiary program (Schmidt and others, 1982) are denoted using an asterisk (*).

*1. The Baid formation is restricted and made part of a group (Jizan) containing a series of new formations.

*2. The Tihamat Asir complex intruded units of the Jizan group and is therefore younger than previously thought (Coleman and others, 1977, 1979a and b). It

was emplaced in the extended continental margin adjacent to contemporaneous oceanic crust.

*3. The Arabian-Nubian Shield split by processes analogous to formation of the East African rift. This continental-rift-valley stage began in middle to late Oligocene time and continued until approximately 20 Ma ago, when three events occurred along the northwest-trending arm of the Afar triple junction. These were extensional foundering of the rift flank and rotation of the Phanerozoic rocks toward the axis of the rift, injection of tholeiitic magma along rift fault planes, and injection of mantle material into the lithosphere, which marked the opening of the juvenile Red Sea and initiation of Miocene sea-floor spreading.

*4. Sea-floor spreading continued until about 15 Ma ago, when isostatic adjustments and heating, thinning, and compositional changes in the continental lithosphere (Gettings, 1982) caused first-stage uplift of the Red Sea escarpment.

*5. First-stage uplift of the escarpment resulted in erosion of the Paleozoic and Mesozoic cover rocks, erosion of the Precambrian shield rocks, and deposition of the very coarse grained Bathan formation.

6. During deposition of the Bathan formation, marine waters invaded the subsiding Red Sea trough filled with oceanic crust. Gray shale, fine-grained sandstone, and conglomerate (Infraevaporatic series of Gillmann, 1968) were deposited in the Red Sea. This series probably correlates with the middle Miocene Globigerina Marls (Gillmann, 1968), which are widely known in the Red Sea basin and contain a Mediterranean fauna.

7. Tectonic quiescence of the region followed cessation of first-stage sea-floor spreading and uplift of the Red Sea escarpment and was marked by deposition of the thick upper Miocene evaporate series and interbedded clastic material (Gillmann, 1968; Stoffers and Ross, 1977).

8. About 5 Ma before present, the following events took place and have continued to the present:

   a) Cessation of evaporite deposition with the deposition of an anhydrite cap rock known as the "S" reflector (Ross and Schlee, 1977).

b) A renewed phase of crustal attenuation and sea-floor spreading in the axial trough (Girdler and Styles, 1974; Coleman, 1977) and further uplift of the escarpment.

c) Deposition of fine-grained continental clastic sediments in the Red Sea and deposition of coarse-grained clastic sediments near shore and onhore in a fluvial environment.

d) Renewed movement on extensional faults with deformation and rotation of the Bathan formation and older Tertiary sequences.

e) Erosion of the Bathan formation and older rocks.

f) Deposition of metalliferous muds in the hot-brine deeps of the Red Sea axial trough.

g) Extrusion of alkali-olivine basalt along the southern Red Sea coastal plain as well as inland on the Arabian Shield. The most recent eruption occurred in historic time near Al Madinah.

h) Diapiric emplacement of salt domes near the coast and in the Red Sea main trough.

9. During the Quaternary Period, continued uplift of western Arabia is reflected by 2-4 m of elevation of the Pleistocene coral reefs; diapiric salt intrusion continues in the Red Sea basin to the present.

RECOMMENDED FUTURE WORK

Rocks belonging to the Tertiary System in western Saudi Arabia have been studied for many years, and, for the most part, these studies have had an economic focus. The Tertiary rocks have not been studied systematically throughout their outcrop area in adequate detail. Studies related to the Tertiary layered rocks include Al-Shanti's study of the Shumaysi formation in the Wadi Fatimah area (1966) and Gillmann's outstanding study of the Tertiary volcanic and sedimentary rocks in the Jizan area (1968). Since 1973, the area between Jizan and Jiddah has been studied (Schmidt and others, 1982), and more detailed work is in progress. The coastal-plain sector between Jiddah and Yanbu has not been systematically studied to date nor have the rocks been correlated with those to the south or north. Several detailed studies have been made that include geophysical work (Blank, 1977; Gettings, 1977; Hall, 1979; Healy and others, 1982, 1983).

The Tertiary rocks indicate potential for economic mineral resources, but prospecting requires further input from

basic geology studies. Nonmetallic minerals including potash, phosphate, and evaporitic salts such as halite, gypsum, anhydrite, and so forth exist or potentially exist in the Tertiary strata; a variety of industrial materials including perlite, pozzolan, building stone, and cement raw materials from the coastal plain have been exploited or may be utilized in the future, and hydrocarbon storage in chambered evaporitic rocks is a potential industrial use of the Tertiary rocks. A continued program of basic and economic geologic investigations of the Tertiary System along the Saudi Arabian Red Sea margin is recommended, as described below.

Study of Tertiary sedimentary rocks from Jiddah to Yanbu al Bahr

The Tertiary and older sedimentary rocks (Usfan formation) on the Red Sea coastal plain north of Jiddah have been studied only in reconnaissance and have not been mapped in detail. Questions remain about the ages of some of these rocks, their composition and stratigraphy, and correlation with rocks to the south (Shumaysi formation and Jizan group). Mineral resource information for these rocks is poor.

Study of base-metal potential of the Amran series, Umm Araj area

Limestone of the Amran series near Umm Araj has been extensively intruded by mafic dikes and sills related to first-stage opening of the Red Sea. These intrusive rocks are known to be hydrothermally altered (Taylor and Coleman, 1977), and they may have significantly altered the host limestone and provided an environment for metal deposition. The Umm Araj limestone should be examined for possible base-metal mineralization; this should include a re-examination study of drill core that intersected the mafic intrusions (Cheeseman and Binda, 1981).

Geochronology of the Cenozoic rocks of the Red Sea coastal plain

A number of potassium-argon dates are available for Tertiary rocks from along the coastal plain, but many of these dates are at variance with other dates from the same units, and most of the units have not been adequately and systematically dated. Some resampling of the coastal-plain Tertiary rocks is recommended in areas where the field relations are well understood, in an attempt to obtain the best possible absolute ages on these rocks. For example, only three dates are available for the Shumaysi formation and three dates for the Baid formation. There is some question as to whether these dates represent samples from flow rocks or hypabyssal sills.

Rare-earth element and oxygen isotope geochemistry of coastal-plain igneous rocks

Rare-earth element and oxygen isotope geochemistry is useful in determining the genesis and hydrothermal alteration of plutonic and volcanic rocks. The Tihamat Asir complex and Red Sea continental dikes in the Ad Darb to Jizan area and basalts from the axial trough of the Red Sea have been sampled and analyzed in some detail (Coleman and others, 1975; Taylor and Coleman, 1977; Coleman and others, 1979a and b), but Tertiary volcanic and intrusive rocks along the coastal plain northward from Ad Darb have not yet been analyzed. Samples on hand and samples collected in the future should be analyzed for their rare-earth element and oxygen isotope compositions in order to understand their mode of origin and subsequent alteration. An understanding of the alteration aspects of these rocks is important for mineral resource studies because an environment of hydrothermal alteration is likely to be an environment of ore deposition as well. Dike and sill specimens from drill core at Umm Araj (Cheeseman and Binda, 1981) should be evaluated chemically because this area may contain hydrothermal mineral deposits.

Paleontologic study of vertebrate fauna from Jizan group rocks

Vertebrate fossils have been collected from the Ayyanah sandstone, and fossil fish material is known from the Baid formation. Existing specimens should be studied systematically and attempts should be made to collect additional specimens as a means of determining the age and paleoenvironment of the Jizan group, correlating units within the group, comparing the fauna and age of the Jizan group with the Umm Himar formation and other Tertiary formations along the northern Red Sea coastal plain, and bridging the vertebrate gap between East Africa and eastern Arabia (Andrews and others, 1978; Hamilton and others, 1978; Thomas and others, 1978; Sen and Thomas, 1979; Madden and others, 1982).

Paleontologic study of the invertebrate fauna and flora of coastal-plain Tertiary rocks

The Baid formation contains ostracods, gastropods, and pelecypods (Gillmann, 1968) that have not been useful in establishing a reliable age but which may be useful for correlation. Fragments of wood have been identified in the Baid formation and in the Ayyanah sandstone, and excellent leaf specimens have been found in the Baid formation in the Jabal Sita area. These have not been examined by a Tertiary floral specialist. Foraminifera and pollen have been studied from the Shumaysi formation (Moltzer and Binda, 1981). Critical examination of the Baid formation and Ayyanah sandstone might also reveal foraminifera and pollen. Further study of the

invertebrate fauna and flora of the Baid, Ayyanah, and Bathan formations and the lower section of the Shumaysi formation is recommended.

Gravity survey of the coastal plain between Jiddah and the Gulf of Aqaba

Gravity data have been acquired for the Red Sea coastal plain between Jiddah and the Yemen border and in a small area north of Jiddah. Unsurveyed areas should be surveyed to provide complete coverage of the coastal plain. The gravity data will be important in developing an understanding of the structure of the coastal plain, for depicting the continental-oceanic crust contact, and as a quantitative mechanism for locating possible subsurface salt domes and zones of metallic mineralization.

Microseismic surveys along the Red Sea coastal plain

Microseismic surveys conducted along the Red Sea coastal plain of Saudi Arabia indicate an unexpectedly high level of seismic activity (Merghelani, 1978, 1979b, 1980, 1981; Merghelani and Gallanthine, 1981). This activity is associated for the most part with transform fault zones and volcanic centers identified by other geologic and geophysical means. Some of the Red Sea transform faults are in or near major industrial and cultural centers, and, for this reason, the surveys should be continued and expanded in order to evaluate the potential for hazardous earthquakes in these areas. An earthquake-hazards reduction program has both human and commercial ramifications, and microseismic surveys are one of the first steps in its planning.

Heat-flow studies

Heat-flow data are available from three holes in the coastal plain of southwestern Arabia along a traverse approximately perpendicular to the Red Sea (Gettings, 1982; Gettings and Showail, 1982). Additional data would provide a systematic heat-flow data set. The data could be supplemented by measuring the heat flow at locations previously drilled for economic purposes, such as the Umm Araj limestone and the Rabigh barite. Heat-flow data, like oxygen isotope data, are indicators of possible hydrothermal activity in rocks and therefore sites of possible mineralization. Tertiary intrusive rocks in the Jizan area are known to be hydrothermally altered (Coleman and others, 1975, 1979a; Taylor and Coleman, 1977), and hydrothermal ore deposits have been found in or near coastal-plain rocks of Tertiary age, such as those at Umm Gerad and Jabal Dhaylan. Heat-flow data therefore provide another geologic parameter that can be useful in mineral exploration programs.

Geologic map of the Red Sea basin at scale 1:2,000,000

Various types of maps have been compiled of the Red Sea and the Red Sea basin, such as the bathymetric chart of the Red Sea at scale 1:2,000,000 (Loughton, 1970), the tectonic map of the Arabian Peninsula at scale 1:4,000,000 (Brown, 1971a, b, and c, 1972), and the geologic map of the Red Sea at scale 1:2,000,000 (Coleman, 1973). These maps are more than a decade old, and substantial earth-science information has accumulated since their publication. Moreover, important data were not included in the earlier maps because they were unpublished or unavailable. A new geologic map of the Red Sea region is recommended to incorporate up-to-date information in a convenient format and should include composition, stratigraphy, structure, mineral resources, and data relating to the plate-tectonic evolution of the basin.

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Appendix 1.--*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia prior to 1947*

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geology of the Farasan Islands, Gizan and Kamaran Islands, Red Sea, Part 3, Echinoidea	Invertebrate paleontologic study of the Farasan Islands, Jizan, and Kameren Islands	Farasan, Jizan and Kamaran Islands	A total of 14 basic species of Echinoides were studied from specimens collected from three limestone and marly limestone units on the Farasan Islands. Four species are known from the Pliocene, but taken together, the collection indicates a Pleistocene age for the limestones	Brighton, A. G.	1931	Geological Magazine, v. 68, p. 323-333	
The gold mines of Midian	Natural history and mineral resource reconnaissance of NW Arabia	Northwestern Saudi Arabia along the coast and partly inland from Maqna to Sharm Ziban	Tertiary outcrop were noted in the Maqna area including the gypsum-bearing parts of the Raghama formation	Burton, R.F.	1879	C. Kegan Paul and Co., London, 244 p.	Reprinted: 1979, Oleander Press, Cambridge, England
Gravity survey of Jizan	Gravity survey in the vicinity of Jizan	Red Sea coastal plain near Jizan	A strip of land 42 km by 80 km was surveyed using ground traverses and Thyason gravimeters; 103 magnetic measurements were also made in the survey area; the gravity data could not differentiate the Tertiary rocks in the subsurface; the crystalline basement descends regularly towards the Red Sea; the Jizan salt dome resulted from Tertiary formations sliding along the basement; magnetic anomalies on the coastal plain result chiefly from magnetic sands	Compagnie Generals de Geophysique	1939	DGMR Open-File Report 217-CGG-JIZ-1, 27 p.	
Rabigh	Reconnaissance study of the Rabigh district	Coastal plain and foothills area east of Rabigh	Conclusions of the report not available for this paper. May be obtained possibly from the DGMR Library	Shaw, G. A.	1936	Saudi Arabian Mining Syndicate Report 3/210/4145, 40 p.	

Appendix 2.--*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1947 and 1960*

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Exploration of the Jizan salt dome	Evaluation of the economic potential of the Jizan salt dome	Jizan salt dome	Jizan salt deposit wes found to be extensive enough to support mining	Baltes, H.	1956	DGMR Open-File Report 68, 3 p.	
Clay investigations of the Jiddah area	Evaluation of the clay resources for use in cement	Jiddah area	Clay resources were identified but were found to be too siliceous for use in cement	Bhutta, M.A.	1960	DGMR Open-File Report 105, 24 p.	
Geomorphology of western and central Saudi Arabie	To describe the physiographic provinces and geomorphology of western and central Saudi Arebia (inferred)	Western and central Saudi Arabia, mostly west of long 48°E.	The physiographic provinces from west to east are Tihama or coastal plain, scarp mountains, the ramped plateau of the Hijaz, Najd, and tne central cuesta region. Many features are related to mid-Tertiary peneplanstion, lakebed deposition, and volcanism. Associated with this period was rifting of Arabia away from Africa development of the ramp faults and uplift of the Asir plateau end the consequent drainege system development	Brown, G. F.	1960	21st International Geological Congress, Copenhagen, sec. 9, p. 150-159	
Geologic map of Tihamat Ash Sham Quadrangle	Preparation of a geologic map at scale 1:500,000 showing principal rock types and structure	lat 16° to 20°N. and long 39° to 42°E. including part of Red Sea	The Tertiary Baid formation was described as well as other Tertiary and Holocene rocks	Brown, G.F. and Jackson, R.O.	1958	USGS Miscellaneous Geologic Investigations Map I-216 A	
Geologic map of the Asir quadrangle	Preparation of a geologic map at scale 1:500,000 showing principal rock types and structure	lat 16° to 20°N. and long 42° to 45° E.	Various Tertiary geologic rocks are described, including a description of the Baid formation type locality	Brown, G.F. and Jackson, R.O.	1959	USGS Miscellaneous Geologic Investigations Map I-217 A	
Geology of Saudi Arabian Red Sea coastal plain and Farasan Islands	General geologic study of area and evaluation of its petroleum potential	Red Sea coastal plain of southwest Saudi Arabia and Farasan Islands	Stratigrephy and structural geology of the Tertiary and Holocene rocks, including paleontological dates and petrograhpic data; petroleum potential appears low	De Golyer and MacNaughton	1953	DGMR Open-File Report 28, 49 p.	Geology of the opposite side of the Red Sea wes evaluatsd as was previous exploratory work
Gravity measurements, Seudi Arabia	Establishment a base station at Jiddah and an initial gravity net in Saudi Arebia	Selected sites throughout Saudi Arabia	A gravity map of the area wes compiled but was not available for this report	Ghalayini, A.K.	1958	DGMR Open-File Report 82, 22 p.	
Sur l'existence du Maestrichtien au Nord de Djeddah (Arabic seoudite)	To briefly examine and report on the geology, paleontology, and age relationships of the Tertiary and older rocks, in particular the Usfen and Shumaysi formations	The coastal plain area for a distance of 110 km northeast of Jiddah	The Usfan and Shumaysi formations are sporadically expoeed in an area northeast of Jiddah near the boundary between the coastal plain and Precambrian foothills for a distance of 110 km. Of particular interest were exposures of the Usfan formation 3 km north of the village of Usfan. The Usfan is a calcareous marine sequence containing a fossil assemblage considered to be Maestrichtian. The Shumaysi was assigned to the Oligocene and Miocene (?)	Karpoff, R.	1957	C. r. hebd. Seanc. Acad. Sci., Paris, 245, p. 1322-1324	
Geology of Umm Gerad barite deposit	Geologic and economic evaluation of the Umm Gerad barite veins	Barite deposit, 20 km northeast of Rabigh	Barite veins, 1-10 feet wide, are in granite-diorite. An exploration shaft was recommended.	MacLean, W. H.	1958	DGMR Open-File Report 83, 3 p.	The veins were noted to be parallel to the Red Sea, implying a Tertiary origin for them

