FRANCE

Geography

Metropolitan France (European territory) is divided into 13 regions, which in turn are sub-divided into 96 departments. France also has four overseas regions (Guadeloupe, French Guiana, Martinique and Réunion), three overseas collectives (St Pierre and Miquelon, Wallis and Futuna, and Mayotte), one unique country (New Caledonia), one overseas country (French Polynesia), one overseas territory (French Southern and Antarctic Land) and five islands in the Indian Ocean (Îles Éparses, Bassas da India, Europa, Juan de Nova, Glorioso and Tromelin).

The landscape of France is made up of three main geological regions: (i) the remains of ancient mountains making up the Hercynian massifs, (ii) the young, high fold mountains in the south and SE, and (iii) the northern and western plains.

The Paris Basin, in north-western France, includes the Beauce and Brie regions, which are important for agriculture. The elevation increases in the Ardennes and Armorican Massifs. The Aquitaine Basin (Basin of Garonne), which is situated to the SW and borders the Pyrénées, is characterized by plateau of limestone and fertile valleys. A third basin runs north–south and it is formed by the valleys of the Rhône and Saône Rivers.

France is mostly flat in the northern and central parts. Towards the south, the central part adjoins the mountainous regions of the Massif Central, attaining elevations of over 1800 m in the Puy de Dome. The northern part has some hilly regions with elevations of 300–400 m.

In the west, a broad flat zone extends inland from the Atlantic coast for ~150 km, or more along the rivers. The south is characterized by the ~400 km long Pyrenees range, (up to 3400 m in elevation), forming the border with Spain and Andorra. The area to the east of the Pyrénées includes the southern part, formed by the coastal area along the Mediterranean Sea, with alternating lowlands, such as the Rhône River delta and the southern extension of the Alps. The east consists in its northern part of alternating lowlands and hilly areas, continuing into the Vosges Mountains (elevations of up to 1424 m), and further south to the Alps and the forelands of the Alps. The Alps attain elevations of 3000–4000 m in France, with a maximum of 4807 m attained at Mont Blanc.

The main rivers in France are:

(i) The Rhône, in the east, which flows north–south, and after flowing through a large delta west of Marseille, enters the Mediterranean Sea;
(ii) The Loire, in the centre, running roughly east–west, and entering the Atlantic Ocean near Nantes;
(iii) The Seine, in the north, running roughly SW–NW and, after crossing Paris, enters the English Channel near Le Havre;
(iv) The Garonne, in the south, flows roughly SE–NW and enters the Atlantic Ocean north of Bordeaux.

The climate varies, depending on geographical location. The western and northern areas are generally influenced by the Atlantic Ocean, with cool, mild winters and moderate summers. In the south, the climate is influenced by the Mediterranean, with mild winters and hot summers.

The country is very fertile and about 35% of the area is arable. Roughly 20% consists of permanent pastures and 27% of forest and woodland [1].

Geology

General

France is situated in the western part of the Moldanubian zone of the Hercynian Orogenic Belt, which runs from the Czech Republic through southern Germany and into France. From east to west, the Moldanubian comprises the Vosges Mountains, the entire Massif Central and the Vendée. The oldest rocks located in Normandie, are Precambrian (Proterozoic Cadomian domain), and were reactivated by the Caledonian and Hercynian events (Figure 1). During the Hercynian, intensive metamorphism affected the older rocks and this event was followed by acid magmatism.

The Saxo–Thuringian zone is situated north of the Moldanubian and is part of the Hercynian. The Saxo–Thuringian can be traced from the Ardennes Mountains in the east, extending beneath the Paris Basin, and cropping out in the west in the Massif Armoricain of Brittany. Sedimentary basins of Upper Carboniferous–Permian age are filled with the molasse of the Hercynian Mountains. The basins are developed either adjacent to the Hercynian, for example, the Hérault Basin, or as intramontane basins. Sedimentation continued throughout the Mesozoic period, filling large depressions in the older basement, or as the result of marine transgressions. Examples are the Paris and the Aquitaine Basins, where sedimentation started during the Triassic and are filled nearly continuously by Jurassic, Cretaceous and Tertiary sediments. Another Tertiary age example in the Moldanubian is the St. Pierre du Cantal Basin [6.2]. Sedimentation in these two basins starts with Triassic sediments and then they are filled nearly continuously by Jurassic, Cretaceous and Tertiary sediments!

