ARGENTINA

Geography

Argentina, South America's second largest country (after Brazil), has a strategic location with respect to the sea lanes traversing the South Pacific Ocean (Drake Passage, Beagle Channel, Strait of Magellan) and the South Atlantic Ocean. The climate is varied, ranging from tundra in the far south to tropical in the north. The topography is likewise diverse, with the rich plains of the Pampas covering the northern half of the country, the rolling to flat plateau of Patagonia to the south, and the Andes extending along the western boundary with Chile.

The Andes are the world's longest continental mountain range, a continuous chain of high land, which runs along the western coast of South America. The range is at least 7000 km long, 200 km–700 km wide (the widest part occurring between a latitude of 18–20° S) and has an average height of ~4000 m. At least one-half, or 3600 km, of this range extends along the western boundary of Argentina.

The Andes range encompasses Argentina, Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela. The Andes range is the highest mountain range outside of Asia. Aconcagua, the highest peak, rising to 6962 m, is the tallest mountain in the Western Hemisphere. Aconcagua is located in the north-western part of Argentina, in Mendoza Province. Also located in Argentina is Laguna del Carbon in Santa Cruz Province, which at -105 m is the Western Hemisphere's lowest point.

The climate is mostly temperate; arid in the SE and sub-Antarctic in SW. The country has abundant natural resources, including copper, iron ore, lead, manganese, silver, tin, zinc, petroleum and uranium [1]. Argentina was the 12th largest silver producer in the world in 2009 [2].

Geology

General

The Andes range is a Mesozoic–Tertiary orogenic belt of mountains along the so-called 'Pacific Ring of Fire', a zone of volcanic activity and orogeny that encompasses the Pacific rim of the Americas as well as the Asia–Pacific region. The Andes are the result of plate tectonic processes and they were created as the result of subduction of oceanic crust beneath the South American Plate. The main cause of the uplift of the Andes is due to the compression of the western rim of the South American Plate resulting from the subduction, from the west, of the Nazca and the Antarctic Plates. To the east, the Andes are bounded by several sedimentary basins, such as the Orinoco, Amazon, Madre de Dios and Gran Chaco Basins, which separate the Andes from the ancient cratons of eastern South America. In the south, the Andes shares an extensive boundary with the former Patagonian terrain.

Along its length, the Andes range is split into several ranges and separated by intermediate depressions. Two of the more prominent ranges are the Cordillera Oriental and the Cordillera Occidental.

The South American landmass consists of a craton, which was created throughout the Brazilian orogenesis in the Late Precambrian and is mostly covered with unfolded younger sediments. There are intrusives of various ages in both the craton and in its cover. Along the Atlantic, the craton breaks off abruptly and this feature, together with its 'jigsaw' fit with the west coast of Africa, contributed to theories of continental drift and plate tectonics. Along the Pacific coast, the craton is bounded by the Cordilleras, an orogenic fold belt which runs north–south. This belt was mainly created throughout Late Mesozoic and Tertiary times by the relative westwards movement of the continent, which resulted in underthrusting of the Nazca and Antarctic Plates from the west. Volcanism has been widespread throughout the Cordillera and it continues in certain areas. An orogenic belt separates the Precambrian Patagonia Massif from the Rio de la Plata Massif to the north, suggesting that the former was part of the old, greater Antarctic continent. A geological map of Argentina is presented in Figure 1.

FIG. 1. Regional geological setting of Argentina 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 South American craton proper is made up of five massifs joined by a series of fold belts. A sixth, the Patagonia Massif, occupies a somewhat different geological position and may be part of the old Antarctic continent. The Patagonia Massif is very poorly exposed. It is probably mainly of Proterozoic age and consists of metamorphic and plutonic, mainly granitic rocks, and has an extensive cover of Palaeozoic rocks.

Though younger sediments are well distributed throughout the continent, three areas of thicker and more continuous sedimentation can be distinguished. One of these is the Paraná Basin, in southern Brazil, Uruguay, Paraguay and northern Argentina.

Permian sediments are widespread throughout the Paraná Basin and usually consist of sandstones, shales and limestones deposited under continental or lagoonal conditions. Coal deposits are relatively common.

