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GEOLOGICAL SURVEY

Geology and petroleum resources of north-central and northeastern Africa

By

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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 Reston, Virginia

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ABSTRACT

Large petroleum deposits in north-central and northeastern Africa are present in the Sirte Basin of Libya, the western Sahara region of Algeria, the Pelagian platform offshore from eastern Tunisia, and in the Western Desert Basin, Gulf of Suez, and Nile Delta in Egypt. Approximately 55 major fields (where estimated recovery is greater than 100 MMBOE), of which 15 are giants (estimated recovery, greater than 1 BBOE), have been found in these provinces. Total estimated ultimate production from existing fields is 60 BBO and 100 Tcf gas; estimated undiscovered petroleum resources are 26 BBO and 93 Tcf gas.

The post-Precambrian sedimentary basins of north Africa were related to the development of the Sahara platform during at least four main tectonic episodes--the Caledonian, Hercynian, Late Cretaceous-early Tertiary, and Alpine cycles. The sedimentary cover of the platform, which includes rocks of all geologic systems, ranges in thickness from less than 1,000 m (3,250 ft) in the south to more than 9,000 m (30,000 ft) along the Mediterranean coast. Paleozoic rocks are primarily continental, deltaic, and nearshore marine sandstone and shale, which are reservoir and source rocks for petroleum in the the central and western parts of the Sahara platform. Early Mesozoic rocks were deposited in a continental and restricted marine environment and contain red beds and evaporites, including salt, which are seals for oil and gas fields. Late Mesozoic and Tertiary rocks are related to the development of the Mediterranean Tethys geosyncline and are characterized by numerous transgressive-regressive cycles of the Tethyan seaway. Marine carbonate and shale facies are dominant in the Upper Jurassic, Cretaceous, and lower Tertiary section of northern Libya, the eastern Tunisia-Pelagian platform, and northern Egypt. Late Tertiary beds are continental clastics on most of the platform, except near the Mediterranean.

Basins in the western Sahara of Algeria, southern Tunisia, and northwestern Libya contain approximately 105 oil and gas fields, of which 17 are major accumulations; these have an estimated ultimate recovery of 13 BBO and 55+ Tcf gas. Estimated undiscovered resources are 8 BBO and 25 Tcf gas. Reservoir rocks are continental and marine sandstones of Cambrian-Ordovician, Silurian, Devonian, Carboniferous, and Early Triassic age. The best source rocks are Silurian graptolitic shale and Devonian and Carboniferous marine shale. Most accumulations are on anticlines or faulted anticlines, many with a long history of structural growth.

Several small onshore fields are present in eastern Tunisia, producing mainly from Cretaceous and early Tertiary marine clastic and carbonate reservoirs. Several gas and oil fields have been found in the offshore Pelagian platform, which contains a thick marine sedimentary section. Reservoirs are Lower and Upper Cretaceous, Eocene, and Miocene carbonate rocks. Lower Tertiary and Upper Cretaceous marine shales probably are the best source rocks. Fields are on anticlines or faulted anticlines. Estimated undiscovered resources are 3.6 BBO and 20 Tcf gas.

The Sirte Basin is oil prone and contains approximately 100 oil fields, 21 of them major accumulations, of which 10 are giants, with estimated ultimate recovery of 37 BBO. Estimated undiscovered resources are 9.4 BBO and 18 Tcf gas. Reservoir rocks are sandstones and quartzites of Cambrian-Ordovician, Early Cretaceous, and basal Late Cretaceous age, and marine carbonates of Late Cretaceous-Paleocene and Eocene age, including reefs and skeletal banks. Source rocks are marine shales of Late Cretaceous, Paleocene, Eocene, and Oligocene age. Most accumulations are on north-northwest to south-southeast trending paleohorsts of Late Cretaceous to Miocene age. Stratigraphic pinchouts, discontinuous sandstones, and isolated reef and other carbonate bodies are common on and near the paleohorsts.

The Western Desert Basin in Egypt has approximately 12 small oil and gas fields that have estimated ultimate recovery of 300 to 500 MMBO, and unknown but small reserves of gas. Estimated undiscovered resources are 1.7 BBO and 5.2 Tcf gas. Reservoirs are Cretaceous and Jurassic sandstones and Upper Cretaceous and Eocene carbonate rocks. Source rocks are Cretaceous and possibly Jurassic marine shales. Fields are mainly on faulted anticlines; some are structural-stratigraphic accumulations. Potential for large accumulations probably is small.

The Suez Graben, which lies within the Gulf of Suez and extends also onshore, is a Tertiary basin that contains approximately 35 oil fields, 13 of which have estimated recoveries, each greater than 100 MMBO. Estimated ultimate recovery from known fields is 6 BBO. Estimated undiscovered resources are 2.4 BBO and 3.2 Tcf gas. Reservoirs are Miocene sandstones and reefy carbonate rocks, Cretaceous and Carboniferous ("Nubian") sandstones, and Eocene carbonate rocks. Source rocks are Upper Cretaceous marine shale and bituminous limestone and Eocene bituminous limestone. The basin is oil prone. Accumulations of oil in the basin are mainly on tilted fault blocks beneath Miocene salt that forms the main seal.

The Nile Delta is gas prone. Several small gas fields have been discovered in Pliocene-Miocene deltaic and nearshore marine sandstone reservoirs. Source rocks are marine and coastal marine carbonaceous shales.

INTRODUCTION

Information sources

The information used in preparing this report was compiled from many sources, particularly from the reports of Said (1962), Conant and Goudarzi (1967), Bishop (1975), El Shazly (1977), Burollet (1967), U.S. Department of Energy (1979), Parsons and others (1980), Brown (1980), Pallas (1980), and Salem and Busrewil (1980), articles from The Oil and Gas Journal and World Oil, and the information files of Petroconsultants, S. A. Additional references are listed in the bibliography. Compilation on the project was completed in 1982; the report does not include data made available since that time.

Geography

The petroleum provinces of north Africa cover an area of about 2 million km^2 (725,000 mi^2) and include parts of Egypt, Libya, Tunisia, and Algeria and the adjacent offshore Mediterranean Sea to a water depth of 1,000 m (3,250 ft) (fig. 1; table 1). The productive provinces lie between about lat 25° and 35° N. and long 0° and 33° E. The topography of this area ranges from relatively flat basins with tablelands and plateaus to the hills or low mountains of the Sinai, Cyrenaica, Jefara, and central Libya. Elevations are generally less than 350 m (1,000 ft) but increase to 350 to 1,000 m (1,000 to 3,000 ft) on the south, where the region is bounded by uplifted areas of Precambrian rocks, including the Ahaggar Massif, Tibesti Uplift, Jabal-Al Uwaynat Uplift, and the Arabian-Nubian Massif (fig. 2). Most of the region is within the great north African (Sahara) desert, and large segments are covered with sand dunes or other eolian deposits. Desert climate with negligible precipitation is prevalent almost everywhere except for the coastal areas of northern Libya and Tunisia, where precipitation is more than 10 inches (25 cm) per year. Temperatures average 80° to 90° F during midsummer and 50° to 60° F in midwinter.

ACKNOWLEDGMENTS

This report benefited from constructive reviews and discussions by J. W. Clarke, C. D. Masters, R. F. Meyer, and K. C. Bayer, all of the U.S. Geological Survey; the members of the Resource Appraisal Group of the U.S. Geological Survey; R. G. Swanson, Shell Development Co.; R. T. Brady, American Overseas Petroleum Co.; P. W. Choquette, Marathon Oil Co.; R. Said, Intergeosearch, Inc.; N. Y. Abraham, Amoco Production Co.; M. V. I. Rhodes, Amoco Egypt Oil Co.; I. Taha, Conoco Coral Co.; and M. G. Barakat, Cairo University.

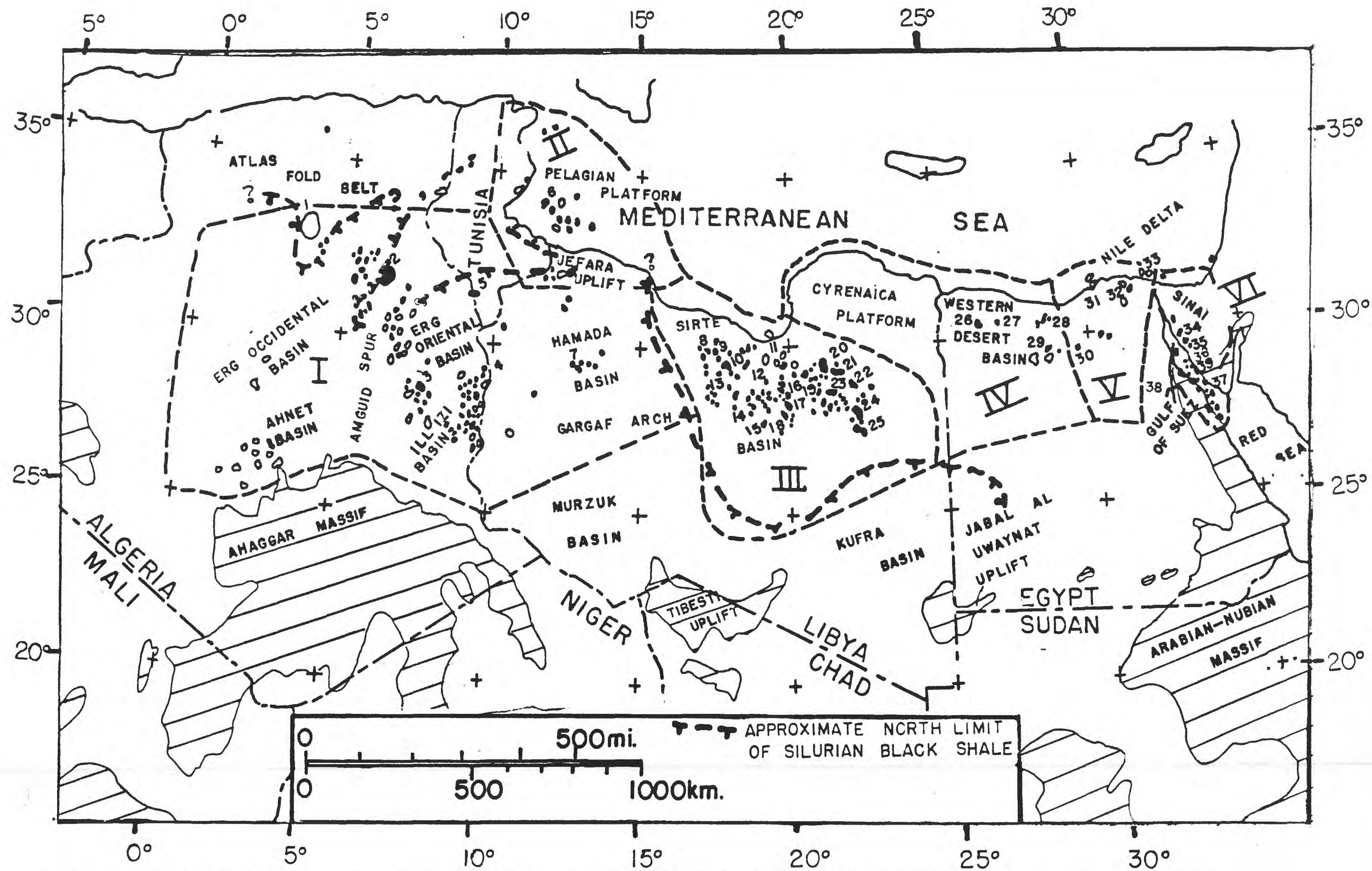

Figure 1.--North-central and northeastern African assessment regions (heavy dashed lines) showing location of oil fields (solid) and gas fields (open). Numbers refer to the main oil and gas fields listed in table 1. Field locations from Petroconsultants, S.A. Assessment regions are: I. Western Sahara region (Erg Occidental, Erg Oriental, and Hamada Basins); II. East Tunisia - Pelagian Platform; III. Sirte Basin, Libya; IV. Western Desert Basin - Cyrenaica Platform; V. Nile Delta - Nile Basin; and VI. Suez - Sinai.

Table 1.--Names of fields numbered on figure 1

Erg Occidental Basin, Algeria

1. Hassi R'Mel

Erg Oriental Basin, Algeria

2. Hassi Messaoud
3. Tamendjelt
4. Alrar
5. El Borma

East Tunisia - Pelagian platform

6. Ashtart

Hamada Basin, Libya

7. Hamadah

Sirte Basin, Libya

8. Mabruk
9. Bahi
10. Dahra-Hofra
11. Hateiba
12. Raguba
13. Ed Dib
14. Sabah
15. Beda, Samah, & Bel Hedan
16. Nasser (Zelten)
17. Waha
18. Defa
19. Intisar - "A"
20. Amal
21. Aguila-Nafoora
22. Abu Tiffel
23. Gialo
24. Messla
25. Sarir

Western Desert Basin, Egypt

26. Umbarka
27. Meleiha
28. El Alamein
29. Abu al Gharadig
30. East Mubarak

Nile Delta, Egypt

31. Abu Qir
32. Abu Madi
33. El Temsah

Suez Basin, Egypt

34. Asl
35. ABu Rudeis - Sidri
36. Belayim
37. Morgan
38. July
39. Ramadan

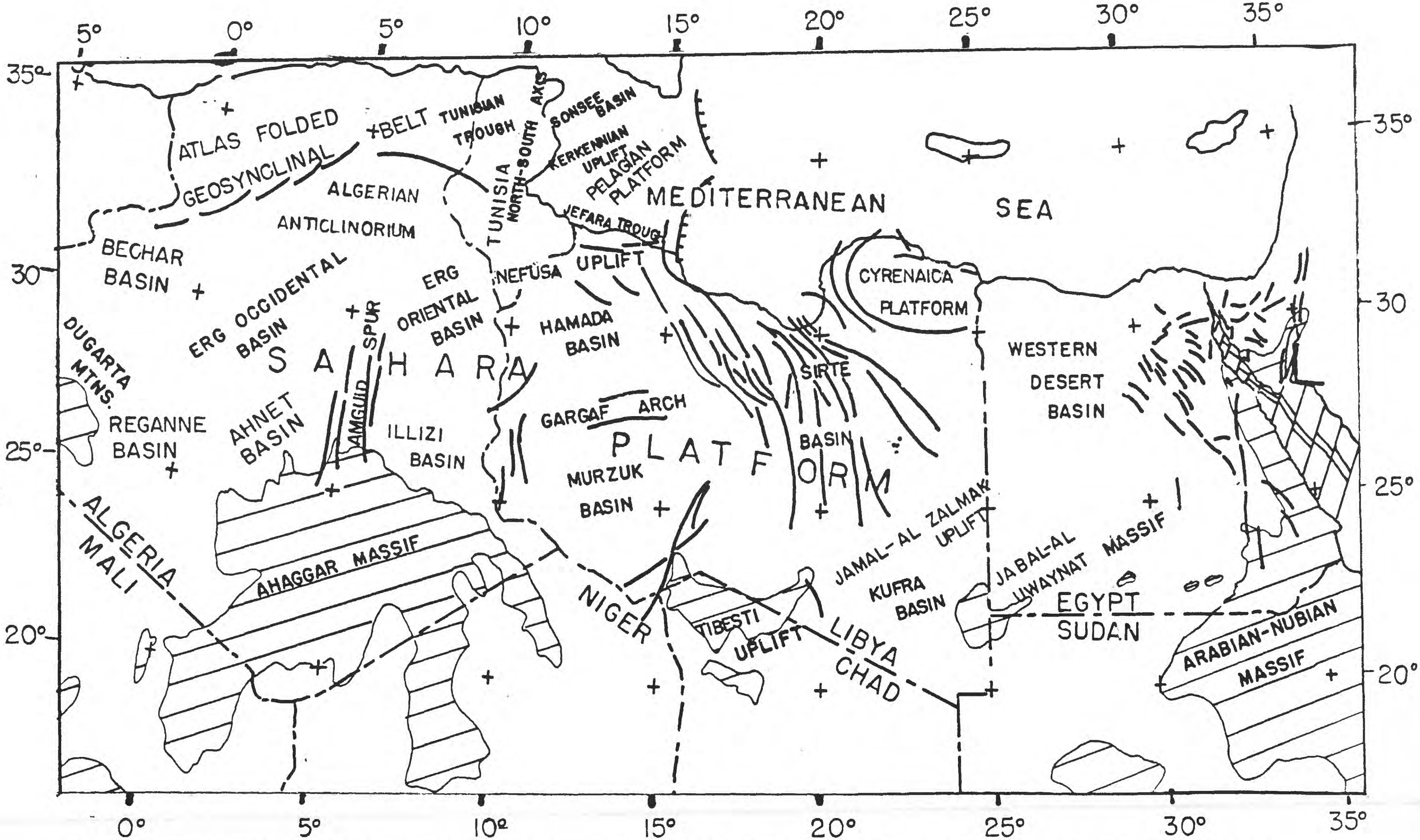

Figure 2.--Generalized regional structure map of north-central and northeastern Africa showing main basins, uplifts, and faults (heavy lines). From Said, 1962; Youssef, 1968; Sander, 1968; Magliore, 1970; Balducchi and Pommier, 1970; Bishop, 1975; Burollet, 1971; El Shazly, 1977; Burollet and others, 1978; Salaj, 1978; Goudarzi, 1980; Parsons and others, 1980; Hamouda, 1980; and Barakat, 1982.

REGIONAL GEOLOGY

Structure

The main north African petroleum basins are on the north African or Sahara platform, which lies between the Ahaggar, Tibesti, Jabal-Al Uwaynet, and Arabian-Nubian Precambrian Massifs on the south and the Mediterranean Tethys geosyncline on the north (figs. 1 and 2). Pertinent works on the structural geology and structural history of north Africa include the following: Said (1962), Conant and Goudarzi (1967), Klitzsch (1968), Sander (1968), Youssef (1968), Goudarzi (1970; 1980), Burollet (1971), Burollet and others (1971; 1978), Schurmann (1971), Bishop (1975), El Shazly (1977), Salaj (1978), U.S. Department of Energy (1979), Brown (1980), El-Etr and Moustafa (1980), and Parsons and others (1980).

North Africa was affected by several episodes of tectonic activity, including (1) late Precambrian, (2) Caledonian (early Paleozoic), (3) Hercynian (late Paleozoic), (4) "Laramide" (Late Cretaceous-early Tertiary), and (5) Alpine (late Tertiary).

The Precambrian basement, which is exposed in several uplifts to the south and has been penetrated in numerous deep wells, consists of schist and gneiss as well as some granite and volcanic rocks. The basement rocks apparently were extensively folded and faulted in Precambrian time (Said, 1962; Bishop, 1975; El Shazly, 1977, U.S. Department of Energy, 1979). At least three orogenic cycles are described that determined the basic structural pattern of north Africa. During this Precambrian interval, much of the tectonic lineation was oriented northwest-southeast, particularly in Egypt where early block faulting occurred (El Shazly, 1977).

Caledonian (Ordovician to Early Devonian) tectonic activity was characterized by general northwest-southeast and east-west trending folding and faulting, which further consolidated the pattern of earlier platform basins and uplifts (Goudarzi, 1980; Klitsch, 1968; El Shazly, 1977; Bishop, 1975). At this time, Paleozoic basins and uplifts were delineated, such as the Hamada, Murzuk, and Kufra Basins, and the Gargaf arch and Sirte high in Libya, the Illizi, Erg Oriental, and Erg Occidental Basins and the Amguid spur in Algeria, and the Western Desert Basin, possibly the ancestral Suez-Red Sea trough, and numerous smaller trough and high trends extending southeast from the Mediterranean in Egypt.

During the late Paleozoic Hercynian tectonic cycle, general uplift of the Sahara platform took place, coupled with superimposed, generally west-east folding trends related to early development of the Tethys geosyncline. Mild subsidence or uplifting continued in most of the Paleozoic basins and uplifts at this time; also several west-east uplifts were initiated, including the Nefusa Uplift and Algerian anticlinorium in northwest Libya, southern Tunisia, and eastern Algeria (fig. 2). Evidence of sagging in the Suez Graben at this time also is documented (Said, 1962; El Shazly, 1977). Widespread erosion of the platform took place at the close of Hercynian activity, and Permian rocks are generally absent or very thin on the platform but are markedly thicker north of the Nefusa Uplift into the Jefara trough segment of the Pelagian platform.

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 and sinistral tectonic movements, associated with the separation of the European and African cratons and the opening of the Mediterranean Tethys geosyncline. In early Mesozoic time, active subsidence and northward tilting of the Sahara platform, accompanied by marine transgression, took place during early downwarping of the Tethys geosyncline. The general orientation of tectonic units at this time continued the northeast-southwest or west-east Hercynian trends. Subsidence was greatest in the Pelagian platform region and in central and northern Algeria where substantial thicknesses of Triassic and Early Jurassic red beds 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.

During Late Cretaceous and early Tertiary time, maximum southward transgression of the Tethys seaway occurred and was accompanied by northwest-southeast horst and graben block faulting and finally by northward sagging of the Sirte Basin region, which continued 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, and 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. Late Cretaceous folding in Egypt trended northeast-southwest and resulted in development of the "Syrian Arc" system, which extended across northern Egypt (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.

Alpine tectonic activity of late Tertiary age did not greatly affect the north African 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 (fig. 2). Increased tectonic activity in the Pelagian platform region and general northward regression of the Mediterranean seaway occurred at this time. During the Miocene, the Algerian Sahara remained generally stable, and block faulting ceased in the Sirte Basin. In Egypt, general uplifting took place during the Oligocene and was followed by early to middle Miocene transgression and continued development of the Nile, Suez, and Red Sea grabens. Regional uplift and folding occurred in the late Miocene, continuing into the early Pliocene, at which time the Nile River system began to develop within the Nile graben, followed by rapid northward migration 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.

