DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Geology and Petroleum Resource Assessment of Onshore Northwestern Africa

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Open-File Report 86-183

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

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1986

Contents

Illustrations

Illustrations (continued)

Tables

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ABSTRACT

The main onshore basins of northwestern Africa are: (1) basins in the Atlas folded geosynclinal belt adjacent to the Mediterranean Sea, (2) the Tindouf, Colomb-Bechar, and Reggane basins of western Algeria and southern Morocco, and (3) the Taoudeni basin of Mauritania and Mali.

Much of the Atlas folded geosynclinal (orogenic) belt contains a very thick but highly disturbed section of marine Paleozoic, Mesozoic, and lower Tertiary carbonate and clastic rocks that includes a substantial thickness of probably highly mature or overmature petroleum source rocks. The small, elongate, infolded Tertiary intermontane basins appear to have some hydrocarbon potential, but limited drilling there has had little success thus far. Accumulations of oil and gas are likely to be small and difficult to find. The Tindouf, Colomb-Bechar, and Reggane basins contain a thick section of marine Paleozoic rocks that has some gas potential and minor oil potential. Carbonate mounds and reefs of Devonian and Carboniferous age in these basins may not have been adequately explored. The Taoudeni is a very large basin and has a high exploration risk. Most of its sedimentary section is early Paleozoic and late Precambrian in age. Problems include questionable source-rock quality, inadequate burial depths in much of the basin, and lack of extensive regional seals. Because of the location of the basin in a remote part of Africa, discoveries would have to be large to be commercial.

U.S. Geological Survey (USGS) estimates of original recoverable petroleum resources (ultimate) of the northwestern Africa onshore provinces as of December, 1982 at probability levels of 95 percent, 5 percent, and statistical mean are for oil: approximately 0.15, 6, and 1.8 BB (billion barrels); and for gas: approximately 0.5, 30, and 12 Tcf (trillion cubic feet).

INTRODUCTION

This investigation of the petroleum resource potential of the onshore northwestern Africa region includes geological, geophysical, production or other petroleum engineering data available through 1982. The resource assessment was conducted by the Resource Appraisal Group (RAG) of the U.S. Geological Survey, Branch of Oil and Gas Resources, following the standard procedures developed since 1974 for domestic petroleum resource analysis (Dolton and others, 1981). The technique requires study of a given area, with particular attention to the geologic factors controlling the occurrence, quality, and quantity of the petroleum resource. Standardization of critical elements of the investigations is achieved by the preparation of data forms for each basin or province, which call for specific volumetric, areal, and rock-quality measurements, as well as the determination of basin analogs for comparison purposes. In addition, finding-rate histories and projections are constructed, when possible. From these data and analyses, various analytical techniques are used to calculate a set of resource numbers.

The assessment process itself is subjective; the results of the geological investigation and of the resource calculations are presented to a team of USGS 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:
(a) a low-resource estimate corresponding to a 95 percent probability of more than that amount; this estimate is the 95th fractile (F_{95}).
(b) a high-resource estimate corresponding to a 5 percent probability of more than that amount; this estimate is the 5th fractile (F_5).
(c) 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 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 province, then a marginal probability is subjectively assessed reflecting the probability that any commercial oil will ever be discovered.

The results of the final estimates are averaged, and those numbers are computer processed using 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.

REGIONAL GEOLOGY

Onshore northwestern Africa includes the West African Craton and the adjacent Alpine Zone (Atlas orogenic belt) to the north (figs. 1, 2). This region has been separated into three assessment provinces: (1) the Atlas orogenic belt (Alpine Zone), (2) the Tindouf, Colomb-Bechar, and Reganne basins, and (3) the Taoudeni basin (fig. 1).

The Alpine Zone includes the complex of uplifts and basins adjacent to the Mediterranean Sea, separated from the southern region by the South Atlas fault. This complex structural region is generallly separated into several structural provinces, including the Rif, Chelif, Kabylia, and Tellian Alpine thrust belts bordering the Mediterranean, and the Moroccan Meseta, Middle Atlas, High Atlas, High Plateaus, Saharan Atlas, and Tunisian Atlas foreland provinces of the middle and southern Atlas (fig. 2).

Summary of Tectonic and Sedimentary History

Reconstructions of the geologic history of the northwestern Africa region are given by several authors, including Klemme (1958), Dillon and Sougy (1974), de Klasz (1974), Caire (1978), Bronner and others (1980), Hinz and others (1981), Seibold (1981), and others, some of which are listed in the references. The geologic history of this region follows a sequence of closely related tectonic and sedimentologic events. The sedimentary cover of onshore northwest Africa ranges in thickness from 3 km (10,000 ft) or less in the cratonic basins of Mauritania, Mali, Niger and Algeria to possibly as much as 10 km (30,000 ft) in the Tindouf and Colomb-Bechar cratonic margin basins and considerably greater than 10 km (30,000 ft) in the adjacent Atlas folded geosynclinal belt (fig. 7). The sedimentary section to the north is primarily

marine in origin, but substantial thicknesses of continental clastics are present to the south in the cratonic basins (fig. 3-6, 7-10).

Late Precambrian (Infracambrian).--Relatively unmetamorphosed rocks of this age are widespread in the Taoudeni basin, where they are as much as 2,000-3,000 m (6,500-10,000 ft) or more thick (Dillon and Sougy, 1974; Bronner and others, 1980). These rocks which crop out extensively along the northern and western, and southern borders of the basin, consist mainly of shale, siltstone, and dolomitic, stromatolitic carbonate with sandstone at the base. Thickness is greatest in the northwestern part of the basin but varies greatly, ranging between zero and 3,500 m (12,000 ft); thickness is greatest in grabens active during deposition. A widespread tillite unit (650 ma) is present in the upper part of the sequence, overlain by mainly continental redbeds and sandstone of latest Precambrian to Early Ordovician age as much as 1,250 m (4,000 ft) thick in parts of the basin.

According to Bronner and others (1980), evolution of the cratonic Taoudeni basin was controlled by two main factors:

1. Local occurrence of high-density crustal material in the Lower Precambrian basement, causing local subsidence during the 1,100 to 650 ma period.
2. Regional Pan-African orogeny (650 ma), which caused increased mobility and subsidence of the craton to shape the final form of the basin interior.

Early and Middle Paleozoic.--The cratonic shelf edge lay near the position of the south Atlas fault. To the north, thick miogeosynclinal and eugeosynclinal facies formed. To the south, the platform underwent several marine transgressions and was covered with a relatively thin blanket of epicontinental clastics and minor carbonate sediments, with relatively thick deposits in the cratonic margin basins such as the Tindouf and Colomb-Bechar (figs. 4, 5, 8). Along the western border of the craton, a thick terrigenous clastic sequence also formed, which was metamorphosed during the Hercynian orogeny. In the Middle Devonian and Early Carboniferous, reef or carbonate mound deposits formed along the north border of the craton in the area of the Tindouf basin.

Carboniferous.--The tectonic and sedimentologic pattern of the early and middle Paleozoic continued into the lower Carboniferous. After Visean time, continental sedimentation prevailed overmost of northwestern Africa until the end of the Paleozoic. The Hercynian orogeny of the middle and late Carboniferous may have been related to collision between the African and North American plates. During this time, the Mauritanides chain of folding and eastward thrusting developed, extending northward as far as the Moroccan Meseta. Evidence of Hercynian orogeny also is found in the basement of the western Atlas and Anti-Atlas uplifts.

Permian.--After the Hercynian tectonic cycle, Africa and Europe formed a single continental block. Most of the northwest African craton was emergent during Permian time, and little or no sediments of this age are present. Some continental red sandstone and conglomerate of possible Permian age are present in subsided areas. Sedimentation at this time was mainly in the graben areas of the Atlas region, where thick clastic beds of Permian age are reported.

Triassic.--The African and North American cratonic plates moved apart in Late Permian and Triassic time, and the continental margins were deformed along lines approximately parallel to the original separation. Graben growth intensified in the Atlas region and along the northwestern African margin. Thick deposits of coarse clastics with redbeds overlain by evaporites, including salt, formed in the grabens and spread outward to cover the craton margins. Farther seaward, sandstone and some limestone deposits formed. Widespread basaltic volcanism occurred near the end of the Triassic.

Jurassic.--In the Atlas and adjacent continental margin areas, and along the rifted western margin of the craton, evaporite deposition continued into the Early Jurassic, followed by deposition of a widespread Middle and Upper Jurassic carbonate facies several hundred meters thick in the shelf regions of the spreading continental masses. The offshore marine carbonate facies grades to terrigenous nearshore marine and continental facies toward the emergent craton, where part of the lower "Continental Intercalaire" sand facies was deposited.

