

## Hydrocarbon Potential in Saudi Arabia

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**ABSTRACT.** Oil was discovered in the Dammam Field and declared commercial in Saudi Arabia in 1938. Since then, continuous exploration activities have revealed many large oil fields. All these oil accumulations are situated in the north-eastern quadrant of Saudi Arabia, where oil companies have concession rights. Geological analysis of sparse and sporadic information in other sedimentary basins outside the quadrant increasingly demonstrates the hydrocarbon potential of these areas. This paper highlights the generalized geological characteristics of the sedimentary areas, especially those outside the present Concession Areas, and illustrates their hydrocarbon potential.

### Introduction

Saudi Arabia's remaining oil reserves as of 1988 year-end are estimated at 255 million bbl which represents 27 percent of the worldwide reserves. Remaining gas reserves are estimated at 181 trillion cu ft which is 5 percent of the worldwide reserves. Most of these reserves are concentrated in a few supergiant and giant oilfields in the northeastern quadrant of the Kingdom, where three oil companies hold concession rights (Fig. 1 and 2). The Concession Areas constitute about 15 percent of the total sedimentary basins in the Kingdom. Only very limited exploration work was conducted outside the Concession Areas. Most of these areas are classified as frontier areas where the structural and stratigraphic framework is currently being outlined. Synthesis of the very limited, sporadic geophysical and geological data available demonstrates the increasing prospectiveness of these areas. Recent commercial oil discoveries in neighbouring countries enhance the hydrocarbon potential of the frontier areas. The preliminary analysis outlined several sedimentary basins and regional arches with potential mature source rock, prospective reservoirs, competent seals and favourable basin evolution.

Based on these conclusions, the Government, in 1986, authorized Aramco (Arabian American Oil Company, now Saudi Arabian Oil Company or "Saudi Aramco") to conduct exploration work in the areas included in its original concession, which includes all the

sedimentary basins of the Kingdom except the Red Sea and its coastal plains. Aramco started exploration activities outside its current Concession Area (Retained Areas) utilizing state-of-the-art geophysical and geological methods. Landsat imagery, aeromagnetic, ground gravity, source rock evaluation, biostratigraphy, surface geology and regional seismic surveying are being utilized in the preliminary evaluation phase.

The overall objective of the current studies is to establish the structural and stratigraphic framework of the sedimentary basins and to define prospective trends where most definitive exploration activities will be applied.

To accomplish the preliminary evaluation in an orderly and scientific manner, widely spaced regional seismographic reflection lines are now being recorded in these frontier areas. An aeromagnetic survey was flown in the northwest and southwest areas of the Kingdom to complete the coverage. Available exploration information is very limited and insufficient for a quantitative basin evaluation to estimate oil yield and accumulation potential. To do such a quantitative study over any basin would require denser controls of source rock distribution, richness and maturation.