The majority of the rocks exposed in the Cordilleras of South America are of Mesozoic and Tertiary age and the main orogenic events took place at this time. Remnants of older rocks and events are present.

In the NW part of Argentina, the Sierras Pampeanas fold belt and the NW striking Palaeozoic orogeny represent geology that is more complicated. Precambrian rocks occur throughout the Andes and these, together with the Palaeozoic rocks, consist of both marine and continental sediments. Granitic intrusives and rhyolitic volcanics are also present. Geosynclines formed throughout the Mesozoic and Cenozoic are found in Chile and westernmost Argentina.

In general, Lower Palaeozoic sediments are better represented in the southern part of the Cordilleras, mainly by marine shales, sandstones and quartzites. The Mesozoic in the south is not metamorphosed [2, 3].

Potentially favourable uranium-bearing areas

Virtually all known Argentine uranium resources are contained within sedimentary rocks in continental or transitional facies from the Permian, Cretaceous and Tertiary periods.

Situated in the NW of the country, the northern sub-Andean region is characterised by the presence of Cretaceous and Tertiary sediments distributed discordantly across Palaeozoic formations. Recent reports on exploration in this area, particularly associated with silver and other metals, are available, although there has been insufficient work done to allow compilation of a uranium resource.

The Pampas Mountain region contains three distinct uranium districts: Cosquin, Los Gigantes and Comechingones. Tertiary continental sediments run north–south between crystalline basement mountain ranges of the Sierra Grande and the Sierra Chica in Córdoba Province, 50 km NW of the city of Córdoba.

The pre-Cordillera region in La Rioja Province, NW of Córdoba, includes the districts known as Guandoacol and Los Colorados. The most important deposit discovered here has been the Urcal deposit, which is hosted in brecciated calcareous conglomerates as peneconcordant lenses. The main Los Colorados deposit occurs as lenticular bodies, hosted in carboniferous sandstones and pelites.

In the Sierra Pintada region, the uranium occurrences in the south of Mendoza Province form the San Rafael district. Palaeozoic, Mesozoic and Cenozoic strata are the host rocks, of which the most important sandstone deposit hosts are the Permian and Permo-Triassic sequences. Uranium occurrences follow various sedimentary models in sandstones and conglomerates, and occur as accumulations in peribatholithic schists, veins and stockworks and calcretes.

In Chubut Province, in Patagonia, uranium occurrences found in Cretaceous sediments were noted as being of little economic importance in 1980. Several occurrences noted by the Comisión National de Energía Atomica (CNEA) in the Cretaceous of Chubut have been the targets of foreign mining exploration companies in recent years [4–7].

Uranium exploration

Historical review of work undertaken and expenditures

The first uranium surveys in Argentina began in 1948 with the assistance of various State entities. From 1950, exploration was pursued more actively by the former Dirección Nacional de Energía Atomica. In 1956, all activities were grouped under the CNEA.

In the late 1960s, it was estimated that 400 000 km² of Argentina could be highly prospective for the presence of uranium deposits based on the geology of the country and the information available on numerous uranium deposits and occurrences.

By the end of 1969, at least 20 000 km² of the areas referred to above had been covered by airborne prospection. Follow-up airborne prospecting of a more detailed character conducted across 5500 km² on a 250 m grid led to the discovery of the Sierra Pintada district in San Rafael (Mendoza Province). The discovered deposits are associated with Permian sandstones, the thickness of the mineralised formation varying in the range 2–12 m, with grades averaging 0.08–0.13% U.

Regular airborne prospection continued and a new uranium-bearing district, Sierra de Pichinan, was discovered in the Chubut Province, 30 km NW of Los Adobes. Various uranium bodies were identified in sub-horizontal sandstones and conglomerates of Cretaceous age. Also throughout the 1960s, the La Estela and Schlagintweit vein deposits were discovered by ground exploration in granitic terrain. The resources were later mined in the production centres of La Estela and Los Gigantes, respectively.

