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Petroleum Stratigraphy of the Northeast Africa-Middle East Region

by

James A. Peterson[1], and James L. Wilson[2]

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (and stratigraphic nomenclature).

[1]USGS Missoula Montana [2]USGS Ann Arbor, Michigan

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PETROLEUM STRATIGRAPHY OF THE NORTHEAST AFRICA MIDDLE EAST REGION

by James A. Peterson and James L. Wilson

ABSTRACT

Carbonate-clastic-evaporite sediments of Infra-Cambrian through Holocene age were cyclically deposited in a relatively continuous belt around the eastern and northern borders of the Nubian-Arabian craton, mainly on a broad shallow-water platform adjacent to the proto-Tethys and Tethys seaway. All or part of the Paleozoic section is absent by non-deposition or erosion over much of the region but reaches a substantial thickness in the subsurface of the Middle East and in northern Africa adjacent to the Mediterranean Sea. Post-Paleozoic deposition was more or less continuous across the entire craton border region in the Middle East and along the northern border of the Sahara platform in North Africa and in Somalia-eastern Ethiopia. Total thickness of preserved sedimentary cover across this vast shallow-water marine platform and bordering oceanic realm is 6,500 to at least 33,000 ft (2 to 10 km) in and adjacent to the Arabian-Iranian basin, 6,500 to 30,000 ft (2 to 9 km) in and adjacent to northern Egypt, Libya, and Tunisia, and 3,500 to 20,000 ft (1 to 6 km) in the Horn of Africa (Somalia).

To varying degrees, similar marine and associated sedimentary rock facies are present in all of these regions, although paleotectonic-stratigraphic interrelationships and continental positions during drift have greatly affected petroleum generation and accumulation in the several regions of the craton border. A series of regional stratigraphic-sedimentary environment and continental-position layer maps attempts to show the relative influence of these factors through geologic time with respect to the relationships between petroleum reservoirs, source rocks, and confining rock facies.

INTRODUCTION

This paper presents an initial attempt to investigate the comparative petroleum stratigraphy of northeast Africa and the Middle East, an area covering approximately 7,000,000 mi^2 (18,000,000 km^2) of the ancestral shallow-water platform adjacent to the proto-Tethys and Tethys seaway. The report emphasizes regional stratigraphic thickness and facies patterns and their relationship to the origin, accumulation, and preservation of petroleum resources. The complex paleotectonic history of this region and its many interpretations are only briefly discussed with respect to their influence on depositional history and stratigraphic interpretations.

Data and information used in preparing this report were compiled from many sources, including a wealth of published papers and information from numerous professional geological journals, articles from The Oil and Gas Journal and World Oil, and the information files of Petroconsultants S.A. Important selected references are listed in the bibliography, although numerous useful published papers on specific oil or gas fields and local studies are not necessarily included. The work on North Africa and the Middle East was completed as part of the ongoing World Energy Resources Program of the U.S. Geological Survey.

PALEOTECTONIC SETTING

Introduction

The North African-Middle East petroleum provinces are a part of the broad sedimentary platform that occupied the northern and northeastern borders of the African-Arabian craton adjacent to the ancestral Hercynian (late Paleozoic) and subsequent Tethyan-Alpine oceans. The main North African petroleum basins lie on the seaward part of the North African or Sahara platform between the Ahaggar, Tibesti, Jabal-Al Uwayanet and Nubian Precambrian Massifs on the south and the Mediterranean deep on the north (figs. 1-20).

The general structural outline of central to eastern Africa is one of broad basins separated by uplifts of Precambrian crystalline rocks. Many of the basins are bounded by normal faults of large displacement. To the east, the crystalline rocks rise to a broad, north-trending region of high plateaus (Ethiopian plateau), separated by a system of rift valleys (fig. 1). East of the plateau and rift belt, the shelf of the African continent slopes eastward across the "Horn of Africa" in eastern Ethiopia and Somalia into the Somali basin of the Indian Ocean, along the present-day passive margin of east Africa.

The Middle East petroleum province forms part of the platform region extending northeastward from the Arabian Shield. The early Phanerozoic tectonic history of this region was that of a Paleozoic continental platform as much as 1,000 mi (3,300 km) wide extending as far northeast as the Alborz Mountains-south Caspian region. After Hercynian movements, rifting and attendant sea-floor spreading is thought to have split this broad platform along the High Zagros Mountains belt in Iran, creating the Alpine (Neotethyan) ocean to the northeast and confining the succeeding marine shelf province to the region southwest of the Zagros Mountains orogenic belt ("crush zone"). This regional tectonic pattern, that of a passive continental margin, continued through mid-Cenozoic time when collision and the main phase of thrusting and folding occurred in the Zagros Mountains and adjacent area. During the orogeny, the entire Middle East Region underwent emergence and erosion to reduce the marine realm finally to the present-day shallow Arabian Gulf foredeep in front of the Zagros fold belt.

Pertinent works on the structural geology and structural history of North Africa include the following: Said (1962), Conant and Goudarzi (1967, Klitzsch (1968), Sander and others (1971, 1978), Schurrmann (1971), Bishop (1975), El Shazly (1977), Salaj (1978), and Parsons and others (1980). Interpretations of the structural history of central and east-central Africa include those by Barnes (1976), Kamen-Kaye and Barnes (1979), Whiteman (1977a, 1979b, 1981), Beltrandi and Pyre (1973), Walters and Linton (1973), Hutchinson and Engels (1972), McConnell (1972), McKenzie and others (1970), Mohr (1971), Pallister (1971), Pilger and Rosler (1976), Tanner (1973) and others. Regional analyses of the tectonic history of the Middle East region include those by Dunnington (1958, 1967), Stocklin (1968), Wilson (1969), Brown and Coleman (1972), Kent (1972), Berberian and King (1981), Koop and Stoneley (1982), Sengor (1984), Alexander (1986) and others.

North Africa and the Middle East were affected by several episodes of tectonic activity, including: (1) Late Precambrian, (2) Caledonian (early Paleozoic), (3) Hercynian (late Paleozoic), (4) Late Cretaceous-Early Tertiary, and (5) Late Tertiary. Each of these events exerted a profound influence on regional and local tectonic patterns, paleogeography, sedimentary facies distribution, and the processes of petroleum generation, accumulation, and preservation.

Precambrian

Significant works on the basement rocks of North Africa include: (1) Said (1962), Sander (1968), Klitzsch (1968), Goudarzi (1970), Bishop (1975), and El Shazly (1977). Those on central and eastern Africa include: (1) Holmes (1965), Anhaeusser and others (1969), Schurrmann (1971), Pallister (1971), Turner (1971a, b), Choubert and Faure-Muret (1971a, b), Tanner (1973), Kroner (1977), Vail (1978), El Raba'a (1978), and Engel and others (1980). Those on the basement rocks in the Middle East include: (1) Powers and others (1966), Brown and Coleman (1972), Kent and Worman (1972), Engel and others (1980), Berberian and King (1981), Koop and Stoneley (1982), Church (1983), and others.

Crystalline basement rocks are extensively exposed in several parts of the Arabian Peninsula and northeastern Africa (fig. 1). The Precambrian basement of northeast Africa consists of schist and gneiss, some granite and volcanic rocks, and metamorphosed sedimentary rocks of Precambrian and perhaps lowermost Paleozoic ages. These basement rocks apparently were extensively folded and faulted in several episodes of orogeny. At least three orogenic cycles are recognized that probably determined the basic structural pattern of North Africa. During this time, much of the tectonic lineation was oriented northwest-southeast, particularly in Eqypt where early block faulting occurred (El Shazly, 1977). A thick section of late Precambrian sedimentary rocks is present in the Taoudeni basin of west-central Africa, but thins eastward and reportedly does not occur east of approximately longitude 5^{o} E.

Detailed studies of basement rocks exposed on the Arabian Shield reveal a complex history of geosynclinal depositional phases, volcanism, igneous intrusion, probable continental and island arc systems, orogenic events, mountain building, rifting and other faulting episodes, probably sea-floor spreading, and intense metamorphism. This complex early history closed with consolidation of the basement in late Precambrian time. During the final orogenic events, many structural elements originated, and recurrent movements on these significantly affected Phanerozoic sedimentary processes and facies distribution.

Paleozoic

Following the final orogenic episodes and concomitant basement consolidation of the late Precambrian-earliest Cambrian (Pan-African Event?), the region of Iran, Pakistan, central Afghanistan, southeastern Turkey and the Arabian Peninsula is thought to have been attached to the African craton (Berberian and King, 1981; Koop and Stoneley, 1982). During Paleozoic and most of Mesozoic time, the extensive area to the north and northeast of the craton constituted a broad, relatively stable, shelf province bordering the northeast continental margin of Gondwanaland (fig. 21). The craton border provinces of North Africa and the Middle East are here referred to as the Sahara (North Africa), Somalia (East Africa), and Middle East platforms (fig. 1). To the north and northeast of the platform region lay the open ocean ("Hercynian ocean" of Berberian and King, 1981). The late Precambrian and Paleozoic sedimentary wedge of the Middle East formed an eastward extension of the equivalent wedge on the north African continental shelf. The Somalia wedge probably was attached to the Middle East platform during Paleozoic, Mesozoic, and Early Tertiary time, although at times these areas were separated by a west-east arch or swell in the vicinity of North Yemen, South Yemen, and northern Somalia.

Caledonian.--In northeast Africa, Caledonian (Ordovician to Early Devonian) tectonic activity was characterized by general northwest-southeast and east-west trending folding and faulting, which further consoloidated the pattern of earlier platform basins and uplifts (Goudarzi, 1970; Klitsch, 1968; El Shazly, 1977; Bishop, 1975). At this time, Paleozoic basins and uplifts were delineated, such as the Ghadames, Murzuk, and Kufra basins, and the Gargaf arch in Libya, the Illizi, Erg Oriental, and Erg Occidental basins and the Amguid spur in Algeria, elements of the Western Desert basin, as well as numerous smaller trough and high trends extending southeast from the Mediterranean in Egypt.

Data are sparse on Caledonian tectonism in much of the Arabian Peninsula region, although possible evidence of epeirogenic movements is suggested by the absence of Silurian-Carboniferous deposits in much of the region (Al-Laboun, 1986). Volcanism at the close of Caledonian movements is reported in northeastern Iran and adjacent area (Berberian and King, 1981).

Hercynian.--During the Hercynian (late Paleozoic) tectonic cycle, general uplift of the Sahara platform took place, coupled with superimposed, generally west-east structural trends related to early development of the Tethyan geosyncline. Mild subsidence or uplift continued in most Paleozoic basins and highs at this time. Widespread deformation occurred in Libya, eastern Algeria and southern Tunisia, where several west-east uplifts were initiated, including the Nefusa uplift and Algerian anticlinorium in northwest Libya, southern Tunisia, and eastern Algeria (fig. 1). Evidence of sagging in the Suez Graben region at this time also is documented (Said, 1962; El Shazly, 1977). Widespread erosion of the Sahara platform took place at the close of Hercynian activity. Permian rocks are generally absent or very thin on the platform but are markedly thicker north of the Nefusa uplift in the Jefara trough segment of the Pelagian platform (fig. 22). Domal uplifting and erosion also may have begun in the region of the Sirte basin in Libya, a precursor to subsequent rifting and downwarping during late Mesozoic and Tertiary time.

The Bur Acaba uplift in Somalia may have been uplifted first in pre-Jurassic time (Beltrandi and Pyre, 1973). Older fault troughs of Karroo age (Carboniferous to Triassic) may be present in the basement floor of the Mandera Lugh basin, and these may extend northward from the Lamu embayment to the south in Kenya. Whiteman (1981) interpreted the Mandera-Lugh trough as a Karroo trough of Late Carboniferous to Early Jurassic age overlain by Cretaceous and Tertiary rocks and containing as much as 25,000 ft (8,000 m) of sedimentary rocks along the axis (figs. 1, 3, 15). The trough may have been part of the Karroo system of troughs extending from the Red Sea to Tanzania during pre-Middle Jurassic time.

The main phase of Hercynian movements affecting the Arabian platform occurred in the late Carboniferous with uplifting and erosion cutting as deep as Cambrian or Precambrian in places (Murris, 1980). Thinning of Paleozoic rocks along the Mosul, Qatar, Hadhramarut, and Huqf-Dhofar Arches and on some more local uplifts appears to be related to rejuvenated movements on older structures and suggests possible earlier movement on these features, although the main movements probably were Hercynian. Hercynian activity is described by Koop and Stoneley (1982) as a rifted continental phase in the Zagros region of Iran where block faulting and regional arching (Zagros high) occurred. Following this event, sedimentary facies patterns tended to parallel the High Zagros suture zone, the site of later growth of the Zagros Mountains belt. Hercynian movements continued through the Early Triassic, at which time local thinning of beds also is attributed to early movements of Eocambrian-Cambrian salt.

Early Alpine (early Neo-Tethyan) (Jurassic-Cretaceous).--During Mesozoic and Tertiary time, most of Africa was above sea level (Kennedy, 1965), and marine deposition took place only in the marginal shelf basins associated with the breakup of the Pangea supercontinent. In North Africa, the Mesozoic and Tertiary basins were initially formed by vertical movements and sinistral tectonic shear, associated with separation of the European and African cratons and the opening of Mediterranean Tethys. In early Mesozoic time, active subsidence and northward tilting of the Sahara platform, accompanied by marine transgression, took place with early downwarp of the Tethyan trough. The general orientation of tectonic elements at this time followed established northeast-southwest or west-east Hercynian trends. Subsidence was greatest in the area of the Pelagian platform and in central and northern Algeria where substantial thicknesses of Triassic and Early Jurassic redbeds and evaporites, including salt, were deposited on eroded middle and late Paleozoic beds. Most of central and eastern Libya and Egypt remained high at this time, except for the northern margin adjacent to Tethys.

The Nogal uplift in Somalia is a northwest-southeast trending paleostructure separating the Ogaden basin (extension of the Somali embayment) and the Cotton basin in northern Somalia (figs. 1, 16). This uplift was present during Mesozoic deposition, and like the Bur Acaba uplift farther south, it also underwent further uplift during Late Cretaceous-Early Tertiary time. Faulting occurred at the close of Jurassic time, and final uplift occurred after Eocene deposition (Barnes, 1976). Coincident with uplift of the Bur Acaba and Nogal highs, downwarping occurred in the Cotton and Ogaden basins, and the Mandera-Lugh basin. The Ogaden, Cotton, and Mandera-Lugh basins form an essentially continuous downwarp, and perhaps qualify as a single basin. Possible differences in these two basins are indicated by geophysical results that show a greater extent of vertical faulting in the floor of the Mandera-Lugh basin (Beltrandi and Pyre, 1973; Whiteman, 1981). The Ogaden basin is part of a sag extending westward from the regional Somali basin (figs. 1, 5).

The central African basins (Upper Nile, Khartoum, Doba Doseo, Chad, and Iullemmeden or Niger basins) are elongate failed rift basins of Cretaceous or Late Jurassic to Tertiary age. They are bounded on both sides by vertical faults with large displacement adjacent to uplifts of exposed Precambrian crystalline rocks. The Upper Nile basin (Sudan trough) is a Y-shaped failed rift depression in southern Sudan made up of northwest and northeast trending rifted segments. Limited published information available on the internal structure of these depressions indicates that they are apparently bounded by steep normal faults of large vertical displacement and contain thick sequences of lacustrine and fluvial-deltaic sediments (figs. 12, 13). Rifting began in latest Jurassic or Early Cretaceous time and continued until Miocene time when sagging of the present-day basin began (Schull, 1984). Several deep, intra-basin horst and graben structures are present, with more than 35,000 ft (10,000 m) of sedimentary rocks in the deepest trough (Schull, 1984; Clifford, 1986).

The Kartoum, Chad, Doba-Doseo (Chari), and Iullemmeden (Niger) basins apparently are similar to the Upper Nile basins in structure, basin fill, and origin. They are broad rift basins formed at approximately the same time as the Mesozoic spreading and opening of the south Atlantic Ocean (Petters, 1981, (figs. 1, 5, 12, 13). The Doba-Doseo basin trends west-east in southeastern Chad and the northern part of the Central African Republic. The central depression of the Chad basin trends northwest-southeast in west-central Chad and southeastern Niger. The north-south trending central depression of the Iullemmeden basin is located along the border between northwestern Niger and Mali. These basins, together with the Upper Nile basins, form a network of rifted intracontinental basins that extend across Africa and that have experienced generally similar structural and depositional histories.