Appendix 2.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1947 and 1960*—Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geological research in Western Saudi Arabia	To determine what geological work would lead to the discovery of economic mineral deposits in Saudi Arabia	Western Saudi Arabia	Except for the Hali area, there is considerable potential for oil discovery along the coastal plain; a significant potential for gypsum exists in the Maqna-Al Bad area and for iron ore near Jiddah	Richter-Bernborg, G. and Schott, W.	1954	DGMR Open-File Report 38, 69 p.	Budget figures were given for exploration costs; favorable recommendations were made for the exploration of water, quartz, and onyx
Barite outcrops at Umm Gerad	Economic evaluation of the Umm Gerad barite veins	Umm Gerad deposit, 20 km northeast of Rabigh	Ore to a depth of 100 feet below surface is estimated at 100,000 tons; first 10 feet contains 96.1 percent $BaSO_4$	Schaffner, D.F.	1958a	DGMR Open-File Report 88, 9 p.	Drill holes were sunk to 100 feet, but recovery was poor
Beach placer near Al Qahmah	Evaluation of beach placer-sand deposits along the Red Sea coast	12-18 km SE of Red Sea village of Al Qahmah, lat 18°N.	Conservative reserves of 3 million tons sand and 182,000 long tons of concentratee. Magnetic fraction is 6.2 percent	Schaffner, D.F.	1958b	DGMR Open-File Report 92, 15 p.	Heavy minerals of the sand are ilmenite and magnetite
Oolitic hematite deposits of Wadi Fatima district	Geologic and economic evaluation of the Wadi Fatimah oolitic iron deposits	Wadi Fatimah-Ash Shumaysi-Usfan	Potentially exploitable oolitic iron is in Eocene sandstone	Schaffner, D.F.	1960	DGMR Open-File Report 112, 8 p.	p.77
Economic geological report for 1375	General economic geological evaluation of the area	Entire Red Sea coastal plain and Hijaz mountains	Salt reserves of the Jizan salt dome estimated at 1 million ton/m depth; barite veins NE of Rabigh show potential; high-grade kaolin deposits were sampled; large gypsum deposits are between Yanbu and Aqaba	Short, A.M.	1956,	DGMR Open-File Report 55, 3 p.	
Red Sea beach sand	Economic evaluation of beach sands along the Red Sea	Entire Red Sea coast line	Analyses were made on 86 beach sand samples. Major economic minerals identified were ilmenite, and zircon	Short, A. M.	1967	DGMR Open-File Report 56, 12 p.	No economically extractable deposit was found
Gravity measurements on Jiddah-Mecca road	Reconnaissance gravity survey of area and establishment of base line	Jiddah-Mecca		Tayim, H. A.	1959	DGMR Open-File Report 99, 3 p.	Data not available for this report; possibly may be seen in the DGMR Library
Geological journey through Saudi Arabia	Evaluation of the mineral potential of Saudi Arabia	Kingdom of Saudi Arabia, mainly the western (Precambrian Shield) part	The Tertiary and coastal plain contains considerable potential for salt, gypsum, possibly clays, and placer deposits	von Gaertner, H.R. and Schurenberg, H.	1954	DGMR Open-File Report 40, 75 p.	A more detailed geological survey of the Tertiary System and coastal plain of the Red Sea was recommended

Appendix 3.--*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1961 and 1972*

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geological-gravimeter investigation of Al Lisan basin	Economic mineral evaluation of the Al Lisan area	Al Lisan area, SE end of Gulf of Aqaba	Economic potential of area is low. no marine beds were found.	Agocs, W.B. and Kahr, V.P.	1962	DGMR Open-File Report 140, 6 p.	Tertiary rocks are exposed in the area, petroleum seeps are reported
Aeromagnetic interpretation of the Jizan area	Basin and subsurface structural interpretation and economic mineral evaluation of the area	Jizan area	Baaement depths range from 0 to more than 15,000 ft. near tha coastline; salt domes other than at Jizan are suggested in the area; an area east of Mashjah is worth exploring based on a positive aeromagnetic anomaly	Agocs, W.B. and Kellar, F.	1962	DGMR Open-File Report 142, 11 p.	The radioactivity data doee not disclose any noteworthy anomalies
General geology of the Wadi Fatimah iron deposite	General geologic study of the iron ore-baaring rocks of the Wadi Fatimah area	Wadi Fatimah batween Jiddah and Makkah	Sedimentary rocks of late Cretaceous or early Eocene age containing oolitic iron beds were divided into three parts: coarse-grained clastic rocks at the base; a middle part of sandstone, fine-grained terrigenous clastic rocks, and two iron beds; and an upper part of fine-grained sandstone, chert, and a basalt sill; thickness 500-1,000 ft.	Al Shanti, A.M.S.	1961	DGMR Open-File Report 131, 9 p.	
Reports on drill holes and exploration of Wadi Fatimah iron ore beds	Economic and mineral resource evaluation of the Wadi Fatimah oolitic iron ore beds	Wadi Fatimah and Shumayai areas between Jiddah and Makkah	See Open-File reports for conclusions	Al Shanti, A.M.S.	1968, 1969a	DGMR Open-File Reports 321, 322, 323, 324, and 336	
Supplementary exploration of Wadi Fatimah iron ore	Exploration of the Wadi Fatimah iron ore for domestic steel works	Wedi Fatimah iron ore area	Iron ore deposits totalling 26 million tons in area 1 and 22 million tons in area 2a were considered for mining	Al Shanti, A.M.S.	1969b	DGMR Mineral Resources Research 1967-68, p. 57-60	Availability of water may determine the choice of initial mining
Oolitic iron-ore deposits in Wadi Fatima	Mapping, detailed geologic study, evaluation of tha economic potential of the oolitic iron ore deposits	Wadi Fatima area between Jiddah and Mecca, lat 21°15' to 21° 45' N.	The oolitic iron beds are contained within the Shumaysi formation of probable Oligocene age; the Shumaysi consists of sandstone, siltstone, shale, pebbly sandatone, volcanic tuff, chert, and oolitic iron and waa deposited in a marine environment; 50 million tons of ore were estimated averaging 44-50 percent iron	Al-Shanti, A.M.	1966	DGMR Bullatin 2, 51 p.	
Rabigh barite deposits	Detailed geologic study of the Rabigh barite area and economic evaluation of its ore-producing potential	Rabigh barita, 21 km NE of Rabigh; centered at about lat 22° 55' N., long 39°9' E.	The barite veins are hydrothermal, of Tertiary age, and controlled by Red Sea rift structure; barite tonnage is 100,000 tons of more than 90 percent $BaSO_4$; aasociated jasperoid maaaes contain anomalous Be, B, and Y	Al-Shanti, A.M.S.	1970	DGMR Mineral Resources Research 1968-1969, p. 51-57	
Umm Lajj coastal sediments	Detailed structural and stratigraphic study of coastal plain Tertiary sediments and their geologic relationship to an offshore seismic survey	Coastal plain of the Red Sea north and south of Umm Lajj	Tertiary sedimentary rocks rest unconformally on the Precambrian basement and consist of a thin basal conglomerate, a thick reef limestone with common chert, a thick gypsum-anhydrite layer, and shala siltstone and fine-grained sandstone. Major faults parallal the coast offset the Tertiary strata; folding in the area appears to ba related to evaporite diapirs	Al Shanti, A.M.S. and Sultan, G.H.	1966	DGMR Open-File Report 281, 18 p.	
Geophysical surveys at Jabal Dhaylan	To test eeveral geophysical methods that would define the Jabal Dhaylan horat bayond its mineralized surface exposures	Jabal Dhaylan, lat 25°35' N., long 37°10' E.	Magnetic and TURAM were unsuitable and SP producad no anomalies; electrical sounding methods were inaccurate but enabled a northward extension of the horst to be identified suggesting additional drilling targets	Arabian Geophysical and Surveying Company (ARGAS)	1970	ARGAS Report 5920-AD, 20 p.	
Geology of the Wadi Yiba quadrangle (19/41 D)	Reconnaissance geologic mapping of the Wadi Yiba quadrangle and mineral resource assessment	lat 19°00' to 19°30' N., long 41°30' to 42°00' E.	NW-trending Tertiary Red Sea dikes crop out in the quadrangle; the dikes are intermittently exposed along strike	Bayley, R.W.	1972	DGMR Geologic Map GM-1, 6 p.	The dikes of Tertiary age were thought to to be Precambrian

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Building marble and cement raw materials in the Arabian Shield and Red Sea coastal plain	To evaluate selected areas of the Shield and coastal plain for marble and cement raw materials	Arabian Shield and Red Sea coastal plain	Investigations to locate marble for building ornamental stone were centered at Jabal Farasan, north of Buraykah, and at Wadi Missir. Large reserves of from 50,000 to several million square meters occur at Jabal Farasan. Suitable marble is found at the Buraykah and Missir sites, also with Wadi Missir being the smallest and containing several hundred thousand square meters of reserves. Raw material for cement were explored in the Yanbu-Umm Lajj region, Rabigh, Jiddah, Buraykah, and Madina. The most favorable sites were the Yanbu-Umm Lajj and Rabigh areas	Berton, Y.	1969a	DGMR Mineral Resources Research 1967-1968, p. 69-74	
Prospecting for nonmetallic minerals, progress report, July 1968	To prospect and identify nonmetallic mineral resources along the Red Sea coastal plain	Red Sea coast, Yanbu to Jabal Dhaylan and 30 km on either side north and south of Rabigh	Substantial resources are found in the Yanbu al Bahr area including limestone, clay for brick manufacture, ornamental stone, and tile and asbestos; limestone, clay, and marble were noted in this Rabigh area	Berton, Y.	1969b	BRGM Open-File Report 69-JED-10, 55 p.	
Geological controls Maaliyah magnetic anomaly	Geological and economic evaluation of the Maaliyah magnetic anomaly	Magnetic anomalies east of Maaliyah (17/42 D)	Study of the area disclosed surface magnetite-bearing veins, lenses, and float and suggested concealed magnetite bodies at depth; of two areas evaluated, the southern one contains several thousand tons of high-grade ore	Bhutta, M.A.	1962a	DGMR Open-File Report 143, 14 p.	
Al Qahmah iron sands	Geologic and economic evaluation of Red Sea beach sands	Beach sands exposed along the Red Sea coast 22 km SE of Al Qamah, at about lat 17°50' N.	Al Qamah beach sands were estimated to contain 0.3 million tons of concentrate averaging 52.4 percent Fe, 1 percent TiO_2, and 9.2 percent silica. Total resources are estimated to be much larger	Bhutta, M.A.	1962b	DGMR Open-File Report 144, 18 p.	
Sampling of Rabigh barite deposit	Economic evaluation and ore appraisal of the Rabigh barite	Area about 21 km NE of Rabigh at about lat 22°55' N., long 39°9' E.	See report for conclueions	Bhutta, M.A.	1963	DGMR Open-File Report 180, 8 p.	
Tonnage estimate of Rabigh barite	Quantitative assessment of the Rabigh barite deposit	Area 21 km NE of Rabigh	See report for conclusions	Bhutta, M.A.	1964	DGMR Open-File Report 229, 6 p.	
Rabigh barite deposits	Economic appraisal of Rabigh barite	Umm Gerad (Rabigh) barite area	The barite occurs in veins of Tertiary age in granodiorite and diorite; veins are 0.5-1 m wide, locally 3 m wide; ore reserves are calculated to be 100,000 tons of 90 percent $BaSO_4$	Bhutta, M.A.	1966	DGMR Open-File Report 271, 4 p.	
Cement raw materials near Jizan and Khamis Mushayt	Appraisal of cement raw materials	Coastal plain and mountainous areas around Jizan and Khamis Mushayt	Coralline limestone N and S of Jizan appears suitable for making cement; local sediments in the Jizan area could supply clay and gypsum for cement and similar deposits are found in the Khamis Mushayt area	Bhutta, M.A.	1968	DGMR Open-File Report 313, 13 p.	
Drilling and stratigraphic geology at Jabal Dhaylan	Economic and stratigraphic study of the Miocene sedimentary rocks	Jabal Dhaylan, lat 25°35' N., long 37°10' E.	Nineteen drill holes established the character of the lead-zinc mineralization; one zone of mineralization is estimated to contain 300,000 tons with more than 10 percent lead-zinc	Bigot, M.	1970	BRGM Open-File Report 70-JED-10, 26 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Possibilities of sulfur mineralization in Saudi Arabia	Evaluation of western Saudi Arabia for potential elemental sulfur deposits	Coastal plain Tertiary rocks northwest of Jiddah	Numerous gypsum outcrops were examined along the Red Sea coast; exposed gypsum in the Maqna area suggests that substantial thicknesses may underlie the coastal-plain alluvium and the Red Sea; because known petroleum (a hydrocarbon source required for the formation of elemental sulfur) is closest to the Maqna area, it is the most favorable for location of elemental sulfur	Bodenlos, A.J.	1969, 1970	DGMR Mineral resources research 1967-68, p. 74-76; USGS Project Report 113, 34 p.	
Geologic map of the Wadi as Sirhan quadrangle	Preparation of a geologic map at scale 1:500,000 showing principal rock types and structure	lat 28°00' to 32°00' N., long 34°30' to 39°00' E.	Numerous areas of Tertiary rocks were mapped along the Red Sea coastal plain and are briefly described in ths legend	Brankamp, R. A. and others	1963	USGS Miscellaneous Geologic Investigation Map I-200 A	
Anomalous metal concentrations in Um Gerad jasperoid	Geochemical evaluation of trace elements in jasperoid of the Um Gersd barite	Umm Gerad barite deposit about 21 km NE of Rabigh, lat 22°55' N., long 39°09' E.	The jasperoid contains anomalous beryllium, yttrium, and boron. Minor element content of jaeperoid suggests metal deposit potential at depth	Brobst, D.A.	1965	USGS Technical Letter 25, 6 p.; USGS Professional Paper 550-C, p. C187-C189.	The vein system containing the jasperoid appears closed and structurally controlled
Eastern margin of the Red Sea and the coastal structures in Saudi Arabia	To summarize the coastal geology of the eastern side of the Red Sea	Western Saudi Arabia and the coastal margin of the Red Sea	Marine and nonmarine sedimentary rocks are found along the Red Sea and volcanic rocks and hypabyssal intrusives are widespread along the coastal zone and at higher elevations inland of Oligocene, Miocene, and younger rocks. Red Sea rifting began in late Oligocene or early Miocene when the flanks of the rift valley were ramped upward. Mid-Miocene marl and evaporites filled the Red Sea trough shortly after ramping. Volcanism continued through the Pliocene to the present day (1250 A. D.)	Brown, G. F.	1970	Philosophical Transactions Royal Society of London, v. A267, p. 75-87	
Tectonic map of the Arabian Peninsula	To compile the first comprehensive tectonic map of the Arabian Peninsula and adjoining areas	Arabian Peninsula and surrounding region	Presents structural data including contours on the bases of the Tertiary, Mesozoic, and Paleozoic for the first time and circumscribes the Red Sea Miocene evaporite basin	Brown, G.F.	1972	DGMR Arabian Peninsula Map AP-2	Subdivides the Tertiary flood basalt fields by age and shows negative magnetic anomaly trends of the Tertiary continental dikes that parallel the Red Sea
The tectonic framework of the Arabian Peninsula	To summarize the tectonic character of the Arabian Peninsula and surrounding areas	Arabian Peninsula, Red Sea, Gulf of Aden, Arabian Gulf, Iran, Oman, and so forth	Arabia was rifted from Africa during the Tertiary. The Red Sea and Gulf of Aden were formed by crustal extension. The Gulf of Aden is underlain by oceanic crust but the Red Sea is more complicated especially by a thick evaporite series. The Red Sea and margins are characterized by extensive faulting including transforms and linear northwest-trending faults hidden under coastal plain alluvium that produced the Red Sea graben and flanking elevated ramp plateaus. The anomalous magnetic pattern suggest a two-stage opening at 22 Ma and 5 Ma with anti-clockwise rotation of the Arabian plots with respect to Africa of 7.6	Brown, G. F. and Coleman, R. G.	1972	Int. Geol. Congress, 24th (Montreal), Proc. sec. 3, p. 300-305	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geologic map of the northwestern Hijaz	Preparation of a geologic map at scale 1:500,000 showing principal rock types and structure	lat 18°00' to 24°00' N., long 35°00' to 39°00' E.	Tertiary and Quaternary rocks assigned to the Raghama (?) formation were mapped between Duba and Muwaylih, around Wajh and Jabal Dhaylan, and between Yanbu al Bahr and Umm Lajj along the coastal plain	Brown, G.F. and others	1963a	USGS Miscellaneous Geologics Investigations Map I-204 A	
Geologic map of the southern Hijaz quadrangle	Preparation of a geologic map at scale 1:500,000 showing principal rock types and structure	lat 20°00' to 24°00' N., long 38°00' to 42°00' E.	Several important areas of Tertiary and Cretaceous (?) outcrops were mapped along the coastal plain including the Shumaysi and Usfan formations	Brown, G.F. and others	1963b	USGS Miscellaneous Geologic Investigation Map I-210 A	
Geochemical survey of Jabal Dhaylan area	To determine the dispersion of lead, zinc, and copper on the coastal plain at Jabal Dhaylan and evaluate this study as a geochemical prospecting tool	Red Sea coastal plain area west of Jabal Dhaylan	Copper concentrations were 2-3 times background; lead samples were 2 to more than 5 times background; and zinc values were 2 to more than 5 time background; background values were established at 25 ppm, 50 ppm, and 150 ppm for copper, lead, and zinc, respectively	Chaumont, P.	1970a	BRGM Open-File Report 70-JED-25, 11 p.	
Mineral exploration in the Jabal Dhaylan area	Field and geochemical study of copper, lead, and zinc mineralization	Jabal Dhaylan lat 25°35' N., long 37°10' E.	Samples from 1,132 m of trenches were assayed from Oligocene and Miocene arkose and limestone and Plio-Pleistocene coral; one area warranted a 19-hole drilling program; mineralization was interpreted to be along prominent paleogeomorphologic features	Chaumont, P.	1970b	BRGM Open-File Report 70-JED-15, 45 p.	
Mineral exploration in the Yanbu al Bahr area	Evaluation of the mineral potential of the Cenozoic rocks of the Yanbu al Bahr area coastal plain	Coastal plain of Yanbu al Bahr area	Three deposits in the Ronge terraces along Wadi Kamal were considered of commercial importance; Tertiary and Quaternary fault planes are the sites of mineralization	Chaumont, P. and Marchasseau, J.J.	1971	BRGM Open-File Report 71-JED-13, 36 p.	
Preliminary exploration of Jabal Dhaylan	Preliminary evaluation of the lead-zinc-copper mineralization of the Cenozoic rocks at Jabal Dhaylan	Jabal Dheylan	Lead, zinc, and copper mineralization occurs in Oligocene arkose, Miocene-Pleistocene channels, Plio-Pleistocene reef limestone, and Tertiary conglomerate	Dadet, P.	1969	DGMR Mineral Resources Research 1967-68, p. 25-27	Future work was recommended; some samples contained 36 percent zinc and 11 percent lead
Zinc, lead, and copper mineralization at Jabal Dhaylan	Geologic and mineral resource assessment of the Cenozoic sedimentary rocks at Jabal Dhaylan	Jabal Dhaylan area within a 25 km radius	The Miocene section is less than 35 m thick and mineral values are too low to warrant exploitation; mineralization is related to post-Miocene tectonics	Dadet, P.	1970	DGMR Mineral Resources Research 1968-1969, p. 18-23	
Mineral occurrences near Umm Lajj	Documentation and assessment of lead zinc, and copper mineralization near Umm Lajj	Red Sea coastal plain area between Umm Lajj and Al Wajh	Lead, copper, and zinc mineralization between Umm Lajj and Al Wajh is confined to stratigraphic intervals of arkose, reef limestone, and conglomerate; the mineralization is similar to Umm Ghaig in Egypt and is controlled by Miocene and younger Red Sea tectonics	Dadet, P. and others	1969	BRGM Open-File Report 69-JED-9, 16 p.	
Same as above	Same as above	Same as above	Same as above	Same as above	1970	Philo. Trans. Royal Soc. London, 267A, p. 99-106.	
Hot brines and recent heavy metal deposits in the Red Sea	To comprehensively summarize current earth science studies of the Red Sea basin	Red Sea and environs	The report in a single volume, including many authors, presents an indepth account of the geophysics, geochemistry bathymetry, structural geology, mineralization, and paleontology, and oceanography of the Red Sea and its margins	Degens, E.T. and Ross, D.A.	1969	Springer-Verlag, New York, 600 p.	This reference is presented because of the importance of Red Sea studies to onshore coastline investigations and because of the numerous reports in the volume that bear directly on the Tertiary coastal sediments