Airborne surveys also resulted in the finding of the Dr. Baulies deposit in the Sierra Pintada district in the Mendoza Province. Mineralisation in the Los Gigantes district consisted of uranium accumulations in the Sierra Los Gigantes granite. The best-known deposit is Schlagintweit, which had initial resources of 1700 tU. The Dr. Baulies deposit was associated with lenticular bodies in Permian sandstones. Initial resources were estimated to be of the order of 12 300 tU at 0.09% U.

In the 1970s, follow-up exploration at and around earlier found occurrences of uranium in Patagonia resulted in the finding of two additional sandstone deposits: Cerro Solo and Cerro Condor. An airborne survey conducted in 1978 in Patagonia assisted in the finding of the small Laguna Colorado deposit, which is hosted in a volcanic environment.

In 1986, groundwork following up airborne survey anomalies identified the Las Termas vein deposit in the Catamarca Province. In the late 1980s, CNEA initiated a programme to evaluate favourable geological units.

The Cerro Solo uranium–molybdenum deposit in Patagonia was the target of exploration activities in the 1990s. Cerro Solo is a sandstone hosted uranium–molybdenum deposit lying at a depth of 50–120 m. The estimated resources are 9230 tU (reasonably assured plus inferred resources [1.8]) at 0.2% U. A pre-feasibility study was followed by preliminary testing of the host palaeochannel structure, based on the results of 56 000 m of drilling. The final feasibility study on Cerro Solo was completed in 2001 and the deposit was offered for public auction. However, Local Law 5001/03 prohibits open pit mining in the province, thereby preventing development of the deposit.

Regional assessment of the overall potential of the country for uranium continued through 2000 and areas of interest were selected for more detailed study. The reinterpretation of old CNEA data and more recent Geological Survey of Argentina data supported continued exploration and geological mapping. An IAEA technical cooperation project was approved to support these activities.

Areas and host environments selected for more detailed study included: Las Termas vein deposit; assessment of host rocks (sandstones) for potential use of in situ leach technology; exploration of targets identified through airborne surveys in Patagonia (sandstone and volcanic); favourability studies in granitic environments (vein type) and metallogenic studies in the Sierra Pintada and Cerro Solo deposit areas.

A reassessment project, including evaluation drilling, laboratory scale testing of treatment methods, resource evaluation, and survey of environmental conditions at the Sierra Pintada production centre was approved in the 1990s and accelerated in 2000.

The 2005 Red Book [9] reports that car-borne gamma ray survey instrumentation was put into operation as recommended under an IAEA technical cooperation project [10].

As shown in Figure 2, industry (non-government) was involved in exploration and drilling throughout 2004–2005, when uranium exploration activity was increasing worldwide. No industry drilling has been reported since 2005. Total exploration expenditure was USD $132 163 663, including 605 492 metres of drilling.