### The Hydrocarbon Potential of the Concession Areas

As of 1987 year-end, sixty discoveries have been es-

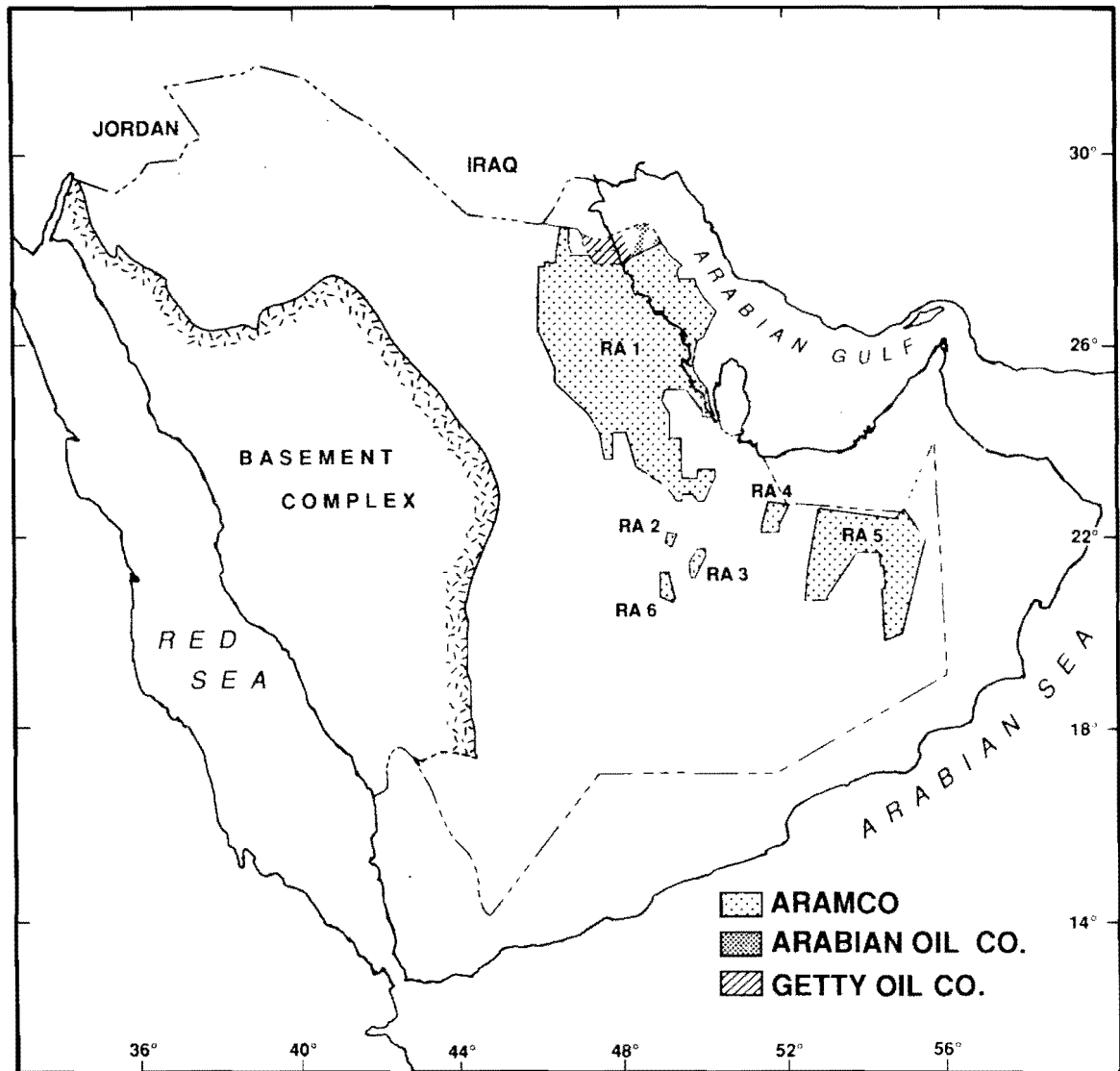


FIG. 1. Hydrocarbon concession areas of Saudi Arabia and Saudi-Kuwaiti divided zone.

tablished as producible fields. Of these fields (59 oil and one gas), 39 are onshore, 4 partly on- and offshore and the remaining 17 offshore. Fifty-two oil and one gas fields are in the Saudi Aramco, 3 oilfields in Getty Oil Company and 4 oilfields in Arabian Oil Company Concession Areas. The last two Concession Areas are within the Partitioned Neutral Zone onshore and offshore, respectively. Commercial oil accumulations of these fields are present in 39 different stratigraphic units (Fig. 3). A total of 231 hydrocarbon accumulations occur within these units. Many oilfields have multiple reservoirs, some containing as many as 11 reservoirs. Almost all oilfields are found in large structural closures developed along regional structural trends controlled by faulted-linear-basement-blocks. The youngest reservoir is Hasbah of Miocene age and the oldest is a Cambro-Ordovician oil reservoir at Abu Jifan field. Generally, the youngest reservoirs exist in

the northeastern offshore areas. The reservoir age becomes older to the southwest. Most of the reservoirs in the northern offshore are Cretaceous sandstone and carbonates, and to the south they are Jurassic carbonates. The number of reservoirs in the fields generally decrease from northeast to the southwest.

The history of oil generation, migration, and accumulation is well documented in Saudi Arabia. Most of the trapped oil was generated from rich, mature, source rocks in two basins. The Gotnia basin in the north and the Arabian basin to the south (Fig. 4). The two basins are separated by the Arabian Shelf. The age of the source rock is Oxfordian-Upper Jurassic (Sargelu Formation in the Gotnia basin and the Hadriya Formation in the Arabian basin). Both are sedimentary basins with gentle regional dips and almost no distinctive subsurface structures. The thickness of the Upper Jurassic section in the two basins is

