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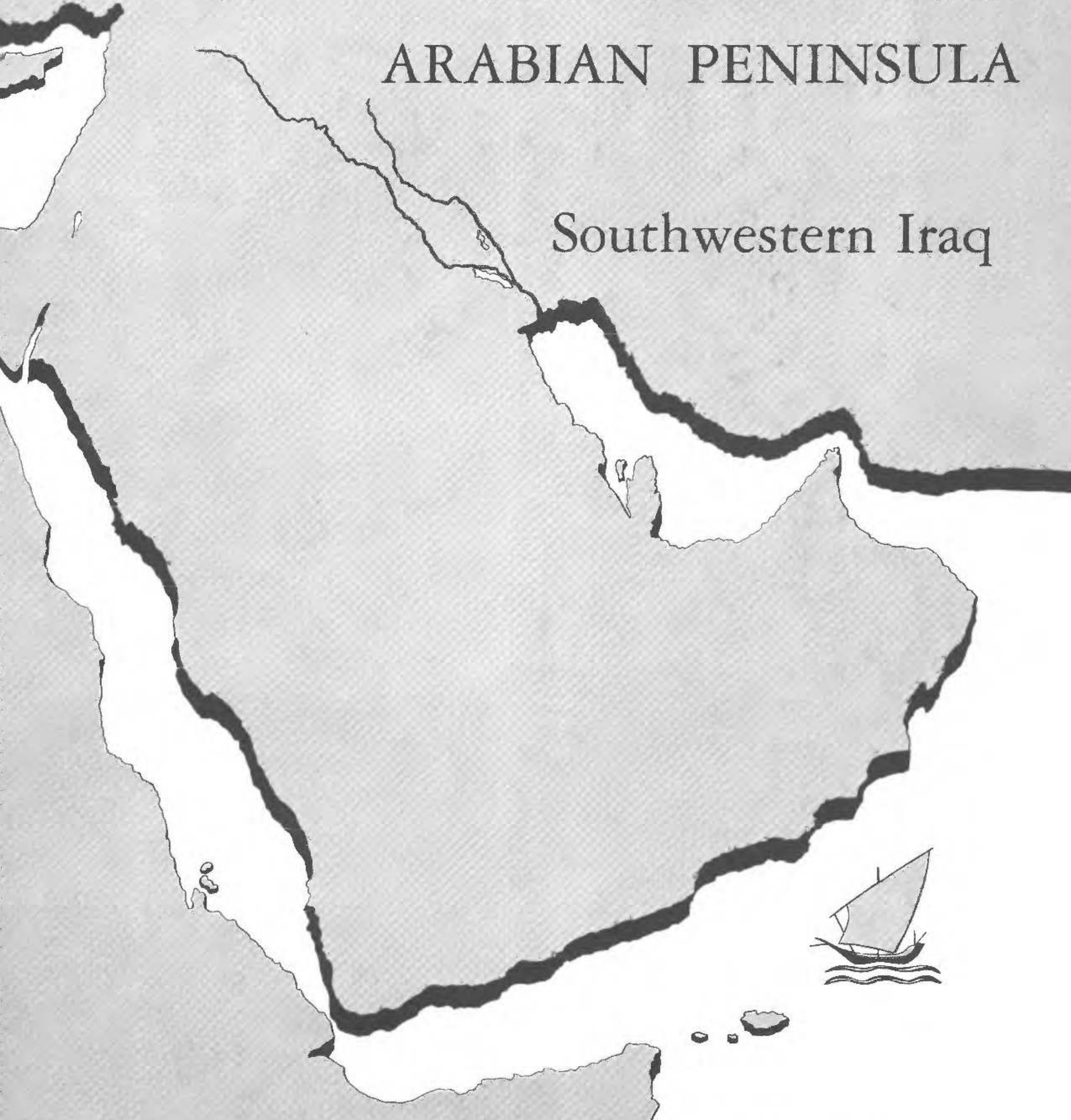
GEOLOGY OF THE ARABIAN PENINSULA

Southwestern Iraq



U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 560–G

Geology of the Arabian Peninsula

Southwestern Iraq

By K. M. AL NAQIB

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 560–G

A review of the geology of southwestern Iraq as shown on USGS Miscellaneous Geologic Investigations Map I–270 A, "Geologic Map of the Arabian Peninsula," 1963

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FOREWORD

This volume, "*The Geology of the Arabian Peninsula,*" is a logical consequence of the geographic and geologic mapping project of the Arabian Peninsula, a cooperative venture between the Kingdom of Saudi Arabia and the Government of the United States. The Arabian-American Oil Co. and the U.S. Geological Survey did the fieldwork within the Kingdom of Saudi Arabia, and, with the approval of the governments of neighboring countries, a number of other oil companies contributed additional mapping to complete the coverage of the whole of the Arabian Peninsula. So far as we are aware, this is a unique experiment in geological cooperation among several governments, petroleum companies, and individuals.

The plan for a cooperative mapping project was originally conceived in July 1953 by the late William E. Wrather, then Director of the U.S. Geological Survey, the late James Terry Duce, then Vice President of Aramco, and the late E. L. deGolyer. George Wadsworth, then U.S. Ambassador to Saudi Arabia, and Sheikh Abdullah Sulaiman, then Minister of Finance of the Government of Saudi Arabia, lent their support to the plan. In November of the following year, 1954, Director Wrather approved the U.S. Geological Survey's participation and designated G. F. Brown responsible for the western Arabian shield region in which he had previously worked under U.S. foreign-aid programs. In January 1955 F. A. Davies, Chairman, Board of Directors, Arabian-American Oil Co., approved Aramco's participation and appointed the late R. A. Bramkamp, chief geologist, responsible for compilation of the area within the Kingdom where the sediments crop out. This responsibility fell to L. F. Ramirez following the death of R. A. Bramkamp in September 1958.

R. A. Bramkamp and G. F. Brown met in New York in February 1955 and planned the program, including scales of maps, areas of responsibility, types of terrain representation, and bilingual names. Thus there was established a cooperative agreement between the Kingdom of Saudi Arabia, the U.S. Department of State, and the Arabian-American Oil Co. to make available the basic areal geology as mapped by Aramco and the U.S. Geological Survey.

The agreement specified publication of a series of 21 maps on a scale of 1:500,000, each map covering an area 3° of longitude and 4° of latitude. Separate geologic and geographic versions were to be printed for each of the quadrangles; both versions were to be bilingual—in Arabic and English. A peninsular geologic map on a scale of 1:2,000,000 was to conclude the project.

High-altitude photography, on a scale of 1:60,000, of the Kingdom of Saudi Arabia was initiated during 1949 by the Aero Service Corp. and completed in 1959. Both third-order vertical and horizontal control and shoran were utilized in compiling the photography. This controlled photography resulted in highly accurate geographic maps at the publication scale which then served as a base for the geologic overlay. The topography of the sedimentary areas was depicted by hachuring and that of the shield region by shaded relief utilizing the airbrush technique.

The first geographic quadrangle was published in July 1956 and the last in September 1962. While preparation of the geographic sheets was in progress, a need arose for early publication of a 1:2,000,000-scale peninsular geographic map. Consequently, a preliminary edition was compiled and published in both English and Arabic in 1958. The second edition, containing additional photography and considerable new topographic and cultural data, was published in 1963. The first of the geologic map series was published in July 1956 and the final sheet in early 1964. The cooperative map project was completed in October 1963 with the publication of the 1:2,000,000-scale "Geologic Map of the Arabian Peninsula" (Miscellaneous Geologic Investigations Map I–270 A).

As work on the quadrangles progressed, geologists, companies, and governments working in areas adjacent to the Kingdom of Saudi Arabia were consulted by Aramco and invited to participate in the mapping project. The number of cooperating participants was expanded to 11, which included the operating oil companies in the peninsula and which are identified elsewhere in this text; the Overseas Geological Surveys, London; the Government of Jordan; F. Geukens, who had worked in Yemen; and Z. R. Beydoun, who had studied the Eastern Aden Protectorate. With the close cooperation of the authors, the new data were added to data already plotted on the base map of the Arabian Peninsula.

As the geological coverage of the peninsular map grew, the need for a text to accompany the map became apparent to both the U.S. Geological Survey and the Aramco geologists. Exploratory conversations were begun by Aramco with companies working in the other countries of the Arabian Peninsula for their participation in the preparation of a monograph on the geology of the Arabian Peninsula. Each author prepared a description of the geology of the area for which he was responsible, as shown in the sources of geologic compilation diagram on the peninsular map. The U.S. Geological Survey undertook the publishing of the volume as a professional paper, and the Government of Saudi Arabia was to finance its printing. It was early agreed that there would be no effort to confine the contributions to a standard format and that no attempt would be made to work out an overall correlation chart other than shown on the "Geologic Map of the Arabian Peninsula." Thus, the individual style of authors of several nationalities is preserved.

Cooperation and relations have been of the highest order in all phases of the work. The project would not have been possible without the full support of the U.S. Department of State, the Kingdom of Saudi Arabia, and all contributors. In fact, the funds which made publication of this volume possible were contributed by the Saudi Arabian Government.

The data provided by the maps and in the professional paper provide information for an orderly scientific and economic development of a subcontinent.

O. A. Seager

O. A. SEAGER,
Arabian-American Oil Co. (Retired).

W. D. Johnston Jr.

W. D. JOHNSTON, JR.,
Former Chief, Foreign Geology Branch,
U.S. Geological Survey.

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[Plates are in pocket]

GEOLOGY OF THE ARABIAN PENINSULA

SOUTHWESTERN IRAQ

By K. M. Al Naqib[1]

ABSTRACT

Southwestern Iraq covers all Iraqi territory south of lat 32° N. and west of the Euphrates River. Slightly to the north, the area's oldest rocks (Lower Triassic?) crop out in the Ga'ara depression where they are succeeded by Middle and Upper Triassic, Rhaetic, and Lower and Middle Jurassic rocks. The Middle Jurassic sequence is unconformably overlain by Cenomanian sandstones and limestones; the gap in sedimentation diminishes away from the Ga'ara area. The Cenomanian deposits are succeeded by Upper Cretaceous limestone. The Cretaceous sedimentation in southwestern Iraq was due to periodic epeirogenetic withdrawals, which are reflected in a series of sedimentary cycles characterized by strong diachronism of the sediments. A sequence of Paleocene and Eocene deposits covers most of the area in long scarpy strips. On the east side the Miocene limestones, evaporites, and clastics overstep the Eocene beds. The Miocene limestone overstepping, however, seems to be more extensive and covers large areas in the west. Oligocene deposits are not recognized in the area, indicating a major pre-Miocene unconformity. The Pliocene and Pleistocene sequence covers the southeastern part of the area, the transition from Miocene to Pliocene deposition seems to be gradational. Descriptions of 27 formations have been made in some detail.

Structurally, the area constitutes a small part of the Interior Homocline of the Arabian Peninsula. It is simple, flat-lying country with very gentle dips to the east and northeast. There are a few depressions in the central parts which may be indicative of deeply buried graben systems accentuated by the solution-collapse effects. There is evidence of relatively strong movements during the Cenomanian and early Miocene times, which influenced the realms of sedimentation more than the epeirogenetic movements during Cretaceous and Tertiary times. In southern Iraq these movements are still active and influence the retreat of the Persian Gulf. Minor linear structural elements, oriented north-northwest and north, occur in the area of Tertiary outcrops. These were possibly initiated on deeply buried old faults which were activated by recurrent disturbances.

Oil was found in commercial quantities in the sand reservoirs of the Zubair Formation, in the Zubair and Rumaila fields, after considerable effort, energy, and investment by the Iraq Petroleum Company, Ltd., and its associate the Basrah Petroleum Company, Ltd.

[1] Of the Iraq Petroleum Company, Ltd.

INTRODUCTION

The area of present review covers a territory of more than 82,000 square kilometers lying south of lat 32° N., and is limited by the Euphrates and Shatt al Arab Rivers on the east and by the Iraq-Saudi Arabia and Iraq-Kuwait borders on the west and south.

During the early 19th century many scientists and scholars who were interested in the archaeology of southern Iraq, a classic area, attempted to explain their findings geologically. Beke (1835) described the geological evidence of the advance of the land at the head of the Persian Gulf and commented on the alluvium of Babylonia and Chaldaea. Ainsworth (1838) gave the geological results of the Euphrates Expedition which was conducted by Colonel Chesney.

With increased demand for oil, interest in the petroliferous area of Mesopotamia and in its geology grew. In 1905, H. Bücking, C. Porro, and Kissling reported on the seepage areas of the Euphrates and Tigris Rivers. Two years later, P. Grosskoff reported on the petroleum deposits of the area for the Turkish Civil List. Geological interest increased and authorities such as Pascoe (1922) made more serious and prolonged surveys and evaluations of the general area. G. W. Halse in 1918 examined the bituminous districts west of Euphrates River.

These surveys in southwestern Iraq, however, were only reconnaissance in nature. Greater attention to the geology of western Iraq was paid by A. H. Noble and L. D. Evans, who spent parts of 1919 and 1920 conducting a general geological reconnaissance of Iraq, the primary aims of which were the establishment of a stratigraphic section for the area and the investigation of the most important structures from the point of view of petroleum.

With the 1925 Oil Concession agreement, the Turkish Petroleum Company, Ltd. (later renamed the Iraq Petroleum Company, Ltd.), commenced an intensive geological reconnaissance in Iraq. In the course of this, H. de Boeckh, who had made some investigation in western Iraq in 1924, revisited the area in the spring of 1925 with S. L. James, G. M. Lees, and F .D. S. Richardson. During 1925–29 A. C. Trowbridge, E. W. Shaw, A. H. Noble, Bourchier, and H. De Boeckh undertook general geological reconnaissance and inspection of the possible oil prospects in western Iraq. Exploratory activities were cut back in 1929 after a decision was made to devote all available resources to the development of the Kirkuk field, where oil had been struck in October 1927.

Interest in the western desert was not confined to petroleum exploration alone. Geologists were intermittently active in investigating potential groundwater supply. An excellent work reporting on the progress of hydrological inquiries in the area was made by W. A. Macfadyen and S. D. Bekhor during April and May 1934. Macfadyen (1938) described the geology of the area in some detail, discussing both stratigraphy and structure in relation to water resources.

Interest in the petroleum possibilities of southern Iraq led to the incorporation, on July 22, 1938, of the Bashrah Petroleum Company, Ltd., an associate of Iraq Petroleum Company, Ltd. A week later a convention was made with the government of Iraq, whereby the Company was granted a 75-year oil concession covering southern Iraq, which extended from the 33d parallel southward to the borders of Iran, Kuwait, and Saudi Arabia. The area of the present review, which comprises most of the southern desert west of the Euphrates River, together with the District of Brasa, occupies the western and southern part of this concession. The convention became operative on November 30, 1938, on which date its ratifying law was published in the Iraqi Government Gazette. Article 4 of the convention required the Company to conduct a detailed geological survey before July 30, 1939.

Company geological field parties and a torsion-balance survey party under contract from the Torsion Exploration Co., Texas, began operations in the area in January and March of 1939, respectively. This early geological investigation varied in scope and nature; it embraced reconnaissance geologic mapping as well as detailed mapping of selected areas and stratigraphic as well as structural studies. It included systematic aerial reconnaissance as well as topographic surveying. The geological field parties operated continuously until May 1941, when exploration was temporarily suspended because of civil disturbances within Iraq and because of the general stringencies imposed by world war. By this date a considerable area of the western desert of Iraq had been examined by geologists. The early investigators in this field included T. F. Williamson, D. C. Rogers, W. T. Foran, H. L. Thompson, H. Hotchkiss, H. Huber, H. Badoux, and F. Kubba under the general direction of the Chief Geologist, N. E. Baker. In September 1940 the torsion-balance party was replaced by a gravimeter party from the Mott Smith Corp., Texas, which left Iraq in April 1941 at the time of the revolt.

During the war years attention was chiefly paid to solving difficult, detailed problems of stratigraphy, partly through laboratory studies of samples collected prior to 1941. Fieldwork was on a restricted scale because of the shortage of staff.

During the years following World War II, geological exploration activities continued in the southern desert. Geological field parties engaged in detailed structural mapping, stratigraphic investigations, and reconnaissance surveying. These were supported by photogeological and topographical surveys and by a limited program of structural drilling of shallow holes with an M. I. Failing rig. The structure drilling was restricted to selected areas such as Luqait, Shagra, Abu Ghar, Takhadid, Dimana, and Galaib and had as its objectives the investigation of gravity anomalies, the confirmation of localized structures, and the clarification of facies changes. Field investigations were discontinued when the Iraqi Government ordered suspension of the Company's exploratory activities in April 1961 as a result of the breakdown of oil negotiations. During the period 1946–61 a great many Company geologists, under the successive guidance of N. E. Baker, F. E. Wellings, and C. E. Thiebaud, contributed to the geological knowledge of the area through field investigations, subsurface studies, laboratory and stratigraphic correlations, and paleontological studies. These contributors, whose work is contained for the most part in unpublished reports of the Company, include C. Andre, A. S. Abbo, R. V. Browne, R. C. van Bellen, Z. R. Beydoun, M. Chatton, J. M. Cox, E. J. Daniel, H. V. Dunnington, E. K. Elliott, G. F. Elliott, H. A. Field, T. Fothergill, D. Glynn Jones, A. S. Halliwell, E. Hart, F. R. S. Henson, J. M. Hudson, R. G. S. Hudson, J. P. Jaccard, A. V. James, K. D. Jones, F. A. Al Kasim, A. P. Leggat, J. McGinty, J. M. Macleod, S. Marchant, S. C. McKinley, G. Medaisko, D. M. Morton, K. M. Al Naqib, S. Nasr, R. M. V. Rabanit, R. M. Ramsden, M. Roy, I. Rolleigh, A. Th. C. Rutgers, V. M. Safar, H. M. Saleh, A. S. Sayyab, A. H. Smout, T. P. Storey, W. Sugden, K. F. M. Thompson, F. J. Venn, P. Walmsley, R. Wetzel, and E. Williams-Mitchell. Non-Company geologists who published reports on the geology of the region are included in the bibliography.

Geophysical work by a combined gravity and magnetic survey party recommenced after the war years in November 1945, the first area to be investigated being Zubair. In the following year, geophysical activities were increased to a scale greater than at any time since 1940. Three geophysical survey parties (one seismic and two gravity and magnetic) of the Robert Ray Co. were engaged on extensive exploratory work in the western desert during 1948 and 1949. Seismic parties of the Independent Exploration Co., Ltd., London, using reflection and refraction techniques, were also deployed in this area. In 1951 two double gravity-magnetic geophysical parties of the Robert Ray Co., and one party of Seismograph Services, Ltd., operated intermittently in the area and were employed in different parts of Iraq according to season. The geophysical surveys were supplemented by topographic as well as aerial surveys. The geophysical investigation continued at about this intensity through ensuing years. In June 1956 the Company, in addition to the contractors' crews, organized its own seismic crew which started operation near Karbala.

After the Suez crisis and sabotage of the Syrian pipelines in 1956, exploration activity was reduced during 1957. However, during the following years, until the suspension of exploration by order of the Iraqi Government in April 1961, full-scale exploratory activities were carried on. By 1964 the gravity survey had covered the entire area of the present review, while seismic-survey coverage was largely confined to particular areas for example, Basra, Qasr Shagrah district, and Shawiyat.

The results of the early geophysical surveys suggested the existence of some potential oil-bearing structures. Accordingly, test wells were drilled on the most promising of them at Zubair No. 1 (Feb. 14, 1948, to Mar. 13, 1948), Nahr Umr No. 1 (Mar. 23, 1948, to Feb. 13, 1949), and Ratawi No. 1 (Nov. 30, 1948, to Mar. 18, 1950). The first two wells penetrated oil sands, Zubair No. 1 between 10,200 and 11,100 feet and Nahr Umr No. 1 below 8,000 feet. In September 1948 the Iraq Petroleum Company informed the Government that oil in commercial quantities had been discovered. More wells were drilled at both places, but the second well at Nahr Umr encountered water; to produce oil for export at the earliest possible time, all the drilling efforts were concentrated at Zubair.

Drilling activities were greatly intensified during 1950, and the transition from exploratory operations to the development of the Zubair field was accomplished. By the end of the year the laying and welding of the entire Zubair-Fao 12–16-inch pipeline was completed, and work on terminal and field installations and facilities was progressing well. At the end of 1951 the first jetty (No. 3) at Fao was completed, together with berthing and mooring dolphins. The M. V. *Niso* was the first ship to berth at the jetty. She sailed with a cargo of 11,043 tons of oil on December 21, 1951. The official inauguration of production from the Zubair field took place on January 10, 1952. In February of the same year, a 50–50 profit-sharing agreement, negotiated in 1951, ws approved by the Iraqi Chamber of Deputies and ratified by the Senate, retroactive to January 1951.

Prior to the commencement of production, 12 wells had been completed in the Zubair field. The increasing exploratory activities of the Company were rewarded by the discovery in 1953 of the Rumaila field, 20 miles west of Zubair. Drilling on a geophysical prospect began on February 21, 1953, and oil was found in the first well, under conditions similar to those prevailing at Zubair.

With this discovery, attention in the following years was directed to the development of the Rumaila field. For the purposes of immediate production, however, reliance was mainly placed on Zubair, where 38 wells had already been completed. The Company switched the emphasis of its activities from Zubair to the development of the Rumaila field in 1955, with the object of increasing the production rate to 8 million tons per year.

In 1953 a 24-inch pipeline was laid between Zubair and Fao. As the development progressed as planned, some effort reverted to exploratory drilling. The exploratory well Rachi No. 1 (June 11, 1956, to Jan. 11, 1957) was drilled to a depth of 12,959 feet, but the results were disappointing. Exploration activities were intensified, and the western desert received further attention which continued until the suspension of exploration in April 1961.

During this period the following wells were drilled west of the Euphrates River: Samawa No. 1 (Aug. 31, 1958 to Nov. 9, 1959); drilled to a depth of 12,602 feet, was plugged back owing to disappointing results; Tuba No. 1 (Mar. 3, to Dec. 27, 1959), on reaching depth of 11,940 feet, was completed as an observation well; and Nahr Umr No. 3 (Mar. 2 to Oct. 11, 1958), with a total depth of 10,109 feet, found oil in the Nahr Umr sands. North-northwest of An Najaf, two wells—Kifl No. 1 (Sept. 21, 1959, to July 8, 1960) and Kifl No. 2 (Jan. 23, to Feb. 28, 1961)—were drilled to total depths of 10,684 and 6,293 feet, respectively, some oil having been found in the Zubair Formation in the first well.

On the deep wells Ideal 100 rigs were used. However, an H 525 Rambler rig was used to drill shallow

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stratigraphic and structural test wells such as Shawiya No. 1, Ghalaisan No. 1, Safawi No. 1, and Ubaid No. 1, which did not exceed 6,600 feet in depth. Shawiya No. 1 (Feb. 15, to Apr. 20, 1960), which was completed at a depth of 5,853 feet, found the Zubair Formation waterlogged. Except for the presence of some gas in the Nahr Umr Formation, the findings were similar in Ubaid No. 1 (Nov. 2, to Dec. 12, 1960), which was completed at a depth of 6,050 feet. The results of the wells Ghalaisan No. 1 (May 15, to July 25, 1960; 6,533 ft) and Safawi No. 1 (Aug. 17, to Oct. 9, 1960; 6,000 ft) were also disappointing, but oil in good quantity was found in the Zubair Formation in Luhais No. 1 (Jan. 17, to Apr. 15, 1961). This well was plugged at a depth of 9,646 feet after the general suspension of exploration in April 1961.

By 1964 there were 39 wells in each of the two oil fields of Rumaila and Zubair. The productive length of the Rumaila fields has proved to be at least 60 kilometers.

Oil production from these fields is maintained by an elaborate modern system of pipelines, degassing stations, tank farms, and oil-terminal facilities. A 16-inch pipeline between Rumaila and Zubair was commissioned in October 1957. To handle an envisaged increase in production rate, the deep-water terminal of Khor al Amaya was constructed in the Arabian Gulf during 1959–62, and a 30- to 32-inch pipeline between Zubair and Foa was laid parallel to the 24-inch pipeline. The old 12- 16-inch pipeline was realined and converted for gas transmission.

ACKNOWLEDGMENTS

The writer greatly appreciates and thanks the management of Iraq Petroleum Company, Ltd., and associated companies for the opportunity to prepare and the permission to publish this paper. Special thanks are due to Dr. C. E. Theibaud, Manager, Exploration Division, and to Mr. H. V. Dunnington, Chief Geologist, for their interest and encouragement; to Mr. G. F. Elliott for reading the manuscript and making valuable suggestions; and to Mrs. I. Barber for the painstaking effort of typing the manuscript. Thanks are also due Mr. H. A. Field for valuable and constructive suggestions and discussion on the region. The author's grateful appreciation is extended to the management of the Arabian-American Oil Co., especially to Mr. O. A. Seager, without whose enthusiasm and sustained advocacy this work would not have been completed.

The author has drawn freely on unpublished Company reports of many colleagues and on papers by authors mentioned in the bibliography. Contributions from all these sources are gratefully acknowledged.

GENERAL GEOMORPHOLOGY

Southwestern Iraq as a whole is relatively flat, though there are very gradual and gentle rises in altitude from east to west and from south to north. The rise in altitude along the Shatt al Arab and Euphrates Rivers is gentle, between Al Faw (Fao) and Bahr al Milh, west of Karbala, amounting to only 245 feet (74.6 meters), whereas southwestward from Al Basrah on the Shatt al Arab to the Iraq–Saudi Arabia Neutral Zone, the rise in altitude is five times as great in about one third of the distance. In the extreme west, at Jabal Unazah (Aneiza), where the borders of Iraq, Saudi Arabia, and Jordan intersect, altitudes are as much as 3,084 feet (940.1 m) above sea level. Even here, the region has a general east-northeast slope, toward the Euphrates—the only perennial river.

The region has been subdivided by various authors into a number of physiographic areas (Macfadyen, 1938; Mitchell, 1956). For purposes of the present review the following subdivisions are recognized:

Mesopotamian alluvial plain covers the area between the Euphrates and Tigris Rivers and comprises flat country surfaced by Recent alluvium (or locally by the marine Hammar Formation).

Sand dune belt, according to Macfadyen (1938), forms an area 10–15 kilometers wide on the east border of the southern desert of Iraq, and separates it from the Euphrates River. It extends from south of An Najaf to the Wadi Batin in the extreme south.

Ad Dibdibba gravel and sand region occupies the southern part of Iraq and is bounded roughly to the north and west by Jaliba, Abu Ghar, Al Busayyah, Jahmah, B'ir Juraybī'āt, and Al Waqisa. Outlying areas of physiographic similarity are to be found near An Najaf and Karbala, in the north.

Al Hajara limestone region includes most of the area under review. The surface is largely made up of limestone outcrops, at some places obscured and littered with residual flints and cherts.

Al Widyan country covers a large area south of the Ga'ara in lat 33°30′ N, and west of long 43° E. It consists of a vast plain gently rising westward so as to appear almost flat. The geomorphic expression of the region is largely a function of the geologic framework of the area and particularly of the lithologic characteristics of the constituent outcrops. The different physiographic belts or areas are discussed below in some detail.

MESOPOTAMIAN ALLUVIAL PLAIN

In southwestern Iraq the Mesopotamian alluvial plain extends west of the Euphrates River as a narrow belt and consists of mudflats and sabkhas, which receive the drainage of the numerous shaibs and wadis during the wet season. The sabkhas are soft rather saline mudflats, which in many places hold moisture even through the dry season; they are, as a result, very difficult to cross. They cover extensive areas between Ur Junction and As Samawah, and hinder transport from the desert to the railway. In the south, sabkhas also occur along the margins of Hawr al Hammar; they extend northward as far as An Najaf. Their magnitude and characteristics vary from place to place.

SAND-DUNE BELT

The rather mobile sand-dune belt covers the eastern part of the territory. It may transgress to any of the other adjacent physiographic zones, the Mesopotamian plain, Al Hajara, or the Dibdibba.

AD DIBDIBBA GRAVEL AND SAND REGION

The Ad Dibdibba zone is distinctive in its physiography; it is largely flat, low, and scrub covered. The Wadi Batin, cut into the Dibdibba plain, forms a conspicuous negative feature which defines part of the Iraq-Kuwait boundary. In southwestern Iraq the Dibdibba extends westward from the Shatt al Arab and Euphrates (Hawr al Hammar) Rivers in the east to the vicinity of Qasr Shaqrah and Al Busayyah and into the Iraq–Saudi Arabia Neutral Zone. Here the terrain is rather flat, having but a few slightly higher isolated elongated hills. The country is covered with gravel and sand. The gravels are of various igneous and quartz pebbles, and the coarse sands are in places cemented into hard grit.

South-southwest of Az Zubair village and very close to the Iraq-Kuwait border, the Jabal Sanam stands out as a solitary and isolated hill. It has an altitude of more than 500 feet in a low-lying region whose altitude elsewhere ranges between 50 and 150 feet above sea level. This prominent and impressive feature is a piercement salt dome (the only one in Iraq), the detailed geology of which is still obscure. The drainage system of Ad Dibdibba is apparently controlled by the Boliya-Ar Rachi topographic feature. The surface is sandy and gravelly with good porosity; and because the rainfall is generally slight, drainage lines have not been significantly incised, except for the long, deep, and very straight Wadi Al Batin, which runs northeastward. The other shaibs and wadi courses on the east side of the Boliya feature show a gradual swing in direction northeast to north toward Hawr al Hammar, as evidenced in Shaib ash Shich, Shaib al Ubtain (Butayn), and Shaib al Adhbi. Most of the courses west of the Boliya-Ar Rachi feature end in gentle closed depressions, forming a kind of internal drainage basin, such as that at Khor Ash Shihiyat.

AL HAJARA LIMESTONE REGION

The Al Hajara region takes its name from the weathered rocky limestone terrane of Huweimi and Shawiya outcrops that extends between Shabicha and Nisab (Ansab), where travel by vehicles is extremely difficult. In this region Ad Dibdibba morphology gives way to a topography which is controlled by a series of scarps that radiate around a point just to the south of the Iraq-Saudi Arabia Neutral Zone. These scarps and alinements, of variable form and size, are from east to west as follows: Al Busayyah, At Traq, At Takhadid, Al Waqisah (Wagsa), Al Qasas, and Al Batn. Each scarp line passing northward takes on a general north-northwest trend extending toward Wadi Al Ghadaf, north of the area. The scarps coincide with different beds of the Dammam and Umm er Radhuma Formations. Their general distribution can clearly be appreciated from the geologic map (pl. 1). In the Hajara region there are a number of broad depressions which form internal drainage systems.

Westward from the Euphrates Limestone Formation, the outcrops are almost flat. The topography changes in the area of Dammam limestones. The main feature in the southern part, beginning north of Alm Ghanzir (lat 30° 17′ N., long 45° 25′ E.), is the big scarp of At Traq, trending generally southward; local embayments face towards the east (for example, Faydat az Zahra, near Shibrumiya, Ad Dayir). Near Kashmat al Muharh, the trend of the scarp swings due east, toward Tuqaiyid, and from there it again trends southward and then disappears east of the north tip of the Neutral Zone. The difference in altitude between the scarp and the low-lying ground west of it is as much as 50 meters.

West of At Traq, a higher ridge trends north-northwest. Toward the north it disappears in the vicinity of Zum, and in the south it plunges underneath the Dibdibba Formation. Another prominent feature is Chabd (Kabd), which is a flat-topped hill farther west, rising 38 meters above the surrounding low-lying country and characterized by the steep cliffs which delimit it. Some distance west of this is another scarp that trends north-northwest.