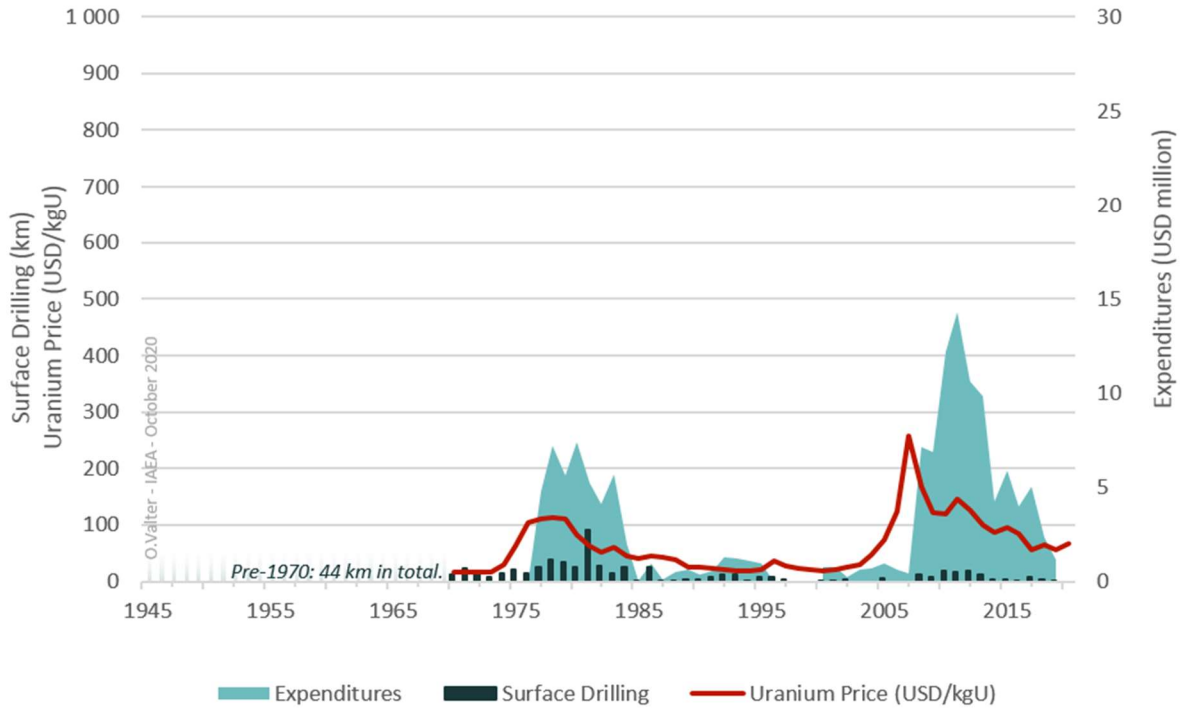

FIG. 2. Domestic uranium exploration data for Argentina. Comparison of exploration expenditures, drilling and uranium market price (US$ current).

Recent and ongoing uranium exploration and mine development activities

The U3O8 Corporation announced the acquisition of Mega Uranium Ltd's South American uranium properties on 8 April 2010. With the Laguna Salada project, one of three major projects in Argentina, the company aimed to increase NI-43-101 compliant resources in the short term. Laguna Salada hosts uranium mineralisation within three metres of the surface in unconsolidated sandy gravel. In 2011, U3O8 Corp. discovered two deposits in the Laguna Salada area, Chubut province, and provided a preliminary economic assessment in 2016. The U-V deposits, Guanaco and Lago Secco, correspond to surficial lacustrine-playa deposits with resources of 3427 and 500 t U respectively at grades of 150-550 ppm. [11, 12].

Calypso Uranium Corporation publicised on 4 August 2009 that it obtained provincial consent for the exploration phase of the Huemul project at Malargüe, in Mendoza Province. According to Calypso Uranium, the Malargüe deposit has the potential to produce uranium again [13].

AREVA NC has investigated its options concerning resources of uranium in southern Argentina and has cooperated with different proprietors, which include Urex Energy Corporation, to support a potential central processing facility. The lowest mineable uranium reserve needed to support such a processing facility was assessed at 8462 tU (22 million pounds of U_3O_8). The idea was that the mining of several satellite orebodies of uranium, controlled by various proprietors, would make available uranium ore feedstock to the central milling facility. Urex Energy has conducted uranium exploration in the Chubut Province, next to CNEA's Cerro Solo uranium deposit.

In 2007, CNEA and the Salta Provincial Government (both through subsidiary entities) moved to a deal to reactivate the Don Otto uranium mine in the Salta Province. This mine was being explored and evaluated to assess the economic feasibility of reopening it. The Don Otto mine is located near to the western margin of the Salta Basin, where sandstone hosted uranium deposits occur in the Yacoraite Formation. The reopening of the Don Otto mine was to be formally started in August 2007 with the aim of producing 30 tU/year, but the project never started. Globe Metals and Mining was formerly working in this area. [14]

Following unsuccessful efforts to auction the Cerro Solo deposit, CNEA, in late 2004, announced plans to clarify its strategy for restarting work at the deposit in southern Chubut Province. Between 2001 and 2004, there was also a change in the Provincial Government whereby the new administration designated the vicinity surrounding Cerro Solo an exclusion zone with respect to a law that forbids open pit mining there. Possible strategies involved creating a collaboration with a private company, starting a new auction for the project or formulating another alternative.

