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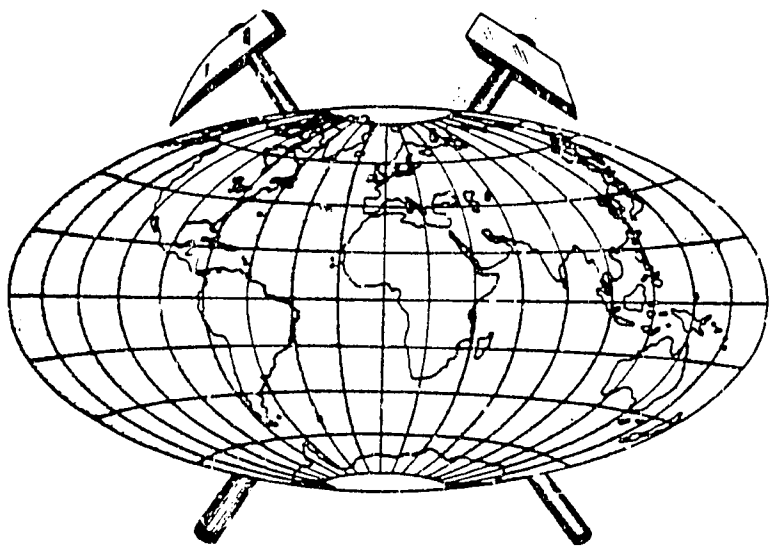
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PN AAT 705

PROJECT REPORT
Morocco Investigation
(IR)MO-2

PRELIMINARY REPORT ON ENERGY RESOURCES OF MOROCCO



Report prepared for the Agency for International Development,
U.S. Department of State.

1983

GEOLOGIC ASSESSMENT OF THE FOSSIL ENERGY POTENTIAL OF MOROCCO

by

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U.S. Geological Survey

The project report series presents information resulting from various kind of scientific, technical, or administrative studies Reports may be preliminary in scope, provide interim results in advance of publication, or be final documents.

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Geologic Assessment of the Fossil Energy Potential of Morocco

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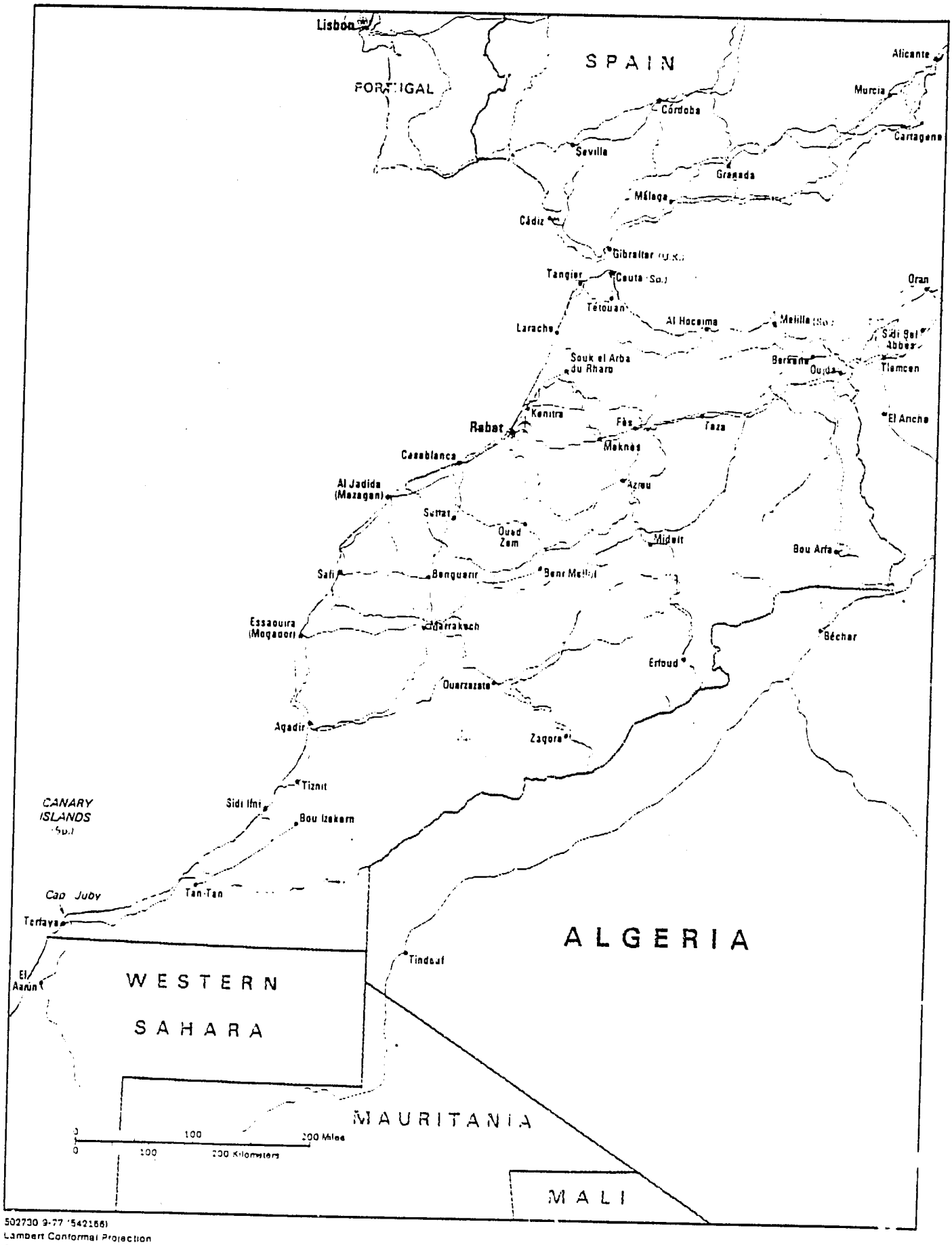
Philip R. Woodside and Glen F. Brown

INTRODUCTION

The purpose of this report is to provide geological information to be used in determining appropriate activities for enhancing the exploration and development of fossil-fuel energy resources in Morocco. Data has been obtained principally from published literature, supplemented to some extent by unpublished information from files of the U.S. Geological Survey. This report was prepared under a Resources Support Services Agreement between the U.S. Geological Survey (USGS) and the Agency for International Development (AID), U.S. Department of State, as a component of technical assistance in the exploration and development of conventional energy resources in AID foreign-mission countries.

Morocco, on the northwestern tip of Africa, has an area of 712,550 km^2 (275,115 sq. mi), including Western Sahara (fig. 1). Its coastline borders both the Atlantic Ocean and the Mediterranean Sea. Morocco resembles California in size and geographic and climatic contrasts; ie, rugged coasts with sparkling beaches, mountains over 4000 m. (13,000 ft.) high, fertile plains, and deserts (American University, 1972). The population of Morocco was estimated as 18.6 million in 1977.



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Lambert Conformal Projection
Standard parallels 8° and 32°
Scale 1:7,500,000

Railroad
Road
Airport

Figure 1. Base map of Morocco.

GEOLOGIC FRAMEWORK

Structurally, Morocco is representative in part of the European (Alpine and Hercynian) platform on the north and in part of the African platform on the south. Thus, it includes a variety of land forms and structural provinces, each strikingly different from adjacent domains. The Mesozoic trend of the High Atlas and Middle Atlas separates two areas, each with Precambrian and lower Paleozoic rocks: the Anti-Atlas on the south and the Meseta region on the north (fig. 2). These areas were folded, metamorphosed, and intruded during the mid-Paleozoic Hercynian orogeny.

The northern peninsula facing Gibraltar encompasses the Rif Atlas (fig. 2), where the beds are Mesozoic or younger, with the exception of a small inlier of ultramatic and metamorphic rocks which may be Precambrian. Overlapping nappes in which these beds crop out mark a western extension of the Alpine orogeny of Europe and the youngest orogenic event in Morocco (fig. 3). In the southern part of Morocco, south of the intensely folded but topographically subdued Anti-Atlas, the Paleozoic sedimentary rocks are exposed in monoclines that dip southeastward into the Tindouf, a structural basin whose floor is as much as 10,000 m (32,000 ft.) below sea level, and which forms the southernmost structural element north of Mauritania (fig. 2). Still farther south, along the Atlantic coast of the former Spanish Sahara, Cretaceous and Tertiary beds dip seaward. The beds are underlain by lenses of Silurian and Devonian rocks which in turn are underlain by crystalline Archean basement.