Still farther west, there are two dominant topographic features: the Wagsa-Jil Raschid scarp and the Al Batn scarp. Both are alined roughly north-northwest and face westward, forming three distinct parallel strips or zones, which are gently tilted to the northeast. The most easterly zone extends from Nisab (Ansab) to Ash Shabakah (Shabicha), and then to the west edge of the very rocky area known as Al Hajara. The second strip, between the Batn and Wagsa scarps, is named Al Basita; this is also rocky in parts, but is not marked by any very distinct drainage system. The zone below the Batn scarp, known locally as Hamrat al Batn, is more dissected than the Basita area; its drainage is poorly defined, and the terrain is dotted with numerous small depressions, each having its own catchment.

Farther north, all these scarps and features tend to lose their distinctive characteristics. West and southwest of An Najaf and Karbala the area becomes rather tabular. Hills (mesas) capped by silicified limestone, occur in the eastern belt and are generally small, being some 10–20 meters above the plain or wadi floor. Old wadis, dating from pre-Zahra or even pre-Fars times, cut only slightly into the stratigraphic succession and reveal minor scarps from time to time, although collapse structures, slumping, and bending of beds generally smooth out the morphology.

Two major scarps dominate the topography of this part of the region: The first of these is the Upper Fars scarp, which forms the first major scarp on the west side of the Mesopotamian structural valley. Its average height is 50 meters; it has a roughly northward trend; and it extends far beyond the limits of the area considered. The second is the Batn az Zawr scarp, which like the Upper Fars scarp is due to differential erosion of regionally tilted rocks. Near the top of the Dammam chalks is a bed of chert, 0.5 meter thick, so competent and resistant to erosion that it virtually controls the steep scarp face which extends for a long distance, and it can be considered as the extension of the Wagsa scarp. This scarp forms the eastern boundary of an extensive Miocene Zahra-Euphrates embayment of deposition that transgressed over all formations in the area, from Miocene to Cretaceous. Erosion of these later sedimentary rocks is responsible for the varied irregular hummock and plain topography of the broad area to the south of Nukayb (Nukhaib).

A number of wadis, including Wadi Arar, Wadi Hamir, and Safawiyat (Shaib) Al Ubaydat, which have their origin in Saudi Arabia drain into gentle depressions south of Nukhayb, such as Khabra al Qatah and Faydat al Adyan.

In the extreme southwestern part of Al Hajara, north of Al Busayyah toward Abu Ghar, the Euphrates limestones form numerous isolated hills, especially in the region of Al Afaif. The Lower Fars Formation, which occurs between the Euphrates limestones and Dibdibba beds, generally forms a pronounced ridge. The drainage here flows toward the north into the sand-dune belt on the west bank of the Euphrates River. The principal intermittent water courses are the Shaib Abu Ghar with its tributaries, Shaib Juda and Shaib Luwaihadh. Some distance farther west, Shaib Sudayr drains a big part of the territory covered by Tuqaiyid limestone, which underlies the Euphrates Limestone Formation. The drainage system in the western desert is characteristically subdivided between those shaibs which drain into the Euphrates River and those with interior drainage into inland depressions, mudflats, and lakes.

The Tuqaiyid, Barbak, and Ghanimi sedimentary-rock units extend north-northwestward from the Al Busayyah area toward al Khirr, where they overlie the Euphrates limestone. The regions covered by these units are generally flat, the dip and slope commonly toward the northeast. The drainage lines have the same trend. These include Shaib al Ghanimi, with its tributaries Shaib al Arjawi and Shaib Abu Finajin, Shaib Ashali, Shaib al Haisam, Rijlat As Salhubiya, Shaib Firk (Firch), Shaib Huwaymi, Shaib Hisb, and Wadi Al Khirr. Most of these lead northeastward to the mudflats and sabkhas bordering the Euphrates River.

Beyond An Najaf, the drainage from the desert is interrupted by the long Upper Fars sandstone ridge of Al Lisan Tar as Sayyid, which trends northward from Tuqtuqanah. The presence of this ridge has given rise to the salt lakes of Bahr Al Milh, which lie east of Shithatha.

Numerous wadis that cross the area from west to east drain into these salt lakes, following a general easterly direction. These include the Wadi al Ubaiyih and Wadi al Ghadaf, which have their origin in Saudi Arabia to the west. In the central parts of Al Hajara there are several depressions into which numerous wadis drain in the rainy season. The Ghanimi depression, which is drained by Shaib al Ghanimi, forms a conspicuous inland drainage system southwest of Al Qusayr. To the south of Ghanimi, the drainage flows mostly into a number of isolated systems each emptying into a depression with no outlet, such as Jahama, Tukayyid, and Faydat as Zahra. Farther west, in the neighborhood of As Salman, there is a group of very deep depressions completely surrounded by cliffs, some of which have a relief of as much as 50 meters. These have no surface outlet, owing to the flatness of the country, and form several topographic closed basins of varying diameter, which may be as much as 15 kilometers. Extensive pools form in some of these depressions after rains. Northwest of this area, the vicinity of Ash Shabakah (Shabicha) and Baraibir is marked by a few important depressions. Several solution holes, such as Ashuriyah and Chebritiyah, occur in the area.

AL WIDYAN COUNTRY

Al Widyan area, within the study region considered, includes outcrops of the Umm er Radhuma, Tayarat, and M'sad Limestones west of the Zahra and Euphrates limits. The topography is more undulating westward, beyond the Tertiary-Cretaceous contact. The country is deeply dissected, with broad, deeply incised wadis, many more than 1 kilometer across, bounded by steep scree-covered and slumped walls attaining altitudes of 40–50 meters. The eastern part of the area is drained chiefly by the Wadi al Ubayyid and its tributaries Wadi Tibaland and Wadi al Mira and by the Wadi al Ghadaf and its tributaries, which all flow generally eastward, ultimately ending in the Bahr al Milh, west of Karbala. The western part of this area is drained by Wadi al Hauran, which flows northeastward. Within this catchment several solution holes of various sizes are irregularly distributed and are limited mostly to the Paleocene beds. These include Wadi al Ghadaf (E. 1188, N. 1195), Jelta (E. 202, N. 1173), Kursa (E. 225, N. 1160), and Wishwashia. Al Umchaimin, in the Al Hamand plain, to the west of the area, is a similar feature (Merriam and Holwerda, 1957).

The origin and mode of formation of these solution holes may vary widely, and some may be attributed to the combined effect of several different mechanisms. For example, for the Al Umchaimin, which is a large depression, Merriam and Holwerda (1957) postulated meteoritic origin, whereas Mitchell (1958) argued for a possible volcanic origin. The majority of the geologists of the Basrah Petroleum Company, however, considered it best explained in a less dramatic manner. They maintained that the initial dissolution probably began along fracture surfaces and so lead to the development of a rudimentary underground drainage pattern. Evidence of this pattern remains in the small tunnels now partly blocked by collapse debris. The vertical drainage through fractures then apparently augmented the underground streams and swallow holes were formed. This stage is possibly represented by holes at Kursa and Wishwashia. Continued dissolution finally resulted in the foundering of the roof and in the formation of a large collapse structure of irregular outline, as at Jelta and Wadi al Ghadaf. Theoretically it would seem that this kind of topographic feature can originate in different ways: the effect of climate on geological structures and rock facies, volcanic activity, or meteoritic impact.

STRATIGRAPHY

GENERAL FEATURES

PHILOSOPHY OF NOMENCLATURE

The incompleteness of the geological record is not peculiar to the systems in Iraq. Establishment of the stratigraphic sequence in virgin territory depends primarily on the background of the investigators and the amount and type of data available. Through the efforts of a great many geologists of the Iraq Petroleum Company and its associated companies, a great mass of geologic, stratigraphic, and paleontologic information and material has been accumulated. After 33 years of investigation the progressive synthesis had reached a stage, toward the end of the last decade, at which the broad patterns of the sedimentation in Iraq were fairly well established. A statement of the stratigraphic synthesis was published by Dunnington, Wetzel and Morton for Paleozoic and Mesozoic units and by Bellen for Tertiary units (Bellen and others, 1959) in the Stratigraphical Lexicon for Iraq sponsored by the Commission on Stratigraphy, International Geological Congress.

The system of rock-unit classification and naming employed by Iraq Petroleum Company geologists is advocated in the code of rules compiled by Ashley and others (1939) as supplemented in recent papers and rulings of the Commission on Stratigraphy.

It has been generally realized that the sedimentation realms were dominated by the proximity of the Arabian shield on one side and by the Zagros (Tethys) geosyncline on the other and that the sedimentary characteristics followed the natural shore-to-basin pattern from the Arabian shield east and northeastward. Furthermore, the sedimentary patterns showed clear diachronism following epeirogenic cycles in western and central Iraq and diastrophic and orogentic movements in northern and northeast Iraq. Of course, an attempt has also been made to define the basic units of the sedimentary cycles. However, because of gaps in knowledge and especially because of paucity of information on the deep subsurface stratigraphy of central Iraq, separate stratigraphic nomenclatures were developed for northern and southern Iraq.

Description of some of the rock units of southwestern Iraq was published by Owen and Nasr (1958), and all the formations except for the newly defined Safawi and lately defined Kifl Formations were redescribed and expanded by Bellen, Dunnington, Wetzel, and Morton (1959).

The present report is chiefly based on the above works, supplemented by later unpublished works of a number of geologists, including especially M. C. Chatton and E. Hart. Some of the original descriptions of individual formations have been revised, redescribed, and expanded, where necessary, to take into account the findings of recent investigations and especially of recent deep wells in the southern and western areas.

TIME UNITS REPRESENTED

In western Iraq the oldest rocks exposed, the Nijili Formation and the overlying Ga'ara Sandstone Formation, are of Middle Triassic age; the Ga'ara is followed unconformably by the Upper Triassic Mulussa Formation, which is succeeded upward by the Rhaetic(?) Zor Hauran Formation and the Liassic (pre-Toarcian) Uba'id Formation. The Bathonian-Bajocian Muhaiwir Formation overlies the Uba'id Formation with probable unconformity. A major unconformity exists between the Middle Jurassic Muhaiwir and the overlying Middle Cretaceous Rutbah Sandstone. All the Middle Triassic, Jurassic, and Lower and middle Cretaceous units are exposed in the Ga'ara depression and Wadi Hauran, which are to the north of the area of review. No detailed account will therefore be given of them.

In the area of present consideration, the exposed rocks range in age through middle and late Cretaceous, Paleocene, Eocene, Miocene, and Pliocene Epochs to Pleistocene and Recent. With the exception of the Al Hamad plain in the extreme western part of Iraq, where the Cretaceous units are succeeded westward by Paleocene formations, the general sequence of the exposed formations is in ascending stratigraphic order to the east. The Oligocene Epoch is not represented by any rock unit in the area, owing to the great unconformity between the Eocene and Miocene Epochs, though there was some tendency in the past to assign an Oligocene age to the Tuqaiyid beds of the Dammam Formation.

In the subsurface sections of the area, the oldest sequence found is the Butmah Formation in the BPC (Basrah Petroleum Company) well Samawa No. 1, which was completed at a total depth of 12,602 feet. This formation is Early Jurassic in age.

GENERAL DISTRIBUTION OF SYSTEMS AND DOMINANT ROCK TYPES

The surface occurrences of the different systems and their general areal distribution in the defined area are illustrated on the geological map (pl. 1). This map shows the presence of a major stratigraphic gap between the Bathonian and Bajocian Muhaiwir Formations, and the overlying Cenomanian Rutbah Sandstone Formation in the Ga'ara area, a little to the north of the area that is considered in detail. This hiatus becomes less important away from the Ga'ara-Khleisia high. The sequence is almost complete in the wells of the Basrah area, but there are successive convergences northwestward, beneath the pre-Cenomanian unconformity. Thus the Cretaceous System is only partly represented in outcrop, the oldest exposed rock units being the Cenomanian and lower Turonian Rutbah Sandstone and M'sad (Mishrif) Limestone, which come to the surface only in the region of the Ga'ara depression, especially in the Wadi Al Hauran area.

The Upper Cretaceous (upper Campanian and Maestrichtian) is represented by the Tayarat limestones, which include subsidiary marls and thin shales. They cover most of the Al Widyan region, where between the Upper Cretaceous and middle Cretaceous (Cenomanian) there is an extensive hiatus. The missing rock units include those of the middle Turonian and lower Campanian cycle, which are widespread in the subsurface in the eastern parts of the region. These rocks include the basinal Khasib limestones, neritic Tanuma shales, and Sadi subbasinal chalks and limestones. Also, the upper Campanian Hartha limestones and the related Safawi evaporites, which are well represented in the subsurface section in western Iraqi wells, wedge out between the westernmost well and the outcrop belt.

The Paleocene series embraces the Umm er Radhuma Formation, which consists of two main limestone units in the surface exposures. These trend north-northwestward along the western Iraqi-Saudi Arabian border. In the Al Widyan area the Umm er Radhuma limestones are exposed both east and west of the Cretaceous outcrops. The Umm er Radhuma is very extensive in the subsurface beneath the western desert.

The overlying Eocene Dammam limestones crop out along parallel belts that are also oriented north-northwestward. These limestones also have a widespread subsurface distribution in the area. The evaporitic Rus Formation is present in the Basrah area as a lateral facies variant at the base of the Dammam.

The Oligocene series is not represented in the area.

The relations of the rock units of the Miocene series are complex. The lower Miocene is perhaps represented by the Euphrates Limestone, which crops out along the east margin of the area and in the Al Busayyah region. The stratigraphic position of the Zahra beds is rather problematical, but they are generally included in the Miocene. They occupy old depressions and wadi floors, occurring as isolated outcrops in the southern and central areas and as extensive sheets in the northern and western parts of the area where they overlie rocks of both Paleocene and Eocene ages. The middle Miocene Lower Fars evaporites cover the Basrah area and follow the general distribution of the Euphrates Limestone. The Lower Fars evaporites are underlain by the clastics of the Ghar Formation, the relationship between the two rock units being one of facies change by intergradation, the incidence of evaporitic components diminishing westward.

In the north the Lower Fars evaporites are succeeded by Upper Fars sandstones and siltstones in the region of Karbala, where they underlie the Recent Mesopotamian alluvium, whereas in the south the Lower Fars is directly followed by the rudites of the Dibdibba Formation, which covers the Dibdibba physiographic region of southern Iraq. In the Basrah area the Dibdibba Formation dips under the Recent marine sediments and alluvium of the Hammar Formation.

The 27 formations recognized in the area are described below, in ascending stratigraphic order, beginning with the Lower Cretaceous Ratawi Formation. The relations of these units to each other and to correlative units in other areas are illustrated on plate 2.

The schematized regional correlation of the current rock units (pl. 2) is based on plates 4 and 6 in Bellen, Dunnington, Wetzel, and Morton (1959), or work by Naqib (1960), and on unpublished diagrams by M. Chatton, E. Hart, and the writer. It illustrates the general horizontal and vertical distribution of the different rock units in broad terms and their relation to counterparts in Arabia. A broad and general tentative subsurface stratigraphic correlation of the rock units in the area is shown on plate 3.

UNCONFORMITIES

The geological column of Iraq contains numerous erosional and nondepositional hiatuses. Most of the unconformities which are recognized and accorded importance in the area are disconformities in which two units of stratified rock are parallel but separated by an erosion surface having appreciable relief. Discernible angular discordance is very rare, except for localized and surficial unconformities of the Zahra beds on irregular topography in the western and southern desert areas. Some of the major disconformities involve very considerable convergences, with progressive cutout of hundreds or thousands of feet of sediments, but the distances over which the convergences are distributed are so large that the angularity is not visible.

In Iraq the geological sequence, from Triassic time to possibly late Miocene, consists of units that preserve their general characteristics over large regions in which the more significant variations are related to paleogeographical position within a basin. The recognizable erosional unconformities relate to epeirogenic movements.

According to Dunnington, Wetzel, and Morton (Bellen and others, 1959), the Upper Triassic (Mulussa Formation) is unconformable on the Middle Triassic (Ga'ara Sandstone). Though there is no apparent angular discordance or convergence, there is a well-marked erosional surface indicating subaerial exposure at the top of the Ga'ara Sandstone.

Only one major unconformity of any significant regional extent has been detected in the Jurassic succession, this being the well-marked break between the Middle Jurassic and Upper Jurassic. There is no recognizable unconformity or sedimentary break at the Cretaceous-Jurassic boundary. According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), the subsurface sections, especially in the north, show an erosional unconformity lying within the Berriasian, though unpublished work by E. Hart and M. C. Chatton has cast doubt on the existence of this break.

The Cretaceous sequence is divided by a number of widespread unconformities of Albian-Aptian, Cenomanian-Albian, Turonian-Cenomanian, and upper Campanian-lower Campanian ages. Near the area of review the most spectacular of these is the onlap of the Cenomanian over eroded extremities of units as old as Middle Triassic. The Cretaceous rock succession terminates at a widespread major erosional unconformity (disconformity) of post-Maestrichtian (or very late Maestrichtian) date, which is followed by Paleocene or younger sediments, the Danian being unrepresented.

The unconformities in the Paleocene and Eocene succession may be of paraconformity type. The most important gap recognized is between the transgressive Eocene (Dammam Formation) and Paleocene(?) and Lower(?) Eocene (Umm er Radhuma Formation).

A major discontinuity exists between the Eocene units and the overlying Miocene sequence, the Oligocene being unrepresented throughout the entire area of study. The southwestern shoreline of the Oligocene sea lay to the northeast of the Euphrates, and the Eocene rock units were subaerially exposed over the whole area through Oligocene time.

In the Miocene and Pliocene succession, unconformities on both large and small scales can be detected. These include the disconformity between the middle Miocene (Lower Fars) and lower Miocene (Euphrates Limestone), the disconformity between the Pliocene (Dibdibba Formation) and middle Miocene (Lower Fars), and the commonly angular unconformity of the Zahra beds on the underlying older rocks, as well as paraconformities and diastems within each of the main units. Finally, the Dibdibba Formation is unconformably overlain by the Recent Hammar Formation.

The present-day erosion surface exposes a sequence ranging from Triassic to Recent. The topography on the whole is flat with gentle east-northeasterly dip and slope. Intermittent wadis cross the region in this general slope direction. Interior drainage basins and depressions locally interrupt the general pattern, which is largely dictated by the dip slopes and strike escarpments of the almost flat-lying sedimentary sequence.

REGIONAL SEDIMENTARY PATTERN AND HISTORY

The individual formations from the surface and subsurface type or reference sections have been treated independently in some detail elsewhere, but in any stratigraphic work it is not sufficient to describe specific rock types or individual sedimentary environments without discerning the broader sedimentary patterns. The reconstruction of these patterns is primarily based on good correlation by fossil content (biostratigraphic units) but also on equivalences in lithology (rock units). Thus a pattern advanced today may later be modified or completely altered in the light of new evidence that leads to a completely different history and picture. With proper correlation and the knowledge of mode of sedimentation, it may be possible to reach a reasonable pattern which could convey the actual history of sedimentation in time and space. The pattern presented here is, of course, subject to the validity of the correlation and to a proper assessment of the mode of sedimentation and modifications introduced during subsequent geological history.

Southwestern Iraq occupies a position between the relatively stable Arabian shield in the west and the highly mobile Zagros belt in the east. The Zagros mountain belt has risen on the site of the great "Tethys geosyncline" which persisted from at least Permian until middle Miocene time.

In this work only the period from Early Cretaceous to Recent is treated because the present information on older rocks in the area is scanty. The Cretaceous to Recent stratigraphic sequence is similar to rocks normally found on stable continental platforms. It is made up of units that are rather widespread. Facies changes are not unusual, but they are generally gradual. The type of sedimentary rocks and erosional unconformities in the successive geological periods indicate that the area was the scene of periodic epeirogenic movements; some tectonism, as evinced by broad swells, depressions, and perhaps block faulting, accompanied regression and transgression of the seas. The western shorelines during these geological periods followed the margins of the Arabian shield, the axis of the basin or geosyncline being far away to the east in western Iran and eastern Iraq. The effects of geosynclinal depositional conditions upon sedimentation in the platform region must have been very small. The Arabian shield, and to a lesser extent the Ga'ara-Khleisia high, must have been the primary source of the sediment that was deposited over western Iraq. In recent unpublished work on the region, great stress has been put on the importance of diachronism as a factor controlling the sedimentary pattern. Dunnington (1958) and Dunnington, Wetzel, and Morton (in Bellen and others, 1959) recognized the prevalence of diachronous contacts of many of the Mesozoic rock units, and Bellen (1956; Bellen and others, 1959) dealt in some detail with the age relationships of facies-dictated Tertiary rock units in which diachronous lateral passage is a characteristic feature. Lately, M. C. Chatton and E. Hart, in as yet unpublished studies, have endeavored to simplify the correlation problems between northern and southern Iraq by recognizing a more extensive contribution of diachronism of rock facies to the sedimentary pattern. Their work affects chiefly the Cretaceous sedimentation cycles, which are briefly defined as follows:

1. Tithonian (Upper Jurassic) to Aptian cycle includes the following formations, in order, from the shore to the center of the basin: Zubair, Ratawi, Yamama, Qamchuqa, Sarmord, Chia Gara, and Balambo.
2. Albian cycle includes the following formations from shore to basin: Burgan, Nahr Umr, Nahr Umr Shales, Qamchuqa, and Balambo.
3. Cenomanian to lower Turonian cycle includes the following basic formations from shore to basin: Rutbah Sandstone, Admadi, Mishrif, Rumaila, Dokan, and Balambo. The Kifl Formation is considered as the lagoonal-evaporitic facies on the shelf at the terminal phase of the cycle.
4. Middle Turonian to lower Campanian cycle includes the following basic recognized formations from shelf to basin: Khasib, Tanuma, Sa'di, Kometan, and Balambo.
5. Upper Campanian to Maestrichtian cycle includes the following formations from shelf to basin: Safawi, Hartha and Tayarat, Shiranish, and Tanjero. The Bekhme and Aqra Limestones may be considered to be the respective equivalents of the Hartha and Tayarat Formations in northern Iraq.

The Tertiary group of sediments in Iraq follows broadly similar sedimentary patterns; however, owing to lack of adequate information the general picture seems rather confused for the Miocene and Pliocene series. The main cycles follow.

1. Paleocene cycle may extend into the lower Eocene. The main formations composing this cycle from shelf to basin include: Upper Radhuma, Aaliji, Sinjar, Khurmala, and Kolosh.
2. Eocene cycle is chiefly confined to the middle and upper Eocene, and it includes the following for-

mations from shelf to basin: Dammam, Rus, Jaddala, Avanah, Pila Spi, and Gercus (red beds).

3. Oligocene cycles are characterized by three reef-controlled cycles that are recognizable in central and northern Iraq; however, they have not been found in southwestern Iraq.
4. Miocene cycles:
    a. Lower Miocene cycle(s) may be more than two cycles. An older cycle includes the Euphrates Limestone, Dhiban Anhydrite, and Sevikagni Formations. A second cycle includes the Jeribe Limestone.
    b. Middle Miocene cycles include the evaporitic Lower Fars sequence and Ghar Formation. The Zahra Formation is problematical and difficult to include in any of the recognized cycles with any certainty. There may be many cycles, as evidenced by the rhythms of the Lower Fars sediments, particularly in the region of full thickness in northern and eastern Iraq.
5. Pliocene and Pleistocene cycles: The Dibdibba, Bakhtiari, Upper Fars, and Lower Fars Formations. These formations certainly represent more than one cycle, but lateral and vertical relationships remain somewhat obscure.

The above Mesozoic and Tertiary and Quaternary cycles constitute merely the main patterns of sedimentation over the whole of Iraq. These broad patterns, however, should not rule out the possibility of minor patterns due to localized cycles, or local movements and environments. Indeed, local divergences from this simple pattern are by no means rare: many minor cycles do in fact occur within the major cycles, sometimes perhaps to the extent of obscuring the broad and generalized (and therefore somewhat oversimplified) outline.

In the general sedimentary province, southwestern Iraq lay in the shelf zone from Triassic to Recent time. During this long interval the area underwent a series of periodic epeirogenic movements with fluctuating intensities which resulted in periodic emergence or submergence of the land. Thus almost all the sedimentary rocks that occupy the area have characteristics of the shelf facies. For a general understanding of the sedimentary history, brief recourse is made to the older outcrop systems of the Ga'ara area.

During Triassic time the sea covered most of the area; its shorelines must have been not far west of the Ga'ara, as (according to Dunnington, 1958) the clastics of the lower parts of the Nijili show continental features. During Middle Triassic time the Nijili saliferous marls and shales and their overlying Ga'ara sandstones and quartzites were deposited. These were succeeded unconformably, though without angular discordance, by the Upper Triassic Mulussa limestones.

These were subsequently covered by the Rhaetic Zor Hauran gypsiferous marls, shales, and marly or oolitic limestones and by the dolomitized and recrystallized Liassic Uba'id limestones, which were succeeded by alternations of limestones and evaporites, indicating intermittent barred-basin conditions during Liassic time. This alternating evaporite sequence is represented in the Butmah shales and limestones, Adaiyah anhydrites, Mus limestones, and Alan anhydrites. The Liassic sequence has not yet been recognized in outcrop, though it is well developed in subsurface sections in the area, as in Samawa well No. 1. According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), however, it is possible that Liassic equivalents do occur at outcrops in the Wadi Hauran area. Toward the basin, during Bajocian and Bathonian times, bituminous black limestones, dolomites, and shales of the Sargelu Formation were laid down; westward, however, the neritic Muhaiwir limestones of the Ga'ara area were deposited. The Middle Jurassic sedimentation was terminated by a major regional unconformity (Bellen and others, 1959). During Late Jurassic time, as a result of a marine transgression cycle over the area, the Najmah limestones and Gotnia evaporites were deposited. Later they were succeeded by the shallow-water Upper Jurassic and Lower Cretaceous Sulaiy Formation.

According to M. Chatton (unpub. data, 1960), sedimentation during the Tithonian-Aptian cycle was continuous, but involved a single major regression and transgression of the sea. It seems that Yamama calcarenites and oolitic limestones were first deposited on Sarmord-type sediments (as in wells Samawa No.1 and Kifl No.1) with which they intergrade. The overlying Ratawi neritic shales and limestones (with subordinate sandstones, Zubair sands, neritic shales, and subordinate limestones) were being deposited contemporaneously in their respective belts of sedimentation. The oscillatory migrations of the belts are distinctly observable in the ratios of sand to shale components that make up the Zubair Formation, and apparent overlap of one formation on the other may be best interpreted as being due to diachronism. The Shu'aiba limestones represent the rapid transgression of the sea at the close of the cycle. In most localities shales similar to the Ratawi were deposited between the Zubair sands proper and the Shu'aiba limestone.

During Albian time, after a brief period of emergence evidenced in the unconformity between the Nahr Umr Formation and the Shu'aiba Formation, the Bur-

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gan sands and Nahr Umr shales and sands were deposited during a transgressive-regressive phase, which was followed by a rapid Mauddud transgression. The Mauddud neritic limestone sedimentation ended with epeirogenic withdrawal and emergence.

The Cenomanian cycle followed the same general pattern, with the additional complication that some kind of high must have formed to account for the growth and deposition of the Mishrif bioherms and biostromes in the Basra area. These are distributed in an arcuate belt, trending north-northwest. As might be expected, the sediments on the two sides of the biohermal belt are different.

In the Ga'ara area the Cenomanian cycle is represented by the Rutbah sandstones, whereas in Kuwait and southern Iraq the corresponding sedimentary sequence comprises the thin sandy Wara Formation, followed by a thick sequence of rock units comprising in turn the neritic shales and marls of the Ahmadi Formation, subbasinal Rumaila chalks and limestone, and Mishrif neritic limestones. The cycle was terminated locally by the deposition of the lagoonal evaporitic Kifl Formation. This indicates that an enclosed basin covered the western part of the region during latest Cenomanian and (perhaps) early Turonian times.

Clastic and neritic limestone sediments of the middle Turonian and lower Campanian cycle limestones are not recognized in the area. The Khasib subbasinal limestones, the Tanuma neritic shales, and the Sa'di basinal chalky limestone are represented in the eastern subsurface sections only. This may indicate that the sea during this period had transgressed over such a large area that the clastic components could not reach the region. The greatest recognized thickness of the Khasib, Tanuma, and Sa'di Formations is found in the Rumaila-Rachi area. It may be that the sand and neritic limestone sedimentation belts of the Turonian and lower Campanian cycle may lie as yet unknown in the area between the westernmost subsurface sections (Ghalaisan well No.1, Samawa well No.1) and the easternmost outcrops (Wadi Hauran and Rutbah areas).

Some indications of the imposition of a new tectonic framework within the depositional basin are apparent in the sediments of the Turonian and lower Campanian cycle. During the succeeding upper Campanian and Maestrichtian cycle, this framework was firmly established. A major uplift of the Middle Cretaceous and older basinal sediments occurred on the site of the present Zagros mountain belt northeast of the area of study, and a deep trough, trending northwest, sank at the foot of this uplift to accomodate vast volumes of flyschlike clastics derived from the newly emerged highlands. At the same time major east-west troughs formed in the Sinjar area of northwestern Iraq and northeastern Syria and at Anah, on the Euphrates River, north of the Ga'ara high. In the Basrah area some warping of the platform on east-west swells and troughs is evidenced in the thickness and facies distribution of the Upper Cretaceous rock units.

These rock units fall into two subcycles, or phases, in southwestern Iraq. The lower subcycle consists largely of the neritic limestones and shales of the Hartha Formation, with its newly recognized evaporatic lagoonal equivalent, the Safawi Formation. The upper subcycle was inaugurated by widespread deposition of globigerinal marls, formerly named the Qurna Formation but now identified with the Shiranish Formation of northern Iraq. It terminated with the deposition of the neritic Tayarat limestone over the whole area.

The energetic tectonism of northeastern Iraq at this time was apparently in the south and west. The relations of the rock units here imply that toward the close of the Hartha sedimentation came a period of quiescence; and in the extreme west, lagoonal basins formed, as evinced by the Safawi Formation. The subsequent deposition of Shiranish marls implies deepening, but there may be a minor unconformity between the two phases. The second phase, wherein the basinal Shiranish marls were deposited over much of the area (except for the extreme west where Tayarat limestones were being laid down), was manifestly transgressive. Toward the end of the Maestrichtian, the area apparently underwent a regressive period whereby the neritic Tayarat limestones migrated eastward in the wake of the Shiranish belt of sedimentation. This cycle was terminated by the major Cretaceous-Tertiary unconformity.

The Cretaceous-Paleocene transition period was one of widespread regression, which exposed most if not all of the region, resulting in a major and extensive unconformity, after which sedimentation recommenced with the deposition of neritic and lagoonal Umm er Radhuma limestones (Paleocene and lower Eocene?) over most of the area.

Bellen (Bellen and others, 1959) state that the proximity of the Ga'ara high resulted in a garland of neritic reef and shoal deposits (the Umm er Radhuma Formation) east of it. This facies has been found to extend to Kifl well No.1, to cover almost the entire area of discussion, and to extend west and southwestward into Saudi Arabia, where the proximity of the Arabian shield has been the deciding factor in the mode of sedimentation of this cycle. In the transition belt the neritic shoal facies of Umm er Radhuma pass eastward, with intergradation, into basinal Aaliji marls and marly limestones. There is also strong evidence for shallowing of the sea and gradual northeasterly retreat, resulting in the migration of the neritic facies line toward the basin.

This regression was followed by a gradual advance of the sea that permitted the formation of semibarred restricted basins in which the evaporitic Rus Formation was deposited in the central and southern parts of the area during early stages of the early Eocene sedimentation. Good evidence of this marine advance exists in the relationship of the open sea basinal sediments of Aaliji and the overlying Rus evaporites in the Kifl region. Northward the neritic Dammam Formation passes into the basinal Jaddala Formation.