Early Cretaceous.--General regression occurred during this time, due mainly to eustatic fall of sea level and perhaps partly related to Jurassic-Cretaceous tectonic activity associated with eastward movement of the African plate with respect to the European plate. Uplift and folding occurred in the High Atlas, Middle Atlas, and Tellian Atlas regions, and the "Tellian furrow" subsided and collected thick deposits of Lower Cretaceous terrigenous sediments in the Rif and Tellian Atlas regions. To the north, pelagic limestones several hundred meters thick of the "limestone chain" were deposited. Most of the northwest African craton remained emergent at this time, when the upper part of the "Continental Intercalaire" sand facies was deposited.

Late Cretaceous.--General transgression occurred at this time and extended along the northern, western, and southern margins of the craton. During part of this time, the northwest African craton may have been isolated from the rest of Africa by a narrow seaway extending from Algeria to Nigeria. Late Cretaceous marine deposits in the Atlas Mountains region and coastal basins of northwest Africa, as much as 2,000 m (6,500 ft) or more thick, are composed of marine carbonate and clastic beds in the lower part grading upward to primarily terrigenous clastics.

The formation of the modern Atlas Mountains was initiated in Late Cretaceous time when inversion of the early Mesozic rift structure began. Uplift in the center of the High Atlas was accompanied by downwarping of adjacent basins on the south and the north (Stets and Wurster, 1982).

Tertiary.--General regression of the craton occurred at the close of Cretaceous time, and the entire northwest African craton remained emergent for the remainder of geologic time. During the early Tertiary, marine deposition continued in parts of the trough connecting the Mediterranean and the Gulf of Guinea, but erosion occurred throughout most of the craton. A thin veneer of Pliocene and younger continental clastics is present, except on the main uplifts. The Paleocene and Eocene section in the Atlantic coastal basins is a relatively thin sequence of marine clastics with thin glauconitic carbonate beds, phosphorite and chert. Regression occurred in late Eocene or early Oligocene time, and a hiatus apparently affected the shelf area in all of the western and southern coastal basins of northwest Africa. A relatively thick

section of fine grained clastic deposits of Oligocene and younger age is present in the deeper water shelf margin and slope areas of these basins.

The Atlas Range underwent a series of strong orogenic movements during the Tertiary, although the Moroccan Meseta apparently remained as a relatively stable block (Stets and Wurster, 1982). Early Tertiary activity continued the inversion movements of the Late Cretaceous accompanied by folding episodes and deposition of conglomerates and other clastics in downwarped areas. Cherty limestone, marl, phosphatic and shell beds and sandstones formed in the Tellian trough and the High Atlas regions at this time. In middle and late Eocene time, folding, uplift and erosion occurred in these areas. Folding also occurred in the Rif region at this time, forming arcuate structures open to the north, and the Kabylia zone was overthrust to the south. Tectonic activity diminished in the Oligocene, when coarse orogenic clastics were deposited in low areas. Thick shale deposits (Numidian flysch) formed north of the Tellian Atlas in northeastern Algeria and northwestern Tunisia.

The major tectonic phase of the Atlas Mountains region occurred in the early Miocene (Caire, 1971, 1978; Dillon and Sougy, 1974; Klemme, 1958). At this time, the south Tellian foredeep between the Tellian Atlas and the southern (Tunisian) Atlas formed and filled with marls and sandstones. A complex system of tight folds, nappes and sedimentary klippe formed in the Tellian Atlas, Kabylia, and Rif regions. Folding, overthrusting, and wrench faulting occurred in the Tellian Atlas. Vertical movements began in middle Miocene time, forming the combination of uplifts and intermontane basins characteristic of the modern Atlas Mountains province. The main intermontane trough areas of the province include: (1) the Chelif-Soumman trough, (2) the Souss trough, which received marine sediments in Pliocene time, (3) the Hodna basin, (4) the Rharb basin, and (5) the Guerif basin (fig. 2).

PETROLEUM GEOLOGY AND RESOURCE ASSESSMENT

Assessment of the onshore northwestern Africa region was completed in 1982, and does not include geologic, production, and other data made available since. The locations of the assessment areas are shown on figure 1. The assessment does not include the northwestern Africa coastal basins, which have been assessed separately (Klemme, oral commun., 1982; Masters and others, 1983). Likewise, the northeastern and central African basins have been assessed separately (Peterson, 1982, 1983, 1985a, 1985b). USGS estimates of conventionally recoverable oil and gas resources in the northwestern Africa onshore provinces are given in table 1 and figures 11-16. Supplementary data pertaining to these estimates are listed in table 2. Assessment of the region was conducted by compiling as much pertinent geological and production data as possible, followed by team assessment by USGS Resource Assessment Group (RAG) personel. The assessment of undiscovered conventionally recoverable petroleum resources includes those resources that can be extracted using conventional methods assuming a continuation of present economic and technologic conditions (Dolton and others, 1981). The assessment does not include inferred resources, which may yet be found in new pay zones or extensions of existing fields. Also excluded from the assessment, even if present, are unconventional resources such as heavy oil deposits, tar deposits, and oil shales, as well as gas in low permeability (tight) reservoirs, gas occluded in coals, gas in geopressured reservoirs and brines, and natural gas hydrates.

No large oil or gas fields have yet been found in the assessment region of onshore northwestern Africa. Several small oil and gas fields have been found in northwestern Morocco, particularly during the 1950's, the earliest in 1932. Many of these fields are depleted or nearing depletion at this time.

Atlas Orogenic Belt.--All of the oil and gas fields within the assessment region of onshore northwestern Africa are in the Atlas orogenic belt (fig. 2). As of 1981, approximately 25 small oil and gas fields had been discovered, the first in 1932 and several in the 1950's, in the Rharb basin of northwestern Morocco. Approximately 10 of these produce oil from fractured metamorphic Paleozoic rocks probably sourced by Mesozoic shales, 7 produce from Jurassic carbonate reservoirs, and 2 from Miocene sandstones. As of 1981, six small gas fields had been discovered in the Rharb basin, producing from shallow Miocene-Pliocene sandstone reservoirs. All of the fields are small, and many are depleted or near depletion. Since 1980, eight additional gas discoveries have been made in the Rharb basin, all from Miocene-Pliocene sandstone reservoirs. Cumulative production from the oil fields as of 1980 is estimated at approximately 30-40 MMB (million barrels).

Several oil and gas fields, most of them small, also have been found in the onshore and offshore areas of the Essaouira basin in southwestern Morocco. This basin, as well as the other coastal basins of northwestern Africa, were assessed separately (Klemme, oral commun., 1982; Masters and others, 1983). The only other fields thus far discovered in the Atlas belt assessment area are one small oil field (Oued Gueterini), approximately 100 km (60 mi) southeast of Algiers in northern Algeria, two small oil fields and one gas discovery in northeastern Algeria, and three small oil fields in the Tunisian Atlas (fig. 2).

A substantial thickness of potential reservoir rocks is present in most of the Atlas region, including Middle and Upper Jurassic, Cretaceous, and early Tertiary dolomite and limestone, some with reefal or biohermal facies. Cretaceous, Jurassic, and Triassic sandstones of potential reservoir quality are present in much of the region, particularly the southern portion. Porous Miocene-Pliocene sandstones likewise are present in most of the intermontane basins, although except for the western region these sandstones are mostly of continental origin. Fractured Paleozoic rocks, productive in the Rharb basin, may be of interest in complex structural plays. To date, approximately 250-300 exploratory wells have been drilled in the Atlas province with minimal success.

Much of the province contains a thick but highly disturbed, and in places, metamorphosed section of Paleozoic, Mesozoic, and early Tertiary carbonate and clastic rocks with probable adequate thickness of potential petroleum source rocks. However, because of complex structural history and deep original burial, the pre-Tertiary source-rocks are likely to be highly mature or overmature in most areas. There appear to be some hydrocarbon prospects in the small, elongate, infolded Tertiary intermontane basins where some drilling has been done with little success to date. However, most of the late Tertiary section is continental in origin with questionable source rock potential, and the older section in these basins has been highly disturbed by Alpine and older tectonism. Lack of good regional undisturbed seals is an additional deterrent. Accumulations of oil and gas are likely to be small and difficult to find.

The potential for conventionally recoverable undiscovered petroleum resources of the Atlas province have been estiimated by the U.S. Geological Survey (Peterson, 1983) at a statistical mean as follows: for oil, approximately 1.5 BB (billion barrels), and for gas approximately 4 Tcf (trillion cubic feet) (figs. 11, 12; tables 1, 2).

Tindouf, Colomb-Bechar, and Reganne Basins.--These intracratonic basins cover an area of approximately 500,000 km^2 (190,000 mi^2) and contain a total sedimentary volume of approximately 2,000,000 km^3 (455,000 mi^3). As of 1981, approximately 100 or more exploratory wells had been drilled in these basins, with no success. A 1983 oil discovery was reported in the northeastern part of the Reggane basin but no details are yet available.