The fault systems of Morocco have recently been interpreted as tensional, resulting from the breaking up of the Pangea landmass and the opening of the Atlantic Ocean. Agadir fault (or the south Atlas line)

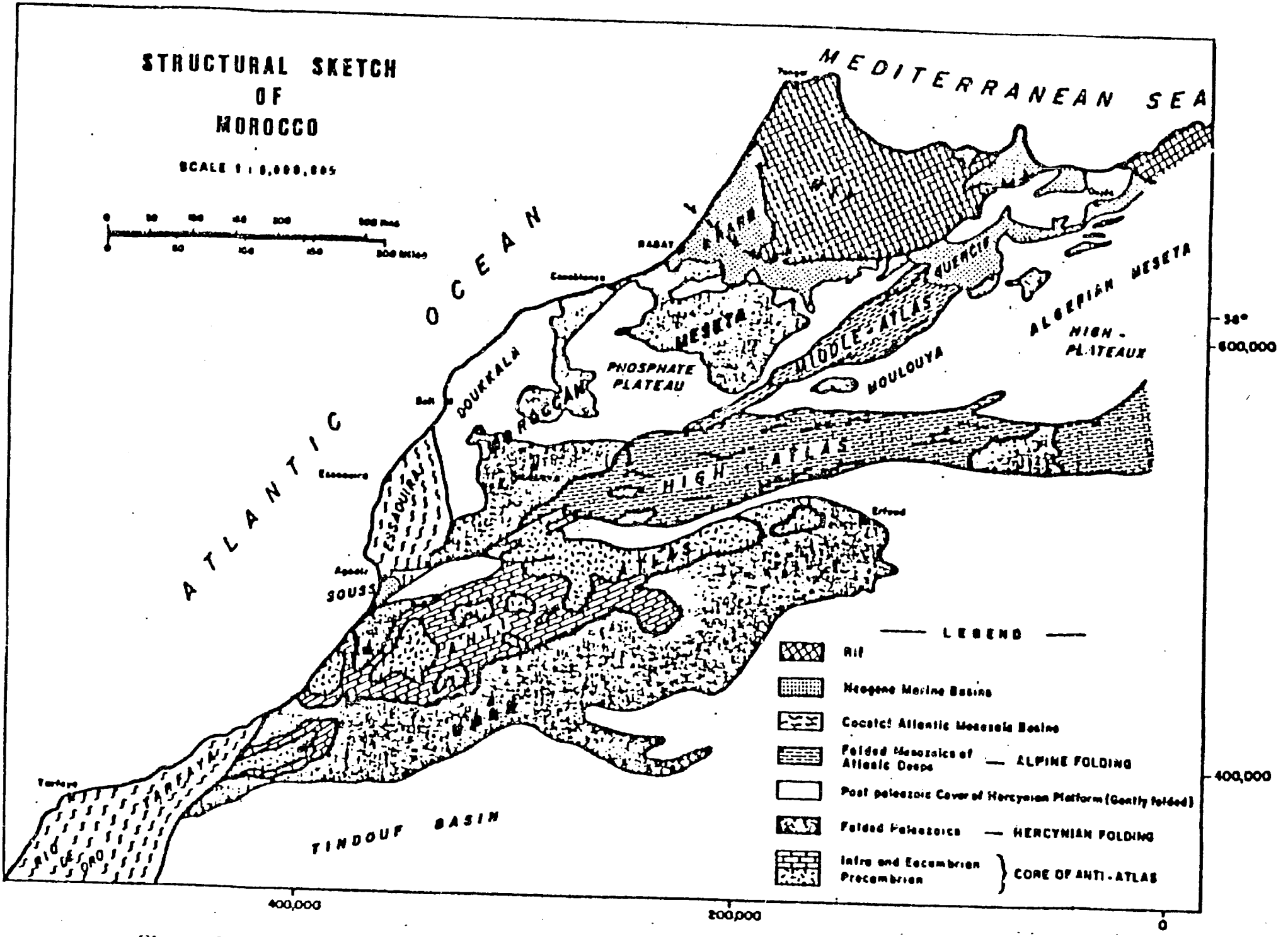
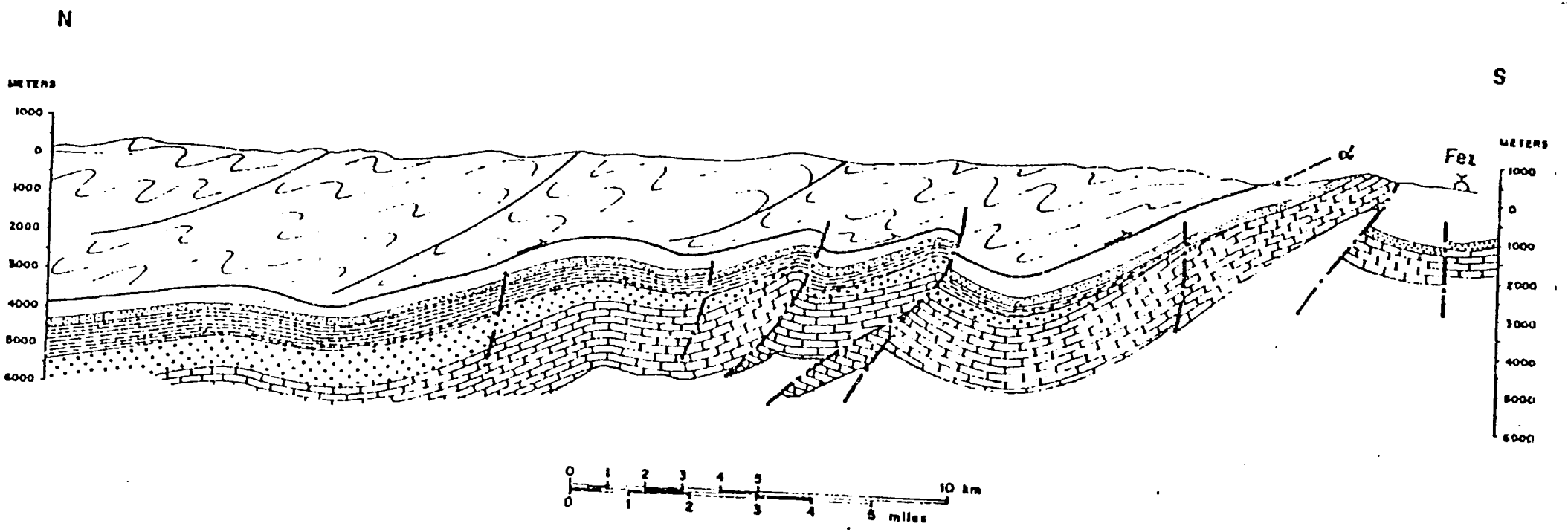


Figure 2. Generalized map of structural features of Morocco (from Michard, 1976)



GEOLOGICAL CROSS-SECTION THROUGH THE

RIF-FOOTHILLS

— L E G E N D —

FOOTHILLS

"NAPPE PRERIFAINE"

FORELAND

MIOCENE — "Marnes bleues" / Basal sandstones

PALEOCENE-CRETACEOUS

JURASSIC — Bajocian / Liassic

TRIASSIC

Figure 3 Geological cross-section through the Rif-Foothills

extends eastward at the southern base of the High Atlas (fig. 4); it is considered by many geologists to be a transform fault that has exercised structural control during several epochs. However, it is only one of several east-northeasterly trending parallel lineations. Conjugate faults, inferred partly from geophysical evidence, parallel the Atlantic coast. A series of horsts and grabens appears to have two dominant structural orientations; those nearest the Atlantic parallel tne Atlantic coast, and those in eastern Morocco parallel the Mediterranean shore. Some grabens are partly filled with salt and other evaporites; they are somewhat similar to the Red Sea graben, but date back to late Paleozoic or perhaps even earlier. The elevation of the Jurassic marine limestone and dolomite that form the crests of the High and Middle Atlas horsts could represent epirogeny during the Alpine orogeny which was accompanied by folding farther to the north.

Basins filled with molasse-type deposits flank the High Atlas on the south, beginning at the Souss plain at Agadir on the Atlantic coast and extending with interruptions northeastward to the Sillon and pre-African lowlands. Similar basins flank the north side of the High and Middle Atlas mountains.