The Eocene cycle was terminated by a period of uplift during which the uppermost part of the Dammam Formation was eroded over an extensive area, including parts of the Arabian Peninsula. Bellen (1959) stated that after the deposition of the Eocene a regression of some importance occurred, followed by a transgression of smaller extent, introducing the first Oligocene cycle.

Three Oligocene cycles are recognized in northern and central Iraq where the sedimentation was controlled by immigating and emigrating organic reefs (Bellen, 1956) back reef, reef, fore reef, and basinal sediments): (1) Anah Limestone, Azkand Limestone, and Ibrahim Formation, (2) Bajawan Limestone, Baba Limestone, and Tarjil Formation, and (3) Shurau Limestone, Sheikh Alas Limestone, and Palani Formation.

The Oligocene series has not been recognized in outcrops nor in subsurface sections in the area including the Afaq well No.1 area. However, there are occurrences of back-reef and reef Shurau in Awasil well No.5: the back-reef and reef Shurau Limestone, the back-reef and reef Bajawan Limestone, and fore-reef Baba Limestone in Falluja well No.1; the basinal Palani, fore-reef Sheikh Alas, back-reef and reef limestone of the Shurau, fore-reef Baba Limestone, and Bajawan back-reef and reef in Musaiyib well No.1; and the basinal Palani and Tarjil, fore-reef Baba Limestone, and back-reef and reef Bajawan Limestone in Dujaila.

These widely scattered occurrences suggest that back-reef and reef Shurau of the first cycles trended northwestward from the area of Awasil well No.5 to Musaiyib well No.1 and Dujaila well No.1 in an arcuate belt and that the lithological belts of the three superimposed cycles apparently shifted repeatedly basinward. Although it may be possible to visualize the present westerly limits of these cycles, their original extent cannot be detected because the Ogliocene Series is absent in southern Iraq, probably removed by erosion during a period of emergence prior to Miocene transgression.

The Miocene transgression resulted in the deposition of the Euphrates Limestone Formation over a wide area presently covering the northern and eastern parts of the study region. The Ghar clastics suggest that it belongs to this early cycle and forms the nearshore deposits; this attribution is, however, arguable. The evaporitic (Dhiban) equivalent of the Euphrates was found in Musaiyib No.1, northeast of the area. This evaporitic unit succeeded the Euphrates Limestone and according to Bellen (Bellen and others, 1959), was precipitated from sea water after the access to the sea arm, probably in the south, became wholly or partly closed.

This cycle was succeeded by the transgressive Jeribe limestones which have been found in wells Awasil No.5, Fallujah No.1, Kifl No. 1, Musaiyib No.1, and Afaq No.1. The transgression may have reopened access to the gulf, a condition that may have brought the evaporitic precipitation to an end and introduced lagoonal sedimentation once again. It is difficult to determine the westerly extent of the Jeribe Limestone. Its areal distribution suggests that before the deposition of the Lower Fars evaporites there had been a short period of emergence and erosion of some of the Jeribe Limestone in the west. The position of the Zahra Formation is rather obscured by the lack of knowledge of the stratigraphic relationships of several formations.

The Lower Fars evaporites were laid down in a restricted basin in the form of a barred gulf or arm of the sea, where the sedimentation was governed by events near the exit of the gulf in which the sediment was deposited. Restriction of the basinal exit, according to Bellen (Bellen and others, 1959), caused the deposition of anyhydrite and salt. Its opening resulted in limestone and in siltstone and shale sedimentation.

After the deposition of the Lower Fars, rapidly rising mountains in northeastern Iraq produced large quantities of detritus. This material was at first deposited in a marine environment and formed the clastic Upper Fars Formation of late Miocene age. Representatives of this formation are seen in the eastern part of the depositional area. Meanwhile, less clastic Middle Fars limestones and siltstones were deposited in the southern part of the depositional area. The large quantity of mountain-derived detritus rapidly forced the sea to retreat. A continental environment spread southward; and sands, sandstones, gravels, and finally thick conglomerates (the lower and upper formations of the Bakhtiari Group of Pliocene age) spread over the marine Upper and Middle Fars Formations.

In the area of the Ga'ara high, the Lower Fars Formation is missing. The western known limit of this formation lies a little to the west of the Euphrates River in the Awasil area. In the south the position of the formation is not clear. The clastic Ghar Formation may be a somewhat detrital facies of the basal beds of the Lower Fars Formation, whereas the Zahra Formation may have been deposited as lacustrine, in places *Chara*-bearing, limestone in landlocked depressions at the end of the period of Lower Fars deposition. Further fieldwork is needed to clarify the stratigraphy in this area.

In the south, land-derived detritus subsequently formed the thick Dibdibba Formation, roughly comparable in lithology to the rocks of the Bakhtiari Group of the north. Part of the Dibdibba may represent part or all of the Middle and Upper Fars Formation of northern Iraq. The Middle Fars, Upper Fars, lower part of the Bakhtiari, and upper part of the Bakhtiari are all absent from the area of the Ga'ara high. Alluvium in the form of lacustrine, estuarine, and fluviatile deposits overlies the upper part of the Bakhtiari Group and the Dibdibba Formation. In the southern part of Iraq, however, a small subrecent transgression is present between the Dibdibba Formation and the alluvium. This has been recently defined as the Hammar Formation.

MESOZOIC

The Mesozoic Era is represented in western Iraq by sedimentary units of Triassic, Rhaetic, Jurassic, and Cretaceous ages, though there are several important gaps in the geological sequence. Triassic and Jurassic units crop out in the Ga'ara area, which lies slightly beyond the study region. Jurassic units have been found in some deep wells in the area, but information on pre-Cretaceous units is generally scanty. Descriptions of the formations are therefore confined to Cretaceous and post-Cretaceous units.

CRETACEOUS

Of the 43 established rock units of the Cretaceous period in Iraq, 18 occur in southwestern Iraq; surface and subsurface sections of these units are described in some detail. The general time gaps in the geological history of the Cretaceous Period have been dealt with in the section on "Unconformities." The Cretaceous sedimentary rocks are as much as 10,000 feet thick.

RATAWI FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Ratawi Formation in BPC well Ratawi No.1 (lat 30°33′22″ N., long 47°05′45″ E.; alt 107.9 ft.; completed Mar. 18, 1950). The formation lies between drilled depths of 10,870 and 11,585 feet (715 ft thick) and takes its name from this well. It is not exposed in the western desert but is found in BPC wells Nahr Umr No. 3, Zubair Nos. 24, 38, and others; Rumaila No. 4; Samawa No. 1; Ghalaisan No. 1; and Safawi No. 1. It is also found in Kuwait, in the Kuwait Oil Co. wells Burgan No. 113, Magwa No. 1, and Umm Gudair No. 1. This formation decreases in thickness northward and westward, mainly owing to a change of facies; thickness in wells Samawa No. 1, Ghalaisan No. 1, and Safawi No. 1 are 285, 219, and 146 feet, respectively.

DETAILED LITHOLOGIC DESCRIPTION

The Ratawi Formation consists of greenish-black shales that are slightly pyritic, massive in the upper part, interbedded in the lower part, and contain stringers and beds of buff pyritic pseudo-oolitic detrital fossiliferous limestones. The upper shaly beds contain some fine quartz silt.

The Ratawi Formation becomes thinner and less shaly to the northwest, for example, in Samawa well No. 1 where it is divisible into three units:

	Thickness (feet)
3. Limestone, compact, slightly porous, dolomitized, detrital, and dolomite with thin shale intercalations	29
2. Sandstone, porous, fine-grained, calcite-cemented, interbedded with thin shales and sandy dolomites	40
1. Limestone, generally tight, finely detrital, commonly characterized by pyritic mud rimming the constituent fragments; locally silty and argillaceous	216

At Ghalaisan well No.1 the sequence is dominantly calcareous. It comprises 219 feet of buff pyritic fine-grained limestones some of which are leached and vugular. Some of the limestones have a chalky matrix and locally grade to buff-gray or gray indurated marls. Minor shale intercalations occur at the top of the sequence and also near the base. There is a considerable and progressive reduction in thickness westward. At Safawi well No.1 the sequence comprises 146 feet of marly gray to white indurated limestones, shelly algal limestones, and arenaceous limestones. Northward and westward this formation grades into Yamama or Garagu Formations.

DIAGNOSTIC FOSSILS

Pseudocyclammina lituus (Yokoyama), *Ostrea rectangularis* Sowerby, and *Terebratula* cf. *squamosa* Mantell are diagnostic of the Ratawi Formation. The lower part of the Ratawi, containing detrital limestone intercalations, has a fauna which includes *Cyclammina greigi* Henson at the top, and *Pseudocyclammina lituus* (Yokoyama), *P.* cf. *lituus*, *P.* cf. *kelleri* Henson, *Trocholina* spp., *Cristellaria* sp., and algal, bryozoan, and stromatoporoid fragments. Macro fossils include *Exogyra sinuata* Sowerby, *Terebratula* cf. *T. squamosa* Mantell, *Anomia* sp., Pecten *(Synocyclonema)* cf. *P. alpinus* Mayer, *?Venus pilatina* Mayer, *Cylindrites* sp., and *Kingena* spp., including *K* cf. *Zeilleria tamarindus* (Sowerby) in Douville.

The shaly part carries locally abundant microfauna, with *Choffatella decipiens* Schlumberger, *Cyclammina* spp., *Trocholina* spp., and *Pseudocyclammina* sp., including *P.* cf. *lituus* (Yokoyama) and *P.* cf. *kelleri* Henson. Abundant *Cyclammina greigi* Henson occurs at the base of this interval.

The thin pellety limestone which marks the boundary with the overlying Zubair Formation contains abundant debris of the alga *Lithocodium aggregatum* Elliott.

In Samawa well No. 1 the formation contains *Cyclammina* sp., *Nautiloculina* sp., *Pseudocyclammina hedbergi* Maync, *P. kelleri* Henson, *P. lituus* (Yokoyama), *Trocholina conica* (Schlumberger), *T. altispira* Henson, *T. arabica* Henson, textularids, valvulinids, algae, gastropods, and ostracodes.

AGE

The age of the Ratawi Formation is Neocomian (Owen and Nasr, 1958), probably Hauterivian and Valanginian by regional correlation (Dunnington and others, 1959). The lower part of the Ratawi is considered to be of Valanginian age, largely from correlation with the better dated Garagu Formation. The age of the upper shaly division is probably Hauterivian, on the basis of the foraminiferal assemblages. This attribution is strengthened by the presence of *Lima carteroniana* d'Orbigny in the immediately overlying Zubair Formation; this form is especially abundant in the Hauterivian of other Tethyan regions (R. G. S. Hudson, unpub. data).

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The contacts of the Ratawi Formation are easily detected on electric self-potential and resistivity logs. The base of the underlying Yamama Formation is set at the top of a thick sequence of fine-grained marly commonly pellety limestone, which has been variously treated in unpublished work by P. M. V. Rabanit, S. N. Nasr, W. Sugden, and others. The upper parts of these limestones should perhaps best be referred to the Yamama Formation of Qatar (W. Sugden, unpub. data), and Owen and Nasr (1958) did identify them with the Yamama of Saudi Arabia.

The age equivalents of the upper shaly measures at the type section of the Ratawi are probably represented by sandstone in the Zubair Formation in Samawa well No. 1. The boundary with the Zubair Formation is diachronous.

The Ratawi Formation is conformably overlain by the Zubair Formation. The contact is placed at the top of a thin pellety limestone that contains abundant algal debris. In Samawa well No. 1 the Ratawi and Yamama contact is recognized by the first appearance of pellety limestone.

The lower part of the Ratawi Formation, containing limestone intercalations, probably corresponds approximately in stratigraphic position to the Garagu Formation of northern and central Iraq. The upper part of the formation is represented by coarse-grained sandstones, silts, and silty shales in the wells of the Awasil area, which have been identified as Zubair Formation. Hence, the upper part of the Ratawi Formation is equivalent in age to the lower part of the Zubair Formation of Awasil, Fullujah, and Mileh Tharthar wells.

ZUBAIR FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Zubair Formation is in BPC well Zubair No. 24 (lat 30°22′00″ N., long 47°36′46″ E.; alt 42.53 ft; completed Aug 22, 1953). The formation lies between drilled depths of 10,368 and 11,645 feet (1,277 ft thick). In the vicinity of the type area in the Zubair oil field, this formation has an average thickness of 1,250 feet. It is widespread in the subsurface sections of southwestern Iraq, where it has been penetrated in BPC wells Ghalaisan No. 1, Kifl No. 1 and 2, Luhais No. 1, Nahr Umr No. 3, Rachi No. 1, Ratawi No. 1, Rumaila wells, Safayi No. 1, Samawa No. 1, Shawiya No. 1, Tuba No. 1, Ubaid No. 1, and Zubair wells and in the Mosul Petroleum Co. well Awasil No. 5.

In a belt extending from Luhais well No.1 (incomplete thickness) to Samawa well No.1 (1,581 ft) and Kifl well No.1 (1,612 ft), the formation shows slight thickness variation. Westward from this belt, the formation abruptly decreases in thickness to 785 feet in Ghalaisan well No.1; therefore, the maximum thickness is to be expected northeast of a line between wells Kifl No.1 and Samawa No.1.

DETAILED LITHOLOGIC DESCRIPTION

The Zubair Formation is heterogeneous and exhibits rapid lateral and vertical variations, though it has a widespread distribution. In the type locality it consists of the following broad, main lithologic units:

	Thickness (feet)
6. Shale, black, pyritic, fissile, with rare intercalations of gray siltstone; four beds (10–15 ft thick) of very fine grained gray cemented sandstones, calcareous in places and grouped into two beds separated by shaly partings in upper half of unit; 18 ft of sandy limestone toward top is separated from overlying Shu'aiba limestone by a shale band	286
5. Sandstone, light-brown, oil-stained, naturally white, fine-grained, with subangular grains; contains subordinate shale alternating with siltstone; comprises possibly 9 sandstone beds; grades abruptly into overlying shales; forms "Third Pay" of Zubair field and "Main Pay" of Rumaila field	428
4. Shale, black to greenish-black, subsidiary gray calcareous silt intercalations, especially toward middle	144
3. Sandstone, light-brown, oil-stained, very fine grained, current-bedded; in places contains thin shaly and carbonaceous or lignitic foliations; intercalated in places with gray siltstone, greenish-gray mudstone, and hard greenish-black fissile resinous shale containing plant remains; grades to underlying and overlying shale through siltstone; constitutes "Fourth Pay" of Zubair field	239
2. Shale, greenish-black, fissile, pyritic, hard; some intercalations of gray locally calcareous siltstone in lower half	127
1. Sandstone, white, in places oil-stained, very fine grained, locally silty, separated from underlying Ratawi Limestone by 10 ft of black shale; grades upward into shale through siltstone	53

At Samawa well No.1 the Zubair Formation, apart from a thin shale band at the top, is represented throughout by characteristically weakly cemented or loose crossbedded quartz sands; streaks of lignitic shale are common but insignificant in amount. Silt and silty shale intercalations are chiefly confined to the lower part of the formation. Northward at Kifl well No.1, the Zubair comprises buff, gray, or white fine to medium unfossiliferous sand and sandstone with pyritic calcareous cement that alternates with thin bands of silt stone, shales, and rare lignite.

The Zubair Formation interfingers basinward laterally and vertically into the Ratawi Formation. The occurrence and relationship of the two formations were dependent on their position on the shield and in the basin. The influence and significance of this phenomenon is indicated in the shale units of the Zubair Formation in the type area.

DIAGNOSTIC FOSSILS AND AGE

Fossils diagnostic of the Zubair Formation are *Orbitolina* cf. *O. discoidea* Gras, *Choffatella decipiens* Schlumberger, *Cristellaria* spp., *Cuneolina* sp., *Trocholina* sp., *Exogyra* sp., *Cerithium* sp., and *Lima carteroniana* d'Orbigny (at base).

According to recent investigation and stratigraphic reinterpretation by M. Chatton, the age of this formation ranges from Valanginian to Barremian over southwestern Iraq. Owing to the strong diachronism of the formation, its age varies according to the paleogeographic position and sedimentary history. In southern Iraq this formation is of Hauterivian and Barremian ages only. Though the full Valanginian to Barremian sequence has been found in wells Samawa No. 1 and Kifl No. 1, farther north the sequence of Zubair Formation may extend into Aptian as it does at Awasil well No. 5. Elsewhere, these age limits may be expanded, extended, or restricted.

CONTACTS AND EQUIVALENT UNITS ADJACENT TO SOUTHWESTERN IRAQ

The contact of the Zubair Formation with the underlying Ratawi Formation is comformable, gradational, and diachronous and is placed at the highest Ratawi limestone bed underlying the shale and siltstone of the Zubair Formation. In wells Kifl No. 1 and Awasil No. 5 the Zubair Formation overlies the Yamama Formation. The contact with the overlying Shu'aiba Formation is conformable and is placed at the top of black fissile shales. In Safawi well No. 1, where the Shu'aiba Formation is missing, the Nahr Umr Formation overlies the Zubair Formation directly, presumably with unconformity.

In Saudi Arabia the Zubair Formation may pass into the Buwaib and Biyadh sandstones, predominantly into the Biyadh.

ECONOMIC ASPECTS

Commercial quantities of oil have been discovered in the sands and sandstones of the Zubair Formation in several localities in southwestern Iraq, including the Zubair oil field, Rumaila oil field, Luhais well No.1, and Kifl well No.1. Present oil production of the Basrah Petroleum Company comes from the two oil fields. The details and reservoir characteristics follow.

Zubair field

The "Third Pay" oil occurs in sands of the Zubair Formation under a cover of dark shales and units of the formation itself. The reservoir section is thus a sandstone shale complex, some 320 feet thick, in which four main and significant members can be distinguished, averaging about 200 feet in total thickness. The oil is undersaturated by roughly 2,000 psi and, therefore, no primary gas cap is present. Water has been struck on both flanks at approximately the same elevation. The quality of the oil varies with structural position, so that crestal wells have a gas-oil ratio of approximately 800 cu ft. per bbl (cubic feet per barrel) and low flank wells, of 600 cu ft per bbl. Oil gravities show a similar trend, suggesting some gravitational segregation of oil within the reservoir. The average value is 36° API. Porosity averages 20 percent permeability, 250–400 millidarcies. A spacing of 1 well to 866 acres on a diamond grid, has been adopted and pressure interference on a small scale has been noted.

The wells average 11,000 feet in depth and are completed by selective-shape charge perforation of the 5½-inch oil string which is cemented through the producing section. Initial flowing pressures average 1,600 to 1,800 psi at 5,000 barrels per day. A feature of production has been the large salt content of wells high in the structure. No water has been detected, but the oil may contain as much as 1,000 pounds of salt per 1,000 barrels. It is believed that this salt is derived from water-saturated siltstones associated with oil sands; a desalting plant is being installed. The reservoir mechanism to date has been expansion of the undersaturated oil. This process has resulted in a steep pressure decline. A poorly effective water drive may be operative on one flank.

The "Fourth Pay" oil occurs in sands of the Zubair Formation, but is separated from the "Third Pay" by some 220 feet of black shale and siltstone. It consists of a thinner but similar sandstone-shale complex, containing, however, a better quality oil of average gravity, 42° API. A large primary gas dome is present. Sand characteristics are less favorable than the "Third Pay", and high-pressure drawdowns are associated with relatively low production rates.

Rumaila field

The reservoir section at Rumaila is in the same geological formation as at Zubair but contains a much higher proportion of sand and the shale and siltstone members are noticeably absent. Porosity averages 25 percent and permeability, 1,000 millidarcies. The oil is even more undersaturated than at Zubair; that is, saturation pressure is 2,500 psi below initial reservoir pressure. A horizontal oil-water level was proved to exist throughout the reservoir.

Some variation of quality with structural position is present but is not nearly so marked as at Zubair. The gas-oil ratio averages 700 cu ft per bbl, and the gravity of the crude, 36° API. The field has only recently gone on production and, so far, by oil expansion. From the characteristics of the reservoir sand, a water drive may be expected.

SHU'AIBA FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Shu'aiba Formation is in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47° 43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 9,962 and 10,132 feet (170 ft thick) and forms a transgressive limestone unit which is fairly widespread in the subsurface sections of southern Iraq wells. It has not yet been found in the Cretaceous outcrops in the western desert. In the subsurface sections throughout the Al Basrah area, its thickness ranges between 150 and 350 feet. West of the Euphrates River it thins to about 100 feet between As Samawah and An Najaf. Farther west the thickness decreases to about 80 feet in the vicinity of Ash Shawiyat and Al Ubaid. In Ghalaisan ash Shabicha the thickness is not more than 30 feet. The Shu'aiba Formation disappears by pinching out in the Safawi well east of Birkat az Zafiri on the Iraqi-Saudi Arabian border.

DETAILED LITHOLOGIC DESCRIPTION

The Shu'aiba Formation consists mainly of cream-colored orbitolinid, detrital, in places chalky, pseudo-oolitic limestones and recrystallized skeletal limestones. Some argillaceous, sandy, and shaly intercalations occur toward the base.

DIAGNOSTIC FOSSILS AND AGE

Orbitolina cf. *O. discoidea* Gras, *Choffatella decipiens* Schlumberger (at base only), and globigerinids in upper parts are diagnostic forms in the Shu'aiba Formation, which is Aptian in age.

CONTACTS AND EQUIVALENT UNITS IN AREAS ADJACENT TO SOUTHWESTERN IRAQ

The contact with the underlying Zubair Formation is conformable and gradational and is taken at the top of the first shale bed below *Orbitolina* cf. *O. discoidea* limestone. Normally the contact is easily picked on the electric logs; however, owing to the gradational nature of the contact, it is sometimes difficult to detect on the logs. The top of the shale is taken as a marker and called the Z/1 marker (see section on "Zubair Formation").

The contact with the overlying Nahr Umr Formation may be unconformable, and it indicates a sharp lithological change from the porous elastic limestones of the Shu'aiba Formation to the silts and shales of the basal Nahr Umr Formation. The contact has been designated as the SH/1 marker and can easily be located at a sharp negative deflection of the selfpotential curve of the electric log, which coincides approximately with a substantial increase of rate of penetration. Above this marker there are local beds of limestone which some authors include in the Shu'aiba Formation; however, for the present purpose they have been considered as reworked limestone deposited in the wake of a regressive sea.

The Shu'aiba Formation passes laterally into the Zubair Formation in Iraq and Kuwait. This explains in part the westward thinning from the Basrah area. It is possibly represented in part by the Biyadh Formation, with which a gradational relationship is postulated.

ECONOMIC ASPECTS

The Shu'aiba Formation is of no direct economic significance, although its equivalent, which has good porosity, contains oil in the Abu Hasa area, Abu Dhabi. In Iraq the formation is marked by a zone in which circulation, is lost; thus drilling is hazardous.

NAHR UMR FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Nahr Umr Formation is in BPC well Nahr Umr No. 2 (lat 30°44'15" N., long 47°41'45" E.; alt 21.7 ft; completed Mar. 4, 1950). The formation lies between drilled depths of 8,688 and 9,321 feet (633 ft thick) and is named after the well. It is extensive in the subsurface, and has been found in all deep subsurface sections in the Basrah area, in the western desert, and in central Iraq and also in the wells of Nahr Umr, Zubair, Tuba, Rumaila, Ratawi, Rachi, Luhais, Ubaid, Samawa, Shawiya, Safawi, Ghalaisan, Kifl, Awasil, and Nafatah.

In its greatest development, the formation trends northward, parallel to the Euphrates River. The maximum thickness of about 1,100 feet is in the subsurface sections of Zubair field. This thickness is comparable to that recorded in Kuwait (average thickness 1,150 ft). This area of great thickness is seemingly confined to a narrow belt, to the east of which the formation is sharply reduced in thickness, whereas to the west the change is gradual. The thickness of this formation in the Rumaila-Luhais area ranges between 900 and 800 feet. Farther west, in the Ubaid Ghalaisan area, the thickness diminishes to between 400 and 600 feet. Northward there is a general reduction in thickness; in the Samawa-Shawiya area the formation ranges between 200 and 500 feet. Farther north in the Awasil and Nafatah areas the formation thins to between 200 and 300 feet.

DETAILED LITHOLOGIC DESCRIPTION

In the type locality the Nahr Umr Formation can be subdivided from core and electric-log evidence into three distinct lithologic units. These units from top to bottom are:

	Thickness (feet)
3. Shale, hard, homogenous, black, interbedded with black to green-gray shale containing streaks of fossiliferous skeletal black limestones some of which contain molluscan shells and sponge spicules	144
2. Limestone, marly and in places dolomitic, orbitolinid, in part globigerinal, with streaks and intercalations of greenish-black shale; predominantly black shale rich in small molluscs and in places containing pyritized slightly calcitic ostracodes, with bands of detrital ?orbitolinid skeletal limestones. (Dair Limestone Member)	118
1. Sandstone, fine- to medium-grained, brown; loosely or well-cemented with well-rounded quartz grains or, in places, glauconite; a few intercalations of black siltstones, shale containing fossil plants, amber, and lignite; streaks of chalky partly detrital limestone	371

These units maintain their general characteristics throughout a large area including Samawa, Ratawi, Rachi, Kifl, Rumaila, and Zubair. Westward and northwestward, however, the shales interdigitate and intergrade laterally into sandstone, and distinguishing the Nahr Umr Formation from the Zubair Formation becomes difficult when one reaches the Safawi area, where the underlying Shu'aiba is missing. Eastward, marl, shale, and limestone replace this sandstone and its terrigenous components. Southward, in Kuwait, the Nahr Umr Formation is lithologically divisible into two members which have been called the Third and the Fourth Sands.

In central Iraq the Nahr Umr is recognized only in the subsurface sections of the Mosul Petroleum Co. wells Awasil No.5, Fallujah No.1, Nafatah No.1, and Mileh Tharthar No.1. In these wells the thickness of the formation ranges between 200 and 300 feet, and the formation comprises coarse- to medium-grained sandstones and subordinate shales. Correlation of the unit, as found in the wells of the Awasil area, with the Nahr Umr Formation of the Basrah area, rests upon lithology and upon homotaxy relative to the preceding Shu'aiba Formation and succeeding Mauddud Formation. In the Awasil and Nafatah areas the unit was originally named the "Nafatah Sand" (H. Huber, unpub. data), but this name has never been sustained by publication and is now obsolete.

The view was prevalent at one time that the Nahr Umr Formation was directly equivalent to the Rutbah Sandstone Formation of the Rutbah-Wadi Hauran region of western Iraq, and the name Rutbah (or Rutba) Sand was originally applied to the unit in Basrah and also to the sequence of formations (Wara, Mauddud, and Nahr Umr) which are now included within the Burgan subgroup of Kuwait (Owen and Nasr, 1958). The name Rutba Sand is a collective name that includes the current Ahmadi, Wara, Mauddud, and Nahr Umr Formations of the Kuwait succession. The term Rutbah (or Rutba) Sandstone is not now applied in the subsurface sections of southern Iraq and Kuwait, as it is now thought that the Rutbah Sandstone Formation of western Iraq is of Cenomanian age and is separated from the Mauddud Formation and underlying Nahr Umr sands by a widespread erosional unconformity. (The Wara Formation of the Basrah area may be directly equivalent to and continuous with the Rutbah Sandstone Formation.)

The Dair Limestone Member thins westward and southward, being replaced by shales and sands. It is not discernible in the Kuwait area.

DIAGNOSTIC FOSSILS AND AGE

Orbitolina cf. *O. discoidea* Gras, *Haplophragmoides* sp., *Cythereis* sp., and ?*Exogyra* sp. are diagnostic of the Nahr Umr Formation. The prominent Dair Limestone Member contains *Orbitolina* cf. *O. discoidea* Gras, and *O.* cf. *O. concava* (Lamarck), algae, and a molluscan fauna including *Plicatula* cf. *P. auressensis* Coquand, *Orbiculoidea* sp., *Neithea dutrugei* (Coquand), and *Exogyra* cf. *E. dieneri* (Blanckenhorn). The formation is Albian in age.

CONTACTS

The contact of the Nahr Umr Formation with the underlying Shu'aiba Formation is conformable and gradational; it is placed at the base of the lowest bedded shales of the Nahr Umr Formation and the top of the shale-streaked limestones that make up the highest division of the Shu'aiba Formation. However, in the Awasil area the Nahr Umr Formation rests upon dolomitized Shu'aiba Formation that includes coarse-grained sandstones in direct contact with coarsely granular dolomites that are entirely free from detrital quartz. An emergent episode and depositional break has thus been inferred between the two formations. This contact becomes undistinguishable in the extreme west, where, owing to absence of the Shu'aiba Formation, it is difficult to separate the Nahr Umr Formation from the underlying Zubair Formation. The overlying Mauddud Formation is both conformable and gradational; the contact is placed at the base of the limestone of the Mauddud Formation and at the top of a black shale section.

EQUIVALENT UNITS IN AREAS ADJACENT TO SOUTHWESTERN IRAQ

Between the Awasil area and Makhul well No.1, the Nahr Umr Formation passes laterally into the limestone-anhydrite-shale-marl sequence of the Jawan Formation, which is between recognizable Mauddud Formation and Shu'aiba Formation. This sedimentary sequence, which is of near-evaporitic facies in its upper parts, contains a marine macrofauna that includes the Albian index fossil *Globiconcha altispira* Whitfield near the base; correlative beds in the Jawan Formation at Jawan have yielded *Knemiceras syriacum* (von Buch), confirming Albian age for the basal Jawan Formation and supporting Albian age for the lower part of the laterally equivalent Nahr Umr. Thin siltstones and silty shales and limestones in the lower part of the Jawan of Makhul well sections may be regarded as far-reaching tongues of Nahr Umr Formation, lying far to the east or northeast of the recognized limits of the unit. The Nahr Umr Formation has been recognized in Kuwait and correlates very well with that in Iraq. In Saudi Arabia its equivalent is included in the Wasia Formation.

ECONOMIC ASPECTS

The upper shaly units of the Nahr Umr Formation form caprocks for any accumulation of oil in the lower sandstones, as they do at the type locality. The Nahr Umr Formation, the Wara Formation, and to some extent the intervening Mauddud Formation, together compose the main reservoir for oil in the Burgan-Magwa-Ahmadi area.

The sand to shale ratio of the unit varies considerably between the various oil fields of the Basrah-Kuwait area. Generally speaking, the sand content increases southwestward and southward. In the Burgan field, for example, this unit is 1,150 feet thick and is made up almost entirely of sand, whereas in its type locality at Nahr Umr well No.2, the sand to shale ratio is 40:60.

MAUDDUD FORMATION

The Mauddud Formation was defined from the subsurface section of Dukhan well No. 1, in Qater, by F. R. S. Henson in 1940, but the definition was revised and amended by W. Sugden in 1958, and a reference section in the Basrah area was described by Owen and Nasr (1958).

REFERENCE SECTION, THICKNESS, AND EXTENT

The reference section of the Mauddud Formation is in BPC well Zubair No. 3 (lat. 30°23′01″ N., long 47° 43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between the drilled depths of 8,517 and 8,923 feet, based on the sharp change in lithology as well as the distinct change in the self-potential curve on electric logs. The limits of the formation were put at 8,457–8,910 feet by Owen and Nasr (1958); however, those are based solely on electric logs without lithologic evidence.