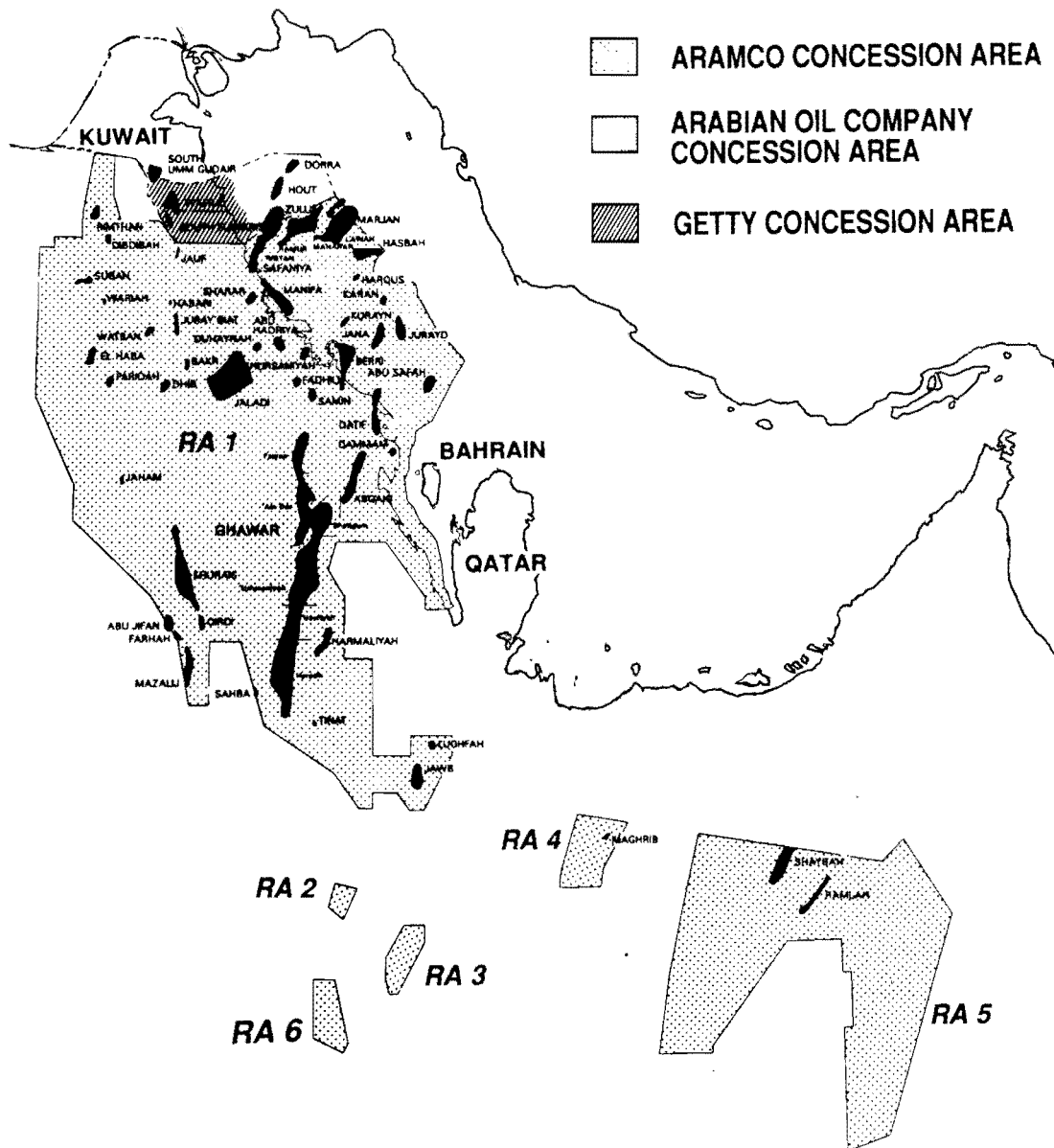


Fig. 2. Oil fields discovered in Saudi Arabia and the Saudi-Kuwaiti divided neutral zone.

almost constant. Both basins originated as starved basins over a broad area in which the subsidence rate slightly exceeded the depositional rate. Starved basin conditions persisted, while the marginal shelf facies continued to build up. The Arabian basin extended from Middle Jurassic (Callovian) to late Upper Jurassic (Kimmeridgian). The Gotnia basin originated in Middle Jurassic (mid-Bathonian) and persisted through Lower Cretaceous time (Hauterivian).

The source rock facies is black to brownish black laminated limestone. It is of uniform total composition, although thin beds may be exceptionally rich or lean in organic content. The dark laminae may contain up to 50 percent organic matter by volume. Oil is interpreted to have originated from primitive life forms

such as plankton and algae, the remains of which were deposited onto and preserved in the anoxic bottom environment of these restricted basins.

Prospecting for petroleum has been continuous in the Concession Areas. Many exploration methods recognized by the oil industry were applied. These include surface geological investigations, shallow hole structural drilling, stratigraphic drilling, gravity and magnetic field measurements, and refraction and reflection seismic methods. These efforts succeeded in defining the major structural oilfields. Although the Concession Areas are considered mature from the exploration aspect, the likelihood of discovering additional reserves is still high. It is true that all the major structures have long been recognized, however, there