Precambrian rocks are exposed in limited areas, mostly in infrastructures within domes and anticlines of the Anti-Atlas and along the eastern border of the former Spanish Sahara. Gneiss, granite, and mica schists are considered to be of Archean age; in some places they are covered by middle Precambrian conglomerate, schist, rhyolite, quartzite, and andesite. Rhyolite, ignimbrite, and andesite volcanic flows in the youngest Precambrian rocks that crop out along the northern edge of the Anti-Atlas

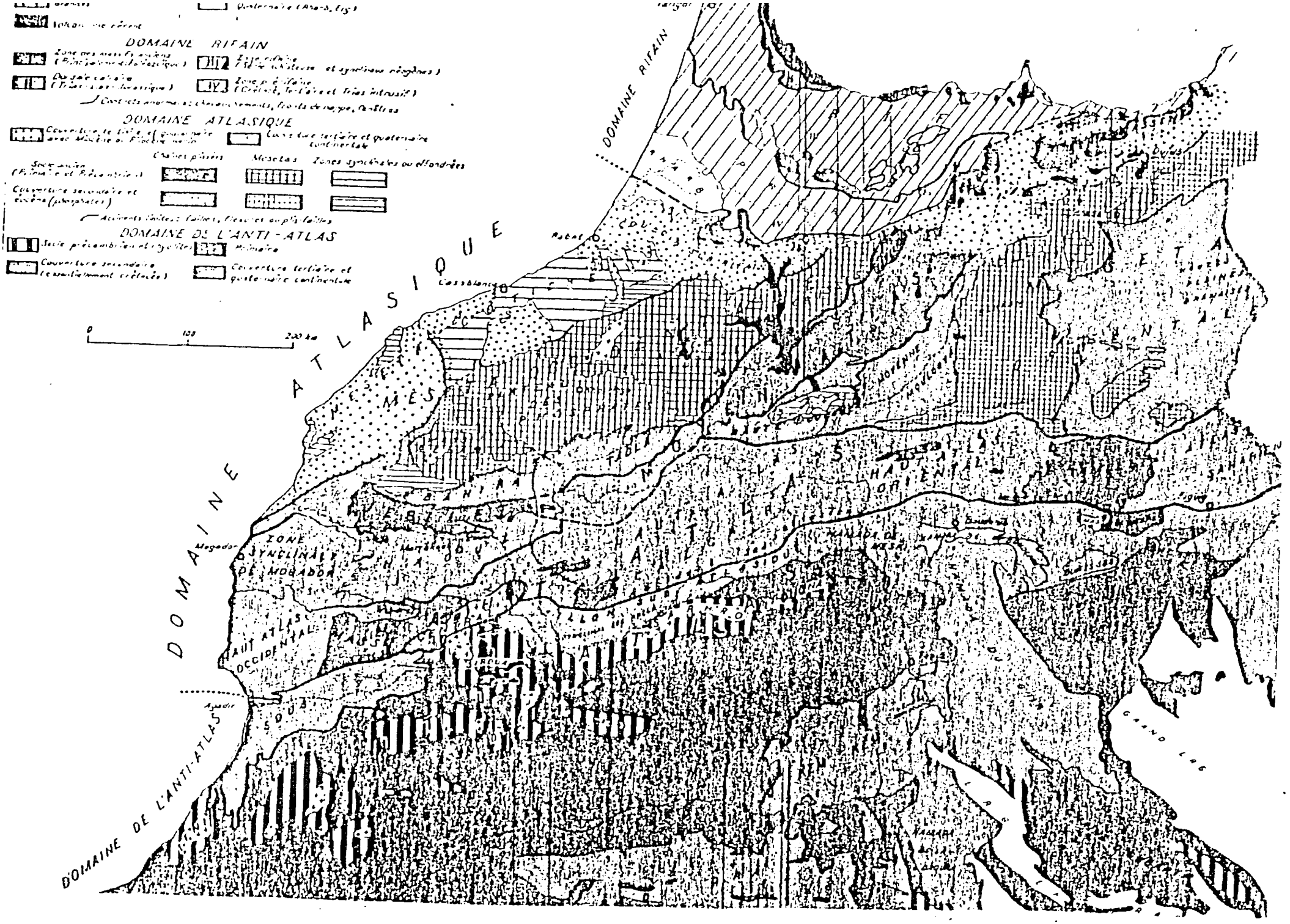


Figure 4. Structural features of Morocco (from Dresch, 1952).

are of special interest because ore deposits elsewhere are related to similar occurrences.

Widespread lower and middle Paleozoic sedimentary rocks were intricately folded, metamorphosed, and intruded during the Hercynian orogeny, both north and south of the High Atlas. These rocks consist mostly of clastics, but include some calcareous strata of Cambrian age.

Permo-Triassic sandstone, conglomerate, and red argillite crop out below Jurassic dolomite and limestone in the northern Atlas and the Meseta. Cretaceous and lower Tertiary beds, including phosphorite, extend along western Morocco into the Spanish Sahara. Neogene beds exposed in marine terraces along the northern coast have been elevated by tilting related to rotational movement. The geologic and physiographic relationships are similar to those along the northern coast of the Red Sea where terraces have also been elevated by tilt involving rotational movement.

Besides the Precambrian plutonic and metamorphic rocks, Hercynian granite also crops out in the Atlas and Meseta regions. Jurassic dolerite sills intrude Paleozoic rocks of the Anti-Atlas; and ultramafic and ophiolitic complexes are present in the central Anti-Atlas and on the Mediterranean shore in the Rif.

Lowland regions, formed on Tertiary and Quaternary terranes south of Casablanca and Rabat, are the most densely populated areas in Morocco and include most of Morocco's agricultural development.

SUMMARY OF CURRENT ENERGY AND MINERAL RESOURCES POSITION

Energy Resources

In 1980, Morocco's total consumption of energy was the equivalent of 33.6 million barrels of oil. Consumption by energy type included: petroleum and related products, 79 percent; coal, 11 percent; hydroelectric power,

9 percent; and natural gas, 1 percent.

Oil production averaging 180 barrels per day for the first 6 months of 1981, was reported by the Oil and Gas Journal, Dec. 28, 1981. Gas production for 1981 averaged 8 million cubic feet per day according to U.S. Bureau of Mines (oral communication). Domestic production of petroleum is less than one-half of one percent of requirements. Approximately 93 percent of the oil production comes from Sidi Rhalem field near Essaouira; the remainder is produced from the Sidi Fili fields near Rabat (fig. 1). A large oil play in Spanish Sahara during the 1960's did not result in discovery of commercial quantities of oil and gas, and offshore drilling also has not produced discoveries. However, shows of gas in 4 tests in the Gharb plain and shows of high pressure and condensate gas in 3 tests in Triassic, Devonian, and Ordovician formations in the Essaouira basin in 1978, and in 1980 and 1981, have raised hopes of establishing new reserves. Oil reserves for Morocco are estimated as 75 million barrels; gas reserves are less than 25 billion cubic feet (DeGolyer and MacNaughten, 1980). Approximately 26.4 million barrels of oil were refined in Morocco in 1980; the following fractions were produced (millions of barrels) gasoline, 2.2; kerosene and jet fuel, 1.2; distillate, 7.8; residual, 10.9; and other, 4.5 (DeGolyer and MacNaughten, 1980). Crude oil is refined in Mohammed by Societe Anonyme Morocaine D'Industrie de Raffinage (SAMIR) and in Sidi Kacem (northwestern Morocco) by the Societe Cherifienne des Petroles (SCP). These two refineries process 96 percent of Morocco's crude oil imports. Imports of refined petroleum products, mostly from France, amounted to more than 5,000 metric tons in 1977 (Jolly, 1981). Oil produced is shared by the Moroccan government and foreign companies on a standard 50/50 basis. Cost of research and exploration is born entirely by the participating

foreign company. The company must pay a 12.5 percent royalty to the government for products marketed and is required to pay a 55 percent tax on profits realized from sale of hydrocarbons.

Anthracite production in Morocco was estimated as 710,000 metric tons in 1979, a figure consistant with those of the preceeding three years, (Jolly, 1981). Production is from the Charbonnages Nord-Africaines (CNA) mines at Jerada near the Algerian border. Anthracite-fueled electric plants furnished about 32 percent of national requirements in 1978 (Jolly, 1981). Discovery of an estimated 44.5 million tons of lignite near Oued Nja resulted from the 1977 exploration program.

The Moroccan government is committed to commercial development of its oil shale and has plans to produce 7,000 bbl/d shale oil by 1986/87. The achieving of this objective will depend on many technical considerations yet to be resolved. Processes to extract oil from shale are still in the experimental stage and as yet no process that is economically viable has been developed. However, with development of a successful processing technique and with dedicated management, the oil shale deposits in Morocco may ultimately be developed. The Moroccan government has held discussions with a number of U.S. companies with a view to obtaining their technical involvement. The technical staff of the World Bank is working closely with Scientific Applications, Inc. (SAI) of Golden, Colorado, the prime consultants to the Moroccan government for their oil shale development. SAI is undertaking a 27-month feasibility study, and this may lead to a change in current plans and efforts. Additionally, officials of the government of Morocco are cooperating closely with all who want to help in development of its oil shales.