The formation is 406 feet thick and is fairly extensive throughout southwestern Iraq. It is recorded in the wells at Nahr Umr, Zubair, Tuba, Rumaila, Ratawi, Rachi, Luhais, Ubaid, Samawa, Shawiya, Safawi, Ghalaisan, and Kifl. From the Shatt al Arab River the thickness of the formation decreases southwestward from 570 to 430 and 350 feet at the Zubair and Rumaila fields and to 380 and 320 feet at Ratawi and Rachi. At Luhais No. 1 it further decreases in thickness to 291 feet. Northward the decrease is also noticeable at Samawa and Kifl, where 90 to 95-foot thicknesses were recorded. These are less than at Shawiya (111 ft) and in the extreme west at Ghalaisan (125 ft). At Safawi and Ubaid there is a great decrease in thickness to about 35 feet. These decreases have generally been attributed to erosion marked by the unconformity between this formation and the overlying Ahmadi Formation.

DETAILED LITHOLOGIC DESCRIPTION

The Mauddud Formation consists mainly of cream-colored microdetrital pseudo-oolitic orbitolinid locally recrystallized limestones and a few thin blue shales; tight, marly, chalky limestones are intercalated especially in the lower half and middle. The limestones are spotted with pyrite. Glauconite has been noted toward the base. These limestones become more porcelaneous northward.

DIAGNOSTIC FOSSILS

Diagnostic fossils of the Mauddud Formation are *Iraqia simplex* henson, *Trocholina altispira* Henson, *T. arabica* Henson, *Orbitolina* cf. *O. concava* (Lamarck, *Rabanitina basraensis* Smout, *Archeolithothamnium* sp., and ?*Bairdia* sp.

A. S. Sayyab (unpub. data, 1956) studied a suite of Cretaceous ostracodes from the Persian Gulf area, including the Cretaceous section from Zubair well No.5. He described a rich characteristic fauna, mostly composed of hitherto undescribed species, from the Mauddud Formation.

In the Mauddud Formation in the western desert wells, the fauna includes rare *Cyclammina* sp., *Oligostegina* sp., *Globigerina* sp., *Cuneolina* sp., *Pseudochrysalidina* sp., *Gumbelina* sp., rotalids, gastropods, bryozoans, and algae.

AGE

The Mauddud Formation is Albian in age. Owen and Nasr (1958) considered the age of the Mauddud Formation in the Basrah-Kuwait wells as Cenomanian. Smout (1956) concurred, though admitting the possibility of Albian age, which was favored by Dunnington, Wetzel, and Morton (in Bellen and others, 1959), who made the following statement:

> In the Basrah and Kuwait wells, according to Owen and Nasr (1958), the Mauddud is represented by organic, detrital, sometimes pseudo-oolitic, cream-colored limestones with occasional green or bluish shale streaks. It ranges in thickness from only 6 feet, within the Burgan field, to a maximum of over 500 feet in parts of the Zubair field. It overlies Albian Nahr Umr Formation conformably, and is overlain by the Wara Formation, which comprises black silty shales and siltstones (Basrah) and sandstone (Kuwait). The Wara underlies the Cenomanian Ahmadi shale and the contact of the Wara with the Mauddud suggests slight disconformity (Owen and Nasr, 1958).

The fauna of the Mauddud in the subsurface sections previously mentioned includes *Orbitolina* cf. *O. concava* (Lamarck), *O. concava* var. *qatarica* Henson (Awasil and Nafatah), *T. lenticularis* Henson, and *Cyclammina* spp. *Orbitolina* cf. *O. discoidea* Gras is recorded from the lower part of the formation at Makhul, Awasil, and other wells.

It is manifest that the Mauddud has been correctly identified in the Basrah-Kuwait area and in northern Iraq, and it is equally clear that the formation must have been deposited more or less synchronously over the whole region from Qatar to Makhul well 1. The acceptance of Albian age for the formation in Qatar (W. Sugden, unpub. data, 1958) is incompatible with the Cenomanian attribution made by Owen and Nasr (1958) and accepted by Smout (1956).

The evidence assembled from northern Iraq unequivocally favors a late Albian age. The cooccurrence of *Orbitolina* cf. *O. concava* (Lamarck) and *O.* cf. *O. discoidea* Gras is sufficient to demonstrate pre-Cenomanian age for the lower part of the formation at Makhul, and the constancy of the associated fauna throughout the formation is strong evidence that the age range of the formation is not great. *Orbitolina* cf. *O. concava* is not restricted to the Cenomanian, as suggested by F. R. S. Henson (unpub. data, 1948), but in northern Iraq, at least, it seems to be indicative of Albian age. Specimens attributed to *Orbitolina* cf. *O. concava* occur below a middle and upper Albian ammonite fauna at Naokelekan. Hence the absence of Cenomanian forms, as *Praealveolina* spp. and others may be more significant in determining between Albian and Cenomanian age than is the presence of *Orbitolina* cf. *O. concava*.

Orbitolina conclava var. *qatarica* certainly lived on into Cenomanian time, for this form is found with a normal Cenomanian fauna of *Praealveolina* spp. in the Rumaila Formation of Basrah and other places (Owen and Nasr, 1958).

Smout (1956) commented that the type locality of *Iraqia simplex* Henson is either Cenomanian or so high in the Lower Cretaceous that a Cenomanian occurrence would not be surprising. In fact, the type locality of this species lies about 700 feet below the top of the Qamchuqa limestone in the Rowanduz Gorge. In that section the top of the Quamchuqa is now considered to be of Albian age, and *Iraqia simplex* ranges here through late and early Albian, in association with *Orbitolina* cf. *O. concava* (Lamarck) and *Orbitolina* cf. *O. discoidea* Gras. Hence the presence of *Iraqia simplex* in the Maududd Formation of Basrah wells is supporting evidence for Albian rather than Cenomanian age.

In Awasil and Nafatah the Mauddud is separated from the Mahilban by an erosional unconformity, though the Mahilban is of sufficiently late Cenomanian age to allow an early Cenomanian age for the Mauddud. It is tempting, however, to correlate the Mahilban-Mauddud unconformity, at Awasil, with the slight disconformity reported by Owen and Nasr (1958) between the Wara Formation and the Mauddud Formation in Basrah and Kuwait.

The Wara Formation (Owen and Nasr, 1958) may be early Cenomanian or even perhaps late Albian, because, according to R. G. S. Hudson (unpub. data), the overlying Ahmadi Formation contains *Turritella amotzi* Shalem, *T. blanckenhorni* Shalem, *Corbula* sp. juv., *Exogyra conica* (J. Sowerby), ?*E. luynesi* (Lartet) and *Aspidiscus (Helladastrae)* juv. cf. *A. semhae* Kossmat. Early Cenomanian age is probable for this assemblage (the late Cenomanian age, suggested by fragmentary *Neolobites* sp. from within the Ahmadi, and by *Metoicoceras* sp. (undescribed species) from the basal *Cythereis bahraini* limestone, is ruled out by the occurrence of *Aspidiscus* sp.).

CONTACTS WITH ADJACENT UNITS

The contact between the Mauddud and the underlying Nahr Umr Formation is conformable and gradational and is placed at the top of a black shale section.

The Ahmadi Formation overlies the Mauddud, perhaps with slight disconformity. In Kuwait, the Wara Formation overlies the Mauddud. The Wara has been observed in certain Zubair wells and in Rachi well No. 1. In the Awasil and Nafatah area the Maddud is unconformably overlain by Mahilban. The Mauddud Formation does not crop out in Saudi Arabia nor in southwestern and western Iraq.

ECONOMIC ASPECTS

The Mauddud Formation is the "Main Pay" limestone or "Second Pay Limestone" of the Bahrain field, and it produces oil in parts of the Burgan field of Kuwait. In the Basrah area these limestones as a rule are barren of oil.

RUTBAH SANDSTONE FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Rutbah Sandstone Formation is at the northeast end of a promontory lying between the Wadi Ubeila and Rutbah, and about 4 kilometers northwest of the settlement of Rutbah, after which the formation is named. The base of the formation is at approximately lat 33°04′20″ N., long 40°12′50″ E.

The formation has a thickness of 23 meters, according to Dunnington, Wetzel, and Morton (in Bellen and others, 1959). This formation is widely exposed around Rutbah and as isolated outliers overlying the Mulussa limestone plateau to the east of Rutbah. It occurs also in the Wadi Hauran, east and west of Muhaiwir. The Rutbah Sandstone Formation transgresses an extensive eroded surface which exposes the Bathonian Muhaiwir Formation in the eastern Wadi Hauran and Ga'ara Sandstone of probable Middle Triassic age in the western part of the Ga'ara depression area. The formation pinches out abruptly to the north and northwest between Ga'ara Sandstone and the M'sad Formation. It thickens considerably to the east where it overlies the Bathonian Muhaiwir Formation and is unconformably overlain by Miocene limestone in the vicinity and east of Muhaiwir.

The Rutbah Sandstone Formation at one time was considered to be of Aquitanian (Oligocene) age in the Muhaiwir area, the confusion arising through misdating of the coral fauna of the Muhaiwir Formation as Oligocene. The name "Hauran sandstone" (Hauran Quartzite) was informally applied to the sandstone during this period of misunderstanding, and, though never defined or published, this name has been fairly widely used for sandy sediments, which occur below the lower Miocene limestones in other areas. The unpublished "Hauran sandstone" is a junior synonym for the Rutbah Sandstone Formation; and its use is now abandoned; it should not be confused with the "Zor Hauran Formation", which is now formally defined as the rock unit which intervenes between the (Liassic?) Uba'id Formation and the (Upper Triassic?) Mulussa Formation, in the Wadi Hauran, below the Rutbah Sandstone Formation, west of Muhaiwir.

The name Rutbah (or Rutba) sand (or sandstone) was formerly applied to the Nahr Umr Formation of southern Iraq, and also to those units of the Kuwait succession which are now collectively designated as the Burgan subgroup (Owen and Nasr, 1958). For the most part, such usage was confined to unpublished reports of oil companies, but Barber (1948) included in his publication a stratigraphic table for the Kuwait succession which groups the Ahmadi, Wara, Mauddud, and Nahr Umr Formations of current classifications as subdivisions of the Rutbah sand.

DETAILED LITHOLOGIC DESCRIPTION

Varicolored, white and ferruginous coarse to fine sands and sandstones, locally cemented to quartzites, make up the formation. Basal parts are possibly of continental origin; the upper parts are marine. No diagnostic fossils have been found.

AGE

The Rutbah Sandstone Formation is pre-Cenomanian or early Cenomanian, as it is overlain by the upper Cenomanian M'sad Formation. It is Upper Triassic to post-Triassic or Upper Triassic, as it is underlain unconformably by Upper Triassic Mulussa Formation. Its age is not ascertained within these units at the type locality.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The Rutbah is underlain by the Mulussa Formation; the contact is unconformable, erosional, and discordant. Overlying the Rutbah is the M'sad Formation, with transitional, gradational contact which is placed at the base of the first definite limestone bed above the continuous sandstone of the Rutbah sandstone.

According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), the Rutbah Formation is homotaxial with the "gres lignitifere" of Zumoffen (1926) and with the so-called Nubian sandstone of the Lebanon and other places. It has been loosely equated with the Nahr Umr Formation of the subsurface sections, with which it may be continuous, but it is much more probable that these two units are genetically distinct and that the Rutbah Sandstone Formation overlies the eroded outcrops of the Nahr Umr in the area between Muhaiwir and Awasil.

Whereas the Nahr Umr Formation is considered to be of early Albian age, grading upward into the late Albian Mauddud Formation, the Rutbah is probably of Cenomanian age at its type locality, where it is overlain by the upper Cenomanian M'sad Formation. The M'sad Formation is probably approximately correlative in age with the Mahilban Limestone of the Awasil area, and the Rutbah Sandstone Formation at Rutbah is probably the same age as part of the hiatus between the Mauddud and Mahilban Formations at Awasil. This interpretation is preferable to the earlier held concept that the Rutbah and Nahr Umr Formations compose a single diachronous sandstone deposit. The Rutbach may also be equated with the Wasia Formation of Saudi Arabia.

ECONOMIC ASPECTS

The Rutbah Sandstone Formation forms a good aquifer in western Iraq, where a number of Iraq Petroleum Company water wells along the pipeline draw their water from this formation.

AHMADI FORMATION

REFERENCE SECTION, THICKNESS, AND EXTENT

The reference section of the Ahmadi Formation is in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47°43′29″ E., alt 51.9 ft, completed Feb. 21, 1951) between drilled depths of 8,070 and 8,517 feet (447 ft thick). The formation is widespread in the subsurface sections of southwestern Iraq in the wells of the Nahr Umr, Rumaila, and Zubair fields and in wells Tuba No.1, Ratawi No.1, Rachi No.1, Luhais No.1, Samawa No.1, Kifl No.1 and 2, Shawiya No.1, Ubaid No.1, Safawi No.1, and Ghalaisan No.1. Thus far the greatest thicknesses of the formation are in the Basrah area and are between 400 and 550 feet. This thickness trend extends to Samawa well No.1 (437 ft thick) and almost to Luhais well No.1 (382 ft thick). Over Ash Shawiyat and Ubaid areas the thickness decreases to about 300 feet. In the extreme west at wells Safawi No.1 and Ghalaisan No.1, recorded thicknesses are 185 and 249 feet, respectively. At Kifl well No.1 a thickness of only 56 feet is recorded.

DETAILED LITHOLOGIC DESCRIPTION

The Ahmadi Formation at the reference subsurface section can be subdivided into three lithologic units, which are from top to bottom:

	Thickness (feet)
3. Shale, greenish-gray, fissile, ostracode-bearing, interbedded with gray ostracode-bearing marl and streaks of arenaceous detrital limestone containing *Cythereis* sp. and *Cytherella* sp.	163
2. Limestone, gray, marly with streaks of green shale (Tuba Limestone Member)	177
1. Shale, light-blue to gray, pyritic, fissile, with streaks of gray soft locally calcareous marls containing *Haplophragmoides*, *Cythereis* sp., and *Cytherella* sp.	107

A similar sequence has been recognized in wells Luhais No.1 and Samawa No.1. However, this formation changes its character westward where it becomes more like the Wara Formation. At Safawi well No.1 it becomes predominantly red, brown, and green fissile somewhat silty shale containing glauconite toward the base. Northward in the Kifl area, the sequence is highly dolomitized and predominantly calcareous.

Glauconitization at the base of Ahmadi may be indicative of shallowing, and a possible unconformable contact with the underlying Mauddud Formation was thus postulated. Southward the Ahmadi Formation has been considered to grade laterally into the Wara Formation of Kuwait, and northward into the Rutba Sandstone Formation.

The neritic Tuba Limestone Member in the Basrah area increases in thickness eastward toward the basin by replacing the shaly components, and the facies becomes more and more Oligosteginal till it cannot be distinguished from that of the Rumaila. In the more basinward areas the upper shales of the Ahmadi merge into the neritic Mishrif Formation.

DIAGNOSTIC FOSSILS AND AGE

Turritella spp., *Corbula* sp., *Exogyra conica* (J. Sowerby), *Exogyra luynesi* (Lartet), *Neolobites* sp., *Parasmilia* sp., *Metoicoceras* sp., *Aspidiscus (Helladastraea)* juv. cf. *Aspidiscus semhae* Kossmat, and species of *Haplophragmoides*, *Flabellina*, *Vaginulina*, *Ammobaculites*, *Gumbelina*, *Lenticulina*, *Frankeina*, *Haplophragmium* have been recognized at most places, but elsewhere *Praealveolina cretacea* (d'Archiac), *Pseudocyclammina* cf. *P. hedbergi* Maync and *Meandro psina* sp. have been recognized and indicate Mishrif influence.

In 1956, Sayyab described a suite of ostracodes from the Ahmadi Formation of the Zubair well No. 5. This suite includes *C. ovata* Roemer and a large and characteristic assemblage of undescribed new species, including some new genera.

The formation is Cenomanian; Sayyab (1956) favors Albian age for this formation on the basis of the ostracode fauna, and W. Sugden (unpub. data, 1958) argues for late Albian age for the presumably correlative lower parts of the Khatiyah Formation of Qatar.

In most of the wells in southern Iraq, the Ahmadi Formation lies unconformably over the Mauddud Limestone, although it is underlain by Wara Formation in places; however, recognition of the Wara in these wells is difficult. The base of the Ahmadi Formation is placed at the base of a shale (at times a gray dense limestone), the M/1 marker. The Ahmadi is overlain by the Rumaila Formation, with which a conformable and intergraduational contact has been postulated. Equivalent units in adjacent areas are the Khatiyah, Wasia, Rutbah Sandstone, and Wara Formations, in part.

ECONOMIC ASPECTS

The Ahmadi Formation constitutes the caprock that retains oil within the underlying sands of the Burgan Subgroup in the Kuwait oil fields. In the Basrah oil fields area of southern Iraq, although the formation is present, there is not thus far any indication that it functions as a caprock. The Ahmadi here is the cause of a great deal of caving in drilling wells, if a well-controlled drilling-fluid system is not maintained.

RUMAILA FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Rumaila Formation is in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951), where is lies between drilled depths of 7,605 and 8,070 feet (465 ft thick). This formation has widespread distribution in southwestern and central Iraq, and owing to facies changes at the expense of its thickness the formation varies considerably from one place to another in the oil fields of southern Iraq. Generally, it ranges in thickness between 140 and 500 feet. Except for local variations, the general thinning is gradual and westward. At wells Samawa No.1 and Shawiya No.1 the thickness decreases to slightly more than 200 feet. In the south between wells Ubaid No.1 and Safawi No.1, the thickness ranges between 170 and 180 feet. Westward the thickness increases slightly, as compared with the thickness at wells Samawa No.1 and Shawiya No.1, to 239 feet at Ghalaisan well No.1. At Kifl well No.1 the equivalents of this formation attain the exceptional thickness of about 900 feet.

DETAILED LITHOLOGIC DESCRIPTION

Lithologically the Rumaila Formation can be subdivided into two units as follows:

	Thickness (feet)
2. Marl, buff to brown, chalky, foraminiferal, oligosteginal; intercalations of crystalline leached-out limestones; chalky to dense limestones; shale streaks	265
1. Limestone, cream-colored, dense, cryptocrystalline; oligosteginal; some is marly with some streaks of shale	200

The lithology of this formation undergoes considerable lateral and vertical variation, depending on the interdigitation of chalky marls and limestones. One such manifestation is observed in wells Kifl No.1 and Awasil No.5, where the formation has been subdivided into three formations—Mahilban, Fahud, and Maotsi. The Rumaila interdigitates with the overlying Mishrif Formation and the underlying Ahmadi Formation, and in the Rutba area it is postulated to merge into the exposed M'sad Formation.

DIAGNOSTIC FOSSILS AND AGE

Diagnostic fossils in the Rumaila Formation are *Oligostegina Globigerina* spp., *Orbitolina concava* var.

qatarica Henson, *Gumbelina* sp., *Nummoloculina* sp., *Begia* sp., miliolids, valvulinids, and rotalids. The formation is Turonian and Cenomanian in age.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The Ahmadi Formation underlies the Rumaila Formation conformably. The contact is placed at the top of the black fissile ostracode-bearing shales. The Rumaila may rest directly on the Mauddud limestones in central Iraq. It is overlain by the Mishrif Formation; the contact is conformable, diachronous, and intergradational at the top of *Oligostegina*-bearing limestone. In the area of wells Samawa No. 1, Ghalaisan No. 1, and Kifl No. 1, the Rumaila Formation is directly overlain by the lagoonal evaporitic Kifl Formation.

The Rumaila Formation is composed of subbasinal facies and may pass into the more basinal Dokhan facies. In facies and age the Rumaila Formation is equivalent to the Mahilban, Fahud, and Maotsi Formations of central Iraq. M. Chatton (unpub. data) recommended adoption of the name Rumaila Formation to replace the three formation names. This formation is not differentiated from the Mishrif Formation in wells of southeastern Kuwait, where these two formations are replaced by the Magwa Formation. The Magwa Formation has been eroded from the crestal areas of the Burgan, Magwa, and Ahmadi structures, but occurs in progressively increasing thicknesses down the flanks.

KIFL FORMATION

The Kifl Formation has been defined by M. Chatton (unpub. data) to include the evaporite facies of the Cenomanian–lower Turonian sedimentary cycle in southern Iraq.

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Kifl Formation is in BPC well Kifl No. 1, (lat 44°11′14.55″ N. long 32°15′08.04″ E.; alt 141 ft; completed July 8, 1960). The formation lies between drilled depths of 4,738 and 4,830 feet (92 ft thick).

The unit has been found in the BPC wells Ubaid No. 1, Shawiya No. 1, Samawa No. 1, Ghalaisan No. 1, Kifl No. 2, and the Mosul Petroleum Co. wells at Nafatah and Awasil. The distribution of this formation is not limited to the region already mentioned but extends to other parts of the country. In southern Iraq, however, the formation passes laterally by interdigitation into the Mishrif Formation, within a zone extending from east of Ubaid to Shawiya and Samawa. Northeastward the two facies are interbedded. At Kifl itself, Kifl evaporites indicate downward gradation into the Rumaila chalks.

DETAILED LITHOLOGIC DESCRIPTION, FOSSILS, AND AGE

The Kifl Formation is predominantly white crystalline anhydrite with streaks of green marl and chalky pelletal limestone locally having an anhydritic matrix; cream-colored porcelaneous anhydritic marly limestone occurs at the base. The Kifl contains uncommon miliolids and textularids. Its age is probably late Cenomanian and early Turonian.

CONTACTS WITH ADJACENT UNITS

The Kifl is underlain by the Rumaila Formation (formerly called Maotsi Formation); the contact is conformable, gradational, and is placed at the change from continuous white, creamy *Oligostegina*-bearing chalky limestone below to anhydritic marly limestone. The Khasib Formation overlies it. The contact is unconformable, with a sedimentary break, and is placed at the change from anhydrite below to shale above. No equivalent units in adjacent areas are recorded.

ECONOMIC ASPECTS

The Kifl Formation has no known economic significance; it may induce trapping of oil in the porous section of the Mishrif Formation.

M'SAD FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the M'sad Formation is in Wadi M'sad al Rutbah, which runs due north for 20 miles from Jebel Tarayat (lat 32°46′ N., long 40°17′ E.) to join the Wadi Hauran at Rutbah (lat 33°02′ N., long 40°07′ E.). The formation is about 211 feet thick. It is widely exposed in the area north of Rutbah; sections have been measured at An Nadhara, Khasm Mulussa, Wadi Semhat, Ras Semhat, Rutbah, Wadi Mulussa, and "Hill 270."

The occurrence of sands and sandy limestones within the unit is a feature of this heterogeneous formation in the area of the type locality. One thin sand bed, remarkably constant over the area of exposure, separates the main, limestone-dominated upper part of the formation from the thin, basal limestone unit.

DETAILED LITHOLOGIC DESCRIPTION

The M'sad Formation consists of alternating shallow marine limestones, shell breccias, microdetrital limestones, chalky buff and white limestones, pink marls, and sandy marls and sands; a thin sandstone tongue occurs near the base.

In the vicinity of the type locality the M'sad Formation grades conformably into and perhaps interdigitates laterally with the underlying Rutbah Sandstone Formation. It underlies an erosional unconformity H. H. Boesch, (unpub. data) over which the Maestrichtian Tayarat Formation transgresses. The Turonian, lower Senonian, and Campanian Stages are not represented by sediments in the Rutbah-Jebel Tayarat area, though formations of these ages enter the succession in the area to the east, southeast, and south.

DIAGNOSTIC FOSSILS AND AGE

No fossils are recorded from the type locality of the M'sad Formation. The limestones of this unit elsewhere carry a rich if ill-preserved macrofauna from which *Nerinea cochleaeformis* Conrad was identified by A. Keller and H. H. Boesch (unpub. data). Rudists, including *Caprinula* sp. and *Eoradiolites liratus* Conrad, were also recorded by A. Keller (unpub. data) but have not been confirmed in postwar collections. Recent collections, identified by R. G. S. Hudson and J. Robinson, include *Nerinea cretacea* Conrad and *N.* cf. *N. gemmifera* Conrad, indicating Cenomanian age, probably late Cenomanian.

The associated microfauna, which is represented throughout the formation, both above and below the thin sandstone previously mentioned, includes *Meandropsina* cf. *M. vidali* Schlumberger, *Cuneolina* cf. *C. cylindrica* Henson, *Dicyclina* cf. *D. qatarica* Henson, rare *Praealveolina* sp., *Begia* spp., *Pseudochrysalidina conica* (Henson), and *Taberina* cf. *T. bingistani* (Henson). The microfauna is probably of late Cenomanian rather than early Cenomanian age and is unlikely to be younger than Cenomanian.

The age of the formation has not been ascertained at the type locality. Elsewhere in the vicinity of the section the formation is middle Cretaceous, early Cenomanian at the base and probably early Cenomanian throughout.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The underlying unit of the M'sad Formation is the Rutbah Sandstone Formation; the contact is gradational and conformable and is placed at the base of the lowest limestone bed above the continuous Rutbah.

The M'sad Formation is overlain by the Tayarat Formation; the contact is unconformable owing to an erosional break in sequence which omits sediments of Turonian to intra-Maestrichtian ages. The contact is placed at the base of the localized basal conglomerate of the Tayarat Formation.

On the basis of age, microfauna, and microfacies, the M'sad Formation is considered to be correlative with the Mahilban limestone of the Awasil area and the Mishrif Formation (part) of southern Iraq, from both of which it may be distinguished by its heterogeneity. Distinction will be difficult in areas where the sand and marl components are subordinate, and in intermediate areas the name M'sad and Mahilban Formation may be necessary.

MISHRIF FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Mishrif Formation is in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47° 43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation is between drilled depths of 7,204 and 7,605 feet (401 ft thick).

In the Basrah fields this formation ranges between 350 and 550 feet in thickness. Its eastern extension is unknown. Thickness trends follow a northerly direction, as if the Mishrif were deposited over a shoal extending basinward from the Arabian shield across the Kuwait-Basrah region, bordered on the east by the main Balambo basin and on the west by a subsidiary, shallower "Rumaila" basin. Thus, geographically, rocks of Mishrif type may be restricted to a narrow belt. To the west the Mishrif is only a few feet thick at wells Samawa No. 1 and Safawi No. 1 and is absent at Ghalaisan well No. 1.

According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), in the Rutbah area of the western desert the Mishrif is probably represented in outcrop by the correlative M'sad Formation which carries a microfauna similar to that of the Mishrif Formation. The rudist *Eoradiolites liratus* Conrad, reported here by A. Keller, is believed to occur also in the subsurface Mishrif Formation (W. Sugden and E. Hart, unpub. data, 1957). The Mishrif Formation is not represented in southeastern Kuwait, where equivalent sedimentary rocks form the upper part of the Magwa Formation.

DETAILED LITHOLOGIC DESCRIPTION

The Mishrif facies, which is thickly deposited throughout the Basrah area, consists of neritic sedimentary rocks, mostly limestones and, in places, shales. The limestones are variable in texture and may be oolitic or pelletal, shelly, and coquinoid types which contain algae, rudists, bryozoans, corals, and miliolids; in places there are indications of offshore deposition.

The following is a detailed lithologic sequence in the type section, based on reinterpretation of the electric logs:

	Thickness (feet)
8. Limestone, fine-grained, limonitic, fresh-water, containing *Charophytes* and marl; interbedded with black shale having some light-buff streaks	50
7. Limestone, white-buff, fine-grained, fractured or stylolitic, marly, partly pseudo-oolitic and microbreccious with streaks of greenish-black shale and pale-buff marl toward base	26

6. Marl, whitish-buff, algal, and greenish-black shale	12
5. Limestone, brown and white, dense, detrital, containing gastropods, rotalids, and sponge spicules; partly pseudo-oolitic and contains rare chalky streaks and thin green shale intercalations	68
4. Limestone, cream to white or brownish-buff, porous, partly very shelly and foraminiferal; contains bands of rudists, *Cisalveolina* sp., *Begia* sp., *Dicyclina* sp., *Dictyoconus* sp., miliolids, and others	136
3. Marl, white to buff, chalky, oil-stained in places	16
2. Limestone, porous, oil-stained, brown to light-buff; leached-out fossils; contains calcite veins and floods of miliolids, *Begia* sp., *Cisalveolina* sp., *Dicyclina* sp. *Taberina* sp., *Praealveolina* sp. and others	58
1. Limestone, buff to brown, algal, contains miliolids or *Cisalveolina* sp.; very dense at base	35
Total	401

At Samawa well No.1 the formation is very thin and barely recognizable, consisting of 32 feet of tight, fine dolomite containing some miliolids.

According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959) the *Chara* limestone which occurs at the top of the Mishrif in near-crestal wells in the Zubair field is missing in most other areas. The limonitization of the upper beds of the Mishrif and the abrupt facies change from algal limestone to globigerinal marly limestones strongly suggests nondeposition and an emergent episode, with erosional termination of the Mishrif. On the other hand, close correlation between wells and fields in the Basrah area does not confirm any significant erosional convergence below the base of the Khasib Formation. In Kuwait, however, the Mishrif and Rumaila Formations and the upper parts of the older Ahmadi Formation were eliminated at the erosional unconformity which preceded the Upper Cretaceous transgression, and the hiatus narrows, significantly, to the limonitized surface atop the Mishrif as the Basrah area is approached (Owen and Nasr, 1958, fig. 5).

DIAGNOSTIC FOSSILS AND AGE

Fossils found in the Mishrif Formation include *Chara* sp., *Permocalculus ireane* Elliott, *Cisalveolina* sp., *C. fallax* Reichel, *C. lehneri* Reichel, *Praealveolina cretacea* (d'Archiac), *P. cretacea* var. *tenuis* Reichel, *Multispirina iranensis* Reichel, *Dicyclina qatarica* Henson, *Taberina bingistani* (Henson), *Pseudochrysalidina conica* (Henson), *Begia* spp., *Coxites zubairensis* Smout, and *Trocholina* spp.

Recent stratigraphic work in Iraq by M. Chatton and E. Hart (unpub. data) dates the Mishrif Formation as Cenomanian and early Turonian. Owen and Nasr (1958) attributed this formation to the Turonian; however, according to Dunnington, Wetzel, and Morton (in Bellen and others, 1959):

> A. H. Smout (1956) has described numerous species of the foraminiferal genus, *Begia*, from the Mishrif formation of the Basrah area. He argues for Turonian age for the rich faunas of the lower part of the unit, but the *Alveolinidae* are of Cenomanian rather than Turonian age in Iran, and the rudist evidence from Rumaila wells and macrofossil evidence as to age of the correlative M'sad Formation are strongly in favour of a Cenomanian attribution also. The upper part of the formation could be Turonian, but the *Permocalculus* flora near to the top of the unit matches that from the Mahilban Formation of the Awasil area (G. F. Elliott, unpub. data) which is separated by unconformity from the presumably Turonian Fahad Limestone.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The contact of the Mishrif Formation with the underlying Rumaila Formation is conformable and is placed at the change from oligosteginal-globigerinal limestone below to neritic limestones, with miliolids, *Begia* spp., and larger Foraminifera above; thus, the contact is one of normal lateral and vertical gradation. The contact with the overlying Khasib Formation is disconformable, owing to a considerable sedimentary hiatus (Bellen and others, 1959). The Mishrif Formation commonly is conformably overlain by a thin evaporitic lagoonal Kifl Formation, as in some of the western desert subsurface sections. In the extreme west, for example at Safawi well No.1, where the Khasib is absent, the Tanuma shales rest directly but unconformably on a few feet of the Mishrif Formation.

The Mishrif Formation may be equated with at least the upper part of the Wasia Formation of Saudi Arabia, though the Wasia is a different facies.

ECONOMIC ASPECTS

According to staff members of the Iraq Petroleum Company (oral commun., 1956), medium oil (26° API) can be produced from the limestones of the Mishrif Formation in the Zubair and Rumaila oil fields of the Basrah Petroleum Company, where it constitutes what is called the "Second Pay."

