MOROCCO

Geography

Morocco is situated in north-west Africa, bordering both the Atlantic Ocean and the Mediterranean Sea and lying between Algeria and Mauritania A large part of Morocco is mountainous. The Rif Mountains occupy the region bordering the Mediterranean from the north-west to the north-east. The Atlas Mountains form the backbone of the country, extending from near Agadir to the north-east. They also host the highest point in the country (Mount Toubkal (4165 m)), which is also the highest point in North Africa.

Most of the south-eastern portion of the country forms part of the Sahara Desert and as such is sparsely populated and economically unproductive. The population primarily lives to the north of the mountainous areas; the desert lies to the south. The coastal climate is Mediterranean, becoming more extreme towards the interior mountainous regions.

The south-western portion of Morocco is sparsely populated and consists mainly of desert flatlands. Aside from its rich phosphate deposits and fishing resources, this area has few natural resources and lacks sufficient rainfall for most agricultural activities. The economy is sustained by nomadic herding, fishing and phosphate mining [1].

Morocco's agricultural production consists of oranges, tomatoes, potatoes, olives and olive oil. The largest industry is phosphate mining. Morocco is the second largest producer of phosphate in the world after China (33 M tonnes in 2018). It is also the largest silver producer in Africa. Its second largest source of income is from nationals living abroad who repatriate money to relatives living in Morocco. The country's third largest source of revenue is tourism: 12.3 million tourists visited the country in 2018 [1].

Geology

The geology of Morocco is extremely varied with numerous geological units and tectonic features ranging from Precambrian to Quaternary in age (Figure 1). Morocco is part of the African Plate and the Atlas Mountain Range is one of the largest intracontinental belts in the world. The igneous rocks include important granite massifs of different ages, basic and ultrabasic rocks, alkaline intrusives and several lava sequences. Tectonically, most of the Precambrian orogenies, as well as the Caledonian, Hercynian and Alpine Orogenies, are in evidence to varying degrees of intensity.

Three principal structural regions, separated by large tectonic uplifts and depressions, may be distinguished from south to north:

(i) The Anti-Atlas region is in part a continuation of the West African Precambrian Shield. It is partially covered in the north and south by Palaeozoic sediments and to the east by more recent rock units. The latest important orogeny in this region is of Hercynian age. However, this event took place without general metamorphism or granitization; only dykes and sills of dioritic and doleritic compositions were intruded;
(ii) The Atlas region consists of a folded Palaeozoic zone, which has been locally metamorphosed and granitized as a result of the Caledonian and Hercynian Orogenies and where the Mesozoic cover has been folded by both pre-Cretaceous and Alpine tectonic events. Gabbros, diorites and alkaline igneous activity resulted from these pre-Cretaceous and Alpine activities. Some of the Hercynian granites are considered to have uranium potential;
(iii) The Rif region principally consists of Mesozoic and Tertiary sediments derived from a northern source and deposited in a geosyncline and subsequently subjected to Alpine tectonics. An older Palaeozoic belt of ultrabasic rocks, surrounded by metamorphic facies, crops out in the northern part of the Rif region [2, 3].

