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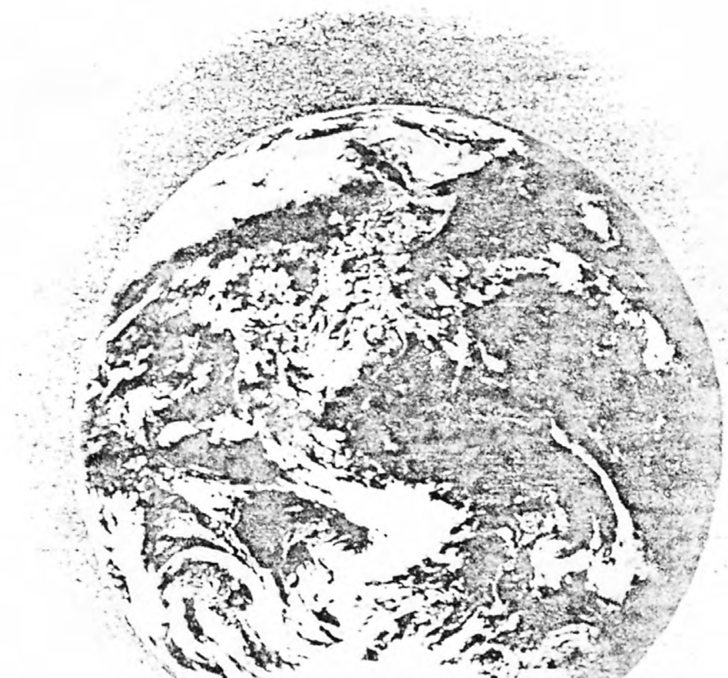
SUMMARY OF DATA AVAILABLE FOR MOROCCO

as of June 10, 1977



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1980

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CONTENTS

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GEOLOGIC FRAMEWORK

Geologic provinces and formations

Structurally, Morocco is partly European (Alpine and Hercynian) and partly the northwestern flank of the African platform. 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 of Precambrian and lower Paleozoic rocks, which uphold the Anti-Atlas on the south and the Meseta region on the north. These areas were folded, metamorphosed, and intruded during the mid-Paleozoic Hercynian orogeny.

The northern peninsula facing Gibraltar encompasses the Rif Atlas, where the beds are Mesozoic or younger with the exception of a small inlier of ultramafic and metamorphic rocks which may be Precambrian. These beds crop out in overlapping nappes that represent a western extension of the Alpine orogeny of Europe, the youngest orogenic event in Morocco. 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 depressed to 10,000 meters below sea level, and which forms the southernmost structural element north of

Mauritania. Still farther south into the former Spanish Sahara, along the Atlantic coast, Cretaceous and Tertiary beds dip toward the sea, off lenses of Silurian and Devonian, which in turn lie on a 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. A fault, called the south Atlas line or Agadir fault, extends northeastward at the southern base of the High Atlas; it is considered by many authors to be a transform fault that has exercised structural control during several epochs. However, it is only one of several northeast (Mediterranean)-trending parallel lineations; a conjugate set of faults inferred partly on geophysical evidence parallels the Atlantic coast. A series of horsts and grabens appears to have two predominant structural orientations; those nearest the Atlantic parallel the Atlantic coast, and those in eastern Morocco parallel the Mediterranean shore. Some grabens are partly filled with salt and other evaporites; these evaporites are like deposits of the Red Sea, 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 folding farther north.

Molasse-type basins flank the High Atlas on the south, beginning with the Souss plain at Agadir on the Atlantic coast and extending intermittently to the northeast to the Sillon and pre-African lowlands. Similar basins flank the north side of the High and Middle Atlas mountains.

Casablanca and Rabat are on the seaward side of a Tertiary and Quaternary lowland; these lowland regions are the most densely populated areas and are the sites of most of Moroccan agriculture.

Stratigraphy

Precambrian rocks are exposed in limited areas, mostly as structures 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. Youngest Precambrian or lower Infracambrian beds cropping out along the northern edge of the Anti-Atlas are of special interest because of their volcanic rocks, which include rhyolite, ignimbrite, and andesite; flows of similar age elsewhere are known to be related to ore deposits.

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 are mostly clastic but include some calcareous strata in the Cambrian.

Permo-Triassic sandstone, conglomerate, and red argillite crop out below Jurassic dolomite and limestone in the northern Atlas and Meseta. Cretaceous and lower Tertiary beds, including phosphorite, extend along western Morocco into the Spanish Sahara. Neogene beds in terraces are elevated by tilting along the northern coast in a manner similar to elevation of terraces along the northern coasts of the Red Sea.

Igneous rocks

Beside the Precambrian plutonic and metamorphic rocks, Hercynian granites crop out in 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.