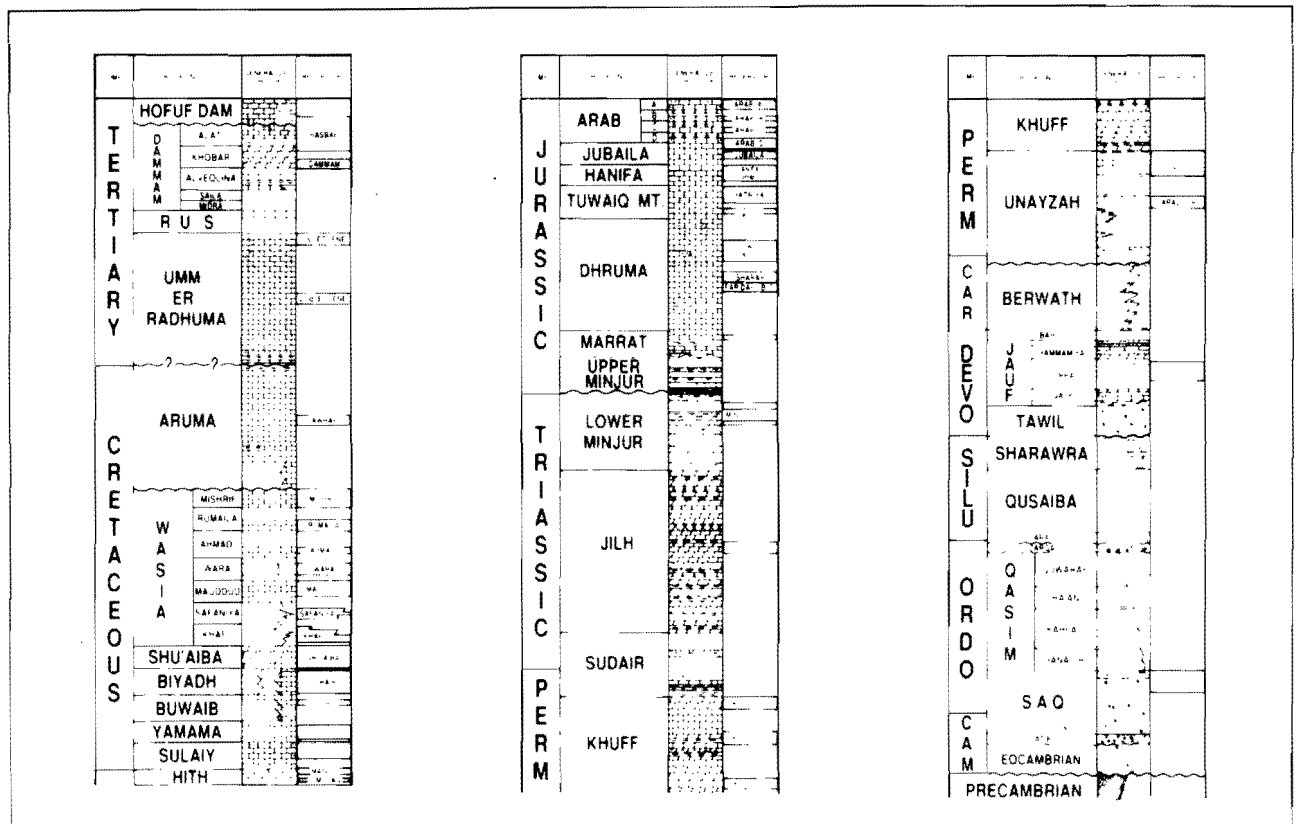


FIG. 3. Generalized Saudi Arabian stratigraphic section formational and reservoir nomenclature.

are still many low relief subtle structures and stratigraphic features which could have trapped petroleum. Most of the remaining features are in areas characterized by severe solution collapse in the shallow section and facies changes which result in seismic velocity variations and time anomalies unrelated to the deep structure of the target reservoirs. Exploration within the Concession Areas requires careful and systematic studies to develop reliable structural interpretations. These interpretations must utilize all geological well control, seismic data, including improved datum and velocity corrections and more innovative interpretation techniques. This is an important phase of exploration which will hopefully lead to another cycle of exploration success within the Concession Areas.

Search for oil and gas in the deeper formations of the oilfields and other tested structures is an important aspect of exploration in the Concession Areas. Many oilfield structures were tested only through the Upper Jurassic, while the potential of the deeper formations remains unevaluated. Jurassic and Cretaceous stratigraphic mapping remains an important exploration goal to define combination traps and stratigraphic traps which are believed to be present, especially

along shelves between sedimentary basins. In addition to future structural and stratigraphic prospecting in the Concession Areas, several oil accumulations have not been fully defined and their accurate delineation may result in additional reserves.

#### The Hydrocarbon Potential of the Frontier Areas

The frontier areas are hereby defined as the sedimentary basins located outside the Concession Areas. For ease of reference, frontier areas are divided into four regions. The Northern region, extending north of Latitude 26.5°N, the Central region between Latitude 26.5°N and 23°N, and the Southern region south of Latitude 23°N up to the southern boundary of the Kingdom and the Red Sea. Since 1963, the Ministry of Petroleum and Mineral Resources has covered selected areas with the reflection seismograph technique. This program expanded during 1975-1986. During this program period extended from 1975 to 1986, about 30 crew years of land seismic survey was completed. Since 1986, the Northern, Central, and Southern regions have been assigned to Saudi