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Preliminary lead isotope investigations of Red Sea brine and galena from Saudi Arabia and Egypt	Evaluation of Red Sea brines as ore-forming fluids using lead isotopes as a "fingerprint" of economic ore deposits; use of lead for determining age of mineralization	Various localities in Saudi Arabia and Egypt and samples from the Atlantis II deep	Red Sea brine leads gave an isochron and model ages of 0; galena from Rabigh is similar in isotopic composition to Red Sea brine lead and is interpreted as Cenozoic in age	Delevaux, M.H. and others	1967	Earth and Planetary Science Letters, v. 3, p. 139-144	
Discuesion on the structure and evolution of the Red Sea and the nature of the Red Sea, Gulf of Aden, and Ethiopia Rift junction	To summarize the current earth-science data of the Red Sea and Gulf of Aden, Ethiopian Rift junction	Red Sea, Gulf of Aden, East-African rift and environs	Summarizes much old and new data and concepts concerning the evolution and structura of the Red Sea and Gulf of Aden triple junction	Falcon, N.L. and others, eds.	1970	Philosophical Transactions of of the Royal Society of London v. 267A, 417 p.	
1971 thermal gradient measurements in sediments in the Atlantis II deep brine pool of the Red Sea	To record temperature gradient in bottom sediment of the Atlantis II Deep during coring operation and to provide supplementary thermal data to recordinga made in 1966 and 1971	Atlantis II Deep of the Red Sea	Six thermal gradient measurements were made in sediments beneath the Atlantis II brine pool. The temperature gradient ranged from 0 to 0.88°C/m and fell moatly in the range from 0.1 to 0.3°C/m. Temperature conditions of the two brine layers in the Deep are controlled by 104°C to 113°C brines entering the lower layer along fracture zones rather than uniform conductive or convective heating from below. The lower brine layer is heated directly by mixing and the upper one is heated by diffusion	Fournier, R. O.	1972	USGS Project Report 148, 11 p.	Published also as DGMR Bulletin 22, Chpt. n, p. N1-N4. (1977).
Geological and geophysical reconnaissance of the Jizan coastal plain	Determination of the sedimentary, stratigraphic, and structural character of the Tertiary rocks in the vicinity of Jizan	lat 16°30' to 17°45' N., long 42°15' to 43°10 E.	Tertiary rocks in the surface and subsurface of the area consist of mafic and silicic volcanic rocks, evaporites, fine and coerse clastic rocks, and granitic and gabbroic intrusions, structure is dominated by Tertiary homoclinal folding and faulting related to Red Sea graben extension	Gillmann, M.	1968	Amer. Inst. Mining and Metall. Engr., Soc. of Petro. Geol., 2nd Reg. Symp., p. 189-208	This report represents the most signifiant study of the Jizan area Tertiary rocks to date
The Hail arch: a key to deformation of the Arabian Shield during evolution of the Red Sea rift	To continue discussion on deformation of the shield as related to pre-Tartiary tactonic features	Arabian Shield of Saudi Arabia	The Hail arch developed its main trend during pre-Permian time and was folded again during the Cretaceous. Regional teneion during the Tertiary caused basalt eruptions along the crest of the arch. The discordant trend of the Hail arch with raspect to the Red Sea rift and Precambrian structures suggests an evolution independent of tectonic elements developed during these periods and compression related to opening of the Red Sea and Gulf of Aden	Greenwood, W. R.	1972a	USGS Project Report 149, 10 p.	Also published as DGMR Bulletin 7, 5 p. (Greenwood, 1972b)
Jizan salt deposits	Geologic and geophysical study of the Jizan salt dome	Jizan	The dome is a piercement salt plug of irregular outline formed by east-west anticlinal deformation and accompanied by normal extension faulting, salt reserves extend to 1,500 m depth and are 1,800 million tons	Herness, S.K.	1964	DGMR Open-File Report 234, 5 p.	
Airborne magnetometer scintillometer survey of Jizan area	Production of airborne geophysical maps of the Jizan area; scale 1: 50,000; 16 maps	Jizan	No interpretation included	Hunting Survey Corp., Ltd.	1962	DGMR files	

Appendix 3.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1961 and 1972*—Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Iron ore, Wadi Fatima, ore dressing tests, July 1963	To evaluate the ore recovery of a Wadi Fatimah sample	Sample from the Wadi Fatimah area between Jiddah and Mecca	Tests on a 40-kg sample of oolitic iron ore from Wadi Fatimah yielded 88.2 percent recovery by sizing at 0.2 mm and 84.6 percent recovery by following with high-intensity magnetic separation of the 0.8-0.2 mm fraction; 92.2 percent recovery was obtained by reduction roasting and low-intensity magnetic separation	Internationale Planungs- und Consulting G.M.B.H.	1963a	DGMR Open-File Report 184, 34 p.	
Barite, Rabigh, mineral dressing study	To conduct and evaluate dressing tests on samples of Rabigh barite	Samples from Rabigh (lat 22°55' N., long 39°9' E.)	Dressing tests were made on four samples from Rabigh. These showed that the ore could be beneficiated from 63.4 to 95.9 percent barium sulfate by crushing to -3 mm, classifying, concentrating the coarse fraction on jigs and the fine fraction on tables, and using a high-intensity magnetic separation after drying. This method was better than floatation or electrostatic separation. The concentrates would be suitable only for drilling mud	Internationale Planungs- und Consulting G.m.b.H.	1964	DGMR Open-File Report 236, 31 p.	
Iron ore of Wadi Fatimah	Estimation of Wadi Fatimah iron ore reserves, iron quality, and iron (Fe) content of the ore	Wadi Fatimah	Area 1 contains 26 million tons of ore; area 2a contains 15 million tons with 45 to 47.5 percent iron and no deleterious properties; various methods will raise the ore content to 51-52 and 58-59 percent	Internationale Planungs-und Consulting G.M.B.H.	1963b	DGMR Open-File Report 185, 18 p.	
Mineral reconnaissance of the Bir al Bayda quadrangle (26/36 A)	Geologic and mineral resource assessment of the Bir al Bayda	lat 26°30' to 27°00' N., long 36°00' to 36°30' E.	Miocene limestone and clastic rocks belonging to the Raghama formation are exposed along the Red Sea	Johnson, R.F. and Trent, V.A.	1965	USGS Technical Letter 37, 13 p.	
Mineral reconnaissance of the southern part of the Wadi Azlam quadrangle (27/36 D)	Geologic and mineral reconnaissance of the area	lat 27°00' to 27°30' N., long 36°00' to 36°30' E.	The only Cenozoic rocks in the area are flat-lying Tertiary to Quaternary basalt	Johnson, R.F. and Trent, V.A.	1966	USGS Technical Letter 43, 4 p.	
Geologic map of Wadi as Surr area (27/35 B)	Geologic and mineral resource assessment of the Wadi as Surr quadrangle	lat 27°30' to 28°00' N., long 35°30' to 36°00' E.	Sandstone, limestone, and gypsum assigned to the Raghama formation are exposed along the coast; no details as to thickness or other aspects of these Tertiary rocks are given	Johnson, R.F. and Trent, V.A.	1967	DGMR Mineral Investigations Map MI-5	
Geophysical and structural aspects of the central Red Sea rift valley	To evaluate a set of aeromagnetic profiles flown across the Red Sea at the latitude of Jiddah	A segment of the Red Sea and coastal line between lat 21°00' and 21°45' N.	Eight aeromagnetic traverses were flown across the Red Sea at the latitude of Jiddah. A high-amplitude anomaly trending northwest was found over the axial trough. A second high-amplitude anomaly was found immediately west of the 1000-m bathymetric contour. Depth estimates to the highly magnetic rock were estimated to be about 2 km by the data. A low-amplitude anomaly was found that trends NW into the Red Sea from a land area south of Jiddah. It appeared to have a much deeper source. The low-amplitude anomaly is similar to dikes, faults, and magnetic trends in the shield rocks	Kabbani, F. K.	1970	Philosophical Transactions Royal Society of London v. A267, p. 89-97.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Raw materials for cement in Yanbu al Bahr area	Evaluation of the Yanbu al Bahr area for raw materials for cement	Yanbu area	Pleistocene reef limestone is abundant as are alumina, clays and gypsum materials as additives; gypsum is available from the Raghama formation of Tertiary age	Laurent, D.	1970	BRGM Open-File Report 70-JED-23, 27 p.	
Umm Gerad barite district	Reevaluation of the Umm Gerad (Rabigh) barite district	Barite outcrops about 21 km NE of Rabigh	Barite veins are exposed over 20 x 3 km in Precambrian plutonic rocks; 1,865 m of veins average 96 percent barium sulfate	Liddicoat, W.K.	1971	DGMR Open-File Report 406, 2 p.	
Tarriary coastal zone of Red Sea and related copper-lead-zinc mineralization	Evaluation of the geology and mineralization of the Jabal Dhaylan area	Area around Jabal Dhaylan centered at about lat 25° 35' N., long 37°10' E.	Stratigraphic position of the Oligocene red-bed strata was defined; copper, lead, and zinc mineralization occurs in Oligocene and Miocene strata and large gypsum deposits were found	Marchesseau, J.	1969	BRGM Open-File Raport 69-JED-20, 57 p.	
Review of Wadi Fatima and Wadi Sawawin iron deposits	Geologic study of the deposits and literature and recommendations for future work	Wadi Fatimah and Wadi Sawawin	The Wadi Fatimah ores were considered of doubtful value because of low iron content and high slag-forming constituents	Marsden, R. W.	1972	DGMR Open-File Report 484, 20 p.	
Salt production possibilities of the Jizan and Farasan Islands area	Evaluation of the salt production potential of the Jizan and Farasan Islands	Jizen and Farasan Islands	Salt reserves at Jizan were estimated at more than 30 million tons within 40 m depth; a NaCl content of 96 percent was considered uneconomic and recommendations were made to move exploration to the Farasans	Mideast Industries, Ltd.	1966	DGMR Open-File Report 279, 13 p.	
Geophysical Survey at Jabal Dhaylan	To evaluate a geophysical survey at Jabal Dhaylan conducted by ARGAS	Jabal Dhaylan, lat 25°35' N. and long 37° 10' E.	A horst of Precambrian rock rocks overlain by Tartiary sedimentary rocks was defined by electrical sounding methods; the same methods showed a northwestarly extension of the structure	Millon, R.	1970	BRGM Open-File Report 70-JED-18, 10 p.	
Geology of the Jabal Samran and Jabal Farasen region	Study of the general geology of the Jabal Farasen region	Jabal Samran and Jabal Farasan region NE of Jiddah	Unconsolidated coarse clastic rocks and clays of Neogene age from 10-50 m thick are in the area as are flat-lying basalts of Quaternary and Tertiary age	Nabert, K.	1969	DGMR Bulletin 4, 32 p.	
Red Sea hot brine area: revisited	To continue previous studies conducted in 1966 in the Red Sea hot brine deeps to ascertain the extent of changes, if any, in the salinity and temperature of the brines	Atlantis II Deep (lat 21° 20' N., long 38°02' E.)	Between 1966 and 1971 the following changes took place in in bottom water of the Atlantis II Deep: 1) the level of the lower water layer rose 7 m, 2) the transition between the lower and upper hot water layers decreased from 5 m to 2 m, 3) the temperatures of the lower and upper water layers increased from 56.5°C. to 59.2° C. and from 44.3°C. to 49.7°C. respectively, 4) the temperature structure in the zone between the upper layer and the overlying normal Red Sea water is more irregular, and 5) calculations show that 0.346 km^3 of water having a minimum temperature of 104°C was added during the 52-month period	Ross, D. A.	1972	USGS Project Report 140, 11 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geological and geophysical study of the Red Sea	To study the geological and geophysical characteristics of the Red Sea, in particular the Arabian continental margin; to further explora and study the hot brine region in the vicinity of lat 21° N.; and to determine if any unknown brine areas exist	Southern part of the Red Sea mostly south of lat 22° N.	Geophysical data collected during the study from the R/V Chain included seismic, magnetic, and gravity. The results showed considerable structure in the continental shelf sediments on the Arabian margin including folds (synclines) and and diapirs. The Pliocene-Pleistocene unconformity detected throughout area. Sediments above the unconformity (S-reflector) vary from 0-500 m. The data indicats the hot brine area is offset by cross fracture zones, suggesting a local source for the hot brines. Bottom photography shows abundaut pillow lavas in the axial trough area of the Red Sea. A heavy-metal halo exists in sediments around the hot brine metalliferous deposits. Anomalous copper concentrations detected 16 km east and 900 m higher than the Atlantis II Deep and a metal-rich layer containing 2 percent copper and 30 percent iron oxide 300 m above the brine pool of Atlantis II Deep.	Ross, D. A. and others	1971	USGS Project Report 133, 110 p.	This report presents preliminary results from the R/V Chain cruise Chain, 100, leg 3. Detailed results are presented in other reports, especially including DGMR Bulletin 22 (Hilpert, 1977)
Cruise report for Tooms' 1970 geochemical cruise in the Red Sea	To collect, analyze, and evaluate water and sediment samples from the Red Sea median valley	Median valley (axial trough of the Red Sea)	Water and sediment samples were collected from 30 stations in the median valley of the Red Sea under supervision of J. S. Tooms. Results of the cruise are not reported in this paper	Skipwith, P.	1970a	DGMR Open-File Report 364, 8 p.	
Red Sea metalliferous sediment and brine research, 1970 cruise report	To survey the area north of the Atlantis II Deep to determine trace element distribution, to make detailed investigations of the deep, and to survey the northern Red Sea coast for heavy minerals, phosphate, or metal concentrations in lagoons	Atlantis II Deep area and northern Red Sea coastline	See report for possible conclusion; none available for this report	Skipwith, P.	1970b	DGMR Open-File Report 369, 12 p.	
Cruise report for Tooms' 1971 geochemical cruise in the Red Sea (Leg 1), April 1971	To obtain background geologic and oceanographic material from the northern Red Sea	Red Sea approximately north of lat 21° N.	The most important conclusion was observation of the lack of a shelf in the northern part of the Red Sea	Skipwith, P.	1971	DGMR Open-File Report 408, 11 p.	
Field trip to the Aqeba area	Reconnaissance study of the geology and mineral potential of the Aqaba area	Gulf of Aqeba area, northwest Kingdom of Saudi Arabia	Conglomerate and arkosic sandstone belonging to the Tertiary are exposed (15 m); fossiliferous limestone of the Raghama was briely described	Trent, V.A. and Johnson,R.F.	1966a	USGS Technical Letter 41, 6 p.	
Reconnaiseance geologic and mineral investigations in the Al Bad quadrangle, (28/35 C)	Geologic and mineral resources investigation of the Al Bad quadrangle	lat 28°00 to 28°30' N., long 35°00' to 35°30' E.	The Raghama formation of Tertiary to late Quaternary age crops out in the quadrangle and consists of gypsum, sandstone, shale, fossiliferous limestone, and conglomerate	Trent, V.A. and Johnson, R.F.	1966b	USGS Technical Letter 50, 18 p.	