Morocco's shale deposits are located in two main areas, Timhadit and Tarfaya, that are estimated to contain large recoverable reserves. The

Bureau of Recherches et de Participations Minieres (BRPM) and the Office National de l'Electricidad (ONE), both agencies of the Moroccan Ministry of Energy and Mines, are engaged in separate projects to develop the oil shale deposits at Timhadite. BRPM is concerned with the production of synthetic crude oil and ONE is concerned with the generation of electricity. Considerable core drilling has been done in the oil shale area, and reserves are estimated to be at least 600 million barrels of oil.

Prospects for the production of uranium in Morocco seem to be limited to recovery from monazite and related minerals in beach sands and to the low-grade uranium ore associated with phosphate. Ordinarily, uranium in phosphate, such as the uranium now produced as a byproduct of phosphate in Florida, is concentrated to only about one-tenth the grade needed for commercial exploitation. Resource estimates for uranium have not been made for Morocco because uranium contents have not been reported for either the monazite or phosphate deposits. The government of Morocco from time to time considered the feasibility of extracting uranium from phosphoric acid but has delayed a decision on issuing contracts to extract the uranium largely because it feels that no commercially viable single-stage extraction process has yet been demonstrated. Morocco does not wish to be the first to take major financial and technological risks in development of the process. However, a feasibility study is almost completed for a uranium oxide plant at Safi. If the study shows the plant to be commercially feasible it would be scheduled to produce 450-600 tons per year by 1985. During 1979, uranium ore bodies were discovered in the Rif mountains near Tarekochid but little is yet known about these occurrences.

Hydroelectric power generation probably will increase in the future. No reports seemed to be available for geothermal energy resource prospects.

Mineral Resources

Most of the following data for mineral resources is summarized from Jolly, 1981. The principal known deposits are the phosphates of the Khouriba complex, Youssoufia, Ben Guerir, Sidi Hajjaj, and Meskala, in Upper Cretaceous and lower Tertiary sedimentary rocks. They are similar to the deposits in Egypt and Jordan. The Bon Kraa deposit in former Spanish Sahara is 60 kilometers from the Atlantic coast and, similar to the Meseta deposits farther north, the dip of younger sediments is seaward. Some phosphatic sediments derived from the older deposits have been reported offshore but have not been mined. The Moroccan phosphate deposits, with those of Bon Kraa, constitute the world's largest known reserve of minable ore. The U.S. Bureau of Mines estimates that Morocco, exclusive of former Spanish Sahara, has 60 percent of world reserves, and these constitute 90.8 percent of Morocco's total mineral exports.

Morocco also produces copper, lead, cobalt, silver, manganese, zinc, antimony, iron ore, and fluorspar. Most of the copper prospects are scattered along the north side of the Anti-Atlas, the largest mines being Bleida and Bou Skour; but prospects and small mines occur throughout the Meseta region. Manganese occurs in the same general region; the Imini mine is 100 kilometers west of Bou Skour. Silver is a byproduct of lead-zinc ore from Touessit near Algeria and the recently activiated Draa Sfar Mine near Marrakech. Aouli and Zeida are large producers of lead and zinc. Pellets produced in eastern Rif from iron ore mined in Northern

Morocco are shipped to Algiers and Europe. Fluorspar comes from central Meseta. Morocco produces about 6 percent of the worlds total cobalt; most production is from the Bou Azzer mine.

Most metallic minerals occur in epithermal or strata-bound deposits peripheral to Precambrian or Hercynian cores of antiforms; many are in metamorphosed lower Paleozoic sedimentary or volcanic rocks. Exploration planning should consider the rhyolite-andesite flows and welded tuffs as potential sites for new ore bodies, especially in the late Precambrian or Infracambrian. Prospects for discovery of new deposits by using new techniques and new structural knowledge should be good.

The younger granites, especially Hercynian where the chemistry is peralkaline, should be examined for rare earths, niobium, tin, and related minerals, some of which may be radioactive. Such a granite is now being mined in southwest Africa, and the plutonic rocks are known to carry cassiterite as a minor mineral. Ore-bearing pegmatites are commonly associated with plutonic rocks.

ENERGY RESOURCE IDENTIFICATION

Petroleum

Past Exploration

Onshore.--Morocco's petroleum history had its inception after World War I when the French began exploring in the Rharb basin (figures 2 and 4). Emmons reported production of 73 bbl/d for 1924; annual production since 1932 is given in table 1. Producible oil was found in the Sidi Kacem region in 1934. As a result of the 150 exploratory wells drilled in Morocco during the 1950's and 1960's only six small oil and minor gas fields were found. The Sidi Rhalem Field in the Essaouira Basin currently is the main producing oil field in Morocco; the Sidi Fili Field in the Rharb

Table 1 - Annual Oil Production of Morocco in thousands of barrels
(Source DeGolyer and MacNaughten, 1980)

YEAR	PRODUCTION	YEAR	PRODUCTION
1931	...	1956	734
1932	7	1957	566
1933	7	1958	560
1934	6	1959	712
1935	4	1960	695
1936	4	1961	603
1937	22	1962	968
1938	27	1963	1,140
1939	27	1964	910
1940	27	1965	782
1941	27	1966	755
1942	41	1967	738
1943	39	1968	674
1944	32	1969	438
1945	26	1970	335
1946	20	1971	172
1947	21	1972	216
1948	100	1973	320
1949	136	1974	191
1950	305	1975	171
1951	587	1976	35
1952	749	1977	167
1953	761	1978	181
1954	881	1979	140.5
1955	765		

basin produces small amounts of oil (fig. 5). Gas production comes from both the Essaouira and Rharb basin.

In 1978 Phillips Petroleum acquired concessions in the Guercif and Misour regions in northern Morocco. They drilled a 13,000-foot dry hole, Tafrata 1-X, in the foothills of the Atlas Mountains. In 1979 the France based Elf Aquitaine company, as operator, and two other companies, acquired a 26,000 sq km concession in the Rharb basin. This group has agreed to spend $66 million over a four-year period for oil exploration.

During 1980, gas reservoirs were discovered by two Moroccan wells. In the Essaouira province, gas under high pressure was discovered in a well near Meskala in a 60-foot interval between depths of 10,000 and 11,000 feet. The second well was near Mechra bel Ksiri in Rharb basin; gas was discovered in a 40-foot interval at a depth of about 2000 feet. BRPM judges both reservoirs to be noneconomic.

In December 1981 the Moroccan Ministry of Energy and Mines announced that ONAREP (the national oil company) had discovered gas and associated condensate in a well at Meskala, about 35 miles southeast of Essaouir at a depth below 3,374 m. Daily flow from the well was 172,000 cubic meters (6.07 million cu. ft.) of gas and 81 cubic meters (510 barrels) of condensate.

Offshore.-- Morocco, like many aspiring oil producing countries, has had its share of petroleum discovery rumors in recent years. Offshore exploration started in 1967 with the issuance of a 20,000 km^2 permit in the Tarfaya maritime basin area (fig. 5). Esso twice found traces of oil, in 1968 and 1972, off the Atlantic coast in the south, but later relinquished these concessions. Ten wells averaging 3,300 m in depth have been drilled in the area at a total cost of $180 million; an additional $20 million has been