KHASIB FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Khasib Formation is in BPC well Zubair no. 3 (lat 30°23′01″ N., long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 7,040 and 7,204 feet (164 ft thick). It has been found in all subsurface sections in southern and western Iraq except in well Safawi No.1. To date (1964) these sections include wells in the Nahr Umr, Zubair, and Rumaila fields; in the wells Rachi No.1, Ratawi No.1, Luhais No.1, Samawa No.1, Kifl No.1 and 2, Ubaid No.1, Ghalaisan No.1, and Shawiya No.1; and in the wells in northeastern Kuwait. The formation was not identified, however, in southeastern Kuwait, where it probably has equivalents in the lower part of the Gudair Formation that are complete. The Gudair thins toward the structural uplift of Burgan, and equivalents of the Khasib and Tanuma Formations are probably eliminated by progressive overlap (Owen and Nasr, 1958). The thickness distribution and variation is complicated by facies interrelation with the overlying Tanuma Formation. The Khasib thickens basinward to the northeast to as much as 300 feet, whereas a belt, 200 feet thick, may follow the Euphrates River very closely between wells Kifl No.1 and Nahr Umr No.3. In the Basra fields the thickness ranges between 17 and 195 feet. At wells Ratawi No.1 and Rachi No.1 thicknesses of 140 and 118 feet respectively, were recorded. Westward, at wells Ubaid No.1 and Ghalaisan No.1, the thickness decreases to 95 and 77 feet, respectively, and in Safawi well No.1 the formation's identity is completely lost.

DETAILED LITHOLOGIC DESCRIPTION

Lithologically, the type section of the Khasib Formation can be subdivided into two units as follows:

	Thickness (feet)
2. Limestone and chalk, light-gray, very marly, slightly dolomitic, with subordinate streaks of black shale	95
1. Shale, dark-gray or greenish-gray, fissile, alternating with globigerinal-gumbelinid and dolomitic fissile buff marly limestones	69

DIAGNOSTIC FOSSILS AND AGE

Fossils found in the Khasib Formation are *Globigerina* sp., *Gumbelina* spp., and *Oligostegina.* Sayyab (1956) identified three new ostracode species from the Khasib Formation of Zubair well No. 5. Other microfossils, which include *Globotruncana lapparenti* subspp. and *G. leupoldi* Bolli from Zubair well No. 1 and *G. stuarti* (de Lapparent) from Nahr Umr well No. 1, were recognized in this formation by Dunnington, Wetzel, and Morton (in Bellen and others, 1959). The Khasib Formation is Senonian (early?), according to Owen and Nasr (1958).

Since Owen and Nasr did not recognize any break within the Mishrif Formation, or within the overlying sequence of the Khasib, Tanuma, and Sa'di Formations, the interpretation that the Khasib-Mishrif contact involves no hiatus in sedimentation implies an older age than late Campanian for the base of the Khasib. The Mishrif Formation is considered to be not younger than Turonian (Owen and Nasr indicated Turonian age, but Cenomanian age for at least the lower part of the Mishrif was argued by others. See section on "Mishrif Formation.") Recently, however, M. Chatton and E. Hart (unpub. data) established the age of this unit as middle Turonian and early Coniacian.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The contact of the Khasib Formation with the underlying Mishrif Formation is disconformable, being between oligosteginal shales above and limonitic limestones with Charophytae below. In Ubaid No. 1 and Kifl No. 1 and 2, the Khasib Formation rests directly on the Kifl evaporites. Owen and Nasr (1958) indicated that the contact between the Khasib and the underlying Mishrif is disconformable in the Basrah area and unconformable on structural highs in Kuwait.

In the Basrah area this unconformity is represented by a thinning of sediments and by a fresh-water limonitic *Chara*-bearing limestone at the top. This limestone is overlain conformably by the transgressive Khasib Formation of the Aruma Group. The contact with the overlying Tanuma Formation is conformable at the change from black fissile shales above to gray marly limestones below.

In northeastern Iraq the Khasib passes into the basinal lower limestones of middle Turonian and lower Coniacian Kometan Formation and Gulneri shales. It is represented in southeastern Kuwait in the lower part of the Gudair Formation.

ECONOMIC ASPECTS

The Khasib Formation has no economic value. It causes some trouble in drilling wells by caving and sloughing.

TANUMA FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type locality of the Tanuma Formation is in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 6,900 and 7,040 feet (140 ft thick). It occurs in all the following deep subsurface sections in southwestern Iraq: wells in the Zubair, Rumaila, and Nahr Umr fields and Ratawi No.1, Luhais No.1, Ubaid No.1, Samawa No.1, Shawiya No.1, Safawi No.1, Ghalaisan No.1, and Kifl Nos. 1 and 2. According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), this formation has not been formally recognized in southeastern Kuwait, where equivalents are probably represented by the lower part of the Gudair Formation, though cut out by onlap convergence in areas of structural uplift; however, it is recognized in northeastern Kuwait (Fox, 1957) in a stratigraphic position similar to that of the type area. In southwestern Iraq the greatest thickness of Tanuma occurs along a trend extending from wells Rachi No.1 (190 ft) to Ratawi No.1 (170 ft), Samawa No.1 (163 ft), and Kifl No.1 (130 ft). Westward from the Basrah area there is gradual thinning of the formation from wells Ubaid No.1 (54 ft) to Shawiya No.1 (49 ft), except at Safawi No.1 (83 ft) where an observable thickness anomaly is due to a complete change of facies of the underlying Khasib Formation. Northwestward there is appreciable thinning toward Ghalaisan well No.1 (15 ft).

DETAILED LITHOLOGIC DESCRIPTION

The Tanuma Formation consists of black shale with streaks of detrital limestone. The shales are fissile and the limestones are gray, marly, microcrystalline, pyritespotted, and detrital; glauconite and dolomite crystals occur throughout. An oolitic limestone streak appears in the upper part of the formation; the ooliths have a core of pyrite or glauconite.

DIAGNOSTIC FOSSILS AND AGE

In the type locality of the Tanuma Formation the detrital limestones contain *Monolepidorbis* sp., *Cristellaria* sp., ostracodes, and bryozoans. A. S. Sayyab in 1956 described some ostracodes, mostly new species, from the Tanuma Formation of Zubair well No. 5. The age of this formation was considered as late Senonian by Owen and Nasr (1958), but the fauna, according to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), seems to justify a late Campanian age. Recently, however, M. Chatton and E. Hart (unpub. data) have considered the age of this formation as late Coniacian. Here it should be remembered that because of the diachronous sedimentation of the formation one may expect extension of the total age limits.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The Tanuma Formation is underlain by the Khasib Formation; the contact is conformable and is placed at the change from black fissile shales above to gray marly limestones below. The contact with the overlying Sa'di Formation is conformable and gradational at the change from globigerinal marly limestone above to black fissile shales below. The Tanuma Formation is recognized in the northern Kuwait subsurface sections. To the southeast it passes into the Gudair Formation. The Tanuma may be correlated with one of the Aruma shales in Saudi Arabia.

ECONOMIC ASPECTS

The Tanuma Formation may be good caprock for the trapping of oil in the Mishrif limestones and to a lesser extent in porous parts of the Khasib Formation. Owing to the tendency of the shales to cave, there may be considerable difficulty in drilling operations.

SA'DI FORMATION

TYPE SECTION, THICKNESS, AND AGE

The type section of the Sa'di Formation is in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 6,013 and 6,900 feet (887 ft thick). No outcrop in southwestern Iraq has so far been designated as Sa'di Formation, although the unit reaches a thickness of 1,279 feet and widespread subsurface distribution, which seems to be in the Rumaila area. Wesward, this thickness decreases to from 500 to 600 feet between wells Samawa No. 1 and Ubaid No.1. Further decreases in thickness to 400 ft, were observed near the Iraqi-Saudi Arabian border. A similar decrease occurs northward, where at Kifl well No. 1. Further decreases in thickness to 400 ft were thickening is recognized at Awasil well No.5 (475 ft) and at Nafatah well No.1 (575 ft). The Sa'di Formation, because of nondeposition and erosional cutout, is not represented in the general Ga'ara-Rutbah area. The true thickness variation cannot be evaluated realistically without paleogeographic and paleogeologic reconstruction of the conditions which prevailed during and after the formation of the Sa'di sediments.

DETAILED LITHOLOGIC DESCRIPTION

The Sa'di Formation can be subdivided into two units in the type locality as follows:

	Thickness (feet)
2. Limestone, white to buff, chalky, marly, slightly dolomitic, fossiliferous with fossil contents decreasing upward; rare green calcareous shale streaks	562
1. Marl, greenish-gray to gray, with rare dolomite crystals and pyrite; globigerinal; ostracode bearing; contains some calcareous dark-gray to greenish-gray shale intercalations; upper 190 ft of this unit is recognized as Hamrina marl	325

These general characteristics persist westward to the vicinity of Ubaid well No.1, and they are also obvious in Kifl well No.1. "Basinwards, as in Nahr Umr No.2 well," according to Dunnington (1958), "the sequence becomes practically all marl with only a few marly limestone beds." Southward toward Kuwait the Sa'di in Bahra well No.1 is between 5,025 and 5,600 feet thick, but thins considerably toward Burgan and eventually disappears.

DIAGNOSTIC FOSSILS AND AGE

The Sa'di Formation is very fossiliferous and contains abundant microfauna and flora, especially in the lower part. The fossil generaly listed are *Bairdia* sp., *Cytherella* sp., *Brachythere* sp., *Nodosaria* spp., *Globigerina* spp., *G. cretacea* d'Orbigny, *Oligostegina*, *Textularia* sp., *Palmula* sp., *Marginulina* sp., *Cristellaria* sp., *Globotruncana angusticarinata* Gandolfi, *G. fornicata* Plummer, *G. lapparenti lapparenti* Brotzen, *G. lapparenti coronata* Bolli, *G. sigali* Reichel, *G. marginata* (Reuess), and *Praeglobotruncana concavata* (Brotzen). Elsewhere, the list may be augmented by the algae *Archaeolithamnium digitatum*, Pfender *Dissocladella undulata* (Raineri) Pia, and *Trinocladus tripolitanus* Raineri.

The Sa'di formation is Santonian and early Campanian in age. Owen and Nasr (1958) considered this unit to be late Senonian age. Recently, however, M. Chatton and E. Hart (unpub. data), because of the discovery of *Praeglobotruncana concavata* (Brotzen) associated with the other fossils, advocated an age of late Coniacian to early Santonian for the Sa'di; the upper part of the Sa'di being younger, they maintained that its age extends to early Campanian. This may well be the case, at least at some localities, owing to the diachronic sedimentary history of the formation.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The contact of the Sa'di Formation with the underlying Tanuma Formation is conformable at the top of black calcareous shale and at the base of white chalky limestone. The contact with the overlying Hartha Formation is an erosional unconformity corresponding to that noted between the Bahra and Gudair Formations in Kuwait (Owen and Nasr, 1958). Westward and southward the subbasinal Sa'di Formation passes into the neritic Aruma and Gudair Formations in Saudi Arabia and Kuwait.

ECONOMIC ASPECTS

The Sa'di Formation has no known economic value. Owing to the swelling nature of the rock constituents, it may cause stuck-pipe problems during drilling operations.

HARTHA FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The Hartha Formation type section is in BPC well Zubair No. 3 (lat 30°23′01″ N. long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 5,590 and 6,013 feet (423 ft thick).

The distribution of this formation in the subsurface sections of southwestern Iraq is extensive: Its thickness ranges between 370 and 765 feet in the Basrah area; gradually increases westward to 1,048 feet in the Ash Shawiya area; and, together with tongues of the Safawi Formation, reaches a maximum of 1,210 feet farther west. From the Kifl area northward toward the Ga'ara massif, the Hartha Formation thins out. Owing to the absence of the intervening Qurna Formation, it is difficult in some places to differentiate the Hartha Formation from the overlying Tayarat Formation, except possibly by detailed micropaleontologic studies. On the east side of the Ga'ara massif the Hartha Formation is only 210 feet thick at Nafatah well No.1. According to Owen and Nasr (1958), this formation thins out toward northern Kuwait but shows little facies change. They maintained that this lithologic unit has not been precisely delimited in low structural wells in Kuwait, and is missing in structurally high areas of southern Kuwait, owing to erosion or nondeposition. "In the Burgan-Ahmadi area erratic variation in thickness from 50 to 300 feet suggests that the earliest deposits of this formation were laid down in hollows eroded at the top of the underlying Gudair Formation, and the lithology suggests a transgressive phase in this area."

DETAILED LITHOLOGIC DESCRIPTION

The Hartha Formation consists of the following lithologic units:

	Thickness (feet)
4. Limestone, thin-bedded, gray, pyrite-spotted, algal, glauconitic, alternating with dark-gray fissile shale.	35
3. Limestone, buff to gray, recrystallized, globigerinal, algal, with some chalky matrix; passes upward into very marly limestone	86
2. Dolomite, light-brown, crystalline, with shale streaks toward the base	214
1. Marl, light-buff, ostracode-bearing, alternating with green calcareous shale which in places passes into argillaceous pyritic mottled glauconitic limestones	88

This lithologic sequence varies from place to place and changes laterally according to the paleogeographic position of the formation; for example, in the western desert there is a general tendency toward increase of dolomite content and interfingering of the Safawi anhydrite.

DIAGNOSTIC FOSSILS AND AGE

Fossils recognized in the Hartha Formation are *Globotruncana* cf. *G. stuarti* (de Lapparent), *Cosinella* sp., *Valvulammina* sp., *Ammobaculites* sp., *Monolepidorbis* sp., *Pseudedomia complanata* Eames and Smout, *Brachycythere* spp., and Bryozoa. In sections other than the type section, the Hartha has yielded *Omphalocyclus macropora* (Lamarck) and *Orbitoides media* in association with *Monolepidorbis* spp. from close to the base of the formation. On the basis of this association, the lower part of the Hartha and the unconformity at its base may be dated fairly closely as being of earliest Maestrichtian or latest Campanian age, probably the latter.

Elsewhere the following fossils were recognized: *Archaecyclus midorientalis* Eames and Smout, *Sid-*

erolites heracleae (Arni), *Rotalia skourensis* Pfender, *Ogivalia parisiensis* d'Orbigny, *Dicyclina schlumbergeri* Munier-Chalmas, and *Cuneolina cylindrica* Henson. The formation is Maestrichtian and late Campanian in age.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The contact of the Hartha Formation with the underlying Sa'di Formation is an erosional unconformity in the Basrah area and also in Kuwait, where it overlies the Gudair Formation. The contact with the overlying Shiranish Formation (formerly Qurna) was stated to be disconformable by Owen and Nasr (1958), and was placed at the top of white chalky glauconitic limestone and at the bottom of soft gray marl. This relationship has recently been contested by M. Chatton (unpub. data), who believes that the contact is conformable. In the extreme west at Safawi well No. 1 this formation is overlain conformably by the newly defined Safawi Formation. Northwestward, where the intervening formation is missing, the Hartha is overlain directly by the Tayarat Formation.

In southeastern Kuwait the term Bahra Formation has been used to include the combined lateral equivalents of the Hartha and the overlying Shiranish Formations, which are apparently less distinguishable in that area than in the northern Iraq fields, or in northern Kuwait, owing to the lateral southward passage of the Shiranish marls into limestones. The Hartha Formation may have its equivalent within the Aruma Formation of Saudi Arabia.

SAFAWI FORMATION

The Safawi Formation is newly defined to include the evaporitic facies of the upper Campanian and Maestrichtian cycles of sedimentation. As exploratory drilling operations progressed westward from the Basrah area, an appreciable amount of evaporite stringers, increasing in thickness westward, was observed in the Hartha Formation. In the BPC well Safawi No.1 these evaporites are so thick that they merit definition as a formation.

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Safawi Formation is in BPC well Safawi No. 1, (lat 30°2′45″ N. long 43°45′50″ E.; alt 1,362 ft; completed Oct. 9, 1960). The formation lies between drilled depths of 2,058 and 2,290 feet (232 ft thick).

This unit, thus far, occurs in the subsurface sections interfingering with the Hartha Formation in the wells Ghalaisan No.1, Kifl Nos. 1 and 2, Shawiya No.1, Ubaid No.1, and Awasil No.5. The occurrence of evaporites in a similar stratigraphic position was observed in the well Makhul No.1, and defined as Dibs Anhydrite Member of the Pilsener Limestone Formation by Dunnington, Wetzel, and Morton (in Bellen and others, 1959).

LITHOLOGIC DESCRIPTION AND AGE

The Safawi Formation is predominantly white, compact hard crystalline anhydrite, with subordinate brown hard crystalline dolomite and buff to gray soft marls. No fossils have been found in it thus far. A Maestrichtian and late Campanian age is assigned to the formation on the basis of its stratigraphic relations with the underlying Hartha and overlying Tayarat Formations.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The lower contact of the Safawi Formation with the Hartha Formation is conformable, and the unit grades into Hartha Formation laterally eastward. The contact with the overlying Tayarat Formation is not well defined owing to the lack of cores; slight unconformity is postulated because of the transgressive nature of the Tayarat.

The Safawi Formation is equated with the Dibs Anhydrite Member of the Pilsener Formation in Makhul well No. 1; the formation has not been recorded in Saudi Arabia.

SHIRANISH FORMATION

In the Basrah area the Shiranish Formation was formerly known as the Qurna Formation; the synonymy is now recognized.

REFERENCE SECTION, THICKNESS, AND EXTENT

The reference section for the Shiranish Formation is in BPC well Zubair No. 3, (lat 30°23′01″ N., long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 5,202 and 5,590 feet (388 ft thick). It occurs in all deep subsurface sections in the Basrah area and in Kuwait. According to Owen and Nasr (1958), the Shiranish Formation ranges in thickness between 250 and 450 feet, being thinnest in the Rumaila field. There is a general thickening of the formation northwestward, and in the Samawa area it attains a thickness of 550 feet. Westward from that area it thins to about 450 feet in the area of Ghalaisan well No. 1. It passes latterally westward into the neritic Tayarat Formation.

DETAILED LITHOLOGIC DESCRIPTION

The Shiranish Formation consists of buff or ash-gray globigerinal marl, in some places dolomitic, and some marly and detrital limestone beds; it is glauconitic toward the base and contains a rich microfauna.

According to Owen and Nasr (1958), the Shiranish marls in the Basrah area pass in southern Kuwait into white to gray dense marly microcrystalline limestone, which in many places contain gray chert nodules. This calcareous facies has not always been distinguished from the adjacent formations. Similar changes have been observed west of Ubaid well No.1; at Safawi well No.1 it appears that all the Shiranish marls have passed into chalky and marly limestone within the Tayarat Formation.

DIAGNOSTIC FOSSILS AND AGE

Fossils found in the Shiranish Formation are *Cytherella* spp., *Bairdia* spp., *Nodosaria* sp., *Globotruncana* spp., *Cristellaria* spp., *Gyroidina naranjoensis* White, *Anomalia* sp., *Marssonella oxycona* (Reuss), *Gaudryina* sp., *Bolivina inc rassata* Reuss, *Buliminella laevis* (Beissel), *Cibicides beaumontianus* (d'Orbigny), *Bolivinoides draco* (Marsson), *Textularia cretosa* Plummer, *Gumbelina* sp., and others. The formation is Maestrichtian in age.

CONTACTS AND EQUIVALENT UNITS IN ADJACENT AREAS

The Hartha Formation underlies the Shiranish with slightly disconformable contact. The overlying Tayarat Formation is conformable and gradational; the contact is placed at the junction of dolomitic limestones above and globigerinal marls below. In the Kifl area the Shiranish is directly overlain by the Aaliji Formation with unconformable contact. In southeastern Kuwait the Shiranish Formation passes into the Bahra Formation and in Saudi Arabia into the Aruma formation.

TAYARAT FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Tayarat Formation is the scarp face and crest of Jebel Tayarat (Tayarat, not Ayarat), 21 miles nearly due south of Rutbah, lat 32°46′ N., long 40°17′ E. A reference section in the BPC well Zubair No. 3 lies between drilled depths of 4,482 and 5,202 feet. The formation is about 98 feet (incomplete) thick at the type locality.

According to Macfadyen (1938), this formation has a widespread outcrop distribution in the Wadian area, south of Rutbah. H. A. Field and K. D. Jones (unpub. data, 1958) described good, but incomplete, sections at Abu Ghar (E. 1183, N. 1156), Jelta solution hole (E. 1202, N. 1173), Wadi Ithayna (E. 1195, N. 1183), Al Jandali (E. 1156, N. 1065), and Wadi Tubal west of Abu Nufuq (E. 1193, N. 1184). (Grid coordinates are shown on pl. 1.) In this general area Field and Jones assigned a minimum thickness of 250 feet for the incomplete Tayarat. South of the Widyan and Kifl areas, this formation was found in all deep subsurface sections and in some of the shallow structural holes in the southern desert west of the Euphrates River.

Owen and Nasr (1958) maintained that in the Basrah-Kuwait area this formation is essentially in the same facies as in the type locality, but it is thicker than in outcrop section. Its greatest thickness, 970 feet, seems to be localized in the Rachi well No.1 area, decreasing westward to about 600 feet in the area of wells Ubaid No.1 and Shawiya No.1. It also decreases in thickness northward from Rachi well No.1; in the wells Samawa No.1 and Ghalaisan No.1, thicknesses of 344 and 296 feet respectively, were recorded.

Dunnington, Wetzel, and Morton (in Bellen and others, 1959) stated:

> Passing northwards from Jebel Tayarat through Jebel Thoba, and towards the western rim of the Ga'ara depression, the Tayarat limestone is cut out progressively, by the erosion of its upper parts, and also perhaps by onlap convergence. In the section of Hill 270 (Lat 33°18′00″ N., long 40°10′30″ E.), and Khasm Mulussa (lat 33°18′30″ N., long 40°07′ E.), the formation is absent, the Palaeocene Umm er Radhuma formation resting discordantly on eroded M'sad formation. The convergence increases northwards, so that, at Ras Semhat, the Umm er Radhuma rests directly on Triassic Ga'ara sandstone.
>
> The details of the erosional convergence from Tayarat to An Nadhara have not been studied.

Owing to the formation's abrupt local lithologic changes and closeness to the Ga'ara massif, further study is needed to elucidate the detailed geological history.

DETAILED LITHOLOGIC DESCRIPTION

The Tayarat Formation consists of rubbly porous limestone that is white, buff, and pink; it is rather chalky, fossiliferous, recrystallized, dolomitized, locally sandy, and is conspicuously more massive at the base.

W. T. Foran (unpub. data, 1940) described the composite Upper Cretaceous section in the Widyan area as follows:

	Thickness (feet)
Umm er Radhuma white chalky limestones with silicified limestone nodules (flint?).	
Unconformity, especially in Wadi Tibal region.	
6. Limestone, purplish-gray, fossiliferous, contains *Loftusia*; yellow marls locally passing to sandstone; gray to white granular gastropodal limestones; and soft yellow limestone	27.2
5. Marl, yellow, varying locally to shale, especially toward southeast; numerous corals in upper part.	19.7
4. Sandstone, yellow, has marly matrix to west, passing into current-bedded ferruginous oolite with rhombohedral calcite in Wadi Ghadfat at Tawil; unit thins out and passes to normal marly shale in region of Wadi Tibal, where it is overlain disconformably by Umm er Radhuma limestones; is comparable with yellow sandstone bed (2 m thick)	

near middle of Tayarat section east of type locality	9.5
3. Marl, yellow, varying to shale	19.7
2. Limestone, gray, hard, dolomitic, rudistid, with several gray marly intercalations (1.4 m) having gritty marly zones, especially toward top and base; contains *Omphalocyclus macropora* (Lamarck), *Eoradiolites*, and corals	32.8–98.4
1. Marl, yellow, with some thin limestone intercalations	48.5

?Unconformity.

M'sad soft yellow limestones containing *Nerinea* sp.

W. T. Foran (unpub. data, 1940) called unit 2 the Tibal dolomitic limestone; units 3, 4, and 5, the Tawil marl; and unit 6, the Tayarat limestone. However, F. R. S. Henson (unpub. data, 1940) and H. A. Field and K. D. Jones (unpub. data, 1958) included all these units in the Tayarat Formation.

Macfadyen (1938) pointed out the presence of a fish bed, in presumably Cretaceous sandy limestones at Gur Ayarat, where abundant teeth but fewer bone fragments and vertebrae were found.

DIAGNOSTIC FOSSILS AND AGE

Fossils in the Tayarat Formation include *Loftusia morgani* Douville and *Omphalocyclus macropora* (Lamarck). According to H. A. Field and K. D. Jones (unpub. data, 1958), the Tayarat limestones contain corals, rudists (including *Eoradiolites?*), gastropods, lamellibranchs, and algae. They maintained that generic identification is often difficult as most of the original structures have been destroyed by recrystallization and some by dolomitization. In addition to the fossils recognized in the type section, the following microfossils have been determined from the subsurface sections: *Lepidorbitoides socialis* (Leymerie), *Orbitoides media* (d'Archiac), *O. apiculata*, *Ogivalia parisiensis* d'Orbigny, *Rotalia skourensis* Pfender, *R. trochidiformis* Lamarck, *Globotruncana* spp., *Dictyoconus* sp., *Dicyclina schlumbergeri* Munier-Chalmas, and *Pseudochrysalidina* sp.

For complete faunal assemblages of the Tayarat Formation, reference to the equivalent Aqra Limestone of northern Iraq is recommended. (See Bellen and others, 1959.) The formation is Maestrichtian in age.

CONTACTS

The lower contact of the Tayarat Formation with the M'sad Formation is an erosional unconformity placed at the base of a localized conglomerate. In southwestern Iraq, with the exception of the extreme western region in the vicinity of Sawafi well No.1, where it is underlain by Safawi anhydrites, this formation overlies the Shiranish Formation (formerly Qurna) conformably with lateral interdigitation.

The upper contact is not present in the type locality, owing to the complete erosion of the overlying formation; however, in the Al Widyan area of western Iraq, though the structural grain of the country is flat, there is strong evidence of an overlap relationship between the Paleocene rocks and the underlying Upper Cretaceous Tayarat Formation.

Macfadyen (1938) described this area as follows: "Nearly the whole of the Wadian (Al Widyan) is covered with flat-lying limestones occasionally conglomeratic. These are believed to be wholly of Eocene and Cretaceous age. Since the lithology is generally similar, and recognizable fossils mostly leached out, the Eocene-Cretaceous boundary appears to unmappable without a great expenditure of time and labour."

According to W. T. Foran (unpub. data, 1940), the contact of the Cretaceous with the overlying Paleocene formations is readily recognizable throughout the exposed area; he placed the contact at the level of the lowest appearance of *Loftusia* and the lowermost chalk containing bluish opaline quartz geodes. One or both of these are commonly near the contact. Later investigators such as H. A. Field and K. D. Jones (unpub. data, 1958) agreed with this view and have placed the contact a short distance above the last appearance of *Loftusia*, at the first recognizable break below the chalk containing nodular cherts and flints. In the deep subsurface sections of southwestern Iraq, the Tayarat Formation is generally overlain by the Umm er Radhuma Formation.

EQUIVALENT UNITS IN ADJACENT AREAS

According to Dunnington, Wetzel, and Morton (in Bellen and others, 1959), "Formations closely comparable with Tayart are known at outcrop in Saudi Arabia (Aruma formations; R.A. Bramkamp and M. Steineke 1952; W.H. Thralls and R.C. Hasson, 1957, and so forth) and in well sections in Arabia, and in Qatar (Sismisima formation, W. Sugden 1958, MS)."

ECONOMIC ASPECTS

The Tayarat limestones are porous and occupy an extensive area in Al Widyan. Macfadyen (1938) stated that this area is an almost flat-lying Eocene and Cretaceous limestone terrane that has very gentle slope and drainage to the east. The annual rainfall averages less than 10 millimeters, and in summer and autumn this area constitutes the most waterless part of Iraq. A very considerable proportion of the rainfall probably percolates deeply underground through solution channels in the limestone, and the ground water is thus beyond reach of shallow wells; however, deep drilled wells near the underground solution channels would probably yield water. A detailed account of this subject was given by Macfadyen (1938, 127–135). Minor quantities of phosphatic material may be found in the fossiliferous and chert beds in the area south and west of Rutbah.

CENOZOIC

TERTIARY

The Tertiary System includes the Paleocene, Eocene, Oligocene, Miocene and Pliocene series. Rocks of Oligocene age are not recognized in southwestern Iraq because of a major break due to nondeposition, pre-Miocene erosion, or both. Tertiary rocks there are composed of more than 6,500 feet of sediments.

PALEOCENE AND EOCENE

Rocks of Paleocene and Eocene age are represented by four formations that are described in succeeding discussion. The upper Eocene is not represented, perhaps because of pre-Miocene erosion.

UMM ER RADHUMA FORMATION

Reference sections and thickness

The Umm er Radhuma Formation was originally named in Saudi Arabia. Owen and Nasr (1958) referred to a supplementary type section from the Basrah area in BPC well Zubair No. 3 (lat 30°23′01″ N., long 47°43′29″ E., alt 51.9 ft, completed Feb. 21, 1951). The unit occurs here at drilled depths of between 2,980 and 4,482 feet. The formation crops out in the western desert of Iraq, where for the convenience of field mapping the exposed part has been subdivided into the Basita Beds and the Ghurra Beds.

The type location of the Basita Beds is at the section of a scarp about 50 kilometers west-southwest of Waqisa wells and 2 kilometers southwest of triangulation point S 85. The type location of the Ghurra Beds is about 8 kilometers southwest of Aydahah, near the track at Saddat al Batn. The formation is 1,502 feet thick (458 m); it has been found in all deep surface sections west of the Euphrates and Shatt al Arab Rivers, more specifically in the wells of Nahr Umr, Zubair, and Rumaila oil fields, Tuba No. 1, Ratawi No. 1, Rachi No. 1, Luhais No. 1, Ubaid No. 1, Samawa No. 1, Shawiya No. 1, Ghalaisan No. 1, and Safawi No. 1. The thickness of this formation is extremely variable; the greatest thickness (1,683 ft) was recorded in the Ubaid well No. 1. The thickness appears to decrease both westward and northward, for at wells Shawiya No. 1 and Ghalaisan No. 1 the thickness is 1,202 and 975 feet, respectively. At the extreme western wall, Safawi No. 1, where the formation is exposed, the thickness in the subsurface section is only 858 feet.

Extent

According to Bellen (Bellen and others, 1959), the Umm er Radhuma Formation is exposed over the western part of Iraq, west of a line joining Nisab (Ansab), Ash Shabakeh, and Al Lasaf. For field-mapping purposes, H. Huber (unpub. data, 1941) recognized two units there, mainly on the basis of their topographic expression as scarps in the otherwise rather flat desert.