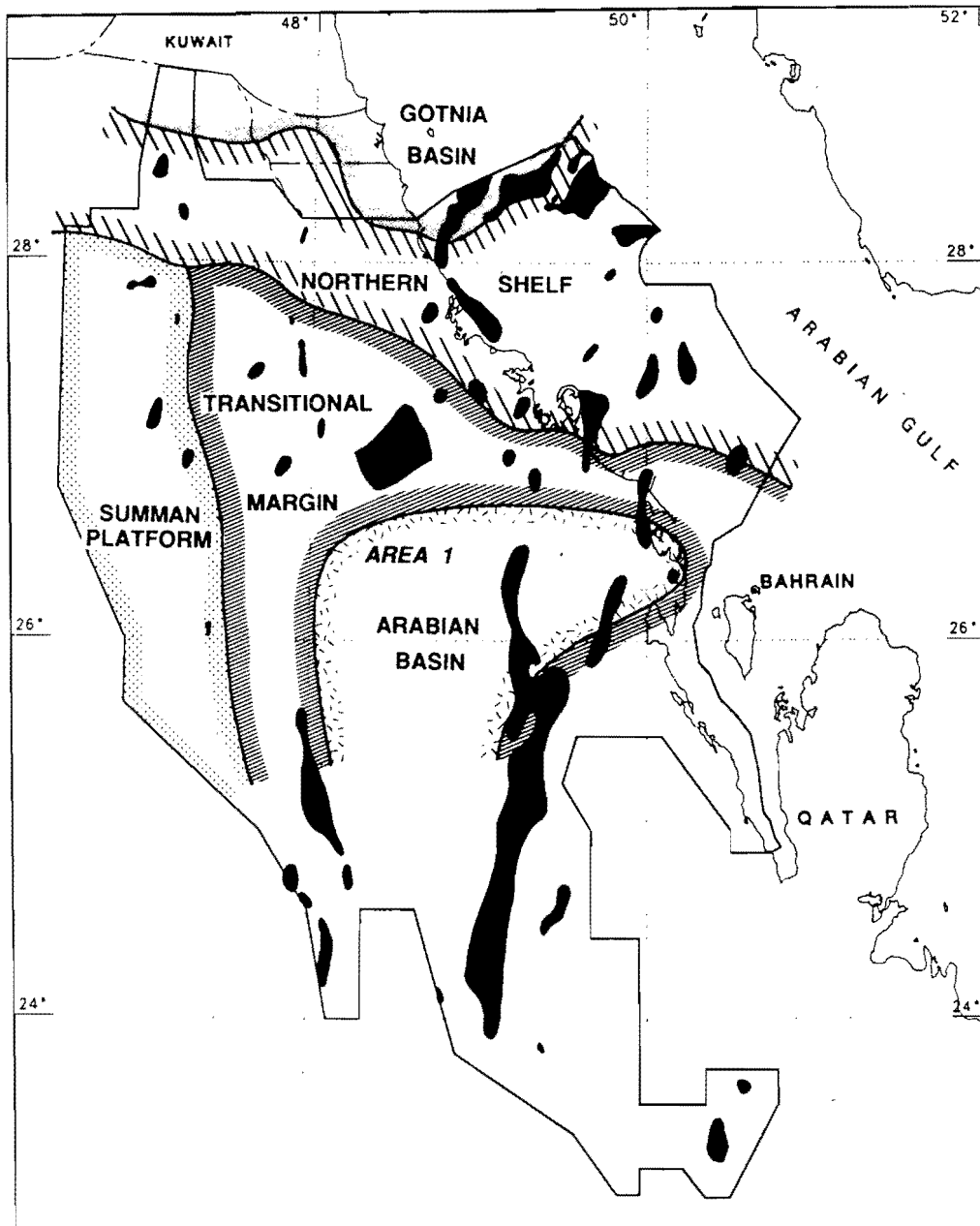


FIG. 4. Source rock basins.

Aramco, while the Red Sea region has remained unassigned until present.

The hydrocarbon potential of the open areas will be reviewed through a generalized interpretation of the very limited data available which is considered to be insufficient for quantitative assessment of potential of the undiscovered oil on the basis of source rock richness, oil yield, maturation and migration efficiency. The present evaluation is therefore, based on various geological analyses using surface maps, aerial photographs, and satellite imagery in conjunction with analysis of gravity, magnetic data, and available seis-

mic coverage. Aeromagnetic surveys were carried out recently in the northwestern and southwestern parts of the Arabian Peninsula to complete the coverage of the Kingdom. Regional reflection seismic lines are being recorded in the frontier areas to increase the understanding of the geological framework.

#### The Northern Area

The Northern Area includes the sedimentary covered area north of Latitude 26.5°N. It is bounded by the basement complex to the west and southwest, and the Concession Area to the east. The Sirhan basin extends southeast to the central graben system, which in-

cludes a series of basins limited by tensional faults (Fig. 5). The Gotnia basin and its southern margin extends along the northern edge of the Northern Area. The Interior Homocline structural province which reflects the attitude of the basement is located in the southwest of the Northern Area. Cretaceous and Jurassic reservoir potential is expected along the eastern and northern limits of this Area. These reservoirs might have received oil generated in the Gotnia basin. To the south and west of the Gotnia basin, pre-Lower Cretaceous (pre-Hauterivian) erosion progressively eliminated Lower Cretaceous and Jurassic reservoirs and, therefore, the reservoir potential of these units decreases in that direction. Further west, the Middle Cretaceous erosion eliminates the Triassic section. On the Jawf arch, the Middle Cretaceous Wasia overlies the Paleozoic sequence. In the Sirhan basin, the presence of the Cretaceous and Paleozoic source rocks

and reservoirs proved by the discovery of oil in Hamza Field in Jordan and a recent oil discovery southeast of Hamza Field in Wadi Sirhan (Fig. 6). The Widyan basin is mainly a Paleozoic basin with indications of good potential source rocks and sandstone reservoir rocks. Oil generated in these two basins may have migrated updip towards the arch. Surface geological investigations reveal the occurrence of many faults in the arch area with the possibility of fault traps, anticlinal traps and combination traps. The recent Silurian-Ordovician gas discovery at Risha field in Jordan attests to the hydrocarbon potential of this area.