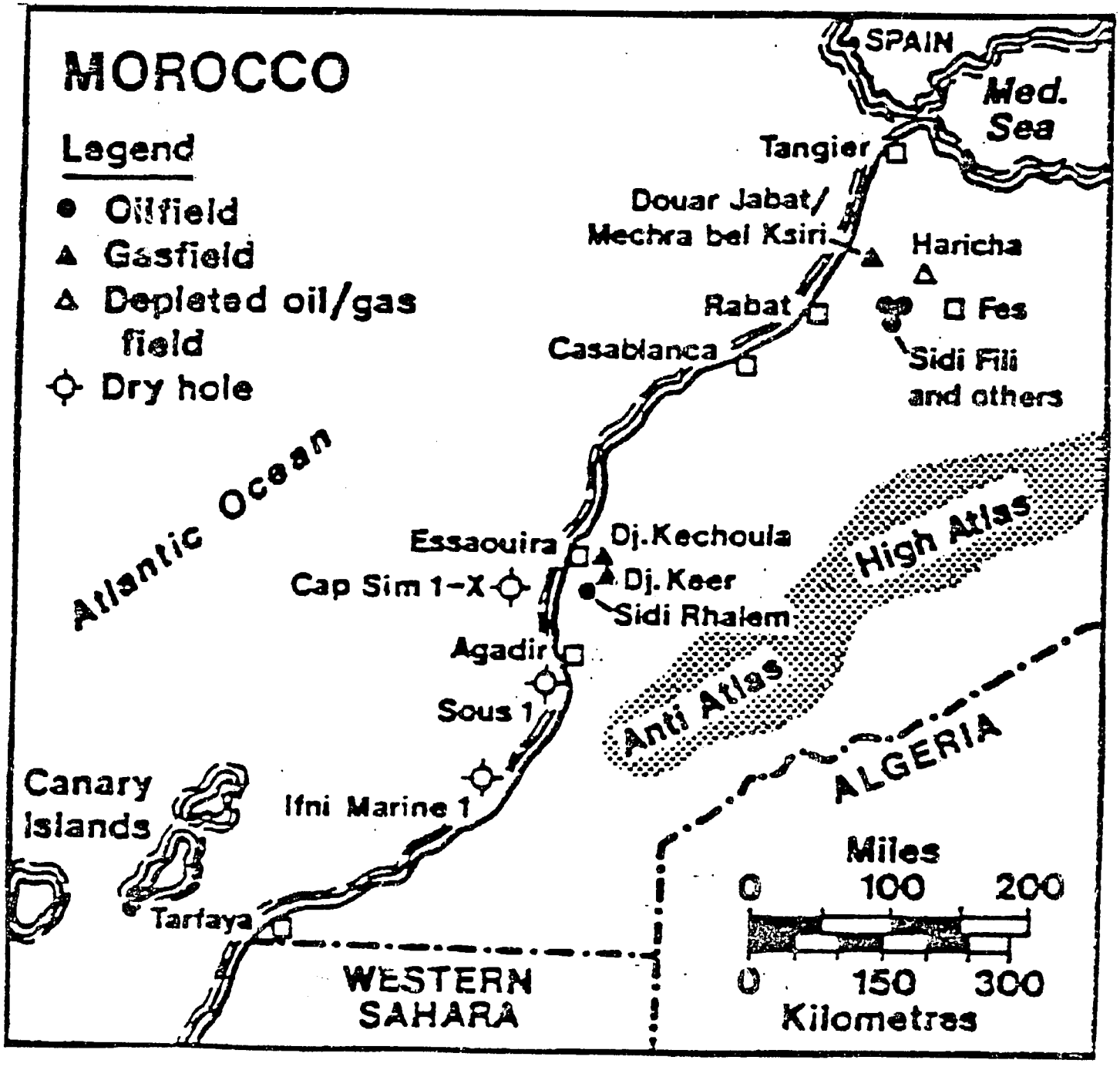


Figure 5. Oil and gas fields of Morocco (AAPG, 1980: Petroleum Economist, 1980).

spent for geological and geophysical surveys. The Esso Mouter Morl No. 1 offshore well, between the mainland and the Canary Islands, was drilled in 1968 to a total depth of 18,600 feet and flowed heavy oil; i.e., gravity less than 20° A.P.I. The well was abandoned because reservoir pressures as interpreted from production tests indicate the oil reservoir is too small to be of economic value.

In 1974, Sun Oil acquired 50 percent interest in two blocks, one being the Sous permit off the Agadir coast and the other the Ifni permit adjoining Sous to the South. The Moroccan Bureau de Recherches et de Participations Minieres (BRPM), was Sun Oil's partner. In 1976 and 1977, Sun Oil drilled two dry holes, the Ifni Marine No. 1 and the Sous No. 1 (fig. 5). As a result of these wells Sun Oil discontinued operations in Morocco.

In May 1976, Phillips, Agip (an Italian company), and Getty Oil, each with a third interest, acquired a 10,000 km^2 concession in the Essaouira basin that extended from 21 km to 120 km off the coast between Essaouira and Agadir, in water depths ranging from 600 to 6,000 feet. BRPM which retained a one-third interest was the title holder to these concessions.

Other awards followed in 1977. Phillips, British Petroleum, Getty, and Agip acquired a 4,000 km^2 permit offshore from Essaouira. In addition, Phillips and British Petroleum also lined up with BRPM to explore blocks covering 35,000 km^2 of territory off the Western Sahara between El Ayaour and Boujdour. In March 1979, Phillips drilled the Cap Sim No. 1-X, a $10-million well which was located 30 km offshore (fig. 5). This well was plugged and abandoned.

Two independent surveys have reported on offshore petroleum potential. A German research study concluded that the continental shelf and the

Canary Islands contained sediments and salt domes. However, the study pointed out that these deposits are in deep water.

In September, 1979, the U.S. National Science Foundation reported that the continental rise may contain substantial accumulations of petroleum, a conclusion based on results of drilling 144 km off the coast. Test holes were drilled by the ship Glomar Challenger in 12,000 feet of water to 5,000 feet.

Present Exploration

BRPM's current plans include a major onshore exploratory drilling program in the pre-Rif, Rharb, Doukala, and Essaouira basins, and encouragement for foreign companies to drill offshore. This exploration plan may be a bit optimistic, considering the geologic complexity of the pre-Rif and the fact that the other areas have undergone some exploration. BRPM is presently engaged in three onshore drilling activities, two in the vicinity of Essaouira on the south central coast and one in the Rharb Valley immediately north of Kenitra. BRPM also has a seismic crew operating in the Boudem area of east-central Morocco.

Four foreign oil companies currently have concessions in Morocco; they are: Phillips, Occidental, the U.S. subsidiary of Belgium's Petrofina, and Elf Aquitaine.

Phillips has terminated all exploration activity in Morocco as a result, in part, of a 13,000-foot dry hole at Guercif in northeast Morocco and unfavorable seismic evaluation of the Middle Atlas area.

Petroleum Geology

To date, about 200 exploratory wells have been drilled in Morocco, and this has resulted in discovery of only small fields which in the country's most productive year, yielded 1,140 million barrels and would produce in 1981

only an estimated 65.7 thousand barrels. Total accumulated production to July 1, 1981 was 12,554 million barrels. The discovery and production record does not augur well for new significant discoveries.

The numerous small oil and gas fields now largely depleted, are along geosynclines of the Atlas-Mountain fold belt and fore-deeps of the geosynclines, particularly along the Atlantic coast. The most productive have been the Rharb, Pre-rif, and the Essaouira (Abda Poukkala) basins.

Basins discussed below have potential as sources of oil and gas, some have been explored by drilling. Drilling is planned or is being considered for others.

Doukkala Basin.-The Doukkala basin which contains Paleozoic sediments extends over an area of 10,000 km^2. Seven wells were drilled in the basin between 1960 and 1977. Although source, reservoir, and cap rocks are present, no commercial oil has been discovered. The exploration targets are reefs of Middle Devonian age; however, these reefs may be thin and small in area.

Hauts Plateaux Basin.--The Hauts Plateaux basin, about 30,000 km^2 in area, is filled with Mesozoic sediments. Exploration during the past 17 years has yielded scant indications of hydrocarbons.

Boudnib Basin.--The Boudnib basin is located on the southern flank of the High Atlas Mountains. Only limited information about the stratigraphy and structure of the area is available. The exploration objectives are traps in Paleozoic sediments.

Deep Rif Basin.--In the area of the Rif, good shows of oil and gas were found at depths between 9000 and 10,000 feet in a BRPM test that

was drilled in 1978/79. Below these, a major fault was encountered and drilling was terminated. No tests of the zones bearing shows have been reported.

This geologic area is an intriguing one because of its complexity. Rocks of Precambrian to Quaternary age, largely continental but including marine and lagoonal types have undergone multiple occurrences of uplift, folding and thrusting. The zones most likely to be oil and gas bearing are expected to be at depths of 12,000 feet or more.

Pre Rif.--Elf Aquitaine has concessions in the pre-Rif area of northern and an additional concession offshore from Larache on Morocco's northern Atlantic coast. Elf Aquitaine plans to spend $66 million over the next three years in deep drilling (Paleozoic formations) in the pre-Rif area. In addition Elf Aquitaine plans to drill as many as 12 tests to provide information on subsurface stratigraphy and structure. The main purpose of these tests is to provide information to help interpretation of the geology below the Rif "slide-over." The complexity of the geology below the "slide over" has prevented a proper evaluation of the pre-Rif formations as a whole.