Appendix 3.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1961 and 1972*—Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Reconnaissance mineral and geologic investigations in the Maqna quadrangle, (28/34 D)	To eveluate the general geologic and mineral resource potential of the Maqna area	lat 28°00' to 28°30' N., long 34°30' to 35°00' E.	Tertiary rocks of the Raghama formation unconformably overlie the Precambrian and consist of a coarse conglomerate and sandstone at the base, 100-150 m of fossiliferous limestone, 300 m of mudstone and gypsum, overlain by limestone and sandstone; total thickness about 500 m	Trent, V.A. and Johnson, R.F.	1966c	USGS Technical Letter 51, 5 p.	The large quantity of gypsum in the area may be potentially economic and should be investigated further; the sulfur potential appeared low; the Al Lisan-Al Bad basins may be faforable environments for oil
Reconnaissance mineral and geologic investigations in the Jabal al Lawz quadrangle, (28/35 A)	As the title	lat 28°30' to 29°00' N., long 35°00' to 35°30' E.	See USGS Technical Letter 51	Trent, V.A. and Johnson, R.F.	1966d	USGS Technical Letter 70, 16 p.	Also see DGMR Min. Invest. Map MI-13 (Trent and Johnson, 1967a)
Reconnaissance mineral and geologic investigations in the Tayyib al Ism quadrangle (28/34 B)	As the title	lat 28°30' to 29°00' N., Gulf of Aqaba to long 35°00' E.	Very little given on the Tertiary rocks; adjacent quadrangle reports cover the Tertiary rocks in more detail	Trent, V.A. and Johnson, R.F.	1966f	USGS Technical Letter 59, 7 p.	
Reconnaissance mineral and geologic investigations in the Haql quadrangle (29/34 D)	As the title	lat 29°00' N. to the Jordan border, Gulf of Aqaba to long 35°30' E.	Conglomerate and sandstone considered of Tertiary age are about 15 m thick	Trent, V.A. and Johnson, R.F.	1967b	DGMR Mineral Investigations Map MI-12	Also, see USGS Technical Letter 72 (Trent and Johnson, 1966e)
Evaluation of the mineralogical and beneficiation characteristics of Wedi Fatimah iron ore	To evaluate the beneficiation characteristics of the Wadi Fatimah iron ore	Wadi Fatimah area approximately 40 km east of Jiddah	Preliminary examinations confirm test results reported in DGMR-185. Floatation methods were found to be discouraging. Reduction roasting, fine grinding, and magnetic separation tests yielded 90 percent recovery but was the most expensive and phosphorous content was high	Wesson, P.A. and Frommer, D. W.	1966	DGMR Open-File Report 345, 32 p.	
The Wadi Fatimah iron ore deposit at the present stage	To review the exploration and beneficiation of the iron ore deposit	Shumaysi-Wadi Fatimah iron ore area	The status of exploration and beneficiation testing of the Wadi Fatimah iron ore was reviewed and preliminary financial estimates were prepared	Zeidler, W.	1969	DGMR Open-File Report 337, 3 p.	
Final plan for exploitation of the Wadi Fatimah iron-ore deposit, area 1, part I, surface mining plan	To reevaluate and updete the exploitation plan for the iron ore deposit	Wadi Fatimah-Shumaysi area	The document updates DGMR Open-File Report 293 and and shows that estimated average costs for extraction of the Wedi Fatimah iron ore can be reduced by 18-43 percent depending on scale of production	Zeidler, W. and Khoja, B.	1969	DGMR Open-File Report 339, 133 p.	

Appendix 4.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1973 and 1982*

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geology and mineralization of the Rabigh quadrangle (22/39 A)	To study the lithology, structure, stratigraphy, and areal geology	lat 22°30' to 23°00' N., long 39°00' to 39°30' E.	Apart from the Precambrian geology, the report describes the structure related to Red Sea rifting and the geologic setting of the barite veins exposed in the quadrangle	Abo Rashid, A. R.	1973	DGMR Open-File Report 476, 37 p.	
Geology and mineralization of the Jabal al Buwanah quadrangle (24/37 A)	To study the structure, lithology, and mineral potential	lat 24°30' to 25°00' N., Red Sea to long 37°30' E.	Tertiary marine sedimentary rocks of the Raghama formation including clastics, limestone, and evaporitas are deposited ou the coastal plain and are structurally deformad by Red Sea tectonics. Rocks may contain lead-zinc mineralization	Alabouvette, B.	1977	BRGM Open-File Report 77-JED-10, 19 p.	
Geology and mineral resources of the Wadi Kamal quadrangle (24/37 C and D)	Raconnaissance geologic and mineral resource evaluation of the Precambrian and younger rocks	lat 24°00' to 24°30' N., Red Sea to long 38°00' E.	The Tertiary Raghama formation is widely exposed and consists of three series; lithologies are sandstone, conglomerate, limestone, fine-grained (argillite) rocks, and gypsum; mineralization was observed and further work was prescribed	Alabouvette, B. and Pellaton, C.	1975	BRGM Open-File Report 75-JED-18, 46 p.	
Geology and mineral exploration of the Al Wajh quadrangle (26/36 C and D)	As the title	lat 26°00' to 26°30' N., Red Sea to long 37°00' E.	The Tertiary Raghama formations is well exposed and consists of three units of of clastic and evaporitic rocks deposited and structurally controlled by Red Sea rift trends	Alabouvette, B. and Pellaton, C.	1979	BRGM Open-File Report 79-JED-5 27 p.	
Geology and mineral exploratiou of the Yanbu al Bahr quadrangle (24/38 C)	As the title	lat 24°00' to 24°30' N., Red Sea to long 38°30' E.	Clastic and argillaceous rocks, limestone, and evaporitic rocks of the Raghama formation crop out as three units controlled by structure of the developing Red Sea basin	Alabouvette, B. and others	1975	BRGM Open-File Report 75-JED-20, 42 p.	
The Wadi Azlam prospect (27/35 D), results of the 1974 program	To evaluate the mineral resource potential of the Wadi Azlam-Duba region	Wadi Azlam-Duba area; lat 27°00' to 27°30' N., Red Sea to long 36°00' E.	The Raghama formation is well exposed consistiug of Oligocene clastic rocks and Miocene reef limestone; copper-lead-zinc mineralization is not economic	Alabouvette, B. and others	1979	BRGM Open-File Report 79-JED-15 38 p.	
Phosphate prospecting in the Azlam trough, 1975-1976	Stratigraphic and sedimentologic investigation of the Azlam trough for possible existence of phosphate deposits	Northwest-trending strip of outcrop between lat 26°30' and 27°00' N., long 36°00' and 36°40' E.	Senonian and Lower Maestrichtian(?) to Oligocene sediments consisting of shale and and conglomerate are found in a NW-trending trough approximately 20 km wide and 100 km long; phosphate in the form of bone fragments is distributed throughout the stratigraphic sequence but not in economic concentrations	Alabouvette, B. aud others	1981	BRGM Open-File Report BRGM-OF-01-15, 50 p.	
Gypsum locality north of Yanbu al Bahr, Bir Ibn Zowayyed area (24/37 C)	Evaluation of the resources and quality of gypsum in the area	Area at about lat 24°25' N., long 37°25' E.	Gypsum occurs in a 1-km^2 area associated with Tertiary sedimentary rocks; it is associated with anhydrite and iron oxides	Al Khatieb, S. O.	1973	DGMR Open-File Report 495, 2 p.	
Geology of the Wadi Atf (17/43 A) and Mayza (17/43 B) quadrangles	To map and evaluate the general geology and mineral resources	Wadi Atf and Mayza quadrangle areas (lat 17°30' to 18°00' N., long 43°00' to 44°00' E.	In addition to the general geology of the quadrangles, the geology of the Tertiary laterite and As Sarat volcanic rocks is discussed	Anderson, R. E.	1979	DGMR Bulletin 25, 33 p.	
Total intensity aeromagnetic map of the northern Hijaz quadrangle and part of the Wadi as Sirhan quadrangle	To compile and publish a total-intensity aeromagnetic map with a 400-gamma contour interval	lat 24°00' to 29°00' N., Red Sea long 39°00' E.	The Miocene continental dikes are depicted strongly on the map	Andreasen, G. E. and Petty, A. J.	1974a	DGMR Geologic Map GM-9, 3 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Total intensity aeromagnetic map of the southern Hijaz quadrangle	Compilation and publication of a total-intensity map with a 400-gamma contour interval	lat 20°00' to 24°00' N., Red Sea to long 42°00' E.	In some areas the Miocene continental dikes are strongly depicted	Andreasen, G. E. and Petty, A. J.	1974b	DGMR Geologic Map GM-12 3 p.	
Total intensity aeromagnetic map of the Tihamat Ash Sham quadrangle and part of the Asir quadrangle	To compile and publish a total-intensity aeromagnetic map with a 400-gamma contour interval	lat 17°00' to 20°00' N., Red Sea to long 44°30' E.	The map depicts NW-trending lineaments related to the Miocene continental dikes along the coastal plain	Andreasen, G.E. and Petty, A.J.	1974c	DGMR Geologic Map GM-14, 3 p.	
Yanbu clays, 24/37 D and 24/38 C	To determine the clay resources of the aree and their suitability for ceramic products	24°00' to 24°30' N. lat and 37°30' to 38°30' E. long	Resources in the area are adequate to supply any demand and tests on the clays showed that they were suitable for use in production of ceramic products.	Arab Consulting Bureau	1977a	DGMR Open-File Report 674, 317 p.	
Yanbu construction end industrial materials	Identification and evaluation of construction and industrial materials	23°50' N. lat to 24°20' N., long 37°50' to 38°20' E.	Abundant expoeures of Tertiary and Quaternary rocks and sediments include the Raghama formation, reef limestone, end unconsolidated gravels and sand	Arab Consulting Bureau	1977b	DGMR Technical Record TR-1977-1, 61 p.	
Tests for barite prospecting, Rabigh area	To determine if certain geopysical techniques could be used to detect subeurface barite	Rabigh barite area 21 km NE of Rabigh; lat 22°55' N., long 39°9' E.	Resistivity profiles and microgravity surveys showed that the barite veins can be identified below surficial cover and estimates of reserves can be made from the geophysical data	Arabian Geophysical and Surveying Company	1974	ARGAS Report 74-ARG-5, 13 p.	
Ground magnetic survey at Umm Araj	To locate areas in the Umm Araj Hanifa, limestone devoid of dolerite dikes	Umm Araj area, 60 km SE of Jizan	Ground-magnetometer surveys in the Umm Araj area located two areas with flat magnetic intensity indicating a probable lack of dolerite dikes. These areas could contain small dikes, and drilling would be required to determine this	Arabian Geophysical and Surveying Company	1976	ARGAS Open-File Report 76-ARG-06, 10 p.	
Geophyaical synthesis report, eastern part of the central Rad Sea	Geophysical survey and evaluation of the lithologic composition and structure	Red Sea area between lat 18° and 24° N. lat	The results indicate that the floor of the Red Sea basin is made of oceanic crust but may be continental with basaltic intrusions near shore; Pliocene and Quaternary sediments overlie the thick Miocene evaporites; the Miocene section appears to be intruded by volcanic dikes, sills, and plugs	Arabian Geophysical and Surveying Company (ARGAS)	1977a	Unnumbered	
Geophysical survey at Ash Sharmah (28/35 D)	Geophysical survey to evaluate Tertiary and possibly older rocks and their lithologic and etructural cheracter	Ash Sharmah	The survey showed 80 m of Tertiary and recent deposits, 100-200 m of Cretaceoue (?) green shales, and in the Aynunah area an interpreted zone of 120-150 m of upper Cretaceous sandstone	Arabian Geophysical and Surveying Company (ARGAS)	1977b	ARGAS Open-File Report 77-ARG-03, 12 p.	
Geophysical surveys at Jabal al Buwana (24/37 A)	Geophysical evaluetion of Tertiary and younger sediments in terms of lithology and thicknesa	lat 24°30' to 25°00' N., Red Sea to long 37°30' E.	Clays and sands, 30-105 m thick, were identified and and may be etructurally controlled by graben tectonics	Arabian Geophysical and Surveying Company (ARGAS)	1977c	ARGAS Open-File Report 77-ARG-05, 5 p.	
Aluminum raw materials in Saudi Arabia	To review the potential for bauxite	Covers Saudi Arabia in general and the As Sarat in particular	Aluminum content is too low and silica and iron contents too high for the As Sarat laterite to have economic potential	Bhutta, M. A.	1973	DGMR Open-File Report DGMR 422, 3 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
The geochemistry of metalliferous brine precipitates and other sediments from the Red Sea	To investigate the geochemistry of sediments from the metalliferous brine deeps of the Red Sea, as partial fulfillment for a Ph.D. at the University of London	Hot metalliferous brine pools of the medial valley of the Red Sea	The Oceanographer and Kebrit Deeps contain brines rich in in H_2S but the sediments have low metal contents. Sediments are not enriched in ore metals in areas of recent volcanism. Other material discussed in this report include changes in the physiochemical conditions of the brines, mineralogy and facies conditions of the sediments, origin of the metal-rich sediments and guidelines for future exploration	Bignell, R. D.	1975	DGMR Open-File Report 544, 276 p.	A closely related report including as authors Cronan, D. S. and Tooms, J. S. is DGMR Open-File Report 552, 25 p. Two other reports are related to the original research and published outside; these are Bignell and others, 1974, Nature, v. 248, no. 5444, p. 127-128 (DGMR Open-File Report 553), and Bignell, 1975, Transactions of the Institute of Mining and Metallurgy, v. 84, p. B1-B6 (DGMR Open-File Report 554)
Metal dispersion as an aid to marine geochemical exploration in the Red Sea	To evaluate the dispersion of metals surrounding Red Sea metalliferous brine areas as an exploration technique	The Red Sea Atlantis II and Nereus Deeps (lat 21° 20' N., long 38°02' E.; lat 23°12' N., long 37°15' E.; respectively)	Geochemical halos of manganese, copper, zinc, and mercury surround the Atlantis II and Nereus metalliferous brine pools in the Red Sea to as much as 10 km distance from the deposits	Bignell, R. D. and others	1975	DGMR Open-File Report DGMR 528, 8 p.	
Summary of the second drilling program at Jabal Dhaylan	To evaluate the structure and character of mineralization at Jabal Dhaylan	Jabal Dhaylan, lat 25°31' N., long 37°10' E.	Four new drill holes were made in a second drilling program at Dhaylan. The Tertiary sedimentary-Precambrian depositional surface dips north. The Miocene thickens in the same direction and is underlain by Oligocene sedimentary rocks. Lead and zinc contents decrease northward in the holes drilled	Bigot, M.	1973a	BRGM Open-File Report 73-JED-8, 18 p.	
Geology and mineralization of the Hanak quadrangle (25/36 B)	As the title	lat 25°30' to 26°00' N., Red Sea to long 37°00' E.	Only Tertiary and Quaternary deposits are found; the Tertiary Raghama formation consists of rhythmic strata of sandstone and clay that dip consistently toward the Red Sea	Bigot, M.	1973b	BRGM Open-File Report 73-JED-14, 15 p.	
Geology and mineral exploration of the Jabal Dhaylan quadrangle (25/37 A)	As the title	lat 25°30' to 26°00' N., long 37°00' to 37°30' E.	Tertiary rocks of the Miocene Raghama formation are widespread and consist of a lower arkose and clay unit unconformably overlain by a more extensive sequence of evaporite rocks and carbonates called the Jabal Dhaylan formation; an underlying basement swell controlled sedimentation and mineralisation of the Raghama	Bigot, M.	1973c	BRGM Open-File Report 73-JED-17, 47 p.	
Geology and mineral exploration of the Umm Lajj quadrangle (25/37 C)	As the title	lat 25°00' to 25°30' N., Red Sea to long 37°30' E.	Numerous outcrops of the Tertiary Raghama formation consist of conglomerate, marl, reef limestone, and evaporites dipping toward the Red Sea; in places the Precambrian-Tertiary contact appears to be a fault	Bigot, M.	1975	BRGM Open-File Report 75-JED-7, 47 p.	