The Umm er Radhuma outcrops form a strip 20 kilometers wide that extends northwestward from Qalib ar Rufayat-Nisab (Ansab), with a few inliers over Ar Ruwagarea, through Habbas and Jal Al Batn. About 25 kilometers southeast of Al Jumaymah, another strip of the Umm er Radhuma Formation crops out under the Zahra Formation and follows the general northwesterly trend. Between Jumaymah and Jal al Batn, the Umm er Radhuma Basita Beds commonly crop out as inliers in the erosion depressions within the Zahra Formation. Farther north, owing to the absence of the Zahra Formation, the two strips of the outcrops form one major belt more than 45 kilometers in width in the region of Hagai al Hawara, especially between Al Lu'ā'ah in the east, and Birkat al Al Aqabah in the west. The region is strewn with outliers of Zahra Formation. Between As Shubrum and Aydahah, several outliers of the Dammam Formation Wagsa Beds occur directly on the Umm er Radhuma Basita Beds. Southwest of the Jal al Batn scarp the Basita Beds are folded and fluted and contain minor contortions from the foot of the scarp itself along a belt 2–5 kilometers wide. In this area the Basita limestone has an extensive outcrop. Farther north, the width of the outcrop on the Iraqi side constricts to 30 kilometers between Al Jill and Athamin, mainly because the greater part of the formation extends into Saudi Arabia. At Athamin as well as Al Athman, outliers of Wagsa Beds of the Dammam Formation can be recognized on the Umm er Radhuma. From Al Jill toward Wagisuh (Wagsa) there is a sharp westward swing, or curve, in the distribution of the outcrop, resulting in the Basita plateau. In this area the Umm er Radhuma is generally confined between the Hagai al Basita-Ash Shaba-Hagai Al Wagsa feature and Al Ghurra. This nearly continuous outcrop ends near Chebritiya, north of where the formation occurs as isolated inliers, seen either within the Zahra Formation on the Dammam Formation. These inliers, which are of variable dimensions, occur in the area of Wadi al Khirr, Al Ghurabiya, Sahb Nauwman, Guwairat al Halib, and Ruwaiyat as Sahal. From this extensive outcrop, northward from Al Makmin (Machmi), only a narrow belt of the Umm er Radhuma crops out along the Az Zawr feature to Wadi Al Ubayyid, where it follows this wadi eastward. In this region the Umm er Radhuma disappears under the Dammam Formation on one side and under the Zahra Formation on the other; however, it reappears west of a line from Faidha al Adyan, Aglat al Khail, and Abu Infuq. Here it covers a large territory south of the Wadi Tibal where dissection causes the Upper Cretaceous Tayarat Formation to form the wadi floors, especially in the Wadi al Jaudali, Shaib al Ubaydat, Wadi al Ubayyid and Wadi al Mira. The general outcrop distribution elsewhere is clearly indicated on the geological map (pl. 1).

In the type locality of the Ghurra Member, the section is only 118 feet (36 m) thick; however, in Safawi well No.1 the unexposed part has a greater thickness. A true thickness measurement for the Basita Beds is difficult to make, owing to the width of the exposure and its relation to the overlying formation. Denudation has removed the highest beds from most of the Basita plain, but the most complete section is probably that of Al Batn at the type locality, where its thickness is only 49 feet (15 m). Here, as the overlying Dammam Formation Wagsa Beds are unconformable, the top of the section may show the highest existing Basita Beds. According to Bellen (Bellen and others, 1959), the thickness of a composite section near Aydahah, in the Batn scarp near the frontier with Saudi Arabia, is 705 feet (215 m).

W. T. Foran (unpub. data, 1940) reported a thickness of 348 feet (105 meters) for the Umm er Radhuma Formation. In the Wadi Ghadaf the thickness was estimated by H. A. Field and K. D. Jones to be more than 50 meters. They found representative sections at Al Hisichiyat (E. 1166, N. 1160) and Al If Hada (E. 1140, N. 1110).

Bellen (Bellen and others, 1959) stated:

> This formation also occurs at surface in western central Iraq. Along the western rim of the Ga'ara depression it transgresses over the pre-Tertiary outcrops of the Maestrichtian Tayarat Formation and the Cenomanian M'sad Formation and Rutbah Sandstone Formation onto deeply eroded Middle Triassic Ga'ara Sandstone. It is absent from the southwestern parts of the Ga'ara and from the Wadi Hauran.

Detailed lithologic description

The Umm er Radhuma Formation consists of anhydritic and dolomitic limestone, which is mostly dull white or buff, microcrystalline, and porous. Chert occurs in the higher part of the formation (Bellen and others, 1959).

In the outcrops at the type location, the Ghurra Beds comprise limestone that is white to gray, partly very hard and recrystallized, saccharoidal, partly leached, and well bedded and that contains oblate siliceous concretions and chert nodules and layers at some levels.

The Basita Beds at the type locality consist of gray marly hard thick to massive-bedded limestones alternating with white and yellow saccharoidal well-bedded limestones and gray dense recrystallized dolomitic thin-bedded limestones containing chert nodules. Hard roughly concentric limestone concretions as much as 75 centimeters in diameter occur sporadically on the Basita Beds between Aydahah and Nisab. Their origin is not fully understood.

In the Al Widyan country the Umm er Radhuma Formation consists mostly of alternating soft friable chalks, sporadic dolomitic chalks, bedded chalky limestones, and thin porcelaneous silicified limestones containing subordinate marl, shale, and chert horizons. Chert, flint, quartz vugs, and geodes are distributed generally throughout the sequence, but are better developed to the south. Some shell banks occur in the limestones, for example, 2 kilometers north of Wishashia (E. 1202, N. 1167). The upper chalky zone contains *Operculina libyca* Schwager. Southward, the formation becomes a fissile yellow shale overlying the *Operculina* horizon and the chalky zone includes several irregular zones of ferruginous and siliceous limestone. In the Al Widyan area a zone composed of large oblate spheroids of siliceous limestone occurs about 20 meters from the base. Owing to the differential hardness, these also strew the plain after erosion of their soft chalky crust. Eastward, the Umm er Radhuma passes into basinal Aaliji facies, as in the Kifl wells.

Diagnostic fossils and age

Fossils in the Umm er Radhuma Formation are rare, but one horizon at the top contains *Alveolina dolioliformis* Schwager, *A. oblonga* d'Orbigny, and *A. ovoidea* d'Orbigny. *Operculina libyca* Schwager has also been reported. R. G. S. Hudson (unpub. data, 1951) recorded *Pseudomilthat (Lucina) gigantea* Deshayes and ?*Turritella* cf. *T. carinifera* Deshayes.

The fossils of the Ghurra Beds are both nondiagnostic and scant; they consist chiefly of *Valvulina* sp., miliolids, rare *Alveolina* sp., molluscs, ostracodes, and algae. In contrast the Basita Beds contain a great variety of fossils. The following were originally determined by F. R. S. Henson and R. G. S. Hudson: *Alveolina* spp., *A. primaeva* Reichel, *Bigenerina* sp., *Dictyoconoides*?, *Dictyoconus* gr. *walnutensis* Carsey, miliolids, *Nummulites* spp., *Operculina libyca* Schwager, *peneroplids*, *Saudia* spp., *S.* cf. *discoidea* Henson, *Spirolina* sp., Textularia, *Valvulina* sp., ostracodes, *Lucina* sp., *Cardita* sp., *C. aegyptiaca* Frass, ?*Lima* sp., *Dentalium*?, ?*Corbula* sp., *Arca* sp., *Tellina* sp., *Venus* sp., *Anomia* sp., *Turritella* sp., *Voluta* sp., *Conoclypeus* aff. *C. delanouei* de Loriol, *Echinolampas* sp., and various other molluscs and echinoids, as well as fish fragments and algae. The formation is Paleocene and early? Eocene in age.

Contacts and equivalent units

The Upper Cretaceous Tayarat Formation underlies the Umm er Radhuma with major unconformity. In the outcropping areas "in western central Iraq, along the western rim of Ga'ara depression it transgresses over the pre-Tertiary outcrops of the Maestrichtian Tayarat Formation, and the Cenomanian M'sad Formation and Rutba Sandstone Formation, onto deeply eroded Middle Triassic Ga'ara Sandstone" (Bellen and others, 1959). For further comments about the contacts, see the section on "Tayarat Formation."

The Rus Formation overlies the Umm er Radhuma conformably in the supplementary type section. In the outcrops of western Iraq, where the Rus Formation is absent, the Dammam Formation Wagsa Beds overlie the Umm er Radhuma Formation unconformably.

The Umm er Radhuma Formation is recognized in Kuwait and Saudi Arabia, the type section of the formation being within Saudi Arabia.

Economic aspects

Ground water.—The areas where the Umm er Radhuma limestones crop out are very dry and arid. From data of Macfadyen (1938) it is inferred that the water supply in these areas is in direct relation to the rainfall and that in deep wells the supply is due to percolation downward by means of solution holes—such as those of Chebretiya, Kusra (E. 1225, N. 1160), Jelta (E. 1202, N. 1173), Wishashia (E. 1202, N. 1167), Mussir al Awaij (E. 1205, N. 1228), and Wadi Ghadaf (E. 1188, N. 1195)—with storage in such cavities or in some porous horizon at depth. He also maintained that because of apparent scarcity of faulting and folding in the desert, the geologic structure is generally of little help in locating water. The varying quality of the waters, where not due to concentration by evaporation, is due to the heterogeneity of the rocks and to the rainfall being in contact with somewhat variable soluble constituents on its way down from the surface. The lithologic character of the strata is extremely variable, and gives rise to some marked quantitative and qualitative differences in the analyses of the waters. For full details, reference to Macfadyen's (1938) work is recommended.

Sulfur and gypsum.—Macfadyen (1938) referred to the occurrence of native sulfur and gypsum at Chebretiya, some 60 kilometers west of Ash Shabakah (Shabicha), where he described the occurrence and formation of solution structures.

> A dry wadi leads into a double swallow hole, and two vast, roughly circular chambers being 35 metres and 60 metres deep, respectively, and each 50 metres in diameter. They are situated close together, so that the chambers intersect, though at the surface they are a short distance apart, the second, deeper, chamber being partially roofed over. At the base of the first a great mass, some 30×20×25 metres in size, of an admixture of white secondary gypsum and native sulphur, which latter has been worked by the Bedouin for ages, the marks of their tools being seen everywhere. The mass must presumably contain something of the order of 1,000 metric tons of free sulphur. Traces of malachite are also found associated. The whole phenomenon seems to have been caused by an acid spring, or the oxidation of underlying pyrites, which has resulted in the presence of free sulphuric acid. The gypsum tastes strongly acid, and is reported to rot the clothes of those who work there, a report fully confirmed by the rotting effect on the cotton bags and paper in which the samples collected were stored. The swallow holes were clearly dissolved out of the limestone seen in the walls, the portion converted into gypsum having now vanished in solution. A channel five metres square, unexplored, leads out underground from the base of the second chamber, in which there is neither gypsum nor sulphur deposited. A rough section was measured in the walls as follows:
>
> 0–3 m. Weathered white shale.
>
> 3–60 m. A series of rather soft limestones, marly limestones, and white chalk. Conspicuous bands of flint at 9 m. and 12 m. At 12–13.8 m. a band of small calcite nodules, simulating casts of larger foraminifera, geodes of quartz crystals, and chalcedony are common, particularly in the lower part. No fossils were recognized.
>
> The strata are nearly flat bedded, but a very slight westerly dip was seen in the section of the walls of the chambers.

Phosphates.—Some traces of phosphates may be found in the Umm er Radhuma Formation in the fossiliferous horizons and in horizons containing chert and flint.

RUS FORMATION

Reference section, thickness, and extent

The type locality of the Rus Formation is in Saudi Arabia at lat 26°19′.5 N., long 50°10′.0 E. A supplementary section in Iraq was given by Owen and Nasr (1958) in BPC well Zubair No.3 (lat 30°23′01″ N., long 47°45′29″ E.; alt 51.9 ft; completed Feb. 21, 1951) and between drilled depths of 2,673 and 2,980 feet (307 ft, or 94 m, thick); however, the formation is thicker elsewhere in the Basrah area, especially between the Zubair field and Luhais well No.1, where evaporites ranging in thickness between 300 and 700 feet have been drilled. Northward, this thick Rus facies extends to wells Samawa No.1 and Shawiya No.1, where it is represented by 200 to 350 feet of evaporites.

This formation does not cropout in the western desert, and it seems to change its facies and pass into limestone east of wells Ubaid No.1 and Ghalaisan No.1, where no Rus Formation has been recognized. The stratigraphic position of the Rus Formation equivalent in outcrop is difficult to define. Bellen (Bellen and others, 1959) has equated the Huweimi (chalk), Shabicha and Sharaf units, and the Wagsa unit of the Dammam Formation with this formation. This would imply that the Rus evaporites pass westward into the Dammam limestones. None of these units has been correlated as yet with any of the limestone beds within the Rus Formation in the subsurface sections. Bellen (Bellen and others, 1959) maintained that none of them is recognizable in wells east of the outcrop area.

Detailed lithologic description

The Rus Formation is predominantly massively bedded white and blue tinted crystalline anhydrite with alternations of thin unfossiliferous limestone, blue shale, and marl. Westward, this evaporitic sequence passes laterally into the Dammam Formation.

Age

The Rus Formation is probably early Eocene (Bellen and others, 1959) in age; no diagnostic fossils have been found. The exact age of the formation is difficult to demonstrate. In the subsurface sections the Rus Formation is sandwiched between the overlying Dammam Formation and the underlying Umm er Radhuma Formation.

According to Bellen (Bellen and others, 1959), the base of the Dammam Formation is of middle Eocene age in subsurface sections but contains a lower Eocene fauna in outcrop. He maintained that it is perfectly possible that the two lower units of the Dammam Formation in the field (the Wagsa Beds and the Sharaf, Shabicha and Huweimi Chalk Beds) change facies toward the offshore regions into part of the Rus Formation as found in the wells. Thus the age of the Rus Formation can indeed be early Eocene. Similar age attribution has been given to this formation in Saudi Arabia (Steineke and others, 1958).

Contacts and equivalent units

The lower contact of the Rus Formation with the Umm er Radhuma Formation is possibly conformable, and the upper contact with the Dammam Formation is unconformable, according to Bellen (Bellen and others, 1959). However, this may be locally conformable, and a gradational contact is advocated on the basis of the lateral facies passage of the two formations.

DAMMAM FORMATION

Type and reference sections

The type locality of the Dammam Formation is in Saudi Arabia at lat. 26°17′03″ N., long 50°07′07″ E. The supplementary type section chosen by Owen and Nasr (1958) from Al Basrah (Basra) area is in the BPC well Zubair No. 3 (lat 30°23′01″ N., long 47°43′29″ E.; alt 51.9 ft; completed Feb. 21, 1951). The formation lies between drilled depths of 1,935 and 2,673 feet (738 ft thick).

Outcrops of this formation in western Iraq were divided into 10 field units for mapping convenience by H. Huber and R. M. Ramsden (unpub. data, 1944–45). According to Bellen (Bellen and others, 1959), these units have no status as formations or even as members, but it is essential and convenient for future investigation to mention their type localities, which are in descending stratigraphic order as follows:

Tuqaiyid Beds, about 5.6 miles (9 km) west of Tukayyid water well on the Tukayyid scarp.

Ghanimi Beds, east of triangulation point C 26, near Khasmn ad Duda on the At Traq scarp.

Barbak Beds, in prominent hills at Barbak and Diud in the southeastern part of the Galaib area.

Rudhuma Beds, in the cliff to the northwest of Chabd, west of Abu Rudhuma.

Chabd Beds, at the north end of the Chabd "structure."

Shawiya Beds, in a small wadi, north-northwest of triangulation point 5.2, to the north of the Ash Shawiyat depression.

Huweimi Beds, 4.3 miles (7 km) west of Ash Shabakah (Shabicha) police post, along the Nukhayb track.

Shabicha Beds, at triangulation point S 25 about 4.3 miles (7 km) west of As Shabakah (Shabicha) police post, along the Nukhayb track.

Sharaf Beds, northeast of the Jil water wells along the track leading to Sulman.

Wagsa Beds, in the vicinity of Waqisah (Wagsa) water wells. The greatest thickness of the Wagsa Beds is on the white cliffs east and north of Wagsa wells, from which the name is taken. At the prominent point S 86, 5 km south of the wells, there is a section nearly 30 meters thick.

Thickness and extent

The Dammam Formation is 738 feet (225 m) thick in Zubair well No. 3. This formation is extensive in subsurface and surface distribution west of the Euphrates and Shatt al Arab Rivers. Its thickness in the Al Basrah oil fields and in the Basrah Petroleum Company exploration wells Luhais No. 1 and Rachi No. 1 ranges between 600 and 800 feet. A slightly greater thickness (835 ft) was found in Ratawi well No. 1. The Company's other exploration wells, such as Samawa No.1, Shawiya No.1, Ghalaisan No.1, and Ubaid No.1, which were drilled directly into the exposed Dammam Formation, penetrated incomplete sections of less than 400 feet, excluding the 350- and 245-foot Rus equivalent section of wells Shawiya No.1 and Samawa No.1, respectively.

The 10 units of the Dammam Formation cover a territory exceeding 200 kilometers in width, in which they generally stand out as scarps and recognizable topographic features. They crop out in ascending sequence toward the east and trend generally north-northwest, almost parallel to the Euphrates River. Minor irregularities in this pattern are due to local topographic depressions such as those found in the As Salman and Ash Shabakah regions, where younger rocks have escaped erosion and thus occur in anomalous position.

Detailed lithologic description

In the reference section, the Dammam Formation consists of cream to gray limestones that are recrystallized, leached out (leaving a honeycomb appearance), very porous, and fossiliferous (abundant *Nummulites* spp.). Blue silty waxy shale streaks or partings occur toward the base; toward the top, the cream to gray limestone passes upward into dark-gray to black limestone, which in places is spotted by pyrite, is porous to fairly dense, and is variably recrystallized and dolomitized.

Because this formation crops out in the western desert in broad, flat-lying, and extensively denuded exposures, the width of which may exceed 200 kilometers, selection of one surface reference section is difficult; no measured thickness can convey the true thickness of the entire formation at one particular point. The great lengths of typical sections on the ground, the distances between sections, the possibility of lateral and vertical variations, and the possibilities of minor intraformational breaks and of extensive differential erosion of the various beds that make up this formation make thickness assessment very difficult. However, for the purpose of field studies, 10 distinct but informal units were recognized in the field. Their type sections are scattered throughout the territory, and their measured thicknesses are valid only for the respresentative sections; therefore, their cumulative thickness cannot be a measure of the true thickness for the Dammam Formation in any of the type sections, except perhaps by sheer coincidence.

The different beds, which generally stand out as scarps on the plain, crop out in ascending order eastward and in belts of variable width that, apart from the few exceptions previously mentioned, generally trend north-northwest. The lithologic descriptions of the informal field units, in ascending stratigraphic order, are as follows:

Wagsa Beds: Limestone succession, white, chalky, intercalated with some yellow more marly beds, particularly in the lower few meters; thickness, 98 ft (23 m).

Sharaf Beds: Limestone, white and gray, saccharoidal, partly vuggy, fossiliferous, well-bedded, becoming massive bedded; recrystallized and siliceous with increase of quartz upward; weathers reddish brown and black toward top; thickness, 52 ft (16 m).

Shabicha Beds: Limestone, gray and white, recrystallized, massive, with thin-bedded intercalations; dense to vuggy; fossiliferous; chert nodules in upper half; weathers grayish brown; thickness, 131 ft (40 m).

Huweimi Beds: Limestone, white and gray, saccharoidal, vuggy, recrystallized, leached-out, nummulitic, well-bedded, with sporadic thick to massive beds; thickness, 102 ft (31 m).

Shawiya Beds: Limestone, white, friable, detrital, succeeded upward by white siliceous nummulitic coarsely recrystallized hard limestone, which weathers red brown and black, thickness, 13 ft (4 m).

Chabd Beds: Limestone, white, soft in the upper part; well bedded with sporadic and local massive or thick beds; weathers gray; thickness, 39 ft (12 m).

Rudhuma Beds: Limestone, mainly gray and white, well-bedded, saccharoidal, some chert nodules; sporadically vuggy and recrystallized. According to H. Huber (unpub. data, 1944), this unit contains a thin bed of gypsum in vicinity of As Salman–As Samawah track near Faydat Ash Shaykh. This possibly indicates influence of the Rus Formation; thickness, 33 ft (10 m). Possible disconformity between this unit and overlying Barbak unit in southern part of Galaib "structure."

Barbak Beds: Limestone, white and gray, medium hard; some marly limestone incalated with siliceous detrital material; also bryozoan and algal hard ringing limestone; weathers reddish brown and black; gray and brown chert nodules throughout; thickness, 81 ft (25 m).

Ghanimi Beds: Limestone, white, generally thin-bedded, some massive beds, especially toward base; includes dense to vuggy, commonly saccharoidal limestone; followed by soft leached out and friable saccharoidal limestones, some of which are highly siliceous and weather dark reddish brown and black; microbreccias and rare stringers of halite and gypsum occur in the limestones, especially near Abu Khanzir; thickness, 52 ft (16 m).

Tuqaiyid Beds: Limestone, gray and white, massive, recrystallized, very hard, passing upward into white thin-bedded saccharoidal sporadically silicified limestones.

A number of these informal units were subsequently combined by R. M. Ramsden and C. A. Andre (unpub. data, 1953) into four informal units, as follows:

1. Tuqaiyid, Ghanimi, Barbak, and Rudhuma unit, consisting of bryozoan-peneroplid limestones and shelf limestones, with a rich fauna containing *Coskinolina balsillei* Davies, *Dictyoconus kohaticus* Davies, *Opertorbitolites douvillei* Nuttall, *Orbitolites complanatus* Lamarck, *Peneroplis damesini* Henson, *P. dusenburyi* Henson, *Praerhapidionina huberi* Henson, *Rhapidionina urensis* Henson, var. *minima* Henson, *R. williamsoni* Henson, *Somalina danieli* Henson var., and *Spirolina cylindracea* Lamarck.
2. Chabd, Shawiya and Huweimi (nummulitic) unit, consisting of nummulitic limestone containing *Alveolina elliptica* (Sowerby), *Dictyoconus kohaticus* Davies, *Halkyardia minima* (Liebus), *Nummulities discorbinus* (Schlotheim), *N. gizehensis* (Forskal), *Orbitolites complanatus* La-

marck, *Peneroplis dusenburyi* Henson, *Rhapidionina urensis* Henson, *R. urensis* Henson var. *minima* Henson, and *Somalina danieli* Henson.

3. Huweimi (chalk), Shabicha and Sharaf unit, in which chalks alternate with chalky limestones that contain badly preserved lamellibranchs. The chalks are white or pink and have a fresh-water appearance.
4. Wagsa unit is a chalky, moderately fossiliferous limestone, with *Operculina libyca* Schwager occurring as a prominent fossil.

Attempts to correlate these field units with the subsurface Dammam Formation have been made by many geologists; however, none of their conclusions can be considered satisfactory because of lack of adequate information and study materials. A most plausible correlation was advanced by Bellen (Bellen and others, 1959). He stated that in the subsurface sections east of the area of outcrops, the base of the Dammam Formation contains middle Eocene fauna consisting of *Alveolina elliptica* (Sowerby), *Nummulites discorbinus* (Schlotheim), *N. gizehensis* Forskal, and *N. lucasanus* d'Archiac. This fauna occurs in the rocks that overlie the Rus Formation directly in the well sections but not in the base of the Dammam Formation in the field. There the basal limestones at the base of the Wagsa Beds contain a lower Eocene fauna with *Operculina libyca* Schwager. The Wagsa Beds in the field appear to lie unconformably on the Umm er Radhuma Formation without intervention of the Rus Formation. In well sections the middle Eocene fauna of the Dammam Formation occurs higher up in the limestone facies of the Huweimi Beds. We also may argue that the limestones containing *Operculina libyca* fauna of the surface exposures grade toward the offshore area into strata of the Rus Formation as found in the wells, and so does the second field unit of the Dammam Formation (Huweimi chalk, Shabicha, and Sharaf Beds) which has no apparent equivalent of Dammam Formation in the wells sections in which the Rus facies is developed. Bellen (Bellen and others, 1959) maintained that both the offshore facies were subsequently covered by the middle Eocene nummulitic limestones, which are normally found in the field at the base of the third unit of the Dammam Formation, the Huweimi (limestone), Shawiya, and Chabd Beds. This unit correlates very well with the base of the Dammam Formation in the wells. The above interpretation, advanced by Bellen, finds further support in the subsequently drilled wells of Samawa No.1, Shawiya No.1 and Ghalaisan No.1. In Samawa well No.1 the sequence consists of the following three units:

	Thickness (feet)
3. Dolomite, buff, leached-out, vacuolar, and dolomitic limestones with gastropods and lamellibranchs at certain horizons	91
2. Limestone, white, recrystallized, locally chalky	90
1. Limestone, white, recrystallized, in places chalky and containing *Nummulites* spp	200

At Samawa well No.1 the Rus Formation itself comprises 245 feet of crystalline anhydrite with marl limestone and marl intercalations. A. Sayyab (unpub. data, 1960) considered this sequence to be very similar to that of other subsurface sections in the Al Basrah area, except for the absence of the upper bryozoan-miliolid limestone, which has possibly been eroded. Furthermore, the nummulitic facies of the above-mentioned unit No.1 which directly overlies the Russ Formation, according to H. A. Halliwell (unpub. data, 1962), can possibly be correlated with Huweimi (limestone), Shawiya, and Chabd Beds.

Farther west, in the wells Shawiya No.1 and Ghalaisan No.1, which were spudded directly into the Huweimi (limestone), Shawiya, and Chabd Beds, the Rus Formation shows indication of gradual change of the facies. In Shawiya well No.1, stringers of anhydrite persist in an otherwise completely dolomitic limestone sequence with a thickness of 350 feet, but in Ghalaisan well No.1 the facies change from evaporite to limestone seems to be complete where the evaporites have not been leached out. If this is true then it is another possible explanation for the absence of the Rus Formation in the surface sections. Bellen (Bellen and others, 1959) maintained that it is possible that percolating ground water may have removed the anhydrite, so that the apparent unconformity is not an original one. Facies change from Wagsa Beds and lower part of the Huweimi (chalk) Beds to Rus Formation remains a possibility because the correlation of upper Huweimi part of the Beds with the lower part of the Dammam Formation in the wells is probable.

Diagnostic fossils and age

The fossils contained in the rock samples from the reference section of the Dammam Formation are on the whole badly preserved; they include such forms as *Lockhartia hunti* Ovey var. *pustulosa* Smout and *Nummulites discorbinus* (Schlotheim). However, a more numerous fauna determined from the surface and subsurface sections, includes algae, silicified wood, fish remains, ostracodes, lamellibranchs, *Meretrix (Cordiopsis) incrassata* Sowerby, *Pecten* sp., *Ostrea* sp., *O. (Pycnodonta brongniarti)* Bronn., cf. *O. multiscostata* Deshayes, gastropods, echinoids, sponge spicules, bryozoans, *Alveolina* spp., *A.* aff. *elongata* d'Orbigny, *A.*

elliptica (Sowerby), *A. elliptica* (Sowerby) var. *nuttalli* Davies, *A. globosa*, *Articulina* sp., *A. iraqii* Henson, *Assilina* sp., *Bigenerina* sp., *B.* cf. *truncata* d'Orbigny, *Coskinolina* sp., *C. balsilliei* Davies, *Dictyoconoides* spp., *D. kohaticus* Davies, *D. cooki*? (Carter), *Dictyoconus* sp., *D. indicus*? Davies, *D. aegyptiensis*, *Discorbis* sp., *Halkyardia* sp., *H. minima* (Liebus), *Linderina* sp., *L. buranensis* Nuttall and Brighton, *L. brugesi*, *Lituola* sp., *Lituonella* sp., *Lockhartia tipperi* Davies, *Meandropsina* sp., miliolids, *Nummulites* spp., *N. beaumonti* d'Archiac and Haime, *N. discorbinus*? Schlotheim, *N. gizehensis* (Forskal), *N. lucasanus* d'Archiac, *N. ?subaticious* Douville, *Operculina* sp., *O. libyca* Schwager, *Opertorbitolites douvillei* Nuttall, *Orbitolites* spp., *O. complanatus* Lamarck, *Peneroplis spp.*, *P.* aff. *carinatus*, *P. damesini* Henson, *P. dusenburyi* Henson, *Praerhapidionina huberi* Henson, *Pyrgo* sp., *Rhapidionina* spp., *R. macfadyeni* ?Henson, *R. urensis* Henson, *R. urensis* Henson var. *minima* Henson, *Rhipidionina* sp., *R. williamsoni* Henson, *Rotalia* sp., *Sakesaria* sp., *Saudi* sp., *S. discoidea* Henson, *Siderina* sp., *Sismondia* sp., *Somalina* sp., *S. danieli* Henson, *Spirolina* sp., *S. huberi* Henson, *S. cylindracea* Lamarck, *Textularia*, *Valvulina* sp., and *V. kitchini* Henson.

The Dammam Formation is middle Eocene, according to Owen and Nasr (1958); however, absence of the upper Eocene has not been proved in Saudi Arabia (Sander, 1952; Steineke and others, 1958). Bellen (Bellen and others, 1959) maintained that the possibility of the base of the formation being late early Eocene cannot be excluded.

Contacts and equivalent units

The contact of the Damman Formation with the underlying Rus Formation is possibly a minor disconformity. There is slight indication of an unconformity between the Rus and the Dammam Formations in well sections, where a gray-green shale approximately 7 feet (2.5 m) thick occurs near or at the base of the Dammam (Bellen and others, 1959). No such unconformity is known to have been found in the field, but the lower part of the Huweimi (chalk) Beds contains white or pinkish chalks of fresh-water appearance (R. M. Ramsden and C. Andre, unpub. data, 1953). On the other hand, the upper part of the Huweimi (limestone) Beds is definitely representative of marine deposition.

Within these chalks of fresh-water appearance, however, are chalky limestones containing lamellibranchs. This disturbing fact has not been properly investigated in the field as yet. To date there is little reason to doubt the existence of a major facies change between lower and upper parts of the Huweimi Beds. In exposures in western Iraq, the Wagsa Beds of the Dammam Formation rest directly on the Umm er Radhuma Formation, presumably with unconformity.

The contact with the overlying Ghar Formation is unconformable. In the eastern sector of this area the Dammam Formation is overlain trangressively with great unconformity by the younger units: Euphrates, Zahra, Lower Fars, and Dibdibba Formations, and Recent alluvium. The Zahra and Euphrates Formations rest directly on the Dammam throughout an extensive sector in the northern part of the area.

The type locality of this formation is in Saudi Arabia at lat 26°17′03″ N., long 50°07′07″ E. The typical Dammam extends into Kuwait. North and northeastward from the study region the formation passes laterally into the basinal Jaddala Formation (as in wells Awasil No.5, Anah No.2, and Falluja No.1).

Economic aspects

Owen and Nasr (1958) stated that:

> due to its natural porosity, enhanced by leaching of fossils, the Dammam Formation is an excellent aquifer, and losses of circulation while drilling through this formation are a common occurrence. In Rumaila and Zubair fields, saline sulphurous waters are encountered. This is also the case in the Burgan-Magwa-Ahmadi area of southeastern Kuwait. However, westward from Burgan the quality of the water progressively improves and in the vicinity of Abdulla the Kuwait Oil Company has developed a supply of industrially usable water carrying some 3,700 ppm of total dissolved solids, some 1,400 ppm of calcium sulphate.

The Dammam limestones cover an extensive part of western Iraq, including most of Al Hajara physiographic belt. A considerable number of wells have been dug and drilled in the area. Many of these wells reach into the Dammam. Most of them are in surface depressions, or not far from the base of scarps, or in some wadi system. Macfadyen (1938) stated that:

> A comparison of altitude and depth of water, taking into account so far as possible the topography and geological structure, does not appear to show any definite relationship between the water wells. Chemical analyses show wide variations, though the general type of water is, with few exceptions, similar throughout the area in both shallow and deep wells and springs.
>
> It may be said with a measure of confidence that the evidence is sufficient to show that there is no true water table in the strong part of the southern desert, i.e., the Hajara, so that a well sited for convenience cannot be expected *a priori* to find water at any known depth. All ground-water supplies seem to be due to local accumulation of rainwater, and successful wells are those sited in or close to natural drainage lines, or in actual storage features, such as depressions with no outlet.
>
> The water supply is thus in very direct relation to the rainfall, and in deep wells the supply is due to percolation downwards by means of fissures or solution holes, and storage in such cavities or in some porous horizon at depth. Thus, wells are best located in close relation to favourable surface features.