Several episodes of igneous activity in north Africa are 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 Libya. The most extensive deposits are the Oligocene-Miocene basaltic volcanic rocks in the Sinai, Suez, Red Sea, and Western Desert regions of Egypt and the late Tertiary-Holocene basaltic volcanics rocks in central and south central Libya.

Stratigraphy and Sedimentation

Rocks of all geologic systems are present on the Sahara platform and adjacent Mediterranean border to the north (figs. 1, and 3-14). Marine transgressions from the north and northwest have periodically covered the platform since Cambrian time, resulting in a more complete and more marine stratigraphic section in those directions. Stratigraphic breaks are more prevalent to the south toward the clastic-source area, which most of the time was located in the shield areas of southern Algeria, Niger, northern Chad, northern Sudan, and southeastern Egypt. The total sedimentary cover ranges in thickness from less than 1,000 m (3,250 ft) in the south part of the platform to more than 9,000 m (30,000 ft) along the Mediterranean coast of Libya and Tunisia, and more than 7,000 m (23,000 ft) in most of northern Egypt (figs. 2, and 4-11).

Paleozoic rocks are absent in parts of central and southern Egypt, east-central Libya, and northeastern Algeria, and elsewhere are more than 3,000 m (10,000 ft) thick in northeastern and northwestern Libya, central and eastern Algeria, and in the Jefara trough on the Pelagian platform (figs. 2, 4-10, and 12).

Mesozoic rocks are less than 500 m (1,600 ft) thick in most of the southern Sahara platform (fig. 13) and are of different thicknesses elsewhere, ranging from less than 1,000 m (3,250 ft) locally on paleostructures to more than 3,000 m (10,000 ft) along the southern margin of the Mediterranean Tethys seaway.

Tertiary rocks are thin or absent over much of the Sahara platform but are more than 3,000 m (10,000 ft) thick on the Pelagian platform, in the Sirte Basin, and in northern Libya and Egypt (fig. 14).

Pertinent works on the stratigraphy of north Africa include the following: Whiteman (1971), Bishop (1975), Burollet (1967; 1980), Burollet and others (1978), and Salaj (1978) in Algeria and Tunisia; Conant and Goudarzi (1967), Klitzch (1968), Goudarzi (1970), Barr and Weegar (1972), Barr and Berggren (1980), Brady and others (1980), Megerisi and Mamgain (1980), and Van Houten (1980) in Libya; and Said (1962), Hassan and El-Dasklouty (1970), Schurmann (1971), El Shazly (1977), and Brown (1980) in Egypt.

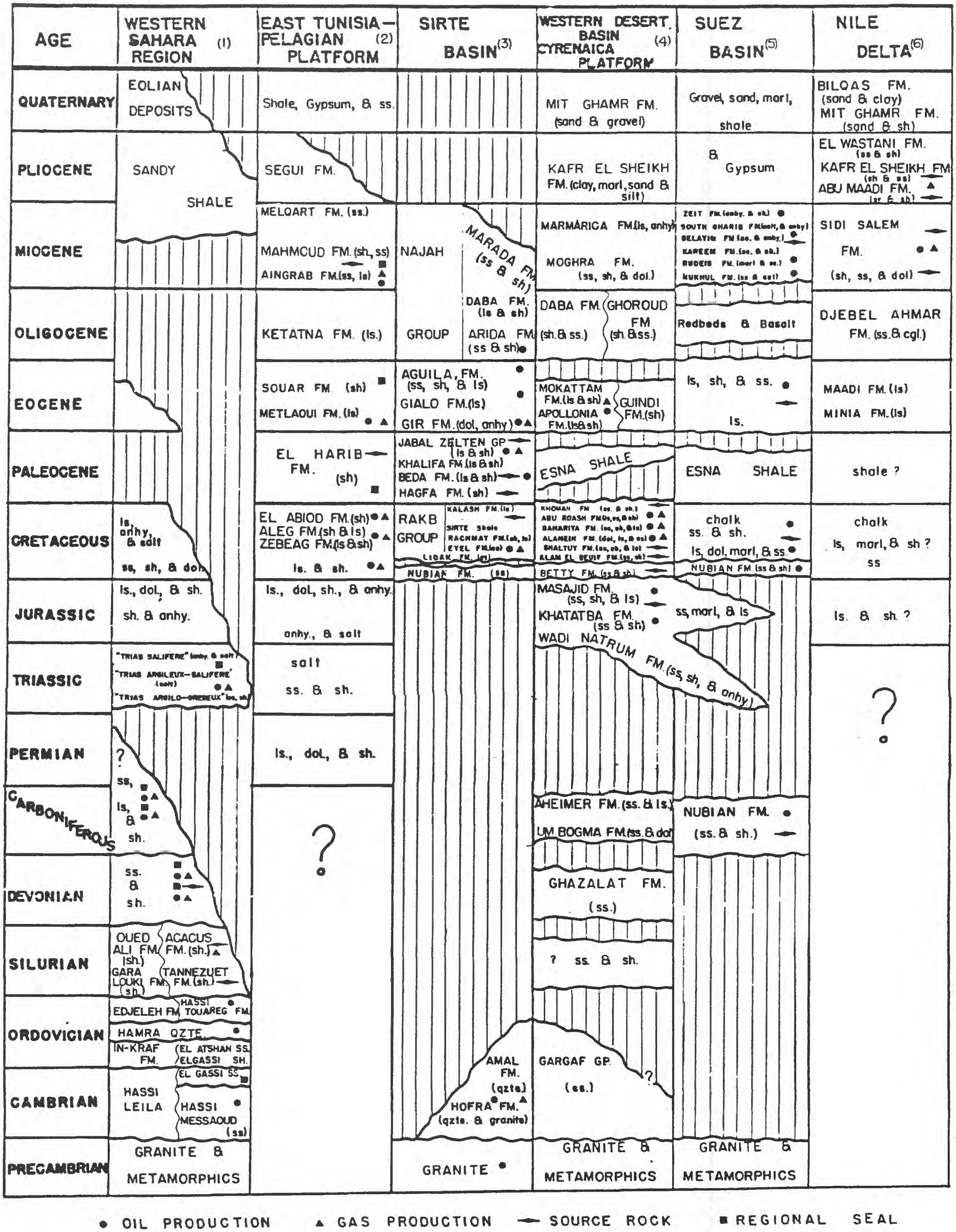

Figure 3.--Generalized composite subsurface correlation chart, north-central and northeastern Africa. From (1) Balduchi and Pommier, 1970; Magliore, 1970; Whiteman, 1971; El Shazly, 1977; (2) Klitzsch, 1968; Bishop, 1975; Burollet, 1967; Burollet and others, 1978; (3) Conant and Goudarzi, 1967; Klitzsch, 1968; Barr and Weegar, 1972; Megersi and Mamgain, 1980; (4) Said, 1962; El Shazly, 1977; U.S. Dept. of Energy, 1979; (5) Said, 1962; Hassan and El-Dashlouty, 1970; Brown, 1980; (6) El Shazly, 1977.

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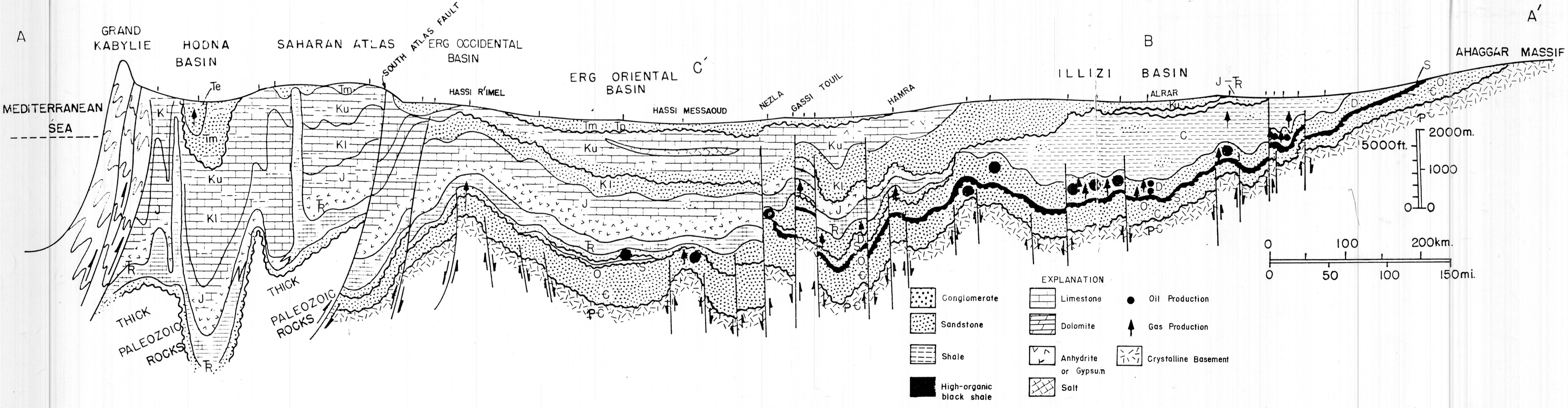

Figure 4.--North-south structural-stratigraphic cross-section A-A' (see fig. 11) northern Algeria to southeastern Algeria.

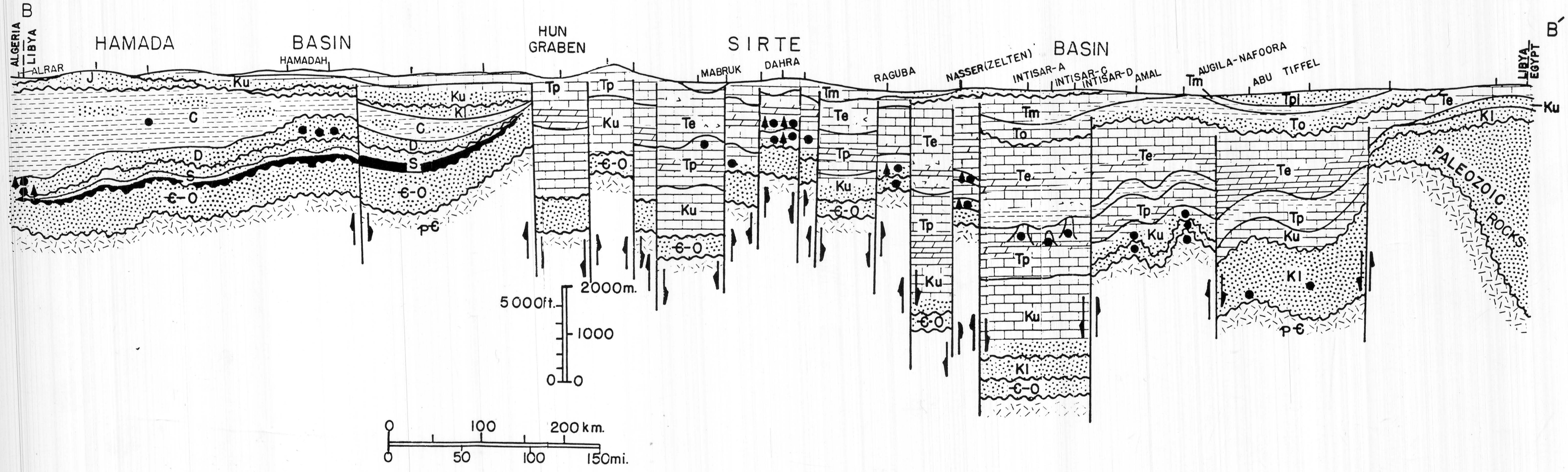

Figure 5.--East-west structural-stratigraphic cross-section B-B' (see fig. 11),west-central Libya to northwestern Egypt. Lithologic explanation on figure 4.

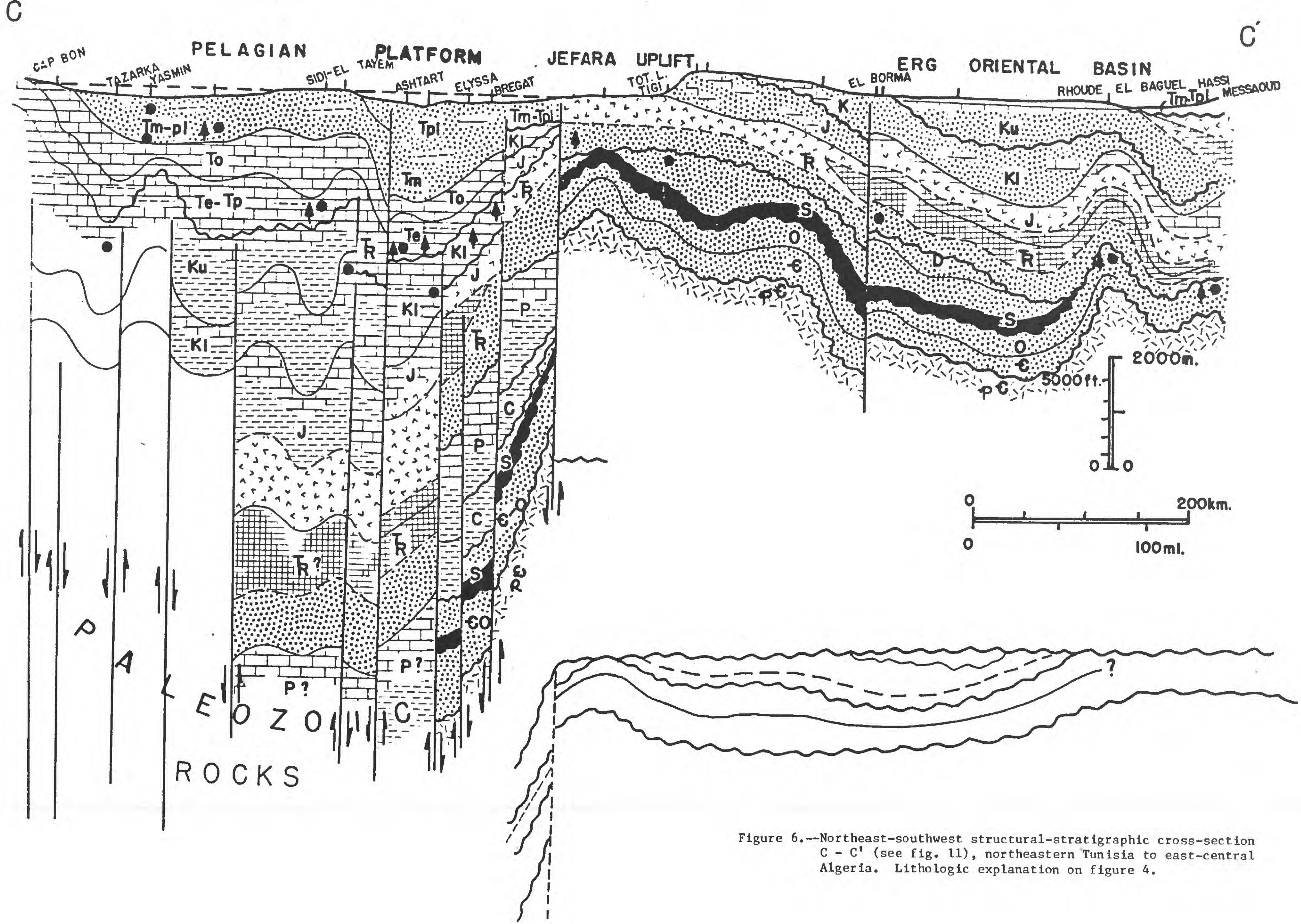

Figure 6.--Northeast-southwest structural-stratigraphic cross-section C - C' (see fig. 11), northeastern Tunisia to east-central Algeria. Lithologic explanation on figure 4.

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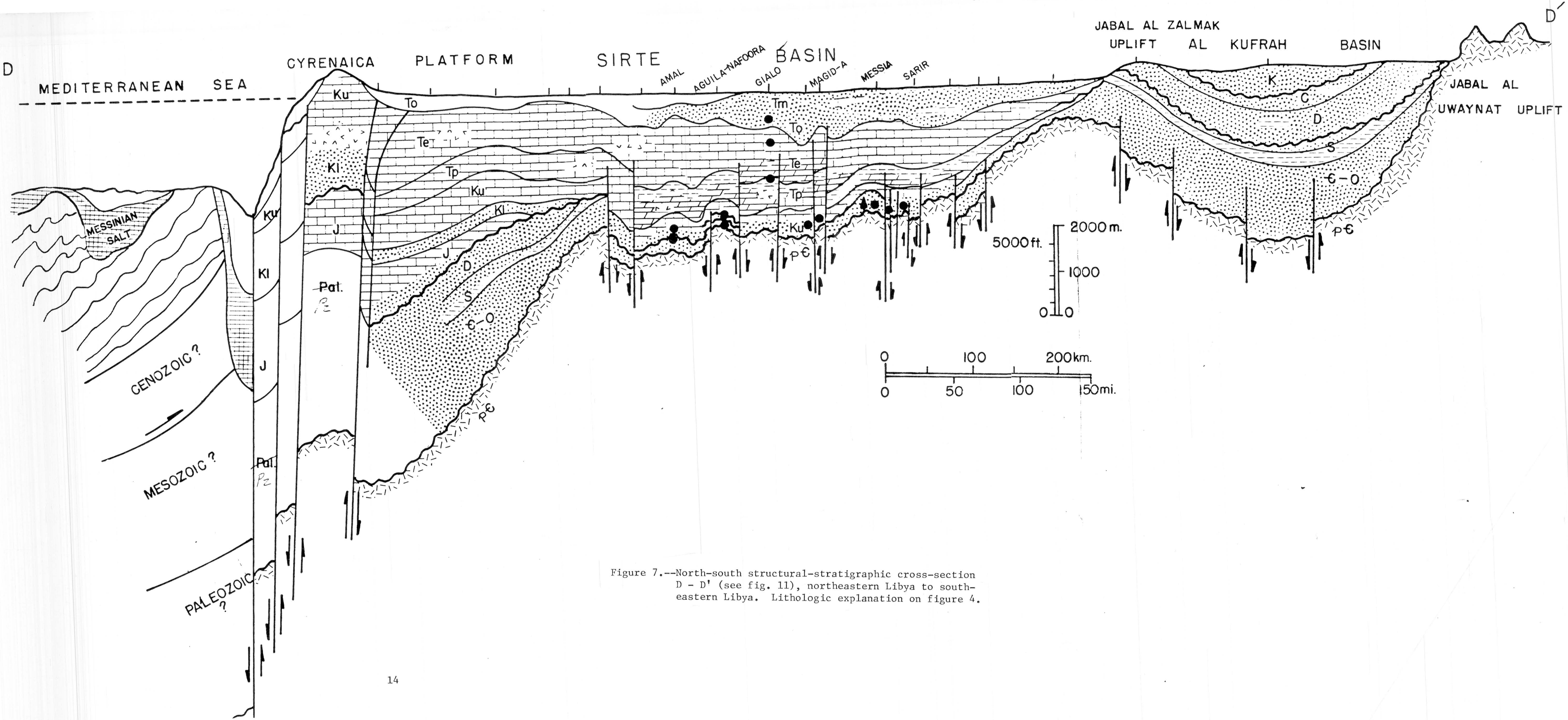


Figure 7.--North-south structural-stratigraphic cross-section D - D' (see fig. 11), northeastern Libya to southeastern Libya. Lithologic explanation on figure 4.

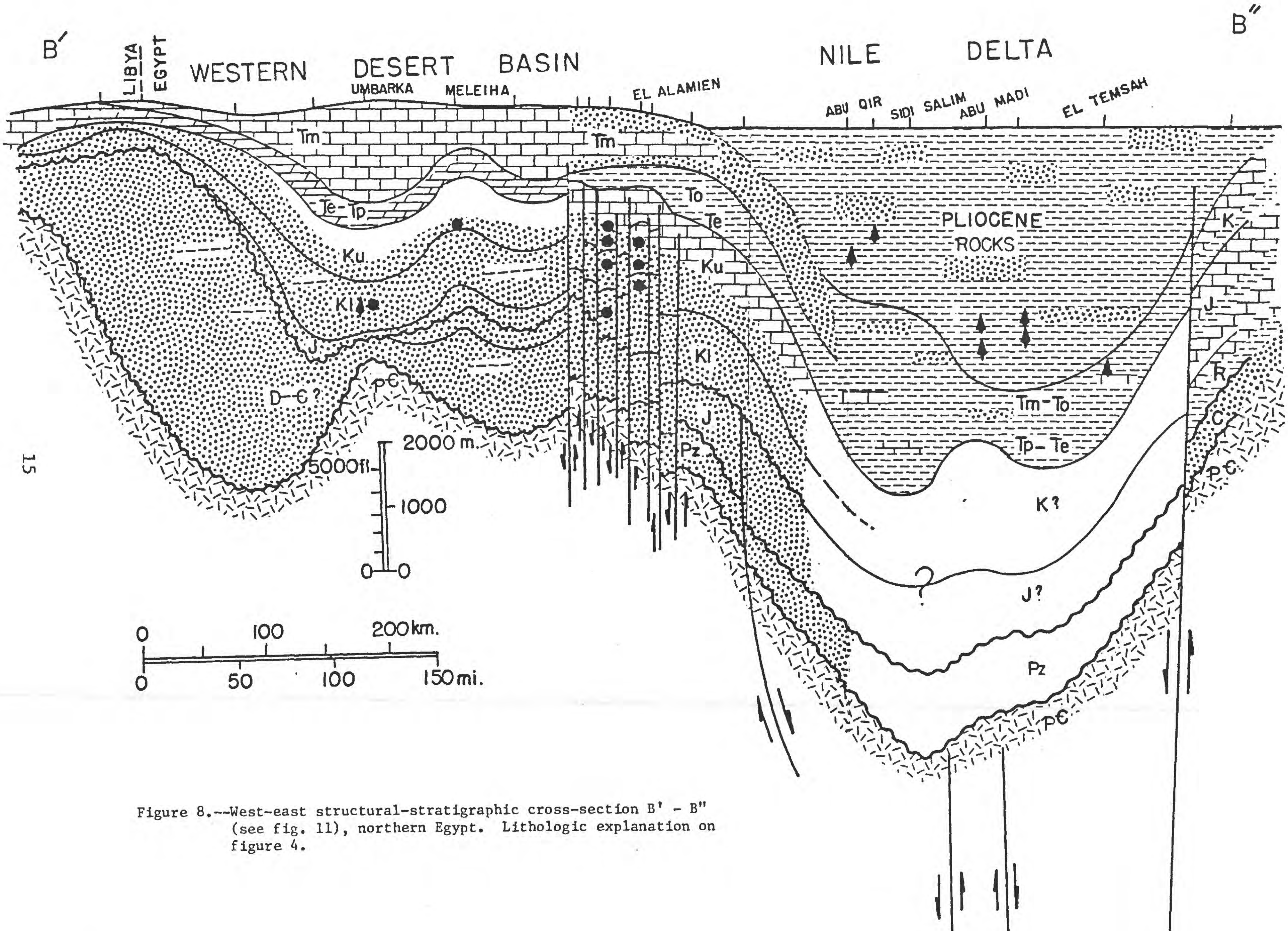


Figure 8.--West-east structural-stratigraphic cross-section B' - B" (see fig. 11), northern Egypt. Lithologic explanation on figure 4.