Potential reservoir rocks in these basins include early Paleozoic, Devonian, and Carboniferous sandstones, which are widespread throughout the region and are important reservoirs in basins to the east. Devonian reefs and early Carboniferous carbonate mounds or bioherms are reported in the Tindouf basin area and may not have been adequately tested by exploratory drilling.

Adequate potential source rocks in these basins include: (1) Silurian high-bituminous black shales, which are reported as the source of most oil in eastern Algerian fields, (2) Devonian and early Carboniferous dark marine-shale beds, which are widespread in this region. The Silurian and perhaps the Devonian shales, may be buried to probable mature to overmature depths in the central parts of the Tindouf and Colomb-Bechar basins, whereas the Carboniferous shales may be immature in much of the region.

These basins are considered to have some gas potential, particularly in deeper horizons, and minor oil potential. The potential for conventionally recoverable undiscovered petroleum resources of the Tindouf, Coulomb-Bechar, and Reganne basins have been estimated by the U.S. Geological Survey (Peterson, 1983) at a statistical mean as follows: for oil, approximately 0.1 BB, and for gas approximately 5 Tcf (figs. 13, 14; tables 1, 2).

Taoudeni Basin.--The Taoudeni intracratonic basin has a total area of approximately 1,300,000 km^2 (500,000 mi^2), with a total volume of Phanerozoic sedimentary cover of approximately 2,500,000 km^3 (560,000 mi^3). As of 1984, three exploratory wells, all dry holes, had been drilled in this immense basin.

Lower and middle Paleozoic quartzose sandstones of potential reservoir quality are widespread in the Taoudeni basin region. Potential source rocks may be present in the Silurian section in the northern part of the basin but probably pinch out to the south. However, it is doubtful if these beds have been buried to adequate depths for thermal maturity. The relatively thick upper Precambrian sandstone, shale, and limestone sequence of the basin is of potential interest for gas. The stromatolitic limestone and dark shale or argillite beds in this section are of potential source-rock quality and should have been buried to adequate depths for maturity. However, except for fracturing, they may not be associated closely with adequate reservoir beds.

The potential for conventionallly recoverable undiscovered petroleum resources of the Taoudeni basin have been estimated by the U.S. Geological Survey (Peterson, 1983) at a statistical mean as follows: for oil, approximately 0.16 BB, and for gas approximately 1.3 Tcf (figs. 15, 16; tables 1, 2).

SUMMARY

Atlas Folded Geosynclinal Belt.--Much of this province contains a very thick but highly disturbed stratigraphic section of marine Paleozoic, Mesozoic, and early Tertiary carbonate and clastic beds that probablly include adequate source rocks for petroleum. However, because of complex structural history, much of the stratigraphic section is metamorphosed and overcooked in most of the region. Accumulations of oil and gas are likely to be small and difficult to find. There appear to be some hydrocarbon prospects in the small, elongate, post-orogenic and infolded Tertiary basins where some drilling has already been done with little success.

Tindouf, Colomb-Bechar, and Reggane Basins.--These basins contain a thick stratigraphic section of marine Paleozoic rocks with some gas potential and minor oil potential. The Devonian and Carboniferous section contains carbonate mounds and reefs, which may not have been adequately explored.

Taoudeni Basin.--This basin is essentially untested, but is a high risk basin in a remote part of Africa. Discoveries would have to be large to be commercial. Most of the sedimentary section is early Paleozoic and late Precambrian with questionable source rock quality, inadequate burial depths in much of the basin, and lack of extensive regional seals.

ACKNOWLEDGMENTS

This report benefited from constructive reviews and discussions by H. D. Klemme and W. P. Dillon, U.S. Geological Survey; F. J. Picha, N. Schneidermann, J. W. Fusso, and L. T. Eisenberg, Chevron Overseas Petroleum; W. F. Bishop, Tenneco Oil Co.; and S. W. Petters, University of Calabar, Nigeria. An earlier version of part of the work was reviewed by J. M. Beall, Shell Pecten Co.

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Table 1.--Assessment of undiscovered conventionally recoverable petroleum resources of onshore Northwestern Africa (Morocco, northern and western Algeria, northwestern Tunisia, Mauritania, and Mali). Resource assessment by USGS as of 12/07/82; see also figures 11 through 16

	Region	Crude oil, in billions of barrels (BB)			Natural gas, in trillions of cubic feet (Tcf)		
		Low $^1F_{95}$	High $^1F_5$	Means	Low $^1F_{95}$	High $^1F_5$	Mean
I.	Atlas folded geosynclinal belt----	0.13	4.21	1.49	0.43	11.55	4.13
II.	Tindouf, Colomb-Bechar, and Reggane basins----------	.00	.52	.10	.00	12.60	5.20
III.	Taoudeni basin	.00	.82	.16	.00	5.24	1.28
	Approximate total of above provinces[2]--	.15	6.00	1.75	.50	30.00	12.00

[1]F 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.

Table 2.--Supplementary and comparative data supporting the resource assessment for onshore Northwestern Africa[1]

	Crude oil, in billions of barrels (BB)	Natural gas, in trillions of cubic feet (Tcf)
Cumulative production to July, 1981		
Atlas folded geosynclinal belt	0.040	0.035?
Tindouf, Colomb-Bechar, and Reggane basins	.00	.00
Taoudeni basin	.00	0.00
Total	0.040	0.035?
Measured reserves to July, 1981		
Atlas folded geosynclinal belt	0.035	0.030
Tindouf, Colomb-Bechar, and Reggane basins	.00	.00
Taoudeni basin	.00	.00
Total	0.035	0.030
Original recoverable resources (ultimate) of the above provinces[2]		
	Oil	Gas
Cumulative production	0.040	0.035
Measured reserves	.035	.030
Undiscovered resources (mean)	1.75	10.61
Total	1.825	10.675
Total oil and gas = 3.5 BBOE		

[1]Cumulative production and reserves are composited astimates from various sources.

[2]Does not include an estimate of inferred reserves.