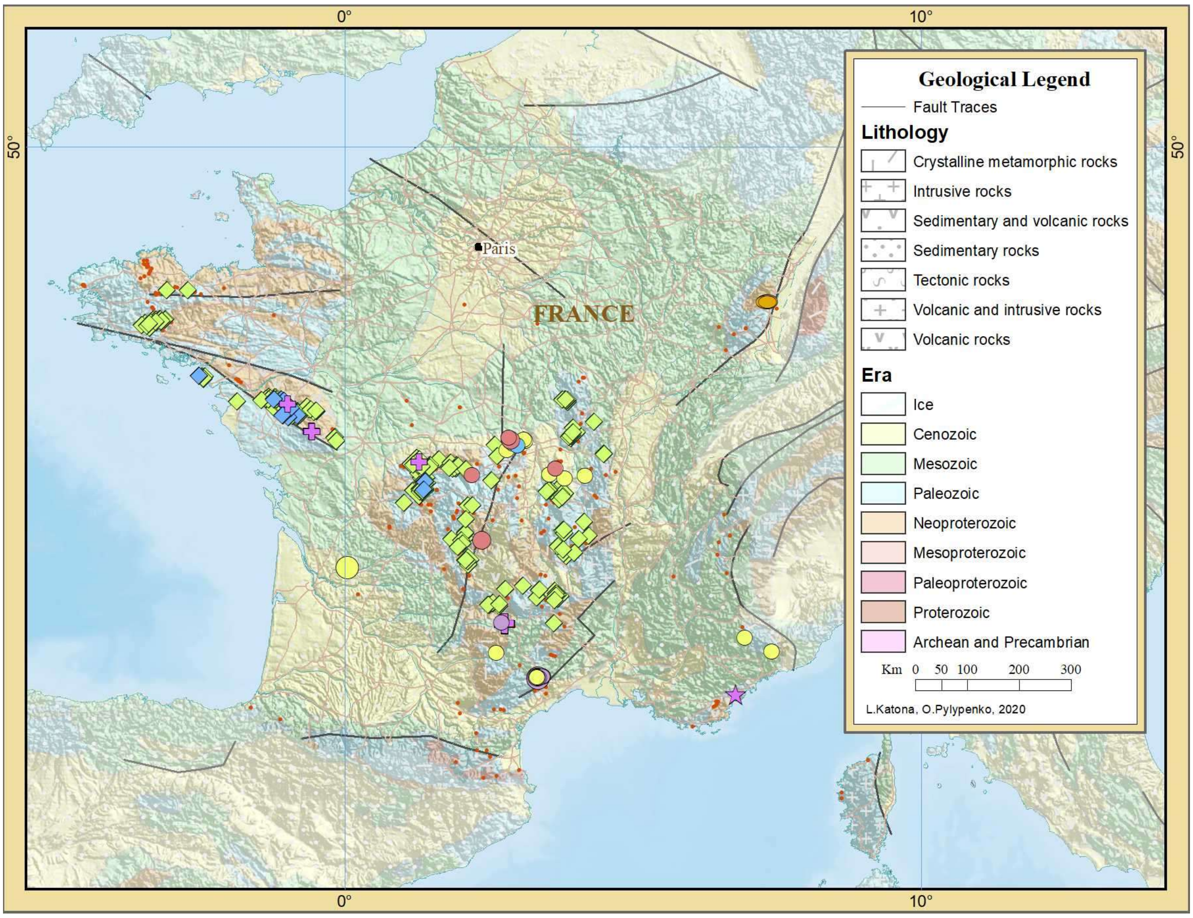

FIG. 1. Regional geological setting of France showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and occurrence legend see World Uranium Geology, Exploration, Resources and Production, IAEA, 2020. A general global geological legend is shown although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

The Pyrénées and the Alps, formed during the Mesozoic, are two prominent features in France. The Pyrénées correspond to a 430-kilometre-long, east–west, intracontinental mountain chain that divide France and Spain. The belt has a long polycyclic geological evolution starting during Precambrian times. The present configuration of the chain is due to the collision between the microcontinent Iberia and the south-western part of the European Plate. The two continents approached each other since the Upper Cretaceous 100 million years ago and collided during Eocene/Oligocene, 55 to 25 million years ago. Intense erosion and isostatic readjustments affected the chain. A cross-section through the chain indicate an asymmetric flower-like structure with steeper dips towards France. The Pyrénées are the result of compressional forces and important sinistral shearing.

The French Alps are the southern part of an extensive Cainozoic orogenic belt called the Alpide belt that stretches through southern Europe and Asia from the Atlantic to the Himalayas. The belt formed during the Alpine orogeny and the Alps arose because of the collision between the African and Eurasian plates. The Alpine Tethys, which was located between these two continents progressively disappeared. As a result, the thick sediments of the Alpine Tethys basin and its Mesozoic and early Cainozoic formations were pushed against the stable Eurasian continent by the northward-moving African continent during the Oligocene and Miocene. Great recumbent folds or nappes were pushed northward sliding on top of each other to form very large thrust faults. Precambrian and Palaeozoic crystalline basement rocks, which are exposed in the higher central regions, are the rocks forming the Mont Blanc.

More specifically, deposits of economic value occur in three groups:

(i) The Saxo–Thuringian zone of the Variscan Orogeny, mainly in schists at the periphery of granitic areas (peri-granitic type);
(ii) The Moldanubian zone of the Variscan Orogeny in granitoids (intra-granitic) or in metamorphic rocks at the periphery of granites;
(iii) The Mesozoic and Cainozoic sedimentary basins of Cantal, Hérault and Gironde.

Examples of group (i) include deposits in the southern part of the Vendée (La Prée). Examples of group (ii) are deposits in Brittany (Bonote), Vendée (Commanderie), and Massif Central (Margnac). Examples of group (iii) are Mas Lavayre (Herault), St. Pierre du Cantal (Cantal), Cerilly (Allier) and Coutras (Gironde).

In the Moldanubian of the Massif Central and in the Vendée, uranium deposits occur in veins associated with leucogranites. In the Massif Central, in the Limousin deposits, uranium veins occur primarily within two-mica leucogranites, whereas in the Vendée, uranium mineralization occurs in the boundary of leucogranites rather than in the surrounding metamorphics. The granites range in age from about 320–300 Ma, whereas the uranium is associated with processes dating from about 280 Ma [3–5].

The vein systems are complex and vary drastically in size. Uranium mineralization is either associated with the intersections of tectonic trends (the most common type), or with fractures within kersantite dykes and at the leucogranite–metamorphic country rocks contact. The mineralized zones are mostly linear in their morphology. Laterally, the zones can extend to over several hundred metres and have thicknesses ranging from less than 1 m up to 15 m. Stockwork mineralization is also often observed.