Appendix 4.--*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1973 and 1982*--Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Geology and mineralization of the Tertiary Red Sea coast of northern Saudi Arabia	To summarize the geology, mineral deposits, and mineralization of the Tertiary rocks and to propose a future mineral exploration program	Red Sea coastal zone, Yanbu al Bahr to Haqna	The Tertiary sedimentary rocks north of Yanbu al Bahr renge from 2,000 to 5,000 m thick and from Cretaceous to Pliocene; the Raghama formation consists of a three-fold stratigraphy thought to range from Oligocene to Pliocene consisting of coarse to fine-grained clastic sedimentary rocks, clays, marl, reef limestones, and evaporites; 28 mineral occurences consist primarily of ores of copper, lead, zinc, and barite of mostly small tonnage and low to high grades	Bigot, M. and Alabouvette, B.	1976	BRGM 76-JED-5, 81 p.	
Aeromagnetic and geologic study of Tertiary dikes and related structures on the Arabian margin of the Red Sea	To document the Tertiary dikes adjacent to the Red Sea margin in Saudi Arabia, outline their main features, and discuss their significant as well as that of related fault patterns with respect to tectonic evolution of the Red Sea margin of Saudi Arabia	Coastal and Precambrian shield margin of the Red Sea as much as 140 km inland, from the Yemen border to the Gulf of Aqaba	Prominent NW-trending dikes of negative and positive polarization crop out along the Red Sea margin of the Precambrian shield from the Yemen border to the Gulf of Aqaba. The dikes are of Tertiary age, averging 22 Ma, and range in composition from gabbro to quartz monzonite. In most of the belt the dikes appear to have been emplaced in a fracture system formed at the close of the first-stage of spreading of the Red Sea. The overall pattern of the dike and fault system suggests a deep-rooted slump failure of shield rocks at the newly formed continental-oceanic margin	Blank, H. R., Jr.	1977	DGMR Bulletin 22, p. G1-G18	
Seismic refraction profile, Kingdom of Saudi Arabia--field operations, instrumentation, and initial results	To present a status report of the field operations, instrumentation, and initial results of the deep seismic refractin profile	Arabian Shield, coastal plain, and Red Sea along a line from the vicinity of Riyadh to the Farasan Islands	A 1,000-km-deep seismic refraction profile across the Arabian Shield and Tertiary Red Sea basin delineates the character of the Precambrian sialic crustal boundary with the Tertiary sedimentary rocks and oceanic crust of the Rad Sea basin, establishing a transition zone between the two structural blocks and the existance of oceanic crust beneath the 6-km-thick sequence of sedimentary and volcanic rocks of the Red Sea continental margin	Blank, H.R. and others	1979	USGS Project Report 259, 49 p.	
The eveporite sequence of the Yanbu-Al Wajh coastal plain, the results of a drilling program	To evaluate the distribution and thickness of the Tertiary evaporite sequence between Yanbu and Al Wajh	Yanbu to Al Wajh (lat 24° 10' to 26°15' N.)	Two drill holes intersected the basement, and three were abandoned. The cored Tertiary section was uniform throughout the area and showed as much as 65 m of evaporites consisting of pure $CaSO_4$ and lees than 10 percent non evaporitic material. Clastic rocks of the Raghama encountered below the evaporite section and are dominantly fine grained. Coral reef rocks of Pliocene to possibly Quaternary age overlie the evaporites	Boardman, R. C.	1980	DGMR Open-File Report DGMR 675, 44 p.	
Strontium isotope stratigraphy of a Red Sea core	To study the strontium isotope geochemistry of Red Sea sediments	Sample from the axial trough of the Red Sea at lat 18°09' N., long 39°53' E.	Data indicate that the silicate fraction of Red Sea sediment is composed of two fractions. The noncarbonate fraction of the sediment was analyzed. The Sr^{87}/Sr^{86} ratios and strontium concentrations result from the mixing of volcanic-basaltic and terrigenous-sialic components	Boger, P. D. and Faure, G.	1977	DGMR Red Sea Research 1970-1975, Bulletin 22, p. P1-P4	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Explanatory notes to the reconnaissance geologic map of the Maqna quadrangle (28/34 D)	Geologic and mineral resource assessment of the Maqna quadrangle	lat 28°00' to 28°30' N., Gulf of Aqaba to long 35°00' E.	The Tertiary Raghama group consists of two formations; Tertiary to Quaternary sedimentary rocks overlie the Raghama; these units consists of approximately 7,000 m of evaporitic rocks, limestone, conglomerate, sandstone, shale, and chert; deposition was in a shallow-water marine to nearshore, possibly non-marine environment	Bokhari, M. M. A.	1981	DGMR Open-File Report DGMR-OF-01-16, 26 p.	
An overview of the geology of western Arabia	To review the geology of western Saudi Arabia as an introduction to a symposium on the evolution and mineralization of the Arabian-Nubian Shield	Western Saudi Arabia	A brief historical account of the geology of western Saudi Arabia is given and a Precambrian stratigraphic account is presented. The Tertiary metallogenic epoch is reviewed. Metallic sulfides are being deposited in the Red Sea today, chiefly in the central trough, a structural and physiographic feature that began in the Pliocene following deposition of a thick Miocene evaporite section. Epigenetic lead-zinc deposits in Saudi Arabia and Egypt have lead isotopic compositions similar to Red Sea brine pool muds indicating genesis under comparable conditions in time and space. Other deposits have dissimilar isotopic compositions. Some onshore deposits correlate with NE-trending Red Sea transform faults. This suggests a genesis related to NE structures rather than to the NW trends so prominent in western Arabia. This suggests a syngenetic or hydrogenetic metalliferous epoch from late Oligocene to mid-Miocene	Brown, G. F. and Jackson R. O.	1979	Pergamon Press, Oxford-New York, v. 1, p. 3-10	
Review and preliminary economic appraisal, Rabigh barite deposits	To evaluate the economic aspects of the Rabigh barite deposits based on previous work	Rabigh barite area, approximately 21 km NE of Rabigh	Metallurgical testing of Rabigh barite samples showed that gravity concentration gave the best results yielding material of 95.8 percent $BaSO_4$, 0.83 percent SiO_2, a specific gravity of 4.2, and 80.2 percent recovery. This concentrate appeared to meet drilling mud standards. The best barite veins are narrow and scattered	Cheeseman, D. R.	1975	DGMR Open-File Report 603, 23 p.	
Cement plant raw material, Jizan area	To identify and evaluate cement raw materials	Coastal plain near Jizan, Farasan Islands, and Umm Araj area	Coastal reef limestone not suitable; limestone in the Farasan Islands has too much chloride, and limestone in the Umm Arsj area appears very favorable to a depth of 15 m; dolerite dikes in the Umm Arsj Jurassic limestone might restrict reserves	Cheeseman, D.R. and Binda, P.L.	1976a	DGMR Open-File Report 530, 45 p.	
Interim report no. 3, Jizan cement raw materials	To update and evaluate the results of first phase drilling for limestone and other cement raw materials	Jizan coastal area, Farasan Islands, and Umm Arsj area	The report covers limestone sampling on the Farasan Islands and clay sampling in in the Jizan area; dolerite of two generations in the Umm Arsj area does not appear to be a problem for limestone quarrying	Cheeseman, D. R. and Binda, P. L.	1976b	DGMR Open-File Report 556, 103 p.	

Appendix 4.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1973 and 1982*—Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Resources of cement raw materials in the Jizan district: Summery report of investigations undertaken or monitored by the DGMR Geology Department	To evaluate the resources for cement raw materials in the Jizan region and assess the potential of the Hanifa limestone at Umm Araj for cement production	The coastal region in the vicinity of Jizan, the Farasan Islands, and the Hanifa limestone outcrops near Umm Araj were evaluated (lat 16°30' to 17°15' N., long 41°30' to 43°10' E.)	A coastal reef limestone project was abandoned as unfavorable after 4 drill holes showed sand overburden greater than 30 m. Timing considerations and logistical problems precluded adequate sampling of the Farasan Island limestones and further work was abandoned in favor of a detailed drilling, sampling, and chemical analysis survey of the Umm Araj area. Work in the Umm Araj area established that the region contains 70 million tons of limestone suitable for cement production in an East (20 million tons) and a Far East area (50 million tons)	Cheeseman, D. R. and Binda, P. L.	1981	DMMR Open-File Report DGMR-OF-01-11, 143 p.	
Interim report on cement plant raw material investigation, Jizan area	To present the results of cement raw material investigation in the Jizan area and summarize the work accomplished to date	Red Sea coastal area north and south of Jizan, Umm Araj area southeast of Jizan, and the Farasan Islands	Visual examination of drill core from the Umm Araj Hanifa limestone suggests suitability of the limestone for cement; however, chemical analysis was required. Drilling at Umm Araj was designed to block out 15 million tons of limestone to 20 m depth. Finding suitable limestone on the coast was considered remote and limestone on the Farasan Islands was found but further work deferred pending results from Umm Araj	Cheeseman, D. R. and others	1975	DGMR Open-File Report DGMR 526, 14 p.	
Coral limestone between Sharm Abhur and Wadi Jirbah	To evaluate the geology and facing-stone potential of limestone	Red Sea coastal area north of Jiddah, Sharm Abhur to Wadi Jirbah	Favorable limestone areas were found along Wadi al Kura, south of Tuwaal, and between Qadimah and Wadi Jirbah	Chevrel, S. and Odent,	1980	BRGM Open-File Report JED-OR 80-7, 15 p.	
Reconnaissance geology of the Jabal Niysqat al Izbah quadrangle (23/38 A)	To map and report lithology, structure, and stratigraphy	lat 23°30' to 24°00' N., long 38°00' to 38°30' E.	Other than small outcrops of Precambrian rocks, the area is predominately Quaternary surficial and coral reef deposits	Clark, M. S.	1980	DGMR Geologic Map GM-59, 6 p.	No Tertiary rocks are exposed
Layered gabbros in southwest Saudi Arabia	To describe the distribution and character of layered gabbros in southwest Saudi Arabia	The Arabian Shield and coastal plain zone of SW Saudi Arabia south of lat 22° N.	Layered gabbros of two widely spaced ages crop out in southwest Saudi Arabia. One set is Precambrian (702–425 Ma) and the other is Tertiary (24–20 Ma). The Precambrian gabbros are well layered but small compared to layered gabbros such as the Bushveld, Stillwater, and Duluth. The Jabal at Tirf mass has granophyrs associated with it in contrast to Precambrian examples	Coleman, R. G. and others	1972	USGS Professional Paper 800-D, p. D143–D150	Reprinted as USGS Project Report 154 (1973)
The volcanic rocks of southwest Saudi Arabia and the opening of the Red Sea	To document the volcanic history of the Asir area and relate it to the tectonic evolution of the Red Sea	Southwestern Saudi Arabia between lat 16°30' and 19° 00' N. and the Red Sea coast to approximately long 43°45' E.	As Sarat flood basalts erupted between 29 and 24 Ma. Diabase dikes, gabbro, granophyre, and rhyolite dikes invaded the Jabal at Tirf rift zone about 22 Ma and were related to initial separation of Arabia from Africa and thus original first-stage sea-floor spreading of the Red Sea basin. Eruptions of later Tertiary and Quaternary alkali-olivine basalts on the coastal plain and tholeiitic basalts in the Red Sea axial trough are related to second-stage spreading that began during the Pliocene and resulted in the formation of the Red Sea axial trough	Coleman, R. G. and others	1975	USGS Project Report 194, 60 p.	Also published in in Hilpert, L.S., ed., 1977, Red Sea research 1970-1975: DGMR Bulletin 22, p. D1-D30