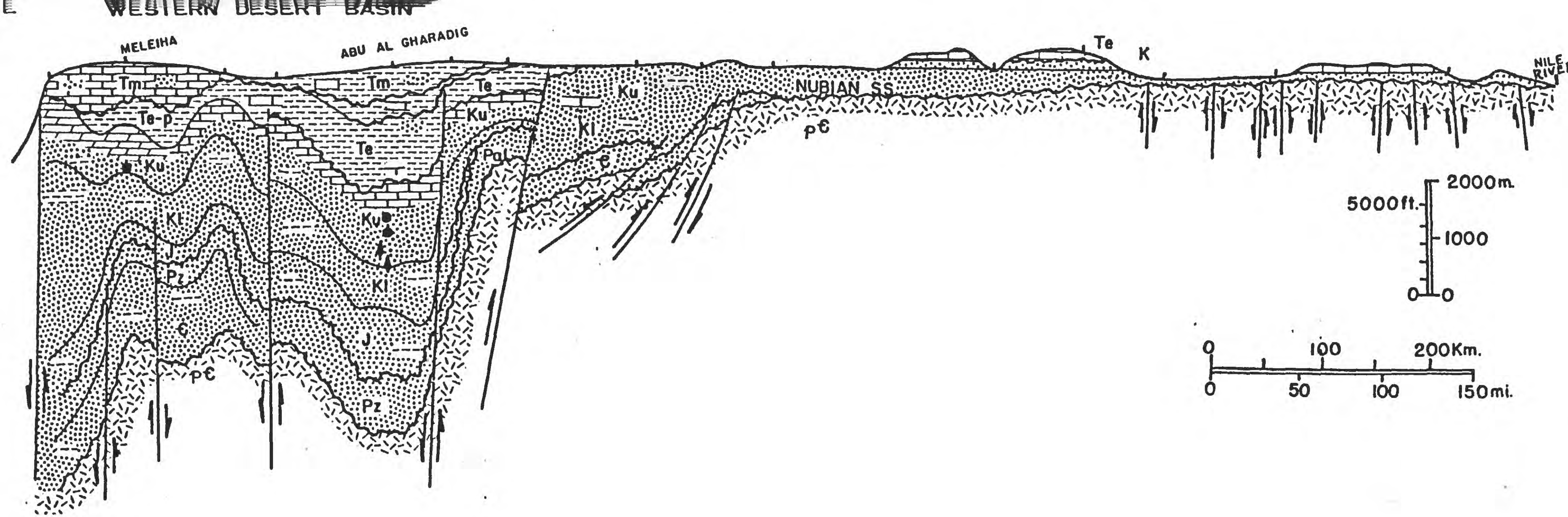


Figure 9.--North-south structural-stratigraphic cross-section E-E' (see fig. 11), northwestern Egypt to southeastern Egypt. Lithologic explanation on figure 4.

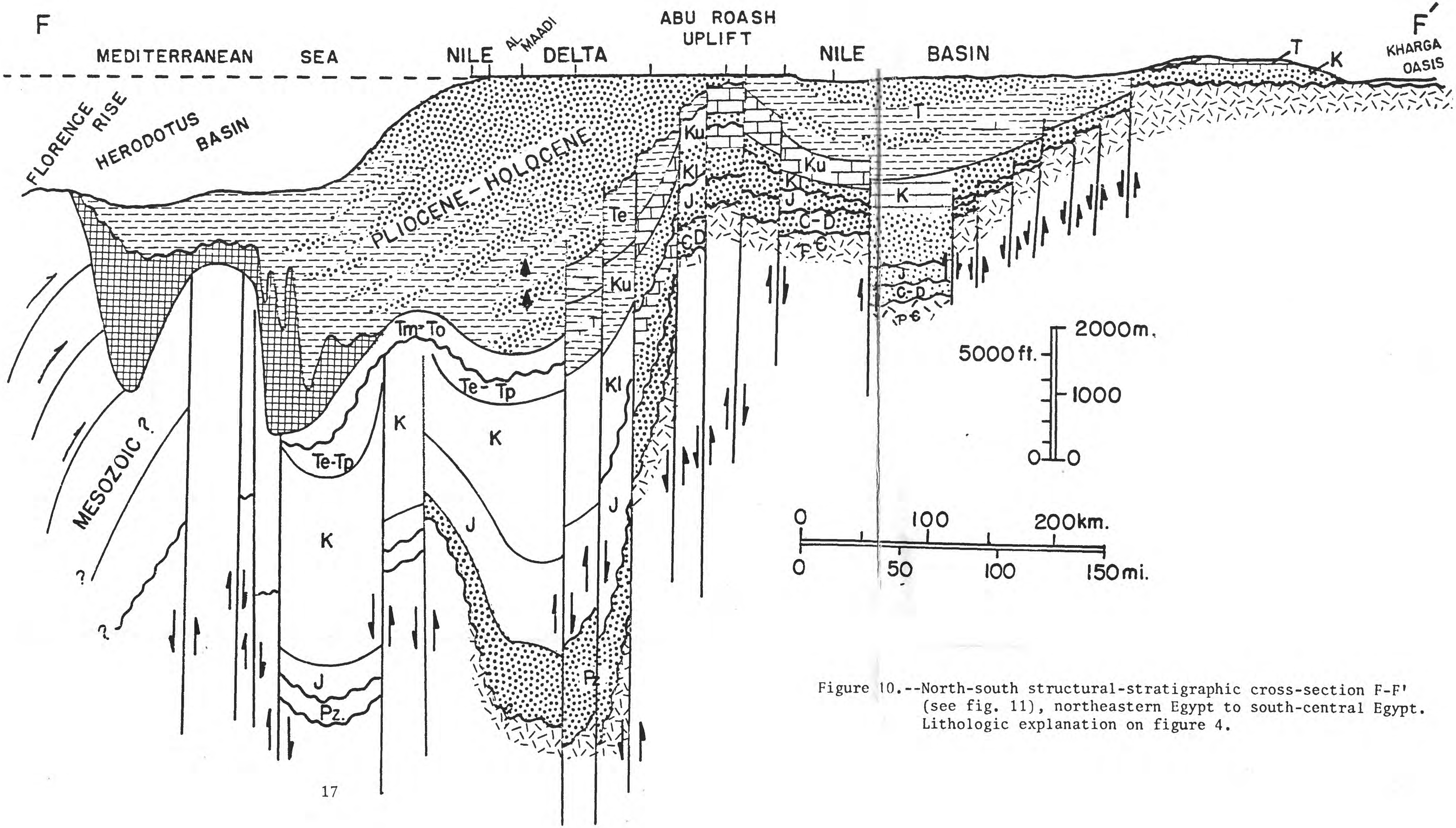


Figure 10.--North-south structural-stratigraphic cross-section F-F' (see fig. 11), northeastern Egypt to south-central Egypt. Lithologic explanation on figure 4.

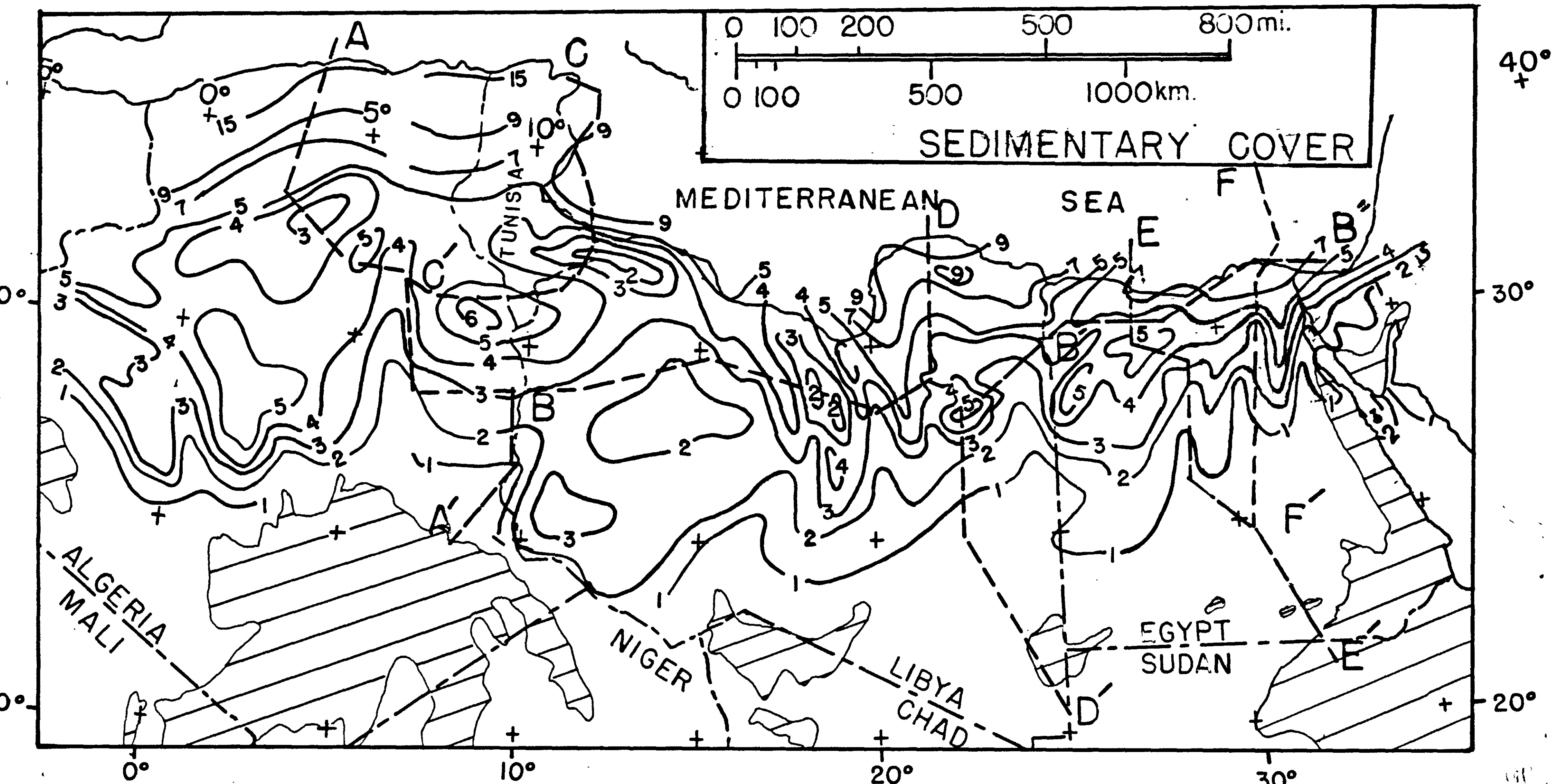


Figure 11.--Approximate thickness in thousands of meters, partly restored where erosion has taken place, sedimentary cover, north-central and northeastern Africa. Compiled from numerous sources. Lines of cross-sections of figures 4 through 10 are shown.

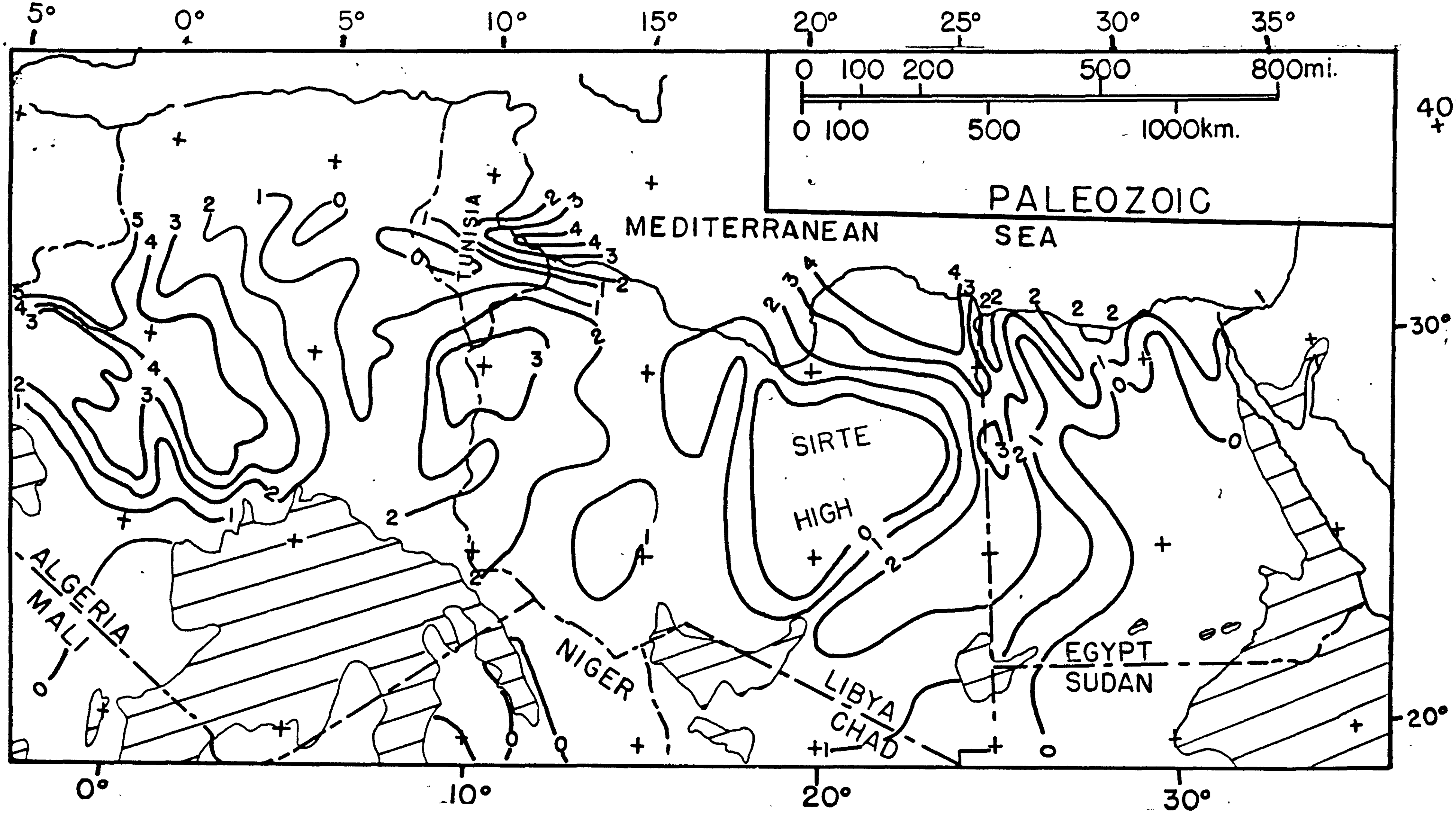


Figure 12.--Approximate thickness in thousands of meters, partly restored where erosion has taken place, Paleozoic rocks, north-central and northeastern Africa. Compiled from numerous sources.

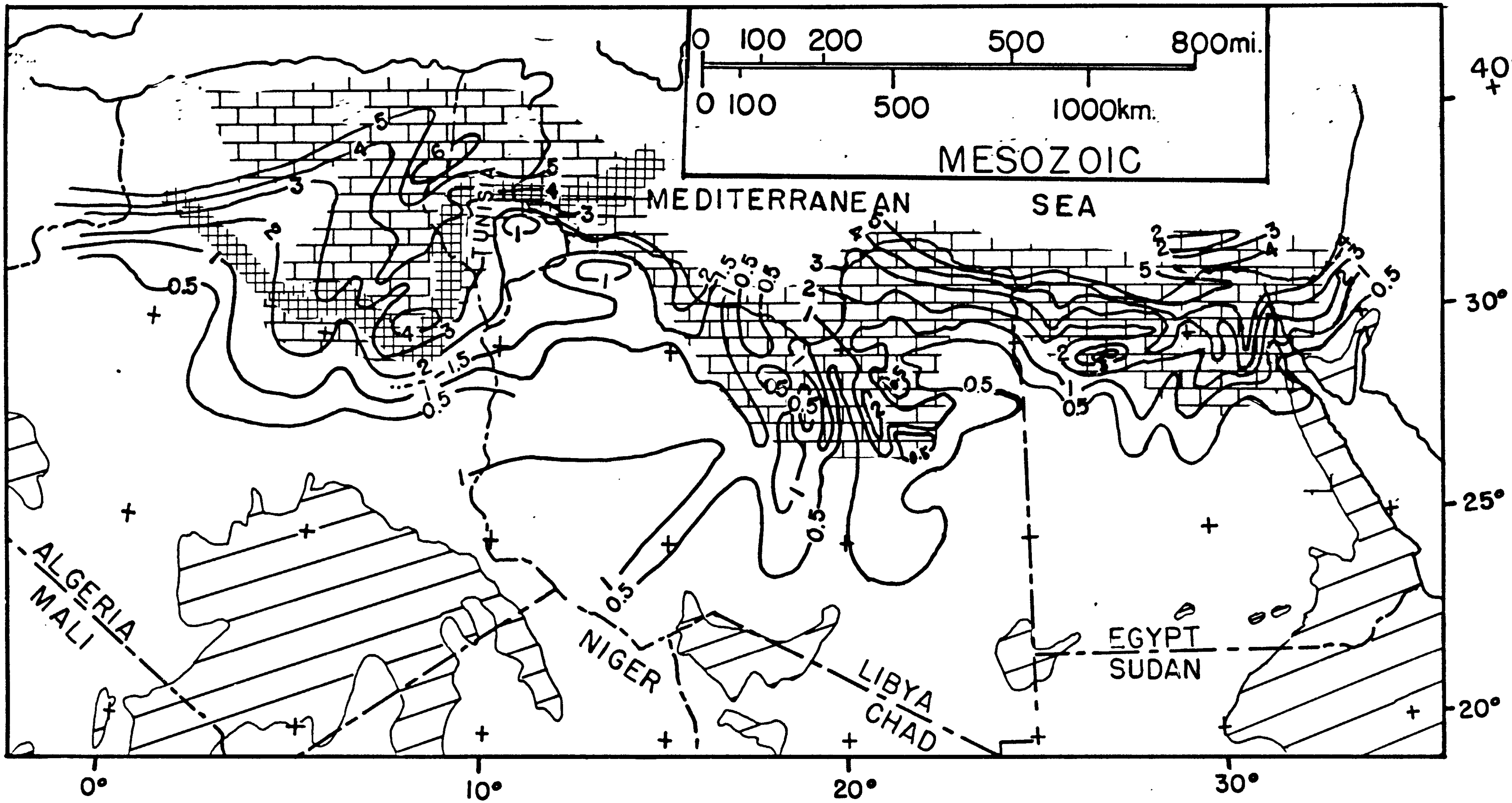


Figure 13.--Approximate thickness in thousands of meters, partly restored where erosion has taken place, Mesozoic rocks. South edge of Triassic salt and distribution of Upper Cretaceous Tethyan carbonate facies is shown. Compiled from numerous sources.