Pitchblende is the main mineral of uranium. Gangue minerals comprise sulphides, haematite, quartz, calcite, fluorite and occasional barite occur.

A typical feature associated with uranium enrichment in granites is episyenitization. This results from leaching of the leucogranites by alkaline solutions and involves the removal of silica (quartz). Studies of fluid inclusions related to this process indicate the solutions were rich in CO_2 and that the episyenitization took place at temperatures of ~350°C and at pressures of 700–800 bar [3].

The continental sedimentation of Permian age is favourable for uranium accumulation. In the Lodève Basin, Hérault, in southern France, deposition started in the lower part (Autunian), which was swampy and rich in plants, and are now represented as bituminous shales. In the lower section, grey sandstones are overlain by carbonates, followed by grey and red sandstones, shales, carbonates and acid pyroclastics and, finally, mostly red sediments [4,–7].

The overlying Saxonian comprises a 1000 m thick red-bed sequence. Uranium mineralization is less common and occurs only in reducing zones, which are related to organic matter occurring in the horizons with the finest grain size (pelite), and possibly in association with ankerite, low temperature albite, chlorite and sulphides. Uranium is usually associated with organic matter and mineralization occurs in lenses or rolls in sands or in sequences containing siltstone/claystone that are also rich in organic matter. At Lodève, fault controlled mineralization is also observed. Pitchblende and coffinite are the main uranium minerals. In addition, uranium exists as microscopic disseminations in carbonaceous matter.

Several deposits are located within lower Tertiary sediments such as Saint Pierre du Cantal and Coutras. For Saint Pierre, the mineralization is contained in a small basin of fossil-wood Oligocene sand embedded by faults in the granitic basement. The Coutras deposit, in the north of the Aquitaine Basin, is contained in Eocene organic matter-rich clayey sand and clay between the surface and a depth of 100m. Geological resources are in the order of 20 000 t U at a grade of 0.1%.

Uranium exploration

Historical review

Domestic exploration

Uranium exploration started in 1946 around known uranium deposits and at several minor occurrences found during radium exploration. The total expenditure was USD $907 741 000 including 12 982 674 metres of drilling (Fig. 2). The early work consisted of geological mapping and radiometry (airborne, car-borne and ground survey) and led, in 1948, to the finding of the small but very rich Henriette deposit (in the Massif Central). Following the discovery of numerous deposits, the area became a major production centre known as La Crouzille. By 1955, deposits had been identified in Hercynian granites at Limousin, Forez, Vendée and Morvan.

During the 1950s and 1960s, exploration was mainly conducted near known deposits, as well as in areas with similar geological settings. Subsequently, work was broadened to terrigeneous formations derived from eroded granite mountains and to sedimentary formations in intra-granitic basins. These are mostly situated south and north of the Massif Central. Basins of Permian age were also of interest and this exploration led to the finding of uranium mineralization in the Hérault Basin.

After the world energy crisis of the early 1970s, the French nuclear programme was accelerated and, after 1974, exploration was intensified. Exploration was conducted adjacent to uranium mining districts and around known showings that had not been previously explored owing to economic considerations. New areas, located mainly in Permian and Tertiary sedimentary basins, were also investigated.

Exploration activity continued at high levels until the mid-1980s, even as the spot market price for uranium continued to decline. While exploration expenses expressed in US$ decreased, they remained high in French Francs. Additional exploration was conducted in the Massif Central, as well as to the NW in the Massif Armoricain, in the Aquitaine Basin to the south and in the Alps.

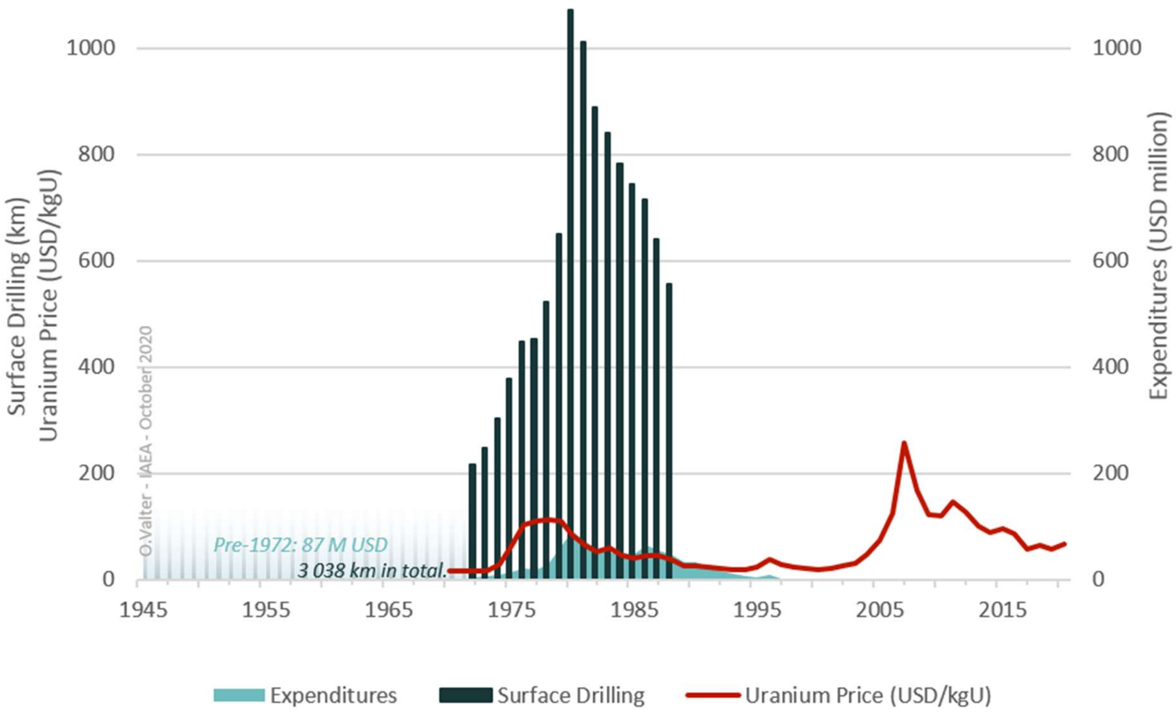

FIG. 2. Domestic uranium exploration data for France. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