Faulting and folding appear to be rare in this desert, so that generally little help is available from the geological structure of the rocks. The varying quality of the waters, where this is not due to concentration by evaporation, is due to contact with more or less soluble constituents in the strata on its way down from the surface. The strata vary from place to place, and so give rise to some marked quantitative differences in the analyses of the waters in question.

MIOCENE AND PLIOCENE

The Miocene and Pliocene are represented by five formations having a maximum aggregate thickness of more than 3,350 feet. The stratigraphic correlation of the units is rather tentative because of lack of adequate information. The correlation adopted is that generally accepted by geologists of the Iraq Petroleum Company.

ZAHRA FORMATION

The Zahra Formation type section is in the small anticline that lies northwest of the depression Faydat Az Zahra, which lies 4.3 miles (7 km) south of Al Busayyah-As Salman track and 40 miles (65 km) west of Al Busayyah.

The Zahra Formation is 328 feet (100 m) thick at the type locality; elsewhere, the thickness of the formation is extremely variable, and it has a widespread but sporadic occurrence. Between the type locality and As Samawah, the Zahra Formation occurs as isolated outliers on the Dammam Formation, predominantly occupying the old topographic depressions and former wadi floors. Typical outcrops are the Zahra outliers of Shaib Abu Al Hazair, 30 kilometers southwest of ‘Ayn Sā‘ī; Faydat Abu Sidaira and Shaib At Tayyar, 40 kilometers southwest of As Samawah; and Shaib Al Ash‘alī, 10 kilometers west of Ayn Hamud.

To the west of this main belt of outcrop, in many topographic depressions, are beds that closely resemble the Zahra Formation. Examples occur in the As Salman group of depressions, such as Lahab and As Salman itself, where characteristic limestones and marls appear. Another good example occurs at Ash Shabakah (Shabicha) where the marls and limestones, lying on eroded surfaces, are slightly folded. Extensive outliers can be found in Shaib Al Ghanimi between Al Burga and Ar Rimtha, on At Traq between Faydat Al Uba’id and Khashm and Dimana, and between Faydat Umm Jalib and Faydat Ar Rudhaima, Traq Al Galaib, and Ash Shawiyyat. The Zahra beds may occur at any altitude in relation to the present drainage system. In the two last-mentioned localities, the beds cap some of the highest points of the two structures there, in places attaining altitudes of 20 to 30 meters above the valley floor, whereas in Ash Shabakah depressions the top of the exposed Zahra beds is in places as much as 30 meters lower than the Eocene limestones. Northward from the type location, towards Galaib, the Zahra Formation thins considerably to only a few meters of white limestone. To the northeast, in the valley of the Shail Al Ghanimi, however, a thickness of more than 100 meters occurs in the normal facies of white limestones and red marls, indicating apparent eastward thickening. In the Zahra-Kabd (Chabd) area, eroded ridges of Dammam (Ghanimi and Chabd Beds) project through the Zahra beds which here commonly show false or exaggerated dips.

Along the southwestern Iraqi border, the Zahra Formation is extensive, commencing in the area of As Sadawiyat, 15 kilometers northwest of Nisab, and following the strip between Johka and Faydat al Batn and the border. In the region of Faydat Al Aghsas and Al Jumaima numerous inliers of Umm er Radhuma (Basita Beds) occur within the Zahra beds. The Zahr Formation extends into Saudi Arabia, near Birkat Al Amya, and reenters Iraq about 12 kilometers east of Al Lifiyah, where it continues northwestward rather irregularly. Farther north, it occupies the wadi floors of the Shaib Hisb, of Ghar as Saigal, and of Wadi al Khirr toward Al Lasaf; west of this line, and in the general area, it occurs as irregular patches, especially in the vicinity of Al Ashuriyah, Al Jamiliyah, and Bir Samit.

The Al Makim-Al Barrit-Al Lasaf region is extensively covered by Zahra beds containing numerous large inliers of Umm er Radhuma beds. The formation forms most of the gravel plain between Wadi al Ghadaf, Wadi al Ubayyiḍ, and Wadi Tibal. It also covers part of the area west of Tar al Bahr. Westerly extensions of the formation occur in the Wadi ‘Ar‘ar, Wadi Hamir in the vicinity of Al Artawiya-Makhot, Shaib Ubaydat, east of Al Ubaydat, Shaib ash Shaykh, Wadi al Ubayyid, and Nukhaib; the formation extends farther north, where it covers the Habbariyah area.

Detailed lithologic description

The Zahra beds consist of gray, white, and red porcelaneous hard locally sandy limestones, which contain occasional *Chara*, fresh-water molluscs, and ostracodes and are interbedded with red sandy marl. Oblong cavities filled with a red sandy material are common in the limestones, especially in the west margin between Shaib Hisb and Wadi Al Khirr, and have been explained as being fossil cavities of roots of old reeds. According to T. F. Williamson and D. C. Roger (unpub. data, 1939), the formation as a whole becomes markedly thicker southward, until in the extreme south, near the Neutral Zone, it becomes a complete succession of grits and marls containing only a few thin fresh-water limestones. However, H. Huber (unpub.

data, 1944), is in favor of including the sands and grits in the locality near the Neutral Zone in the Dibdibba Formation.

The succession may consist of strata of white and reddish-brown marls, sandy marls, sands, irregular pinkish-white chalky concretional limestones, and conglomeratic or brecciated river deposits such as those at Saigal and As Salman.

In the Wadi Tibal and Wadi Al Ubayyid area the formation consists mostly of fresh-water limestones and coarse conglomeratic river deposits composed of recrystallized limestones of the Umm er Radhuma and Tayarat Formations.

Diagnostic fossils and age

Fossils in the Zahra Formation are rather rare; they occur mostly in the limestones and include *Chara* sp., *Melanoides tuberculata* Mueller, *Lymnaea*, *Planorbis* sp., *Vivipara*, and ostracodes. Some of the limestones show tubular holes probably made by reed stalks.

The age of this formation is still an open question, but opinion favors a Miocene (Fars) age. According to R. M. Ramsden and C. Andre (unpub. data, 1953), the formation overlies marls containing *Ostrea latimarginata* Vredenburg in the Shaib Hisb area; however, it could also be equivalent to the Euphrates Limestone, and thus be of early Miocene age.

Contacts and equivalent units in adjacent areas

The Zahra Formation may rest on any of the older units; the base of the type section is obscured by debris and cannot be seen, but a few kilometers to the southwest the white limestone beds rest on the brown Dammam limestones.

In the As Salman area, H. Huber (unpub. data, 1944) found, at the base of the Zahra, a coarse-grained red sandstone, 13 meters thick, succeeded by well-bedded limestones containing sporadic marly intercalations. These bedded limestones contain numerous *Planorbis* sp., *Lymnaea* sp., *Ostracoda*, and *Chara*, but locally they may vary to gray cavernous limestones composed entirely of stalks and seeds of *Chara*. At Ukhaidir and in the Shaib Hisb the bedded limestones overly marls containing *Ostrea latimarginata* Vredenburg (indicative of Lower Fars), and near Takayyid (Tuqaiyid) the Zahra Formation rests on a pebble bed which has been taken to represent the Ghar Formation. Along the southwest border of Iraq the Zahra rests unconformably on beds of either Umm er Radhuma or Dammam Formation. The Zahra Formation unconformably underlies Recent gravels and sand in the Rudhuma-Chabd area. It may be partly equivalent to the Hofuf Formation of Saudi Arabia and may also be equated with the Euphrates and Ghar Formations of southwestern Iraq.

EUPHRATES LIMESTONE FORMATION

Type and reference sections

The type section of the Euphrates Limestone Formation is near Wadi Fuhaimi at lat 34°15′58″ N., long 42°08′09″ E., outside the study region. In southwestern Iraq, however, C. Andre and P. J. Walmsley (unpub. data, 1952) referred to good exposures in Shaib Hish, 30 kilometers southwest of An Najaf; Wadi Al Muhari, southwest of As Shinafiyah and Sha‘ib Firk (Firch); and Sha‘īb Abū Marīs, southwest of As Samawah. In the Al Busayyah area, a section just north of the Abu Ghar police post was described by T. F. Williamson and D. C. Rogers (unpub. data, 1939).

Thickness and extent

In the type section, which is outside of the study region, the thickness of the Euphrates Limestone Formation is only 26 feet (8 m). The Euphrates crops out over a wide area west of the Euphrates River where it overlies the older rocks transgressively, thus forming the eastern part of the western desert of Iraq, west of Karbala. The outcrop may exceed 100 kilometers in width. The Euphrates has a thickness of 15 meters in Wadi Al Ubayyid, less than 30 kilometers west of Qasr al Ukhaidhir; slightly south of Khan ar Runbah, it attains a 20-meter thickness. In this general area the width of outcrop decreases to about 50 kilometers, except for the few westerly isolated, scattered outliers. In the Kifl well No.1 the Euphrates-Jeribe Limestone Formation is 143 feet thick. These outcrops extend as far south as As Samawah, where they apparently disappear under the younger rocks; however, the Euphrates reappears farther south in the area of Makhfar (Shurtat) al Qusayr, from where it extends southwestward, swinging southward from the vicinity of Qal‘at Abū Ghār, to an area south of Qulban Layyah, where the outcrop width may be as much as 50 kilometers. H. Huber (unpub. data, 1944) estimated a thickness of 30 to 35 meters for the Euphrates in the vicinity of Qal‘at Abū Ghār.

Detailed lithologic description

In the type section the Euphrates Limestone Formation consists mainly of shelly, chalky well-bedded recrystallized limestones. West of Karbala the Euphrates consists chiefly of pseudo-oolitic generally soft marl-limestones, with chalky aspects and a few recrystallized bands.

In As Samawah and Makhfar Shurtat al Qusayr areas, the Euphrates consists of white limestones (some with pinkish tints) and marly, sandy limestones, having a few siliceous intercalations and thick beds of loosely consolidated rounded sand, indicating the gradual influence of the Ghār clastics. Farther south this influence is strongly manifested in the section at a small hill just north of the Qal'at Abū Ghār police post, where the following section was described by T. F. Williamson and D. C. Rogers (unpub. data, 1939):

	Thickness (meters)
6. White, sandy, marly, fossiliferous limestone, with abundant lamellibranchs, *Clausinella* sp	½
5. White calcareous grit	1
4. White calcareous marl grading into above	4
3. Pale greenish-white sand	4
2. White, sandy calcareous marls, slightly and locally ironstained	3
1. White marly limestone	½

South of Al Busayyah the Euphrates perhaps passes completely into the clastic Ghar Formation.

Diagnostic fossils and age

At the type section of the Euphrates Limestone Formation the following fossils were recognized: *Dendritina* sp., *Rotalia beccarii* Linn, miliolids, gastropods, lamellibranchs, and a rare Bryozoa, *Cellepora* sp. (Bellen and others, 1959).

In this area the fossils are rare and poorly preserved, they include a fauna of lamellibranchs—including *Clausinella* sp. and *Ostrea latimarginata* Vredenburg—and also gastropods and the foraminifer *Peneroplis farsensis*. The formation is early Miocene, according to Bellen (Bellen and others, 1959).

Contacts and equivalent units

In the type section the Euphrates Limestone Formation overlies the Oligocene Anah Limestone unconformably; however, in the southwestern desert this formation, being transgressive, overlaps older formations. The base of the Euphrates southwest of Karbala is a marked *Clausinella*-lumachelle horizon. In some places, the base is slightly conglomeratic, sandy, and commonly current bedded, as in the Sha'īb Abū Marīs, or marly and chalky as at Shaib Hisb. The Euphrates rests unconformably on the Ghanimi to Shawiya beds northwest of Shaib Hisb, whereas to the southeast they may lie on the Ghanimi and Barbuk beds.

According to Bellen (Bellen and others, 1959), the Euphrates in the type area is covered by Jeribe Limestone Formation. In the western desert however, according to C. Andre and P. J. Walmsley (unpub. data, 1952), the Euphrates underlies the Lower Fars Formation and passes upward and laterally grades into it. The Lower Fars Formation west of the Karbula-An Najaf area is marked by a line of sabkha deposits along the west bank of the Euphrates River. It may be directly overlain by the Dibdibba Formation, as in the area of Qulban Layyab.

The Euphrates Limestone Formation is equated with the Ghar Formation, which is considered to be the clastic facies of the Euphrates, and with the Serikagni Formation, which is considered to be the basinal facies of the Euphrates. The Zahra Formation may well be the fresh-water facies of the Euphrates. These relationships are rather complex and require verification by additional investigations.

Economic aspects

Water supplies.—Macfadyen (1938) pointed out the presence of a narrow and sharply defined zone of springs of economic importance along the east border of the southern desert. They lie mainly between the Euphrates and the overlying Lower Fars Formation and other younger formations, including the Recent alluvium. These springs include Ayn Ubaira, Ar Rahhālīya group (lat 32°46′ N., long 43°23′ E.; alt 90 m above sea level), Ayn Fashash, Ayn al Bakhaiti, Ayn Zanga, Ayn Umm Shilla, Ayn Faidhia, Ayn Soda, Ayn ed Din (lat 32°41′ N., long 43°23′ E.), Ayn Umm al Khers (lat 32°37′ N., long 43°26′ E.), Shithatha group (lat 32°34′ N., long 43°29′ E.), Ayn Erbid, Ayn al Hamra, Ayn Abeid, Ayn Barkat, Khan ar Rahbah (lat 31°44′ N., long 44°19′ E.), Ayn Hassan, Ayn al Gayiani, and Ayn Seyid (lat 31°00′ N., long 45°27′ E.).

According to Macfadyen (1938),

> The total of water from these springs is not less than 150 cusecs (425 centicumecs), and this appears to be a permanent and invariable supply. It is very unequally distributed, over 100 cusecs (283 centicumecs) being yielded by the Shithatha group alone, while other of the springs are very small.
>
> The quality of the water varies slightly from spring to spring, but the analyses form a homogeneous group of saline water, characterized by moderately high magnesium, moderate calcium sulphate, high sodium chloride, and low carbonates. It is interesting to observe the approach of the Euphrates water towards this composition at the top water season in September. The springs often contain a little sulphurated hydrogen. The water is therefore not of the best quality, but it is drinkable and it is used extensively for irrigation of date and other fruit gardens. The temperature of water varies from 24° to 27°C, most springs being about 26°C.

These springs are replenished from rainfall in the southern desert that drains underground toward the Euphrates River, down both dip and slope; water of the Euphrates basin that makes its way southward along the strike of porous strata in the Euphrates limestone or lower fars beds; and, to a much lesser degree, by rainfall in the northeastern Iraqi mountains that makes its way beneath the Mesopotamian plain in the Euphrates Formation. (For further details see Macfadyen, 1938.)

Hydrocarbons.—Because the Euphrates Limestone Formation is extensively exposed in the area, the chance of finding accumulations of hydrocarbons in it is rather remote, though oil and gas in good quantities have been found in it elsewhere, as in the Jambur and Bai Hassan oil fields of northern Iraq.

GHAR FORMATION

Type section, thickness, and extent

The type locality of the Ghar Formation is in BPC well Zubair No. 3, (lat 30°23′01″ N., long 47°43′29″ E., alt 51.9 ft; completed Feb. 21, 1951). The formation occurs between drilled depths of 1,513 and 1,935 feet. It is 422 feet (129 m) thick. This formation has been recognized in the Basrah Petroleum Company oil fields of Zubair and Rumaila, in Nahr Umr wells, and in the BPC wells Tuba No.1, Rachi No.1, Ratawi No1, and Luhais No.1. In southern Iraq its thickness ranges between 300 and 500 feet; it shows thinning and change of facies eastward, northward, and westward by gradual passage to marly or silty sandstone. At Kifl well No.1 this interval is represented by the Jeribe limestone, whereas in the outcrop area it is possible that the Ghar sandstones pass into the Lower Fars marls and limestones and into the Euphrates limestones, which cover a considerable territory.

According to Owen and Nasr (1958), "the thickness of the Ghar Formation increases in a southwesterly direction towards what is believed to be the source area. Representative thicknesses in the southern Iraq fields are Nahr Umr No.1, 350 feet; Zubair No.3, 422 feet; and Rumaila No.7, 544 feet."

Detailed lithologic description

The Ghar Formation consists of: coarse sand, containing pink, black, and colorless gravel pebbles and locally having a calcareous cement; sandy limestone; marl; and streaks of gypseous blue clayey shale. In the outcrop area the entire Ghar formation seems to pass laterally into the Euphrates Limestone Formation, or it could be included with the Dibdibba Formation, in the absence of the intervening Lower Fars Formation, because of their close lithologic familiarities.

In this last respect Owen and Nasr (1958) stated, "that the division of the Kuwait Group into Dibdibba, Lower Fars, and Ghar Formations depends essentially on the presence of the Lower Fars beds, and where these are absent or only questionably developed, it has been found practically impossible to separate accurately the two clastic formations of the Dibdibba and Ghar. When this occurs, reference can usually be made only to the Kuwait Group."

The age of this formation is unknown, for fossils are absent, but it is considered to be early Miocene, though Owen and Nasr (1958) assigned to it an Oligocene and early Miocene age.

Contacts and equivalent units

The contact of the Ghar Formation with the underlying Dammam Formation is unconformable and is marked by the absence of proved Oligocene strata. The contact with the overlying Lower Fars Formation is gradational, without evidence of unconformity; in the absence of the intervening Lower Fars Formation, the Dibdibba Formation may overlie the Ghar Formation unconformably?, but it has been very difficult to recognize or separate them with great accuracy.

From stratigraphic considerations, the Ghar Formation seems to be equatable with the Hadruth Formation of Saudi Arabia.

Economic aspects

Regarding the geologic occurrence of oil and gas in Iraq, the staff of the Iraq Petroleum Company (unpub. data, 1958) stated that very viscous sulfurous heavy oil (20° API) occurs in the lower limestone beds of the Lower Fars Formation, the upper Sands of the underlying Ghar Formation, and at Nahr Umr. This oil is locally called "First Pay."

LOWER FARS FORMATION

The heterogeneous Lower Fars Formation is the basal (evaporitic) division of Pilgrim's (1908) tripartite "Fars Series," according to Owen and Nasr (1958). The name Lower Fars was first published by Busk and Mayo (1918). In Iraq, equivalents of the Lower and Middle Fars were called the Hamrin Stage by Pascoe (1922), but the Middle Fars is so poorly developed outside Iran that it has long been included as an Upper Fars division, the term "Lower Fars" being arbitrarily used for the evaporitic Miocene below the highest bedded anhydrite.

Reference section, thickness, and extent

BPC well Nahr Umr No.1 (lat 30°45′ N., long 47°40′ E.; alt 21.5 ft) was completed Feb. 10, 1949; the Lower Fars Formation lies between drilled depths of 1,090 and 2,093 feet (1,003 ft thick). This formation has been found in the subsurface sections of the Basrah oil fields at Nahr Umr, Zubair, and Rumaila and at wells Tuba No.1, Ratawi No.1, Rachi No.1, and Luhais No.1. According to Owen and Nasr (1958) it ranges in thickness from 1,003 feet at Nahr Umr to 600 feet at Zubair and 300 feet at Rumaila. However, the thickness shows great local variations; for example, westward the thickness of Lower Fars at Luhais well No.1 is about 390 feet, and a similar thickness was found at Kifl well No.1, north of the area of present discussion. To the south in Kuwait the Lower Fars, according to Owen and Nasr (1958), is readily recognizable in the Kuwait Oil Company's well Raudhatain No.1 between drilled depths of 345 and 704 feet. Farther east in Kuwait, in the Jal-es-Zor escarpment along the north side of Kuwait Bay, is a 125-foot unit of Lower Fars equivalent. In the western desert this formation crops out in the area of Qasr Shaqrah, Dafina, Qasr Naba, Qasr Abu Ghar, Al Busayyah, Al Buwaib, and Khashmat ibn Hallaf. Isolated outliers of the Lower Fars lying above the Euphrates occur at Sha'īb Abū Marīs, 30–35 kilometers west and southwest of As Samawah. Farther north, outliers of Lower Fars Formation are found at Al Muhair and Quwairat al Habbusa, southwest of As Shinafiyah, and at Khan ar Rahbah and Qarat as Saba. Extensive outcrops spread west of An Najaf in the area around Az Zigla and Gur al Hibari.

In the Gur al Hibari area the Lower Fars Formation has been subdivided into two units; the lower is yellow limestone with some white chalk bands and green and red marls, and the upper is selenite. The lower unit is considered to be much more persistent. In the Qasr al Ukhaidir area the thickness of the lower unit does not exceed 130 feet, and the width of continuous outcrop is not great, but outlying hills of it occur almost as far west as the Nukhaib police post, some 130 kilometers west of where the formation disappears under the overlying sandstones and marls. As for the upper unit, T. F. Williamson and D. C. Rogers (unpub. data, 1939), after a study of the north-trending cliff which passes east of the Bahr al Milh, maintained that the sequence is a lateral variant of the basal small section of the Upper Fars Formation; this is clearly exhibited at the Nuqtah Cliff section on the track between Shithatha and Karbala where the basal beds of the Upper Fars Formation contain much crystalline selenite. Northward these beds show such an increase of gypsum that 15 kilometers northwest of the Tazaza village, distinct white beds of selenite can be distinguished. These attain thicknesses of as much as 5 feet (1½ m) and stand out as hard bands among marls and a sandstone sequence. South of the Shithatha-Karbala track only the lower unit is recognizable. It forms numerous outliers in the area of Wadi al Ubayyid. Even along the base of the scarp toward An Najaf there is comparatively little continuous outcrop. Here the formation dips gently to the northeast, with the result that only a few isolated outliers of limestones and green marls can be seen resting on the Euphrates Limestone Formation. These are present in the low ground from near the Euphrates river to As Samawah, beyond which there are practically no further occurrences until the group emerges again from the sabkhas near Makhfar al Qusayr. From here southward the Lower Fars appears to be insignificant, and its name has, for the sake of uniformity, been applied to the rather marly fossiliferous beds above the Euphrates and below the more definitely sandy beds of the Upper Fars and Dibdibba Formations. In places the Lower Fars is very thin. It consists mainly of greenish marls with abundant selenite crystals, and sporadic "oyster beds" occur containing very numerous *Ostrea latimarginata* Vredenburg, pectens, and *Clausinella* sp. One good example of these "oyster beds" can be seen just west of the track from Al Busayyah to An Nasiriyah at a point about 10 kilometers north of Qasr Naba. At Al Busayyah, Laiyah, and farther south, the grits and marls rest directly on the Euphrates Limestone Formation.

Detailed lithologic description

The Lower Fars Formation is an evaporitic sequence; it comprises the lithologic units given below:

	Thickness (feet)
4. Mudstone, gray and red, with subordinate streaks of nodular gypsum; some red-blue marl and loamy grit.	258
3. Limestone, buff, sandy, porous, shelly, fossiliferous (Clausinellid), in part oolitic or cherty and porcelaneous, alternating with gray clayey mudstones, shales, marls, and rare streaks of selenite	321
2. Selenite beds alternating with gray-blue mudstones and brown-blue marls	249
1. Limestone, pinkish-white, sandy, in part oolitic or very shelly, recrystallized with rare streaks of blue mudstone especially toward base	175

To the south, in Kuwait, the Lower Fars consists mainly of anhydrites, gypsum, clays, marls, and shallow-water limestones containing *Ostrea latimarginata*, *Clausinella* sp., and *Quinqueloculina* sp. Farther south into Kuwait, in the Val-es-Zor escarpment along the north side of Kuwait Bay, there is a 125-foot unit of fine-grained sand, silt, and clay carrying *Ostrea latimarginata*, *O. vestita*, lamellibranchs, and other fossil forms. This unit is locally called the Zor Formation.

According to T. F. Williamson and D. C. Rogers (unpub. data, 1939), the thickness of the Lower Fars Formation in this southwestern region is insignificant in comparison with that attained in the Iranian and north Iraqi foothills.

Westward from the Euphrates River, the Lower Fars Formation becomes generally and gradually less evaporitic and passes into clastic sedimentary rocks laterally and vertically.

Diagnostic fossils and age

The fossils of the Lower Fars Formation include *Ostrea latimarginata* Vredenburg, *Clausinella* sp., pectens, gastropods, *Quinqueloculina* sp. and other miliolids, ostracodes, and other forms. Owens and Nasr (1958) considered the age of this formation to range from early to middle Miocene.

Contacts and equivalent units

The underlying contact of the Lower Fars Formation with the Ghar Formation is conformable and gradational in the Basrah area; in the Karbala, An Najaf, and As Samawah areas the Lower Fars Formation overlies the Euphrates Limestone Formation conformably.

The contact with the overlying Dibdibba Formation is gradational (Owen and Nasr 1958). Northward, the Upper Fars replaces the Dibdibba Formation gradually. Here the Lower Fars Formation is considered as being equivalent to the Dam Formation in Saudi Arabia and the Zor Formation in Kuwait.

Economic aspects

In the Basrah area the basal limestones of the Lower Fars Formation and the upper sandstones of the Ghar Formation generally contain very viscous sulfurous heavy oil (20° API). The two zones constitute what is called the "First Pay." The Lower Fars anhydrites and shale can act as caprock under favorable circumstances for the accumulation of oil.

DIBDIBBA FORMATION

Reference section, thickness, and extent

Macfadyen (1938) mentioned Birjisiya (lat 30°22′ N., long 47°38′ E.) as the type locality for the Dibdibba Formation. Since his account, however, the thickness of the material exposed in the hand-dug water well at Birjisiya has been far exceeded in nearby Zubair, where numerous wells of the Basrah Petroleum Company have penetrated deeper than 1,000 feet (305 m). Owens and Nasr (1958) did not specify a type locality but merely mentioned the presence of the Dibdibba Formation at the surface and in all drilled wells on the Dibdibba plain. In the BPC well Zubair No. 3 this formation lies between the ground surface and a drilled depth of 935 feet.

It is as much as 1,160 feet (354 m) thick in the northernmost wells of the Zubair oil field. The formation has extensive distribution in southern Iraq, for it covers the area between the Shatt al Arab River in the east and Haur al Hammar and the Euphrates River in the north. Westward, the outcrop trends from Tall al Muqaiyir Dafina, Qasr Shaqrah, to Al Amghar, where it extends farther west to Jan Khirsan, Al Buwaib, Adam, Abu Radham, Tukayyid, and the Neutral Zone. Southward, it extends into Kuwait and Saudi Arabia. The region covered by this formation is known as Ad Dibdibba.

This formation shows gradual decrease in thickness westward. In the Rumaila field it decreases to some 500 feet; farther west, to about 160 feet in the vicinity of Luhais well No.1. Northeast of Abu Ghar, a thickness of 196.8 feet (60 m) has been noted. Still farther west the formation disappears completely. According to Dunnington (1958), "thinning takes place also towards the south where over 700 feet (243 metres) occur in the southern wells of the Zubair oil field." Northward and eastward this formation disappears under the Recent alluvium.

Northward, the Dibdibba Formation passes into the Upper Fars Formation which crops out as a scarp between Ur Junction and Al Shararain. Here the Upper Fars consists of about 8 meters of sandy marl containing selenite, which dips gently to the northeast. These marls are practically surrounded by sabkha. Farther northwest, in the sandhills south of As Samawah, the few Upper Fars sandstone inliers outcrop from the sabkha. To the southeast of An Najaf, very little is seen of this formation, as the Lower Fars Formation extends under the recent deposits of the Euphrates River valley. A thickness of at least 154 feet (50 m) for this formation was measured by T. F. Williamson and D. C. Rogers (unpub. data 1939) in the scarp east of Ukhaidhir. Farther north, this formation forms the prominent scarp, which overlooks the Bahr al Milh and Abu Dibs from the east, and extends eastward toward the Euphrates. The cliff extends south-southwest and then turns sharply to the east to An Najaf. The base of the formation follows roughly the line of the foot of the cliff. In this area it comprises a series of brown, red, yellow, and green marls containing some sandstone bands and, at the base, some disseminated selenite crystals.

Detailed lithologic description

The composition of the Dibdibba Formation is, "mainly sand and gravel of igneous rocks, including pink granite, various liver-coloured and slate-grey intrusives, dolerites, etc., and white quartz pebbles. Not infrequently the rock is cemented to a hard grit." (Macfadyen, 1938).

Similar lithological sequence occurs in the subsurface sections of the Zubair field where the Dibdibba

Formation consists chiefly of coarse sands grading into gravel with subordinate arenaceous limestone beds and gypsum streaks.

In the northern part of the Dibdibba area, in a low ridge southwest of Un Junction, coarse- and medium-grained Upper Fars sandstones grade southward into the pebbly Dibdibba Formation.

Between the Tukayyid scarp, Jalib Al Amghar, and the north tip of the Neutral Zone, a great thickness of pebbly sandstones, grits, and fresh-water limestones occurs. H. Huber (unpub. data, 1940) included in the Dibdibba Formation the loose sands and loosely cemented sandstones that occur in the depression between the Tukayyid (At Traq) scarp and the Neutral Zone and the Eocene beds in the west. In these sandstones Huber observed some pebbly beds. In several places along the Tukayyid scarp from Khashmat al Masasah to Jalib al Amghar, as well as along the north boundary of the Neutral Zone, the Dibdibba sandstones and grits contain intercalations of fresh-water limestones. Some of the limestones, especially to the west of the Tukayyid well, are dark greenish brown and contain coarse rounded sand. The limestones are well bedded (+0.20 m) and very hard and contain *Chara* sp., *Planorbis* sp., and *Radix*.

Several small hills in the vicinity of the Tukayyid well are composed of a bedded, at places sandy, dense gray and white limestone; at many places it shows reddish tints and contains remains of *Chara*. Some dark gray thick-bedded hard limestones containing *Chara* also occur. Between this well and Al Karatha, similar *Chara*, bearing limestones are interbedded with sandstones and grits on top of the scarp along the track leading to Jalib Al Amghar and to Maghaizil and along the northwest border of the Neutral Zone. Some conglomerates occur in the vicinity of Ad Dayir.

R. M. Ramsden and C. Andre (unpub. data, 1953) stated that the exposed part of this formation can be divided in ascending order, into two recognizable units: Chilawa Sandstone and Rafaiya Gravel.

Chilawa Sandstone.—The Chilawa Sandstone consists of bedded unfossiliferous sandstones and grits. A type section at Chilawa near triangulation point 130 m (coordinates 1.672,401.44 E.; 88.7,596.94 N.) exposes approximately 180.4 feet (55 m) of gritty white, pink, and green sandstone. The white sandstones have a calcareous cement and form terraces and erosional plains. The pink sandstones are softer than the white and probably contain some calcium sulfate and grains of sulfur. The green sandstones are generally uncemented and slightly marly. Small brown quartz pebbles are scattered throughout the section. This unit forms the upper part of the Al Busayyah-Qasr Shawrah scarp and passes eastward across the Dhafir plains to the Boliya axis. The exposures can be seen in the scarps at Twai al Hashash, Khabra or Rachi, and Jarishan to the south. The unit can also be found dispersed along and adjacent to the Al Basrah-Jalibra track, north and south of Hawr al Hammar, where it forms the main exposed part of the Dibdibba Formation.