Essaouira Basin.--The Essaouira Basin includes an area of 10,000 km^2 that is partly offshore and partly onshore. The basin contains five oil and/or gas fields, all of which produce from sediments of Jurassic age. Geology of the basin is very complex; the post-Liassic stratigraphic succession is shown in figure 6. The fields are: Mt. Kechoula (gas), Mt. Keer (gas), Sidi Rhalem (oil), Ndark (gas with 50% nitrogen), and Toukimit (gas with condensate). At least a dozen structures including 8 in the pre-Jurassic strata have been drilled. Sediments older than Jurassic are known to contain gas and perhaps condensate, in fact the

discovery of gas and condensate in the well drilled in this basin by ONAREP in December 1981 is reported to be in the Triassic sedimentary sequence.

Offshore Basins.--In the Tarfaya "basin" south of the Essaouira Basin, marine Liassic sands and shales are difficult to distinguish from the overlying Dogger sands and shales. Although calcareous rocks comprise most of the Jurassic section, anhydrite is common in the lower part of the section. This 2,000 to 2,500 m-thick transgressive sequence reached it furthest shoreward advance during Late Jurassic time.

The regression which started in the late Jurassic was accompanied by deposition of red shales and sandstones in the south and east. The culmination of this regression occurred during the Early Cretaceous and is marked by the deposition of continental and littoral sandstones and variegated shales. Eary Cretaceous reefs are reported to occur beneath the northwest coast line. An unconformity is suggested with the Lower Cretaceous. The thickness of the basal Cretaceous rock section increases westward, an indication of uplift and possible erosion in the east and subsidence in the south.

The Late Cretaceous was a period of widespread transgression. The basal beds of this transgression are composed of dolomites, shales, and locally anhydrite. The upper Cretaceous attains a maximum thickness of 750 m. Cretaceous rocks are most everywhere overlain by sediments of Paleocene and Eocene age.

Prospects for hydrocarbons in the Moroccan offshore area are not encouraging because current information indicates that subsurface structures are small and reservoir and source rocks are scarce.

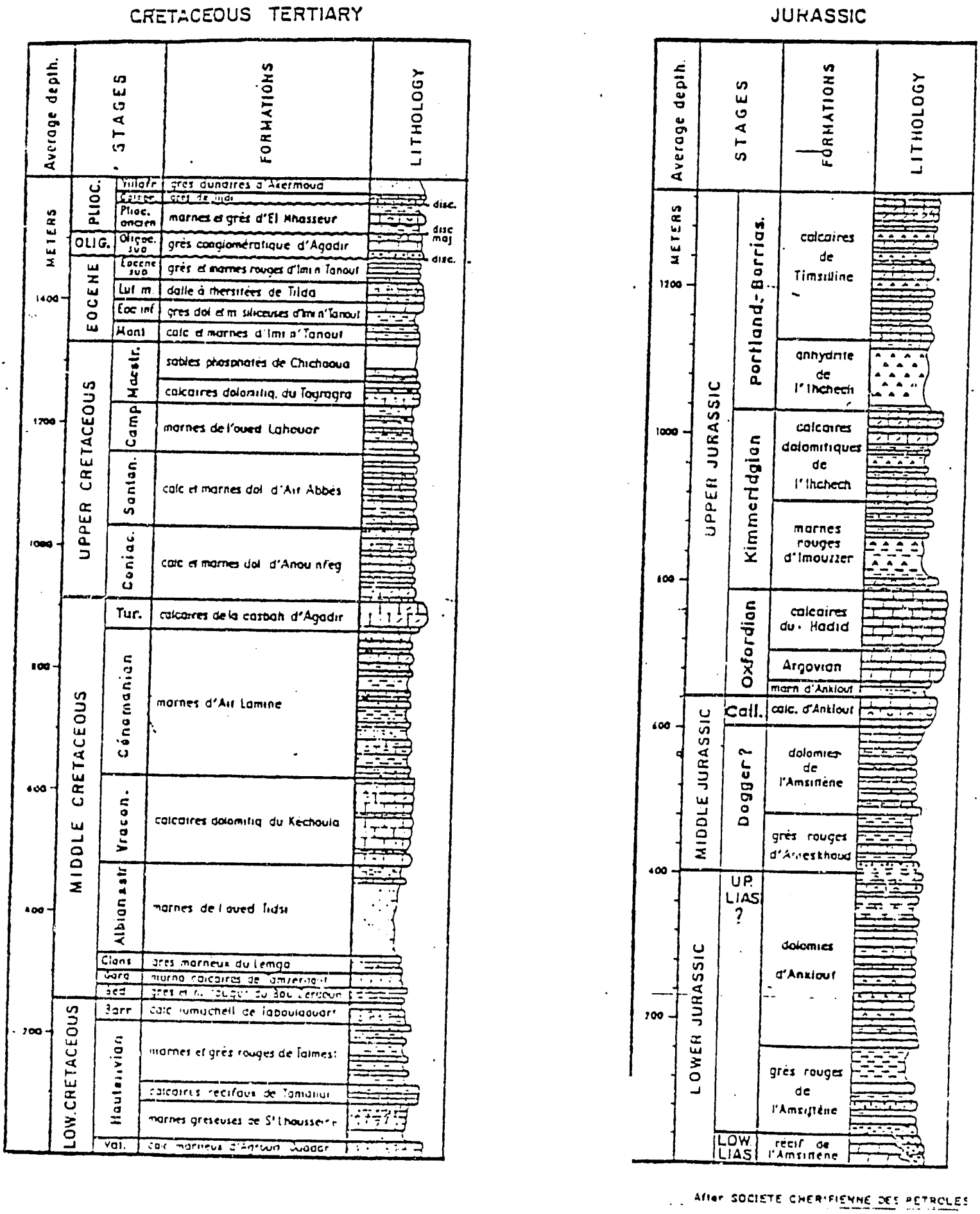


Figure 6. Stratigraphy of the Essouira Souss Basin onshore area.

Hydrocarbon prospects offshore of Morocco consist primarily of salt domes and Devonian reefs at relatively great depths. Unlike the salt-dome structures in the Gulf of Mexico outer continental shelf (OCS) where there are multi-reservoir possibilities, one or possibly two prospective reservoirs may occur in the sedimentary sequence above salt domes in the Atlantic Coast OCS of Morocco. The results of OCS off-Morocco drilling by Esso and the Phillips group indicate that the potential reservoirs are small and are the result of complex structural deformation.

Phillips, as operator for the Phillips/Getty/AGIP/ British Petroleum group, has drilled two offshore wells at a cost of $10 million a well. The objective of both wells was a Devonian reef. Both wells were dry with minor oil shows. The second well was drilled between patch reefs exposed onshore and an outer reef barrier that was encountered by the first Phillips OCS well. The rationale of the exploration was based on oil industry investigations in the areas of the Great Barrier Reef of Australia which revealed an intermediate smaller oil-bearing reef inshore, from the barrier reef. Unfortunately, distribution pattern of the Great Barrier Reef has not proven applicable to offshore Morocco.

Conclusions

1) Exploration in the Essaouira area, Southwest Morroco has the greatest possibilities of finding hydrocarbons; deep exploration in the Rif basin probably has marginal possibilities for success.

2) Based on information from previous exploration, shallow Jurassic sediments do not contain reserves in quantities sufficient to justify exploration costs.

3) Pre-Jurassic prospects will most likely yield natural dry gas, yields of oil or condensate-rich gas are possible.

Coal

Research and investment to encourage developments in coal production, principally in the Jerada region, have been continuous since 1929. The production of coal, 710,000 metric tons in 1979, is expected to reach 1 million tons in 1981 with a projected tonnage of 1.5 million by 1984/85.

Approximately 80 percent of total production is used domestically, mostly as fuel in the thermal electric power plant at Jerada.

Anthracite deposits at Jerada are the principle coal resources in Morocco (fig. 7). Coal is known at many localities, but other economic deposits have not been discovered. The Jerada mine has proved coal reserves of about 20 million tons and probable reserves of 36 million tons. The coal has a relatively high calorific value--6,600 to 7,000 kcal/kg, and low ash--4 to 5 percent.

Coal Geology

Most anthracite in Morocco is in beds of Carboniferous age; lesser amounts are found in older Varician folded zones. The Sahara region may contain coal beds, but the region has not been fully explored. Minor amounts of Permian to Pliocene brown coal or lignite are reported to occur at several isolated localities. (fig. 7).

Jerada area.--The anthracite near Jerada occurs in a 9 X 25 km area where it is exposed in a faulted east-trending syncline. The coal-bearing strata, averaging 750 m thick and unconformably overlying a marine sequence of lower Westphalian age, (Carboniferous) have been subdivided into (from top to bottom):

1. The Jerada Formation, 250 m thick, that contains the five coal beds now being mined. The coal beds range from 0.4 to 0.75 m in thickness and aggregate 2.5 m thick.