In 1977–1981, the Government supported exploration with an expenditure totalling US $38 million. This financial aid could represent up to 35% of the cost of a project and it was provided in both France and abroad. For these subsidized projects, the operator was obliged to reimburse the Government if an economically viable deposit was exploited. At the end of the 1980s, exploration activities declined and were mainly concentrated in areas adjacent to mines. After 1994, exploration was only conducted in the north-western part of the Massif Central and in the Permian Basin at Lodève. Exploration was terminated in 1996 in the Permian Basin and in 1998 in the Massif Central [8, 9].

Exploration abroad

To ensure the supply of uranium for the French nuclear programme, French mining companies were encouraged to explore abroad and to this end exploration has been carried out in Australia, Canada, Gabon, Indonesia, Kazakhstan, Mongolia, Niger, South America and the USA. In 1979, exploration was being conducted in 19 different countries. As shown in Table 4.2, yearly exploration overseas increased from less than US $10 million to a maximum of over US $68 million in 1980. The following years show a steady decrease from the maximum reached in 1980 to below US $6 million by 1990. With the exceptions of 1993 and 1994, yearly expenses were below US $20 million and even below US $10 million in the years to 2001. Thereafter, an increase in exploration expenses occurred owing to an increase in the prevailing spot market price of uranium (Fig. 3 and Table 1). As of January 2019, total non-domestic exploration expenditure is USD $1564 million.

Potentially-favourable uranium-bearing areas

In general, uranium mineralization occurs in rocks formed by the Variscan (Hercynian) Orogeny, in sedimentary basins of Carboniferous–Permian or Tertiary age, formed in Variscan rocks, and in larger sedimentary basins at the periphery of Variscan regions and containing erosional materials from the Variscan regions.

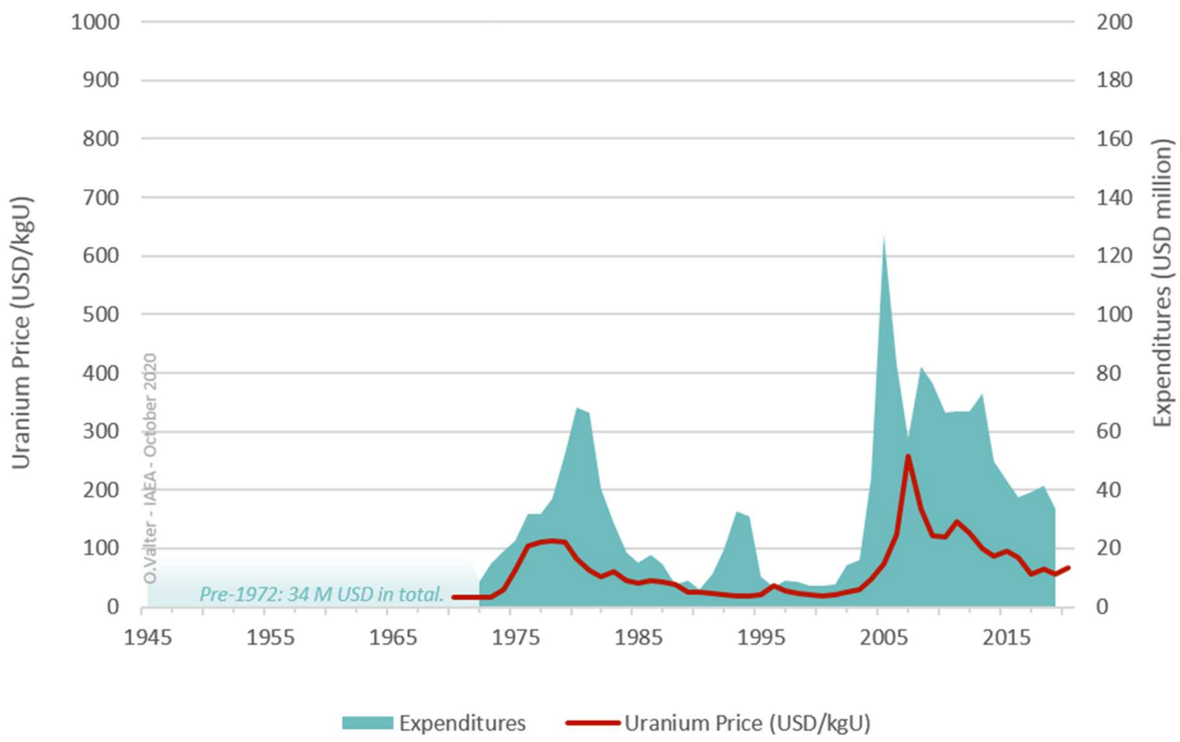

FIG. 3. Non-domestic uranium exploration data for France. Comparison of exploration expenditures, drilling and uranium market price (US$ current) [8, 9, 10].