### The Central Area

The Central Area includes the sedimentary basins to the east of the Arabian Shield between Latitudes 26.5°N and 22.0°N. The eastern border of the Central Area marks the Concession Area. The structural and

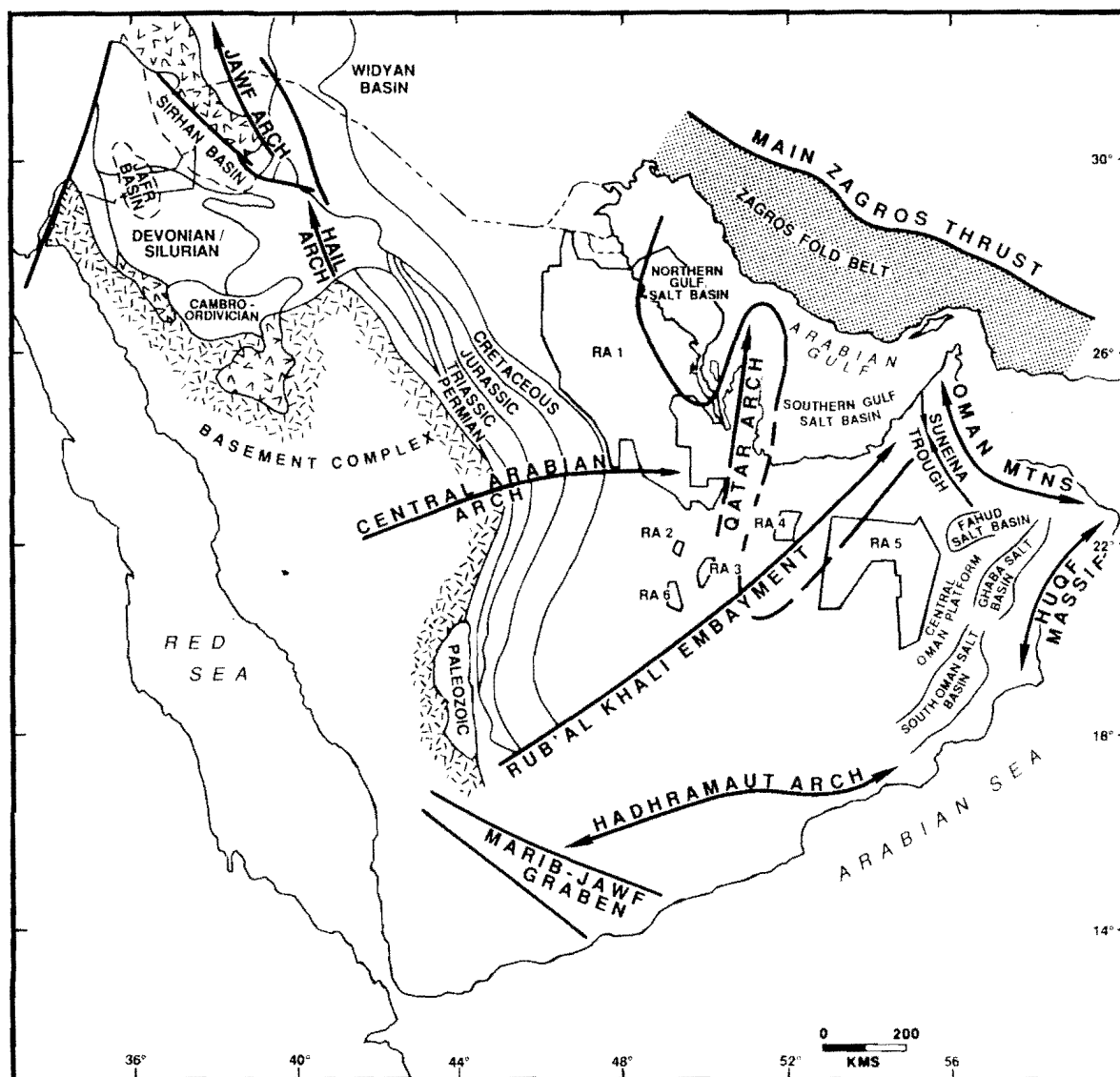


FIG. 5. Regional structural elements.