MAPS

Geologic maps.--Mapping for economic purposes supposedly at a scale of 1:100,000 or larger was expected to be complete in 1977 1/, according to the U.S. Bureau of Mines. The country has been covered by geologic mapping at a scale of 1:500,000 2/ and most of it at 1:200,000 3/ scale: maps at a scale of 1:100,000 extend down to 29°30' N., and many areas are covered at 1:50,000 scale. The last seem somewhat uneven. The former Spanish Morocco is covered by a set of 14 sheets at 1:50,000 and 1:400,000 scale (1952) which may need review. Sheet 6, of the World Geological Atlas 4/, at 1:10,000,000 scale, published in Sydney, is good but difficult to read.

Structural maps.--A 1:2 million-scale map 5/, published in 1975, is the best source for the northern provinces. Sheet 13 of the new metamorphic map of Europe 6/, scale 1:2,500,000 (1973), and the tectonic map of Africa 7/, scale 1:5,000,000 (1968), are not as clear as the 1:15,000,000-scale tectonic map 8/ of 1968.

Former Spanish Sahara.--Geology at 1:500,000 scale, 1971 9/, seems to be at least partly a copy of Medina's map of 1952 10/ (scale 1:2,000,000 and Medina, Viña, and Cabezón's map of 1958 11/ (scale 1:500,000).

Most of the country has been mapped several times at different scales, except former Spanish Sahara. It probably has also been covered by aerial photography at about 1:50,000 scale.

1/ 1964-1977, Carte Géologique du Maroc: Morocco, Ministère du Commerce, de l'Industrie des Mines, et la Marine Marchande; Direction des Mines, de la Géologie de l'Energie; Division de la Géologie, Editions du Service Géologique du Maroc-Notes et Mémoirs, scale 1:100,000.

2/ 1946-1959, Carte Géologique du Maroc: Morocco Direction des Mines et de la Géologie, Service Géologique, scale 1:500,000.

3/ 1932-1971, Carte Géologique du Maroc: Morocco Direction des Mines et de la Géologie, Service Géologique, scale 1:200,000.

4/ 1975, Atlas Géologique du Monde: UNESCO Commission for the Geologic Map of the World, sheet 6, scale 1:10,000,000.

5/ 1975, Carte Structurale du Maroc (Provinces du Nord): Morocco Direction des Mines et de la Géologie, Division de la Géologie, scale 1:2,000,000

6/ 1973, Metamorphic map of Europe, sheet 13: UNESCO Subcommission for the Cartography of the Metamorphic Belts of the World (Commission for the Geological Map of the World), scale 1:2,500,000.

7/ 1968, Carte Tectonique de l'Afrique: Assoc. African Geological Surveys and UNESCO, scale 1:5,000,000.

8/ 1968, Carte Tectonique de l'Afrique: Assoc. African Geological Surveys and UNESCO, Commission for the Geological Map of the World, scale 1:15,000,000.

9/ Ratschiller, L. K., 1970-71, Spanish Sahara (Northern) Geology: Geological Institute of University of Trieste, vol. XVIII, Fasc. 1, scale 1:500,000.

10/ Medina, Manuel, 1952, Bosquejo Geológico del Sáhara Español: Madrid, Instituto Geológico y Minero de España, scale 1:2,000,000.

11/ Medina, Alfonso de Alvarado, Viña, José de la, and Cabezón, Carlos Muñoz, 1958, Mapa Geologico del Sahara Español y Zonas Limítrofes: Madrid, Instituto Geológico y Minero de España, scale scale 1:500,000.

Landsat image analysis.--Standard color composites of Landsat imagery probably need computer-enhancement. If possible, imagery should be enhanced by using methods devised by George Harris, Jr., and colleagues at Sioux Falls, S. D., which incorporate a laser film recorder. Digital enhancement using ramp stretch and ratio stretch, as developed by L. C. Rowan, H. W. Blodget, and others, of selected areas of potential mineralization or extension of known mineralization should be tried, especially in Anti-Atlas. The grabens where salt has been found should be tested by Landsat imagery for mineralization originating from sea-floor spreading.

Principal references

In addition to the maps mentioned above, see the following:

1. Ager, D. V., 1974, The Western High Atlas of Morocco and their significance in the history of the North Atlantic: Geol. Assoc. London Proc., v. 85, no. 1, p. 23-41.
2. Spain, Instituto Geológico y Minero, 1969, Stratigraphic correlations of borings in the Spanish Sahara: Spain Inst. Geol. y Minero, Bol. Geol. Minero, v. 80, no. 3, p. 235-251 (including English summary and Dutch map).
3. Blodget, H. W., and Anderson, A. T., 1973, A comparison of Gemini and ERTS imagery obtained over southern Morocco, in Symposium on significant results obtained from ERTS: U.S. Natl. Aeronautics and Space Admin. Spec. Pub. 327, p. 265-272, illus., sketch map.
4. Brückner, W. D., and others, 1975, Facies comparison of late Proterozoic-early Paleozoic rock units in southeast Newfoundland and southwest Morocco (abt.): Geol. Soc. America Abs. with programs, v. 7, no. 1. p. 32-33.