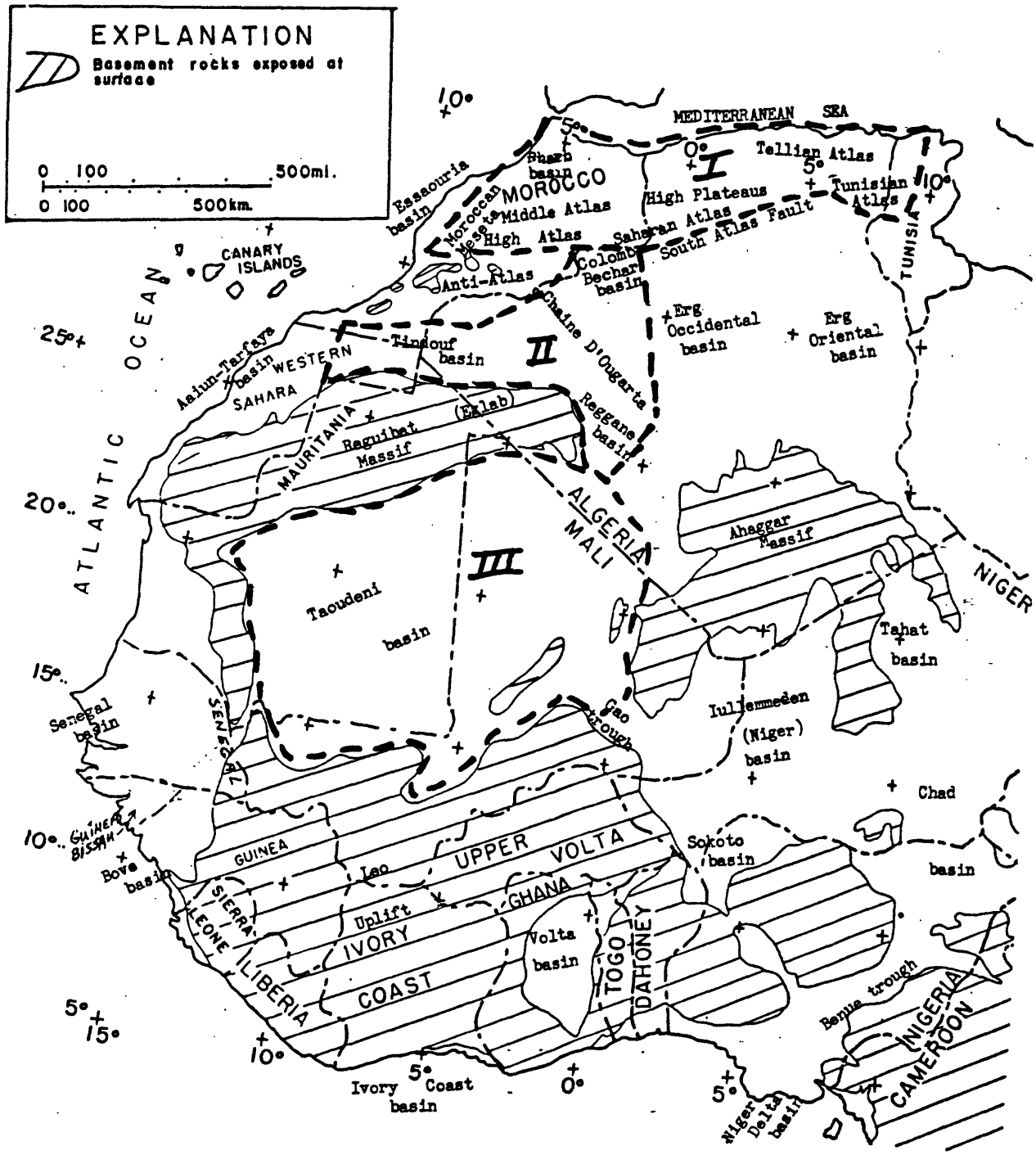

Figure 1. Index map, Northwest Africa, showing main basins and uplifts and assessment area: I - Atlas folded geosynclinal belt; II - Tindouf, Colomb-Bechar, and Reggane basins; III - Taoudeni basin.

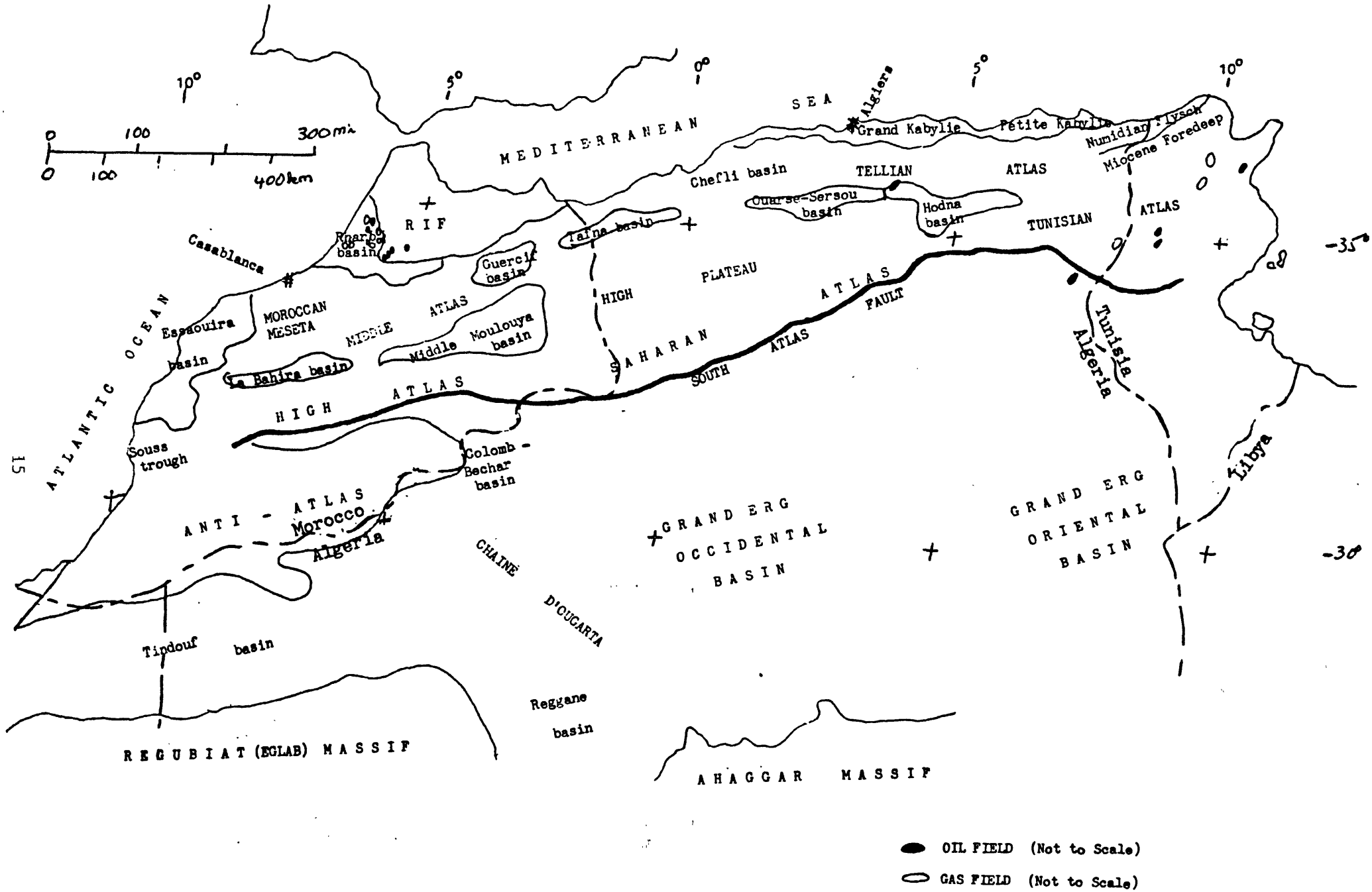

Figure 2. Index map, Atlas folded geosynclinal belt and adjacent area, showing main basins and uplifts and main oil and gas fields. Oil and gas fields in central and eastern Algeria and southern Tunisia not shown. Sources: Caire (1971, 1978), Faure-Muret and Choubert (1971), von Rad and others (1982), Petroconsultants files.

Stratigraphic symbols used on figures 3-6.