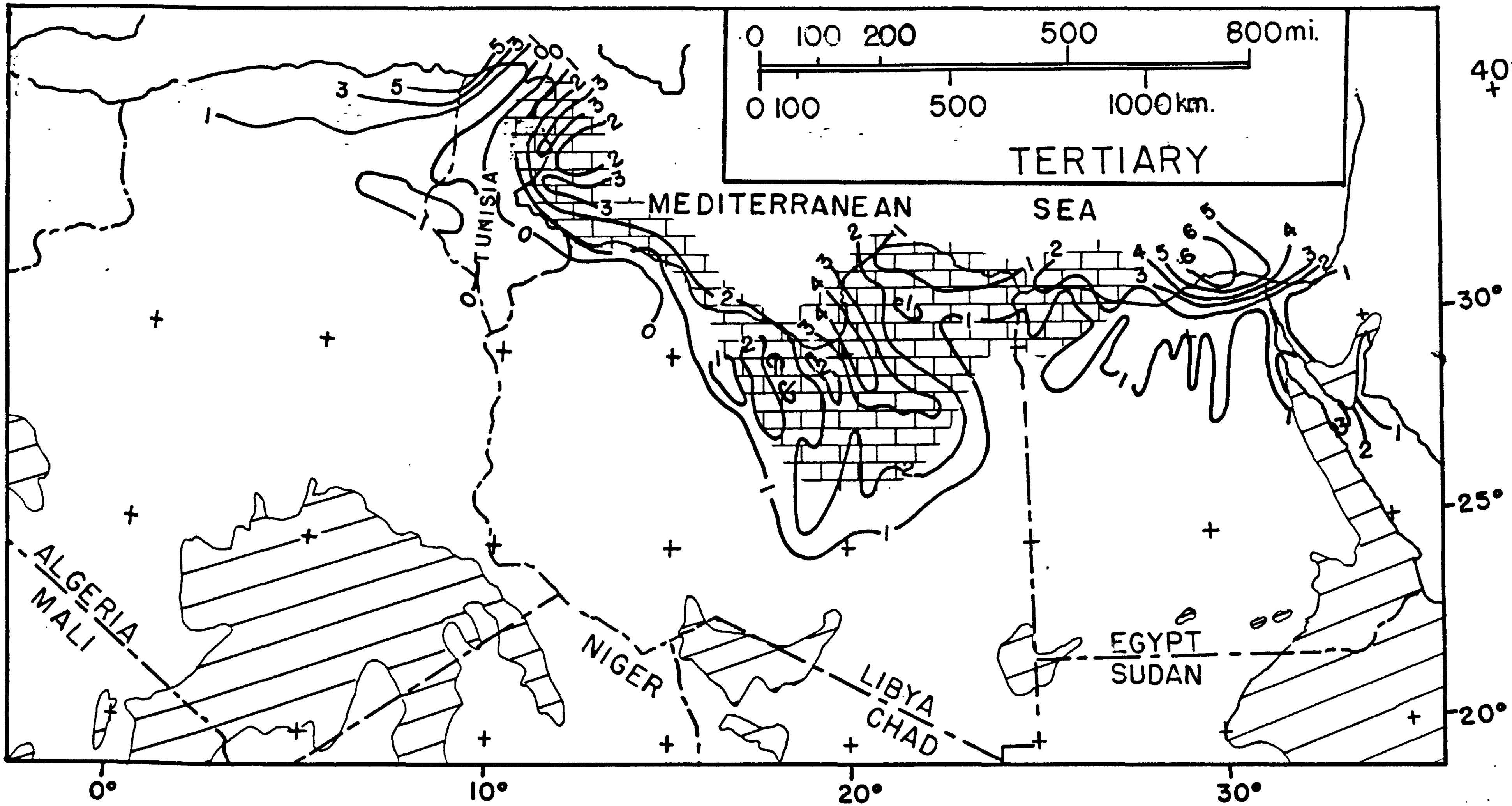


Figure 14.--Approximate thickness in thousands of meters, partly restored where erosion has taken place, Tertiary rocks, north-central and northeastern Africa. Distribution of early Tertiary Tethyan carbonate facies is shown; contains evaporites in Sirte Basin. Compiled from numerous sources.

Basement

Basement rocks in the north African Sahara are granitic, volcanic, and metamorphosed sedimentary rocks of Precambrian and perhaps, in part, lowermost Paleozoic age (Sander, 1968; El Shazly, 1977; Goudarzi, 1970; Klitzsch, 1968). At least three orogenic cycles of Precambrian age, which have been described, determined the basic structural pattern of the African continent.

Cambrian - Ordovician

Except where eroded on Hercynian uplifts, conglomerate and sandstone of Cambrian age overlie basement rocks in all basin areas of the platform. Cambrian-Ordovician rocks are thin or absent in parts of the Sirte Basin and on the Algerian anticlinorium and in much of Egypt (figs. 2, 3, 5, 7, 9, and 10) but are 1,000 m (3,250 ft) thick or more in central and northwestern Algeria, northwestern and southeastern Libya, and on the Cyrenaica 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 till is present in the uppermost Ordovician. Cambrian and Ordovician sandstones are reservoirs in numerous fields in Algeria, southern Tunisia, and Libya.

Silurian

Ordovician rocks are overlain unconformably by widespread black to dark gray, commonly bituminous graptolitic shale of Silurian (Gothlandian) age, 300 m (1,000 ft) or more thick in places, which are the main source beds for petroleum in Algeria and parts of Tunisia and northwestern Libya (figs. 3-7, and 12). The bituminous shale beds are overlain by a regressive marine sandstone unit, which is present in most of the Sahara platform except where removed by Hercynian erosion.

Devonian

Devonian rocks, 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 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 1,000 m (3,250 ft), in the Illizi, Ahnet, Bechar, and Tindouf (southwest of Bechar) Basins in Algeria, and the Hamada Basin and Cyrenaica platform in Libya (figs. 2-7).

Carboniferous

Carboniferous rocks 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 Illizi, Ahnet, Bechar, and Tindouf Basins of Algeria. The Carboniferous marine transgression spread across most of the Sahara platform from the west and northwest, and erosion rook place on several of the main uplifts at this time, including the Algerian anticlinorium, Nefusa Uplift, Amguid spur, and other associated north-south uplifts, Gargaf Arch, Tibesti-Sirte Arch, and Jamal-Al Zalmuk Uplift (figs. 2-7). Carboniferous rocks are thickest, 1,000 m (3,250 ft) or more, in the Illizi, Ahnet, Bechar, and Tindouf Basins in Algeria, the Hamada Basin and the Jefara trough in northwestern Libya, and 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).

Permian

Permian rocks apparently are absent on almost all of the Sahara platform 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, including reefal carbonate deposits, 4,000 m (13,000 ft) or more thick (Bishop, 1975; Burollet and others, 1978) (figs. 2, 3, and 6).

Triassic

After Hercynian emergence, Mesozoic transgression from the north (Tethys) deposited a widespread marine and continental clastic unit ("Trias Argilo-Greseux") in northern and central Algeria, which unconformably overlies beds ranging in age from Carboniferous to Cambrian or Precambrian (figs. 3, 4, 6, and 13). These rocks are productive oil and gas reservoirs in Algeria and southern Tunisia. Thin Triassic clastic beds also are present in northern Egypt, the Sinai, and the Gulf of Suez (El Shazly, 1977). In the western Sahara, the basal Triassic clastic unit is 0 to 500 m (0 to 1,600 ft) 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 1,000 m (0 to 3,250 ft) or more thick and are the main regional seal for numerous Triassic and Paleozoic oil and gas fields in Algeria, northwestern Libya, and southern Tunisia.

Jurassic

Lower Jurassic (Lias) salt and anhydrite 0 to 500 m (0 to 1,600 ft) or more thick overlie Triassic evaporites in central and northern Algeria and Tunisia, and in northwestern Libya north of the Nefusa Uplift. These beds grade into overlying Upper Jurassic marine fine clastic deposits and limestone 0 to 500 m (0 to 1,600 ft) thick in northern Algeria and southern Tunisia and more than 1,000 m (3,250 ft) thick in eastern Tunisia and the Pelagian platform north of the Nefusa Uplift (Bishop, 1975). The Upper Jurassic carbonate facies, which represents the first widespread transgression of the Tethyan sea, is also present in northeastern Libya and northern Egypt and in northeastern Egypt adjacent to the Mediterranean coast (figs. 4, 6, 7, 9, 10, and 13). Jurassic continental sandstone beds may be present in the "Nubian" sandstone facies in southern Libya and Egypt.

Cretaceous

Periodic transgressions of the Tethyan sea 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. It is questionable whether the maximum Cretaceous transgression established a narrow linkage between the Tethys and south Atlantic oceans through Niger and Nigeria (Furon, 1963; Kennedy, 1965; Nairn, 1978; Reyment and Reyment, 1980; Petters, 1979a, 1979b).

Lower Cretaceous beds are represented by part of the continental "Nubian" sandstone facies ("Continental Intercalaire" in Algeria) in Egypt, southern Libya and southern Algeria. The "Nubian" grades northward into a nearshore marine facies, which contains some marine limestone in northern Algeria, Tunisia, northwestern and northeastern Libya, and northern Egypt. 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 the "Nubian" and its Lower Cretaceous marine equivalent ranges from 100 to 200 m (325 to 650 ft) or less in the south to 1,000 m (3,250 ft) or more in northern Algeria, Tunisia, the Pelagian and Cyrenaica platforms, and northern Egypt (figs. 4-10, and 13). Thickness of these rocks may be 3,000 m (10,000 ft) 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 into the Mediterranean Tethys region, accompanied by north-northwest to south-southeast rifting, which formed the Sirte Basin 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 to predominantly carbonate beds, which may be reefy on horst blocks, and dark marine shale, which is thicker and highly bituminous in adjacent grabens. In the Erg Occidental and Erg Oriental Basins in Algeria, Upper Cretaceous rocks are marine carbonate and clastic deposits and some evaporites, including a thin salt layer (figs. 4 and 6). Upper Cretaceous rocks are thickest in basinal areas bordering the Mediterranean in north Africa and are 1,000 m (3,250 ft) 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. 4, 10, and 13). Marine phosphatic beds of latest Cretaceous age are present in west-central Egypt.

Tertiary

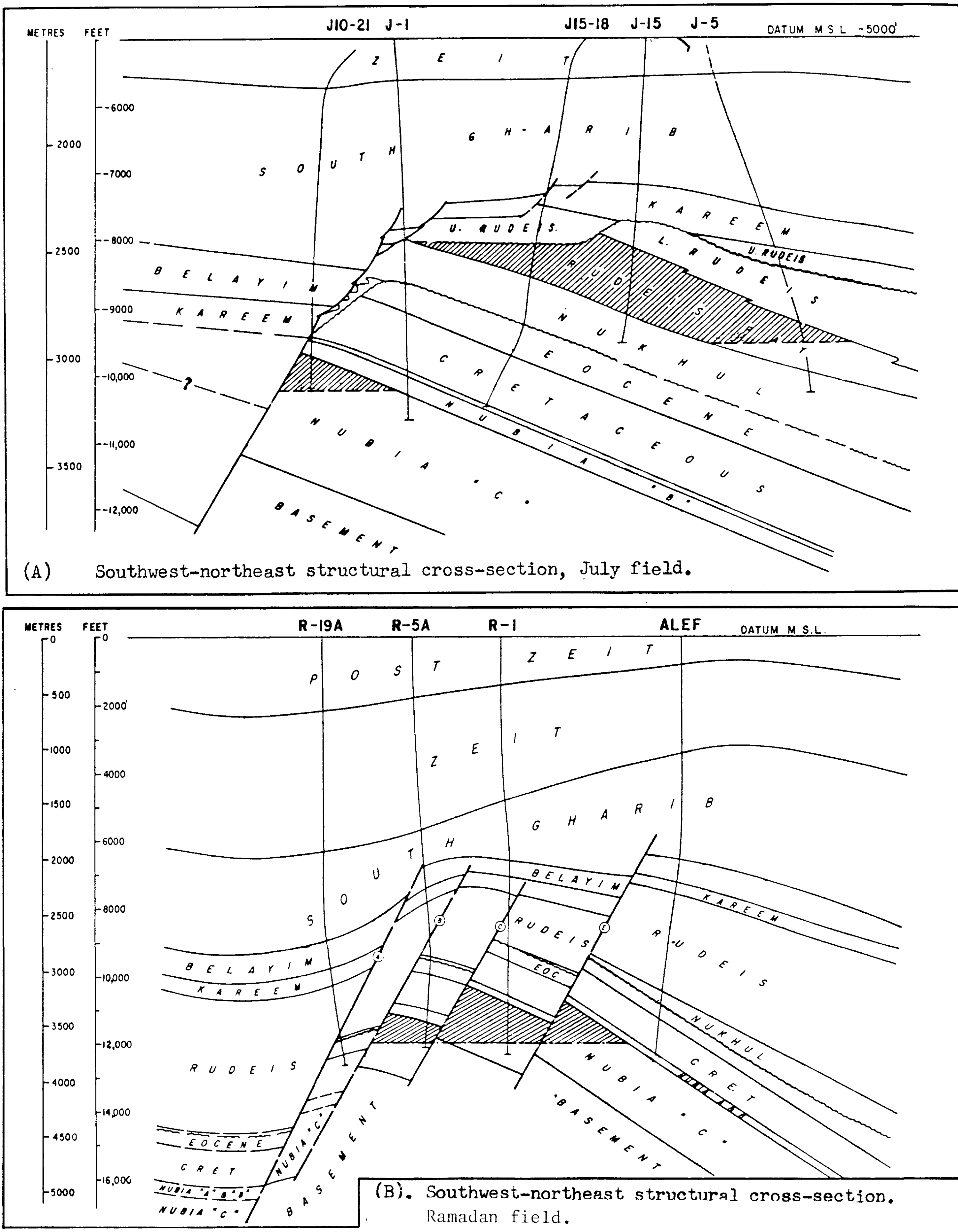
Tertiary rocks that have petroleum potential in north Africa are confined to the region bordering the Mediterranean Tethys seaway, including the Sirte Basin, the Pelagian platform, Western Desert Basin, Nile Delta, and the Nile and Suez Grabens. Tertiary sedimentary facies are primarily marine carbonate and fine clastic deposits as much as about 3,000 m (10,000 ft) thick, except for the deltaic, alluvial, and marine clastic deposits of the Nile Delta, which are 5,000 m (16,000 ft) thick or more (fig. 15). The Tethys marine transgression, which began in Late Cretaceous time, continued into the early Tertiary and extended as far south as central Egypt and southern Libya, where preserved Tertiary rocks are mainly remnants of a thin carbonate and fine clastic section not more than a few hundred meters thick (figs. 9 and 10). 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. 3 and 4).

Paleocene and Eocene carbonate rocks and marine shale are as much as 2,000 to 3,000 m (6,500 to 10,000 ft) thick in northeastern Tunisia, the Pelagian platform, and the Sirte Basin, In these areas, this facies contains reef or carbonate mound buildups, including the nummulites reservoir facies, which are good reservoir rocks, and widespread marine shale of Eocene age, which are good seals. According to El Shazly (1977), parts of northern Egypt may have been structurally high during the Paleocene-Eocene, as these beds are more sandy and thinner than beds to the south, where marine carbonate rocks are more prevalent. Equivalent beds in the Gulf of Suez are mainly marine carbonate and fine clastic beds, where thickness of more than 500 m (1,600 ft) is greater than that in surrounding areas and indicates subsidence of the Suez graben at this time.

Clastic sedimentation, including thick northerly derived molasse deposits in Tunisia, was more dominant in Oligocene time, which also was a time of uplift and erosion in much of the eastern Sahara and Egypt. Relatively thick marine carbonate beds are present in the Pelagian platform but tend to be shaly rather than reefy. In the Sirte Basin, Oligocene rocks are primarily marine shale.

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 are significant oil reservoirs. During the middle and late Miocene, widespread regression of the Tethys Sea occurred, related to Alpine orogeny in the Mediterranean region. 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 500 m (1,600 ft) thick grade from



(A) Southwest-northeast structural cross-section, July field.

(B). Southwest-northeast structural cross-section. Ramadan field.

Figure 15.--Structural cross section. A, southwest-northeast, July field, Suez Basin; B, southwest-northeast, Ramadan field (Brown, 1980). Oil accumulations shown by cross-hatching. Zeit and South Charib Formations are Miocene evaporite units.

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, are increasingly sandy and deltaic upward.

Quaternary

During Quaternary 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 800 m (2,500 ft) 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.

PETROLEUM GEOLOGY

Sirte Basin

The Sirte Basin in northeastern Libya contains approximately 100 oil fields, 21 of them major accumulations (greater than 100 MMBO), of which at least 10 are giants (greater than 1 BBO), and 8 gas fields; it is the most economically important north African petroleum province (fig. 1; table 2). The largest field is Sarir, which has an estimated ultimate production of 6.5 BBO (fig. 1; table 2). The basin is oil-prone; only one major gas field, Hateiba (17 Tcf) in the north-central part, has been found. To date, approximately 15 BBO have been produced in the basin; remaining reserves are approximately 23 BBO; and undiscovered resources means are estimated to be 9 BBO and 18 Tcf gas (figs. 16 and 17). The basin covers about 500,000 km^2 (190,000 mi^2) and contains approximately 1,800,000 km^3 (440,000 mi^3) of sedimentary cover, primarily of Mesozoic and Tertiary rocks.

Paleozoic rocks are generally thin or absent in the basin owing to late Paleozoic Hercynian uplift. However, erosional remnants of fractured Cambrian-Ordovician quartzite beds, as much as 600 m thick, are reservoir rocks in several oil fields of the basin, particularly in the western part (figs. 5, 7, and 12). Subsidence and northward tilting of the Paleozoic high began in Late Cretaceous time as the Mediterranean Tethys geosyncline opened and the Cretaceous seaway transgressed southward. The subsidence was accompanied by the formation of a northwest-southeast horst and graben system, which set the basic structural pattern of the modern basin. Growth of the horst and graben system continued until Paleocene time, after which the basin began to sag and finally was covered by widespread late Neogene continental deposits several hundred meters thick. Basal Upper Cretaceous or upper Lower Cretaceous sandstones of different thicknesses unconformably overlie Precambrian or Cambrian-Ordovician rocks in most of the basin area. These clastic beds grade upward into Tethyan carbonate and shale

Table 2.--Data on major fields, north central and northeast Africa
(MMBO, million barrels of oil; BBO, billion barrels of oil; Tcf, Trillion cubic feet; mD, millidarcy; cond., condensate; N, net; G, gross; GOR, gas/oil ratio; pct., percent; ss., sandstone)

Field name and discovery date	Structure	No. of producing wells	Depth to top of pay	Reservoir (Age and lithology)	Thickness of pay	Porosity and permeability	Cumulative Production	Proved ultimate production	Oil: Gravity (API)	Oil: Sulphur (percent)	Remarks
ALGERIA											
Alrar (1954)	Anticline & stratigraphic	37?	2075-2460 m	Dev. ss.	6-14 m (N)	6-25 pct. 35-7000 mD	122 Bcf (1969) 12 MMB cond. (1971)	5.6 Tcf gas 300 MMB Cond. 235 MMBO	47.5	Low	On production 1965; water drive; cond./gas ratio: 67.5 B/MMCF gas
Draa El Tamra (1971)	Anticline-stratigraphic		3700 m	Lower Tri. ss.	30 m (av) (N)	15 pct. 150 mD		100 MMBO	45	0.1	On production 1975; GOR: 1300; water drive
Edjeleh (1975)							178 MMBO (1979)	220 MMBO			On production 1957
El Agreb-Zotti-El Gassi (1960)	Faulted anticline	83	3065 m	Camb. ss.	70 m (N)	13-23 pct. 30-100 mD	213 MMBO (1978)	525 MMBO	45-48	0.12	On production 1960; GOR: 1040; water drive
El Borma (ouest) (1967)	Faulted anticline	8	2378 m	Lower Tri. ss.	45 m (N)	14-20 pct. 45-380 mD	54 MMBO (1978)	100 MMBO	43		On production 1969; GOR: 1250; water and solution gas drive
Gassi Touil (1961)	Faulted anticline	93	1390-1690 m	Lower Tri. ss.	68 m (N)	15 pct. 15-100 mD	305 MMBO (1978)	500 MMBO 2.7 Tcf gas	43-47	0.02	On production 1963
Guellala and Guellala NE (1969)	Faulted anti-cline-stratigr.	2+	3324-3600 m	Lower Tri. ss.	95 m (G)	15 pct. 150-200 mD	42 MMBO (1978)	130 MMBO	40-45	0.1	On production 1972; GOR: 1300; water drive
Haoud Berkaoui (1965)	Anticline	10	3175-3225 m	Lower Tri. ss.	27 m (N)	2-16 pct. 10-130 mD	132 MMBO (1978)	300 MMBO 1.3 Tcf gas	43-46	0.1	On production 1965; GOR: 1319
Hassi Messaoud (1956)	Anticline-stratigraphic	350	3110 m	Camb. ss.	180 m (N)	2-13 pct. 0-1000 mD	2.7 BBO (1979)	9 BBO 7 Tcf gas	43-49	0.13	On production 1956; GOR: 790; water & solution gas drive; gas injection 1976
Hassi R'Mel (1957)	Dome and stratigraphic	152+	2135-2185 m	Lower Tri. ss.	52 m (N)	5-22 pct. 100-1000 mD	2.5 Tcf gas; 135 MMB cond. (1978)	50-75 Tcf gas 3.0 BB Cond.	53		On production 1961; gas/cond. ratio: 45B/MMCF; water & gas expansion drive
Mereksene (1974)	Anticline	10	2100 m	Dev. ss.			56 MMBO (1978)	250 MMBO			On production 1975
Ohanet (1960)	Faulted anticline	38	1690-1710 m	Dev. ss.	22 m (N)	0-24 pct. 0-2000 mD	103 MMBO (1978)	130 MMBO 0.5 Tcf gas?	43	0.1	On production 1961; GOR: 1040; Gas cap & solution gas drive
Rhourde El Baguel (1962)	Faulted anticline	56	2550 m	Camb. ss.	500 m (N)	1-10 mD	277 MMBO (1979)	460 MMBO	35	0.31	On production 1962; GOR: 10,040; gas expansion drive