Opposition to new mining ventures or plans to reactivate mining was expressed in other parts of the country throughout 2007–2009. Protests were held against exploration for uranium in a UNESCO World Heritage area, Quebrada de Humahuaca (Jujuy Province). Protests counter to mining projects for uranium in the west of Catamarca Province took place on 6 November 2007. CNEA suspended exploration for uranium that was under way in Catamarca Province owing to budgetary constraints.

A proposal in June 2004 to reactivate the Rafael mining–milling complex (Sierra Pintada mine) was submitted to provincial and national licensing authorities. The environmental impact assessment was prepared and studies established that past operations had not adversely impacted the quality of water in the area. Mendoza Province authorities disallowed the proposed project and demanded remediation be conducted prior to restart of production. Local Law 7722 was adopted, which bans the use of sulphuric acid in operations for mining and this further confounded plans to restart activities for mining [8, 15–24].

From 2010 to 2019, successful exploration was carried out on several areas.

From 2012 to 2018, activities at Cerro Solo ore deposit was related to environmental baseline surveying.

Ur America Ltd has focused its efforts on developing its properties in the San Jorge Basin, Province of Chubut. They surround known high-grade deposits and historical mines such as the Cerro Solo deposit. Three deposits were discovered, Graben, Plateau West and Plateau East with total resources of 7350 t U at a grade of 265 ppm. The Cretaceous host rock (Los Adobes Formation) is comprised of fluviatile to lacustrine siltstones, sandstones and conglomerates [25].

In 2007, Blue Sky Uranium started exploration on the Amarillo Grande Project, Rio Negro Province. The Ivana deposit was discovered in 2016 with resources of 8625 t U at a grade of 207 ppm U [1.25]. The project is located at the SE border of the Neuquen Basin filled with Mesozoic and Cenozoic sedimentary and volcanic deposits. The formations present at the Ivana deposit are continental epiclastic and pyroclastic rocks of the Oligocene-early Miocene Chichinales Formation that were deposited unconformably over the rocks of the North Patagonian Massif. The lower member of the Chichinales Fm, host to the Ivana U-V mineralisation, is cross-bedded medium- to coarse-grained sandstone with silicified logs and plants-wood debris [26].

In 2017-2019, Sophia Energy S.A., UrAmerica Ltd and Blue Sky Uranium Corp reported exploration activities. Sophia Energy S.A. continued the exploration of the Laguna Sirven deposit in the Santa Cruz Province. In 2018, a radiometric airborne survey was carried out covering the whole project [27].

In January 2018, UrAmerica Ltd, Uranium One, UrAmerica Argentina and the Government of Argentina signed a memorandum of understanding whose main purpose is to promote cooperation and the joint development of uranium exploration and production focused on ISL [27].

In 2019, Blue Sky Uranium Corp announced the first PEA for Amarillo Grande project, as well as an updated resource estimate. Exploration in 2019 continued to focus on expanding the mineralisation close to the Ivana deposit. The first half of the year included pit and auger sampling, with Induced Polarisation geophysical survey and up to 4 500 m of RC drilling planned for the second half of the year [27].

Uranium resources

As of 1 January 2019, the total identified resources of Argentina are 38 740 tU at the cost category <130 USD/kgU and belong to seven projects (Cerro Solo, Don Otto, Ivana/Amarillo Grande, Laguna Colorada, Laguna Salada, Meseta Central, Sierra Pintada) [27]. New inferred resources of 8 730 tU have been reported for the Ivana deposit. Reasonably assured resources and inferred resources, as of 1 January 2019, are recorded in Tables 1 and 2. Historical variations in these are shown in Figures 3 and 4 [27, 28].

Prognosticated conventional resources were reported as 1400 tU at <US $130/kgU. These resources exist in the La Volanta deposit in the Cerro Solo area, Chubut Province.