T - Tertiary

Tpl - Pliocene

Tm - Miocene

To - Oligocene

Te - Eocene

Tp - Paleocene

K - Cretaceous

Ku - Upper Cretaceous

Kl - Lower Cretaceous

Ks - Senonian

Kt - Turonian

Ka - Aptian

Kn - Neocomian

J - Jurassic

Ju - Upper Jurassic

Jm - Middle Jurassic

Jl - Lower Jurassic

Tr - Triassic

Pz - Paleozoic

P - Permian

C - Carboniferous

D - Devonian

S - Silurian

O - Ordovician

Σ - Cambrian

pΣ - Precambrian

pΣu - upper Precambrian

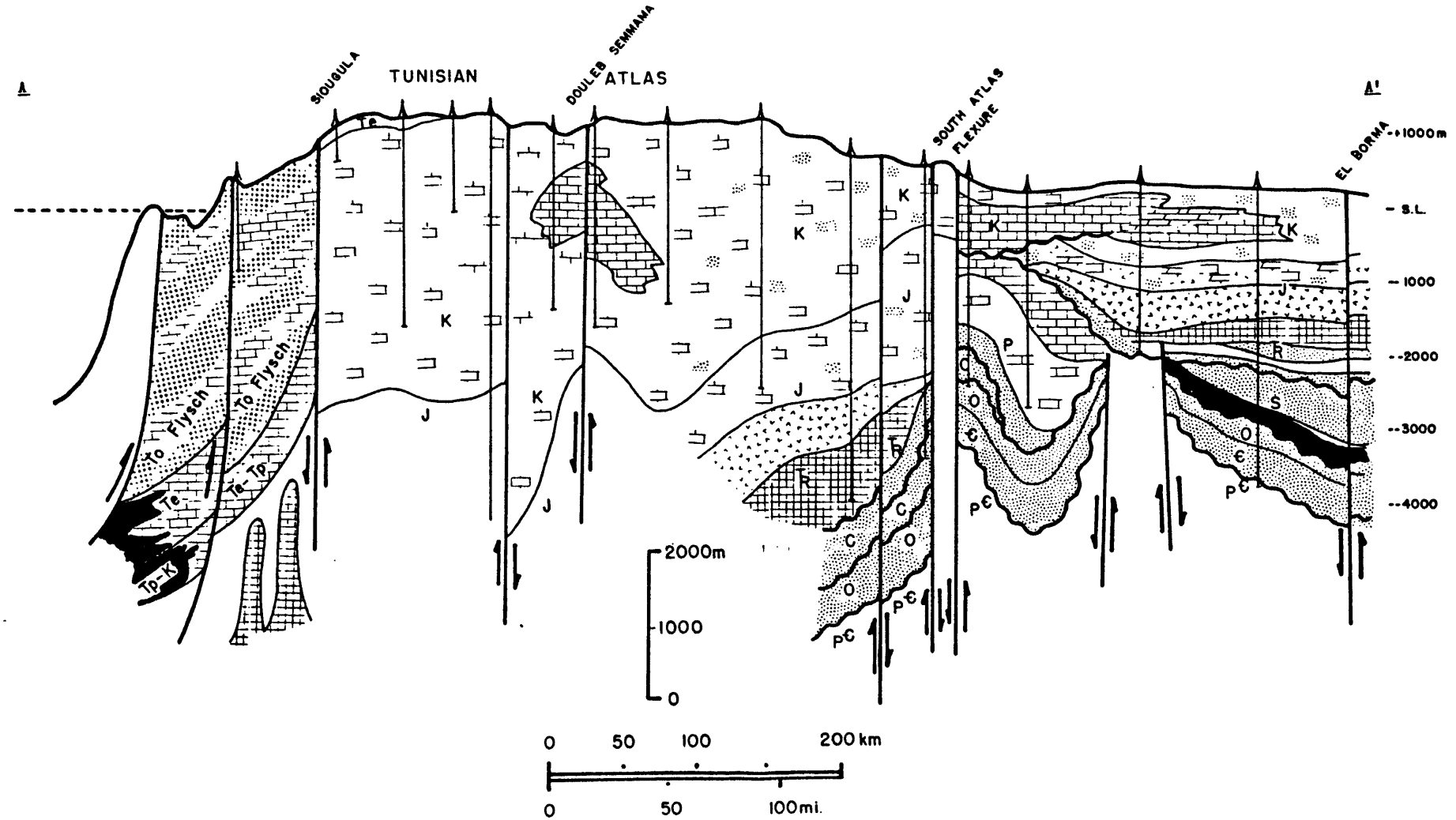

Figure 3. North-south generalized stratigraphic-structural cross-section A-A', Tunisian Atlas and adjacent area. Line of cross-section shown on figure 7. Sources: Burollet (1971), Caire (1971, 1978), Bishop (1975).

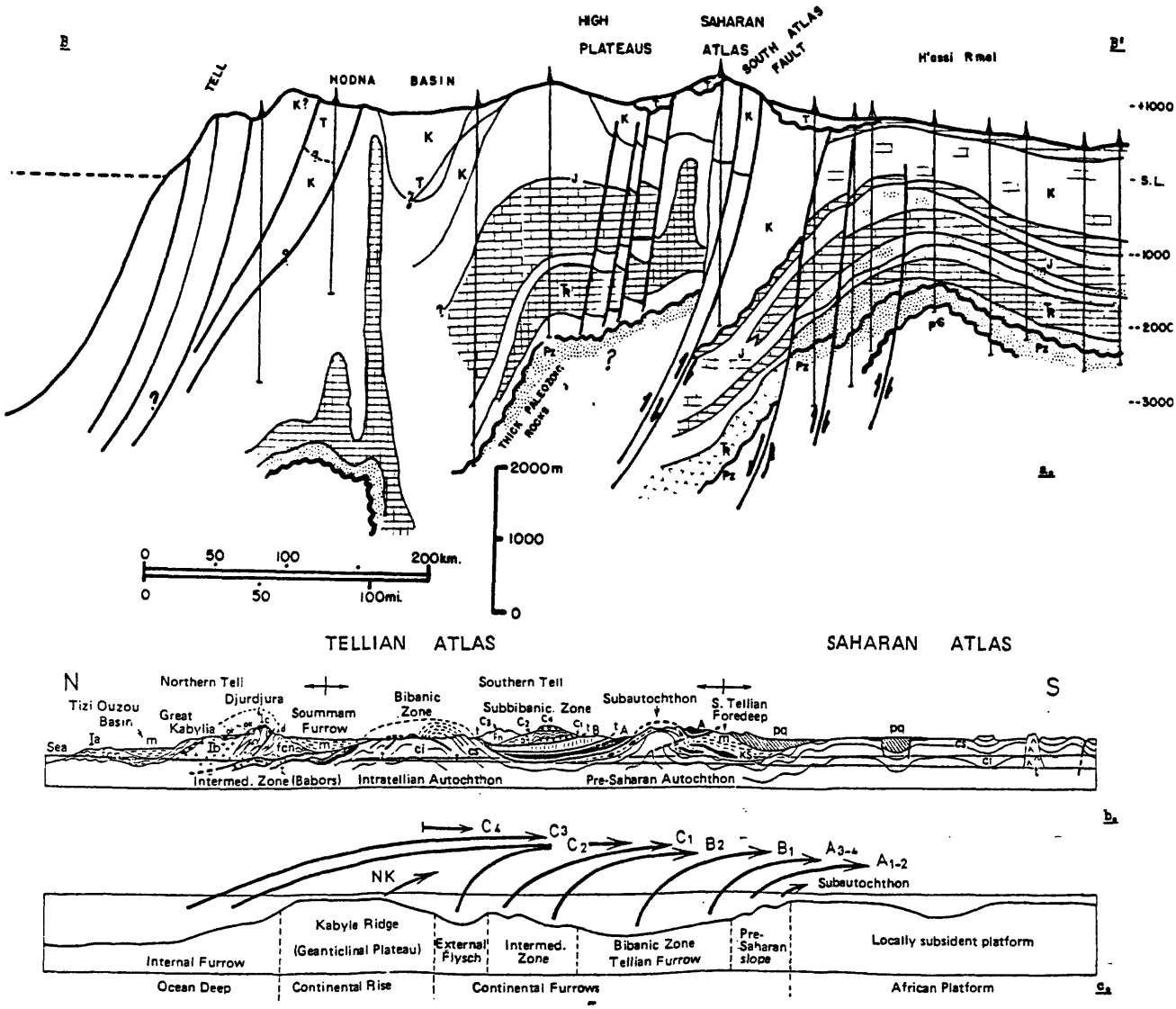

Figure 4. (a) North-south generalized stratigraphic-structural cross-section B-B', Tellian Atlas and adjacent area. Line of cross-section shown on figure 7. Sources: Caire (1971, 1978), Burollet (1971). (b) Schematic, composite north-south section through the Tellian and Saharan Atlas at the longitude of the Great Kabylia (after Caire, 1978, fig. 3), approximately along line of cross-section (a). From south to north: t) dome of Triassic salt; ci) Lower Cretaceous; cs) Upper Cretaceous; pq) Plio-Quaternary basin (characteristic of the Tunisian Atlas) and Plio-Quaternary subsident zone on the border of the Saharan Atlas; m) Lower Miocene of the south Tellian foredeep with "Sedimentary Klippes" (KS); AO Unit A (= nappe A); t) triassic cushions supporting Units B and C; B) Unit B (= nappe B); C_1) Plate C_1 (conglomeratic Senonian derived from the Intermediate Zone, Babors type); C_2) Cretaceous flysch (fc); C_3) Oligo-Miocene, Numidian flysch (fn) or lateral equivalents; C_4 synorogenic Lower Miocene; cs, ci) Cretaceous of the parautochthonous Bibanic Zone; m) Lower and Upper Miocene (postnappes sequence of the Sheliff-Soumman furrow); f cn) Cretaceous to Paleocene allochthonous flysch; t) Triassic; Id) Southern Kabyle flysch; Ic) Limestone Chain; Ib) basement of the Kabylia; Ia) Northern Kabyle flysch; ec) splinters of the Limestone Chain; ok) Oligo-Miocene of the Kabylia (Kabyle oligo-Miocene); m) postnappe Miocene of the Tizi Ouzou Basin. (c) Senonian paleogeography: The arrows show the origin, the sense of displacement, and the order of superposition of the nappes (overthrust units).