Table 2.--Data on major fields, north central and northeast Africa--Continued

Field name and discovery date	Structure	No. of producing wells	Depth to top of pay	Reservoir (Age and lithology)	Thickness of pay	Porosity and permeability	Cumulative production	Proved ultimate production	Oil: Gravity (API)	Oil: Sulphur (percent)	Remarks
Stah (1971)				Dev. ss.			50 MMBO (1978)	350 MMBO			On production 1975
Tin Fouye-Tabankourt (1960)	Faulted anticline	64	890-1545 m	Dev. ss. Ord. ss.	66 m (G)	8-20 pct. 60-400 mD	186 MMBO (1978)	280 MMBO	40	.14	On production 1967; GOR: 11-1030; water drive
Zarzaitine (1957)	Faulted anticline	169	513-1272-m	Carboniferous ss. Dev. ss.	345 m (G)	13-28 pct. 15-500 mD	568 MMBO (1978) 462 Bcf gas 1971	900 MMBO 1.0 Tcf gas	42-52	0.06	On production 1957; Gas cap & water drive; main reservoir, Lower Dev. ss.
Timedratine (1961)	Faulted anticline	15	1710-2455 m	Dev. ss.	46 m+ (N)	19 pct. 1-2000 mD		100 MMBO+	40-41	0.07-0.1	On production 1964; GOR: 1120-1235; gas expansion & water drive
TUNISIA											
Ashtart (offshore) (1971)	Faulted anticline	16	2735 m	Eocene nummu-lites ls.	77 m (N)	17 pct. 19 mD	88 MMBO (1979) 30 Bcf gss (1978	325 MMBO ? gas	29	0.9	On production 1973; wster drive; water injection 1975
El Borma (1964)	Faulted anticline	58	2338 m	Lower Tri. ss.	57 m (N)	18 pct. 200-500 mD	288 MMBO (1979) 366 Bcf gas 1979	450 MMBO ? gas	43	0.8	On production 1966; water drive
Isis (offshore) (1974)	Reef?	2	2480 m	Upper Cret. dol. and ls.		17 pct. 100-400 mD		100-350 MMBO			Production delayed by border dispute with Libya; oil shows in Lwr. Cret.
LIBYA											
Augila-Nafoora (1966)	Stratigraphic-structural	124	2415-2622 m	Upper Cret. ss. & ls.; Tert. ss Prec. granite	5-25 m (N)	25 pct. 11 pct.	715 MMBO (1974)	1.8 BBO	35		On production 1966; GOR: 400; two wells produce from basement rocks
Amal (1959)	Faulted nose	118	2981-2930 m	Upper Cret. ss. Camb. ss.	91 m (G) 244 m (G)	11 pct. 50 mD	686 MMBO (1981)	4.2 BBO	35	0.14	On production 1966; GOR: 752; solution gas & wster drive; production also from lower Tert. & fractured basement
Bahi (1958)	Anticline	44	1775 m	Upper Cret.-Paleocene ls. & dol.; Camb.-Ord. ss.	10 m (G)		315 MMBO (1981)	600 MMBO	39-44		On production 1970; GOR: 163; water drive

Table 2.--Data on major fields, north central and northeast Africa--Continued

Field name and discovery date	Structure	No. of producing wells	Depth to top of pay	Reservoir (Age and lithology)	Thickness of pay	Porosity and permeability	Cumulative production	Proved ultimate production	Oil: Gravity (API)	Oil: Sulphur (percent)	Remarks
Beda (1959)		58	859-1192 m	Paleocene ls. and dol.	10-31 m (N)	15-30 pct. 10-33 mD	76 MMBO (1974)	600 MMBO, (initial in-place)	33-37	0.45	On production 1964; GOR: 100-140; water drive
Bu Attifel (1968) (Abu Tiffel)	Anticline	29+	4115-4237 m	Lower Cret. ss.	152 m (G)		457 MMBO (1981)	1.2 BBO	40	0.1	On production 1972; GOR: high
Dahra west and Dahra east (1958)	Anticline and reef	213	903-1676 m	Paleocene-Upper Cret. ls. & dol	21-42 m (G)	22-27 pct. 80-100 mD	422 MMBO (1981)	470 MMBO+ 94 Bcf gas	36-42	0.04-0.22	On production 1962; GOR: 290-432; water and solution gas drive
Defa (1960)	Faulted anticline	78	1676 m	Paleocene-Upper Cret. ls. and chalk			772 MMBO (1981)	1.8 BBO	34-38	0.28	On production 1964; GOR: 280
Ghani (1977)		39					7.7 MMBO (1981)	150 MMBO			
Gialo (1961)	Faulted anticline	200	679-1084 m	Paleocene-Eocene ls. & dol.; Oligocene ss.	7-12 m+ (N)		1.7 BBO (1981)	3.5 BBO	31-39	0.52	On production 1964; GOR: 168
Hateiba (1963)	Anticline	15 (gas)	2621 m	Upper Cret. carbonate				17 Tcf			On production 1977; 82 pct. methane
Intisar-A (1967)	Stratigraphic (reef)	19	2870 m	Paleocene ls. and dol.	195-365 m (G)	21-27 pct. 2-200 mD	654 MMBO (1981)	750 MMBO	43-45		On production 1968; GOR: 1336; water injection
Intisar-D (1967) (Idris-D)	Stratigraphic (reef)	14	2697 m	Paleocene ls. and dol.	300 m (G)	22 pct. 4-500 mD	903 MMBO (1981)	1.5 BBO	37-40		On production 1968; GOR: 511; water injection
Jebel (1962)	Anticline	36	2403 m	Upper Cret. ss. Camb.-Ord. ss.	58 m (G)	18-26 pct. 10-300 mD	154 MMBO (1981)	230 MMBO 1.1 Tcf gas	38-43		On production 1964; GOR: 848; water and gas cap drive
Lehib-Dor Marada (1965)	Anticline	20		Upper Cret. ss. Camb.-Ord. ss.			75 MMBO (1981)	130 MMBO	47-52		On production 1967; GOR: 3000; water drive
Messla (1971)	Stratigraphic wedgeout	86	2515-2650 m	Lower Cret. ss.	27-76 m (N)	17 pct. (av.) 500 mD (av.)	74 MMBO (1979)	1.5 BBO	39.6	Low	On production 1976; GOR: 380; water drive

Tsble 2.--Dsta on major fields, north central snd northeast Africs--Continued

Field name and discovery date	Structure	No. of producing wells	Depth to top of pay	Reservoir (Age and lithology)	Thickness of pay	Porosity and permeability	Cumulative production	Proved ultimate production	Oil		Remarks
									Gravity (API)	Sulphur (percent)	
Nasser (Zelten) (1959)	Faulted anticline	212?	1524- 2320 m	Paleocene-Eo- cene ls. (reef) Upper Cret. ls.	55-98 m (G)	2-40 pct. 100 mD	1.97 BBO (1981)	2.2 BBO 1.35 Tcf gas	37-39	0.23	On production 1961; GOR: 345-683; water & solution gas drive; main reservoir is Paleocene-Eocene reef
Ora (1962)		29	1639- 2264 m	Paleocene-Upper Cret.ls.; Camb.-Ord. quartzite		18-25 pct. 20 mD 3 pct. 12 mD	96 MMBO (1981)	100 MMBO	30-35	0.22-0.33	On production 1965; GOR: 168-474; water drive
Raguba (1961)	Faulted anticline- stratigraphic	67	1545 m	Upper Cret.car- bonate & ss.; Camb.-Ord. ss.	213 m (G)	15-28 pct. 100-200 mD	545 MMBO (1981)	750 MMBO 2 Tcf gas	40-42	0.27	On production 1963; GOR: 938; water drive and gas cap drive
Ssmah (1961)	Faulted anticline	21	1838- 1926 m	Upper Cret. ls. & ss.; Camb.- Ord. quartzite	50 m (G) 30 m (G)		336 MMBO (1981)		33-37	0.25	On production 1963; GOR: 118
Sarir (1961)	Faulted anticline	97	2620- 1684 m	Upper Cret. ss.	150-6000 m (G)	18 pct. 200-300 mD	4.3 BBO	6.5 BBO	37-38	0.25	On production 1966; GOR: 60-225; water drive
Waha (1959)	Faulted anticline	82	469- 1910 m	Eocene ls. Upper Cret. ls.	133 m (G)	10-26 pct. 1-890 mD	799 MMBO (1981)	1.4 BBO	34-38	0.24	On production 1963; GOR: 404; main reservoir, Upper Cret. ls.
Zella (1977)	Anticline	41	1951 m	Eocene dol. and ls.	101 m (G)	21 pct.	26 MMBO (1981)	110 MMBO	47-49		On production 1978; GOR: 1032.
EGYPT											
Abu Masdi (1967) (Nile Delta)	Anticline- stratigraphic	5 (gas)	3296 m	Lower Pliocene ss.	3 m (N)		48 Bcf (1980)	2.5 Tcf gas 60 MMB cond.			On production 1974; 91 pct. methane
Belayim Land (1955)	Fault block- stratigraphic	105+	1570- 2600 m	Miocene ss. and cgl.	132 m (N)	15-25 pct. 100-1000 mD	310 MMBO (1979)	450 MMBO	17-22	2.6-3.2	On production 1955; water and solution, gas drive
Belayim Marine (1961)	Fault block- stratigraphic	17	1950- 2800 m	Miocene ss. Upper Cret. ss. and ls.	20-170 m (N)	13-25 pct. 16-680 mD	226 MMBO (1979)	450 MMBO	26-31	1.4-2.5	On production 1962; GOR: 390; solution gas and water drive

Table 2.--Data on major fields, north central and northeast Africa--Continued

Field name and discovery date	Structure	No. of producing wells	Depth to top of pay	Reservoir (Age and lithology)	Thickness of pay	Porosity and permeability	Cumulative production	Proved ultimate production	Oil: Gravity (API)	Oil: Sulphur (percent)	Remarks
EPK-X (1979)		5	1402 m	Miocene ss.				100 MMBO	20		On production 1979
EF-85								100 MMBO?			
October (1977)	Fault block-stratigraphic	15	3350 m	Miocene ss.; Upper Cret. ss. Jur.-Cret. ss.	154 m (N)	12-20 pct. 100-200 mD	17 MMBO (1980)	400 MMBO	26-31		On production 1979; GOR: 107-211
July (1977)	Fault block-stratigraphic	23	2438-2895 m	Miocene ss.; Paleozoic ss.	380 m (N)	18-24 pct. 100-200 mD	184 MMBO (1979)	750 MMBO			On production 1973; water flood 1978; some production from Cret. ss.
Morgan (1965)	Fault block-stratigraphic	86	1550-1750 m	Miocene ss.	83 m (N)	22 pct. 20-685 mD	590 MMBO (1979)	1.3 BBO	26-33	1.6-2.4	On production 1967; GOR: 600-242; solution gas drive, waterflood 1972
Ramadan (1974)	Fault block	16	3020-3299 m	Upper Cret. ss. & ls.; Carboniferous ss.	77 m+ (N)	13-18 pct. 100-200 mD	150 MMBO (1979)	700 MMBO	32		On production 1974
Ras Budran (1978)	Fault block-stratigraphic	3	3200 m	Jur.-Cret. (Nubian) ss.	378 m (N)	14 pct. 100-200 mD		100 MMBO	26		On production 1982
Ras Gharib (1938)	Fault block-stratigraphic	190+	425-630 m	Miocene reef ls.; Upper Cret ss.; Pal. ss.	420 m (G)		236 MMBO (1980)	260 MMBO	24-27	2.9-3.1	On production 1943; GOR: 196; water drive.
Shaab Ali Mar (1977)	Fault block	12	1600 m	Miocene ss.			21 MMBO (1979	200 MMBO			On production 1978

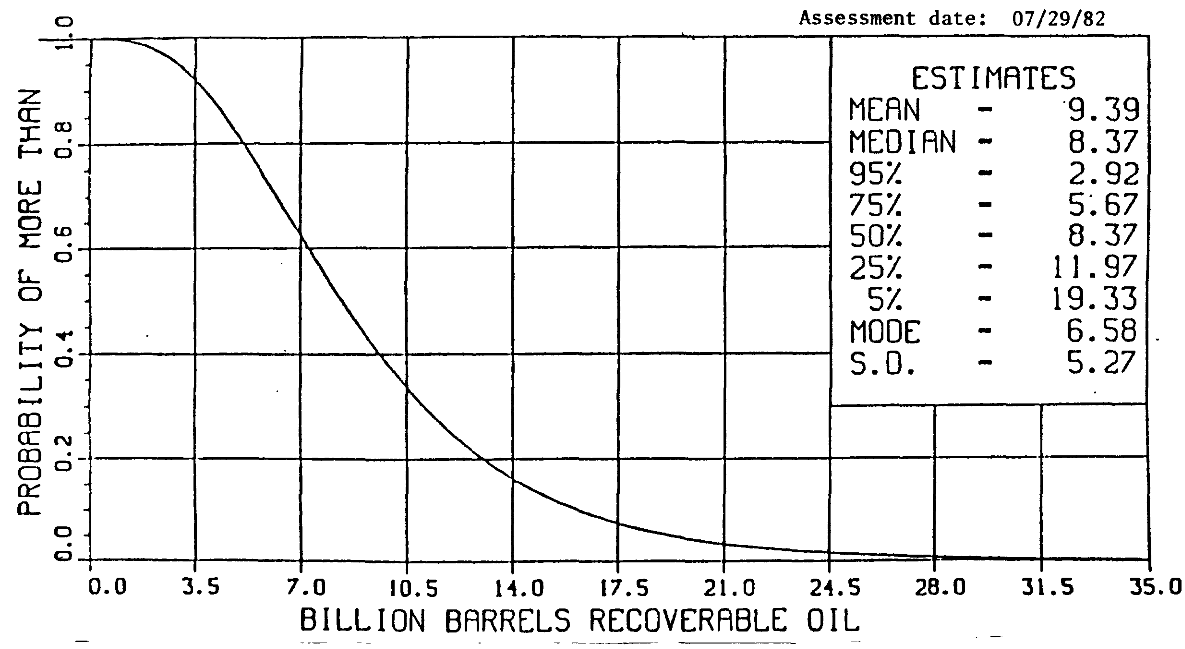


Figure 16.--North Africa; Sirte basin, Libya, undiscovered recoverable oil.

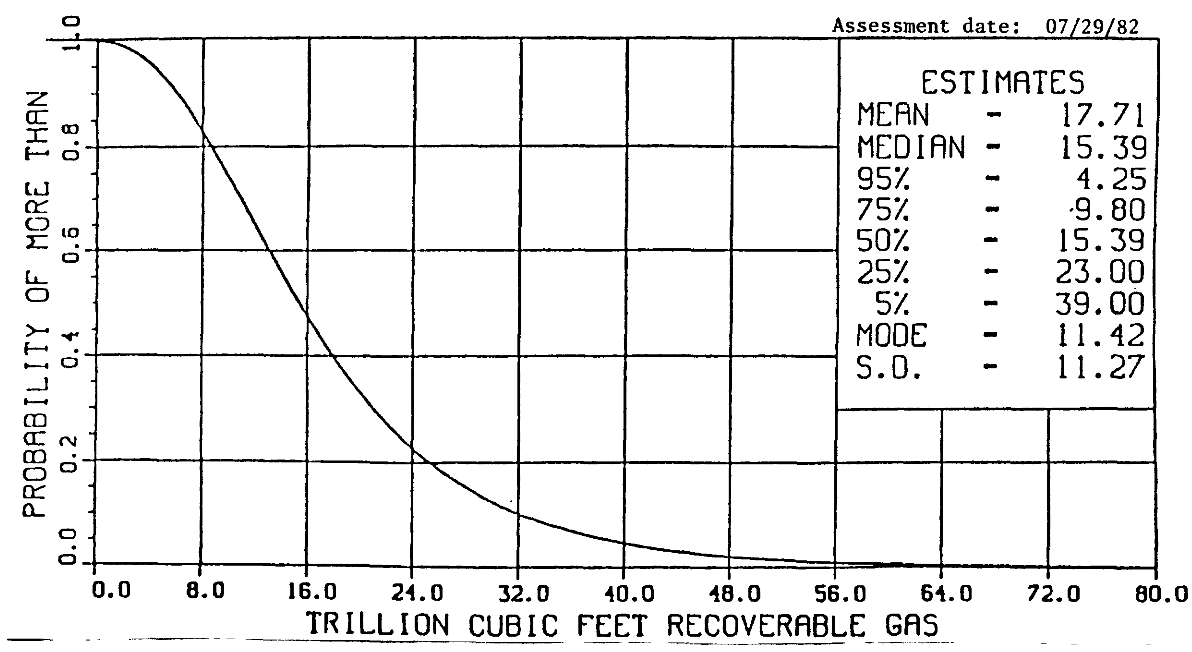


Figure 17.--North Africa; Sirte basin, Libya, undiscovered recoverable total gas.

facies of Late Cretaceous and early Tertiary age. Reservoir rock facies, both clastic and carbonate reef or mound bodies, were deposited on or near the paleohorsts, and fine-grained organically-rich shale or shaly carbonate units in the paleograbens, particularly during regressive marine phases of the cycles. Widespread transgressive marine shale beds of early Eocene age and overlying regressive evaporite deposits provide regional seals for the major petroleum deposits in the province.

Major oil accumulations occur along or adjacent to horst blocks. The following combination of factors makes the Sirte Basin one of the world's more productive petroleum provinces: (1) large paleostructures (paleohorsts) that have a long period of growth; (2) good reservoir rocks, in many places isolated in impermeable shale; (3) adequate bituminous source rocks in several parts of the section closely associated with, and in some places capping, clastic or carbonate reservoirs; (4) periodic deposition of transgressive marine shale facies, which provides regional seals for petroleum accumulation; (5) adequate but not excessive depth of burial and source-rock maturity; and (6) stable basin that shows little recent disturbance of earlier formed traps.

Reservoirs.--The main productive reservoirs are lower Tertiary reef or organic carbonate mound beds, sandstone beds of Early Cretaceous and earliest Late Cretaceous age, fractured quartzites of Cambrian-Ordovician or Precambrian age, and, in at least one place (Aguila-Nafoora field), fractured Precambrian granite (Williams, 1972). Nine of the 21 major fields produce from carbonate reservoirs and 12 from clastic reservoirs (Parsons and others, 1980). Fractured Cambrian-Ordovician quartzites are productive on several of the major horst blocks; Lower Cretaceous and basal Upper Cretaceous sandstones are productive on structures in the eastern part of the basin; and latest Cretaceous-Paleocene and Eocene reef or carbonate mound reservoirs are productive in the central part of the basin, primarily on horst blocks and from adjacent pinnacle reefs on horst-block flanks or within the grabens. Minor production is obtained from Eocene and Oligocene-Miocene sandstone reservoirs in the eastern part of the basin.

Source Rocks.--The main source rocks and their organic carbon content (Parsons and others, 1980) are: (1) Cretaceous shale (0.5 to 3.5 percent; average 1.91 percent), (2) Paleocene shale (0.5 to 2 percent; average 0.95 percent), (3) lower Eocene shale (0.5 to 2 percent; average 0.87 percent), and (4) Oligocene shale (0.5 to 1.5 percent; average 0.99 percent).

Seals.--Regional seals, some of which contain the main source-rock beds, are Upper Cretaceous shale and argillaceous limestone; lower Paleocene shale, argillaceous limestone, and anhydrite; upper Paleocene-lower Eocene shale, argillaceous limestone, and anhydrite; and Oligocene shale.

Traps.--Of the 22 major fields, 18 are on structural highs, generally faulted, and 3 are classed as stratigraphic traps (table 2) (Parsons and others, 1980). Generally, however, a close relationship exists between paleostructural growth and major reservoir distribution resulting in a strong stratigraphic influence on structural accumulations. The heavily faulted nature of the basin is favorable for fault traps on the flanks of major structures, and the paleostructural history of the basin is of interest with respect to undiscovered stratigraphic traps in both sandstone and carbonate reservoirs.

Western Sahara Region

Erg Occidental, Erg Oriental, Illizi, Hamada, and Ahnet Basins are Paleozoic and early Mesozoic cratonic basins, which occupy the western part of the Sahara platform in east-central Algeria, southern Tunisia, and northwestern Libya (figs. 1 and 2). Approximately 75 oil and 30 gas fields are present, of which 17 are major accumulations (greater than 100 MMBOE). A major part of the reserves is in the supergiant Hassi Messaoud oil field (9 BBO) and the Hassi R'Mel gas field (50 to 75 Tcf) (figs. 1, 4, and 6; table 2). The undiscovered resource means are estimated at approximately 8 BBO and 25 Tcf gas (figs 18 and 19). Approximate size of the assessed area is 700,000 km^2 (265,000 mi^2), and total volume of sediments is 2,500,000 km^3 (550,000 mi^3), primarily of Paleozoic and early to middle Mesozoic age. The area is bounded on the south by the Ahaggar Massif, on the north by the Atlas folded geosynclinal belt and Pelagian platform, on the west by the Chaine d'Ougarta Mountains and Bechar Basin, and on the east by the Sirte Basin. The Murzuk and Kufra Basins in southern Libya are not included in the assessment because of minor potential for hydrocarbon resources.

The sedimentary cover of the assessed area ranges from less than 1,000 m (3,250 ft) to more than 6,000 m (20,000 ft) in thickness and consists of continental and marine platform sandstones and minor marine shales of Cambrian through Carboniferous age, overlain unconformably by Triassic and younger Mesozoic rocks (figs. 3, 5 and 10). Upper Carboniferous and Permian rocks are absent or very thin. Rocks of Triassic age consist of a basal sandstone overlain by a widespread sequence of anhydrite or gypsum, salt, and red beds of Triassic and Early Jurassic age. The red bed-evaporite section grades upward to nearshore marine sandstone, shale, and carbonate beds of Jurassic and Cretaceous age. Carbonate and some evaporite beds containing minor salt are common in the upper part of the Upper Cretaceous section, which is overlain unconformably by Miocene or Pliocene continental clastic beds in most of the area. Upper Cretaceous sandstone overlaps older Mesozoic and Paleozoic beds to the south toward the Ahaggar uplift (massif) and the African craton, which was the major clastic-source area in Paleozoic and Mesozoic time.