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
The Miocene Tihama Asir ophiolite and its bearing on opening of the Red Sea	To determine if exposed igneous rocks on the coastal plain are part of the early Red Sea ocean crust	Red Sea coastal area, Tihamat Ash Sham and Asir areas, between lat 16°30' and 19°00' N.	Evidence presented suggests that the exposed Tihama Asir dike complex is the sheeted-dike part of an eroded but nondismembered ophiolite and that the Miocene Red Sea ocean crust was accreted to the continental margin in the Tihama Asir area	Coleman, R. G. and others	1979a	Evolution and mineralization of the Arabian-Nubian Shield, v. 1, p. 173-186	Also, published as USGS Project Report 255, 34 p. (Coleman and others, 1979b)
Reconnaissance geology of the Duba quadrangle (27/35 D), with a section on qualitative airborne geophysical interpretation	General geologic and mineral resource reconnaissance	lat 27°00 to 27°30' N., long 35°30' to 36°00' E.	A section of 1,800 m of Cretaceous and Oligocene clastic and carbonate rocks flanked by Tertiary faults on the east side of the succession	Davies, F. B., with Irvine, J.L., and Bin Abri, F.	1980a	DGMR Geologic Map GM-57, 23 p.	No Tertiary mineralization was observed. Also DGMR Open-File Report 665, 49 p. (1979)
Reconnaissance geologic map of the Wadi Thalbah quadrangle, (26/36 A), with a section on qualitative airborne geophysical interpretation	General geologic and mineral resource reconnaissance evaluation	lat 26°30' to 27°00' N., long 36°00' to 36°30' E.	Mesozoic and Tertiary sedimentary rocks belonging to the Azlam and Raghama(?) formations were deposited in a structural trough; exposures are poor for the Azlam formation; geophysical data indicate a thickness of 1,500-2,000 m for the Tertiary section; the rocks consist mainly of clastic types and limestone	Davies, F. B., with Irvine, J.L., and Bin Abri,	1981	DGMR Geologic Map GM-42, 32 p.	Also, 1980, DGMR Open-File Report 732, 73 p. (Davies, 1980b.) Published also as DGMR Open-File Report 596, 66 p. (Frets, 1977)
Preliminary report on uranium, thorium, and lead contents and lead isotopic composition in sediments from the Red Sea	To evaluate the isotopic composition of sediments from the Red Sea Deep Sea drilling project, Leg 23B	Central part of the Red Sea at the approximate latitude of Jiddah	Two sediment samples were collected from the Atlantis II Deep (sites 226 and 227) and one from siltstone within the evaporite sequence at site 228. U-Th-Pb data are also presented on pore water and basalt from site 226. Leads from the near-surface sediments are dominantly of mantle derivation. Origin of these leads appears to be from weathering of young mantle-derived volcanic rocks of the Red Sea region. Leads from sediments of the deeps appear to have a pelagic sediment derivation	Delevaux, M. H. and Doe, B. R.	1977	DGMR Red Sea Research 1970-1975, Bulletin 22, p. 01-04	
Reconnaissance geology of the Ra's at Tarfa quadrangle (17/42 C)	Geologic and mineral resource assessment	lat 17°00' to 17°30' N., long 42°00' to 42°30' E.	Tertiary rocks are not exposed in the quadrangle but occur in the subsurface based on geophysical evidence and drilling. The area is covered by extensive Quaternary deposits and Pleistocene reef coral deposits	Fairer, G. M.	1979	DGMR Geologic Map GM-41 4 p.	
Reconnaissance geology of the Jabal Fayfa quadrangle (17/43 C)	To record and evaluate the geology and mineral resources of the quadrangle	Southwest Saudi Arabia (lat 17° 00' to 17°30' N., long 43°00' to 43°30' E.	Wajid Sandstone of Cambrian to Ordovician age is exposed in a downdropped and intensely faulted zone at the SW corner of the quadrangle. Deformation of the Wajid and its position are related to crustal attenuation prior to Red Sea rifting	Fairer, G. M.	1981a	DMMR Open-File Report USGS-OF-02-1 18 p.	
Reconnaissance geology of the Sabya quadrangle (17/42 D)	To record and evaluate the geology and mineral resources of the quadrangle	Southwest Saudi Arabia (lat 17°00' to 17°30' N., long 42°30' to 43°00' E.	In addition to Precambrian rocks, the quadrangle is underlain by the Wajid Sandstone, Tertiary gabbro, diorite, granophyre, and granite, and Quaternary basalt. Some Tertiary mafic rocks are layered, and some are associated with granophyre. These intrusions indicate differentiation	Fairer, G. M.	in press	USGS Miscellaneous Document (Interagency Report 362), 26 p.	
Reconnaissance geology of the Aba al Qazaz quadrangle (26/36 B), with a section on qualitative airborn geophysical interpretation	Geologic reconnaissance and mineral resource assessment	lat 26°30' to 27°00' N., long 36°30' to 37°00' E.	Late Cretaceous to Tertiary sedimentary rocks were deposited in a Tertiary graben; in Tertiary and Quaternary rocks gravels extensively floor wadis in the area	Frets, D.C., and others	1980	DGMR Geologic Map GM-43, 19 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Delineation of the continental margin in the southern Red Sea region from new gravity evidence	To further delineate the nature of the crust underlying the shelf sediments of the Red Sea margin and the relationship of this crust to the Arabian Shield	Red Sea coastal area in the vicinity of Jizan, including the Farasan Islands (study area bounded by lat 16°15' to 17°30' N., and long 41°30' to 43°20' E.	145 new gravity stations were established. At the Arabian Shield-Tihama boundary, a 4-5 mgal/km gravity gradient exists, a row of high anomalies exists immediately west of the boundary, and a trough-like grsvity low exists over the Faraaan Islands. Two models were evaluated as a basis for interpreting the character of the rocks underlying the coastal plain. The data support a model of oceanic crust underlying the coastal plain beneath a veneer of sediments and lends support to a two-stage sea-floor spreading model for evolution of the Red Sea basin	Gettinga, M. E.	1977	DGMR Bulletin 22, p. K1-K11	
A tabulation of radiometric age determinations for the Kingdom of Saudi Arabia	To provide a computerized tabular record of all radiometric age determinations	Saudi Arabia	The data set includes 841 radiometric age determinations of which 78 are Tertiary	Gettings, M. E., and Stoeser, D. B.	1981	USGS Interagency Report 353, 52 p.	
Ultramafic inclusions and host alkali-olivine basalts of the southern coastal plain of the Red Sea	Study of the Al Birk basalts and construction of a petrologic model to explain their genesis	Al Birk lava field, including Jabal Haylah and Jabal Beqarah, lat 17°45' to 18°50' N., Red Sea coastal plain	The Al Birk lavas are Pleistocene, young in age, and contain a variety of inclusions and xenocrysts such as harzburgite, websterite, gabbro, and exotic material such as sandstone; harzburgite occurs only where basalt erupted through oceanic crust; megacrysts and cumulate inclusions are found only where magmas treversed Precambrian crust	Ghent, E. D. and others	1979	USGS Project Report 244, 37 p.	Also published as American Journal of Science, v. 280-A, p. 499-527 (1980)
Geology of the Rabigh quadrangle (22/39 A)	To evaluate the geology and mineral resources of the quadrangle	The Red Sea coastal plain encompassing part of the Hijaz foothills; lat 22° 30' to 23°00' N., long 39°00' to 39°30' E.	The quadrangle contains extensive exposures of Tertiary sedimentary rocks and Tertiary and Quaternary olivine basalt. The sedimentary rocks crop out on the coastal plain in low-lying areas mostly adjacent or peripheral to basalt outcrops. The sedimentary rocks consist of conglomerate, arkosic sandstone, white-weathering shale, limestone, and massive gypsum. Important barite vein cropout at Umm Gerad. These are of Tertiary age and are controlled by north-trending trending structures parallel to the Red Sea for the most part and associated with its tectonic evolution	Gilboy, C. F. and Skiba, W. J.	1978a	DGMR Open-File Report 739	
Geology of the Khulays quadrangle (22/39 C)	To evaluate the geology and mineral resources of the quadrangle	NW of Jiddah, lat 22°30' to 23°00' N., long 39°00' to 39° 30' E.	Tertiary and possibly Cretaceous sedimentary rocks are exposed in three main areas of the quadrangle around the periphery of Tertiary to Quaternary basalt tongues. These rocks consist, from oldest to youngest, of conglomerate and fossiliferous limestone, phosphatic sandstone, and gypsiferous arkosic sandstone interbedded with mudstone. The Tertiary volcanic flow rocks are composed of alkali-olivine basalt and represent erosional remnants of flows that filled paleovalleys west of the Hijaz escarpment. The tongues are distal extensions of Harrat Rahat	Gilboy, C. F. and Skiba, W. J.	1978b	DGMR Open-File Report 741	The authors did not assign the Teritary sedimentary rocks to a formation(s), but they are mapped as Usfan formation (Cretaceous ?) and Shumaysi on I-210A (Brown and others, 1963)

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
A tentative synopsis of the geology of the Seudi Arabian sedimentary basin in relation to phosphate proepecting	To analyze the Cambrian to Neogene stratigraphy of Saudi Arabia as a basis for guiding phosphate exploration in the Kingdom	Arabian Peninsula and surrounding area	Paleogeographic depositional baein reconstructions are presented for the Phanerozoic sedimantary rocks ae well as summary date on thicknessea and facies variatione of thaea rocks; recommendations are made for prospecting the Red Sea cc-stal area for phosphate rocks ae well as areas in the northern and southern parta of the Arabian platform	Glintz-boeckel, C.	1981	BRGM Open-File Report BRGM-OF-01-23, 145 p.	
Geologic map and sections of the Jabal 'In quadrangle (21/41 C)	To map, evaluate, and interpret the general geology and mineral resourcee	Jabal 'In quadrangle batween lat 21°00' and 21°30' N., long 41°00' and 41°30' E.	Tertiary volcanic, intrueive, and sedimentary rocks crop out over a wide area in the central, northern, and northeastern quadrants of the quadrangle. Hornblende latite dikes and silis are dated at 21.6 Ma. Tertiary lakebed sediments consist of limestone, chert, and oolitic iron beds and are presumed to overlie the olivine basalt flows of Harrat Hadan, which are aa thick as 500 m, are dated at about 15 Ma, and ere deeply eroded but well exposed	Gonzalez, Louis	1973	DGMR Geologic Map GM-2, 7 p.	
Geology of the Jabal Shada quadrangle (19/41 A)	To map, evaluata, and interpret the general geology and mineral resources	Jabal Shada quadrangle (lat 19°30' to 20°00' N., long 41°00' to 41°30' E.	Tartiary volcanic and aedimentary rocks crop out in the southeastern part of the quadrangle in a northwest-trending linear belt asaigned to the Baid formation. The rocks consist of tuffaceous marl siltstone, sandetone, limeetone, and olivine basalt	Greenwood, W. R.	1975	DGMR Geologic Map GM-20, 10 p.	
Palinspaetic map of the Red Sea area prior to Miocene sea-floor spreading	To compile the principal structurel trends of the Nubian and Arabian segmants of the African shield and determine whether theee trends favor sea-floor spreading for development of the main trough of the Red Sea	The entire Red Sea from the northern tip of the Gulf of Suez to the Straits of Bab el Mandeb and both coastal margins as much as 200 km inland (lat 12° 30' to 30°00' N., long 32°00' to 46°00' E.)	Good-quality relinement of of Precambrian trends is achieved north of lat 16° N. by coastline-to-coastline palinspastic closure of the Red Sea supporting the concept of ehore-to-shore oceanic cruet. Structural mismatches north of lat 16° N. and overlap of continental edges south of lat 16° N. are attributed to extensional tectonics, crustal ettenuation, incomplete knowledge of location of the continental edgee, and incorporation of sialic cruet by oceanic crust	Greenwood, W. R. and Anderson, R. E.	1975	USGS Project Report 197, 23 p.	Also published in Hilpert, L.S., ed., 1977, Red Sea research 1970-1975: DGMR Bulletin 22, p. Q1-Q6
Geology of the Wadi Hali quadrangle (19/41 B), with a section on aeromagnetic investigations	Geologic end mineral reeource evaluation	lat 18°30' to 19°00' N., long 41°30' to 42°00 E.	Numerous Miocene continental dikes of diabase and gabbro composition trend NW across the quadrangle; flows of Quaternary olivine basalt cover substantial parts of the SW part of the quadrangle	Hadley, D.G.	1975a	DGMR Geologic Map GM-21, 19 p.	
Geology of the Al Qunfudhah quadrangle (19/41 C)	Geologic atudy and mineral resource aaeeesment	lat 19°00' to 19°30' N., long 40°30' to 41°30' E.	The Baid formation is well exposed in the quadrangle in a NW-trending zone in the central part of the area; it ie composed of conglomarate, sandstone, siltstona, limestone, and siliceous and nonsiliceoue tuff; mafic volcanic flows, mainly endeeite, are intercalated within the layered strata; gabbroic dikee cut the Baid	Hadley, D.G.,	1975b	DGMR Geologic Map GM-19, 11 p.	
Reconnaiseance geology of the Musaylim quadrangle (19/40 B)	Geologic study and mineral resource aasessment	lat 19°30' to 20°00' N., long 40°30' to 41°00' E.	The Miocene Baid and Pliocene Bathan formations crop out in the east-central pert of the quedrangle, es well as Tertiary granite; the Baid consiste of tuff, limestone, and tuffaceous siltstone; the Bathen is a polymictic conglomerate; Miocene continental gabbro dikes are also exposed	Hadley, D.G.,	1980	DGMR Geologic Map GM-34, 7 p.	Also U.S. Geological Survey Saudi Arabian Project Report 272 (1979)