TABLE 1. NON-DOMESTIC EXPLORATION AND DEVELOPMENT EXPENDITURES (US$ million) [10]

Year	2016	2017	2018	2019 (est.)
Exploration expenditure	34	35	35	30
Development expenditure	n.a.	n.a.	n.a.	n.a.
Total	34	35	35	30

[a] n.a.: not available.

Recent and ongoing uranium exploration and mine development activities

From 1999, no domestic uranium activities have been conducted in France. Overseas, Compagnie Générale des Matières Nucléaires (COGEMA, formerly Commissariat à l'Energie Atomique (CEA)), AREVA (formerly COGEMA) and Orano (formerly AREVA) have been focusing on targets in Niger, Mongolia, Kazakhstan, Finland, Canada and Australia. AREVA is likewise directly or indirectly engaged in activities for exploration or development of uranium via its subsidiaries. In 2017, Orano was created because of restructuring and recapitalizing of the nuclear conglomerate AREVA. In Niger, Kazakhstan and Canada, Orano is engaged in mining operations and projects for uranium. Besides, without being the operator, it keeps shares in a number of research projects and mining operations in different countries [68]. The costs for finding of 1 kgU in total conventional resources, including uranium produced until 2003, amounts to US $10.61. This compares with roughly US $2/kgU for the world average [11].

Uranium resources

Identified resources

After the shutdown in 2001 of the last uranium mine, any indicated resources no longer exist in France. UDEPO [6.12] lists a total of 43 deposits (or mining areas). Three of which are dormant; the sandstone deposits at Coutras, the vein deposit at Montulat and the Saint Hippolyte black shale deposit. All the others have been depleted. These deposits are minable using open pit [6.8]. The variations in historical resources are shown in Figures 3 and 4.

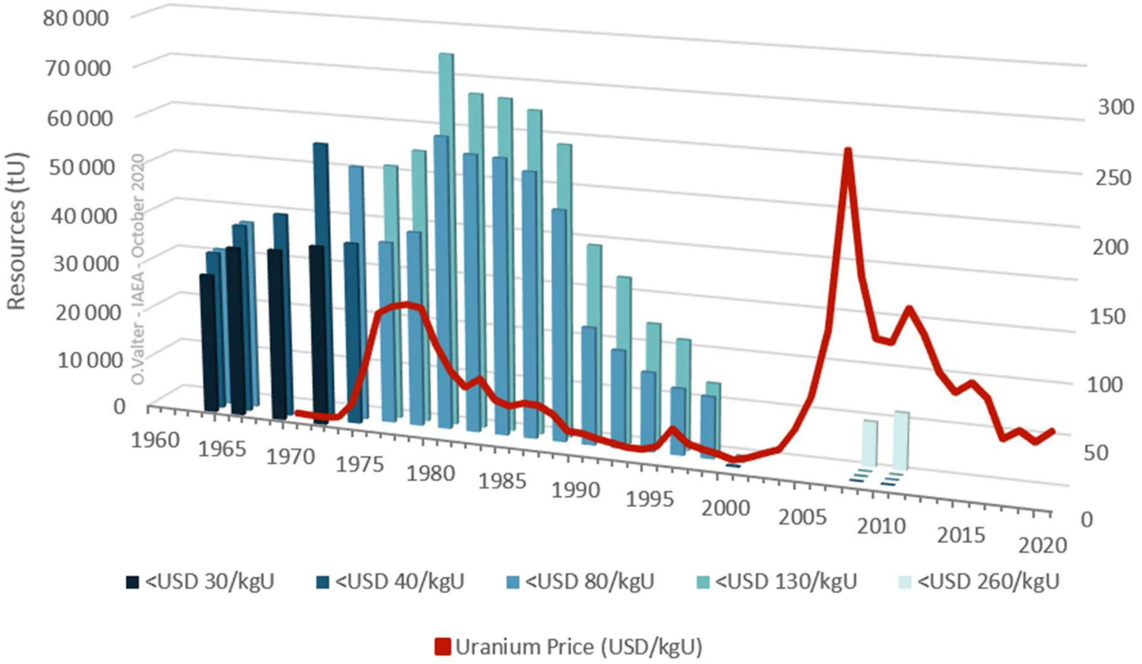

FIG. 3. Historical variation of recoverable reasonably assured resources within various cost categories in France. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