In the Middle East, according to Berberian and King (1981) and Koop and Stoneley (1982), the tensional phase that followed termination of Hercynian movements in the Early Triassic resulted in a Middle Triassic opening of the Alpine (Neo-Tethyan) ocean along the Zagros suture in the position of the present-day High Zagros Mountains. The early Alpine phase is referred to by Koop and Stoneley (1982) as a passive miogeoclinal stage after separation along the Zagros suture zone. In Late Jurassic-Early Cretaceous time a carbonate shelf margin developed in the vicinity of the present-day High Zagros belt, probably related to normal faults formed during preceding extensional movements.

Progressive subsidence parallel to the High Zagros belt occurred in the foreland region to the southwest with deposition of thick, shallow water, mainly marine carbonates with northwest-southeast facies boundaries parallel to the existing carbonate margin (Berberian and King, 1981). Subsidence and sedimentation patterns in the Middle East became more complex and intra-shelf basins developed. Some movement of Infracambrian salt also occurred at this time and affected local thickness of contemporaneous sedimentary units. During the Cretaceous, some salt structures may have reached the surface (Koop and Stoneley, 1982). Early Cretaceous uplift of the Arabian Shield also occurred with eastward transport of deltaic and nearhsore marine clastics from western source terranes. According to Naqib (1966), faulting and graben development in a north-south alignment occurred in the Late Jurassic and Early Cretaceous in parts of Saudi Arabia. Alternating movements occurred in the vicinity of the shelf margin along the Zagros belt with concurrent reef or carbonate mound growth, and associated evaporite basins developed in shelf depressions to the southwest. In Jurassic time, faulting was initiated in southernmost Saudi Arabia related to eventual collapse of the Gulf of Aden depression in Late Tertiary time (Murris, 1980).

During Late Cretaceous time, the final continental collision and closing of the early Alpine (Neo-Tethyan) ocean occurred in the Zagros Mountains region. This event formed the main structural features of present-day Iran and resulted in the first important terrigenous clastic facies from the adjacent Zagros orogen to the northeast. Significant uplift also occurred along the Mosul arch in Syria (Metwalli and others, 1974). In Turkey and northeast Syria, orogenic movements beginning in the mid-Late Cretaceous occurred with the formation of an early phase of movement along the west-east Taurus Mountains chain. To the south of here, a foredeep trough (Kastel foredeep) formed and received thick flysch deposits from the orogen to the north (Ala and Moss, 1979). During Late Cretaceous time, vertical and strike-slip faulting accompanied by east- west graben-like troughs occurred on the Arabian shelf (Naqib, 1966; Murris, 1980).

Middle and Late Alpine (close of Cretaceous to early Miocene).--In north central and northeastern Africa, during the Late Cretaceous and early Tertiary, maximum southward transgression of the Tethyan seaway occurred and was accompanied by northwest-southeast horst and graben block faulting and finally by northward sagging of the Sirte basin region, continuing into Miocene time. Fold and fault trends in northern Egypt at this time were generally northeast-southwest and were accompanied by the development of numerous local small basins and uplifts (El Shazly, 1977). Active subsidence continued during the late Mesozoic and early Tertiary in the Pelagian and Cyrenaica platform regions, where a total of several thousand meters of Cretaceous and lower Tertiary carbonate and clastic deposits accumulated. Late in Cretaceous or early Tertiary time, however, the Cyrenaica platform was faulted and uplifted, perhaps in conjunction with strong block faulting of the Sirte basin. The Pelagian and Cyrenaica platforms and the Western Desert basin were probably parts of the once continuous northern margin of the Sahara platform before its breakup by Sirte basin block faulting and northward tilting in mid-Mesozoic time. Deeply buried blocks of the original platform border may be present in the northern and offshore parts of the Sirte basin. During Late Cretaceous time northeast-southwest structural trends developed in Egypt as part of the "Syrian Arc" system, which extends across northern Egypt, Jordan, and Syria (El Shazly, 1977). Early Tertiary tectonic trends, however, were controlled by northwest-southeast or north-south faults in eastern Egypt associated with early development of the Nile Valley and the Suez and Red Sea grabens.

Late Tertiary tectonic activity did not greatly affect the North African (Sahara) platform except for broad epeirogenic movements. Present tectonic trends on the platform tend to be oriented north-south or northwest-southeast, although some prominent features have generally west-east trends. Increased tectonic activity on the Pelagian platform and general northward regression of the Mediterranean seaway occurred at this time. The Algerian Sahara remained generally stable during the Miocene, and block faulting ceased in the Sirte basin. In Egypt, broad uplift took place during the Oligocene and was followed by early to middle Miocene transgression and by continued development of the Nile, Suez, and Red Sea grabens. In east-central Africa, Barnes (1976) identified movement on the Bur Acaba and Nogal uplifts in Somalia at this time.

Several episodes of igneous activity in North Africa have been recorded, including those of Paleozoic age in southeastern and southwestern Egypt and Libya, Mesozoic age in Libya and Egypt, and late Tertiary to Holocene age in Egypt and farther west in Libya. The most extensive extrusive deposits are Oligocene-Miocene basaltic rocks in the Sinai, Suez, Red Sea, Arabian Shield, and Western Desert regions of Egypt and Saudi Arabia and the late Tertiary-Holocene basalts in central and south central Libya.

The plateau and rift belt of Ethiopia and northern Kenya forms the northern part of the central plateau and rift province that extends for approximately 2,000 mi (3,000 km) from the province of Zambezia in Mozambique on the south to the Red Sea on the north. This belt is characterized by a broad, uplifted plateau of Precambrian crystalline rocks, largely mantled by Cenozoic volcanics, referred to as the Central Plateau or East Africa Swell south of Lake Turkana (Lake Rudolft) in northwest Kenya and as the Ethiopian-Somalian Plateau or Ethiopian Swell to the north (fig. 1). The central part of the regional plateau is cut by systems of rift valleys about 25 to 33 mi (40 to 50 km) wide, most of them trending north-northeast or north-northwest and some north-south. The main valleys are elongate and are several kilometers long but associated with them are shorter branching and en-echelon fault systems. In northwestern Kenya, the regional plateaus are separated near Lake Turkana by a depression, which may have provided an ancestral connection between the depositional basins of Somalia and Kenya and those of Sudan (Holmes, 1965).

The Central Plateau and Ethiopian-Somalian Plateau underwent several stages of uplift that began in late Mesozoic time and extended into Pliocene-Pleistocene time (Mohr, 1971). Faulting and rifting of the plateau probably occurred in Miocene and later time. The Tertiary uplift and rift system may have followed lines of weakness related to older mobile belts in East Africa, for example the Mozambique belt of late Precambrian to early Paleozoic age (Holmes, 1965; McConnell, 1972; Pilger and Rosler, 1976; Kamen-Kaye and Barnes, 1979). Volcanic activity associated with development of the plateau and rift system began as early as Late Cretaceous time and continued in several stages through Pleistocene and Holocene times.

Growth of the final and major phase of the rift systems progressed from north to south, beginning in the northern part near the Red Sea in late Oligocene to early Miocene time and becoming progressively younger to the south, mainly of Miocene and younger age in the main Ethiopian rift system and the Central plateau and rift system to the south (Pilger and Rosler, 1976). During development of the rift systems, basaltic and other volcanic flows and tuffs, as thick as 6,500 ft (2,000 m) or more, accumulated along the central rifted part of the Ethiopian Plateau (fig. 14). The floors of the rift blocks apparently are underlain by relatively flat-lying Mesozoic marine sediments. Fault displacement along the graben borders may reach 3,000 to 7,000 ft (1,000 to 2,000 m) in some cases (fig. 14).

The northern part of the plateau and rift belt is occupied by the Red Sea and Gulf of Aden depressions and the smaller depressions of the Suez, Gulf of Aqaba, and Dead Sea farther north. The pre-rift growth of this region took place in latest Cretaceous and early Tertiary time. The Red Sea and the Gulf of Aden areas may have been depressed during Jurassic and Cretaceous time (Whiteman, 1968), but the main subsidence of the grabens probably began in the early Tertiary. Uplift and arching of the African-Arabian shield culminated near the close of Eocene time; widespread volcanism occurred, and the African-Arabian shield began to spread apart, resulting in the initial Red Sea rift (Lowell and Genik, 1972). Sea-floor spreading followed, and vertical faulting with displacements of several thousand meters ultimately occurred on both sides of the rift (figs. 1, 5, 17). This activity continued through Oligocene time, and by early Miocene time the Red Sea margins essentially had attained their present form, although sea-floor spreading, volcanism, and sedimentary infilling have continued to the present. The Gulf of Aden followed a sequence of events similar to that of the Red Sea, but initiation of the main phase of rifting was somewhat later. The present structure of the Red Sea depression is that of a deep rift, complicated by extensive faulting of the floor and overlying sediments, draping of sediments over fault blocks, and a complex of salt structures (fig. 17).

In the Middle East, Koop and Stoneley (1982) refer to the middle and late Alpine (Late Cretaceous-Miocene) period of tectonic growth as the collision phase. Complex plate margin tectonism occurred and a subduction zone developed along the Zagros suture where recurrent movement occurred along major faults, many inherited from earlier fault trends, some as old as Precambrian. Concurrently, increased subsidence and a flysch foredeep developed immediately southwest of the collision zone. Intra-shelf structural features underwent movement, and crustal compression resulted in thickening of the continental crust in the Zagros foreland. To the west in Saudi Arabia, closure was initiated along the main north-south anticlines, probably in part salt-assisted, and these features began to affect sedimentary facies patterns across the shelf. Early in the Tertiary, the Gulf of Aden fault system was rejuvenated and by Late Oligocene time rifting and sea-floor spreading began.

Post Early Miocene.--In northeast Africa, regional uplift and folding occurred in the late Miocene and continued into the early Pliocene, when the Nile River system began to develop within the Nile graben, followed by rapid northward advance of the Nile Delta into the Mediterranean region. Active subsidence of the Suez and Red Sea grabens continued in the Pliocene, at which time the Red Sea probably became connected with the Indian Ocean through the Gulf of Aden.

In late Miocene-Pliocene time, major tectonism occurred in the Zagros Mountains region (Zagros orogeny), and most of the Arabian Peninsula became emergent. South-westward thrusting and folding occurred at this time, and the foothill structures of the Zagros fold belt were intensely folded, uplifted and enveloped by a thick conglomeratic facies (Bakhtyari Formation) derived from the uplifted High Zagros belt ("crush zone"). Berberian and King (1981) estimate shortening during this phase to be about 20 percent. The main Zagros depocenter migrated progressively southwestward to its present position in the Persian (Arabian) Gulf.

In Syria and southeastern Turkey, intense compressional thrusting and folding occurred in the Taurus Mountains during the Miocene-early Pliocene main phase of Alpine orogeny (Ala and Moss, 1979). At the same time, compressional foreland folding developed to the south, which contains essentially all the oil fields thus far found in this region.

STRATIGRAPHY AND SEDIMENTATION

Introduction

Rocks of all Phanerozoic geologic systems are present in northeast Africa and the Middle East. Marine transgressions from the north, northwest, and northeast have periodically covered the platform provinces since Cambrian time, resulting in a more complete and more marine stratigraphic section in those directions. Stratigraphic breaks are more prevalent to the south and southwest toward the clastic source area, which most of the time was located in the shield areas of southern Algeria, Niger, northern Chad, northern Sudan, southeastern Egypt, and western Arabia. The total sedimentary cover in northeast Africa ranges in thickness from less than 3,500 ft (1,000 m) on the south part of the platform to more than 30,000 ft (9,000 m) along the Mediterranean coast of Libya and Tunisia, and more than 20,000 ft (7,000 m) in most of northern Egypt (figs. 5, 6-11). The sedimentary cover of central Africa is confined to a series of isolated large rift basins containing mainly Mesozoic and Tertiary continental deposits. The continental basins are limited on the east by the Ethiopian plateau and rift valley province, where the Precambrian basement is exposed in broad, high plateaus. In this region, the rift valleys and adjacent areas are covered by thick volcanics of Late Cretaceous to Holocene age probably underlain by a thin section of Jurassic and Cretaceous marine and continental carbonate and clastic beds. The Red Sea basin to the north contains as much as 15,000 ft (5,000 m) or more of middle and late Cenozoic clastic, carbonate and evaporite deposits.

Total sedimentary thickness, excluding Cenozoic volcanics, in the Horn of Africa (Somalia and eastern Ethiopia) is less than 3,000 ft (900 m) in central Ethiopia, thickening to as much as 15,000 ft (5,000 m) or more in southeastern Ethiopia and in the coastal region of Somalia. In the Middle East, original thickness of the sedimentary cover is less than 5,000 ft (1,500 m) in the near-shield area of central Saudi Arabia and is probably 40,000 ft (12,000 m) or more in southwestern Iran and northeastern Iraq (figs. 5, 18-20).

The stratigraphic section of the Middle East region includes rocks ranging in age from late Precambrian to Holocene. Significant erosional or non-depositional breaks are present in all parts of the section, particularly in the Paleozoic on the Arabian platform and in parts of the Zagros region, so that probably nowhere in the region is there present a complete stratigraphic section of all ages (figs. 18-20). Phanerozoic depositional history is dominated by carbonate and clastic sedimentation, mainly marine, across a broad stable platform attached to the African-Arabian craton and bounded on the north and northeast, first by the Hercynian ocean, and later by the Alpine Neo-Thethyan oceans. Frequent marine trangressions and regressions across this broad platform, coupled with a relatively complex tectonic history in parts of the region, resulted in variable sedimentary facies and numerous breaks in sedimentation. Such a paleogeographic-paleotectonic history tended to leave a more or less cyclic sequence of carbonate-evaporite or clastic-carbonate deposits in much of the region. The Paleozoic sequence is dominated by marine and continental clastic deposition, which changes to a dominantly marine carbonate-evaporite section in the Late Permian. This thick blanket of lower and middle Paleozoic sandstone originally may have covered much of the African-Arabian craton and probably provided the major sand source for most of the younger sandstone facies in the region during frequent periods of emergence, along with subsequent marine transgression and reworking. Regional unconformities are recognized in the Paleozoic section in the Cambrian, pre-Devonian and early Carboniferous. Pre-Permian Paleozoic carbonate rocks are restricted to minor occurrences in the Cambrian, Lower Devonian and Carboniferous. The Mesozoic and early Cenozoic section is more complete and is dominated by marine carbonate and evaporite facies. Frequent breaks in sedimentation also occur in this section but most are relatively minor compared with those in the Paleozoic.

Paleozoic

In North Africa, Paleozoic rocks are absent in parts of central and southern Egypt, east-central Libya, and northeastern Algeria, and elsewhere are more than 10,000 ft (3,000 m) thick in northeastern and northwestern Libya, central and eastern Algeria, and in the Jefara trough on the Pelagian platform (figs. 6-11, 21). During most of Paleozoic time, the interior of the African continent was largely emergent, and Paleozoic rocks are not reported in the subsurface of the central African basins, although in some of the basins the basal beds overlying basement could be of late Paleozoic age (Petters, 1979a, b, 1981). The extensive Paleozoic deposits of the North African (Sahara) platform are generally absent, except for the lower beds of the "Nubian" Sandstone, south of a line running through southern Egypt, northern Sudan, central Chad, and northern Niger (fig. 21). Coarse clastic rocks of Carboniferous, Permian-Triassic, and perhaps Early Jurassic age are present in the Karroo facies of southeastern and eastern Africa, which extends northward into Kenya and possibly into southern Ethiopia and southwest Somalia (figs. 15, 16, 21). In the subsurface of the African coastal basins bordering the Indian Ocean north of Madagascar, the Karroo continental coarse clastic facies is interbedded with marine fine clastic rocks and evaporites, including salt of Permian-Triassic age. The evaporite beds may extend northward as far as the Mandera-Lugh basin.

The Nubian sandstone facies of the African Sahara, which extends southward into northern Sudan and northern Ethiopia and possibly eastward into Jordan, is probably present in the subsurface in parts of the Red Sea basin, Afar depression, and northernmost Somalia. In Egypt and Libya, the Nubian contains beds of probable Carboniferous age, some of which may be present in the Nubian beds of east-central Africa. Sandstone remnants of probable Ordovician age also are reported in northern Ethiopia (Beyth, 1973).