TABLE 1. REASONABLY ASSURED RESOURCES BY DEPOSIT TYPE (tU) [28]

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	2 890	4600	4600
Volcanic-related	2240	4000	4000
Surficial	0	2420	2420
Total	5130	11 020	11 020

TABLE 2. INFERRED RESOURCES BY DEPOSIT TYPE (tU) [28]

Deposit type	<US $80/kgU	<US $130/kgU	<US $260/kgU
Sandstone	10930	20090	21140
Volcanic-related	1 800	6 170	6 170
Surficial	0	1 460	1 460
Total	12730	27720	28770

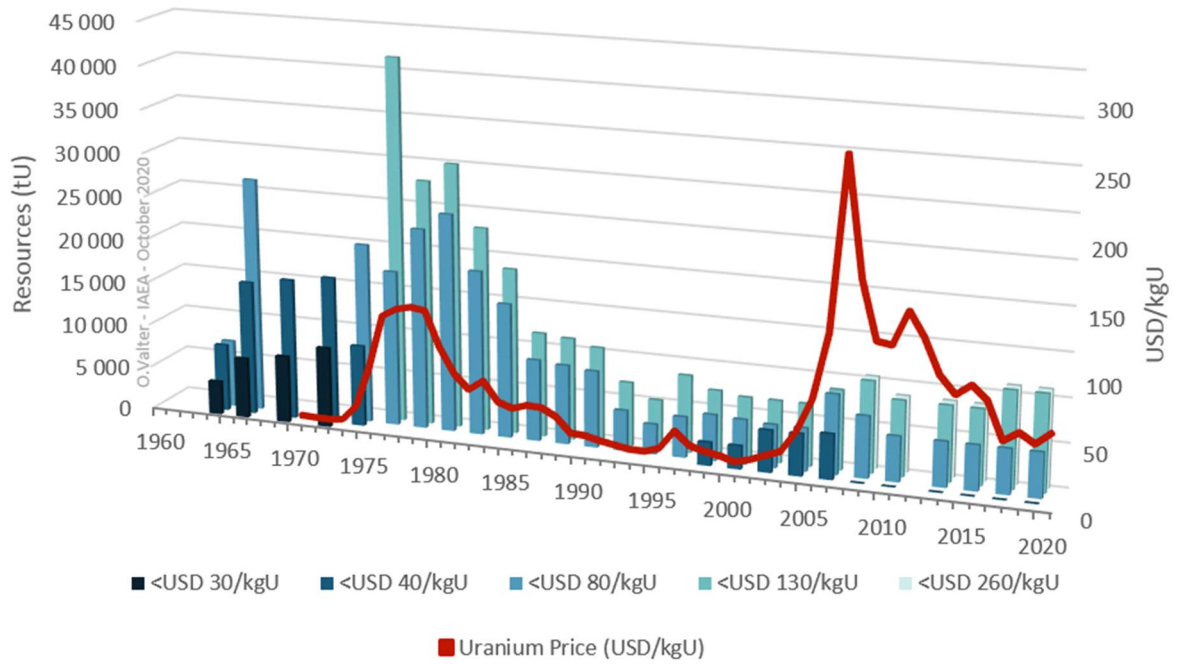

FIG. 3. Historical variation of recoverable reasonably assured resources within various cost categories in Argentina. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