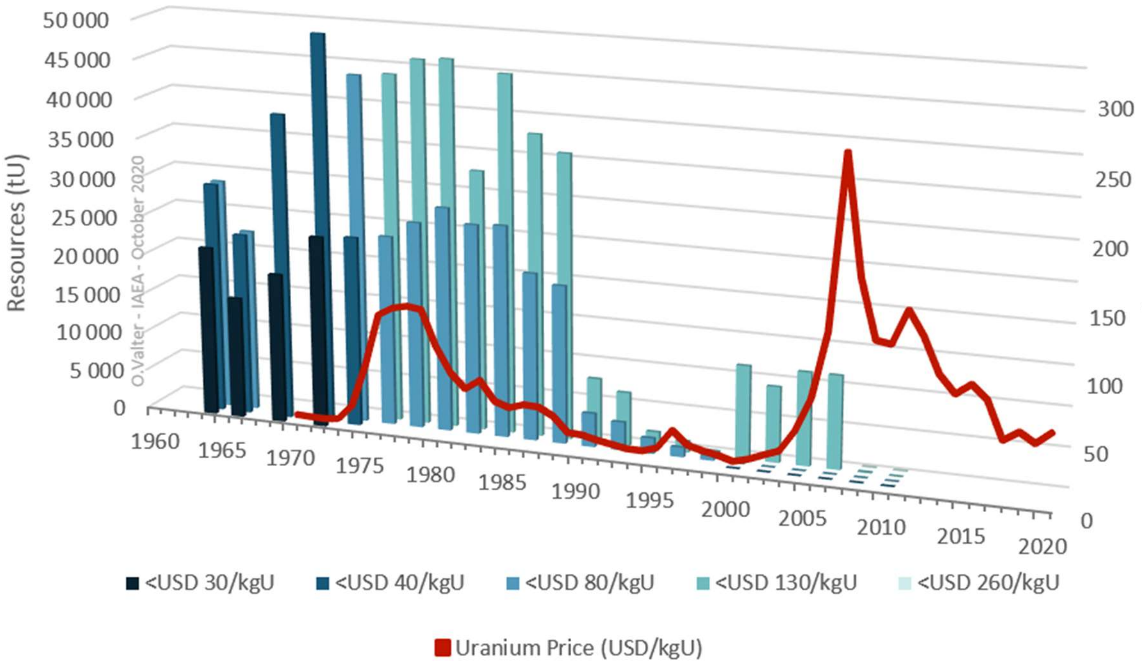

FIG. 4. Historical variation of recoverable inferred resources within various cost categories in France. Periods where no resources are shown in any cost categories are periods where resources were not reported, either by the Member State of as a secretariat estimate.

Undiscovered resources

No systematic appraisal has been carried out for undiscovered resources.

Potential for new discoveries

France is one of the most intensively explored countries. With the exception of deposits, which are dormant owing to economic and/or ecological reasons, no new exploration areas may be found at a reasonable depth. The deeper parts of fertile granites and sedimentary basins may have some potential. However, at present these are not of economic interest.

Uranium production

Historical review

Details of historical uranium production are given in Figure 5. Total historical French production through the end of 2018 is 80 978 t.

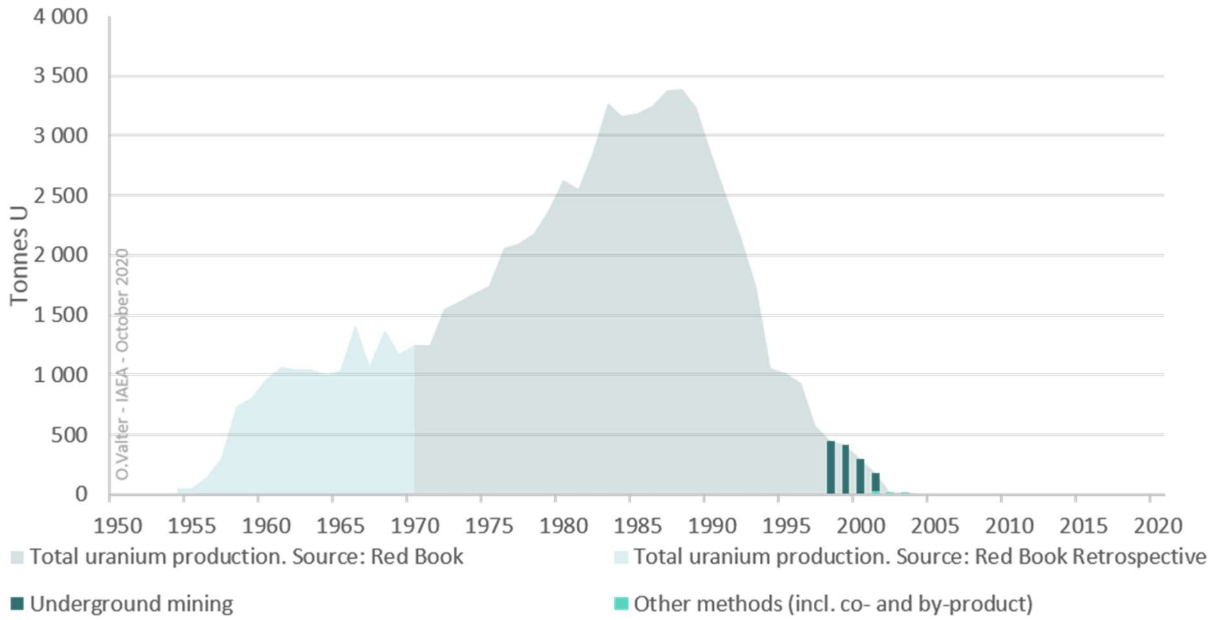

FIG. 5. Historical uranium production in France (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

Uranium has been produced from at least 200 different sites, with production ranging from less than 1 tU to at least 5000 tU (Bois Noirs, Le Bernardan, Lodève district, Margnac). Due to mine closures, production of uranium in France has dropped continually after 1990. Because of the shutdown of Lodève and Le Bernardan in 1997 and 2001, respectively, there is currently no uranium producing operation in France. Since 2002, any generation recorded has been achieved as the result of site reclamation.

Status of production capability

After 2001, all ore treatment plants were closed, demolished and the sites recovered. Just 2–3 tU/year are still recovered on resins used throughout water cleaning processes at the outflow from the former Lodève mine. The resins are eluted at the Malvesi refinery and the uranium recovered.
There are no current proposals to develop addition production centres.