The total thickness of Paleozoic rocks in the Middle East region is speculative because of little or no control in much of the area. Greatest thicknesses are probably in excess of 15,000 ft (4,500 m) in Oman and probably in southwestern Iran, northeastern Iraq, and northern Syria and Turkey (fig. 21).

Cambrian.--Except where eroded on Hercynian uplifts, conglomerate and sandstone of Cambrian age overlie basement rocks in all basin areas of the Sahara platform in North Africa. Cambrian-Ordovician rocks are thin or absent by Hercynian or post-Hercynian erosion in parts of the Sirte basin and westward on the Algerian anticlinorium and eastward in much of Egypt (figs. 2, 6-11) but are 3,000 ft (900 m) or more thick in central and northwestern Algeria, northwestern and southeastern Libya, and on the Cyrenaican platform in northeastern Libya and northwestern Egypt. These clastic beds are continental in origin to the south but contain marine shale and sandstone beds to the north and northwest, particularly in the Ordovician part of the section. In parts of North Africa, glacial and periglacial deposits are present in the uppermost Ordovician. Erosional remnants of fractured Cambrian-Ordovician quartzites as much as 2,000 ft (600 m) thick, are horst-block reservoir rocks, sourced by Mesozoic bituminous shales in several oil fields in the Sirte basin, particularly in the western part (figs. 6, 9). Cambrian-Ordovician sandstones unconformably overlain by Triassic sandstones and evaporites are the most important reservoirs in Algerian fields, sourced by Silurian (Gotlandian) graptolitic shales (Magliore, 1970; Balducchi and Pommier, 1970; Bishop, 1975). Devonian and Carboniferous marine shale beds may be additional source rocks for some oil and gas accumulations in southeastern Algeria.

On the Arabian Peninsula, the oldest sedimentary rocks above the basement are the terrestrial and marine carbonate, clastic and evaporite beds (including salt) of the Huqf Group, which is probably of Eocambrian age (Murris, 1980). The Huqf is a thick sequence of sandstone and carbonate overlain by an evaporite section that contains the thick Hormuz Formation salt beds (fig. 19) and equivalent stromatolitic carbonates. The Hormuz salt occurs in four separate salt basins, identified in Oman (Ara salt), southwestern Iran and the Perisan Gulf (figs. 15-20). Halokinetic movement of this salt in early Mesozoic and later time is responsible for enhancement of numerous oil field structures in the Persian Gulf and Fars region of Iran and in Oman. The structural magnitude of some major onshore fields in eastern Saudi Arabia may be enhanced by salt movements. According to Murris (1980), each area underlain by salt exhibits a somewhat different combination of salt structure styles probably dependent on thickness of salt and overburden as well as the nature of other tectonic movements in the region. The salt also acted as an important detachment horizon during folding and thrusting in the Zagros Mountains and foothills region in Cretaceous and late Cenozoic time.

The Cambrian carbonate and clastic section is estimated to range between 1,500 ft (450 m) and 6,000 ft (1,800 m) in southeastern Turkey and northeastern Syria (Ala and Moss, 1979).

Infracambrian-Cambrian, Cambrian-Ordovician, and Middle Paleozoic sandstone and carbonate beds are reservoirs in several relatively small oil fields in Oman (fig. 1).

Ordovician, Silurian, and Devonian.--In North Africa, sandstone beds of Ordovician age are unconformably overlain by widespread black to dark gray, commonly bituminous graptolitic shale of Silurian (Gothlandian) age, 1,000 ft (300 m) or more thick in places. These beds are the main source rocks for petroleum in Algeria and parts of Tunisia and northwestern Libya (figs. 6-9). The bituminous shale beds are overlain by a regressive marine sandstone unit, which is present on most of the Sahara platform except where removed by Hercynian erosion.

Rocks of Devonian age, which unconformably overlie Silurian sandstone beds, are marginal marine or continental sandstone, siltstone, and shale beds, which become more marine to the north and northwest. Carbonate beds intertongue with clastic beds to the west, and Devonian reefs are reported in the Bechar and Tindouf basins of western Algeria and southwestern Morocco.

Devonian rocks are absent because of Hercynian and post-Hercynian erosion in much of north-central and northeastern Algeria, northwestern Libya, the Sirte basin, and most of Egypt. They are thickest, as much as about 3,300 ft (1,000 m), in the Algerian basins and in the Ghadames basin and Cyrenaica platform of Libya (figs. 2, 6, 8, 9).

In the Middle East, rocks of Ordovician, Silurian and Devonian ages are primarily marine and terrestrial blanket sandstone deposits with some shale and siltstone, sourced from the African-Arabian craton to the southwest. Widespread regressive sand deposition took place in the Early Ordovician, although graptolitic shales are present in Saudi Arabia as well as to the northeast in the Zagros region and in central Iran. Most of these sand deposits may be derived from reworking of Cambrian-Eocambrian beds on the craton to the southwest.

Part or all of this section is absent in parts of the Middle East region, probably because of Hercynian erosion. Silurian and Devonian rocks may be absent in places because of Caledonian epeirogenic uplift in parts of Saudi Arabia, Iran, Iraq, and Oman (Berberian and King, 1981), where Devonian, Carboniferous, or in some cases Permian, rocks rest unconformably on Ordovician or older sandstone and shale. A more complete section has been observed in the Zagros Mountains and foothills, where Silurian graptolitic shales are believed to be the source for gas in overlying Permian or Triassic reservoirs. In Turkey and southeastern Syria, Ordovician and Silurian clastics, 3,000 to 6,000 ft (900 to 1,800 m) thick, including bituminous shales, are present, overlain locally by a thin Devonian clastic section or by Permian-Carboniferous rocks in most places (Ala and Moss, 1979). In the Zagros basin region, Late Ordovician to Silurian emergence took place and continued until late Paleozoic time (Berberian and King, 1981). Szabo and Kheradpir (1978) report that in the vicinity of the Zagros suture, mid-Permian rocks rest on a truncated Silurian to Infracambrian surface.

Carboniferous.--Rocks of Carboniferous age in North Africa are shallow-water marine and nonmarine sandstone, siltstone, and shale, which are unconformable on Devonian rocks in most of Libya and southern Algeria, but are probably conformable in the basins of southeastern and western Algeria. The Carboniferous marine transgression spread across most of the Sahara platform from the west and northwest, but erosion took place on several of the main uplifts at this time, including the Algerian anticlinorium, Nefusa uplift, Amguid spur in Central Algeria, and other associated north-south uplifts, the Gargaf arch, Tibesti-Sirte arch, and Jamal-Al Zalmuk uplift (figs. 1, 2, 6, 8, 9). Carboniferous rocks are thickest, 3,000 ft (900 m) or more, in the southern and western Algerian basins, in the Ghadames basin, and the Jefara trough in northwestern Libya, and on the Cyrenaica platform in northeastern Libya. Several hundred meters of Carboniferous sandstone and shale are also present in parts of northeastern Egypt, particularly in the Suez basin, which probably was subsiding at this time (Said, 1962). Parts of this section are sandstone reservoirs in some of the Suez basin oil fields.

Hercynian movement in Carboniferous time resulted in erosion and development of a regional unconformity that affected much of the Middle East region. Relatively thin sandstone and minor carbonate beds, resting on Devonian and older rocks are present in parts of Arabia and Iraq. Remnants of Late Carboniferous to Permian glacial deposits are reported in Saudi Arabia and also in Oman, where they are part of the Paleozoic oil field reservoir section (Powers, 1966; Koop and Stoneley, 1982). Carboniferous beds thicken northward in Syria and Turkey, where a significantly greater amount of carbonate rock is present (Ala and Moss, 1979).

Permian.--Permian rocks apparently are absent on almost all of the Sahara platform in North Africa as a result of prolonged Hercynian emergence. Thin clastic beds of possible Permian age may be present in the northwestern part of the Hamada basin south of the Nefusa uplift, which rose rapidly at this time. Concurrently, the east-west Jefara trough, immediately north of the Nefusa uplift, was strongly downwarped and received a great thickness of fine clastic and carbonate units of Permian age 13,000 ft (4,000 m) or more thick, including reefal carbonate deposits, (Bishop, 1975; Burollet and others, 1978) (figs. 1, 2, 8, 22). Displaced remnants of the Permian reefal section appear in Sicily and Turkey as well as in the southern Alps, giving evidence of a perhaps extensive fringe of Permian carbonates bordering Gondwanaland on the north.

Carbonate and clastic rocks of Permian age ranging up to at least 4,000 ft (1,200 m) thick are present throughout most of the Middle East region (fig. 22). These rocks are primarily terrestrial and shallow water marine sandstones along the eastern and northern borders of the Arabian Shield and grade eastward into marine carbonate and evaporite facies, underlain by thin sandstones. A shelf-margin organic carbonate or reefal facies is present along the Zagros Mountains belt in Iran, southwest of which intra-shelf carbonate and interbedded evaporite facies are present in a broad belt parallel to the shelf margin (fig. 22). Permian as well as Triassic anhydrite beds are probable seals for most hydrocarbon accumulations in Permian reservoir sandstones or carbonates. The basal Permian sandstones contain glacial deposits in southern Saudi Arabia and Oman (Helal, 1965; Powers, 1966). Permian rocks thin along the Qatar arch, possibly reflecting early growth of this paleostructure. Oil is produced from Permian sandstone and carbonate reservoirs in Oman (fig. 1, 22). Permian carbonate reservoirs contain major accumulations of gas in eastern Saudi Arabia, the Gulf region, and in the Fars region of Iran (figs. 1, 22). Source rocks for this gas are thought to be Silurian bituminous shales beneath the pre-Permian Hercynian unconformity. Possible other sources are Permian marine shale or limestone beds, or graptolitic marine shale beds reported from Ordovician sections in parts of this area.

Permian time represents the establishment of widespread carbonate platform deposition that continued through Mesozoic and most of early Tertiary time in the Middle East. Local sources of clastics emerged in the High Zagros region at this time. Permian rocks in Syria and southern Turkey are primarily marine, in part reefal, carbonate facies underlain by marine shales and some sandstone (Ala and Moss, 1979).

Mesozoic

Mesozoic rocks are less than 1,500 ft (500 m) thick on most of the southern Sahara platform (fig. 23) and are variable in thickness elsewhere in North Africa, ranging from less than 3,000 ft (900 m) locally on paleostructures to more than 10,000 ft (3,000 m) along the southern margin of the Mediterranean Tethys seaway.

Mesozoic rocks are present in all of the main central and east African basins but represent a wide range of depositional environments, including shelf carbonate and clastic beds of Jurassic and Cretaceous age in Somalia and Ethiopia, deep-water marine clastic and evaporite beds in Kenya, and continental fluvial-lacustrine beds in the central African interior basins.

Mesozoic rocks in the Middle East form a northeasterly thickening wedge of primarily carbonate-evaporite facies ranging in thickness from less than 1,000 ft (300 m) in central and northern Saudi Arabia to more than 15,000 ft (4,500 m) in the Mesopotamian basin of Iraq and in parts of the Zagros fold belt region (figs. 18-20, 23).

Triassic.--After Hercynian emergence, Mesozoic transgression from the north (Tethyan ocean) resulted in deposition of a widespread marine and continental clastic unit ("Trias Argilo-Greseux") in northern and central Algeria and Tunisia, which unconformably overlies rocks ranging in age from Carboniferous to Cambrian or Precambrian (figs. 3, 5, 7, 24). These rocks are as much as 1,500 ft (500 m) thick in Algeria and southern Tunisia where they are oil and gas reservoirs. The basal Triassic clastic unit is 0 to 1,500 ft (0 to 500 m) thick and grades upward into a marine shale, dolomite, anhydrite, and salt unit ("Trias Argileux-Salifere"), which in turn is overlain by the "Trias Salifere," a predominantly salt unit. These beds are 0 to 3,300 ft (0 to 1,000 m) thick or more and are the main regional seal for numerous Triassic and Paleozoic oil and gas fields in Algeria, northwestern Libya, and southern Tunisia. Thin Triassic clastic beds also are present in northern Egypt, the Sinai, and the Gulf of Suez (El Shazly, 1977).

Triassic rocks are not known in central and east-central Africa but possibly may be buried at great depths along the Somalia coast and offshore and in the Mandera-Lugh and Lamu basins of Somalia and Kenya.

Rocks of Triassic age, as much as 3,000 ft (900 m) or more thick, are present in the eastern part of the Arabian Peninsula region, except for the southern part in Yemen and part of Oman (fig. 22). The Triassic represents regressive, arid conditions following the Late Permian transgression. Clastic deposition increased at this time in a broad region bordering the eastern and northern margins of the Arabian Shield. To the east in the Gulf and Zagros basin region, a restricted carbonate-redbed-evaporite sequence (Dashtak Formation) developed to the southwest of a shelf margin organic carbonate facies (Khaneh Kat Formation) extending northwest-southeast in the High Zagros Mountains and the foothills fold belt (figs. 18-20). Triassic evaporites are a regional seal for Permian gas deposits (Murris, 1980) and also contain good reservoir rocks but are generally non-productive of hydrocarbons, except for gas in a few fields in the Zagros fold belt (fig. 1). Possibly this is related to lack of associated Triassic or other source rocks (Murris, 1980).

Jurassic.--Lower Jurassic (Lias) salt and anhydrite, as much as 1,500 ft (450 m) or more thick, overlie Triassic evaporites in central and northern Algeria and Tunisia, and in northwestern Libya north of the Nefusa uplift. An upper Liassic platform facies is present in the north-south lineament of Tunisia ("Jurassic Ranges") where a series of faulted uplifts expose up to 1,000 ft (300 m) of carbonate at the western edge of the Pelagian block; these strata give way farther west to basinal facies. The Liassic beds grade into overlying Middle and Upper Jurassic marine fine clastic deposits and limestone

1,500 ft (450 m) or more thick in northern Algeria and southern Tunisia and more than 3,500 ft (1,000 m) thick in eastern Tunisia and on the Pelagian platform north of the Nefusa uplift (Bishop, 1975). The Middle and Upper Jurassic carbonate facies, which represents the first widespread transgression of the Tethyan sea in North Africa, is also present in northeastern Libya and northern Egypt and in northeastern Egypt adjacent to the Mediterranean coast (figs. 2, 6, 8, 25). Jurassic continental sandstone beds may be present as part of the "Nubian" sandstone facies in southern Libya and Egypt.

Rocks of Jurassic age are present in the east-central African coastal basins in Somalia, Kenya, and Ethiopia (figs. 3, 25). These rocks constitute a primarily marine carbonate and fine clastic facies deposited on the western shelf of the regional Somali basin, which may be a southern arm of the Mesozoic Tethyan Middle East Arabian shelf. This facies reaches a western zero edge that runs approximately north-south in central Ethiopia (figs. 14-16, 25). Thickness is approximately 3,000 to 13,000 ft (1,000 to 4,000 m) in Somalia, eastern Ethiopia, and eastern Kenya but is less than 1,000 ft (300 m) on the Nogal uplift and in the vicinity of the Bur Acaba uplift (figs. 14-16, 25).

The basal Jurassic unit (Adigrat Sandstone), ranging in thickness from less than 100 ft (30 m) to more than 325 ft (100 m), represents the initial deposits of the widespread Tethyan marine transgression of the east African, Arabian, and north African continental shelf. This unit is probably latest Triassic and Early Jurassic age in the coastal basins of Somalia and is younger to the northwest, becoming uppermost Jurassic in age near its western limits in central Ethiopia, where it grades upward into Early Cretaceous sandstone beds. To the south, in the Mandera-Lugh basin and the Lamu embayment, the Adigrat probably merges into the upper part of the Karroo facies or the Mansa Guda Formation (figs. 3, 16,). In the shelf area, the Adigrat grades upward into the Hamanlei Formation (Antalo Limestone of northern Ethiopia), primarily a Tethyan marine shelf carbonate facies of Middle and Upper Jurassic age (figs. 3, 14-16). The Hamanlei is composed of fossiliferous limestone, some gray shale, and minor amounts of siltstone or fine sandstone. Oolitic and coralline limestone beds occur in southern Somalia and parts of Ethiopia, and anhydrite is interbedded cyclically with dolomite and limestone in northern Somalia. The carbonates become more shaly and are interbedded with dark gray marine shale in the Somali embayment and the Mandera-Lugh basins and Lamu embayment (figs. 15, 16). The Hamanlei Formation ranges in thickness from less than 1,000 ft (300 m) to more than 6,500 ft (2,000 m) in Somalia and eastern Ethiopia and thins and becomes more sandy to the west toward the depositional limit in Ethiopia.