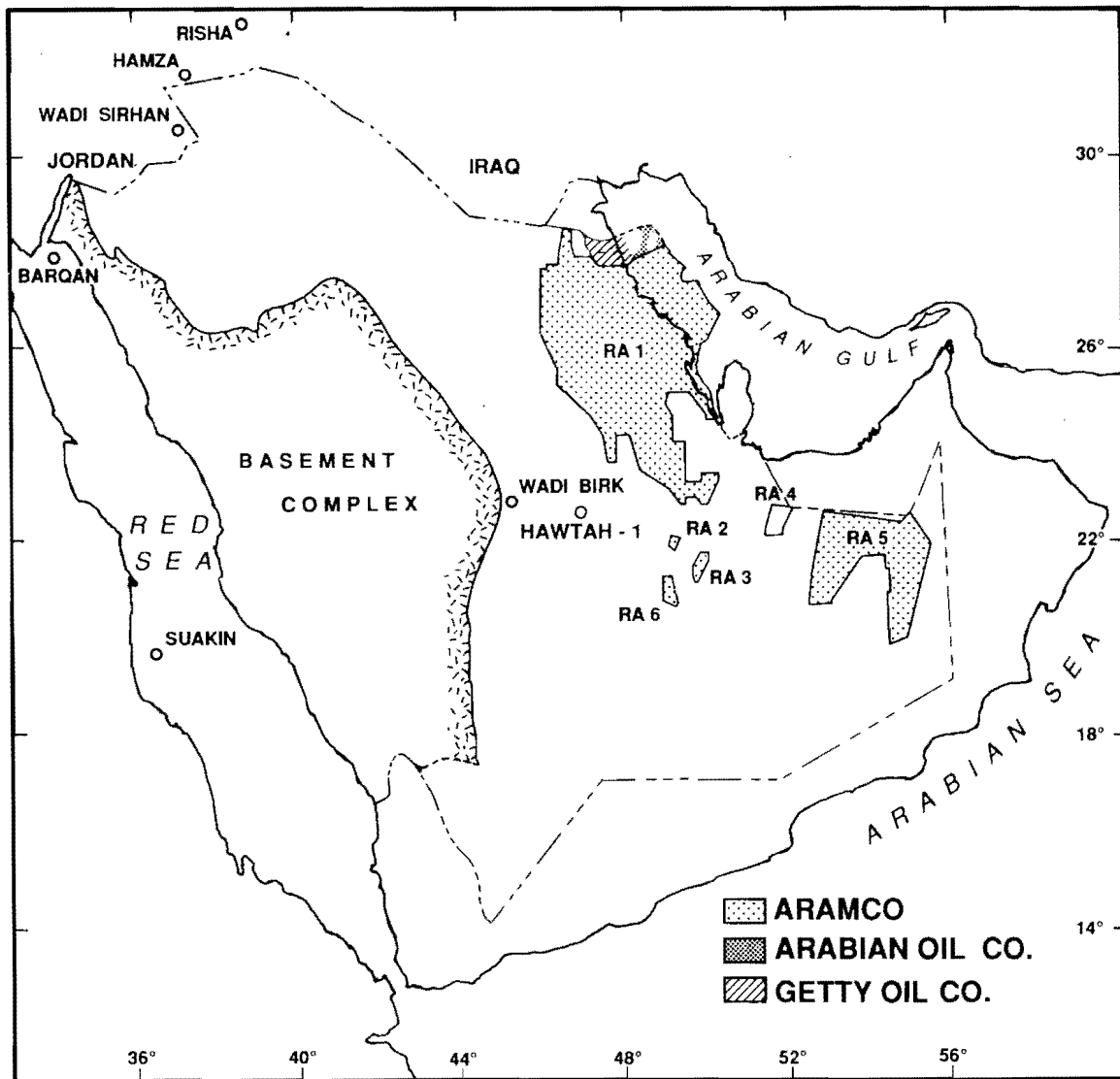


FIG. 6. Hydrocarbon concession areas of Saudi Arabia and Saudi-Kuwaiti divided zone.

sedimentary geology of the area was influenced by the Central Arabian arch which is currently considered a major exploration target (Fig. 5). The Central Arabian arch is a low angle, east-plunging major structural feature with surface expressions. During the Mesozoic period, the axis represented a transitional boundary between two regions; more basinal areas to east and north characterized by a largely marine succession of Middle Jurassic to early Cretaceous, and a stable shelf area to the south with more shallow marine, locally with non-marine clastics. Seismic information from a few widely spaced regional lines revealed several linear blocks and anticlinal axes extending north-south over the basement faults. A few deep holes demonstrate that the Silurian Qusaiba shale is a rich and mature source rock over an extensive area. The hydro-

carbon potential of the Central Area was upgraded recently by encountering light gravity oil in a water well at Wadi Birk (Fig. 6) on the outcrop of the Khuff Formation and the discovery of oil in Paleozoic sedimentary rocks in the Hawtah-1 wildcat and the Khurais area fields. Geochemical characteristics of the Wadi Birk and Hawtah-1 oils indicate that it is similar in composition to Paleozoic oil found 300 km to the east at Tinat Field, indicating possible migration from mature source rock deeper in the basin. This would imply significant transport of oil through a reservoir or a series of reservoirs and eventual oil leaks updip at outcrops. If this were the case, the Paleozoic structural and stratigraphic traps downdip should be prospective for oil. An equally possible source for the oil at Wadi Birk is the basal Khuff shales and dolo-

mites in the vicinity. However, either source upgrades the petroleum potential of the Paleozoic sequence in the Central Area. Mesozoic oil potential is possible to the east of the Sulaiy escarpment. West of the Sulaiy outcrop, lack of prospective section, shallow burial and proximity to outcrop with potential ground water incursion all downgrade the Mesozoic petroleum potential.

In addition to structural traps, updip stratigraphic or porosity pinchouts and pre-Khuff clastic outliers preserved between faulted basement blocks, are additional potential trap mechanisms.

#### **The Southern Area**

The Southern Area includes the sedimentary covered area east of the Arabian Shield south of Latitude 22°N to the southern border of the Kingdom. This area is partially explored east of the southern extension of the Tuwaiq escarpment. Previous exploration activities included ground gravity and magnetic, regional refraction, reconnaissance reflection and scattered structural and stratigraphic wells. Integration of this data outlined the configuration of the Mesozoic and Cenozoic formations.