Environmental activities and sociocultural issues

After the shutdown of the last mines in Hérault (1997) and at Bernardan (2001), reclamation and decommissioning efforts focused on these sites. Regulations demand mothballing and restoration of closed mining and milling facilities, including waste dumps and tailings facilities, in order to minimize any release of potentially harmful substances and thereby ensure that a broad range of specific standards are met. Expenses for decommissioning totalled nearly FFr 793 million (US $134 million) through 2000. Monitoring the quality of both air and water in the neighbourhood of these facilities is ongoing.

Additional information on environmental and remediation activities is provided in Refs [13, 43].

French Guiana

Geography

French Guiana is located on the north-eastern coast of South America, bordering the Atlantic Ocean. As an Overseas Department of France, French Guiana is part of the European Union and is the largest landmass in the EU outside of Europe. In contrast, compared with other South American countries, French Guiana has the smallest landmass and the smallest population. The country's economy is heavily dependent on France for subsidies, trade and goods. The main industries are fishing (accounting for three quarters of foreign exports), gold mining and timber. In addition, the Guiana Space Centre at Kourou contributes 25% of GDP and employs ~1700 people.

There is very little manufacturing. Agriculture is largely undeveloped and is mainly confined to the area near the coast, sugar and bananas being two of the main cash crops. Tourism, especially eco-tourism, is growing. Natural resources include bauxite, cinnabar (mercury), gold (widely scattered), kaolin, timber and fishing.

The climate is tropical, hot and humid, with little seasonal temperature variation. Summers are dry and winters rainy. Low-lying coastal plains rise to hills and small mountains, the highest point being Bellevue de I'Inini at an elevation of 851 m [15].

Geology

French Guyana is part of the Guiana Shield, a large massif extending from the Amazon to the Atlantic Ocean (Figure 1).

It is composed of old Precambrian formations dated between 3500 and 2700 Ma. The shield comprises several geological units: the southern peneplain, the Inini synclinorium, the central granite massifs and the northern synclinorium. The southern peneplain consists of granito-gneisses corresponding to metagabbros, metagranodiorites and metagranites ('Guyanese Granites') dating from 2075 ± 7 Ma. To the north, the peneplain straddles the Inini synclinorium, mainly composed of the Paramaca series (micaschists, aluminous paragneisses, conglomerates and black quartzites) with a thickness of about 1 km. The Upper Paramaca is made of various lavas (basalt, andesite, dacite and rhyolite).

The central granite massifs consist of granites, granodiorites and quartz diorites plutons dating from 2150–2050 Ma. Pegmatite veins are common. The north of French Guiana corresponds to a synclinorium composed of the Paramaca series on which are unconformably overlying sandstones, quartzites, conglomerates and black schists of the Bonidoro and Orapu series. They are intruded by the well-represented 'Caribbean Granites'. The largest intrusions are surrounded by migmatites. Pegmatite veins and bodies are common and carry some mineralization. Rocks of the Shield are all dated between 2500–1600 Ma. [16]