5. Choubert, G., and Faure-Muret, A., 1970, International Colloquim on Precambrian correlation, Agadir, Rabat, May 3-23, 1970, excursion guide, western and central Anti-Atlas: Morocco, Service Géol. Notes and Mém. no. 229, 243 p., geol. maps.

6. Choubert, G., 1972, Correlation of the Precambrian: France Centre National de la Recherche Scientifique in collaboration with Morocco Service Géologique, France Centre Nat. Recherche Sci. Colloques Internat., no. 192, 389 pages. Also Morocco, Service Geol. Notes and Mém., no. 236.

7. Kanes, W. H., and others, 1973, Moroccan crustal response to continental drift: Science, V. 180, p. 950-953.

8. Le Pichon, X., Sibuet, J. C., and Francheteau, Jean, 1977, The fit of the continents around the north Atlatnic ocean: Tectonophysics, v. 38, p. 169-209.

9. Michard, Andre, 1976, Elements de geologie Morocaine: Morocco Direction Mines and Géol., Service Géol., Notesand Mém. no. 252, 408 p.

10. Morocco Direction de Mines, de la Géologie, et de l'Energie, 1977, Catalogue des Publications de la Direction de Mines de la Géologie et de l'Energie: Morocco Div. Geol., Editions, Rabat, Morocco, 130 p.

11. 242 citations on Moroccan stratigraphy and structural geology in GeoRef*, mostly published in the last 8 years.

*GeoRef is a computerized bibliographic data base maintained by the American Geological Institute, Falls Church, Va.

MINERAL RESOURCES**

The principal known deposits are the phosphate sources of the Khouriba complex, Youssoufia, Ben Guerir, Sidi Hajjaj, and Meskala, in Upper Cretaceous and lower Tertiary sedimentary rocks similar to the deposits in Egypt and Jordan. The Bon Kraa deposit in former Spanish Sahara is 60 kilometers from the Atlantic coast, and like the Meseta deposits farther north, younger sediments dip toward the sea. Some phosphatic alluvium from the older deposits has been reported offshore but has not been mined. The Moroccan phosphate deposits, with those of Bon Kraa, constitute the world's largest known reserve of minable ore, estimated at 35 percent of the total at $8.00 per ton, 47 percent at $12.00 per ton, and 43 percent at $20.00 per ton. 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, iron ore pellets, and fluorspar, besides phosphate rock. Most of the copper prospects are scattered along the north side of the Anti-Atlas, the largest mine being at Bou Skour, but prospects and small mines extend throughout the Meseta region. Manganese occurs in the same region with the Imini mine 100 kilometers west of Bou Skour. Silver is a byproduct of lead-zinc ore from Touessit near Algeria. Aouli and Zeida are large producers

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**Most data in this section are from the U.S. Bureau of Mines commodity reports and Agard, J., and others, 1962, Carte metallogenique du Maroc: [Rabat], Morocco Direction des Mines et de la Geologie, 3 sheets, scale 1:2,000,000.

of lead and zinc. Iron ore pellets are produced in eastern Rif and shipped to Algiers and Europe. Fluorspar comes from central Meseta. Smaller productions include nickel, cobalt, antimony, and barite.

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.

ENERGY RESOURCES*

Oil and gas fields are being depleted; in 1976, Alem** estimated production to be 400 barrels per day and 6,500 thousand cubic feet of gas per day. A large oil play in Spanish Sahara produced no oil or gas during 1960-1970, and offshore drilling has produced no prospects. The oil-bearing sediments farther south seem to be missing in offshore Morocco. The only exception is one producing wildcat well in the Essaourisa coastal Mesozoic basin, where an oil and gas pay in the Upper Jurassic is now being tested. Some oil shale may become commercial. Uranium deposits seem limited to beach sands--monazite and related minerals of uranium, thorium, rare earths, and magnetite.

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*Most information in this section comes from U.S. Bureau of Mines commodity reports and the American Association of Petroleum Geologists Bulletin.

**Alem, Amid, 1976, Morocco: American Association of Petroleum Geologists Bulletin, v. 60, no. 10, p. 1771.

One coal mine at Jerada near Algeria produced 574,000 tons of anthracite coal during 1974.

Hydroelectric power from runoff of the High Atlas may produce some energy, but I have found no reference to it as a potential source.

The possibility exists that low-grade uranium ore associated with the phosphate may be produced as a byproduct when the phosphate is mined and washed; however, there are no figures about the grade--only a report that some uranium is associated with the phosphate. Ordinarily, uranium in phosphates is concentrated to only about one-tenth the grade needed for commercial exploitation, but it is now a byproduct in Florida.

The younger granites, especially Hercynian where the chemistry is peralkaline, should be examined for rare earths, columbium, 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 or are associated with ore-bearing pegmatites.