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Data of publication	Number and publisher	Remarks
Reconnaissance geology of the Wadi Dhahaban quadrangle (18/41 D)	Geologic and mineral resource evaluation	lat 18°00' to 18°30' N., long 41°30' to 42°00' E.	The quadrangle is abundantly invaded by northwest-trending Miocene continental gabbro dikes; in places the dikes are as wide as 300 m and are offset by east-trending faults interpreted to be Red Sea transform faults; most of the western half of the quadrangle is overlain by Quaternary alkali-olivine basalt	Hadley, D.G.	1981a	DMMR Technical Record USGS-TR-01-2, 22 p.	
Reconnaissance geology of the Wadi Amq quadrangle (18/41 C)	Geologic and mineral assessment	lat 18°00' to 18°30' N., long 41°00' to 41°30' E.	Except for a narrow coastal strip, all of the quadrangle is covered by Quaternary alkali-olivine basalt	Hadley, D.G.	1981b	DMMR Technical Record USGS-TR-01-3, 5 p.	
Reconnaissance geology of the Jabal Hashehiah quadrangle (17/41 B)	Geologic and mineral resource assessment	lat 17°30' to 18°00' N., long 41°30' to 42°00' E.	Most of the quadrangle is covered by Quaternay alkali-olivine basalt; abundant cinder cones are dominated by pyroclastic material; several types of xenoliths and xenocrysts are found in the lava and cinder cones; several continental gabbro dikes trend NW across the NE corner of the quadrangle.	Hadley, D.G.	1981c	DMMR Technical Record USGS-TR-01-4, 11 p.	
Reconnaissance geology of the Manjamah quadrangle (18/41 A)	Geologic and mineral resource assessment	lat 18°30' to 19°00' N., long 41°00' to 41°30' E.	Quaternary basalt abundant in southeastern part of the quadrangle and some basalt is in the NE part of the quadrangle; small outcrops of Baid and Bathan formations are found along the eastern part of the quadrangle; three Miocene continental dikes trend across the NE corner	Hadley, D. G.	1981d	DMMR Technical Record USGS-TR-01-5, 10 p.	
Reconnaissance geologic map of the Jabal 'Afaf quadrangle (20/40 C)	Geologic study and mineral resource assessment	lat 20°00' to 20°30' N., long 40°30' to 41°00' E.	Miocene continental gabbro dikes crop out in the quadrangle in a NW trend	Hadley, D.G., and Fleck, R.J.	1980a	DGMR Geologic Map GM-33, 10 p.	Also U.S. Geological Survey Saudi Arabian Project Report 271 (1979a)
Reconnaissance geologic map of the Al Lith quadrangle (20/40 C)	Geologic study and mineral resource assessment	lat 20°00' 20°30' N., long 40°00' to 40°30' E.	Tertiary continental gabbro dikes and the Pliocene Bathan formation are well exposed in the quadrangle; the type locality of the Bathan is in the quadrangle and consists dominantly of a coarse-grained to boulder polymictic conglomerate	Hadley, D.G., and Fleck, R. J.	1980b	DGMR Open-File Report GM-32 10 p.	Also U.S. Geological Survey Saudi Arabian Project Report 270 (1979b)
Bibliography of the Red Sea, its margins, and its rift extensions	To provide a bibliographic base as a research tool for guiding current and future work on the Red Sea and its environs	The greater Red Sea area	The bibliography contains 1,369 entries covering all major and obtainable earth-science references related to the Red Sea and its margins and rift extensions (Dead Sea, east African, and so forth). The bibliography is geographically and topically indexed	Hadley, D. G. and Schmidt, D. L.	1975a	USGS Project Report 198, 133 p.	Also published in Hilpert, L.S., ed., 1977, Red Sea research 1970-1975: DGMR Bulletin 22, p. R1-R46
Total-intensity magnetic anomaly map of the Red Sea and adjacent coastal areas, a description and preliminary interpretation	To compile and interpret the available total-intensity magnetic data of the Red Sea as a means of better understanding the structural evolution of the Red Sea	Red Sea	The compiled aeromagnetic map shows large-amplitude linear anomalies over the axial trough and subdivided linear anomalies over the main trough indicating that most of the Red Sea is underlain by oceanic material. A two-stage opening is suggested based on synthetic sea-floor spreading models. The models indicate an early stage of opening between either 40 and 34 or 29 and 24 Ma ago and a second-stage spreading beginning about 4.5 Ma ago	Hall, S. A. and others	1976	USGS Project Report 206, 36 p.	Also published in Hilpert, L. S., ed., 1977, Red Sea research 1970-1975: DGMR Bulletin 22, p. F1-F15, and as USGS Project Report 275 (Hall, 1979), 260 p.

Appendix 4.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1973 and 1982*—Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Saudi Arabian seismic deep-refraction profiles: final project report	To present and interpret the data from the seismic deep-refraction profile	1,000-km-long zone from the vicinity of Riyadh to Dammam to Dammam Island in the Farasan group	Seismic energy from energy released at 6 shot points was recorded by 100 seismographs along a 1,000-km-long line transecting the Arabian platform, Shield, coastal plain and a part pf the Red Sea; the Precambrian crust is composed of two 20-km-thick layers that thin to a total thickness of 20 km at the weetarn edge of the Shield; the Red Sea shelf and coastal plain are interpreted to be underlain by oceanic crust	Healy, J. H. and others	1982, 1983	DMMR Open-file Report USGS-OF-02-37, 141 p.	
Red Sea research, 1970-1975	Publication of research results on the Red Sea sponsored by DGMR for the period 1970-1975	Red Sea and adjoining areas	Papers related to the geochemistry, structure, geophysics, oceanography, age of mineralization of Red Sea brines, and sedimentary history of the Red See are presented; 17 papers in the volume	Hilpert, L. S., ed.	1977	DGMR Bulletin 22, chs. A-R	
Evaporite study project, interim report on reconnaissance survey of November 1976	To evaluate the evaporitic rocks and to recommend a program for their study along the Red Sea coastal plain with particular referance to the coastal sabkhahs and Tertiary evaporites	Kingdom of Saudi Arabia and the Red Sea coastal plain from the Gulf of Aqaba to Jizan	Evaporitee in the world mineral industry and their distribution in Saudi Arabia are described. A program for study of the evaporites is outlined, and results of a recon trip are presented	Imperial College of Science and Technology	1976	DGMR Open-File Report DGMR 611, 19 p.	
The Red Sea Tertiary evaporite complex, potash potential	To assess the potential of the Red Sea basin for potassium salts based on a review of the nature and origin of world-wide economically exploitable potassium salts	The report presents worldwide data on potassium salts and their exploitation and focuses on a model for Rad Sea potash explorstion	The presence of a thick halite sequence in the Red Sea suggests the possibility of presence of potassium salts. A model is presented that suggests potassium salts would most likely be found in the southern part of the Red Sea. It concludes that water replenishment was from a northern source. Potash tracea in a borehole on the Farasan Islands conforms to the suggested model. An exploration program is racommended for the eastern margin of the Red Sea	Imperial College of Science and Technology	1979	DGMR Open-File Report DGMR 691, 24 p.	
Paleomagnetic study of the As Sarat volcanic field, southwestarn Saudi Arabia	To determine the Tertiary rotation of Arabia relative to Africa	Harrat As Sarat lat 17°35' to 18°15' N., long 43°10' to 43° 30' E.	139 oriented samplas were collectad from 4 stratigraphic sections containing 42 magnetically acceptable flows of which 243 were normally magnetized snd 18 were reversely magnetized; a paleomagnetic pole was defined at lat 78.8° N., long 247.8° E.; the data support the hypothesis of a displaced dipole source for the Earth's field in late Oligocene to early Miocene time and that the Arabian plate was more equatorial during this period than lata Oligocene to Miocene; comparison with the African pola indicates an opening of 2° of the Red Sea since 5 Ma ago and of at least 4° since 29 - 24 Ma ago	Kellogg, K. S. and Reynolds, R. L.	1980	USGS Tachnical Record 14 (Interagency Report 360), 31 p.	
USGS/DGMR geophyeical investigations in Saudi Arabian seismic refraction profile, status report no. 2, with a section on operational stratagy	To conduct a deep-seismic refraction profile across Saudi Arabia from Riyadh to the Farasan Islands	Along a transact from near Riyadh to the Farasan Islands	The report describes the objectivee and technical layout of the seismic refraction profile including instrumenta and methods employed	Lamson, R. J. and Blank, H. R.	1978	USGS Project Report 234, 41 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Saudi Arabian seismic refraction profile data set, volumes 1 and 2	To compile and present for distribution and use the processed data acquired from the soundings of the seismic refraction profile	Vicinity of Riyadh to the Farasan Islands	The report presents the complete set of record sections from each seismic recorder station and single-page plots of first-arrival times for sections along the entire refraction profile	Lamson, R. and Leone, L.	1980	USGS Interagency Report 298, 859 p. (v. 1) and 109 p. (v. 2)	
Raw materials for a cement plant in the Rabigh area	Evaluation of the Tertiary and Quaternary geology of the area for cement raw materials	Rabigh area	All raw materials suitable for the establishment of a cement plant in the Rabigh area were found and tested; abundant Quaternary limestone resources were found	Laurent, D.	1974a	BRGM Open-File Report 74-JED-7, 29 p.	
Raw materials for a cement plant in the Jizan area	Evaluation of cement plant raw materials	Jizan area, Farasan Islands, and Umm Araj area	Most raw materials for cement manufacture were found in the area including limestone, clay, gypsum, and aluminious material; Umm Araj appears to be the best site for the plant	Laurent, D.	1974b	BRGM Open-File Report 74-JED-15, 25 p.	
Drilling at Ra's Baridi for the Yanbu cement plant project	Evaluation of cement raw materials in the Yanbu area	Ra'e Baridi, about lat 24° 15' N. and long 37°35' E.	The Ra's Baridi reef limestone was drilled on a 500-m grid spacing; limestone reserves of 76 million tons at a depth less than 15 m were established; clay, though high in chloride content, and gypsum is available	Laurent, D. and Al Habshi, A.	1975	BRGM Open-File Report 75-JED-5, 46 p.	
Reconnaissance for pozzolan in the pyroclastic cones of the harrats	To examine and evaluate the pyroclastic cones of the harrats of western Saudi Arabia for use in producing pozzalenic cement and lightweight concrete	Harrats al Kiehb, Rahat (north), Lunayyir, Bugum, Hutaymah and the Jiddah to Jizan coastal region	143 samples from the Harrats were analyzed for their pozzolanic properties. Suitable pozzolanic properties were obtained from ejecta from several cones at Harrat al Hutaymah, tuff south of Jiddah, and at Jabal ath Thiniyah. More detailed work was recommended	Laurent, D. and Al Nakhebi, Z. A.	1979	BRGM Open-File Report 79-JED-18, 60 p.	
A perlite deposit at Jabal Shama	Evaluation of the composition and stratigraphy of perlite-bearing volcanic rocks and expansion tests	Area centered at about lat 20°45' N. and long 39°40' E.	Lenses of perlite are interlayered with rhyolite flows; both bedded and brecciated perlite was found; expension tests were poor, but the material might be suitable as lightweight aggregate for certain types of cement	Laurent, D.	1976	BRGM Open-File Report 76-JED-24, 18 p.	
Prospecting for pozzolan on Harrat Lunayyir	Evaluation of the potential for pozzolan on the harrat	Harrat Lunayyir, lat 24°50' to 25°30' N., long 37°20' to 38°10' E.	Samples from 44 localities were chemically analyzed; only one cinder cone yielded material suitable for pozzolan; many cones bored on the samples contained material suitable for lightweight aggregate	Laurent, D. and Chevrel, S.	1980	BRGM Open-File Report JED-OR 80-13, 39 p.	
Map of potential industrial rock deposits of the Yanbu al Bahr quadrangle (24 C)	Evaluation of the rocks of the quadrangle for industrial ores	lat 24°00' to 25°00' N., long 37°30' to 39°00' E.	Many consolidated and unconsolidated rocks show potential for industrial uses such as for cement, plaster, ornamental stone, lightweight aggregate, and so forth	Laurent, D. and Odent, B.	1980	BRGM Open-File Report 80-JED-4	
Engineering geological map of Jiddah	Evaluation of the subsurface and surface geology of Jiddah; establishment of a topographic base map	Metropolitan Jiddah	Jiddah is underlain in increasing age by unconsolidated Quaternary gravels, sands, and silts, a loosely consolidated detrital reef limestone, and industrial massive coral limestone	Laurent, D. and others	1973	DGMR Geologic Map GM-8	
Drilling of gypsum deposits between Yanbu (24/38 C) and Umm Lajj (25/37 C) as a potential raw material for plaster	Evaluation of surface and subsurface data from Tertiary rocks as a potential source of plaster raw material	Yanbu to Umm Lajj	77 surface samples were analyzed as well as samples from 38 drill holes, totaling 658 m; gypsum beds measured 11.4 m at Sharm Mahar, and 15.23 m at Marsa Maqbarah; overall reserves exceed 300 million tons; the gypsum is generally suitable for plaster manufacture	Laurent, D. and others	1978	BRGM Open-File Report 78-JED-8, 47 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
The Maqna gypsum (Raghama formation)	To assess the Maqna area for gypsum resources and determine the origin of gypsum	Vicinity of Maqna and Al Bad, lat 28° 10' to 28°35' N., long 34° 40' to 35°03' E.	Bedded gypsum is found in the Raghama formation consisting of a sequence of conglomerats, reef limestone, sandstone, marl, and gypsum and ranging from Cretaceous to upper Miocene. The Maqna gypsum succession averages 130 m thick and is as much as 180 m thick. Area 4 contains contains exploitable gypsum reeerves.	Le Nindre, Y. M.	1981	DMMR Open-File Report BRGM-OF-01-18, 21 p.	Total gypsum reserves for the most promising areas were calculated in this report
Fluorite and barite in Saudi Arabia	To document the major known fluorite and barite occurrences in Saudi Arabia	Saudi Arabia west of long 46°E.	Fluorite wes documented at 25 localities and barite at 22 localities in weetern Saudi Arabia. The principal fluorite occurrences are Ablah, Nuqrah, and Jabal Sayid and for barite, Rabigh, Al Aqiq, and Maqna. None of these occurrences warrant additional study. Future exploration should focue on post-Murdama granitic intrusions, Hulayfah group volcanoeedimentary rocks, and Red Sea Miocene evaporite sequences	Lhegu, L.	1981	DMMR Open-File Report BRGM-OF-01-30, 29 p.	
Paleocene vertebretes from coastal deposits in the Harret Hadan area	To investigate the stretigraphy, lithologic composition, age relationships, and paleontology of the Umm Himar sedimentary rocks	Umm Himar area at about lat 21°10' N. and long 41°25' E.	Fossil vertebrates were collected from 17 localities in a 3-m mudstone interval of the Umm Himar formation, which consists of three members with a thickness of more than 22 m; the members are composed mainly of mudstone, mudstone and shale, and dolomitic limestone; the vertebrates include sharks, rays, lungfish, turtles, and primitive crocodilians; the fossils establish a Paleocene age for the sequence and an estuarine depositional environment	Madden, C.T. and others	1979	USGS Project Report 269, 29 p.	
A proposal for microseismic investigations on the eastern margin of the Red Sea using a portable microearthquake network	To propose studies of microseismic activity along the Red Sea margin of western Arabia	Saudi Arabian Red Sea coastal plain	Epicenters in the Red Sea appear to be relatad to transform faults. Some of these transform faults appear related to structures of similar trend on the coastal plain of weetern Arabia. Study of these structures is proposed by use of portable microseismic equipment	Marghelani, H. M.	1977	DGMR Open-File Report 653, 23 p.	
Red Sea geophysical cruise, 31 October-24 November 1979	To study the structure of the Red Sea	Red See	Bathymetric magnetometer and gravity surveys were made along 44 traverses in the Red Sea from the RRS Shackleton	Marghelani, H. M.	1979a	DGMR Open-File Report 709, 3 p.	
Seismicity of the Tihamat-Asir region	Survey of the microseismic activity in the Tihamat-Asir region	Region between approximately Ad Darb and Jizan, lat 16° 50' and 17°50' N.	At 17 seismic recording stations, 14 minor earthquakes were recorded between 23 January and 16 February 1978	Marghelani, H. M.	1979b	USGS Project Report 261, 20 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Author(s)	Date of publication	Number and publisher	Remarks
Seismicity of the Yanbu region	To establish if seismic activity exists in the Yanbu region because of the industrial development and population growth of the area	lat 23°30' to 26°00' N., long 36°30' to 39°30' E.	Using 5 portacorders at 12 different locations over the the period 20 January to 30 April 1979, 27 small-scale earthquakes were recorded and 109 events were detected; earthquake activity was most intense under Harrat Lunayyir and some epicenters were located in the Red Sea and southwestward from the harrat; the earthquakes were interpreted to be related to movement on Red Sea transform faults and NW-trending faults on land caused by salt diapersion, uplift of the continental block, and potential volcanism at the harrat	Merghelani, H. M.	1981	USGS Technical Record 16 (Interagency Report 371), 32 p.	
Interstitial waters of late Quaternary Red Sea sediments and their bearing on submarine lithification	To evaluate the depositional environment and sea-level conditions of the Red Sea by assessment of interstitial waters of the 11,000- to 20,000- year-old aragonitic layer	Red Sea between approximately lat 17° and 21° N.	The Red Sea has been an environment for extensive deep-sea calcium carbonate deposition. Magnesian carbonate predominated during interglacial periods due to higher temperatures and salinities. During glacial times the Red Sea was isolated from the Indian Ocean increasing its salinity. Because of this, aragonite was deposited instead of magnesian carbonate. Pore-water salinities from the samples collected during the Chain Cruise 100, Leg 3, were normal, suggesting active interchange between the aragonitic layer waters and postglacial lower salinity seawater	Milliman, J. D.	1977	DGMR Bulletin 22, p. M1-M6	
Micropaleontology and palynology of the middle and upper members of the Shumaysi formation	To obtain a reliable age for the middle and upper members of the Shumaysi formation and assess their depositional environment	Shumaysi outcrops and drill holes 40 km east of Jiddah	Abundant micro flora and fauna were found in the middle and upper members of the Shumaysi formation. The palynomorphs show a large variety; whereas the microfauna is dominated by the genus Ammobaculites. The oolitic ironstones of the Shumaysi are interprated to have formed in a lacustrine depositional environment similar to modern Lake Chad. The upper member appears to have formed in a low-salinity estuarine environment. The authors favor an Eocene age for the Shumaysi	Moltzer, J. G. and Binda, P. L.	1981	Bulletin of the Faculty of Earth Sciences, King Abdulaziz University, v. 4, p. 57-76	
Construction materials, nonmetallic mineral occurrences, and engineering geology around Jiddah	Evaluation of nonmetallic mineral resources and construction materials	Metropolitan Jiddah and vicinity	Deposits of limestone, gypsum, sand, and gravel are being exploited in the area, clay for brick making is found in the aree, salt is available in the subsurface but is not being exploited at present	Morris, P. G.	1975	DGMR Technical Record TR-1975-1 45 p.	
Geology of the area north of Wadi Fatimah	Geologic evaluation of the rock types, structure, stratigraphy, and age relationships	Area between lat 21°50' to 21°40' N., long 39°15' to 39°45' E.	Tertiary deposits in this area include the Shumaysi formation of Oligocene to Miocene age and Pliocene(?) conglomerate, sand, and shale	Nebert, K. and others	1974	Center for Applied Geology (Jiddah) Bulletin 1, 31 p.	
Preliminary investigation of clay occurrences between Rabigh and Masturah	Evaluation of the resources and quality of clays for use in alumina extraction	Coastal area between lat 22°45' and 23°10' N.	Al_2O_3 content of the clays are less than 15 percent and therefore too low for alumina extraction; for lightweight aggregate, clay reserves are estimated at 25 million tons and may be considerably higher	Odent, B. and Al Habshi, A.	1980	BRGM Open-File Report JED-OR 80-20, 24 p.	