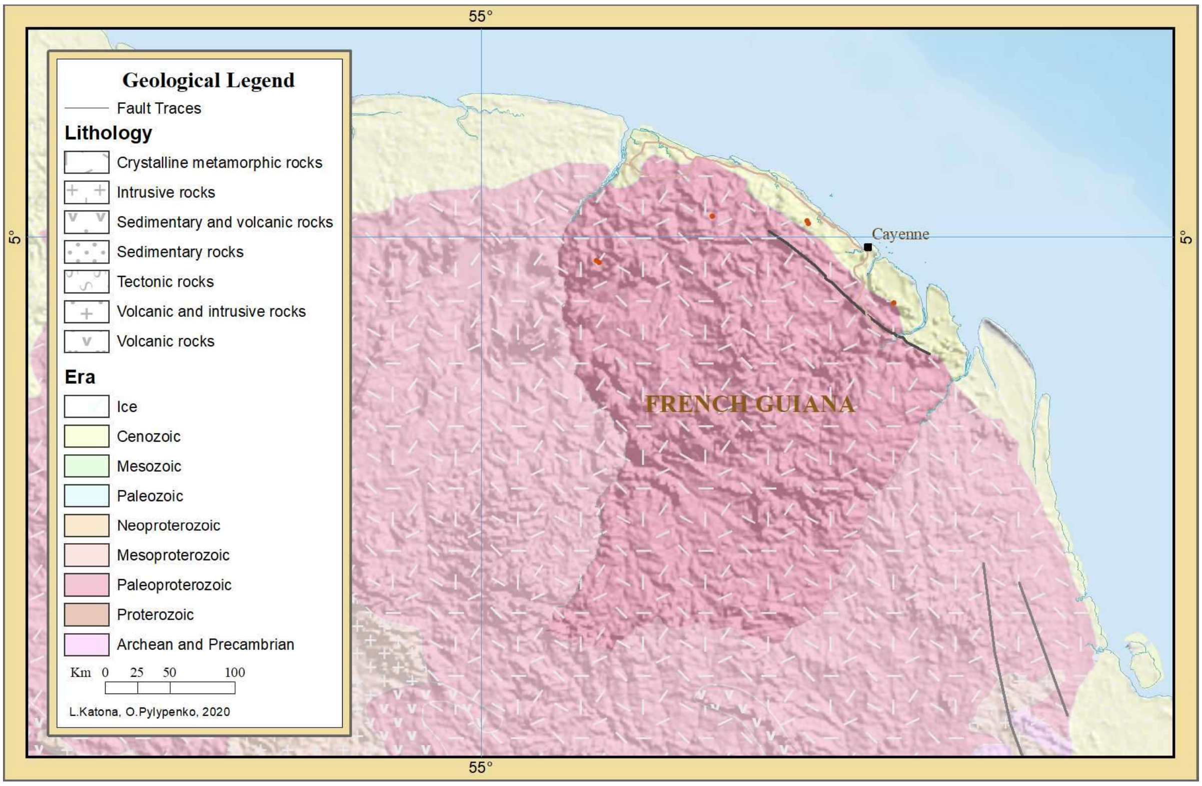

FIG. 6. Regional geological setting and uranium mineralisation of French Guiana. For the general uranium deposit and occurrence legend see World Uranium Geology, Exploration, Resources and Production, IAEA, 2020. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Well-developed late dolerite dykes crosscut all the above formations with a NNW preferential direction. Late Cainozoic terranes (carbonates) are very rare and have only been found in drill holes. Dismantled ferruginous and bauxitic laterites formed during Mesozoic and Cainozoic times are present in various topographic levels.

Quaternary formations are located along the coast and are represented by thin layers (8–15 meters) of marine clay, sand and pebbles originating from alteration and erosion of the Precambrian Shield. The youngest contain a large proportion of organic matter (peat and shells).

Uranium resources

No reports on previous or current uranium exploration are available. There are no uranium or thorium resources or production reported in UDEPO or in the literature. French Guiana has not submitted any Red Book reports (any uranium related activity reported to the Red Book would be provided in the country report for France).

Within the Montagne de Kaw depression, strong anomalies were found related to radon emanations. Caribbean pegmatites are often autunite-rich. Columbo-tantalates and ilmeno-rutiles are weakly anomalous [17].

Potential for New Discoveries

As in the surrounding countries, IUREP recognized there is some potential for quartz pebble conglomerate and Proterozoic unconformity related deposits associated with the Shield area [18]. Also, vein and disseminated mineralization within pegmatites can be present. Black shales are locally well developed in some areas.

New Caledonia

Geography

New Caledonia is a 'special collectivity' or unique portion of France located in the region of Melanesia in the south-west Pacific. It is about 1200 km east of the Australian coast. It comprises a main island, Grande Terre, the Loyalty Islands and several smaller islands.

The climate of the islands is tropical and rainfall is highly seasonal, brought by trade winds that usually come from the east. Annual rainfall averages about 1500 mm on the Loyalty Islands, 2000 mm at low elevations on eastern Grande Terre and 2000–4000 mm at high elevations on Grande Terre. The western side of Grande Terre lies in the rain shadow of the central mountains and annual rainfall averages 1200 mm. There are two main seasons: a dry season, and a warm, wet season. The dry cooler months last from April to November with daily temperatures in the range 17–27°C. During the wet season (December–March), the temperature can reach 32°C.

New Caledonia contains a considerable wealth of industrially critical elements and minerals, including about one-quarter of the world's nickel resources. Mining is therefore a significant industry that greatly benefits the territory's economy 19].

4.6.9.2. Geology

For a relatively small island, the geology of New Caledonia is quite complex (Figure 7). The stratigraphic record begins with marine sediments being deposited in the Mesozoic. The succession is quite thin, but a thick Eocene section is present.

FIG. 7. Regional geological setting of New Caledonia (France). A general global geological legend is shown although not all geological units necessarily occur on this particular map.

New Caledonia belongs to the circum-Australian group, along with New Guinea and New Zealand. Thicknesses of up to 13 000 m of Eocene strata are preserved along this trend. Grande Terre consists mostly in sedimentary, volcanic and ultrabasic rocks from Permian (280–225 Ma) to Tertiary (65–1.5 Ma). Metasediments of Cretaceous age predominate in the extreme north-west. Basalt is present in the western portion of the north-western part of the island. Small outcrops of marine sediments of Mesozoic and Eocene age intermix with granites in the central part of the island. Ultrabasic rocks and 'blue schist' glaucophane-bearing metamorphics occupy the south-eastern quarter of the island. Radiometric dating of the metamorphism peak is 44 Ma while the cooling ages range from 40 to 34 Ma. They indicate a rapid unroofing and exhumation of the metamorphic units in the north and a synchronism with the emplacement of the ophiolitic nappe (38–34 Ma). A zone of intense faulting runs the entire length of the island through its centre. The terms of 'geosuture' and "la grande faille" are locally used to indicate the degree of faulting, although the magnitude of movement and relative throw are debated. Shear zones are measured in widths of kilometres, although descriptions of the character of the shears are fragmentary. This fault is correlated to the faulting along the Owen Stanley Mountains of Papua New Guinea.

The island is quite heavily mineralized; several deposits are economic (notably nickel and chromium) [19].

Uranium Exploration

There has been no reported uranium exploration on New Caledonia. However, given the fact that several French organizations have undertaken exploration for uranium in several States in Africa, it is therefore likely that New Caledonia has already been considered as a target for uranium exploration.

Uranium Resources

There are no known uranium occurrences in New Caledonia. Based on the complexity of the geology and the relative intensity of the mineralization of the island, as well as apparently favourable host rocks, IUREP assigned speculative resources in a range of 1000–10 000 tU to New Caledonia [20].

Potential for New Discoveries

The shear zones along the 'geosutre' present the best potential host environment for uranium deposits. Mylonite zones within the shear zones appear to have most potential. Primary type deposits may be present in the metamorphics as veins, stocks and pipes, especially where organic-rich (phyllite, etc.) metasediments contact impervious rocks [20]. Owing to the country's size and rock types present, the potential for any discovery is rated as low.

4.6.9.6. Comments

There has been no past production in New Caledonia. New Caledonia has no nuclear power generation.

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