The Hamanlei Formation is overlain by the Late Jurassic Uarandab Formation, a marine unit primarily of marly or shaly limestone and gray shale. Gypsum beds also are present in northern Somalia and in eastern Ethiopia. The uppermost Jurassic is represented by the Gabre Darre Formation, a marine gray shale and limestone unit less than 100 ft (30 m) to about 1,500 ft (450 m) thick, widely distributed in Somalia and eastern Ethiopia.

Rocks of Jurassic age are 5,000 ft (1,500 m) or more thick in parts of the Middle East, thinning to an erosional limit along the borders of the Arabian Shield and to a depositional limit in southeastern Oman and central South Yemen (fig. 25). Jurassic facies are dominated by shallow water marine carbonate deposits as part of the regional carbonate shelf extending across North Africa and the Middle East along the southern border of the Tethyan ocean (north border of the Gondwana continent). Following regression in Late Triassic time, and beginning with Jurassic time, the Middle East and Sahara platform regions underwent several episodes of marine transgression-regression. Each succeeding main transgressive phase advanced farther across the shelf, a general characteristic of worldwide Jurassic history. During Early Jurassic time, shelf carbonate deposition became dominant and widespread in the southeastern part of the Middle East platform and along its shelf margin in the vicinity of the High Zagros Mountains. To the north, in west central and eastern Iraq and western Iran, intra-shelf basinal and evaporitic carbonate facies formed in the Mesopotamia basin region to the west of the high Zagros belt. At the same time, terrigenous clastics were mixed with the carbonate facies along the western edge of the shelf adjacent to the Arabian Shield. Throughout the Early and Middle Jurassic, clastic deposition, including terrestrial and nearshore marine sandstones, was more prevalent along the southwestern border of the Jurassic Tethyan sea. Regression from the shelf occurred at the close of Early Jurassic time, resulting in deposition of gypsiferous beds in much of the eastern platform region. To the south in Oman and South Yemen, Early Jurassic deposits are absent or thin and are apparently overlapped by Middle Jurassic transgressive facies.

The Middle Jurassic transgressive carbonate facies spread widely to the west across the Middle East platform, overlapping Lower Jurassic clastic and mixed clastic-carbonate deposits along the entire craton border. A broad blanket of cyclically deposited carbonate sands or grainstones alternating with argillaceous carbonate beds (Dhruma Formation), covered much of the platform (Murris, 1980) and extended southwest from the Rub al Khali basin across North Yemen. At this time the connection with the Jurassic Somalia basin to the south may have been complete. A prominent clastic source appears to have been present in the vicinity of the Hadhramaut arch in South Yemen and Oman, which at times may have separated the Arabian shelf province from that in Somalia-Ethiopia. This uplift area, at this time, may have been a part of equivalent uplifts in northeastern Somalia.

To the north on the less restricted shelf in the Mesopotamian intra-shelf basin, evaporitic deposition was replaced by deeper water argillaceous carbonate and calcareous shale facies. These facies relationships suggest that the Middle Jurassic transgression was mainly the result of eustatic sea-level rise rather than intensified tectonic movement or climatic change. The Middle Jurassic transgression apparently did not completely envelop the shelf region to the west of the Mosul arch, as evidenced by the presence of relatively thick Lower and Middle Jurassic carbonate and evaporite facies in Syria and southeastern Turkey (Ala and Moss, 1979).

Late Callovian and Oxfordian time represents a major transgression of the Peninsula region, and probably most other shelf provinces of the African-Arabian craton. Shallow water shelf deposits spread widely across the shelf, overlapping older beds and extending far to the southwest into North Yemen, South Yemen, and probably into the Somalia-Ethiopia-Kenya region. During this time, a blanket of cyclically deposited banks of porous oolitic limesand (packstone or grainstone) and bioclastic carbonate beds built up across the shelf, particularly along and adjacent to the regional Qatar arch. Subsequent diagenesis, including minor early dolomitization, of these rocks aided in forming the widespread belt of superb reservoir rock facies (Tuwaiq Mountain, Hanifa, Jubaila, and Arab Formations) in central Saudi Arabia, which contain many of the major oil accumulations of the Middle East province.

The Hanifa-upper Tuwaiq Mountain transition appears to represent the beginning of gradual regression following the widespread Oxfordian transgression. During this time, the thinly laminated argillaceous and pelloidal carbonate facies of good source-rock character was deposited under restricted circulation conditions in depressions on the partly emergent shelf. The main concentration of this facies is in central Saudi Arabia northwest of the Qatar arch and farther north in the Mesopotamian intra-shelf basin (fig. 25). These beds show alternating quiet water and more agitated water conditions, suggestive of fluctuations in sea level during deposition. The presence of anhydrite crystals in some laminae suggest that the organic matter may have accumulated and been preserved under conditions of somewhat elevated salinity. These relationships suggest that the Hanifa-upper Tuwaiq Mountain high-organic facies represents a temporary regression followed by an early transgressive phase as marine waters deepened on the shelf, following exposure and diagenesis of the underlying carbonate banks. The Hanifa grades upward into the overlying basal deeper water micritic limestone beds of the Jubaila Formation, which in turn are overlain by the Arab D oolitic grainstone banks and capping anhydrite that complete the subcycle. The Arab D beds may represent a still-stand progradation episode prior to deposition of evaporite as part of the final intermittent but overall regressive phase of the Late Jurassic.

Important source rock facies of Jurassic age are also reported in Middle Jurassic beds and some in Lower Jurassic beds on the Arabian shelf (Ayres and others, 1982). Important carbonate reservoir facies, in addition to the Tithonian Arab A, B, C, and D units, include Jubaila and Hanifa oolitic and bioclastic grainstones, the Tuwaiq Mountain and Dhruma Formations in Saudi Arabia and the Darb and Araeg Formations in the southern Persian Gulf and adjacent onshore area to the southwest.

The latest Jurassic (Tithonian) cycles of the Middle East represent widespread regression of the Jurassic seas from the platform in conformity with worldwide regression at this time. The platform became restricted in marine circulation, and evaporitic environments prevailing during regressive phases, were cyclically interbedded with oolitic grainstones representing short transgressive and progradational fluctuations in the overall main regressive cycle. The final regression deposited the relatively thick and widespread Hith anhydrite and equivalent evaporite beds throughout much of the platform region. During this regressive phase, salt (Gotnia Formation) also was deposited in the Mesopotamian basin to the northeast, and some salt beds were deposited in the Rubal Khali basin, as well as thick salt deposits in the Sadah graben to the southwest in North Yemen and South Yemen (fig. 25). The Hith and Arab anhydrites and equivalent salt beds form a regional seal covering vast areas of the platform as far east as much of the Gulf region and the foothills fold belt in Iran (figs. 18-20, 25). According to Berberian and King, (1981) and Koop and Stoneley, (1982), the top of the Jurassic represents a regional unconformity in the Middle East region.

Cretaceous.--Periodic transgressions of the Tethyan sea in North Africa continued across the Sahara platform during the Cretaceous, becoming increasingly more widespread with time, and reaching as far south as northern Sudan and southern Libya in Cenomanian time. The maximum Cretaceous trangression may have established a narrow linkage between the Mediterranean Tethys and south Atlantic oceans through Niger and Nigeria (Furon, 1963; Kennedy, 1965; Nairn, 1978; Reyment and Reyment, 1980; Petters, 1979a, b).

Lower Cretaceous beds in North Africa are represented by part of the continental "Nubian" sandstone facies ("Continental Intercalaire" to the west) in Egypt, southern Libya and southern Algeria. The Nubian grades northward into a nearshore and some deeper water marine facies, which contains some marine limestone in northern Algeria, Tunisia, northwestern and northeastern Libya, and northern Egypt. The age of the Nubian is questionable; the lower part may be as old as Carboniferous and the upper part as young as Late Cretaceous in places. Thickness of these beds and their Lower Cretaceous marine equivalents ranges from 300 to 600 ft (100 to 200 m) in the south to 3,000 ft (900 m) or more in northern Algeria, Tunisia, the Pelagian and Cyrenaica platforms, and northern Egypt (figs. 6-10). Thickness of these rocks may reach 10,000 ft (3,000 m) or more in the subsurface of northern Egypt along the Mediterranean coast.

During Late Cretaceous time, the northern part of the Sahara platform continued to tilt northward toward the Mediterranean Tethys region, accompanied by north-northwest to south-southeast rifting, which formed the Sirte basin graben and horst structures and probably affected parts of northern Egypt. Upper Cretaceous rocks are dominated by a thick Tethyan shelf carbonate and offshore marine shale facies to the north, which becomes intertongued with nearshore marine and continental sandstone facies to the south. In the Sirte basin, a basal nearshore marine sandstone unit, resting on Cambrian-Ordovician or Precambrian rocks, is present. The basal sandstone is thickest on horst blocks and grades upward into predominantly carbonate beds, which may be reefal on horst blocks and adjacent slopes, and dark marine shale, which is thicker and highly bituminous in adjacent grabens. In the Erg Occidental and Erg Oriental basins in central and eastern Algeria, Upper Cretaceous rocks are marine carbonate and clastic deposits and some evaporites, including a thin salt layer (figs. 6, 8, 28). Upper Cretaceous rocks in North Africa are thickest in basinal areas bordering the Mediterranean and are 3,000 ft (900 m) or more thick in northern Algeria, eastern Tunisia, the Pelagian platform, graben troughs of the Sirte basin, and several small Late Cretaceous basins in northwestern Egypt (figs. 6-10). Marine phosphatic beds of latest Cretaceous age are present in west-central Egypt, Israel, and Jordan.

Sandstones of Middle Cretaceous and basal Late Cretaceous age are important oil reservoirs in the eastern part of the Sirte basin, and carbonate rock reservoirs of Late Cretaceous age are productive on horst blocks in the central part of the basin. Marine Cretaceous shales, mainly deposited in adjacent downdropped grabens, are the source of these oils (Parsons, and others, 1980). Nubian sandstone beds of Cretaceous and older age are productive on tilted fault blocks in the Suez graben. Lower Cretaceous carbonate reservoirs and Cretaceous sandstones also are productive in several Western Desert basin anticline or faulted anticline fields in Eygpt, sourced by marine Cretaceous shales. Lower and Upper Cretaceous sandstone and carbonate reservoirs sourced by Cretaceous marine shales are productive in small fields in Tunisia and the offshore Pelagian platform.

The Jurassic-Cretaceous boundary is unconformable in parts of the Horn of Africa (Somalia, eastern Ethiopia, and Kenya), particularly in the vicinity of major uplifts such as the Nogal and Bur Acaba highs and to the west in Ethiopia (figs. 1, 3, 14-16). In basinal areas such as the Lamu embayment and the Mandera-Lugh and Ogaden basins, however, the unconformity may be absent or greatly diminished (Kamen-Kaye and Barnes, 1979). Further evidence of regression at the close of the Jurassic includes the presence of extensive deposits of gypsum or anhydrite (Main Gypsum) in the uppermost Jurassic-Lower Cretaceous section in eastern Ethiopia and parts of northern Somalia (figs. 3, 14-16). In coastal Somalia, Lower Cretaceous beds are primarily shaly limestone and limestone, some of which is reefoid (Cotton and Garba Harre Formations). In the Lamu embayment, Lower Cretaceous rocks are primarily marine gray shale and shaly limestone underlain by sandstone and shale beds, which may also be of Early Cretaceous age (fig. 3).

Rocks of Late Cretaceous age are represented by the Gumburo Group in Ethiopia and Somalia and by marine shale, sandstone, and minor limestone in the Lamu embayment in Kenya (figs. 3, 14-16). The lower unit of the Gumburo is a marine sequence of marly limestone and shale (Mustahil Limestone) that contains lenticular rudist reefs; it seems to be best developed in the vicinity of the Bur Acaba uplift, although it is not distinguishable in all places in the subsurface (Barnes, 1976). The Mustahil is gypsiferous in the upper part and grades into the overlying Ferfer Gypsum Formation on the north flank of the Bur Acaba uplift. Elsewhere in Somalia and eastern Ethiopia, the Upper Cretaceous section comprises the undifferentiated Gumburo Group, which is primarily marine fossiliferous limestone, reefoid in places, and dark gray marine shale. To the south, rocks of Late Cretaceous age are primarily marine shale with minor limestone. In the vicinity of the Bur Acaba uplift and extending northwestward into Ethiopia, a tongue of the Gumburo limestone and gray shale facies (Belet Wen Formation) is overlain by the Jesomma Sandstone of latest Cretaceous to Paleocene age.

Rocks of Cretaceous age are approximately 3,000 to 5,000 ft (1,000 to 1,500 m) thick along the Somalia coastal belt and thin westward and northward to less than 1,500 ft (450 m) in much of eastern Ethiopia. In southern and eastern Kenya, 10,000 ft (3,000 m) or more of Cretaceous rocks are present.

Limited information is available on the internal stratigraphy of the central Africa interior basins (Upper Nile, Khartoum, Doba-Doseo or Chari, Chad, and Iullemmeden or Niger basins). Wells drilled in these basins have penetrated a sedimentary section 10,000 to 15,000 ft (3,000 to 4,500 m) or more thick, reportedly mainly continental and lacustrine clastics of Cretaceous and Tertiary age, little of which is exposed in outcrops on basin borders. Most of this stratigraphic section apparently is of Cretaceous age. Sedimentary thickness reaches 20,000 ft (6,000 m) or more in the main inner basin rift troughs. The basal part of the section may be of Jurassic or earlier age, and rocks probably of Carboniferous and Devonian age are reported in a well drilled in the northwest part of the Iullemmeden basin (Petters, 1981). On the southeast border of this basin, an outcropping sequence of Late Jurassic, Cretaceous, and early Tertiary age contains some marine clastic and carbonate rocks of latest Cretaceous and Paleocene age (Petters, 1979a, b), which is also present in the basin interior. The basal unit (Damergou sequence) is composed of conglomerate, sandstone, and clay of Late Jurassic and Early Cretaceous age (Gundumi and Illo Formations of northwest Nigeria, "Continental Intercalaire" of southwest Niger) that is also present in the Chad basin. The basal clastic unit is overlain by the Ajaouk sequence, a Late Cretaceous (Maestrichtian) marine cycle of sandstone, siltstone, and mudstone with some lignite (Taloka Formation), overlain by mudstone, gypsiferous shale, and marl (Dukamaje Formation). The Maestrichtian cycle is overlain by beds of the Paleocene marine cycle, which in ascending order consist of the Wurno Formation (siltstone, fine sandstone and carbonaceous mudstone), the Dange Formation (marine phosphatic shale), and the Kalambaina Formation (marl and phosphatic shale). On the outcrop, the Paleocene cycle is overlain by continental beds of clay and sandstone (Gwandu Formation or Dosso sequence) of Eocene age.

A somewhat similar sequence is present in the southwest part of the Chad basin (Petters, 1979a, b) where the basal continental redbed unit (Damergou sequence or "Continental Intercalaire") is approximately 6,500 ft (2,000 m) thick in the graben floor of the basin and thins to 3,000 ft (900 m) or less on the basin borders. These beds are mainly of Early Cretaceous age; the basal part may be partly of Permian to Jurassic age. The overlying Ajaouak sequence (Late Cretaceous-Paleocene) of marine and continental sandstone, siltstone, green and gray shale, and some limestone is approximately 3,500 ft (1,000 m) thick. The post-Paleocene Dosso sequence consists of approximately 1,000 ft (300 m) to 2,000 ft (600 m) of coarse fluvial sandstone and lacustrine clay beds. Detailed descriptions of the lithology, fossil content, and distribution of these units are given by Petters (1979a, b, 1981).