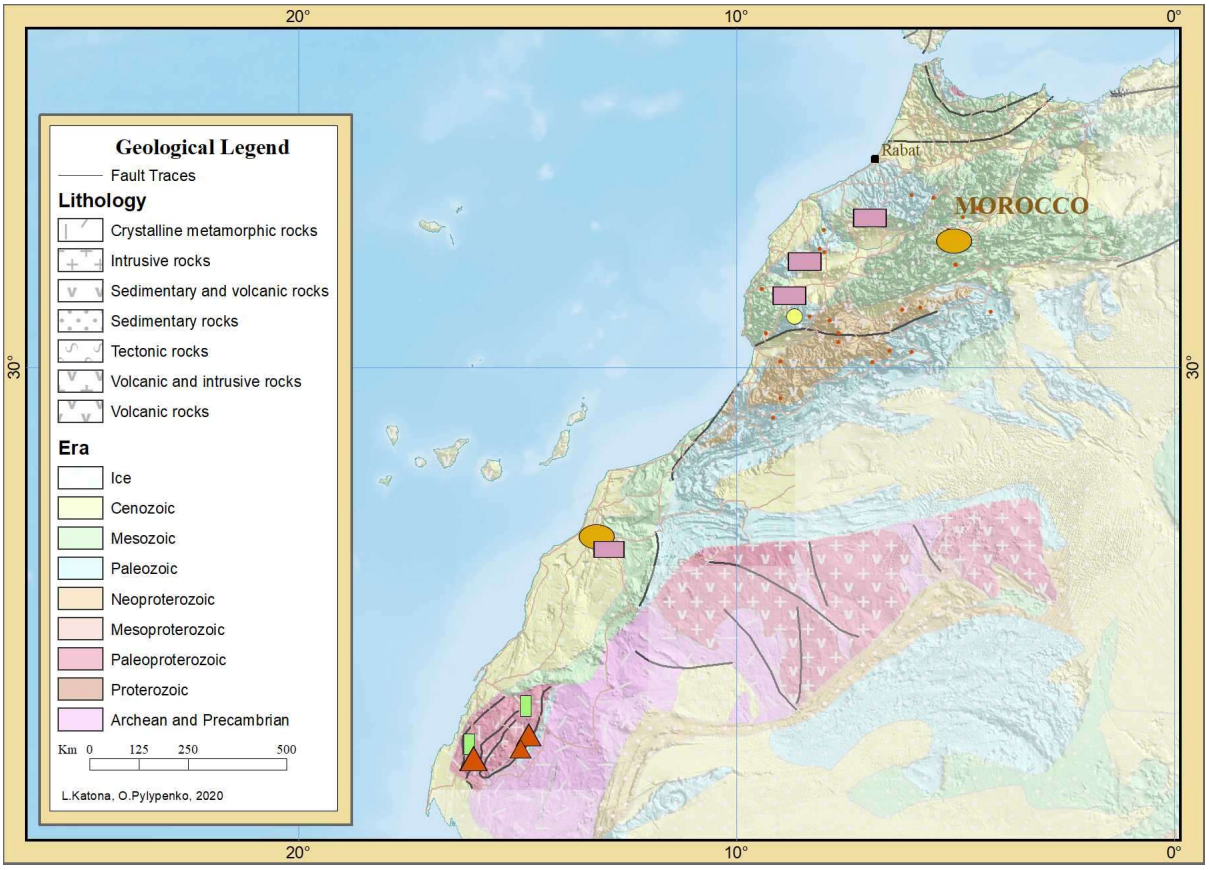

FIG. 1. Regional geological setting of Morocco showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see World Uranium Geology, Exploration, Resources and Production, IAEA, 2020. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Uranium exploration

Uranium exploration was first undertaken in Morocco in 1946. In 1946–1953, uranium exploration was carried out by France's Atomic Energy Commission (CEA) in collaboration with Morocco's Mining Research and Investment Office (BRPM). A joint Moroccan–French company, Société Marocaine de Recherches et d'Etudes Minières carried on exploration in 1953–1956. In 1970, a radiometric reconnaissance survey covering 1800 km² was conducted jointly by the United Nations and the BRPM.

After 1974, the BRPM increased its efforts. Two areas were selected for further study. A reconnaissance programme was conducted over the Permo-Triassic of the Haute Moulouya and numerous anomalies were identified at the base of the Triassic, and these were tested by core drilling. In the Haut Atlas Occidental, a uranium-bearing sandstone horizon was discovered in the Cretaceous continental sequence of Imin Tanout (Marrakesh Province). A drilling programme was undertaken along 15 km of outcrops that recorded radioactive anomalies. In 1979 and 1980, exploration activities continued in the Cretaceous of the Haut Atlas Occidental, in the Permo-Triassic of the Haute Moulouya and in the Precambrian areas of the Anti-Atlas. A geochemical programme to investigate the basement of the Nord Mesetien was carried out with the assistance of the IAEA. Another IAEA assisted programme surveyed the area of the Boutonnière de Bou Azzer El Graara.

During 1981–1982, exploration in the continental Cretaceous rocks of the Haut Atlas Mountains (Harrakesh Province) continued. Elsewhere, prospecting was carried out in the Ouarzazate Tertiary Basin, near the middle reaches of the Moulouya River, and in the Precambrian areas of the Anti-Atlas. Car-borne reconnaissance was conducted in north-eastern Morocco. Owing to budgetary constraints

in 1983–1984, a planned aerial spectrometer survey of the Haut Atlas Occidental was postponed. Despite this, geological and radiometric surveys and drilling were carried out in selected areas in the Anti-Atlas.

In 1985, a geophysical helicopter survey was undertaken covering an area of 8000 km² in the Haut Atlas, targeting both uranium and base metals, using magnetometric, electromagnetic and spectrometric methods. This resulted in the discovery of numerous uranium and uranium–thorium anomalies. The anomalies detected by the 1985 helicopter survey were evaluated, but the results were discouraging and no economic uranium concentrations were found. As a result, further work was terminated.