Present-day regional structure of the area is primarily the result of Hercynian orogeny (Magliore, 1970), modified in some places by early Mesozoic extensional tectonism and Alpine compressional stresses. Individual basins may have been in existence since early Paleozoic time (Magliore, 1970; Balducchi and Pommier, 1970; Bishop, 1975). Most of the oil and gas fields are in structural traps associated with larger paleostructural features that originated during Caledonian tectonic movements and also were strongly affected by Hercynian movements, which to a large degree determined the present structure of the western Sahara (Magliore, 1970; Balducchi and Pommier, 1970; Bishop, 1975). A major part of both the oil and gas reserves of the region are in two large domal structures associated with large Hercynian paleostructural areas, the Hassi Messaoud oil field, and the Hassi R'Mel gas field. Both these structures are on large paleostructural trends that show mild growth during the Caledonian and relatively strong growth accompanied by significant erosion during the Hercynian. Many of the smaller fields also show evidence of relationship to Paleozoic, particularly Hercynian, paleostructural growth.

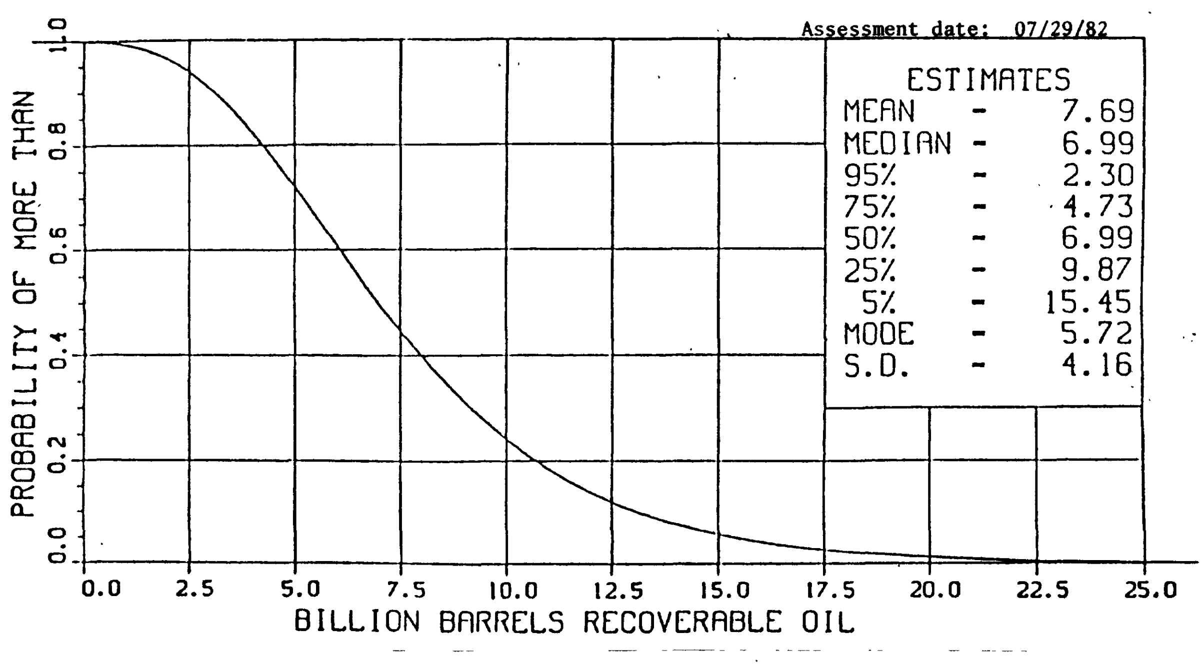


Figure 18.--North Africa; Erg Occidental, Erg Oriental, and Hamada basins, undiscovered recoverable oil.

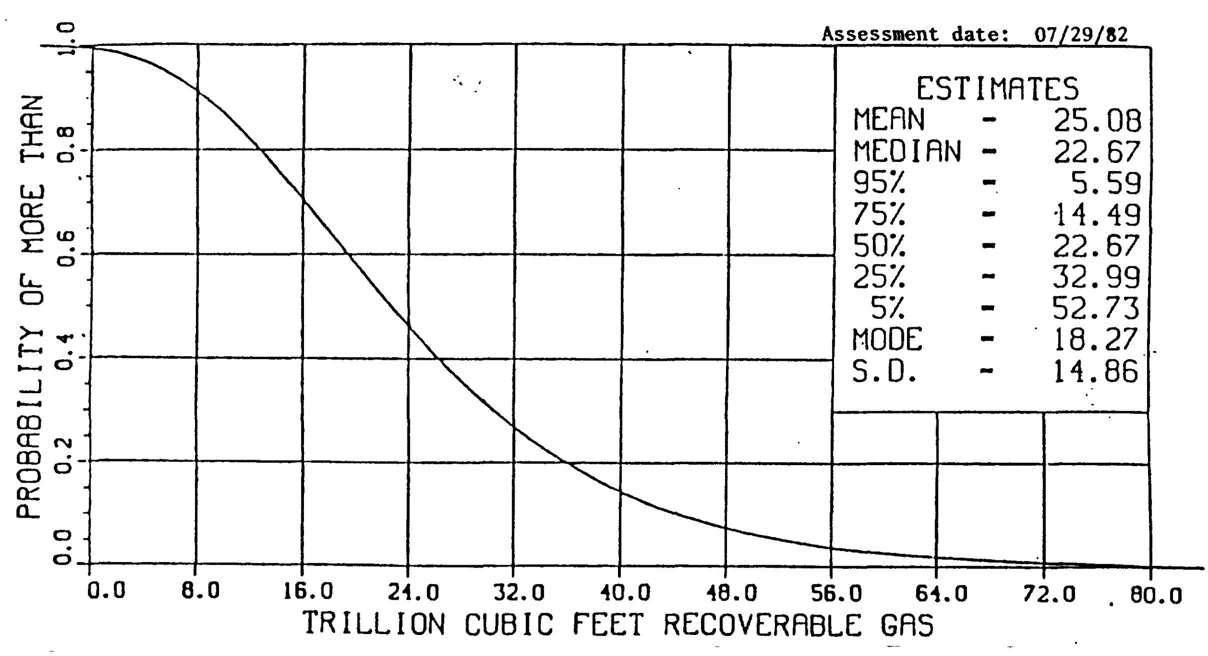


Figure 19.--North Africa; Erg Occidental, Erg Oriental, and Hamada basins, undiscovered recoverable total gas.

Reservoirs.--The productive reservoirs in order of importance are Cambrian-Ordovician, basal Triassic, Devonian, and Carboniferous sandstones. Most of the oil is in Cambrian-Ordovician sandstones, dominated by the supergiant accumulation at Hassi Messaoud, which accounts for about 75 percent of the total oil reserves in these basins. A major part of the gas reserves is in basal Triassic sandstone reservoirs in the supergiant Hassi R'Mel gas field and in several gas fields south of the Hassi Messaoud oil field (fig. 1). Almost all these gas accumulations are at substantially higher structural levels than are the major oil accumulations in the vicinity of the Hassi Messaoud field (fig. 4). These relationships, coupled with aspects of paleostructural and erosional history of the area, suggest the possibility of early gravity separation of oil and gas into large paleostructural-stratigraphic accumulations, for which the Silurian black shale beds are the main source rocks, associated with the regional central Algerian Hercynian paleostructure at the time of hydrocarbon generation and migration, probably during Cretaceous time. Subsequent tectonic activity, perhaps Laramide or Alpine or both, may have resulted in redistribution of the earlier and broader gravity-separated accumulations into localized structural-stratigraphic accumulations of primarily gas or primarily oil, depending on position of the final structure within the original accumulation.

Gas and some oil are present in Devonian and Carboniferous sandstone reservoirs in the Illizi Basin in southeastern Algeria (figs. 1 and 4). Most of these are small deposits except for the Alrar gas field (5.6 Tcf). Devonian sandstone reservoirs are also productive in the Ahnet Basin on the northwest flank of the Ahaggar uplift.

Source Rocks.--Silurian highly organic, graptolitic shale is the major source rock for oil and gas in the western Sahara (Magliore, 1970; Balducchi and Pommier, 1970; Bishop, 1975). Marine shale beds in the Devonian and Carboniferous section are possible source rocks for some of the oil and gas accumulations in the Illizi and Ahnet Basins, although Silurian highly organic shale is the probable main source. Shallow gas without oil in Devonian sandstone reservoirs in the Ahnet Basin gas fields (fig. 1) may be biogenic, although deeper drilling for possible associated oil accumulations is needed for confirmation.

Seals.--The Triassic-Lower Jurassic regional evaporite section is the major seal for fields producing from the basal Triassic and Paleozoic clastic section (fig. 4). Carboniferous and possibly Devonian shale beds are seals for many of the fields south of the Triassic pinchout in the Illizi and Ahnet Basins.

Traps.--All known oil and gas fields are on anticlines, faulted anticlines, or domes. Early stratigraphic-paleostructural trapping and draping over early structures are probably important aspects of the major accumulations, and unconformity or reservoir pinchout traps are commonly associated with the main structural accumulations.

Suez-Sinai

There are approximately 40 oil fields in and adjacent to the Suez graben, at least 10 of which are larger than 100 MMB (million barrels) (table 2). Largest are the Belayim Marine, Morgan, and Belayim Land fields, which have estimated ultimate recoveries of 1.1 BBO, 1.1 BBO, and 550 MMBO respectively (figs. 1 and 15; table 2). Few gas or gas-condensate accumulations have been found, but approximately 2.5 BBO have been produced; remaining reserves are approximately 3.5 BBO, and undiscovered resource means are estimated at 2.4 BBO and 3.2 Tcf gas (figs. 20 and 21). Active exploration of the Suez Basin has been underway since the 1950's, and the province now is at an intermediate exploration stage. Considerable deeper drilling is needed but may be hampered by problems of seismic resolution beneath the thick Miocene salt section.

Some authors have proposed that mild subsidence of the Suez Basin area dates from late Paleozoic time or earlier (Said, 1962; El Shazly, 1977; Barakat, 1982). However, the main development of the Suez-Red Sea graben system was in post-Eocene time when eastern Egypt became part of the Red Sea spreading center.

Paleozoic and Mesozoic rocks are thin or absent in part of the Suez-Sinai region but are thicker northward toward the Mediterranean. The base of the sedimentary section is the "Nubian" sandstone sequence, which is partly Carboniferous or older and partly Jurassic to Early Cretaceous in age. Upper Cretaceous carbonate and clastic beds overlie the Nubian in much of the region, and in turn are overlain by Eocene and Paleocene limestone and shale (fig. 3). Oligocene rocks are apparently absent or thin in the Suez basin; Eocene rocks are overlain unconformably by a thick Miocene section, as much as about 3,000 m (10,000 ft) thick, of shale, evaporite, and carbonate beds. Pliocene and younger carbonate, evaporite, and shale beds overlie the Miocene evaporites in most of the basin area. Structure of the region is complicated by severe block faulting and tilting related to development of the northeast African rift belt. Most of the oil accumulations are related to the tops or flanks of fault-block structures, which were growing before and during Miocene deposition (figs. 2 and 15).

Drilling in the Egyptian Sinai region east of the Suez Basin thus far has been unsuccessful. Much of the area is highly faulted and fractured and has a relatively thin sedimentary cover. However, in the coastal region to the north, the sedimentary cover is markedly thicker, and the presence of Mesozoic Tethyan carbonate facies and additional Paleozoic beds increase the potential there.

Reservoirs.--Oil is produced from the Nubian sandstone beds of Carboniferous and Cretaceous age, early Tertiary reefal or mound carbonates, and Miocene sandstone and carbonate reservoirs, including reefs. Most of the reserves are in Miocene sandstone reservoirs. Significant production is obtained from Nubian sandstones, and some production also is obtained from early Tertiary carbonate reservoirs (table 2). Reservoir bodies, both sandstone and carbonate, are commonly discontinuous, related to sandstone truncation or pinchout on fault-block paleostructures or discontinuous organic carbonate bodies (fig. 15). Fracturing is common in all types of reservoirs.

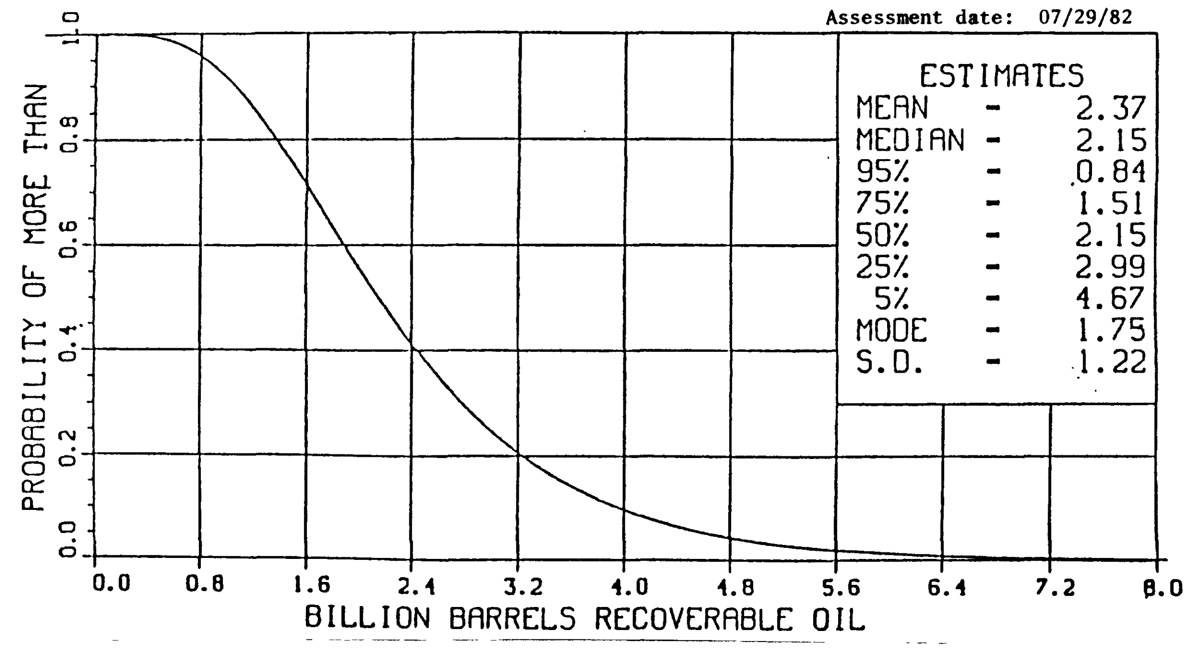


Figure 20.--North Africa; Suez-Sinai province, Egypt, undiscovered recoverable oil.

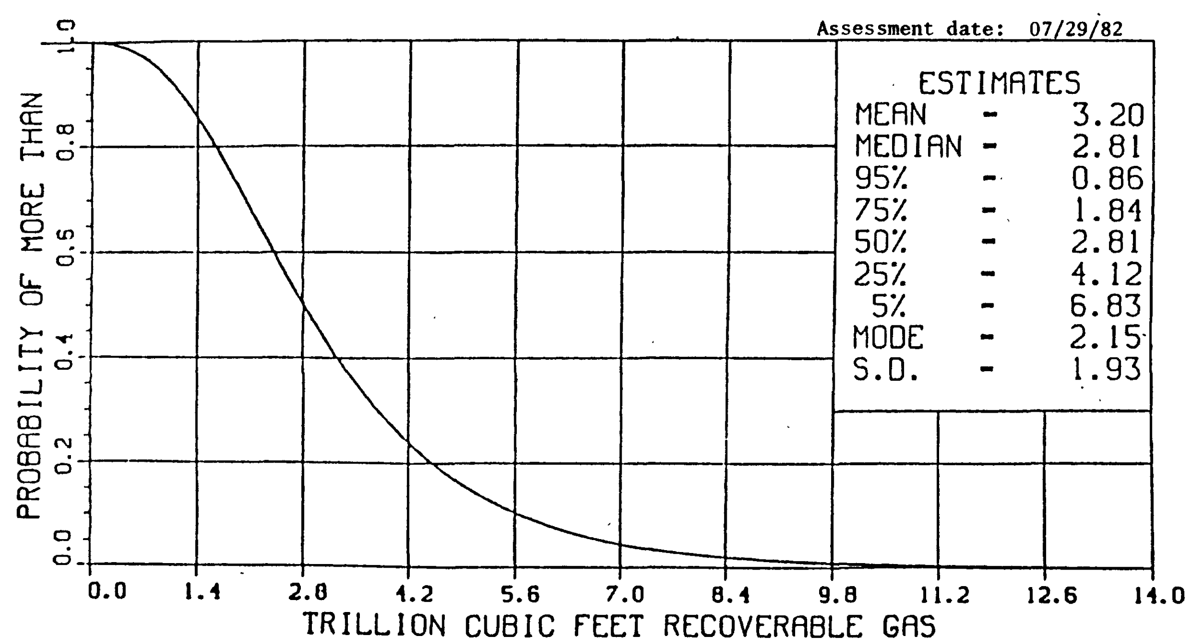


Figure 21.--North Africa; Suez-Sinai province, Egypt, undiscovered recoverable total gas.

Source Rocks.--Upper Cretaceous marine shale and bituminous argillaceous limestone beds are the main oil-source rocks; Eocene bituminous argillaceous limestone is a secondary source; and Jurassic limestone rich in organic matter also is a possible source. Lower Miocene organically-rich Globigerina shales are potential source rocks but apparently are immature except for those in the southern part of the basin adjacent to the Red Sea. Gas accumulations that have been found thus far are insignificant, although deeper drilling is needed in order to evaluate fully the apparent oil-prone nature of the basin.

Seals.--The middle Miocene anhydrite and salt section is the main seal throughout the basin, draping over fault-block structures and pre-middle Miocene carbonate buildups.

Traps.--Most fields are on anticlines or faulted anticlines associated with sediment draping over tilted fault blocks in pre-Miocene rocks. However, stratigraphic variations, in the form of updip sandstone pinchouts at unconformities or faults and discontinuous reefal carbonate bodies, are common and result in combination structural and stratigraphic traps.

Western Desert Basin - Cyrenaica Platform

This province is structurally complicated and has undergone several episodes of folding and faulting, coupled with a long history of post-Paleozoic marine transgression and regression related to the southern margin of the Tethys and proto-Tethys seaway. Except for the somewhat mountainous part of the Cyrenaica Platform in Libya, most of the area, particularly the Western Desert in Egypt, is relatively flat. Much of the subsurface, however, is broken into a pattern of northwest-southeast and northeast-southwest faults and local paleotectonic basins and uplifts. Paleozoic rocks, primarily clastic deposits, which are thin to absent in central and southern Egypt, are markedly thicker north of about lat 28° N. and in the Cyrenaica platform region. A major unconformity separates the Paleozoic and Mesozoic sequences, and Permian through Triassic rocks are absent in most of the region (figs. 8-10). Mesozoic and early Tertiary rocks are primarily marine and continental clastic beds in the lower part, grading upward to a marine carbonate and clastic section deposited during the main transgressive stage of the Tethyan geosyncline. Marine Cretaceous rocks are very thick in some of the subsidiary basins. Post-Eocene sediments form a relatively thin cover of mainly fluviatile and nearshore marine beds associated with development of river systems flowing northward toward the Tethys Ocean. Ultimately, these drainage systems were consolidated into the main Nile River system in Egypt, which occupied the Nile Basin or graben south of Cairo after early Pliocene time. Because of the complicated structural history of the region, various facies changes and unconformities are common and over short distances, particularly in the Mesozoic section.

Until recent years petroleum exploration in this province was sparse, although several relatively deep wells were drilled before 1970. Thus far, exploratory success has not been high; no finds have been made in Cyrenaica; and as of 1982, 10 small oil or oil and gas fields and two small gas fields had been discovered in the Egyptian Western Desert. Cumulative production from these fields is approximately 150 MMBO, and estimated ultimate recovery is 300 to 500 MBBO. Estimated undiscovered resource means are 1.7 BBO and 5.2 Tcf gas (figs. 22 and 23).

Reservoirs.--Production thus far has been from Jurassic and Cretaceous sandstones and Lower Cretaceous and Eocene carbonate reservoirs. Paleozoic sandstones of reservoir quality should be present in much of the area, and the Jurassic carbonate section may have potential in Cyrenaica. Sandstone and carbonate beds of Miocene age are of interest but may be too shallow for significant potential.

Source Rocks.--Cretaceous marine shales are the main source rock units in the Western Desert area and are also present in Cyrenaica. Carboniferous and Jurassic marine shales are of probable source-rock quality. Eocene dark marine shales are potential source rocks but are probably immature in most of the area. Silurian graptolitic shale may be present, but deeper drilling is needed before source-rock quality and distribution can be evaluated.

Seals.--Widespread regional sealing beds probably are not present, although shale beds are common in the Early and Late Cretaceous and early Tertiary and may provide local seals. Evaporite beds of appreciable thickness or extent are not known. The lack of regional seals and the discontinuities in source-rock units, related to complex paleostructural history of the region, lessen the petroleum potential here.

Traps.--Most fields are on faulted anticlines, some are structural-stratigraphic accumulations related to reservoir discontinuities on faulted paleostructures. The possibility of stratigraphic traps should be good because of the complex and lengthy structural-stratigraphic history, but the potential for large accumulations is probably small.