Wells drilled in the interior of the Upper Nile basin are reported to have penetrated a continental and lacustrine clastic section more than 13,000 ft (4,000 m) thick of Cretaceous and Tertiary age similar in lithology to that of the Chad and Doba-Doseo basins. Most of the stratigraphic section is Cretaceous in age and consists of lacustrine, fluvial, alluvial, and floodplain sandstone, conglomerate, and shale. In much of the basin, 20,000 ft (6,000 m) or more of sedimentary rocks are present, and the deepest interior trough contains more than 35,000 ft (10,500 m) (Schull, 1984). Organic-rich lacustrine shales of Aptian-Albian and Cenomanian age, present in the central parts of the basin, apparently are the source beds for oil accumulations in lacustrine-fluvial reservoirs of Cretaceous and early Tertiary age (Schull, 1984). Rocks of late Paleozoic age, mainly sandstone, present at some outcrop localities in parts of Sudan, particularly to the north, could be present in the floor of the Upper Nile and Khartoum basins. The Gedaref and Eritrean sandstone of Jurassic age and the Yirol Formation (sandstone, shale and conglomerate) of latest Jurassic-Early Cretaceous age crop out near the borders of the Upper Nile basin (Whiteman, 1971a, b). Much thicker equivalents of these beds apparently are present in the basin subsurface.

Rocks of Cretaceous age in the Middle East province are variable in thickness, ranging from generally less than 3,000 ft (900 m) in central Saudi Arabia, western Iraq, Oman and North and South Yemen, to more than 5,000 ft (1,500 m) in much of Iran, Iraq, eastern and southeastern Saudi Arabia, eastern Oman, and the southern Gulf region (figs. 18-20, 26-28). Cretaceous facies in these areas are dominated by cyclic deposition, either carbonate-evaporite or sandstone-carbonate cycles throughout the region.

Following the regressive Late Jurassic evaporitic phase, normal marine shelf carbonate deposition again spread widely across the Middle East Platform. The Lower Cretaceous Thamama Group and equivalents overlie the Jurassic evaporite section disconformably in several high areas, including the Qatar arch, parts of the Arabian shelf, and much of Iraq and Iran (Berberian and King, 1981; Koop and Stoneley, 1982), although deposition probably was relatively continuous in the main basinal areas.

The lower Thamama deposits tend to be confined to basinal areas and were not deposited in the region of the Mosul arch and the Hadhramaut arch. The lower Thamama cycle consists of argillaceous limestone and carbonate grainstone (Sulaiy Formation) overlain by primarily carbonate grainstone (Yamama Formation). In the basinal area of northeastern Arabia, the Sulaiy facies contains petroleum source rocks (Ayres and others, 1982). The lower Thamama is separated by a disconformity from the upper Thamama cycle, and probably was not deposited in the region of the Hadhramaut arch.

The upper Thamama cycle (upper Neocomian-Aptian Zubair and overlying Shu'aiba Formations) begins the dominantly Middle Cretaceous cyclic pattern of shield-derived clastics, including widespread quartzose sands, overlain by transgressive marine shelf carbonates. Four additional Cretaceous clastic-carbonate cycles (Wasia Group) were repeated above the upper Thamama cycle. During deposition of these cycles, terrestrial and deltaic deposits built eastward from the shield source terrane and were overlain by widely transgressive marine shelf carbonate deposits. The sand facies probably results from reworking and redeposition of Paleozoic and early Mesozoic sand (Nubian facies?) derived from the African-Arabian craton. Sand influx reached a maximum in Albian time when the regressive and early transgressive Burgan deltaic sands and associated deposits spread to the northeast into the Kuwait area adjacent to the southern Mesopotamian basin (figs. 18, 19, 27). Burgan sands are well-sorted, fine- to medium-grained and generally uncemented. These sands probably were deposited as deltaic distributaries and in many cases are interstratified with coal and carbonaceous silts.

During deposition of the upper Thamama and Wasia Groups, the Cretaceous seas widely transgressed the platform and shield regions, probably reaching a much greater source of sand than previous cycles. Important regressive sandstone and transgressive carbonate reservoir formations were deposited during this time, including the Zubair, Burgan, Khafji, Safaniya, and Wara sandstones and the Shu'aiba, Mauddud, and Mishrif carbonates (figs. 18,19, 27). In intra-shelf depressed areas to the east, argillaceous limestone or shale facies were deposited, in some cases comprising bituminous petroleum source rock facies, which in part intertongues with or underlies shelf sand facies. These include the Kazhdumi (Albian), Shu'aiba (Albian-Aptian), and Nahr Umr Formations. Each main cycle is commonly disconformable with the succeeding one, culminating in development of the pre-Senonian unconformity, which affected most of the Middle East region after deposition of the Wasia Group.

Upper Cretaceous facies are dominated by cyclic deposition of carbonate and fine clastic units of the Aruma Group. However, Senonian cycles are not so clearly defined as those of previous Mesozoic cycles. during this time, the Middle East was subjected to widespread orogenic movements, which significantly influenced sedimentation patterns. Regional uplift occurred at the end of Turonian time, accompanied by complex plate-margin tectonics along the Zagros suture zone associated with the beginning of the Alpine orogeny (collision phase). These movements caused the intra-shelf basins and highs to accentuate, resulting in more rapid thickness and facies changes on the shelf as well as in the extensive trough area to the east, the main depocenter of which shifted westward with time. A major clastic source developed along the High Zagros belt, together with a series of foredeep bains to the southwest of this orogenic belt. The foredeep basins then filled with flysch and deeper water sediments from adjacent highlands to the east. To the southwest, a major clastic source area developed, possibly related to arching in the Gulf of Aden-southern Red Sea region. Evaporites formed in the northern end of the Arabian shelf where a graben complex formed and was filled locally with unusually thick Late Cretaceous deposits of shale and argillaceous limestone, partly bituminous. Important petroleum reservoirs in the Upper Cretaceous section include the Hartha, Mishrif, Shiranish, Ilan, and Sarvak carbonates. In the Gulf and in the foothills fold belt, numerous shale seals, some of regional extent, are present in the Upper Cretaceous section. Some of these, particularly the Gurpi Shale, also are important source rock facies, where they are buried deeply enough to be mature as in the Zagros fold belt and Arabian-Iranian basin.

To the north in southeastern Turkey and northeastern Syria, Cretaceous deposits are 5,000 to 10,000 ft (1,500 to 3,000 m) or more thick, and are generally dominated by basinal deposits to the east and marine shelf carbonates, incuding rudist reef complexes, to the west. Equivalent rocks in the Lebanon-Israel-Jordan region are as much as 5,000 to 15,000 ft (1,500 to 4,500 m) or more thick, mainly of marine shelf carbonate facies with rudist reefs in places.

Cenozoic

Tertiary rocks with petroleum potential in North Africa are confined to the region bordering the Mediterranean Sea, including the Sirte basin, the Pelagian platform, Western Desert basin, Nile Delta, and the Nile and Suez grabens. Tertiary sedimentary facies in this region are primarily marine carbonate and fine clastic deposits as much as 10,000 ft (3,000 m) thick, except for the deltaic, alluvial, and marine Oligocene and younger clastic deposits of the Nile Delta, which reach 16,000 ft (5,000 m) or more (fig. 29, 30). Tertiary rocks are thin or absent in the western Sahara region of Algeria and western Libya, and where present are primarily continental clastic beds of Miocene-Pliocene age a few hundred meters thick or less (figs. 6, 8, 29, 30).

Paleocene and Eocene carbonate rocks and marine shale are as much as 6,500 to 10,000 ft (2,000 to 3,000 m) thick in northeastern Tunisia, the Pelagian platform, and the Sirte basin. In these areas, this facies contains reef or carbonate mound buildups, including the nummulitic reservoir facies, and widespread marine shale of Eocene age that provide good regional seals. According to El Shazly (1977), parts of northern Egypt may have been structurally high during the Paleocene-Eocene. Sediments of this age are thinner and more sandy than equivalent beds to the south. Concurrent subsidence of the Suez graben area also is indicated by a greater thickness of Paleogene beds in that area.

Clastic sedimentation, including thick northerly derived molasse deposits in Tunisia, was more dominant in Oligocene time, also a time of uplift and erosion in much of the eastern Sahara and Egypt. Relatively thick marine carbonate beds are present on the Pelagian platform but tend to be shaly rather than reefy. In the Sirte basin, Oligocene rocks are primarily marine shale that blankets most of the basin, indicating regional subsidence and tilting of the entire basin area and cessation or diminishing of horst and graben growth.

The final transgression from the Mediterranean region took place during the early Miocene, when marine carbonate and shale beds were deposited in eastern Tunisia, the Pelagian platform, Sirte basin, Cyrenaica platform, Western Desert basin, and in the Suez graben where reef beds of this age are significant oil reservoirs. During the middle and late Miocene, widespread regression of the Alpine sea occurred, concurrent with culmination of Alpine orogeny to the north. Continental and nearshore marine deposits are prevalent in beds of this age, and thick deposits of calcium sulfate and salt were laid down in the Suez graben, the Red Sea, and the central Mediterranean.

The Sahara platform was a region of general uplift during the Pliocene; deposits of this age are relatively thin or absent over most of the platform. Continental clastic deposits are present in parts of Algeria and southern Tunisia, and marine Pliocene beds are present in Tunisia, in offshore areas of the Pelagian platform, and in northern Libya and northern Egypt. In the Gulf of Suez, Pliocene sediments as much as 1,500 ft (450 m) thick grade from marine clastic deposits in the south to continental gravel and sand in the north. According to El Shazly (1977), at this time the proto-Nile River formed in the Nile graben, a fracture system more or less parallel to the Red Sea graben. Post-Miocene sediments several thousand meters thick in the Nile Delta north of Cairo consist of shallow marine sand and shale that, because the modern delta was forming, become increasingly sandy and deltaic upward.

During Holocene time, the Mediterranean shoreline in north Africa regressed slightly to the north, and a veneer of dune, small lake, and alluvial sand and fine clastic units was deposited on the Sahara platform. The Nile Delta accumulated as much as about 2,500 ft (800 m) of sand and clay. Some oolitic carbonate beds were deposited along the Mediterranean coast, and several hundred meters of marine clastic deposits accumulated on the Pelagian platform.

Lower Tertiary reefal or carbonate mound beds are important reservoirs in the Sirte basin, primarily on horst blocks in the central parts of the basin. In a few large oil fields, Tertiary pinnacle reefs form isolated reservoir bodies on the flanks of horst blocks or within the grabens. Organic-rich source marine shales of Cretaceous, Paleocene, and Eocene age are closely associated with these reservoirs (Parsons and others, 1980). Regional shale and argillaceous limestone seals of Late Cretaceous and early Tertiary age are present throughout most of the Sirte basin. Eocene and Miocene carbonate rocks are productive reservoirs in a few small fields in Tunisia and the offshore Pelagian platform region. Upper Cretaceous and lower Tertiary marine shales are the probable source of these hydrocarbons. In the Suez graben, early Tertiary and Miocene reefal or carbonate mound bodies are the more important reservoirs for petroleum trapped beneath Miocene salt or anhydrite beds on tilted fault blocks in pre-Miocene rocks. Lower Miocene bituminous foraminiferal marls and shales are the primary source rocks for these accumulations. Upper Cretaceous marine shale and bituminous limestone and Eocene bituminous limestone are secondary sources. Productive reservoirs at small gas fields in the gas-prone Nile Delta are deltaic and shoreline sandstones and siltstones of Pliocene-Miocene and possibly early Tertiary age, sourced by interbedded marine and deltaic carbonaceous shales.

In Somalia and eastern Ethiopia, Tertiary rocks are represented by the upper part of the Jesomma Sandstone and the Auradu, Taleh, and Karkar Formations of Paleocene and Eocene age. The Jesomma Sandstone is of latest Cretaceous and Paleocene age (Kamen-Kaye and Barnes, 1979) and is widely distributed in eastern Ethiopia and central Somalia (figs. 3, 14-16). The Auradu of Paleocene and early Eocene age is a marine fossiliferous limestone unit as thick as 1,500 ft (450 m) or more in northern Somalia but changes to a deeper water facies of marine shale and argillaceous limestone to the east and southeast in Somalia. The Auradu is overlain by and interbedded with a sequence of interbedded gypsum, limestone, and shale (Taleh Formation), which changes eastward and northward primarily to dolomite and to the south and southeast to sandstone, red and green shale.

Post-Eocene sedimentary rocks generally are absent in northern Somalia and eastern Ethiopia but are present in east-central and southeast Somalia along the coastline, where they are represented by 3,500 ft (1,100 m) or more of marine sandstone, shale, and limestone in the Lamu embayment. Rocks of Tertiary age are approximately 1,500 to 3,400 ft (450 to 1,100 m) thick in most of Somalia north of the Bur Acaba uplift and reach thicknesses of 10,000 to 16,000 ft (3,000 to 5,000 m) in parts of the Lamu embayment to the south (figs. 14-16, 29). Tertiary sedimentary rocks generally are absent or very thin in the vicinity of the Bur Acaba uplift and in Ethiopia approximately west of 45^{o}, except for beds of probable early Tertiary age in the upper part of the Jesomma Sandstone. A substantial amount of the lower Tertiary section may have been removed by post-Eocene uplift and erosion on the Somalia-Ethiopia shelf so that complete sections of Tertiary rocks are present only eastward along the Somalia coast, in the Lamu embayment, and offshore in the Somali basin.

In central Ethiopia, Tertiary rocks are primarily of volcanic origin associated with growth of the rift valley system. As much as 6,500 ft (2,000 m) or more of basaltic and other volcanic flows, tuffs, and tuffaceous sediments are preserved in highlands bordering the rift valleys. These volcanic rocks are probably interbedded with continental and lacustrine tuffaceous sediments in the subsurface of the rift valleys. Tertiary rocks exposed in the Afar depression, which adjoins the southern Red Sea and Gulf of Aden depressions, are primarily Pliocene-Pleistocene fluvial and lacustrine gravels, sands, clays, tuffs, and other volcanic rocks, and some lacustrine limestones or marls (Taieb, 1975; Kursten, 1975) as thick as several hundred meters. These rocks intertongue northward with Pliocene-Pleistocene evaporitic beds 3,500 ft (1,100 m) or more thick (Danakil Formation and basalt of Hutchinson and Engels, 1972).

As much as 16,000 ft (5,000 m) or more of Oligocene and younger Tertiary marine and continental clastic, evaporite, and carbonate sediments are present in the Red Sea depression (figs., 3, 17, 30) (Lowell and Genik, 1972; Ahmed, 1972). Oligocene and lower Miocene rocks consist primarily of continental and marine sandstone and shale, in places interbedded with volcanic rocks. Near the center of the basin, middle and upper Miocene rocks are mainly evaporites and fine clastics that include thick deposits of salt and grade westward to marine sandstone and siltstone, shale, and *Globigerina* marl. Upper Miocene-Pliocene beds (Desset series) are primarily marine clastics with coral reefs overlain by Quaternary evaporites (including salt) and marine clastics.

Outcropping rocks of Tertiary age in the vicinity of the Upper Nile basin in Sudan are represented by the Hudi Chert of lacustrine origin, equivalents of which may make up much of the relatively thick Tertiary section in the subsurface. Outcropping Late Tertiary and Pleistocene deposits in central and southern Sudan are represented by gravel and sand beds of the Uum Ruwaba Formation, which may be as thick as 1,600 ft (500 m) or more in downfaulted depressions (Setlow, 1982). Lake Sudd, a proposed Pleistocene lake, is believed to have occupied parts of the area of the upper Nile basin, generally in the region of the extensive modern Sudd swamp (Whiteman, 1971a, b).

Tertiary and younger rocks in the Middle East are 10,000 ft (3,000 m) or more thick in the fold belt of southwestern Iran and thin westward to a zero line in central Saudi Arabia (figs. 18-20, 29, 30). Deposition of shallow water marine and shelf carbonate and evaporite beds (Umm er Radhuma Formation and equivalents and the overlying Rus anhydrite and carbonate) of Paleocene and early Eocene age continued on the Arabian platform without significant interruption in the transition from Cretaceous to early Tertiary time. The Zagros Mountains belt continued to rise, and strong clastic influx continued from the rising orogen. The adjacent marine foredeep to the southwest continued to subside rapidly, receiving a thick flysch and molasse facies, which grades westward to a thick deposit of open-marine, deeper-water shale (Pabdeh Formation) in southwestern Iran. Widespread regression and emergence occurred over much of the region in late Eocene time, and continued into the early Oligocene when marine transgression recurred. The Oligocene-lower Miocene transgressive phase was confined to the main subsiding trough in southwestern Iran and northeastern Iraq where the marine Asmari Limestone and equivalent beds were deposited. The Asmari is overlain by thick evaporite deposits (Gachsaran Formation) in the trough region, which in turn are overlain by a thick coarse clastic facies of continental origin (Bakhtyari Formation and equivalents), derived from the rising Zagros Mountains. At this time, the main phase of Zagros Mountain building occurred. Contemporaneous growth of the adjacent fold complex to the southwest resulted in wide variations in thickness of the Bakhtyari deposits.