In 2007, Australia's Toro Energy Ltd signed a memorandum of understanding with Morocco's Office National des Hydrocarbures et des Mines (ONHYM) for the exclusive rights to evaluate the potential of three areas known to host uranium mineralization. During 2007, these areas were evaluated and one of them, Haute Moulouya, was considered to have potential for sediment hosted uranium. In June 2008, Toro Energy indicated that it planned to terminate the memorandum of understanding with Morocco and focus on its activities in Australia and other areas [3].

Uranium resources

No known conventional uranium deposits in Morocco have been reported to the Red Book.

In 2009, a factsheet from ONHYM indicates that the Wafagga uranium occurrence, located 90 km south-west of Marrakesh, has a preliminary resource estimate of 500 tU at a grade of 600 ppm U. It states that the mineralization is likely to be of the roll front type and occurs in the Hauterivien Cretaceous. The estimate is based on results of radiometric and 'track etch' measurements; percussion, rotary and diamond drilling; and underground workings [4].

In 2015, ONHYM estimated resources of 35 Mt at 121 ppm U (4273 t U) on the Aghracha prospect in surficial fluvial-valley formations. U-Th-REE-rich granite and carbonatite veins and dykes are also present in the same area. The Taguendest prospect further south in surficial formations is estimated at 1963 t U, 170 ppm. The same document mention large U-Th-Nb-Ta-REE resources associated to intrusive carbonatite plutons: Glibat Lafhouda, 49 Mt at 430 ppm U (43 000 t U); Twihinatte, 560 Mt at 212 ppm U (118 500 t U) [5].

Undiscovered resources

Numerous uranium occurrences are known to exist in the Anti-Atlas, the Haut Atlas Occidental et Central, the Meseta and Moyen Atlas and the Haute Moulouya. Geologically, these occurrences are mainly associated with Precambrian, Cambrian and Palaeozoic granites and sediments of Cambrian–Cretaceous age.

Speculative resources estimated by the 1983 IUREP Orientation Phase Mission were in the 70 000–180 000 tU range [6].

Unconventional resources

Very large resources of uranium hosted by phosphate deposits are known to exist in Morocco [7].

Potential for new discoveries

Morocco offers a number of possibilities for the discovery of uranium resources.

Within the Precambrian, there are both acidic crystalline rocks and volcanics, as well as continental clastic sedimentary rocks such as conglomerates, sandstones and shales. To date, no uranium

mineralization has been found. The area underlain by such rocks in southern Morocco is quite extensive and theoretically should be prospective for uranium.

A few uranium anomalies have been found in the continental sandstone facies of the Georgian (Lower Cambrian) in the eastern part of the Anti-Atlas Mountains. Stratiform uranium occurrences have been discovered at the base of the Cambrian–Ordovician continental sediments, just to the south of the Hoggar Massif in Algeria. There are extensive areas of Lower Palaeozoic rocks in the Anti-Atlas and contact zones with Precambrian rocks in the same region that may be favourable for hosting uranium mineralization.

The Carboniferous sediments are principally marine in origin but may include continental facies in the eastern part of the country. A large number of radioactive anomalies and a few occurrences of uranium have been found in the Permo-Triassic rocks of the western and central Haut Atlas region. Copper mineralization often accompanies these occurrences. There are large prospective areas within these stratigraphic units.

The Upper Jurassic sandstones of the Moyen and Haut Atlas contain several radioactive anomalies in association with copper mineralization. These rocks have been little prospected in the past. Uranium in concentrations of 80–200 ppm U is known in central Morocco in phosphatic limestones of Maastrichtian–Lutetian age. The Hercynian granites of the Atlas region should have potential for vein deposits and could also be potential sources of hydrogenic sandstone uranium deposits in various formations. The sequences of acid volcanics interbedded with Miocene sandstones, such as those at Ras Tarf, have potential to host uranium mineralization [3]. Potentially large resources of uranium could also be associated with the phosphate deposits.

Uranium production

There has been no uranium production in Morocco. However, in Belgium, 686 tU were recovered during 1985–1998 from phosphates imported from Morocco.

Future projects

On 22 October 2007, AREVA signed an agreement with Morocco's national phosphate company, Office Chérifien des Phosphates, to develop joint cooperation and research initiatives regarding extraction of uranium contained in phosphoric acid produced from Moroccan phosphate ore. The project is terminated.

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