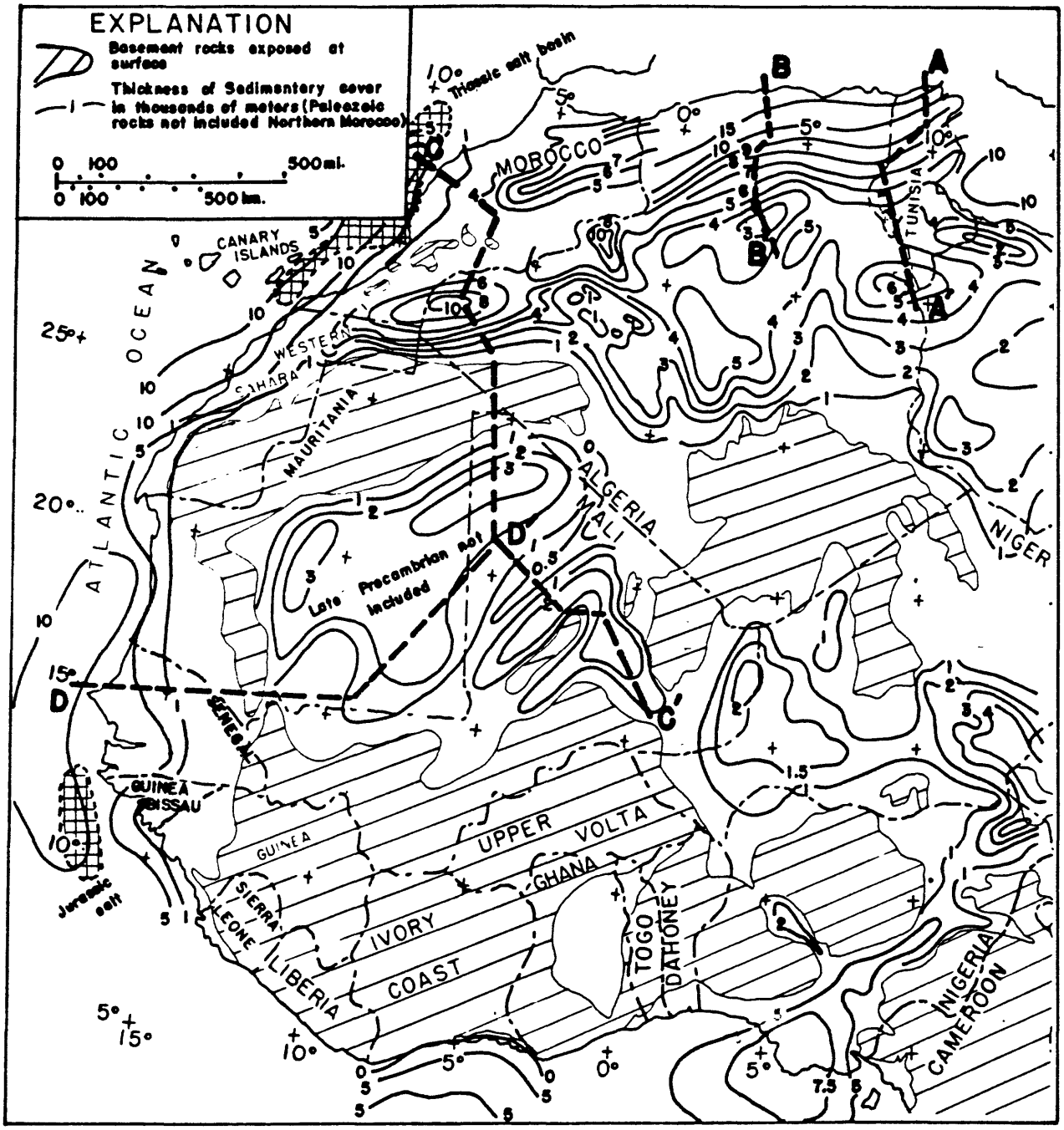

Figure 7. Approximate thickness, sedimentary cover, Northwest Africa. Lines of cross-sections (figs. 3-6) are shown. Sources: Choubert and Faure-Muret (1971a, c), Machens (1973), Dillon and Sougy (1974), von Rad and others (1982).

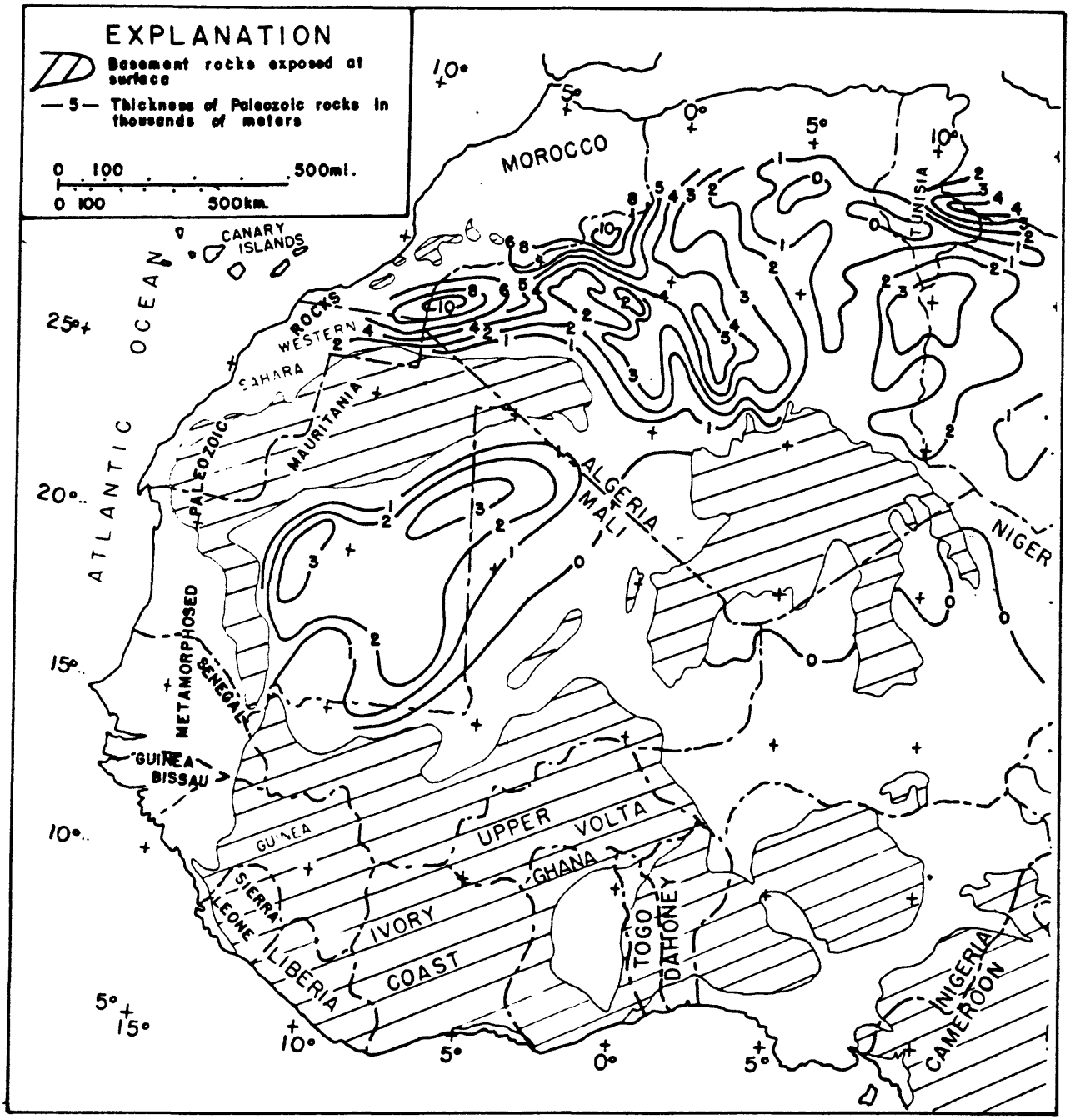

Figure 8. Approximate thickness, Paleozoic rocks, Northwest Africa. Sources: Klemme (1958), Magliore (1970), Whiteman (1971), Bishop (1975), von Rad and others (1985).