East Tunisia - Pelagian Platform

The east Tunisia-Pelagian Platform petroleum province is a stable platform, which underwent progressive subsidence during Mesozoic and Tertiary time. Approximately three-fourths of the region is offshore in water less than 200 m deep. It is bounded on the west by the north-south axis lineament in Tunisia and on the south by the west-east trending Nefusa uplift, a paleostructural feature mainly of Hercynian and later age (fig. 2). The southern segment of the Pelagian Platform includes the west-east Jefara trough, which subsided rapidly in late Paleozoic and early Mesozoic time when it received several thousand meters of Permian clastic and carbonate and Triassic-Lower Jurassic evaporite deposits.

Marine Paleozoic rocks of unknown thickness probably underlie the shelf. Paleozoic rocks are mainly marine and continental sandstones and shales on the Sahara platform south of the Nefusa uplift, but in general they are thicker and contain more marine facies northward toward the Mediterranean. Rocks of this age are as much as about 5 km thick in the Egyptian Western Desert and Cyrenaica areas and probably also to the west in the Atlas geo-synclinal belt (figs. 4, 6, 7, 9, and 12). Hence, a substantial thickness

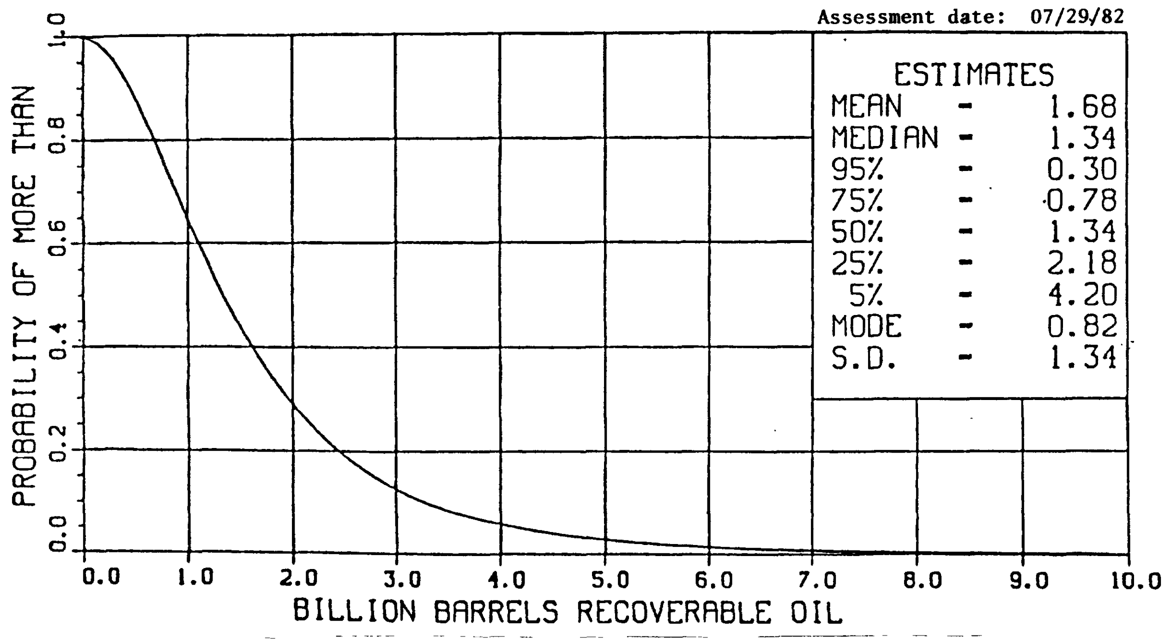


Figure 22.--North Africa; Cyrenaica Platform-Western Desert, Egypt, undiscovered recoverable oil.

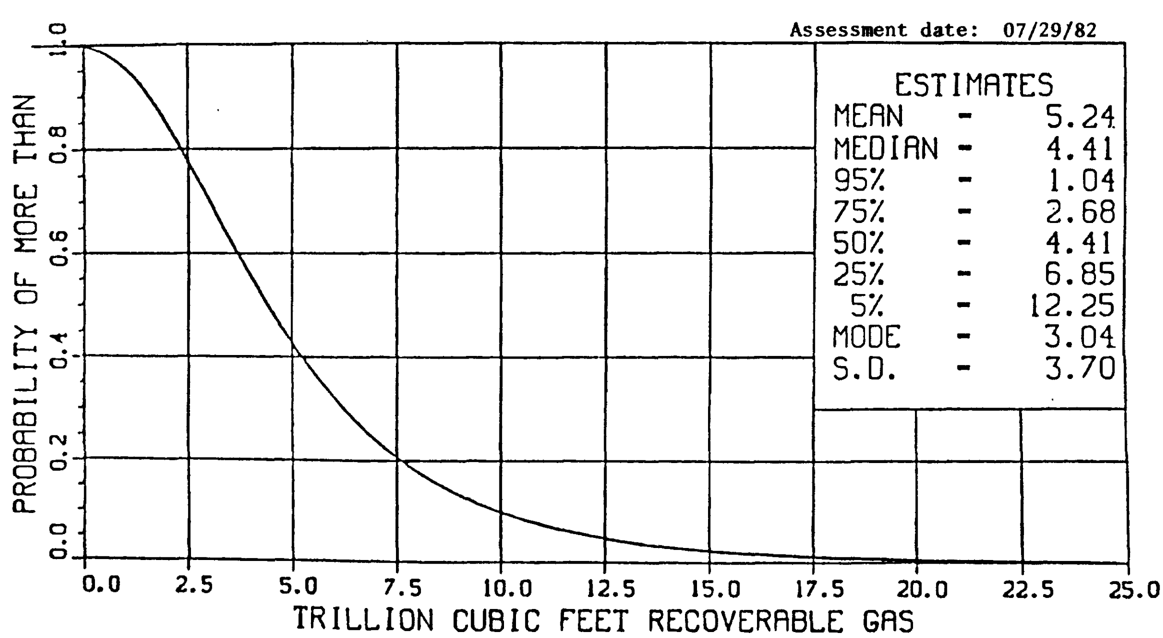


Figure 23.--North Africa; Cyrenaica Platform-Western Desert, Egypt, undiscovered recoverable total gas.

of Paleozoic marine rocks should be expected at depth on the Pelagian Platform. Triassic and Lower Jurassic rocks are mainly anhydrite or gypsum, salt, and red beds. Overlying the evaporite section is a sequence of Upper Jurassic, Cretaceous, and lower Tertiary carbonate and shale deposits, which are probably as much as about 5 km thick. The upper Tertiary sequence consists of marine clastic, shale, and carbonate sediments of different thicknesses and probably reflects increased Oligocene and later Alpine tectonic activity in the Atlas geosynclinal belt and Mediterranean regions. The Pelagian platform was heavily block faulted in late Tertiary time.

Onshore exploration in eastern Tunisia has led to the discovery of a few small- to medium-sized oil and gas fields producing mainly from Cretaceous and lower Tertiary reservoirs. In recent years, offshore exploration on the Pelagian Platform has intensified, and several oil and gas accumulations have been found, two of which appear to be major fields (fig. 1; table 2). Undiscovered resource means are estimated at 3.6 BBO and 20.1 Tcf gas, most of which should be offshore (figs. 24 and 25).

Reservoirs.--Production thus far is from Lower and Upper Cretaceous, Eocene, and Miocene carbonate reservoirs. Lower and Upper Cretaceous sandstones, shoreward of the carbonate facies, are potential reservoirs. Carbonate and sandstone beds of potential reservoir quality also are present in the Upper Jurassic and perhaps the Paleozoic sections, although generally deep.

Source Rocks.--Upper Cretaceous-lower Tertiary shales probably are the most important source rocks in the region. Shales of source-rock quality also are present in the Lower Cretaceous and the Miocene section and may be present in the post-evaporite Jurassic limestone and shale sequence.

Seals.--Shale beds in the Lower and Upper Cretaceous, lower Tertiary, and Miocene sequences are widely distributed seals in the east Tunisia-Pelagian Platform province. Middle Cretaceous evaporites also are present. The thick and widespread Triassic-Lower Jurassic evaporite sequence is an effective seal for potential pre-salt gas accumulations.

Traps.--As far as is known, all fields are on anticlines or faulted anticlines. The region is heavily faulted, and the possibility of fault traps as well as stratigraphic traps related to carbonate mounds or reefs is of interest. Salt structures are present in the Jefara trough in the southern offshore part of the area, but significant production apparently has not yet been obtained from these structures.

Nile Delta - Nile Basin

The Nile Delta assessment area includes the delta proper, the Nile valley or graben, and the adjacent region to the west and east to approximately lat 27° N. (figs. 1 and 2).

Early formation of the Nile Delta coincides with late Miocene and early Pliocene uplift, folding, and regression associated with the Alpine orogeny

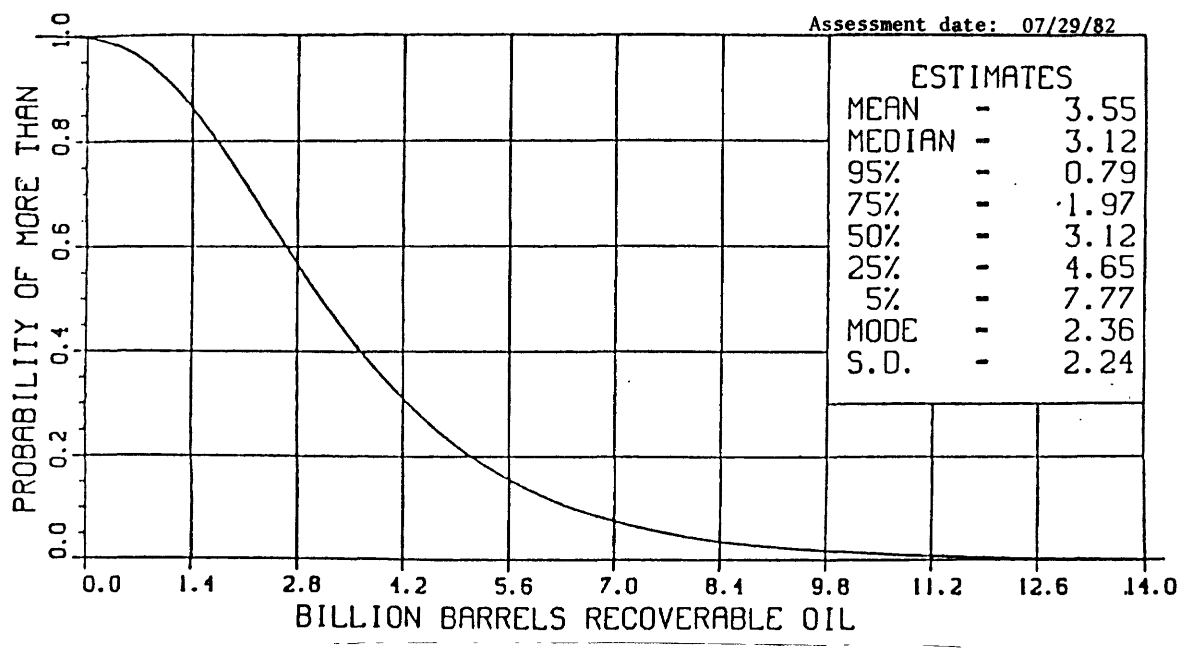


Figure 24.--North Africa; East Tunisia-Pelagian Platform-Northwest Libya province, undiscovered recoverable oil.

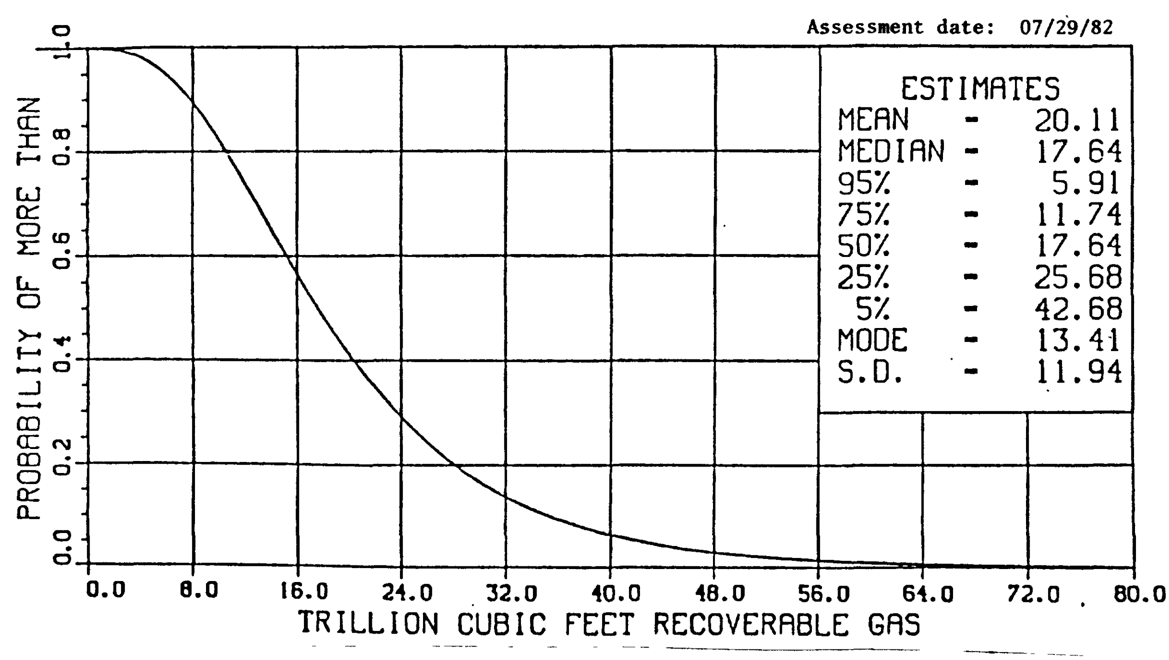


Figure 25.--North Africa; East Tunisia-Pelagian Platform-Northwest Libya province, undiscovered recoverable total gas.

(El Shazly, 1977; Said, 1962, 1981; Barakat, 1982). The Nile valley fracture system or graben developed at this time approximately parallel to the Red Sea graben and extended southward at least as far as the Egypt-Sudan border. Pliocene and younger deltaic and marine clastic sediments are as much as about 4 km thick in the northern and offshore part of the modern Nile Delta (figs. 8, 10, and 14). These beds are underlain by Miocene marine and nearshore marine clastic, carbonate, and discontinuous evaporite sediments that may be 2 km or more thick in parts of the delta region. Lower Tertiary beds are thin in the vicinity of Cairo at the southern end of the Nile Delta but thicken southward and northward to more than 2 km (fig. 14). These beds are intermixed marine clastic and carbonate deposits and some deltaic beds. Clastic content is higher to the north.

Drilling in the Nile Delta has not yet penetrated the pre-Tertiary beds, but on the basis of regional patterns, at least 6 to 8 km (20,000 to 25,000 ft) of marine carbonate and clastic Mesozoic Tethyan beds should underlie the Tertiary section in the deltaic province. Paleozoic rocks, mainly sandstone and some shale, 2 km (7,000 ft) or more thick, also should be present, giving a maximum anticipated sedimentary thickness in the delta of 10 km (33,000 ft) or more (figs. 8, 10, and 11-14).

Exploration in the Nile Delta is in its early stages, but several gas discoveries have been made in recent years. The delta appears to be gas prone, and some of the gas may be biogenic, although potential for oil source rocks may be greater in the marine pre-Pliocene deposits. Mean undiscovered resources are estimated at 1.1 BBO and 21.4 Tcf gas (figs. 26 and 27).

Reservoirs.--Productive reservoirs in the Nile Delta are deltaic and shoreline sandstones and siltstones of Pliocene-Miocene and possibly early Tertiary age. Potential reservoir rocks in the deeper section include carbonate and clastic beds of early Tertiary, Cretaceous, and Jurassic age and sandstones of Paleozoic age.

Source Rocks.--Marine and deltaic carbonaceous shale of Pliocene age, interbedded with deltaic and alluvial sandstone reservoirs, are probable sources for gas in the known fields. Potential source rocks for both oil and gas may be present in lower Tertiary, Cretaceous, and Jurassic marine beds.

Seals.--Marine shales, interbedded with clastic reservoirs, are the main seals for gas accumulations in the delta. Marine shale beds and some evaporites in the pre-Miocene section are good potential seals for deeper exploration.

Traps.--Existing fields are on seismically mapped anticlinal structures. Conditions are favorable for stratigraphic or combined stratigraphic-structural traps in the deltaic section as well as in the underlying Tethyan carbonate facies.

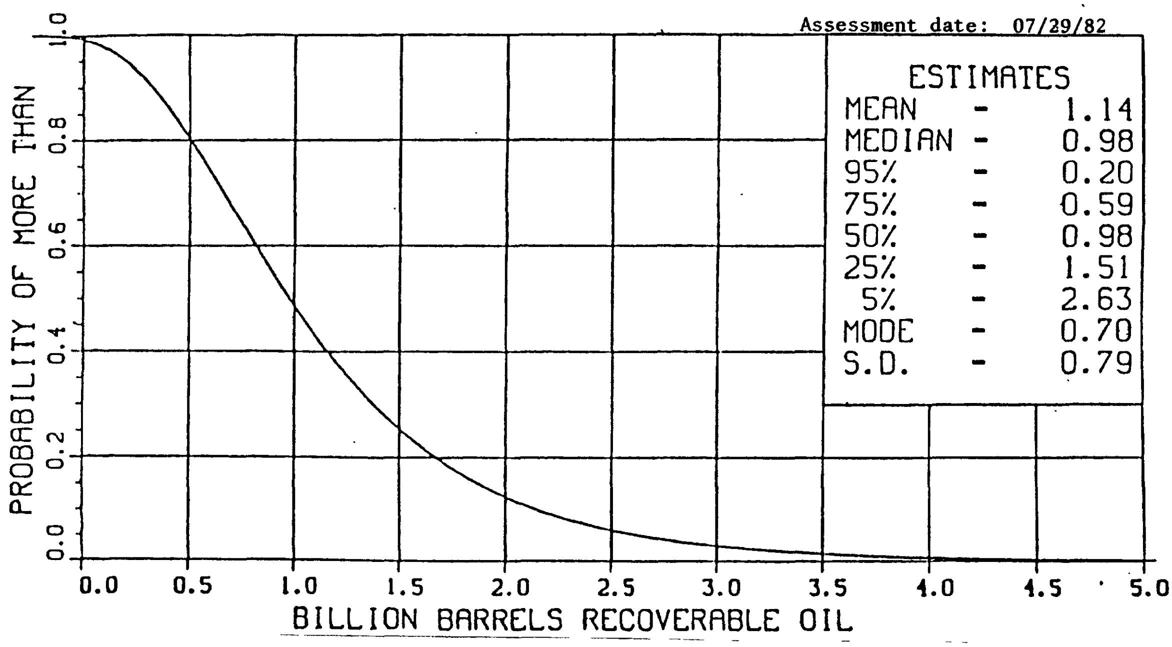


Figure 26.--North Africa; Nile Delta-Nile basin, Egypt, undiscovered recoverable oil.

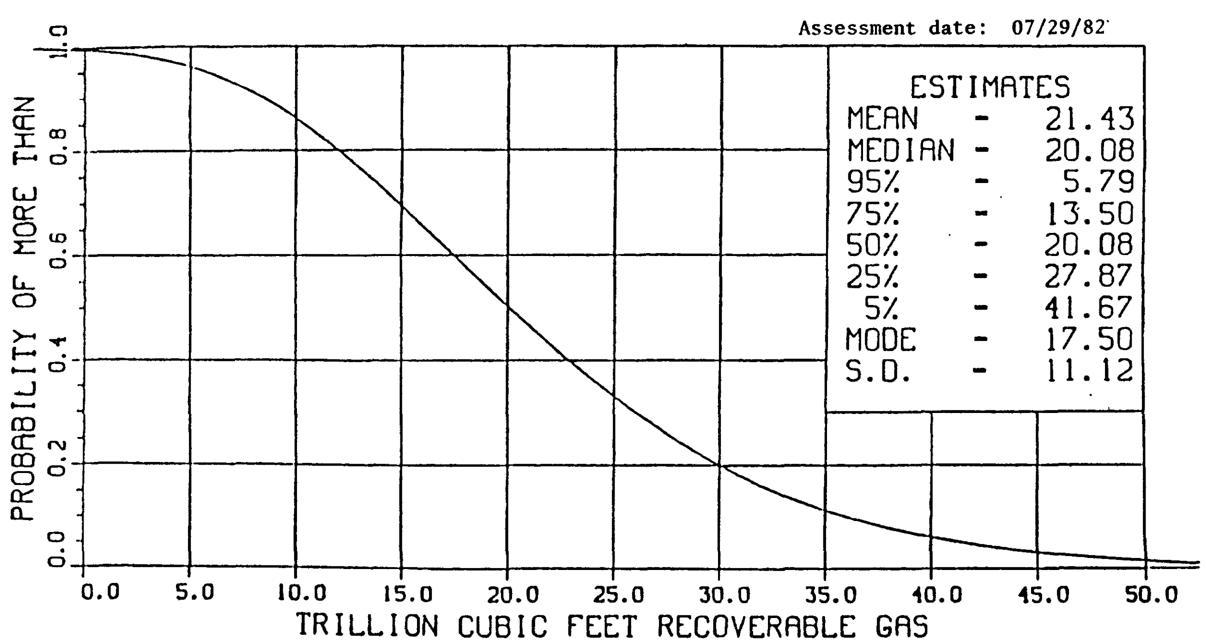


Figure 27.--North Africa; Nile Delta-Nile basin, Egypt, undiscovered recoverable total gas.