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Prospecting for pozzolan in the Al Birk region	Examination and evaluation of the chemical and mechanical properties of possible pozzolanic materials	Al Birk lava field, lat 17° 45' to 18°50' N., Red Sea coastal plain	Analyses of 61 samples showed material suitable for light-weight aggregate; four cinder cones contained material with pozzolanic properties	Odent, B. and Roger, J.	1980	BRGM Open-File Report JED-OR 80-45, 29 p.	
Outcrops of limestone on the periphery of Harrat Hadan	To define the distribution of and evaluate the suitability of limestone surrounding Harrat Hadan for industrial uses, principally reconstituted marble and to evaluate the basalt for industrial use	Harrat Hadan and surrounding area (lat 21°20' to 22°10' N., long 41°15' E. to 41°40' E.	Four limestone sites on the periphery of Harrat Hadan contain stone suitable for the manufacture of reconstituted marble. Reserves are not large. Basalt in the vicinity of Radwan could be used for aggregate and rock wool. The Tertiary limestone beds are exposed sporadically but extensively around the periphery of the harrat. Chemical analyses show that the limestone is dolomitic in the southern part of the area	Odent, B.	1981	DMMR Open-File Report BRGM-OF-01-13, 28 p.	
Alumina tenors in laterite and saprolite from the As Sarat Mountains	To reevaluate the As Sarat laterite and saprolite for potential aluminum extraction in light of new, more efficient processes for extracting alumina from low-grade ore	As Sarat Mountains between lat 17°30' and 17°50' N., long 43°05' and 43°30' E.	Five target zones on the west periphery of the laterite show significant alumina tenors in porcellanite, yellow fine-grained laterite, and white saprolite. Reserves of more than 21 percent alumina are calculated at 35 million tons. Kaolinite is the predominant clay. Clay in the laterite is unsuitable for producing structural clay products	Odent, B. and Al Habshi, A.	1981	DMMR Open-File Report BRGM-OF-01-16, 39 p.	
Tertiary laterite of the As Sarat mountains	Map and description the geologic setting and composition of the As Sarat laterite	Harrat As Sarat, lat 17° 35' to 18°15' N., long 43°10' to 43°30' E.	The laterite covers an area of about 1,000 km^2 in the Asir mountains; its formation ceased with extrusion of the As Sarat lavas; mineralogy and chemistry indicate that the laterite is not an ore of aluminum or iron; alunite, an ore mineral of potash and alumina, is present, but its distribution is poorly known	Overstreet, W. C. and others	1977	DGMR Bulletin 21, 30 p.	Also U.S. Geological Survey Saudi Arabian Project Report 146 (Overstreet and others, 1973)
Geologic map of the Yanbu al Bahr quadrangle (24 C)	Compilation of the geology of quadrangle at 1:250,000 scale	lat 24°00' to 25°00' N., long 37°30' to 39°00' E.	The Tertiary Raghama formation is extensively exposed in the the quadrangle; the Raghama consists of 7 units and is composed of conglomerate and arkosic sandstone, reef limestone, marl, gypsum, and anhydrite; basalt flows are both older and younger than the Raghama; no significant base metal deposits are known, but important construction materials are available	Pellaton, C.	1979	DGMR Geologic Map GM-48-A, 16 p.	
Geology and mineral exploration of the sedimentary cover between Al Bad and Al Muwaylih	To explore for phosphate and lead and zinc in the Miocene sediments	Red Sea coastal plain between Muwaylih and Al Bad (lat 27°40' to 28°17' N., long 35°27' to 35°01' E.	Sedimentary rocks belonging to the Cretaceous and Paleogene were mapped and described; other sedimentary rocks as young as Miocene and Pliocene are found. No significant phosphate or lead-zinc mineralization was discovered	Remond, C. and others	1980	BRGM Open-File Report JED-OR 80-26, 79 p.	
Mineral deposits in western Saudi Arabia	To describe and summarize the principal mineral deposits of western Saudi Arabia	The Precambrian shield and coastal plain of western Saudi Arabia and the Red Sea	In addition to the Precambrian mineral deposits of western Saudi Arabia, the the report discusses the principal charecteristics of the Tertiary metallic and nonmetallic mineral deposits and the Red Sea metalliferous muds	Roberts, R. J. and others	1975	USGS Project Report 201, 60 p.	

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Prospecting for industriel rocks around Jizan	To evaluate the Jizan area for rocks suitable for industrial raw materials	Jizan coastel plain in an area bounded by lat 16°00' to 17°30' N., long 42°20' to 43°10' E.	Utilizable industrial materials include sand for concrete and asphalt, sandy loam for structural clay, gypsum as a retardant for cement manufacture, and pyroclastic rocks for pozzolan and lightweight aggregate	Rogar, J.	1980	BRGM Open-File Report JED-OR 80-21, 83 p.	
Raw materials for structural clay products in the Abha-Khamis Mushayt area	Evaluation for raw materials suitable for structural clay products	Asir plateau in the vicinity of Abha and Khamis Mushayt	Wadi silts are possible sources of structural clay products; As Sarat laterite might be suitable with the addition of kalinite for ceramic tile products	Rooney, L.F. and Al-Koulak, Z.	1978	USGS Project Report 226, 26 p.	
Results of recent expeditions to the Red Sea - Chain, Glomar Challenger, and Valdivia expeditions	To summarize recent expeditions to the Red Sea by the research vessels Chain, Glomar Challenger, and Valdivia	The Red Sea	Results from the Chain cruise defined the reflector-S acoustic layer at the top of the Miocene; bottom temperatures in some of the hot brine pools increased from 1966 to 1971 on the order of 3°-4° for the two thermal layers. Results from the Glomar Challenger showed that the Red Sea is underlain by Miocene evaporites and rock salt, that interstitial waters from sediment cores increase steadily in salinity with depth approaching NaCl saturation near the boundary with the evaporites, and that metalliferous shales containing two suites enriched in vanadium and molybdenum and in zinc (as much as 5 percent by weight) are widespread. The Valdivia showed recent lava flows in the axial trough, brine pools being controlled by recent tectonics, evaporites a requirement for the brine deposits, variation in chemical composition of the brine deeps, and sediments enriched in iron and manganese often above basalts in the axial zone	Ross, D. A.	1977	DGMR Bulletin 22, p. B1-B14	
Shallow structure and geologic development of the southern Red Sea	To evaluate and interpret continuous seismic-reflection profile data for part of the Red Sea	Central trough zone of the Red Sea south of lat 22° N.	Thirty-four shallow seismic-reflection profiles made across the Red Sea show that it developed in two stages. Early or pre-Miocene uplift created crustal thinning and initial development of the Red Sea basin. During the Miocene, the Red Sea was a basin of evaporite deposition and was isolated from the Indian Ocean. The reflection date show that a dietinct acoustic reflector (s) marks cessation of evaporite dsposition and is widespread in the Red Sea at the top of the Miocene. Marine water circulation became established in the Pliocene through the Straits of Bab el Mandab and circulation was closed between the Red Sea and the Mediterranean. Sea-floor spreading bagan during the Pliocene-Pleistocene causing development of the axial-trough sone	Ross, D. A. and Schlee, J. S.	1977	DGMR Bulletin 22, p. E1-E18	Also published as USGS Project Report 152, 41 p. (1973b) and GSA Bulletin v. 84, p. 3827-3848 (1973a)

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Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
A geophysical study of the Red Sea axial trough between lat 20.5° and 22° N.	To evaluate and interpret bathymetric, gravity, and magnetic data collected aboard the R. V. Chain during March 1971	Shelf and axial trough areas of the Red Sea between lat 20°30' and approximately 22°10' N.	The data show that the axial trough is not continuous but is divided into two sections separated by an intertrough zone. The intertrough zone contains a thick sediment cover and is magnetically flat. It may be either a fracture zone into which sediments and salt have flowed or a sediment-covered spreading axis. Previously recognized transverse magnetic anomalies were confirmed on the basis three-dimensional computations. A model was developed that accounts for the anomalies as the magnetic culmination of a series of short spreading axes that have been offset by closely spaced transform faults	Searle, R. C. and Ross, D. A.	1977	DGMR Bulletin 22, p. J1-J13	
Red Sea transform faults deduced from mangetic anomalies	To investigate NE-SW-trending magnetic anomalies in the axial part of the Red Sea and to delineate the borders of the anomalies and establish how they are related to NNW-SSE-trending magnetic anomalies present over most of the Red Sea trough	Axial part of the Red Sea between lat 20°30' and 22° 30' N., long 37°30' and 39°00' E.	Large anomalies lie in a N-S trend coincident with the trend of the axial trough. However, individual anomalies strike NE-SW, and two double sets of these as 4 anomalies represent axial trough-spreading axes in a NE-SW trend that are offset by a NNE-SSW-trending transform fault. Spreading rates normal to the main trend of the Red Sea from these data and data utilizing a model simulated from the Heirtzler time-scale are 1.1 $cm\text{-}y^{-1}$, and 1.7 $cm\text{-}y^{-1}$ for the southern and northern anomalies, respectively	Searle, R. C. and others	1973	USGS Project Report 157, 7 p.	Data also in Hilpert, L. S., ed., 1977, Red Sea research 1970-1975: DGMR Bulletin 22, p. J1-J13
The Red Sea and coastal plain of the Kingdom of Saudi Arabia	Review of studies conducted along the Red Sea coastal plain of Saudi Arabia and the Red Sea	Red Sea Coastal plain from the Gulf of Aqaba to the Yemen border and the whole of the Red Sea	This report comprehensively summarizes previous earth-science studies in the Red Sea basin and along its margins, Saudi Arabia in particular; it reviews the theories related to the evolution and tectonic development of the Red Sea basin	Skipwith, P.	1973	DGMR Technical Record TR-1973-1, 149 p.	
Geology of the Wadi Azlam quadrangle (29/36 C)	Geologic and mineral resource evaluation	lat 27°00' to 27°30' N., long 36°00' to 36°30' E.	A sequence of Tertiary clastic rocks and limestone that total 1,000 m or more exposed in the quadrangle; Ostrea crassisima indicates a Miocene age	Smith, J.W.	1979	DGMR Geologic Map GM-36, 30 p.	

Appendix 4.—*Synopsis of geologic, mineral resource, geophysical, and other earth-science studies conducted under sponsorship of the Saudi Arabian Government on Cenozoic rocks and environments of the Red Sea and western Saudi Arabia between 1973 and 1982*—Continued

Abbreviated title	Objective of work	Area of study	Major conclusions	Authors	Date of publication	Number and publisher	Remarks
Sedimentary history of the Red Sea	To summarize the sedimentary studies made on Leg 23 of the Deep Sea Drilling Project (DSDP) and to compare them with previous work	The Red Sea and a part of the Gulf of Suez	Based on 20 drill holes in the Red Sea and onshore, the composition and stratigraphy of the Red Sea can be described as follows: the sediments are composed of six major constituents, biogenic, volcanogenic terrigenous, authigenic evaporitic, and brine precipitates; the sediments are dominantly silty clays, some sites were mainly clayey silts; sedimentary structures include bedding, banding, laminations, grading, and bioturbation; stratigraphically the Red Sea sedimentary sequence is divided into four units, from oldest to youngest: evaporites, Unit IV (Miocene) dark-gray dolomitic silty claystone, Unit III (Pliocene), grey micarb-rich nanno-detrital silty claystone, Unit II (Pliocene), and gray micarb-rich detrital silty clay nanno-ooze and chalk, Unit I (Pleistocene).	Stoffers, P. and Ross, D. A.	1977	DGMR Bulletin 22, p. H1-H19	
Prospecting in the sedimentary formations of the Red Sea coast between Yanbu al Bahr and Maqna, 1968-1979	Evaluation of the mineral deposits and potential of the Cretaceous and Tertiary sedimentary rocks	Red Sea coast, Yanbu al Bahr to Maqna on the Gulf of Aqaba	The report, divided into two main parts, discusses the geology and mineral prospecting work by BRGM during 1968-1979 north of Yanbu. The coastal plain stratigraphy is subdivided into Cretaceous-Eocene, Dhaylan formation, Raghama formation, and Pliocene-Quaternary formations; mineral resource investigations focused on metallic and nonmetallic deposits and phosphate of the Azlam trough; mapping was carried out as needed to supplement previous mapping; the only metallic deposit of any consequence remains Jabal Dhaylan with 500,000 tons of more than 7.7 percent zinc ore; small amounts of phosphate (6 percent P_2O_5) were encountered in the Azlam trough; nonmetallic resources of clay, limestone, and gypsum are favorable near Yanbu	Vazquez-Lopez, R. and Motti, E.	1981	DMMR Technical Record BRGM-TR-01-1, 77 p.	
Reconnaissance geology of the Wadi Sadiyah quadrangle (20/40 A)	Geology and mineral resource assessment	lat 20°30' to 21°00' N., long 40°00' to 40°30' E.	Several large Tertiary dikes of gabbroic composition strike NW across the quadrangle	Wisr, K. L. and Hadley, D. G.	1975	USGS Project Report 193, 27 p.	
Volcanic and sedimentary processes in the Red Sea axial trough	To show photographic evidence of the varied and irregular character of the sea floor in a volcanic and tectonically active area	Atlantis II, Chain, and discovery deeps of the central Red Sea (lat 21°10' to 21°30' N., long 38°00' to 38°10' E.	Volcanic features observed in the Red Sea axial trough are typical of other mid-oceanic ridge sites. Flows, pillow lavas, and rock fragments were photographed. Sedimentary cover is thin in areas of recent volcanic activity. Sediments are thin and are reworked by bottom currents and biological organisms. Mound-building organisms (polychaete worms?) inhabit the region between the hot brine waters and overlying normal (22° C) Red Sea water	Young, R. A. and Ross, D. A.	1973	USGS Project Report 158, 34 p.	Also published in Hilpert, L.S., ed., 1977, Red Sea research 1970-1975: DGMR Bulletin 22, p. I1-I13