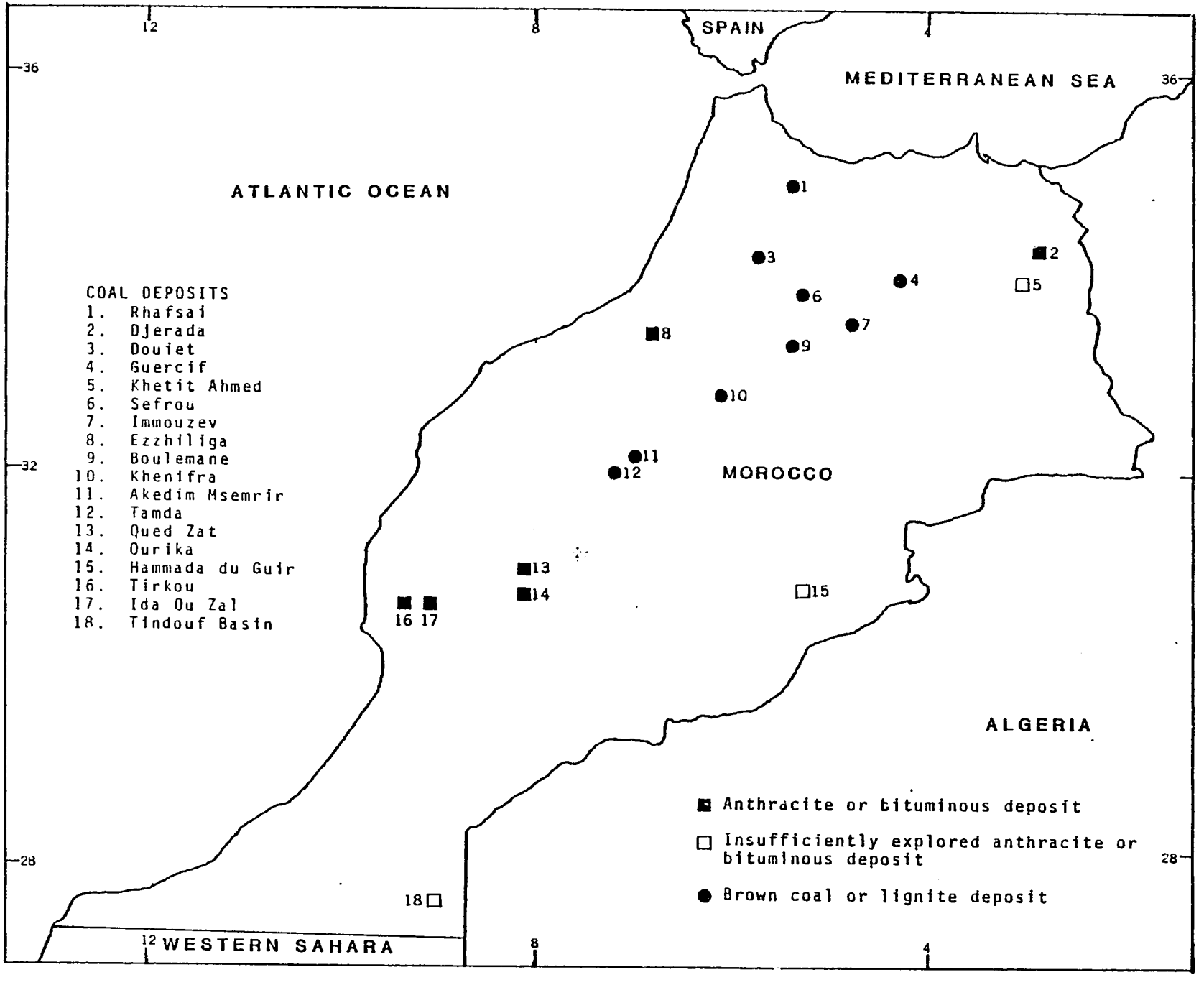


Figure 7. Coal deposits of Morocco

2. The Jebl Checkhar Formation, 100 to 250 m thick, that contains one coal bed too thin for exploitation.

3. The Sidi Brahim Formation, ranging from 280 to 360 m in thickness; the upper 100 to 180 m includes three coal beds too thin or discontinuous for mining; the lower 180 m contains a coal bed of minable thickness, but it has not yet been evaluated.

Other anthracite areas.--Anthracite-bearing rocks of Carboniferous age are known at Ezzhiliga, Oued Zat, Ourika, Tirkou, and Ida Ou Zal (fig. 7). The coal beds in each area are considered to be too thin for mining. Coal deposits of Carboniferous age are shown on maps in the Khetit Ahmed area some 65 km southwest of Jerada (fig. 7), but no characteristics of the occurrences are given. The coal-bearing strata are at some unspecified depth; the surface rocks in the area are considered to be Mesozoic in age. The unexplored coal deposits at Hammada du Guir and in the Tindouf basin (fig. 7) are based on extension of the known coal-bearing Carboniferous aged strata in Algeria. Potential of the two areas can only be hypothesized until exploration is done.

Brown coal or lignite areas.--Beds of brown coal or lignite in the nine areas shown on figure 7 are thin and lenticular and have been of no economic interest. However, Jolly (1981) reports that 44.5 million tons of lignite were discovered during exploration by BRPM in 1977 at Oued Nja (about 25 km north of Sefrou) (fig. 7), but no indication of the economic value was given.

Oil Shale

Geology

Oil shale in Morocco occurs in three areas:

1. In the Rif Mountains south of Tangier.
2. In the Middle Atlas Mountains at Timahdit and near Beni Mellal about 150 km to the southwest.
3. Near the Atlantic coast east of Tarfaya near the southern border of the country.

Oil shale in the Rif Mountain area occurs in the Tangier shales that extend over an area of 400 km^2. The oil shale occurs in allochthonous Cretaceous formations. The shale has a total workable thickness of 23 m and contains 8.6-13 percent oil.

In the Middle Atlas Mountains oil occurs in bituminous marl which underlies the surface at Timahdit, 62 km southeast of Rabat. The deposit is 140 m thick and is Late Cretaceous (Senonian and Maestrichtian) in age. These oil-bearing deposits are cut by a thrust and related high-angle faults. The high-angle faults have a reported displacement of about 90 m. Between 600 to 800 million barrels of oil are estimated to be recoverable from 1.2 billion tons of marl; this amounts to 15 to 26 gallons per ton of shale. About 93 percent of Morocco's shale oil reserves are in this area.

Near Tarfaya, oil shale is interbedded with bituminous limestone and occurs in the Arhabarla Limestone Formation of Late Cretaceous (Senomian) age. The deposits are poorly exposed over an area of 1550 km^2. The bituminous sequence consists of 3-m thick beds of marly argillaceous limestone and intercalations of black shale. These deposits yield 6 percent oil, equivalent to 50 to 80 liters of oil per ton. Direct combustion of these low grade deposits is being considered for generating electric power.

Oil Shale Development Plans

The Moroccan government has announced its intention to develop the country's oil shale reserves. Current plans envisage only a limited exploitation of these reserves. A shale oil production of 50,000 bbl/d has been projected for the late 1980's. Even this relatively small-scale project if realized, could supply a large part of Morocco's future energy requirements; current requirements are only about 80,000 bbl/d. The government apparently allocated funds to be expended at a rate of $185 million per year for the next five years to finance a program to develop shale oil production. The amount allocated would appear to represent only part of the cost of the program, but it would represent close to 5 percent of the annual budget of the government. In late 1979 the government gave priority for immediately implementing construction of a shale-oil-fired-direct-combustion-generating facility at Timahdit. Initially, the facility is to generate 250 megawatts and ultimately, 1,000 megawatts. The capacity of the facility will be 2,500 tons of shale per day. Considerations to develop an in-situ process at Timahdit have been abandoned, and a surface retorting system for which the design is still to be selected, is expected to follow completion of the direct combustion unit. The retort system is to be the primary system for oil recovery. The surface retort was selected because it will be able to use the same mining and mineral feed systems as the power generating unit while the retort is still in the planning and test application stages. The in situ method is still experimental, particularly as it applies to distillation of Moroccan oil shale.

Also Moroccan energy officials from BRPM have expressed interest in the so called "NTU" process which was developed during the late forties and early fifties. This is a labor intensive, batch-processing method and is outmoded

in the opinion of many knowledgeable of oil shale technology. However, this method could provide important socioeconomic benefits if used collaterally with other oil shale processes.

Since 1975 the Moroccan government has carried out field studies, feasibility studies, and experiments on oil shale extraction, direct burning for power plants, and oil distillation from shale in surface retorts and in-situ. Industrial methods have been evaluated under contracts with process holders such as Tosco, Union Oil of California, Paraho, Klockner, Lurgi, Babcock, Occidental, and Neftechnimpormekport.