Emergence and erosion continued on the Arabian shelf through most of post-Eocene time, and the main Zagros depocenter shifted progressively westward to its present-day position in the Persian Gulf.

SUMMARY AND CONCLUSIONS

The depositional and tectonic record of the Middle East and North Africa platforms illustrates an extensive history of unusually favorable events and conditions, which in total combine to make this region a premier petroleum province. Several authors have addressed the question of why the Middle East is such a prolific petroleum province, including Lees (1950), Law (1956), Dunnington (1967), Kamen-Kaye (1970), Kent and Warman (1972), Murris (1980), Ayres (1982), and Abdubrahma and Kendall (1986). Consensus is apparent on the major tectonic-stratigraphic factors involved: (1) exceptionally large size of the area and long stability of the platform region through most of Phanerozoic time, (2) depositional cycles that provided widespread organic-rich, source-rock facies (now thermally mature), along with closely associated high quality carbonate and clastic reservoir facies, and (3) a history of relatively mild tectonic movements sufficient to form large paleostructural traps with large drainage areas and unusually efficient horizontal and vertical migration paths, but not strong enough to destroy earlier accumulations. An important additional trapping factor is halokinetic movement of salt during and after deposition of the main petroleum bearing section. With respect to preservation of the originally trapped major oil accumulations, particularly in the large structures of Saudi Arabia, the probable major influence of the regional anhydrite seals of Triassic age deserves comment. Huge volumes of natural gas are trapped beneath these seals in carbonate reservoirs of Permian age. If the Triassic anhydrite beds were not present, vertical migration of much of this gas through fractured or porous overlying carbonate rocks would have initially filled traps beneath the Jurassic Hith anhydrite seal or would have displaced earlier-trapped oil beyond the spill-point. Under these conditions, much of the oil generated from Jurassic source rocks would have migrated westward to form major heavy oil or tar deposits in and near the outcrop belt of central Saudi Arabia, leaving major gas accumulations in the structural traps of the shelf province.

Judging from world paleogeographic maps (Smith and Briden, 1977; Bambach and others, 1980; Ziegler, personal communication, 1986), the position and orientation of the Gondwana continent exerted a profound influence on the nature and distribution of Phanerozoic sedimentary facies and associated potential reservoir, source, and seal rocks of the Sahara and Middle East platforms. The unique latitudinal positions of the Gondwana platform belt through geologic time, coupled with associated tectonic events, ultimately may have determined the generation, migration, accumulation, and preservation capacity for the immense hydrocarbon resources of the region. During early Paleozoic time, most of the ancestral Gondwana continent comprised the Africa, South America, Australia, Antarctica, and India cratons, and associated minor attached continental fragments (fig. 21). Gondwana was oriented with North Africa and the Middle East on the south, generally within the southern polar region. By Silurian and Devonian time, Gondwana had rotated clockwise and drifted northward to a position where the Sahara and Middle East platforms faced to the north into the open warmer water ocean. In late Carboniferous time, further northward movements and clockwise rotation led to collision between Gondwana and Larussia (the ancestral North America-west Europe continent), creating the proto-Tethys ocean. After this time and until final closing of the Tethys seaway in the Late Tertiary, the platform belt faced generally northeastward toward the open ocean, located at variable positions within the tropical to subtropical equatorial to subequatorial region between

30^{o} N. and 30^{o} S. (figs. 21-29). The regional sedimentary record of this vast continental margin shelf province can be interpreted as representing a progressive sequence of events related to continental positions and accompanying tectonic episodes.

1. Pre-Infracambrian.--Consolidation of the basement - a complex of tectonic-sedimentary events, the record of which is now intensely metamorphosed and intruded by subsequent igneous activity.

2. Infracambrian - Cambrian (approximately 700-500 m.y.B.P.).--Primarily continental and shallow water marine coarse clastic deposition with some stromatolitic carbonate and fine clastics. The presence of glacial and periglacial deposits in the Infracambrian section confirm a higher latitude position at this time. During Cambrian time, the Middle East and Sahara platforms were generally on the west-facing margin of Gondwana in the vicinity of the southern hemisphere subequatorial and temperate belts approximately between 15^{o} and 55^{o} S. Clastic deposition dominated most of this time, interrupted by deposition of the thick Hormuz salt in late Infracambrian and Early Cambrian time on the western margin of Gondwana.

3. Late Cambrian - Carboniferous (approximately 500-300 m.y.B.P.).--By Ordovician time, the south-facing Sahara-Middle East platforms were in the southern polar latitudes below 50^{o} S. Widespread marine regression (probably eustatic) of the craton occurred and clastic deposition prevailed, including early Paleozoic glacial and periglacial deposits recognized in the western Sahara and on the Arabian Peninsula. These deposits orginally may have been widespread across the platform region, but in much of the area have been removed by later Paleozoic erosion.

   By Silurian time, Gondwana had been rotated and drifted northward to place the Sahara-Middle East platforms into a north-facing position at approximately 30^{o}-45^{o} S. Marine nearshore coarse clastic deposition continued, but during the early transgressive stage of the Silurian sea euxinic high-organic black shale deposits, perhaps associated with rapid evolution of graptolitic and other planktonic faunas, were deposited on the shallow subtropical shelf in the northern part of the platform belt. These deposits are widespread in the central and western Sahara regions and, except where removed by Hercynian and later erosion, should be present in much of the subsurface of northern Egypt, Iraq, and Iran.

   The early Silurian transgressive phase continued through Devonian and early Carboniferous time, when the platform belt was positioned within the proto-Tethys tropical to subtropical belt at approximately 10^{o}-30^{o} S. (fig. 21). Clastic deposition continued to prevail but progressively became more marine, and with continued northward drift of Gondwana carbonate deposition occurred at times in the outer shelf region. Epeirogenic Hercynian movements on the platform, probably related to collision between Gondwana and Larussia (creation of the Pangea supercontinent), resulted in widespread erosion or non-deposition over much of North Africa in late Carboniferous and Early Permian time. Gondwana rotated clockwise at this time, and the Middle East platform drifted southward to a position between 30^{o}-45^{o} S. Glacial and periglacial deposits identified in southern Saudi Arabia and Oman are believed to be part of the extensive region of late Carboniferous-Early Permian continental glaciation covering South America and southeastern Africa at this time (de la Grandville, 1982).

4. Permian-Triassic (approximately 300-200 m.y.B.P.).--Permian-Triassic was a time of worldwide regression, probably partly related to initial breakup of the Pangea supercontinent and creation of new oceanic troughs, along with continued Early Permian continental glaciation. Widespread deposition of redbed, evaporite, and carbonate facies began in the Late Permian, including significant shelf-margin reefoid buildups. Beginning in Late Permian time, the Sahara-Middle East platform belt became oriented in a northwest-southeast direction between approximately 0^{o}-30^{o} S. (figs. 22, 24) within the optimum environment for carbonate deposition. Concomitant rifting and opening along the Zagros suture zone created the final form of the Middle East shelf, which persisted more or less in this form until Late Tertiary time. Subsequent to this event, the Middle East shelf margin remained relatively constant along the Zagros belt. Redbed, clastic, carbonate, and evaporite deposition continued on the shelf through Middle Triassic time, when regional regression, probably eustatic, was accompanied by erosion and widespread deposition of continental coarse clastics (fig. 24).

5. Jurassic-Cretaceous (early Alpine) (approximately 200-75 m.y.B.P.).--During and after the breakup of Gondwana and the opening of the Mediterranean extension of the Tethys ocean beginning in Triassic time, the North Africa-Middle East region formed a single continental mass (figs. 24-29). The Sahara-Middle East platform belt continued to be oriented northwest-southeast along the southwestern border of the Tethyan tropical to subtropical seaway between approximately 20^{o} N.-30^{o} S. The platform remained in this position until approximately the close of Jurassic time, when slow northward drift shifted the platform belt to approximately between 15^{o} N. and 25^{o} S., where it remained relatively fixed through most of the Cretaceous. A warm, shallow water, easterly trade wind environment with optimum organic carbonate deposition prevailed within this belt and continued with some modification into the Tertiary. The main clastic source area on the Arabian-Nubian shield to the southwest remained low and probably under dry climate conditions throughout most of this time as documented by extensive eolian deposits in the Carboniferous-Cretaceous Nubian Sandstone beds. Stream flow and influx to the shelf region therefore was minimal, further enhancing the clear water carbonate environment. During higher sea-level transgressive (probably eustatic) phases, organic carbonate bodies and grainstone facies built up along the shelf margin and on intrashelf highs such as the Qatar and Central Arabian arches. Deeper water argillaceous carbonate muds, some with relatively high organic carbon content, accumulated in intrashelf lows. During regressive lower sea-level stages, partial exposure and early diagenesis of organic and grainstone carbonate facies occurred. At the same time, shelf margin carbonate buildup continued along the Zagros belt, which acted as an effective sill for marine waters circulating across the shelf. The shelf margin also was probably an important upwelling belt for maximum production of marine plankton, which drifted into the shelf province and were preserved in sites of anoxic bottom conditions, particularly during low sea-level stages. These deposits make up the better source-rock facies of the shelf sequence. During maximum regression and lowest sea-level phases, evaporites formed in the intrashelf lows and at times across most of the restricted shelf (e.g., Hith Anhydrite).

Collision along the Zagros belt, accompanied by uplift and thrusting from the east and northeast, closed the Tethyan ocean late in Cretaceous time and created an active highland terrigenous clastic source area along the ancestral Zagros and Oman Mountains belt, accompanied by strong subsidence of the adjacent foredeep to the southwest.

6. Middle Alpine (close of Cretaceous to early Miocene) (approximately 75-15 m.y.B.P.).--Following the Late Cretaceous collision and closure of the eastern ocean, the African-Arabian continent drifted slowly northward and rotated slightly counterclockwise to reach its approximate modern position by late Miocene-Pliocene time (fig. 30). The Tethyan-Mediterranean seaway remained open through late Oligocene or early Miocene time, and cyclic marine shelf carbonate-evaporite deposition continued along the margin of the seaway (fig. 29). However, with continued uplift and terrigenous clastic influx along the Zagros uplift, the shallow-water Arabian shelf seaway was progressively confined to a much narrower shelf carbonate belt in eastern Saudi Arabia and southwestern Iraq. Concomittant increase in clastic influx from the African-Arabian Shield further diminished organic carbonate production in the western shelf region. Shelf carbonate deposition prevailed along the Mediterranean margin during the Paleogene, but retreated northward as a consequence of increased clastic influx from the African craton during Oligocene-Miocene time. Northward drift and ultimate collision of the African-Arabian and Eurasian land masses resulted in cut off of the Mediterranean from the main Tethys seaway and caused mid to late Miocene evaporite deposition (including salt) in the central Mediterranean, Suez and Red Sea grabens (Messinian salt), and in the Mesopotamian-Arabian trough (Gachsaran evaporites).

Comparisons.--Although the Middle East is rightfully recognized as the world's premier petroleum province, containing the world's largest oil resources, appropriate comparisons can be made with other significant provinces of approximately equivalent size, e.g., the West Siberian basin and the Rocky Mountain Cordilleran shelf (fig. 31). Each of these is unique in certain characteristics of stratigraphic and tectonic history, but many similarities to the Middle East are present, particularly with respect to total petroleum generating capacity of the sedimentary rock complex.

The West Siberian basin is essentially a Mesozoic-Cenozoic basin with a history of cyclic deposition similar to that of the Middle East, except that the sedimentary section is almost totally marine shallow water clastics vs. marine carbonate and evaporites in the Middle East. Similar Jurassic and Cretaceous sea-level fluctuations (probably eustatic) and significant intrabasin paleostructural growth affected depositional cycles in both areas. However, probably in part because of differing paleolatitudinal positions, radically different but highly efficient source, reservoir, and seal facies resulted. During most of Mesozoic time, the West Siberian basin was positioned between approximately 50^{o} and 60^{o} N. latitude. The basin was adjacent to broad, low-lying clastic source terranes under temperate moist climate conditions, with a resulting high influx of terrigenous clastics into a shallow water shelf environment, subjected to cyclic sea-level fluctuations (Clarke and others, 1978; Peterson and Clarke, in press). Major reservoir and seal facies were deposited during times of transgressive or still-stand sea-level, and major subjacent source-rock facies deposited during regressive, restricted circulation conditions. The entrance to the basin was on the north, where the North Siberian Ridge formed a major sill across which northern waters entered the basin. The sill was probably an important upwelling belt for high production of marine plankton, which concentrated in low regions of the basin during low sea-level stages. Under these depositional environmental conditions, in contrast to the Middle East, carbonate and evaporite deposition were essentially absent, but production and preservation of organic matter was high. Likewise, because of widespread and efficient reservoir facies, migration and accumulation efficiency was high. In addition to regional shale seals, widespread permafrost, both Pleistocene and modern, is an effective seal in the northern part of the basin.

Under these contrasting paleolatitudinal and sedimentary environment conditions, the Middle East and West Siberian basin petroleum provinces have generated and accumulated high volumes of total hydrocarbon resources, approximately 2,000 BBOE and 1,000 BBOE in place, respectively. Approximately 60 percent of the West Siberian resources are in the form of natural gas, but the total makes this basin one of the world's most important. Although the generation capacity of both these provinces is exceptionally high, the preservation factors are of utmost importance in both cases, primarily related to the stage of structural development. The Middle East shelf and the West Siberian basin are both essentially intact in their original form because post-hydrocarbon accumulation structural growth has not been strong enough to destroy or significantly alter the high volume of original resources.

Although approximately equivalent in area, the Rocky Mountain Cordilleran shelf of western United States and Canada contrasts with the West Siberian and Middle East provinces in the relatively low conventionally recoverable hydrocarbon resources (approximately 200 BBOE (in place) (Dolton and others, 1981; Derro and others, 1977). However, both western Canada and the United States contain large resources of heavy oil and tar sands (Carrigy, 1980), which if added to the conventionally recoverable resources total at least 2,000 BBOE (in place) of total original generating capacity for the Rocky Mountain shelf. The Rocky Mountain sedimentary sequence of Cambrian to Cenozoic age was influenced by cyclic depositional processes similar to that of the Middle East, although because of different paleolatitudinal positions, sedimentary facies of similar ages are quite different. Paleozoic facies in the Rocky Mountains are dominated by tropical to subtropical carbonate and evaporite deposition, and Mesozoic and Tertiary facies by northern latitude marine clastic deposition, the approximate opposite of the Middle East. In contrast with the Middle East, however, the Rocky Mountain shelf underwent several episodes of strong orogenic movements, both epeirogenic and thrusting, during late Paleozoic-early Mesozoic, Late Cretaceous-Early Tertiary, and Late Tertiary times. These movements had significant effects on reservoir and source-rock alteration, and petroleum migration paths. Furthermore, thrusting along the shelf margin and strong vertical uplift over much of the shelf in Late Cretaceous and Tertiary times resulted in the destruction or remigration of many earlier accumulations. In Canada, broad emergence of the shelf region in Late Cretaceous and Tertiary time probably resulted in remigration of earlier accumulations and ultimately in degradation, water washing, and oxidation of migrated oils to form extensive heavy oil and tar deposits.

From the standpoint of petroleum generation capacity and province size, the Rocky Mountain shelf can be compared with the Middle East and the West Siberian basin. In contrast to these premier petroleum provinces, however, the detrimental effects of intense post-accumulation tectonic movements ranks the Rocky Mountain region comparatively low in conventionally-recoverable resources.

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SELECTED REFERENCES

Ahmend, S. S., 1972, Geology and petroleum prospects in eastern Red Sea: American Association of Petroleum Geologists Bulletin, v. 56, p. 707-719.

Al-Laboun, A. A., 1986, Stratigraphy and hydrocarbon potential of the Paleozoic succession in both the Tabuk and Widyan basins, Arabia, in Halbouty, M. T., ed., Future petroleum provinces of the world: American Association of Petroleum Geologists Memoir 40, p. 373-397.