Most of the major structures were tested through the Mesozoic with limited success. In the Aramco Retained Area 5, Lower Cretaceous oil is proved in the Shaybah Field, Upper Jurassic oil in the Ramlah Field, and Upper Jurassic gas in the Kidan Field. In the north Rub'al-Khali, small oil accumulations in the Cretaceous were discovered in the Shutfah and Maghrib Fields.

The regional structure of the Southern Area is dominated by the Rub'al-Khali basin which is mainly a Tertiary feature with late Cretaceous history. The south and west of the basin is bounded by the Interior Homocline. The eastern flank of the basin is bounded by the Kidan-Shaybah-Ramlah terrace (Fig. 5).

Interpretation of the limited gravity and magnetic data indicates the occurrences of several anticlinal and basinal trends in the western half of the Southern Area. Seismic information from the south of the Rub'al-Khali suggests the occurrence of very thick lower Paleozoic sediments in rifted basins.

Source rocks in the Middle Cretaceous are recognized and documented in the north central Rub'al-Khali. A few structures, that were mapped, were found to contain limited accumulations. Several plays are anticipated in the Upper and Middle Cretaceous along the flanks of the major structures. The Mesozoic and Paleozoic hydrocarbon potentials are not completely known. Recent discoveries in Yemen and

Oman enhanced the petroleum potential of the Southern Area.

#### **The Red Sea Area**

Petroleum potential in the Red Sea area is only partially known. Seismic work conducted by the Ministry of Petroleum and Mineral Resources in the mid-sixties outlined the general structure of this extensive sedimentary province. A few exploratory wells drilled on structures interpreted from that survey encountered limited successes. Condensate and natural gas were discovered in the Bargan structure at the northern end of the Red Sea (Fig. 6). Other exploratory wells in the central and southern Red Sea were interpreted to have been drilled on salt structures. The prospective clastic section below the salt lacked the desirable trapping geometry. Modern digital seismic techniques using high pressure and large volume air-gun seismic energy sources and long streamers were never tried in the Red Sea area. It is expected that the design of the proper field parameters using the modern equipment and instrumentation will resolve several geophysical problems and result in the seismic energy penetrating below the salt. The structural and depositional model of the Red Sea is interpreted to be a rifted and faulted basin since the Eocene time. The resultant fault blocks were active during various times creating several basins with various thicknesses of sediments. Recent condensate and gas discoveries in the northern and southern Red Sea enhanced its petroleum potential. The reprocessing of previous seismic recordings utilizing state-of-the-art technology may eliminate numerous interferences and result in better quality seismic sections. Interpretation of the reprocessed section will result in more accurate subsurface picture. This will, hopefully, enhance the basement reflector. Prospective areas may justify additional infill and detail seismic lines.

#### **Conclusion**

Excluding a narrow outcrop band bordering the Arabian Shield, most of the sedimentary covered areas in Saudi Arabia are prospective for the discovery of additional petroleum reserves. Only the Concession Areas are well explored and considered mature. Even in these Concession Areas, which are less than 15 percent of the total sedimentary covered areas, the prospect of discovering additional reserves is quite high. The source rock studies indicate that about 60 percent of the oil generated in the Gotnia and Arabian basins was trapped in the present fields. This shows clearly that there are still additional petroleum reserves to be found in the Concession Areas. The exploration plan for these Concession Areas involves the review and analysis of the extensive geological and



geophysical information collected over the last 50 years and the recording of limited number of high resolution seismic lines to better define the structural and stratigraphic leads which will be identified from data review.

For the frontier areas, the reconnaissance exploration phase, which started in 1986 by Saudi Aramco, will continue to establish the structural and stratigraphic framework of the sedimentary covered areas through the recording of widely spaced regional seismic probe lines, gravity, magnetic, surface geologic investigation and analysis of available deep well information. Interpretation of all these data will prioritize different areas and identify prospective trends and plays which could be detailed later on by recording additional seismic.

To ensure the success of the exploration plan, most geological and geophysical studies are being done at Saudi Aramco at its headquarters in Dhahran. It is recognized that exploration activities will be continuous on a viable sustained level for effective utilization of exploration resources, training and development of Saudi earth scientists and professionals. State-of-the-art and leading edge technology in exploration will be utilized, especially in geologically complicated areas.

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## الإمكانات البترولية في المملكة العربية السعودية

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وزارة البترول والثروة المعدنية ، الظهران ، المملكة العربية السعودية

المستخلص . اكتشف الزيت في المملكة العربية السعودية في حقل الدمام وأعلن عن وجوده بكميات تجارية عام ١٩٣٨ م . ومنذ ذلك التاريخ ، استمرت عمليات التنقيب دون توقف وأدت إلى اكتشاف العديد من الحقول الكبيرة . وتتركز الحقول الرئيسية في القطاع الشمالي الشرقي للمملكة حيث توجد امتيازات شركات البترول . واتضح من دراسة وتحليل المعلومات الجيولوجية المتفرقة من الأحواض الرسوبية الأخرى خارج القطاع الشمالي الغربي ازدياد أهميتها البترولية .

ويستعرض هذا البحث المميزات الجيولوجية العامة للمناطق الرسوبية ، وخصوصاً تلك التي تقع خارج الامتيازات البترولية الحالية بقصد توضيح أهميتها البترولية .