To implement development of its oil shale deposits, the Moroccan government has engaged Science Applications Inc. (SAI) of Golden, Colorado to plan, develop, and design a full-scale commercial shale oil production industry. The industry is to be developed in stages, under three contracts totalling $3.7 million. The ultimate aim of this plan is to achieve energy self-sufficiency, (current energy requirements are estimated as equivalent to 150,000 bbl/d of oil) by 1990-95. Total investment for the proposed oil-shale development program has been estimated by the World Bank as $3.5 billion. The government of Morocco is confident of obtaining substantial financing.

SAI is proceeding immediately to install the "T3" process (name derived from the intials of (Timahbit, Tangier, and Tarafays) for its upgraded version of the modified NTU process. The goal is to produce 7,000 bbl/d of shale oil by 1986/87. Production capacity of the retort will be 80 tons of shale oil. A loan of $240 million to finance this first stage has been authorized by the World Bank.

Under terms of the first contract SAI is now making a 27-month feasibility study to obtain data needed for designing a commercial plant. SAI's second

contract calls for preparation of a detailed plan outlining steps to be taken from installing an operating shale oil industry by 1995. SAI's third contract involves study of Morocco's total energy resources and its energy needs until the year 2000. At present, only the frist contract has been signed and implemented. Details and terms of the other two contracts are yet to be negotiated.

The actual quantity and quality of shale-oil reserves are currently being re-evaluated by SAI. The results of this study will help determine whether surface retorts or in-situ combustion would be the most efficient method to exploit oil shale deposits.

Current Status of Oil Shale Development

ONE.--ONE's ultimate goal is to produce 1,000 MW of electric power. ONE has investigated the use of pulverized oil shale to be fired in a specially designed steam generator. The process is based on Russian and German experience derived from burning pulvarized low-grade coal. A 1,000-ton sample of Timahdite oil shale was tested during 1976-1977 in a commercial steam generator by Deutche-Babcock.

ONE plans to have an oil-shale-fired power plant operational by 1985 and to decide by 1987 whether expansion of this power plant is feasible.

The Germans and Russians shortly will have the results of their technical and economic study concerning all aspects of constructing and operating an electric power station at Timhadite. These studies will be used by the Ministry of Energy and Mines in deciding whether to start construction of the station. The price that ONE will be charged for the shale oil will be a decisive factor in success of the projection.

As ONE's needs are for finely pulverized oil shale for steam generating, or, alternately a fluidized-bed combustion technique, it is essential that ONE's technical personnel be kept current of developments in plant design and combustion techniques. This is especially true inasmuchas pulverized oil shale and fluidized combustion, as applied to oil shale, are essentially new. As yet there has been limited application from which to draw experience.

BRPM.--BRPM's goal is to produce 50,000 bbl/d of synthetic crude oil (syncrude) suited for processing in the existing refinery at Mohammedia. BRPM's immediate plan is to construct and operate a retort processing plant. BRPM expects to have its demonstration retort operational by late 1983; and to decide at a later date whether to expand the facility.

BRPM is developing a new retorting process called "T3" after the initals of Morocco's three oil shale deposits at Timahdite, Tarfaya, and Tangier. The "T3" process consists of two retorts designed to increase the capacity of each individual retort and to recover all residual carbon. Fine particles below 13mm (.5 inch) are fed into "T3" retorts. Pulverized oil shale will be necessary for firing into a specially designed steam generator. SAI discussed their current feasability study with TSRPM and World Bank officials. Indications are that the World Bank will grant a loan for the construction of a "T3" pilot plant.

Analogy to Colorado Oil Shale

The Rangely oil shale project in Northwest Colorado has often been referred to as analogous to the Timahdite oil shale site in Morocco.

The Rio Blanco Oil Shale Co. (a partnership owned by Gulf Oil Corp. and Standard Oil Co., Ind.) has recently completed the results of its pilot test conducted during October 13 to December 31, 1980. During this period Rio

Blanco produced 1,750 barrels of shale oil. For the spring of 1981, Rio Blanco has a production target of 17,000 to 25,000 barrels of shale oil. Production from a 50,000-bbl/d plant, to be built at the site, probably will not begin before 1987. However, construction would begin before 1987.

This first in-situ process demonstration is to be followed by a larger test burn in a 400 foot high by 60 foot square retort this spring. The retort is an underground cubicle containing oil shale that has been fractured by blasting. The first retort was 166 feet high by 30 feet square and yielded 1,040 barrels of shale oil in tanks and 710 barrels of oil equivalent in vapor. This modified in situ (MIS) process involves mining about 30% of the planned retort volume of oil shale then transporting it to the surface. The oil shale left in the retort is rubberized. The retort then is ignited with a mixture of natural gas and air.

Rio Blanco will probably not decide before 1984 whether to commercialize further oil shale development by open pit mining or by the in situ process which would produce 2,000 bbl/d of oil from 4,400 tons/day of shale.

OBSERVATIONS AND RECOMMENDATIONS

Petroleum

Many reports and maps have been published on the geology of Morocco including those in French and the few articles in English, but these are not orientated toward petroleum exploration. Isopach maps of specific reservoirs have not been made nor has information on source beds been obtained. Isopach maps have been compiled for geologic time periods, but these have only limited value for petroleum exploration. The French based most of their studies of stratigraphic units on seismic time velocities and fossils with little or no consideration given to lithology. Little has been done to relate seismic

time to rock type as can be done with core samples obtained from drilled wells. Essentially no study has been made to relate the stratigraphy of one basin to another. All existing studies pertain to isolated parts of different basins.

Moroccan government officials are strongly convinced that it has attractive, although not large, petroleum reservoirs. The Moroccan petroleum sector is now supported by a $50 million World Bank loan that is being used in exploratory drilling for oil and gas. However, little funding and effort is being used to systematize existing geological information specifically for the purpose of encouraging petroleum exploration. The usual petroleum exploration practice is to conduct regional petroleum geology studies that include stratigraphic and structural interpretation to identify possible hydrocarbon source and reservoir rocks, and suitable structural and stratigrphic traps for hydrocarbons. In addition the presence of suitable sealing ("cap") rock must be identified. Under a well-designed exploration program, geological investigations should precede the drilling program, however, this has not usually been the case in Morocco. The consequence has been that the optimum drilling site has not in all cases been selected.

The numerous oil and gas shows reported in almost all wells drilled in Morocco may be the result of misinterpretation of excessive additives in mud used during drilling. Organic matter in the mud additives is reflected as "hydrocarbons" on the logging instruments.

A program of technical assistance is recommended to systematize all geologic, seismic, exploration, and production information on the petroleum resources of Morocco with the objective to evaluate and delineate localities that may have potential for the discovery of additional production.

Concomitantly with this assistance program, a training program in geologic and seismic interpretation and exploration and production techniques

might be presented to Moroccans through a series of seminars such as those planned in Ecuador in the near future.

Coal

Coal, both anthracite and lignite or brown coal is known at many localities in Morocco. However, only at Jerada have mines been developed in the anthracite; exploration at some areas of anthracite occurrence indicate that beds are too thin to mine. Three areas that have potential for anthracite beds remain essentially unexplored.

Even though the discovery of 44.5 million tons of lignite was reported in the Oued Nja area, little is known about the many lignite areas. Most reports refer to the lignite beds as being thin, lenticular, and of no economic interest.

A program of technical assistance to collect, synthesize, and evaluate all available data on anthracite and lignite characteristics and occurrences is recommended with the objective to study the feasibility of utilizing coal for fuel in thermal power plants in Morocco.

Also a program of exploration should be undertaken in the Khetit Ahmed area, the Hammada du Guir area and the Tindouf basin to verify the existence of anthracite and evaluate its potential.

Oil Shale

Processes to extract oil from bituminous rocks in Morocco have not yet been developed to the commercially economic stage, as is the case even for the relatively high-grade deposits in the United States. Various processing methods are being considered by the Moroccan sector and with the development of a successful technique and with dedicated management, the oil shales of Morocco may ultimately be developed. Technical assistance to develop

processes is not recommended; rather, a program of collection and synthesis of basic geologic and analytical data might be supported. Additionally, some assistance in the technical training of Moroccan personnel in various aspects of oil shale exploration might be undertaken.

Little mention is made of by-product (nahcolite, alumina, soda ash, etc.) recovery with the shale oil. Such products if recoverable can improve the economics of shale oil production. Analytical studies are suggested for determining costs and income of recovery of by-products.

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