Ala, M. A., 1974, Salt diapirism in southern Iran: American Association of Petroleum Geologists Bulletin, v. 58, p. 1758-1770.

Ala, M. A., and Moss, B. J., 1979, Comparative petroleum geology of southeast Turkey and northeast Syria: Journal of Petroleum Geology, v. 1, p. 3-27.

Ala, M. A., Kinghorn, R., and Rahman, M., 1980, Organic geochemistry and source rock characteristics of the Zagros petroleum province, southwest Iran: Journal of Petroleum Geology, v. 3, p. 61-89.

Alexander, R. G., Jr., 1986, California and Saudi Arabia--Geologic contrasts, in Halbouty, M. T., ed., Future petroleum provinces of the world: American Association of Petroleum Geologists Memoir 40, p. 291-315.

Alsharhan, A. S., and Kendall, C. G., St. C., 1986, Precambrian to Jurassic rocks of Arabian Gulf and adjacent areas--their facies, depositional setting, and hydrocarbon habitat: American Association of Petroleum Geologists Bulletin, v. 70, p. 977-1002.

Anhaeusser, C. R., Mason, R., Viljoen, M. J., and Viljoen, R. P., 1969, A reappraisal of some aspects of Precambrian shelf geology: Geological Society of American Bulletin, v. 80, p. 2175-2200.

Ayers, M. G., Bilal, M., Jones, R. W., Slentz, L. W., Tartir, M., and Wilson, A. O., 1982, Hydrocarbon habitat in main producing areas, Saudi Arabia: American Association of Petroleum Geologists Bulletin, v. 66, p. 1-9.

Baker, N. E., and Henson, F.R.S., 1952, Geological conditions of oil occurrence in Middle East fields: American Association of Petroleum Geologists Bulletin, v. 36, p. 1885-1901.

Balducci, A., and Pommier, G., 1970, Cambrian oil field of Hassi Messaoud, Algeria, in Geology of giant petroleum fields: American Association of Petroleum Geologists Memoir 14, p. 477-388.

Bambach, R. K., Scotese, C. R., and Ziegler, A. M., 1980, Before Pangea--The geographies of the Paleozoic world: American Scientist, v. 68, p. 26-38.

Barnes, S. U., 1976, Geology and oil prospects of Somalia, east Africa: American Association of Petroleum Geologists Bulletin, v. 60, p. 389-413.

Barr, F. T., and Berggren, W. A., 1980, Lower Tertiary biostratigraphy and tectonics of northern Libya, _in_ Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: London, Academic Press, p. 163-192.
Barr, F. T., and Weegar, A. A., 1972, Stratigraphic nomenclature of the Sirte Basin, Libya: Petroleum Exploration Society Libya, Tripoli, 179 p.
Bein, A., 1976, Rudistid fringing reefs of Cretaceous shallow carbonate platform of Israel: American Association of Petroleum Geologists Bulletin, v. 60, p. 258-272.
Beltrandi, M. D., and Pyre, A., 1973, Geological evolution of southwest Somalia, _in_ Sedimentary basins of the African coasts, part 2: Association of African Geological Surveys, p. 159-178.
Berberian, M., and King, G.C.P., 1981, Towards a paleogeography and tectonic evolution of Iran: Canadian Journal of Earth Sciences, v. 18, p. 210-265.
Beydoun, Z. R., 1966, Geology of the Arabian Peninsula, eastern Aden Protectorate and part of Dhufar: U.S. Geological Survey Professional Paper 560-H, 49 p.
_____1977, Petroleum prospects of Lebanon, Reevaluation: American Association of Petroleum Geologists Bulletin, v. 61, p. 43-64.
_____1985, The geological setting and tectonic framework of the Middle East, _in_ Source and habitat of petroleum in the Arab countries: Proceedings, OAPEC Seminar, Kuwait, p. 5-72.
Beydoun, Z. R., and Dunnington, H. V., 1975, The petroleum geology and resources of the Middle East: Scientific Press, Beaconsfield, 99 p.
Beyth, M., 1973, The Paleozoic-Mesozoic sedimentary basin of the Mekele Outlier, north Ethiopia, _in_ Blant, B., ed., Sedimentary basins of the African coasts: Association of African Geological Surveys, p. 179-190.
Billo, S. M., 1983, Petroleum geology of the Arabian Peninsula: Oil and Gas Journal, March 14, 1983, p. 91-101.
Bishop, W. F., 1975, Geology of Tunisia and adjacent parts of Algeria and Libya: American Association of Petroleum Geologists Bulletin, v. 59, p. 413-450.
Brady, T. J., Campbell, N.D.J., and Maher, C. E., 1980, Intisar "D" field, Libya, _in_ Halbouty, M. T., ed., Giant oil and gas fields of the decade 1968-1978: American Association of Petroleum Geologists Memoir 30, p. 543-564.
Brown, G. F., and Coleman, R. G., 1972, The tectonic framework of the Arabian Peninsula: 24th International Geological Congress, sec. 3, p. 300-305.
Brown, R. N., 1980, History of exploration and discovery of Morgan, Ramadan, and July oil fields, Gulf of Suez, Egypt, _in_ Miall, A. D., ed., Facts and principles of world petroleum occurrence: Canadian Society of Petroleum Geologists, Calgary, p. 733-764.
Burollet, P. F., 1967, General geology of Tunisia, _in_ Guidebook to the geology and history of Tunisia: Petroleum Exploration Society of Libya, 9th Annual Field Conference, p. 51-58.
_____1969, Petroleum geology of the western Mediterranean basin, _in_ The exploration for petroleum in Europe and North Africa: London, Institute of Petroleum, p. 19-30.
_____1971, La Tunise, _in_ Tectonics of Africa: Paris, UNESCO, p. 91-100.
_____1980, Petroleum potential of the Mediterranean basins, _in_ Miall, A. D., ed., Facts and principles of world petroleum occurrence: Canadian Society of Petroleum Geologists, Calgary, p. 707-722.
Burollet, P. F., Magnier, P., and Manderscheid, G., 1971, La Libye, _in_ Tectonics of Africa: Paris, UNESCO, p. 409-416.

Burollet, P. F., Mugniot, J. M., and Sweeney, P., 1978, The geology of the Pelagian block: the margins and basins off southern Tunisia and Tripolitania, _in_ Nairn, A.E.M., Kanes, W. N., and Stehli, F. G., eds., The ocean basins and margins, v. 4B, The Western Mediterranean: Plenum Press, New York and London, p. 331-362.

Choubert, G., and Faure-Muret, A., 1971, Chaines Plissees du Precambrian superior (Folded ranges of the upper Precambrian), _in_ Tectonics of Africa: Paris, UNESCO, p. 295-349.

Clark, R. H., 1975, Petroleum formation and accumulation in Abu Dhabi: Ninth Arab Petroleum Congress, Proceedings, Dubai, 20 p.

Clarke, J. W., Girard, O. W., Jr., Peterson, J. A., and Rachlin, J., 1978, Petroleum geology of West Siberian basin and Samotlor oil field: Oil and Gas Journal, May 8, 1978, p. 311-328.

Clifford, A. C., 1986, African oil-past, present, and future, _in_ Halbouty, M. T., ed., Future petroleum provinces of the world: American Association of Petroleum Geologists Memoir 40, p. 339-372.

Conant, L. C., and Goudarzi, G. H., 1967, Stratigraphic and tectonic framework of Libya: American Association of Petroleum Geologists Bulletin, v. 51, p. 719-730.

Daniel, E. J., 1954, Fractured reservoirs of Middle East: American Association of Petroleum Geologists Bulletin, v. 38, p. 774-815.

Dean, W. T., 1980, The Ordovician system in the near and Middle East: International Union of Geological Sciences, Publ. no. 2, 22 p.

de la Grandville, B. F., 1982, Appraisal and development of a structural and stratigraphic trap oil field with reservoirs in glacial to periglacial clastics, _in_ Halbouty, M. T., ed., The deliberate search for the subtle trap: American Association of Petroleum Geologists Memoir 32, p. 267-286.

Deroo, G., Powell, T. G., Tissot, B., and McCrossan, R. G., 1977, The origin and migration of petroleum in the Western Canadian sedimentary basin, Alberta: Geological Survey of Canada Bulletin 262, 136 p.

Dolton, G. L., Carlson, K. H., Charpentier, R. R., Coury, A. B., Crovelli, R. A., Frezon, S. E., Khan, A. S., Lister, J. H., McMullin, R. H., Pike, R. S., Powers, R. B., Scott, E. W., and Varnes, K. L., 1981, Estimates of undiscovered recoverable conventional resources of oil and gas in the United States: U.S. Geological Survey Circular 860, 87 p.

Dunnington, H. V., 1958, Generation, migration, accumulation and dissipation of oil in northern Iraq, _in_ Weeks, L. G., ed., Habitat of Oil: American Association of Petroleum Geologists, p. 1194-1251.

_____1967, Stratigraphical distribution of oil fields in Iraq-Iran-Arabia: Institute of Petroleum Journal, v. 53, p. 129-161.

El-Etr, H. A., and Moustafa, A. R., 1980, Delineation of the regional lineation pattern of the central Western Desert of Eqypt with particular emphasis on the Bahariya region, _in_ Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. III: Academic Press, London, p. 933-954.

El-Raba'a, S. M., 1978, Structural and metamorphic evolution of the basement complex of Sudan: Precambrian Research, v. 6, p. A-17.

El Shazly, E. M., 1977, The geology of the Egyptian region, _in_ Nairn, A.E.M., Kanes, W. H., and Stehli, F. G., eds., The ocean basins and margins, v. 4A: Plenum Press, New York and London, p. 379-444.

Engel, A.E.J., Dixon, T. H., and Stern, R. J., 1980, Late Precambrian evolution of Afro-Arabian crust from ocean arc to craton: Geological Society of American Bulletin, v. 91, p. 699-706.

Frost, S. H., Bliefnick, D. M., and Harris, P. M., 1983, Deposition and porosity evolution of a Lower Cretaceous rudist buildup, Shuaiba Formation of eastern Arabian Peninsula, in Harris, P. M., ed., Carbonate buildups--a core workshop: Society of Economic Paleontologists and Mineralogists, Core Workshop No. 4, p. 381-410.

Furon, R., 1963, Geology of Africa: Hafner, New York, 377 p.

Gealey, W. K., 1977, Ophiolite obduction and geological evolution of the Oman Mountains and adjacent areas: Geological Society of America Bulletin, v. 68, p. 1183-1191.

Gill, W. D., and Ala, M. A., 1972, Sedimentology of Gachsaran Formation (Lower Fars Series), southwest Iran: American Association of Petroleum Geologists Bulletin, v. 56, p. 1965-1974.

Glennie, K. W., Boeuf, M.G.A., Hughes-Clarke, M. W., Moody-Stuart, M., Pilaar, W.F.H., and Reinhardt, B. M., 1973, Late Cretaceous nappes in Oman Mountains and their geologic evolution: American Association of Petroleum Geologists Bulletin, v. 57, p. 5-27.

Gorin, G. E., Racz, L. G., and Walter, M. R., 1982, Late Precambrian-Cambrian sediments of Huqf Group, Sultanate of Oman: American Association of Petroleum Geologists Bulletin, v. 66, p. 2609-2627.

Grunau, H. R., 1985, Future of hydrocarbon exploration in the Arab world, in Source and habitat of petroleum in the Arab countries: Proceedings, OAPEC Seminar, October 1984, Kuwait, p. 451-499.

Harris, P. J., Frost, S. H., Seiglie, G. A., and Schneidermann, N., 1984, Regional unconformities and depositional cycles, Cretaceous of the Arabian Peninsula, in Schlee, J. S., ed., Interregional unconformities and hydrocarbon accumulation: American Association of Petroleum Geologists Memoir 36, p. 67-80.

Hassan, F., and El-Dashlouty, S., 1970, Miocene evaporites of Gulf of Suez region and their significance: American Association of Petroleum Geologists Bulletin, v. 54, p. 1686-1696.

Hassan, T. H., and Azer, S., 1985, The occurence and origin of oil in offshore Abu Dhabi: Proceedings SPE Middle East Technical Conference and Exhibition, March 1985, Bahrain, p. 143-155.

Haynes, S. J., and McQuillan, H., 1974, Evolution of the Zagros suture zone, southern Iran: Geological Society of American Bulletin, v. 85, p. 739-744.

Helal, A. H., 1965, On the occurrence and stratigraphic position of Permo-Carboniferous tillites in Saudi Arabia: Geol. Rundschau, v. 54, p. 193-207.

______1968, Stratigraphy of outcropping Paleozoic rocks around the northern edge of the Arabian shield (within Saudi Arabia): Deutsch. Geol. Gesell. Zeitschrift, v. 117, p. 506-543.

Holmes, A., 1965, Principles of physical geology: Ronald Press, New York, 1288 p.

Hull, C. E., and Warman, H. R., 1970, Asmari oil fields of Iran: American Association of Petroleum Geologists Memoir 14, p. 428-437.

Hutchinson, R. W., and Engels, G. G., 1972, Tectonic evolution in the southern Red Sea and its possible significance to older rifted continental margins: Geological Society of American Bulletin, v. 83, p. 2989-3002.

Ibrahim, M. W., 1983, Petroleum geology of southern Iraq: American Association of Petroleum Geologists Bulletin, v. 67, p. 97-130.

James, G. A., and Wynd, J. G., 1965, Stratigraphic nomenclature for Iranian Oil Consortium Agreement area: American Association of Petroleum Geologists Bulletin, v. 49, p. 2182-2245.

Kamen-Kaye, M., 1970, Geology and productivity of Persian Gulf synclinorium: American Association of Petroleum Geologists Bulletin, v. 54, p. 2371-2394.

_____1971, A review of depositional history and geological structure in Turkey, in Campbell, A. S., ed., Geology and history of Turkey: Petroleum Exploration Society of Libya, p. 11-138.

_____1972, Permian Tethys and Indian Ocean: American Association of Petroleum Geologists Bulletin, v. 56, p. 1984-1999.

_____1978, Permian to Tertiary faunas and paleogeography: Somalia, Kenya, Tanzania, Mozambique, Madagascar, South Africa: Journal of Petroleum Geology, v. 1, p. 79-101.

Kamen-Kaye, M., and Barnes, S. U., 1979, Exploration geology of northeastern Africa-Seychelles basin: Journal of Petroleum Geology, v. 2, p. 23-45.

Kashfi, M. S., 1976, Plate tectonics and structural evolution of the Zagros geosyncline, southwestern Iran: Geological Society of American Bulletin, v. 87, p. 1486-1490.

Kennedy, W. Q., 1965, The influence of basement structure on the evolution of the coastal (Mesozoic and Tertiary) basins of Africa, in Salt basins around Africa: Institute of Petroleum, London, p. 7-15.

Kent, P. E., 1970, The salt plugs of the Persian Gulf region: Trans. Leicester Literary and Philos. Society, v. 64, p. 56-88.

Kent, P. E., and Hedberg, H. D., 1976, Salt diapirism in southern Iran: American Association of Petroleum Geologists Bulletin, v. 60, p. 458.

Kent, P. E., and Warman, H. R., 1972, An environmental review of the world's richest oil-bearing region--the Middle East: 24th International Geological Congress, Proceedings, sec. 5, p. 142-152.

Klemme, H. D., 1958, Regional geology of circum-Mediterranean region: American Association of Petroleum Geologists Bulletin, v. 42, p. 477-512.

_____1984, Oil and gas maps and sections of Arabian-Iranian basin: U.S. Geological Survey Open-File Report 84-353.

Klitzsch, E., 1968, Outline of the geology of Libya, in Geology and archaeology of northern Cyrenaica, Libya: Petroleum Exploration Society of Libya, 10th Annual Field Conference, p. 71-78.

Koop, W. J., and Stoneley, R., 1982, Subsidence history of the Middle East Zagros basin, Permian to recent: Royal Society of London, Philosophical Transactions, pt. A, v. 305, p. 149-168.

Kroner, A., 1977, The Precambrian geotectonic evolution of Africa: Plate accretion versus plate destruction: Precambrian Research, v. 4, p. 163-213.

Kursten, M.O.C., 1975, Stratigraphic units of northern Afar, in Pilger, A., and Rosler, A., eds., Afar between continental and oceanic rifting: Interunion Commission on Geodynamics, Scientific Report no. 16, v. 11: E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 168-170.