Rafaiya Gravel.—The Rafaiya Gravel is thick in the area between the Boliya axis and the west flank of the Zubair anticline, where it forms a layer of well-rounded exotic pebbles. These pebbles are composed of igneous, metamorphic, sedimentary, and conglomeratic rocks, the character and source of which have not yet been investigated in detail. Individual cobbles may be as large as 15 centimeters in diameter. The lateral and vertical limits of this unit are difficult to define in the east. To the west the gravel is not found west of the Boliya axis, perhaps in part because of erosion. At Boliya it forms a single layer of pebbles overlying gypseous and sandy earth which is a few feet thick. At Rafaiya (grid coordinates 1732 E., 932 N.) the type section of the unit, moderately coarse gravel lies at the surface; the pebble layers can also be found in the walls of the large waterhole. In the south, extensive tracts of coarse gravel, mainly quartz, are found in the Adan region. The true correlation of these still remains to be decided.

Diagnostic fossils and age

Ostracodes, *Chara* sp., *Planorbis* sp., and *Radix* are found in the Dibdibba Formation in isolated surface limestones in places west of Basrah, and according to Hudson and others (1957) their age is not known. Dunnington, Wetzel, and Morton (in Bellen and others, 1959) stated, "This formation probably ranges from "late" Miocene through Pliocene to early Pleistocene, but no fossil evidence has been produced to support or add precision to this range." On the age of Dibdibba Formation Hudson and others (1957) wrote, "Direct evidence of age is not available; comparison with other areas in the Middle East suggests that the Dibdibba Formation is late Miocene or Miocene and Pliocene."

Contacts and equivalent units

The contact of the Dibdibba Formation with the underlying Lower Fars Formation is conformable and gradational. The Upper Fars Formation has not been recognized in the subsurface sections of southern Iraq, where equivalents are probably included within the lower parts of the Dibdibba Formation. Wherever the Lower Fars Formation shows a change of facies into a clastic type, the differentiation of it from either the overlying Dibdibba Formation or the underlying Ghar Formation is very difficult. In the western outcrops, according to T. F. Williamson and D. C. Rogers (unpub. data, 1939), the Dibdibba Formation overlies the Euphrates Limestone Formation and the Lower Fars Formation. In the extreme southwest where the Dibdibba cannot readily be distinguished from the clastic variant of Lower Fars, if present, or from Ghar Formation, it rests unconformably with great overlap on the Dammam Formation.

The Hammar Formation and Quaternary gravels and alluvium overlie the Dibdibba; the contact is unconformable. Hudson and others (1957) stated:

> The solid rock underlying the Mesopotamian plain and outcropping west of Har Al Hammar is that of the Dibdibba Formation (Macfadyen, 1938, p. 103; Mitchell, 1956, p. 400). This succession is of sand and pebble beds, often cross-bedded, occasionally calcareous or gypsiferous and cemented, and with some silt and clay. To the west of Zubair the Dibdibba beds are capped by pebbles and boulder beds of igneous, metamorphic, or sedimentary rocks, * * * [and] above these older rocks there is a surprisingly small thickness, rarely exceeding 100 feet, of unconsolidated Recent sediments, in which the succession seems to be fairly constant, being one of marine beds, followed by alluvium, variously estuarine, lacustrine, or fluviatile. The marine beds are here called the Hammar Formation.

In southern Iraq the Dibdibba Formation is considered to grade eastward and northward into Upper Fars Formation and the Bakhtiari Group beneath the Mesopotamian Alluvia and to crop out in central, eastern, and northern Iraq as distinctly recognizable units. The equivalent of this formation in Saudi Arabia may be found as gravel and sandstone in the Hofuf Formation.

Economic aspects

The Dibdibba Formation comprises gravels and coarse-grained sandstones which can make a good aquifer. In the Dibdibba region of southern Iraq the water supply is chiefly dependent on the rainfall; owing to the high porosity of the Dibdibba sandstone and sands, much of the water may sink into the ground and be stored or may drain into local surface depressions in which some water gradually percolates into the ground and some evaporates. The underground drainage is toward the Euphrates and Shatt al Arab Rivers, down both dip and topographic slope. The movement of the ground water in the Dibdibba region will certainly be affected and influenced by the general ground water of the Mesopotamian basin. (See Macfadyen, 1938.) Water in great quantities can be found stored in this formation, but its quality may be highly variable.

The gravelly components of the formation locally are manually collected and sold for concrete aggregates and for surfacing the roads.

QUATERNARY

The Quaternary is represented by Pleistocene and Recent (Holocene) sediments, which may not exceed 300 feet in thickness. The marine Hammar Formation only has been described below. The top of the Recent sediments in the area is constantly acted upon by factors of current denudation or deposition.

HAMMAR FORMATION

TYPE SECTION, THICKNESS, AND EXTENT

The type section of the Hammar Formation is in BPC well Zubair No. 31 (lat 30°31′00″ N., long 47°36′34″ E.; alt 20.3 ft, completed Oct. 24, 1953) between 20 and 41 feet of drilled depth. The formation is 21 feet thick. This Recent marine formation occurs in the subsurface sections on the southern limits of Hawr al Hammar in the northern sector of the Zubair oil field, where the type section is located.

Eastward across the Shatt al Arab, north of Bandar Shapur, Thomas (in Lees and Falcon, 1952) reported a succession of marine shelly silts overlain by fresh- or brackish-water silts containing ostracodes. The brackish-water silts total at least 20 feet in thickness, and the lower marine silts are possibly 60 feet thick. On the northeast side of Hawr Al Hammar, this formation was found in the Nahr Umr wells, close to the Shatt al Arab, where it consists of 32 feet of shell marl containing lamellibranchs, gastropods, bryozoans, and other forms in a fauna almost identical with that of the Hammar Formation in the type section. According to Hudson and others (1957), this formation extends as far south as Al Faw (Fao), in the extreme south of Iraq, where a number of water wells were drilled in soft silts to a depth of 30 feet. They stated that "the general succession was one of a lower marine silt with abundant shells and an upper silt with ostracodes and occasional crab debris, probably estuarine. There was a slight difference between the succession in the various wells, the greatest thickness of the estuarine silt being 20 feet (well No.3) and that of the marine silts being 30 feet (well No.2)." The fauna of the marine silts is that of the Hammar Formation.

The only evidence of the northward extension of this formation, according to Hudson and others (1957), is that of W. A. Macfadyen (in Lees and Falcon, 1952) who reported 35 feet of alluvium with marine Foraminifera at Al Amarah, 95 miles north-northwest of Al Basrah. Mitchell (1958) discovered a Recent marine fauna near An Najaf at altitudes of 40.7 to 41.3 meters above present sea level.

DETAILED LITHOLOGIC DESCRIPTION

In the type section the Hammar Formation consists of two main units:

	Thickness (feet)
2. Clay, gray, with thin washes of shells consisting predominantly of *Abra cadabra*; local crab debris; the lowest foot consists of shell marl containing an abundant and varied fauna, including abundant echinoid debris	7
1. Sand, coarse and very coarse, poorly graded, rarely cemented, and some silt; some of the sand is windblown; abundant small shells of marine organisms concentrated in thin bands and washes	14

DIAGNOSTIC FOSSILS AND AGE

The Hammar Formation is of Recent age. Its fauna was described fully by Hudson and others (1957), who stated that:

The common fossils, in order, are: Lamellibranchs—*Pitar belcheri, Brachidontes variabilis, Corbula sulculosa, Abra cadabra*; Gastropods—*Minolia adyma, Hinia idyllia*. The forms identified are listed below."

Gastropoda *Anachis* (*Zafra*) *melatoma* (Melvill and Standen), *Calyptraea chinensis* (Linne), *Cerithium amirantium* E. A. Smith, *Chrysallida callista* (Melvill) *Chrysallida irenae* Eames and Wilkins, *Crassispira* (*Clathrodrillia*) *lucida* (G. and H. Nevill), *Cuma carinifera* (Lamarck), *Cyclostrema supremum* Melvill, *Fossarus stoliczkanus* Nevill, *Gemmula multiseriata* (E. A. Smith), *Gibberula* (*Cystiscus*) *mazagonica* (Melvill), *Hamarilla bicarinata* Eames and Wilkins, *Hinia idyllia* (Melvill and Standen), *Lienardia soror* (E. A. Smith), *Mangelia pellyi* (E. A. Smith), *Meioceras* sp. *Melanella* (*Polygireulima*) *bivittata* (H. and A. Adams), *Minolia edyma* Melvill, *Mitrella blanda* (G. B. Sowerby), *Natica* (*Cochlis*) *tranquilla* Melvill and Standen, *Obtortio* (*Alabina*) (*Fenella*) *purpureoapicata* (Preston), *Odostomia eutropia* Melvill, *Pyrunculus abbreviatus* Eames and Wilkins, *Retusa inconspicua* (A. Adams), *Retusa*?, *Siphonium* cf. *maximum* (G. B. Sowerby), *Stenothyra minima* (G. B. Sowerby), *Strioterebrum* (*Noditerebra*) *edgari* (Melvill), *Triphora acuta* (Kiener), *Turbonilla* (*Chemnitzia*) *galactodes* Melvill, *Turritella terebra* Lamarck.

Lamellibranchia: *Abra cadabra* Eames and Wilkins, *Abra Telline, Barbatia fusca* (Bruguiere), *Brachidontes variabilis* (Krauss), *Corbula sulculosa* A. Adams, *Cuna coxi* Eames and Wilkins, *Leionucula layardi* (A. Adams), *Mactra olorina* Philippi, "*Ostrea*", *Pholas manillensis* Philippi, *Pitar belcheri* (G. B. Sowerby), *Placuna, Tellina* (*Psammotaea*) *methoria* Melvill, *Tellina, Yoldia tropica* Melvill.

Scaphopoda: *Dentalium quadriapicale* G. B. Sowerby, *Dentalium.*

Bryozoa: *Acanthodesia savartii* (Audouin), *Mucronella trispinosa* (Johnston), *Mucronella*?.

Anthozoa: *Paracyathus* sp. nov., corals indet., Pennatulacea.

Cirripedia: *Balanus.*

Decapoda: *Callianassa* sp. nov., crab fragments, echinoid plates and radioles.

The fauna of the Hammar formation is without doubt of Recent age, all forms existing in the present seas, some of them now living in the shallow coastal waters of the Red Sea, Trucial Coast, Oman Coast, and Persian Gulf.

CONTACTS AND EQUIVALENT UNITS

The Hammar Formation is underlain, probably unconformably, by the Dibdibba Formation. It is overlain by Recent lacustrine or estuarine alluvium which consists of 20 feet of buff and red silt and some sand and pebbles. The top 3 feet of the alluvium contains abundant salt and gypsum crystals. Toward the middle the silt contains the brackish-water ostracodes *Cyprideis litoralis* (Brady) and, more rarely, *Limnocythere.* Thus, the silt is considered as estuarine and the remainder of the alluvium as fluviatile or lacustrine.

The equivalents of this Recent marine formation are expected along the coastal line of Arabia and over Arabia to be manifested in different and highly variable lithologic and facies forms.

ECONOMIC ASPECTS

No economic value has so far been attributed to the Hammar Formation, although some of the higher parts in the Recent alluvium that are scattered along the highway between Al Basrah and Al Amarah have been utilized for brick making in the Brick Kiluf.

STRUCTURE

STRUCTURAL PROVINCE OF SOUTHWESTERN IRAQ

Iraq, in general both geologically and geographically, has been influenced by the proximity of the Precambrian Arabian shield (Furon, 1963) and the Zagros province of the Tethyan geosyncline. Tectonically, it can be subdivided into three major interrelated units, each with its distinct and characteristic tectonics and geologic history. These units from northeast to southwest are: (1) the major and complex overthrust or "nappe" belt, (2) the autochthonous folded belt, and (3) the unfolded area (Dunnington, 1958; Naqib, 1960).

An elaborate analysis of the tectonic construction of the Middle East in general, including northern Iraq, has been made by Henson (1951), who stressed the important role played by pre-Miocene vertical movements in the unfolded area and in the folded zone. Henson considered that folding due to late Tertiary compression was superimposed on and molded against an earlier deep-seated block-faulted framework, inherited from the pre-Miocene history of the region. Other accounts by Boeckh and Viennot (1929), Lees and Richardson (1940), and Lees (1950a, b, 1951, 1953) have accepted uncomplicated compressional folding, with a broad "normally folded zone" intervening between the "nappe front" and the unfolded "foreland."

A rather different quadripartite subdivision was introduced by Mitchell (1959), who included Iraq in (1) the Stable Shelf, (2) the buckled Labile Shelf of the Foreland, (3) the autochthonous border folds, and (4) the Iranides of his Orthogeosynclines of southwest Asia.

The tripartite division into unfolded, folded, and "nappe" zones, on the dominantly northwest-southeast trend of the Zagros, is appropriate for post-Miocene time and is harmonious with existing concepts of a Cretaceous and Pliocene geosyncline developing on the same Zagros trend, with its axis migrating more or less progressively southwestward until the orogeny in Pliocene time. Conditions in Jurassic and pre-Jurassic time were somewhat different. The basinal trend ran more nearly north to south than northwest to southeast in the known Jurassic stages, and the Jurassic and Cretaceous transition was probably a time of tectonic disturbance, including widespread uplift and tilting of fault-bounded blocks on the west margins of the basin. Several deduced faults of this age are directed north to south, across the Zagros trend. The axes of thickest basinal deposition for the Jurassic stages underlie thin accumulations of shallow-water Lower Cretaceous sediments. Figure (1) shows the major tectonic zones of Iraq and their characteristic elements.

The "nappe" zone is confined to a narrow belt in the remote northeastern part of Iraq and consists of an area of highly complex tectonics featured in extensive overthrusts; the rocks generally show some low-grade regional metamorphism (slates, phyllites, and schists). The area has undergone extensive igneous activity, including extrusion of basalt, spilite, and andesite, accompanied by some explosive vulcanism, evidenced by pyroclastics and tuffs and also by intrusion of dolerite, mafic rocks, and granite. The topography of this area contrasts sharply with that of the simple-fold mountainous country of the zone of autochthonous folding farther southwest. It follows a surprisingly linear northwest-southeast trend from Rayat in northern Iraq to Bandar Abbas in southwestern Iraq.

The second unit forms a wider belt that extends in a general northwest direction in the northeastern part of Iraq and falls into three arcuate segments that bulge southwestward. This zone has an average width of about 100 miles (160 km), and the alinements of individual folds and the belt itself follow the Zagros swing from east-west in the north to northwest-southeast in the south. The segments of the autochthonous folded belt have been overridden by the linearly trending overthrust belt (Gansser, 1955) in the northeast as if they had differential lateral displacement along lines of crustal weakness perhaps with north-south Caledonian trend.

The boundary between the folded and unfolded zones is abrupt. The southernmost and westernmost anticlines of the folded zone—Jebels Sinjar, Sheikh Ibrahim, Sadid, Makhul, and Hamrin North and Hamrin South—are surprisingly large folds, tens of miles long, and in some places rise several thousands of feet out of the adjacent synclines. The boundary follows a more or less arcuate line, from northwest-southeast in the southeast to east-west in the northwest, but it is offset sharply in the area west of Qaiyarah. Here its course is picked out by the north-south alinement of the pitching ends of five rather small and low anticlines. The line plunges below alluvium in the plains east of Bagdad or is offset northward, near Naft Khaneh, to the foot of the exposed Iraq-Iran frontier folds.

In this unit the anticlinal folds are simple and sharp, generally without faulting and subordinate thrusting. The structures are en echelon and are separated by broad synclines. In this zone, the intensity of folding, as reflected in the magnitude of the amplitude of the fold system, diminishes gradually southwestward from the region of high complexity in the northeast to a stable and tectonically undisturbed zone in the west. Thus, indeed, according to Dunnington (1958), there is an overall tendency for anticlines to increase in amplitude and tightness as the "nappe front" is approached, the most northeasterly folds being themselves thrust and locally overturned. There are, however, many departures from the superficially natural expectation that the folds should diminish in strength with increasing distance from the thrust front. Thus, Hamrin North, Makhul, and Sinjar are much more developed and much more elevated than the anticlines that occur immediately to the north and northeast, whereas flat, low domes appear between steep, narrow neighboring anticlines in the middle of the zone. Other oddities include the great elevational differences between adjacent anticlines of otherwise similar dimensions, the pitching down of successive anticlines along linear features, and the appearance of marked asymmetry in some folds and of opposed asymmetry in some pairs of adjacent folds. These and other anomalies substantiate the opinion of Henson (1951) that the late Tertiary folding in the folded zone was intimately affected by a preexisting complex of faults, which left residual features to buttress or deflect folding and which predisposed the region to react in irregular and complex fashion to simple tangential pressures.

The unfolded zone includes an extensive area of central, southern, and western Iraq; the Jebels Sinjar,

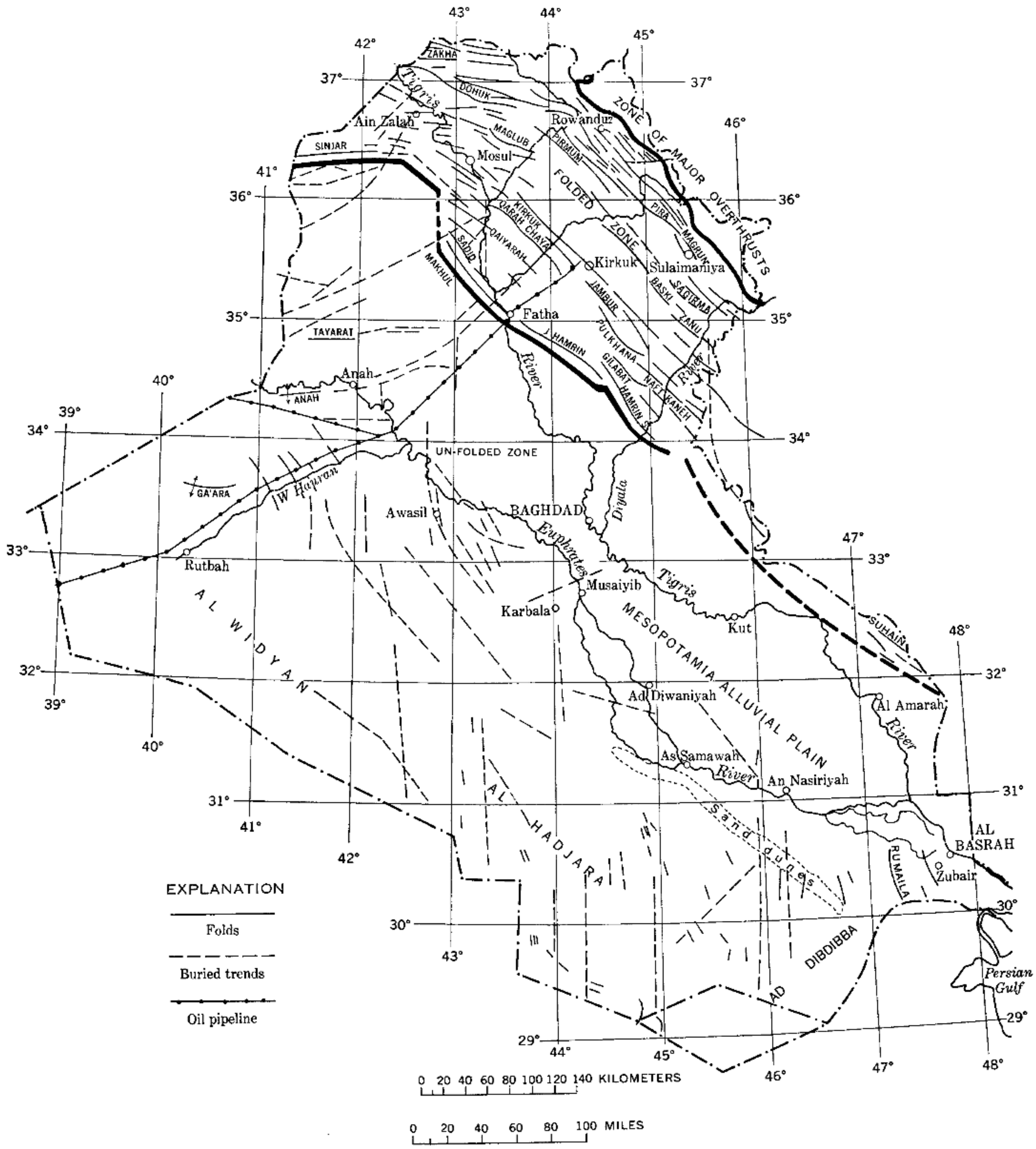

Figure 1.—Tectonic map of Iraq.

Makhul, and Hamrin mark the northern and eastern limits. The present discussion covers only the southwestern part of this area. The structural unit itself is characterized by relative absence of surface structural features except for a few folds of small amplitude and structural depressions many of which may be of only superficial origin.

In the unfolded zone, but northwest of the area discussed, a single broad dome with an east-west alinement occurs in the Ga'ara depression north of the Wadi Hauran. This dome, which exposes Lower Triassic(?) rocks in its center, is on the flank of a very broad uplift, which may reflect basement arching. Farther north, a second prominent east-west fold, narrow but gentle, is known at Anah on the Euphrates; its fault-trough setting strongly indicates a fault origin for the anticline itself. Gentle folds may occur between the Tigris and Euphrates Rivers in front of the autochthonously folded zone under the flat-lying Pliocene, Pleistocene, and Recent sediments. A few minor folds, trending northwest, occur in the neighborhood of Hit and Ramadi.

The unfolded area considered falls within the Interior Homocline of the Arabian tectonic framework defined by Aramco geologists. Here, with the exception of the Miocene and post-Miocene rock units, exposures of rocks from the Cretaceous System upward shift east in almost parallel strips, and their structural features appear in general to be of the simplest nature. They are almost flat over wide areas, with slight dip, measureable only in a few meters per kilometer, toward the east or northeast. The salient features of the area are Jabal Sanam in the Basrah area, depressions which may be structural basins, and some disturbed scarps. The structural profile across the area (pl. 4) portrays the general structural relationships of the different systems in surface and subsurface. At the surface the Cretaceous exposures do not convey any impression of diastrophism.

The Batn-Ghurra escarpment of Paleocene and lower Eocene(?) rocks is irregular and roughly alined in a north-northwest direction. It is extensive and variable with uncertain origin. In the Al Makmin (Machi) area it shows slight sagging. The Batn scarp in general has a very gentle east dip, and in certain places (for example, Lifiya) it consists of a simple typical erosional scarp with folded Basita Beds about 2 kilometers to the west. Reversals in dip over the scarp can be seen in places, for example near 'Aydahā, where closely folded beds occur more than 1 kilometer west of the scarp. In many places, beds of the Zahra Formation are also involved in local folding.

The Waqisah scarp in the area of Al Jill-Wagish, according to F. J. Venn (unpub. data, 1957), is of erosional origin. It shows well-bedded horizontal limestones commonly with more than one scarp because of differential erosion. They show no "draping" toward the foot of the scarp except for occasional but random collapse of the scarp edges.

The At Traq escarpment is generally alined north-northwest between Tukayyid and Abu Khanzir, though there are several swings from the general trend along its length. There are definite signs of faulting on the scarp, as at Khashm ad Duda and Khashm ad Dimand. At the south end of Khashm al Mahasa there are no obvious signs of faulting, but the "scarp face" is essentially the steepening south flank of an anticline. The feature is made up of folded very weathered Tuqaiyid Limestone and overlying Zahra Beds. The area here looks slightly complicated, perhaps because of the cover of Zahra Beds. Minor anticlinal features can be observed west of the At Traq scarp, as at Kabd (Chabd), Uba'id, and Faydat Ar Radhuma.

Slightly northwest of the At Traq scarp is the Galaib scarp, where surface geology indicates a north-northwest faulting trend and general lineation in a similar direction, which is manifested also in the trend of the escarpment to the northwest of Galaib. This is considered to be a fault scarp having a possible throw of 100 feet in Ash Shawyyat area. Eighteen miles north of here, in the area of Shaikhiya-Dhiriyat, is a series of parallel folds which show two axial trends introducing the additional north-south trend which may be related to the structural grain of the Salman area.

In the central part of the area between the Waqisah scarp in the west and At Traq belt in the east is a series of depressions which, considered as a group, show alinement in a north-northeast direction, convergent with the trend seen from Tukayyid through At Traq, Chabd, Galaib, and Ash Shawyyat. The As Salman depression forms one of the largest of this group. This is enclosed by high escarpments with repeated north-northeast trend surrounded by a horizontal plateau. About 100 kilometers northwest of the As Salman group of depressions is the Ash Shabakah (Shabicha) depression, which shows small anticlinal and synclinal folds in the Zahra Beds.

East of the At Traq group of scarps, Ghanimi anticlines, trending north-northwest and south-southwest, and Abu Ghar, a gentle north-south fold, are the dominant features. Between Abu Ghar and Al Basrah there is a slight topographic feature, which may be structural expression and which can be seen in the Shagra and Boliya areas.

Apart from the slight structural features of Ratawi, Rumaila, and Zubair there is no significant feature in the Al Basrah area except the dominating Jabal Sanam, which rises high above the surrounding flat country. Here, according to Boeckh and Viennot (1929), the old rocks project from below the Cenozoic cover. They stated that the rocks show a great resemblance to the Cambrian of the Persian Gulf.

The structural manifestations previously mentioned have been attributed to several different factors by various authors. Some stressed the role of diastrophism and epeirogenic movements, and others emphasized the role of solution collapse. According to Dunnington (1958), "gravimetric data and slight structural manifestations in the flat-lying Tertiary cover provide evidence of important buried structural elements throughout the 'unfolded area'." Lateral variations in sedimentary thicknesses over small distances are deductible, and it is concluded that most of these variations are controlled by pre-Miocene faulting of various dates, the relief due to faulting having been erased at the surface by subsequent erosion and deposition. The tectonic pattern suggested by the evidence is a complex one, resulting from interplay of vertical movements on fault trends which are oriented predominantly north to south, east to west, northwest to southeast, and northeast to southwest, the importance of individual trends showing marked local variations. Some of the prominent detected structural features are continuous for some tens or even hundreds of miles. Some pass beyond the limits of the region considered into Saudi Arabia. A few transgress directly across the limit of the unfolded area into the folded zone.

Where directional characters can be read into the complications, one or more of the four main tectonic trends discerned in the unfolded area is generally found to be involved. As a few important tectonic features on these trends pass directly from folded into unfolded terrain, it is argued that the folded zone was probably traversed prior to folding by a tectonic network comparable with the network that is now detectable in the unfolded area.

STRUCTURAL HISTORY

The Arabian shield dates from pre-Cambrian time. Since then, during various geological periods, the sea has transgressed and regressed over its margins. Western Iraq has undergone this sedimentary history as part of the fringing region (shelf) of this shield, the structural history of the area being reflected in the mode of sedimentation. From Triassic time this was controlled by the presence of the Ga'ara-Khleisia feature in the north and the Arabian shield proper in the southwest. The Triassic sediments indicate epicontinental conditions. The various unconformities in the geological sequence, considered with the nature of the sediments, point to several epeirogenic movements which caused the advance and retreat of the sea over the area. Duration and extent of these movements are highly varied. The main ones occurred during late Bathonian and early Callovian times. The emergence was followed by a major transgression heralding the deposition of the Upper Jurassic Najmah limestones. A minor movement during late Berriasian and early Valanginian times has also been postulated to account for the deposition of the Yamama limestones on the Sulaiy Formation.

During the rest of Cretaceous time the area underwent a series of sedimentary cycles caused by marine transgressions and regressions. There are indications in the Cenomanian cycle that certain structural positive features, probably arcuate and extending from the Rumaila area, gave rise to the Mishrif reef. It was during the middle Turonian and lower Campanian cycle that the east-west-trending Anah graben trough formed. This trough continued subsiding during Maestrichtian time to accommodate the great thickness of sediments accumulated.

The Ga'ara high must have been near shore during the Cenomanian time, from the evidence of the Rutbah sandstones, and a slight transgression followed, culminating in the deposition of the Mishrif (or M'sad) Formation.

Late Cretaceous time was mainly a period of transgression, in which neritic limestones, including tongues of basinal sediments from the east side, were deposited.

The Eocene deposition was followed by a long period of emergence, which was ended by the deposition of the Euphrates limestones over most of the eastern parts of the area, while the western parts perhaps remained above sea level.

Further transgression during middle Miocene time led to the deposition of the clastics of the Ghar and lacustrine Zahra deposits and evaporites of the Lower Fars. During this period a more extensive area was covered, as evinced by the extensive Zahra beds.

During late Miocene and Pliocene times the Dibdibba clastics were deposited, the material derived possibly from a rapidly rising mass of the Arabian shield.

Since then, the central part of the area seems to have undergone relatively more uplift than the remainder, as can be seen in the distribution of the Zahra beds. Rejuvenation of the wadi system exposure area of Upper Cretaceous rocks may be considered as an indication of a sudden uplift and readjustment.

GRABEN SYSTEM

There is no direct indication of a graben system in the area; however, gravity-survey results, sedimentary history, and some seismic investigations demonstrate that even the flat-lying western desert area is underlain at depth (and locally at not very great depth) by buried structural elements and grabenlike faults of very considerable throw and shift. Some of these can be traced for very great distances into and across neighboring countries and some through a series of complex gravity features far into the zone of late Tertiary folding. The major tectonic elements of southwestern Iraq are shown in figure 1.

According to Dunnington (1960), the ages and trends of movement of these faults, and the nature of the faults themselves, remain for the most part obscure. Some, trending approximately east to west, may be identified with fair certainty as delimiting major troughs of subsidence which originated during Senonian time; thus, the east-west-trending Anah anticlinal structure has been formed on the site of a graben trough which dented and broke the Ga'ara-Khleisia block during early Late Cretaceous time. Others, including some of north-south alinement, appear from subsurface evidence outside the area considered here, to have moved significantly in very Late Jurassic or very Early Cretaceous times, though they may have had a much older existence and may have been slightly dislocated in later times. There is the possibility of As Salman depressions being basically manifestations of a deep buried graben system, though greatly influenced and accentuated by subsequent solution collapse phenomena. A similar argument is also applicable to the other depression and solution features of the area. However, with the present degree of knowledge and the inadequacy of available data, it would be dangerous to give rein to speculation and imagination.

SUMMARY

The study region comprises more than 82,000 square kilometers of southwestern Iraq and lies in the northeast side of the Arabian Peninsula. We owe much if not all our knowledge of the geology of this area to the exploration for oil, over almost a quarter of a century, by the Iraq Petroleum Company and its associate, the Basrah Petroleum Company.

In western Iraq near the Ga'ara area the oldest rocks are considered to belong to the Lower Triassic(?). They are succeeded by the Rhaetic, Liassic, and Bajocian-Bathonian sequence. In the same area a major erosional gap exists between the Middle Jurassic and the middle Cretaceous. This gap narrows away from the Ga'ara massif. Thus, it is possible to recognize successive occurrences of the intervening formations basinward.

The Cretaceous System shows strong diachronism and a history of sedimentation characterized by sedimentary cycles, which were controlled by the epeirogenic withdrawals over the Arabian platform. The basic near-shore to basin sequences are hardly recognizable there, the sediments having been laid down close to the old shorelines. The main Cretaceous cycles are: Tithonian (Upper Jurassic) to Aptian, Aptian, Cenomanian to lower Turonian, Middle Turonian to lower Campanian, and upper Campanian to Maestrichtian.

Similar cycles are detectable in the Tertiary, but their significance can only be appreciated if other areas of Iraq are considered. In particular, the understanding of Miocene stratigraphy is in a state of flux and requires a great deal of investigation. The Oligocene Series is not recognized in the area.

Structurally, the area lies in the Interior Homocline of the Arabian Peninsula. It is flat-lying country with gentle dips to the east and northeast. Minor northwest- and north-trending linear structural features occur in the Tertiary outcrop area. These may be due to recurrent disturbance along old lines of weakness, accompanied by the dissolution of the evaporites in the Paleocene and Eocene sequence. Solution-collapse structure is well developed in many places.

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