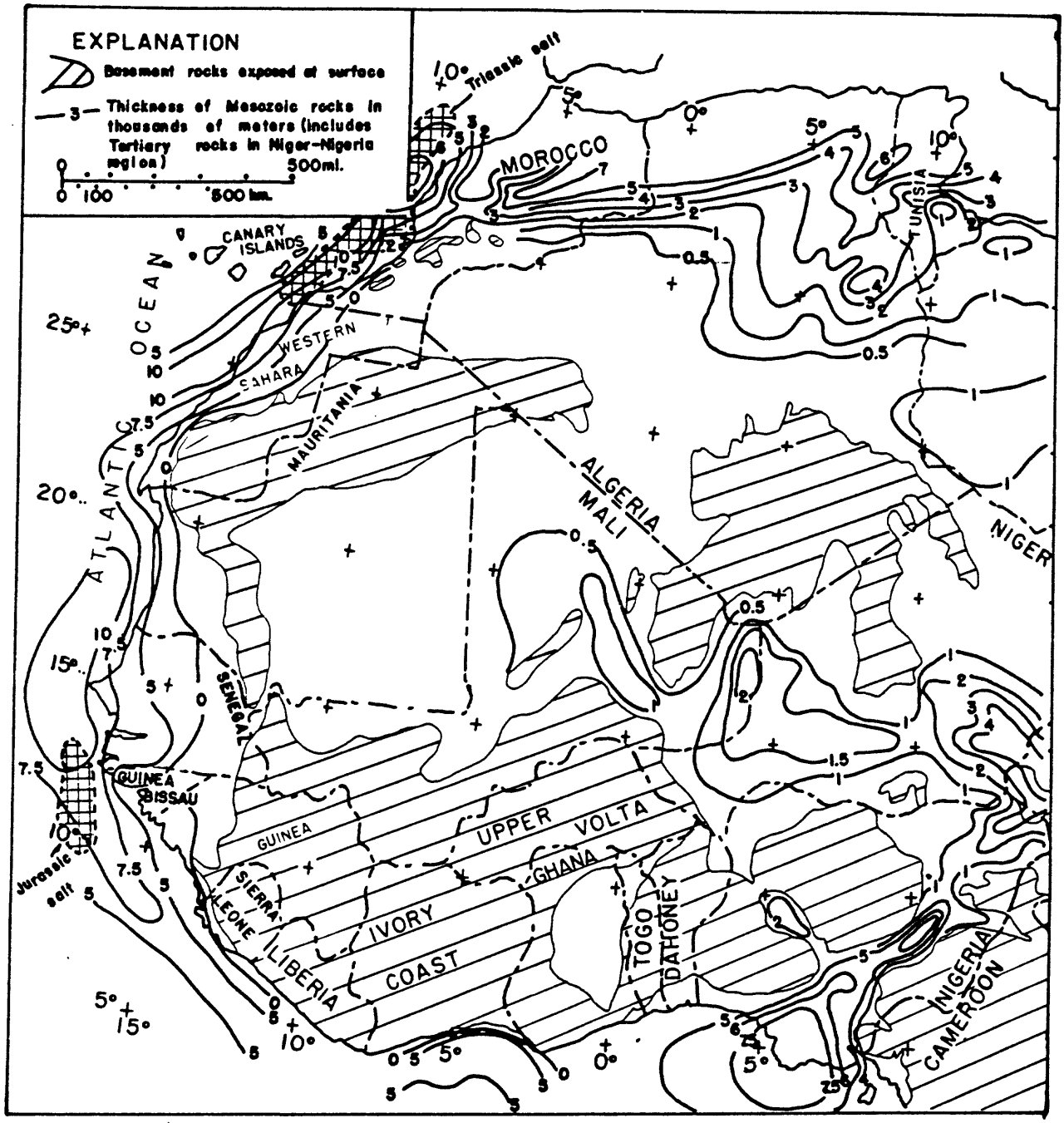

Figure 9. Approximate thickness, Mesozoic rocks, Northwest Africa.
Sources: Klemme (1958), Machens (1973), Bishop (1975), van Houten (1980), von Rad and others (1982).

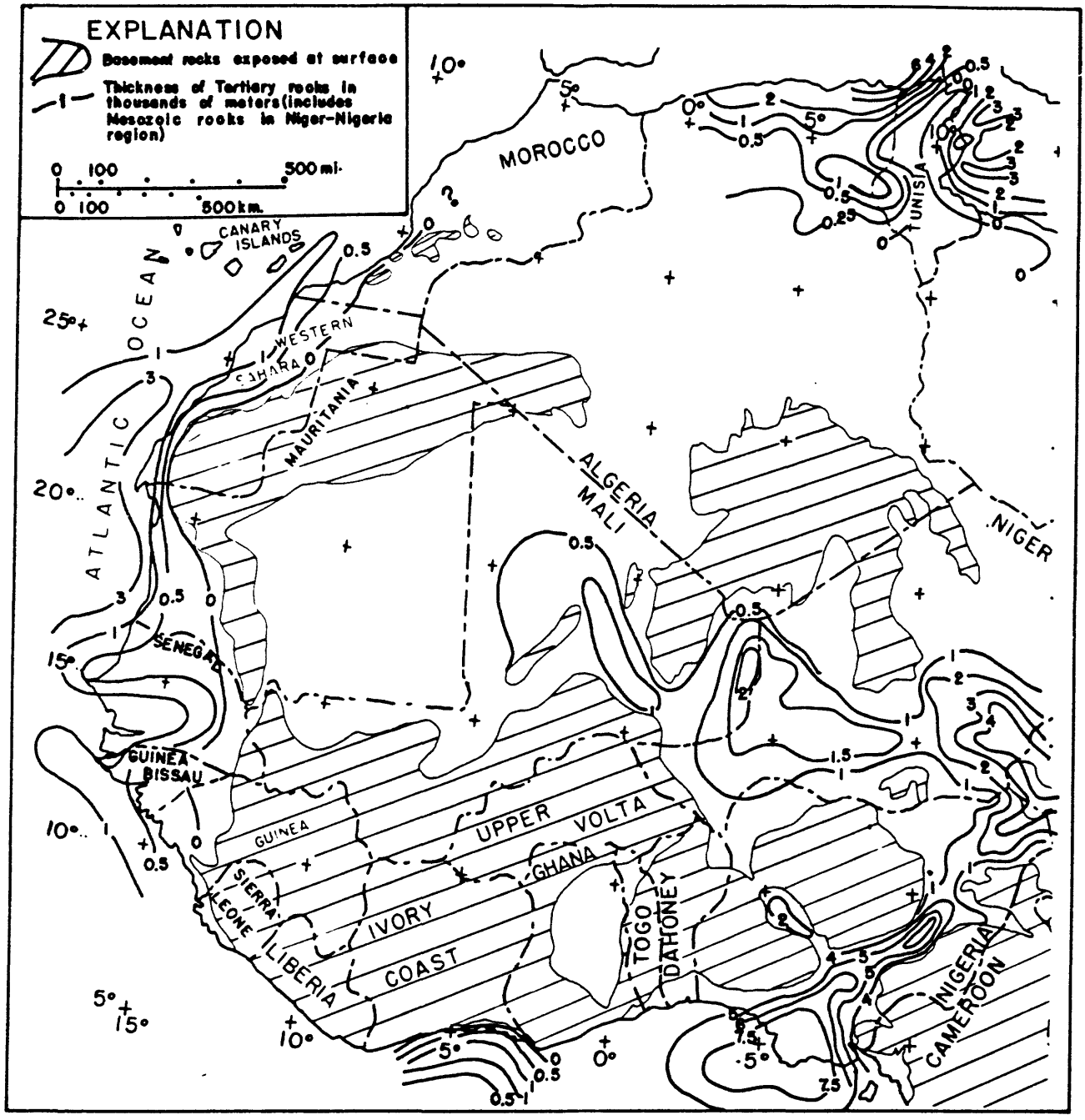

Figure 10. Approximate thickness, Tertiary rocks, Northwest Africa. Sources: Machens (1973), Bishop (1975), von Rad and others (1982).

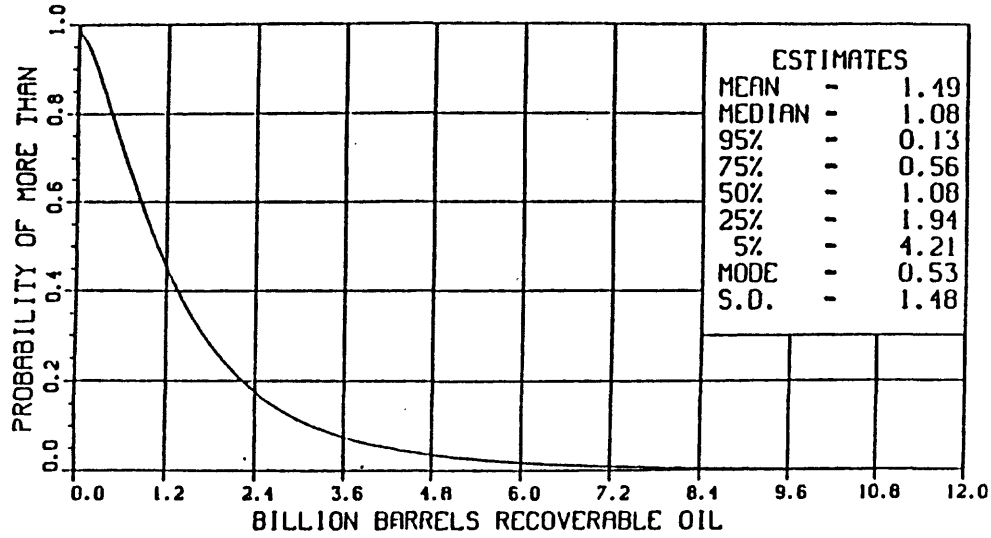

Figure 11. Northwest Africa, Atlas folded geosynclinal belt--undiscovered conventionally recoverable oil.