Laughton, A. S., Whitmarsk, R. B., and Jones, M. T., 1970, The evolution of the Gulf of Aden: Royal Society of London Philosophical Transactions, v. 167A, p. 227-265.

Law, J., 1957, Reasons for Persian Gulf oil abundance: American Association of Petroleum Geologists Bulletin, v. 41, p. 51-69.

Lees, G. M., 1953, The Middle East, in Science of Petroleum: Oxford University Press, v. 6, pt. 1, p. 67-72.

Lowell, J. D., and Genik, G. J., 1972, Sea-floor spreading and structural evolution southern Red Sea: American Association of Petroleum Geologists Bulletin, v. 56, p. 247-259.

Masters, C. D., Klemme, H. D., and Coury, A. B., 1982, Assessment of undiscovered conventionally recoverable petroleum resources of the Arabian-Iranian basin: U.S. Geological Survey Circular 881, 12 p.
McConnell, R. B., 1972, Geological development of the rift system of eastern Africa: Geological Society of American Bulletin, v. 83, p. 2549-2572.
McKenzie, D. P., Davies, D., and Molnar, P., 1970, Plate tectonics of the Red Sea and east Africa: Nature, v. 226, p. 243-248.
Megerisi, M., and Mamgain, V. D., 1980, The Upper Cretaceous - Tertiary formations of northern Libya, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: Academic Press, London, p. 67-72.
Metwalli, M. H., Philip, G., and Moussly, M. M., 1974, Petroleum-bearing formations in northeastern Syria and northern Iraq: American Association of Petroleum Geologists Bulletin, v. 58, p. 1781-1796.
Mohr, P. A., 1971, Outline tectonics of Ethiopia, in Tectonics of Africa: UNESCO, Paris, p. 447-458.
Moody, J. D., Glennie, K. W., and Reinhardt, B. M., 1974, Late Cretaceous nappes in Oman Mountains and their geologic evolution: discussion and reply: American Association of Petroleum Geologists Bulletin, v. 58, p. 889-898.
Morton, D. M., 1959, The geology of Oman: Fifth World Petroleum Congress, Proceedings, sec. 1, paper 17, p. 227-290.
Murris, R. J., 1980, Middle East: stratigraphic evolution and oil habitat: American Association of Petroleum Geologists Bulletin, v. 64, p. 597-618.
Naqib, K. M., 1967, Geology of the Arabian Peninsula, southwestern Iraq: U.S. Geological Survey Professional Paper 560-G, 54 p.
Nairn, A.E.M., 1978, Northern and eastern Africa, in Moullade, M., and Nairn, A.E.M., eds., The Phanerozoic geology of the world, the Mesozoic, A: Elsevier, Amsterdam, p. 329-370.
Omara, S., 1964, Diapiric structures in Egypt and Syria: American Association of Petroleum Geologists Bulletin, v. 48, p. 1116-1125.
Pallister, J. W., 1971, The tectonics of east Africa, in Tectonics of Africa: UNESCO, Paris, p. 511-542.
Parsons, M. G., Zagaar, A. M., and Curry, J. J., 1980, Hydrocarbon occurrences in the Sirte basin, Libya, in Miall, A. K., ed., Facts and principles of world petroleum occurrence: Canadian Society of Petroleum Geologists, Calgary, p. 723-732.
Peterson, J. A., 1985a, Geology and petroleum resources of central and east-central Africa: U.S. Geological Survey Open-File Report 85-589, 48 p.
_____1985b, Geology and petroleum resources of north-central and northeastern Africa: U.S. Geological Survey Open-File Report 85-709, 54 p.
Peterson, J. A., and Clarke, J. W., 1986, West Siberian oil-gas province: U.S. Geological Survey Open-File Report [in press].
Petters, S. W., 1979a, Stratigraphic history of the south-central Sahara region: Geological Society of American Bulletin, v. 90, p. 753-760.
_____1979b, West African cratonic stratigraphic sequences: Geology, v. 7, p. 528-531.
_____1981, Stratigraphy of Chad and Iullemmeden basins (West Africa): Eclogae Geol. Helv., v. 74, p. 139-159.
Picard, L., 1960, Geology and oil exploration of Israel: Fifth World Petroleum Congress, Proceedings, sec. I, paper 16, p. 311-336.

Pilger, A., and Rosler, A., 1976, Temporal relationships in the tectonic evolution of the Afar Depression (Ethiopia) and the adjacent Afro-Arabian rift system, in Pilger, A., and Rosler, A., eds., Afar between continental and oceanic rifting, Proceedings of International Symposium on the Afar region and related problems, v. 2: E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 1-25.

Powers, R. W., Ramirez, L. F., Redmon, C. D., and Elberg, Jr., E. L., 1966, Geology of the Arabian Peninsula: sedimentary geology of Saudi Arbia: U.S. Geological Survey Professional Paper 560-D, 147 p.

Reyment, R. A., and Reyment, E. R., 1980, The Paleocene trans-Saharan transgression and its ostracod fauna, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: Academic Press, London, p. 245-269.

Ricateau, R., and Riche, P. H., 1980, Geology of the Musandum Peninsula (Sultanate Oman) and its surroundings: Journal of Petroleum Geology, v. 3, p. 139-152.

Rigassi, D., 1971, Petroleum geology of Turkey, in Campbell, A. S., ed., Geology and history of Turkey: Petroleum Exploration Society of Libya, 13th Annual Field Conference, p. 453-482.

Said, R., 1962, The geology of Egypt: Elsevier Publishing Co., Amsterdam, 377 p.

_____ 1981, The geological evolution of the River Nile: Springer-Verlag, New York, 151, p.

Salaj, J., 1978, The geology of the Pelagian block: the eastern Tunisian platform, in Nairn, A.E.M., Kanes, W. N., and Stehli, F. G., eds., The ocean basins and margins, v. 4B, The Western Mediterranean: Plenum Press, New York and London, p. 361-416.

Sander, N. J., 1968, The pre-Mesozoic structural evolution of the Mediterranean region, in Geology and archaeology of northern Cyrenaica, Libya: 10th Annual Field Conference, Petroleum Exploration Society of Libya, p. 47-70.

Sass, E., and Bein, A., 1982, The Cretaceous carbonate platform in Israel: Cretaceous Research, v. 3, p. 135-144.

Schlumberger Technical Science, Inc., 1981, United Arab Emirates and Qatar: Schlumberger Well Evaluation Conference, 271 p.

Schneidermann, N., 1970, Genesis of some Cretaceous carbonates in Israel: Israel Journal of Earth Science, v. 19, p. 97-115.

Schull, T. J., 1984, Oil exploration in nonmarine rift basins of interior Sudan (abs.): American Association of Petroleum Geologists Bulletin, v. 68, p. 526.

Schurrmann, H.M.E., 1971, Gulf of Suez and northern Red Sea area, and Western Desert, in Tectonics of Africa: UNESCO, Paris, p. 417-427.

Sengor, A. M. C., 1984, The Cimmeride orogenic system and the tectonics of Eurasia: Geological Society of America, Special Paper 195, 82 p.

Sethudehnia, A., 1978, The Mesozoic sequence in southwest Iran and adjacent areas: Journal of Petroleum Geology, v. 1, p. 3-42.

Shaharistani, H., Al- and Atiya, M. J., 1972, Vertical migration of oil in Iraq oil fields: Geochim., Cosmochim., Acta, v. 36, p. 929-938.

Soliman, F. A., and Al Shamlan, A., 1982, Review on the geology of the Cretaceous sediments of the Rub Al-Khali, Saudi Arabia: Cretaceous Research, v. 3, p. 187-194.

Smith, A. G. and Briden, J. C., 1977, Mesozoic and Cenozoic paleocontinental maps: Cambridge University Press.

Steineke, M., and Bramkamp, R. A., 1952, Mesozoic rocks of eastern Saudi Arabia (abs.): American Association of Petroleum Geologists Bulletin, v. 36, p. 909.

Steineke, M., Bramkamp, R. A., and Sander, N. J., 1958, Stratigraphic relations of Arabian Jurassic oil, in habitat of oil: American Association of Petroleum Geologists, p. 1294-1329.

Stocklin, J., 1968, Structural history and tectonics of Iran: Review: American Association of Petroleum Geologists Bulletin, v. 52, p. 1229-1258.

Szabo, F., and Kheradpir, A., 1978, Permian and Triassic stratigraphy, Zagros basin, southwest Iran: Journal of Petroleum Geology, v. 1, p. 57-82.

Taieb, M., 1975, Evolution of Plio/Pleistocene sedimentary basin of the central Afar (Awash Valley, Ethiopia), in Pilger, A., and Rosler, A., eds., Afar between continental and oceanic rifting, Inter-union Commission on Geodynamics, Scientific Report No. 16, v, II: Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 80-87.

Tanner, P. W. G., 1973, Orogenic cycles in East Africa: Geological Society of American Bulletin, v. 84, p. 2839-2850.

Tasman, C. E., 1949, Stratigraphy of southeastern Turkey: American Association of Petroleum Geologists Bulletin, v. 23, p. 690-691.

Tikrity, S. S., and Al-Ani, A. A., 1972, Precambrian basement of Iraq: 8th Arab Petroleum Congress, Proceedings, sec. B-3, no. 96, p. 1-6.

Turner, D. C., 1971a, Nigeria, in Tectonics of Africa: UNESCO, Paris, p. 255-260.

_____1971b, The sedimentary cover in Nigeria, in Tectonics of Africa: UNESCO, Paris, p. 403-405.

Vail, J. R., 1978, Outline of the geology and mineral deposits of the Democratic Republic of the Sudan and adjacent areas: Institute of Geological Sciences, Overseas Geology and Mineral Resources, no. 49, London, 68 p.

Van Houten, F. B., 1980, Latest Jurassic-Early Cretaceous regressive facies, northeast Africa Craton: American Association of Petroleum Geologists Bulletin, v. 64, p. 857-867.

_____1983, Sirte Basin, north-central Libya: Cretaceous rifting above a fixed mantle hotspot?: Geology, v. 11, p. 115-118.

Walters, R., and Linton, R. E., 1973, The sedimentary basins of coastal Kenya, in Sedimentary basins of the African coasts, part 2: Association of African Geological Surveys, p. 133-158.

Walther, H. W., 1972, Salt diapirs in southeastern Iran: Geol. Jahrb., v. 90, p. 359-387.

Wells, A. J., 1969, The crush zone of the Iranian Zagros Mountains, and its implications: Geological Magazine, v. 106, p. 385-394.

Whiteman, A. J., 1971a, The geology of the Sudan Republic: Clarendon Press, Oxford, 289 p.

_____1979b, Structural geology of Sudan, in Tectonics of Africa: UNESCO, Paris, p. 433-444.

_____1981, East Africa basins: reserves, resources, and prospects, in Petroleum exploration strategies in developing countries: United Nations Meeting, Hague, Proceedings, United Nations Natural Resources and Energy Division, p. 51-98.

Wilson, H. H., 1969, Late Cretaceous and eugeosynclinal sedimentation, gravity tectonics, and ophiolite emplacement in Oman Mountains, southeast Arabia: American Association of Petroleum Geologists Bulletin, v. 53, p. 626-671.

Wilson, H. H., Glennie, K. W., and Hughes Clarke, M. W., 1973, Late Cretaceous nappes in Oman Mountains and their geologic evolution: discussion and reply: American Association of Petroleum Geologists Bulletin, v. 57, p. 2282-2290.

Wilson, A. O., 1984, Jurassic source rocks in the western Arabian Gulf area: Seminar on Source and Habitat of Petroleum in Arab Countries, OAPEC, Kuwait, 9 p.

Wolfart, R., 1968, Tectonics and paleogeographic development of the mobile shelf in the area of Syria and Lebanon (in German): Deutsch. Geol. Gesell. Zeitschr., v. 117, (1965), p. 544-589.

_____ 1983, The Cambrian system in the near and Middle East: International Union of Geological Sciences, Publ. No. 15, 72 p.

Youssef, M. I., 1968, Structural pattern of Egypt and its interpretation: American Association of Petroleum Geologists Bulletin, v. 52, p. 601-614.

Ziegler, A. M., Personal communication, World Paleogeographic Maps, 1986.

ILLUSTRATIONS

Figure 10.--North-south structural-stratigraphic cross-section D-D', northwestern Egypt to southeastern Egypt (see fig. 5).

Figure 11.--North-south structural-stratigraphic cross-section E-E', northeastern Egypt to south-central Egypt (see fig. 5).

Figure 12.--West-east structural-stratigraphic cross-section F-F', Iullemmeden and Chad Basins (see fig. 5). Figures 12-17 are from Peterson (1985a): vertical exaggeration approximately 50 times.

Figure 13.--West-east structural-stratigraphic cross-section G-G', Doba-Doseo and Upper Nile Basins (see fig. 5).

Figure 14.--West-east structural-stratigraphic cross-section H-H', western Ethiopia to Indian Ocean (see fig. 5).

Figure 15.--West-east structural-stratigraphic cross-section I-I', northern Kenya to Indian Ocean (see fig. 5).

Figure 16.--North-south structural-stratigraphic cross-section J-J', southeast Kenya to Gulf of Aden (see fig. 5).

Figure 17.--West-east structural-stratigraphic cross-section K-K', southern Red Sea depression (see fig. 5). Geologic age abbreviations as follows: Q - Quaternary; Tm - Miocene; Te - Eocene; K - Cretaceous; J - Jurassic.

Figure 18.--Northwest-southeast and east-west structural-stratigraphic cross-section L-L', northwestern Saudi Arabia to High Zagros Mountains across Mesopotamian basin of Iraq and Kuwait, and Zagros fold belt of southwestern Iran. Data from Petroconsultants and other sources. Vertical exaggeration on figures 18-20 approximately 75 times.

Figure 19.--Southwest-northeast structural-stratigraphic cross-section M-M', Arabian Shield to High Zagros Mountains across Arabian shelf, Persian Gulf and Zagros fold belt (see fig. 5). Data from Petroconsultants and other sources.

Figure 20.--Southwest-northeast structural-stratigraphic cross-section N-N' Gulf of Aden to Zagros Mountains area in southeastern Iran (see fig. 5). Data from Petroconsultants and other sources.

Figure 21.--Approximate thickness of Paleozoic rocks in thousands of feet, partly restored where erosion has occurred. Thickness pattern for eastern Iraq, southwestern Iran and adjacent area is tentative because of sparsity of control in older part of section. Data from many sources. Large numbers on figures 21, 22, 24-30 are approximate paleolatitudinal positions, modified from Smith and Briden (1977), Bambach and others (1980), and Ziegler (1986). Abbreviations (v) Visean, (w) Westphalian. Inset shows approximate position of Sahara and Middle East platforms in Middle Ordovician and Early Carboniferous times. Arrows show probable wind directions.

Figure 22.--Approximate thickness in general facies of Permian rocks in thousands of feet, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in Permian time. Arrows show probable wind directions.

Figure 23.--Approximate thickness of Mesozoic rocks in thousands of feet, partly restored where erosion has occurred. Data from many sources.

Figure 24.--Approximate thickness and general facies of Triassic rocks in thousands of feet, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in Middle Triassic time. Arrows show probable wind directions.

Figure 25.--Approximate thickness and general facies of Jurassic rocks in thousands of feet, partly restored where erosion has occurred. Data from many sources. Abbreviations: (L) Lias, (V) Volgian. Inset shows approximate position of Sahara and Middle East platforms in Middle Jurassic time. Arrows show probable wind directions.

Figure 26.--Approximate thickness of Cretaceous rocks in thousands of feet, and Neocomian facies, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in middle Neocomian time. Arrows show probable wind directions.

Figure 27.--Approximate thickness of Cretaceous rocks in thousands of feet, and Middle Cretaceous (Wasia) facies, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in Cenomanian time. Arrows show probable wind directions.

Figure 28.--Approximate thickness of Cretaceous rocks in thousands of feet, and late Senonian facies, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in late Senonian time. Arrows show probable wind directions.

Figure 29.--Approximate thickness of Cenozoic rocks in thousands of feet, and Paleocene-Eocene facies, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in middle Eocene time. Arrows show probable wind directions.

Figure 30.--Approximate thickness of Cenozoic rocks in thousands of feet, and Oligocene-Miocene facies, partly restored where erosion has occurred. Data from many sources. Inset shows approximate position of Sahara and Middle East platforms in early Miocene time. Arrows show probable wind directions.