RESOURCE ASSESSMENT

Procedures

The resource assessment of this region was conducted by the Resource Appraisal Group (RAG) of the U.S. Geological Survey, who followed the standard procedures developed since 1974 for analysis of domestic petroleum resources. The technique, briefly, requires study of a given area, particularly of the geologic factors controlling the occurrence, quality, and quantity of the petroleum resource. Critical elements of the investigations are standardized by the preparation of data forms for each basin, which includes listing specific volumetric, areal, and rock-quality measurements as well as determining basin analogs for comparison purposes. In addition, finding-rate histories and projections are constructed where possible. From these data and analyses, various analytical techniques are used as a means to calculate a set of resource numbers. Not considered in this assessment are resources of heavy-oil deposits, tar deposits, and oil shales, as well as gas in low-permeability reservoirs, in occlusions in coal, in geopressured shales and brines, and in natural-gas hydrates.

The assessment process itself is subjective; the results of the geologic investigation and of the resource calculations are presented to a team of assessment specialists who make their personal estimates, conditional upon recoverable resources being present. Initial assessments are made for each of the assessed provinces as follows:

(1) A low resource estimate corresponding to a 95-percent probability of more than that amount; this estimate is the 95th fractile (F_{95}).

(2) A high resource estimate corresponding to a 5-percent probability of more than that amount; this estimate is the 5th fractile (F_5).

(3) A modal ("most likely") estimate of the quantity of resource associated with the greatest likelihood of occurrence.

The individual estimates are then posted and averaged, and the results are debated from the perspective of the personal experiences of the individual assessors; a second and third iteration of the procedure may follow depending on consensus. If no commercial oil has been heretofore discovered in the basin, then a marginal probability is subjectively assessed that reflects the probability that any commercial oil will ever be discovered. The results of the final estimates are averaged, and those numbers are computer processed by means of probabilistic methodology (Crovelli, 1981) to show graphically the resource values associated with a full range of probabilities and to determine the 95th fractile, the 5th fractile, and the mean, as well as other statistical parameters.

Assessment

The locations of the north African petroleum provinces are shown in figure 1. Unconditional estimates by the USGS of oil and gas resources in these provinces are shown in table 3 and figures 16-29. Data supporting these estimates are supplied in table 4.

Table 3.--Assessment of undiscovered conventionally recoverable petroleum resources of north-central and northeastern Africa (Egypt, Libya, eastern Tunisia, Pelagian Platform, and central Algeria).

Resource assessment by USGS as of 7/29/82; see also figures 16 through 29.

Region	Crude oil in billions of barrels (BB)			Natural Gas in trillions of cubic feet (Tcf) and billions of barrels of oil equivalent (BBOE) @ 6,000 cu ft/bbl.		
	Low (F_{95}) 1/	High (F_5) 1/	Mean	Low (F_{95}) 1/	High (F_5) 1/	Mean
I. Erg Occidental, Erg Oriental, and Hamada Basins of central Algeria northwest Libya	2.3	15.4	7.7	5.6	52.7	25.1
II. Eastern Tunisia, Pelagian Platform, and northwestern Libya	0.8	7.8	3.6	5.9	42.7	20.1
III. Sirte Basin, Libya	2.9	19.3	9.4	4.3	39.0	17.7
IV. Cyrenaica Platform, Libya, and Western Desert, Egypt	0.3	4.2	1.7	1.0	12.3	5.2
V. Nile Delta - Nile Basin, Egypt	0.2	2.6	1.1	5.8	41.7	21.4
VI. Suez - Sinai province, Egypt	0.8	4.7	2.4	0.9	6.8	3.2
Total of the above north Africa provinces 2/:	15.3	39.3	25.9	55.6	137.2	92.7

1/ F_{95} denotes the 95th fractile; the probability of more than the amount F_{95} is 95 percent. F_5 is defined similarly.

2/ Totals are derived by statistical aggregation; only the mean total equals the sum of the component parts.

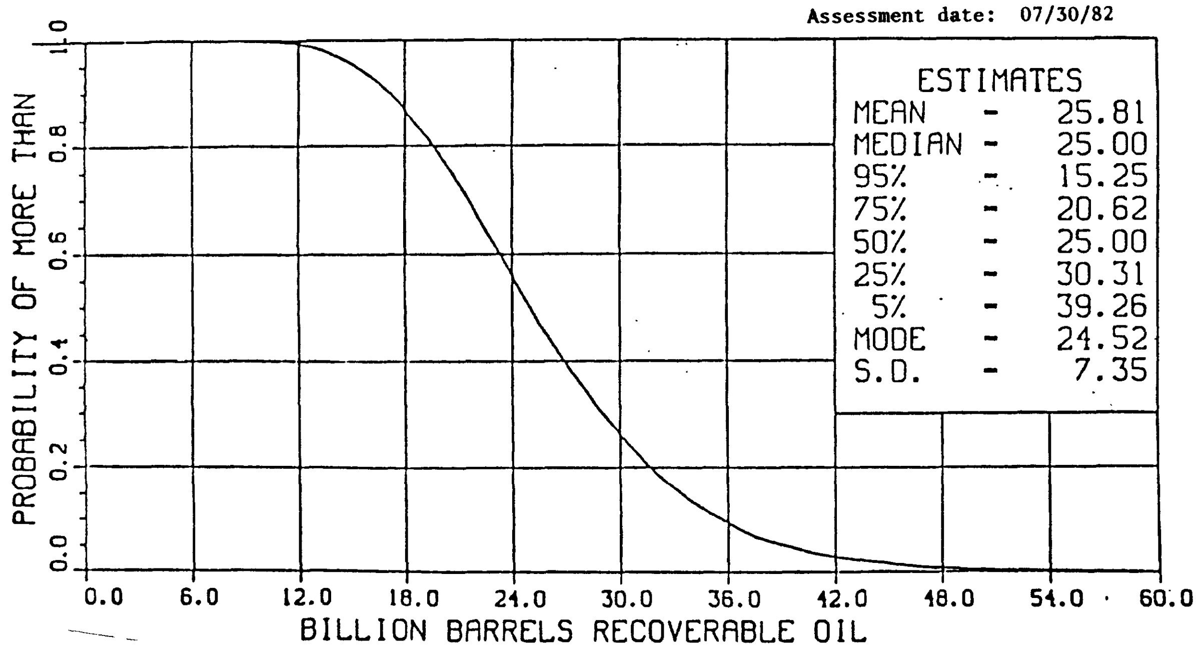


Figure 28.--North-central and Northeastern Africa, aggregate undiscovered recoverable oil.

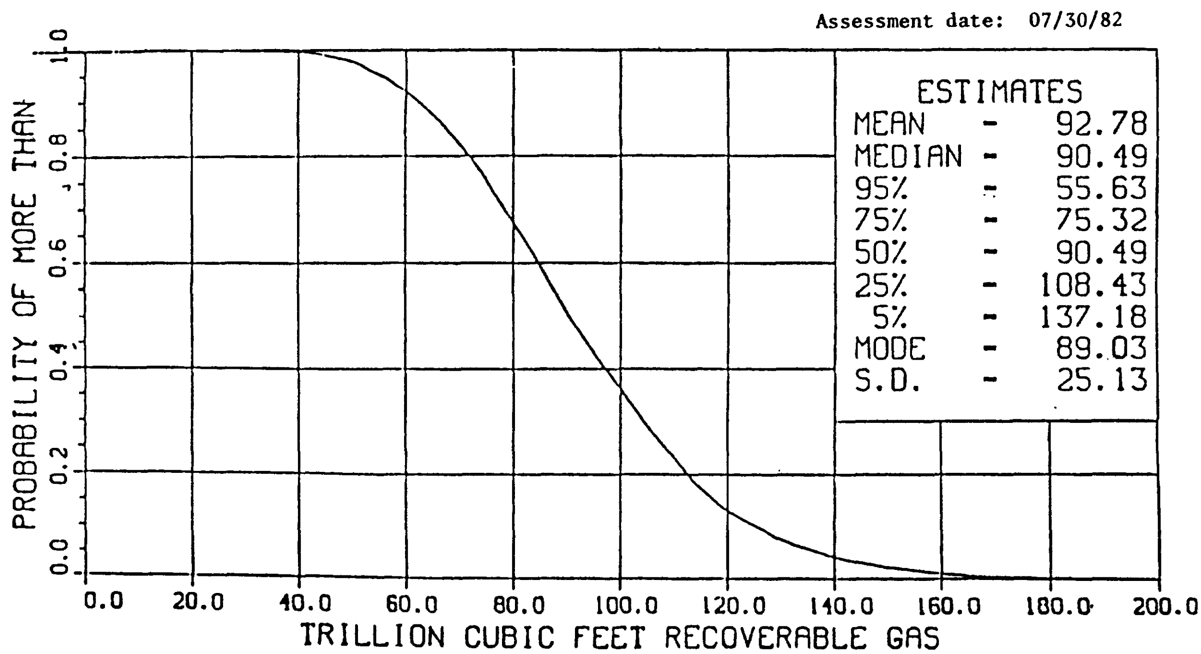


Figure 29.--North-central and Northeastern Africa, aggregate undiscovered recoverable total gas.

Table 4. Supplementary and comparative data supporting the resource assessment for north-central and northeastern Africa[1]

	Crude oil (BB)	Natural gas (Tcf)
Cumulative production to 7/81		
Erg Occidental, Erg Oriental, and Hamada Basins	5.50	5
Eastern Tunisia, Pelagian Platform, and northwestern Libya province	.40	+[2]
Sirte Basin	13.70	+[2]
Cyrenaica Platform - Western Desert	.15	+[2]
Nile Delta - Nile Basin	.00	+[2]
Suez - Sinai province	2.50	+[2]
Total	22.25	5+ (est.)
Measured reserves to 7/81		
Erg Occidental, Erg Oriental, and Hamada Basins	7.50	50
Eastern Tunisia, Pelagian Platform, and northwestern Libya province	.60 ?	+[2]
Sirte Basin	23.30	+[2]
Cyrenaica shelf - Western Desert	.25	+[2]
Nile Delta - Nile Basin	+[2]	+[2]
Suez - Sinai province	3.50	+[2]
Total	35.15	50+ (est.)

Original recoverable resources (ultimate) of the above provinces[3]

	Oil	Gas
Cumulative production	22.25	5+
Measured reserves	35.15	50+
Undiscovered resources (mean)	25.80	92.8
Total	83.20	147.8+

Total Oil and Gas = 108+ BBOE

1/ Cumulative production and reserves are composited estimates from various sources.

2/ Quantity positive but data unavailable. Total estimate, this paper.

3/ Does not include an estimate of inferred reserves.

Comments

Erg Occidental, Erg Oriental, and Hamada Basins

- o Estimate of gas resources is uncertain because of disagreement in published assessment figures on size of the supergiant Hassi R'Mel gas field, which range from 35 to 75 Tcf ultimate recovery.
- o The Erg Occidental basin tends to be gas prone; most of the oil fields are in the Erg Oriental basin.
- o Widespread Triassic-Jurassic evaporite section is the major seal for most of the large oil and gas fields.
- o Most (75-85 percent) of the cumulative production and identified oil and gas reserves is from the supergiant Hassi Messaoud oil field (11 BB) and the supergiant Hassi R'Mel gas field (35-75 Tcf).
- o Source rocks for both oil and gas are primarily the Silurian (Gotlandian) graptolite shale beds. However, deeply buried post-Silurian gas source rocks may be present in the western part of the Erg Occidental basin adjacent to the geosynclinal belt.

Eastern Tunisia, Pelagian platform, and northwestern Libya

- o The sedimentary section is very thick, but few pre-Upper Cretaceous tests have been drilled.
- o Available information indicates that no large fields have been discovered as yet, but a large part of the offshore area has not been adequately tested. Resource assessment is difficult because of the relatively unknown character of the pre-Tertiary stratigraphic section and the deeper structure.
- o Salt structures are widespread in the offshore area.

Sirte Basin

- o Except for the offshore area, the basin is relatively well explored. Indications are that reservoirs will be absent or poor in offshore area.
- o Potential exists for downdip stratigraphic traps on large structures, including horst blocks.
- o Tertiary reef or carbonate mounds are targets for further exploration.

Cyrenaica Platform - Western Desert

- o Lack of an evaporite section and other adequate regional seals are unfavorable factors.
- o Lack of widespread mature source rocks may be unfavorable, although Silurian graptolite shale may be present at depth in northwestern Egypt, northeastern Libya, and in the offshore area.

- Tectonic movements have resulted in many small Mesozoic and Cenozoic basins with irregular and localized distribution of source rocks, seals, and reservoirs.

- Area is not well known, and potential is present for unusual and anomalous petroleum accumulations.

Nile Delta - Nile Basin

- The Nile Delta appears to have gas potential, but deeper source rocks may be post-mature because of high geothermal gradient offshore.

- Success ratio is relatively high, but field development is minimal and little information is available on reserve estimates.

Suez-Sinai

- Potential for stratigraphic traps beneath the Miocene salt section is relatively untested.

- Some difficulty is reported in getting good seismic records beneath the salt section.

- Production so far is almost exclusively oil, perhaps because of the sapropelic nature of source rocks and insufficient depth of burial for gas.

SELECTED REFERENCES

Abdine, A. S., 1981, Egypt's petroleum geology--Good grounds for optimism: World Oil, v. 193, no. 7, p. 99-112.

Arabian Gulf Oil Company, Exploration Staff, 1980, Geology of a stratigraphic giant - the Messlah Oil Field, in Salem, M. J., and Busrewik, M. T., eds., The geology of Libya, v. II: London, Academic Press, p. 521-536.

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. 477-488.

Barakat, M. G., 1982, General review of the petroliferous provinces of Egypt with special emphasis on their geological setting and oil potentialities: Cambridge, Mass., Massachusetts Institute of Technology, Technology Adaptation Program, TAP Report 83-1, 87 p.

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, Tipoli, 179 p.

Bellini, E., and Massa, D., 1980, A stratigraphic contribution to the Paleozoic of the southern basins of Libya, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: London, Academic Press, p. 3-56.

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.

Blant, G. (ed.), 1973, Sedimentary basins of the African Coast, v. 2, South and east coasts: Paris, Association of African Geological Surveys.

Bobbitt, J. E., and Gallagher, J. O., 1978, The petroleum geology of the Gulf of Suez: Offshore Technology Conference 3091.

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, R. N., 1980, History of exploration and discovery of Morgan, Ramadan and July oilfields, Gulf of Suez, Egypt, in Miall, A. D., ed., Facts and principles of world petroleum occurrence: Calgary, Canadian Society of Petroleum Geologists, p. 733-764.

Burollet, P. F., 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.

Burollet, P. F., 1971, La Tunise, _in_ Tectonics of Africa: Paris, UNESCO, p. 91-100.

__________ 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.

__________ 1980, Petroleum potential of the Mediterranean basins, _in_ Miall, A. D., ed., Facts and principles of world petroleum occurrence: Calgary, Canadian Society of Petroleum Geologists, 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: New York and London, Plenum Press, p. 331-362.

Caire, A., 1977, The central Mediterranean mountain chains in the Alpine orogenic environment, _in_ The ocean basins and margins, v. 4, The Mediterranean Sea: New York, Plenum Press.

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.

Crovelli, R. A., 1981, Probabilistic methodology for oil and gas resource appraisal, U.S. Geological Survey Open-File Report 81-1151.

Dingle, R. V., 1978, South Africa, _in_ The Phanerozoic geology of the world II, The Mesozoic, A: Elsevier, Amsterdam, p. 401-434.

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: New York and London, Plenum Press, p. 379-444.

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

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

Goudarzi, G. H., 1970, Geology and mineral resources of Libya--a reconnaisance: U.S. Geological Survey Professional Paper 660, 104 p.

__________ 1980, Structure--Libya, _in_ Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. III: London, Academic Press, p. 879-892.

Hamouda, A., 1980, Petroleum potential: Ouargla region, Triassic basin, Algeria, in, Halbouty, M. T., ed., Giant oil and gas fields of the decade 1968-1978: American Association of Petroleum Geologists Memoir 30, p. 539-542.

Haq, B. U., and Aubry, M. P., 1980, Early Cenozoic calcareous nannoplankton biostratigraphy and paleobiogeography of North Africa and the Middle East and trans-Tethyan correlations, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: London, Academic Press, p. 271-304.

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.

Kanes, W. H., Ehrlich, R., and Schamel, S., 1979, Tunisia - plate tectonics and hydrocarbon accumulations of contiguous areas [abs.]: American Association of Petroleum Geologists Bulletin, v. 63, p. 477.

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: London, Institute of Petroleum, p. 7-15.

Klitzsch, E., 1963, Geology of the northeast flank of the Murzuk Basin: Revue Institut Francais du Petrole, v. 18, p. 97-113.

__________ 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.

Kogbe, C. A., 1980, The trans-Saharan seaway during the Cretaceous, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: London, Academic Press, p. 91-96.

Laubscher, H., and Bernoulli, D., 1977, Mediterranean and Tethys, in Nairn, A. E. M., Kanes, W. H., and Stehli, F. G., eds., The ocean basins and margins, v. 4A: New York, Plenum Press, p. 1-28.

Magliore, P. R., 1970, Triassic gas field of Hassi er R'Mel, Algeria, in Geology of Giant Petroleum Fields: American Association of Petroleum Geologists Memoir 14, p. 489-501.

McConnell, R. B., 1967, East African Rift System: Nature, v. 215, p. 578-581.

McKenzie, D. P., Davies, D., and Molnar, P., 1970, Plate tectonics of the Red Sea and East Africa: Nature, v. 226, p. 243-248.

Megatelli, A., Said, A., and Sarber, D. G., 1969, Exploration in Algeria: Past, present and future, in The exploration for petroleum in Europe and north Africa: Institute Petroleum Brighton Proceedings, p. 271-278.

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: London, Academic Press, p. 67-72.

Nairn, A. E. M., 1978, Northern and eastern Africa, in The Phanerozoic geology of the world II, The Mesozoic, A: Amsterdam, Elsevier, p. 329-370.

Pallas, P., 1980, Water resources of the Socialist People's Libyan Arab Jamahiriya, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. II: London, Academic Press, p. 539-594.

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: Calgary, Canadian Society of Petroleum Geologists, p. 723-732.

Petters, S. W., 1979a, Stratigraphic history of the south-central Saharan region: Geological Society of America Bulletin, v. 90, p. 753-760.

__________ 1979b, Western African cratonic stratigraphic sequences: Geology, v. 7, p. 528-531.

Pomeyrol, R., 1968, Nubian sandstone: American Association of Petroleum Geologists Bulletin, v. 52, p. 537-590.

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: London, Academic Press, p. 245-269.

Ross, D. A., and Uchupi, E., 1977, Structure and sedimentary history of south-eastern Mediterranean - Nile cone area: American Association of Petroleum Geologists Bulletin, v. 61, p. 872-902.

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

__________ 1980, Oil in Egypt (abs.), in Miall, A. D., ed., Facts and principles of world petroleum occurrence: Calgary, Canadian Society of Petroleum Geologists, p. 998.

__________ 1981, The geological evolution of the River Nile: New York, Springer-Verlag, 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: New York and London, Plenum Press, p. 361-416.

Salem, M. J., and Busrewil, M. T., 1980, The geology of Libya, vols. I, II, and III: Academic Press, London, 1155 p.

Sander, N. J., 1968, The premesozoic 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.

Sanford, R. M., 1970, Sarir oil field - desert surprise: American Association of Petroleum Geologists Memoir 14, p. 449-476.

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

Sinha, S. C., 1980, On the application of geophysical logging in the assessment of ground-water potential in Al Hamadah al Hamra basin, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. II, p. 643-658.

Sinha, S. C., and Pandey, S. M., 1980, Hydrogeological studies in a part of Murzuq basin using geophysical logs, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. II, p. 629-634.

Terry, C. E., and Williams, J. J., 1969, The Idris "A" bioherm and oilfield, Sirte Basin, Libya - its commercial development, regional Paleocene geologic setting, and stratigraphy, in The exploration for petroleum in Europe and north Africa: London, Institute of Petroleum, p. 31-48.

UNESCO, 1971, Tectonics of Africa: Paris, UNESCO, 602 p.

United States Department of Energy, 1979, Joint Egypt/United States report on Egypt/United States cooperative energy assessment, v. 2, Annex I, Energy resources of Egypt: Washington, D.C., U.S. Department of Energy, 184 p.

Van Houten, F. B., 1980, Latest Jurassic-Early Cretraceous 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.

Weissbrod, T., 1970, Nubian sandstone: discussion: American Association of Petroleum Geologists Bulletin, v. 54, p. 522-526.

Whiteman, A. J., 1968, Formation of the Red Sea depression: Geological Magazine, v. 105, p. 231-246.

__________ 1970, Nubia Group: origin and status: American Association of Petroleum Geologists Bulletin, v. 54, p. 522-526.

__________ 1971, "Cambro-Ordovician" rocks of Al Jazair (Algeria); a review: American Association of Petroleum Geologists Bulletin, v. 55, p. 1295-1335.

SELECTED REFERENCES (continued)

Williams, J. J., 1972, Aguila field, Libya: depositional environment and diagenesis of sedimentary reservoir and description of igneous reservoir, in Stratigraphic oil and gas fields: American Association of Petroleum Geologists Memoir 16, p. 623-632.

Wiman, S. K., 1980, Miocene (Messinian) regression and early Pliocene (Zanclean) transgression in northeastern Tunisia, in Salem, M. J., and Busrewil, M. T., eds., The geology of Libya, v. I: London, Academic Press, p. 117-126.

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

Zaghloul, Z. M., El Ayouty, M. K., and El Sawy, M. M., 1974, The subsurface Miocene evaporites in the Gulf of Suez region and their genetic relation with petroleum: Egyptian Journal of Geology, v. 18, p. 77-86.