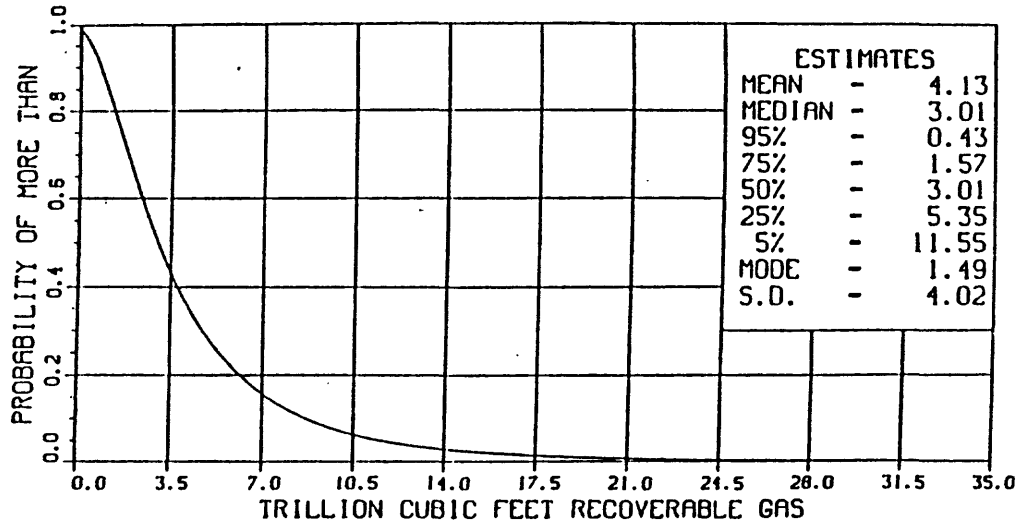

Figure 12. Northwest Africa, Atlas folded geosynclinal belt--undiscovered conventionally recoverable gas.

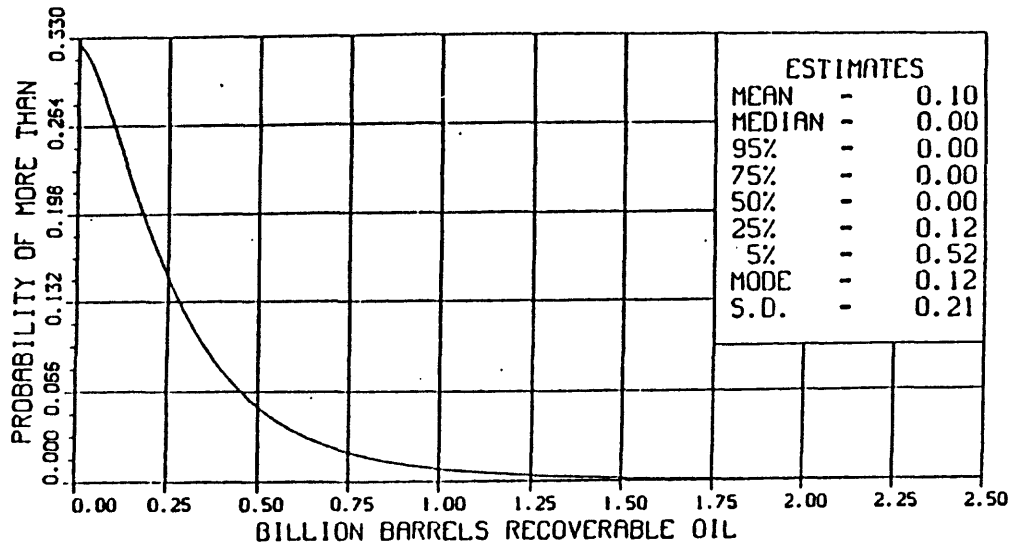

Figure 13. Northwest Africa, Tindouf, Colomb-Bechar, and Reggane basins--undiscovered conventionally recoverable oil.

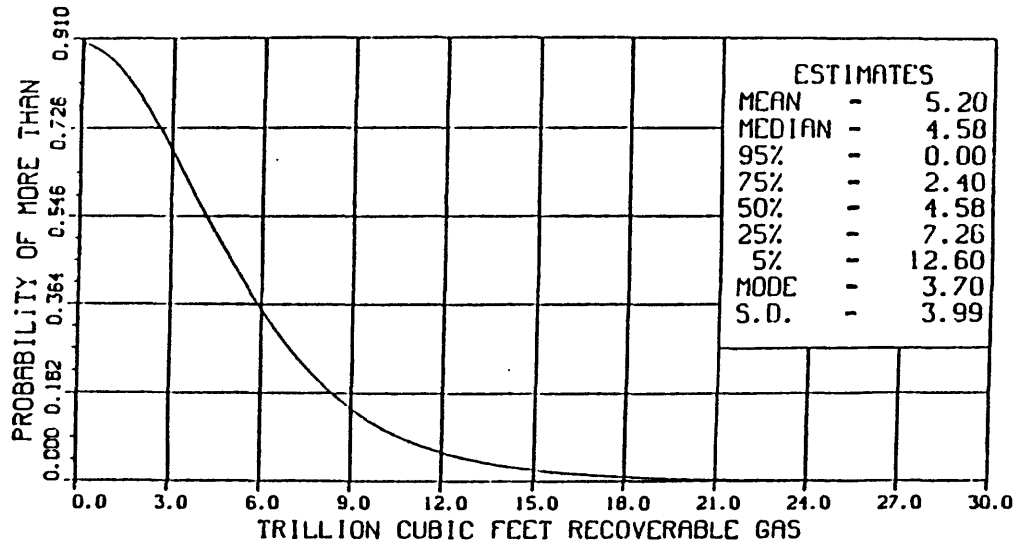

Figure 14. Northwest Africa, Tindouf, Colomb-Bechar, and Reggane basins--undiscovered conventionally recoverable gas.

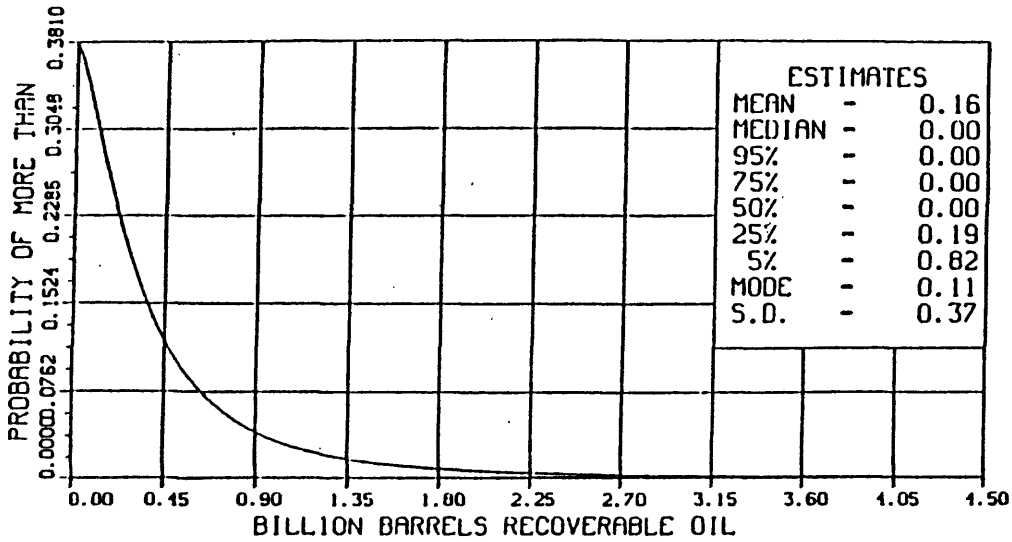

Figure 15. Northwest Africa, Taoudeni basin--undiscovered conventionally recoverable oil.

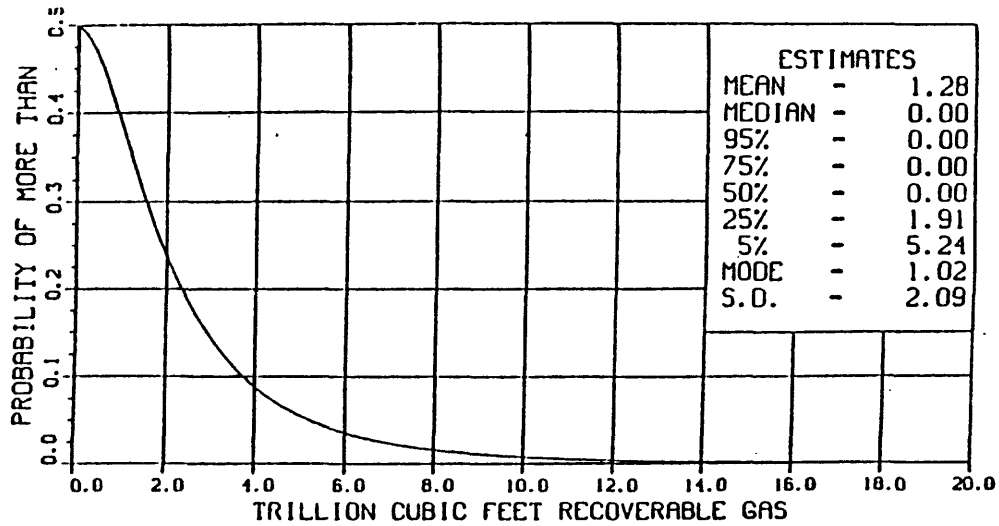

Figure 16. Northwest Africa, Taoudeni basin--undiscovered conventionally recoverable gas.