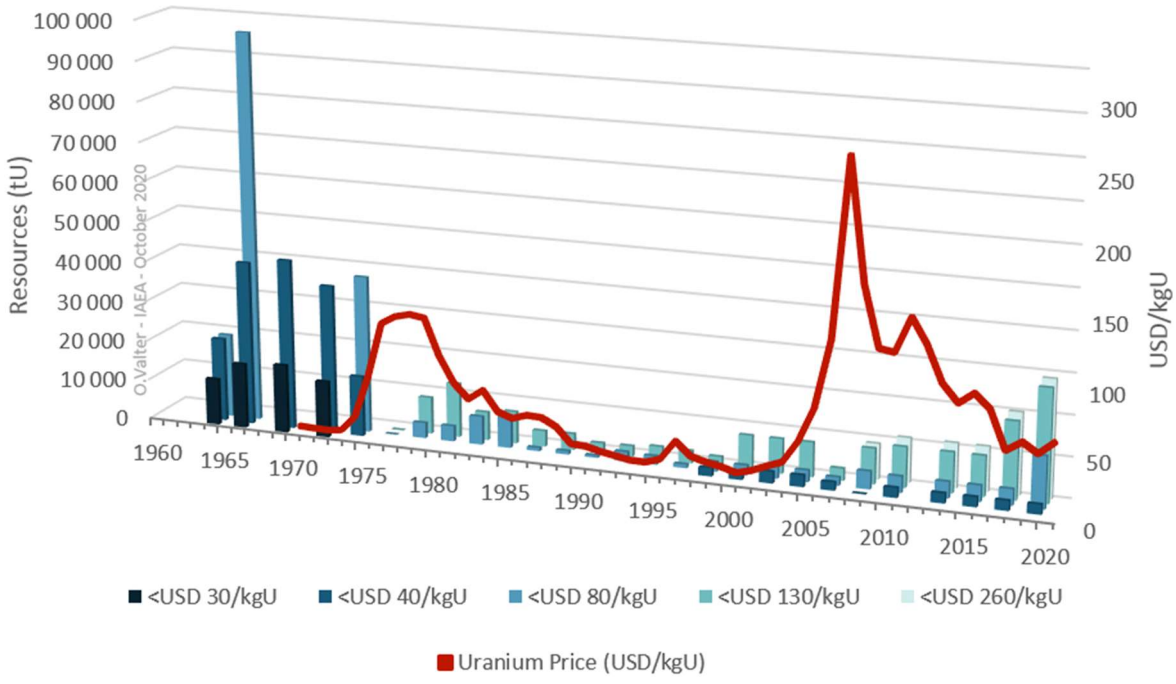

FIG. 4. Historical variation of recoverable inferred resources within various cost categories in Argentina. Periods where no resources are shown in any cost categories are periods where resources are not reported, either by the Member State or as a secretariat estimate.

Potential for new discoveries

There are extensive regions of Argentina where only limited exploration has been undertaken. Considering the extent of the potentially favourable areas and the number of occurrences discovered in earlier exploration programmes, there remains significant potential for new discoveries to be made.

As already mentioned, uranium occurrences have been identified or exploration or mining activities have been carried out in favourable geological environments in seven provinces.

CNEA reported 2000 uranium occurrences in Argentina that are of interest and remain to be explored. This total includes five occurrences in Chubut Province and one each in Catamarca and Santa Cruz Provinces where no activities have been carried out. The total potential resource for these seven sites is reportedly ~6200 tU [7].

13 810 tU of prognosticated resources are reported and correspond to five sandstone type deposits in the Cerro Solo uranium district (Cerro Solo, El Ganso, Puesto Alvear, El Molino and Arroyo Perdido).

Uranium production

Argentina started production of uranium concentrates in 1952. Chronologically, its activities consisted of the following steps:

(a) 1952: Pilot plant in Córdoba, heap leaching, percolation and mechanical agitation;
(b) 1954: Experimental plant at Malargüe (Mendoza Province);
(c) 1963: New plant at Malargüe, mechanical agitation and solvent extraction (80 t ore/d.;
(d) 1963: New plant at Don Otto (Salta Province), heap leaching, 'calcio' pre-concentration (100 t ore/d). Pre-concentrates (2–3% U) were produced at Malargüe and Don Otto and further refined to yellow cake at the Córdoba plant;
(e) 1970: Expansion and application of ion exchange at the Don Otto plant (200 t ore/d);
(f) 1977: New plant at Pichinan (Chubut Province), heap leaching, ion exchange (200 t ore/d);
(g) 1978: Expansion of Malargue, application of ion exchange, solvent exchange (200 t ore/d);
(h) 1979: New plant at San Rafael (Mendoza Province), heap leaching, ion exchange (500 t ore/d).

All of the abovementioned plants processed uraniferous minerals from deposits of the sedimentary sandstone type and all were operated by CNEA.

In 1982, the Los Gigantes production centre (Córdoba Province) went into operation. It had a capacity of 1600 t ore/d of low-grade (300 ppm U) ore using the heap leaching and ion exchange processes. The plant was operated by a private company [4, 13].

Up to the end of 2008, 2839 tU in concentrate was produced by open pit mining. Of this total, 1097 tU was processed at a conventional mill by heap leaching, including treatment of mine water and restoration of the environment. Details of historic production data are summarised in Figure 5 for a total of 2463 tU.

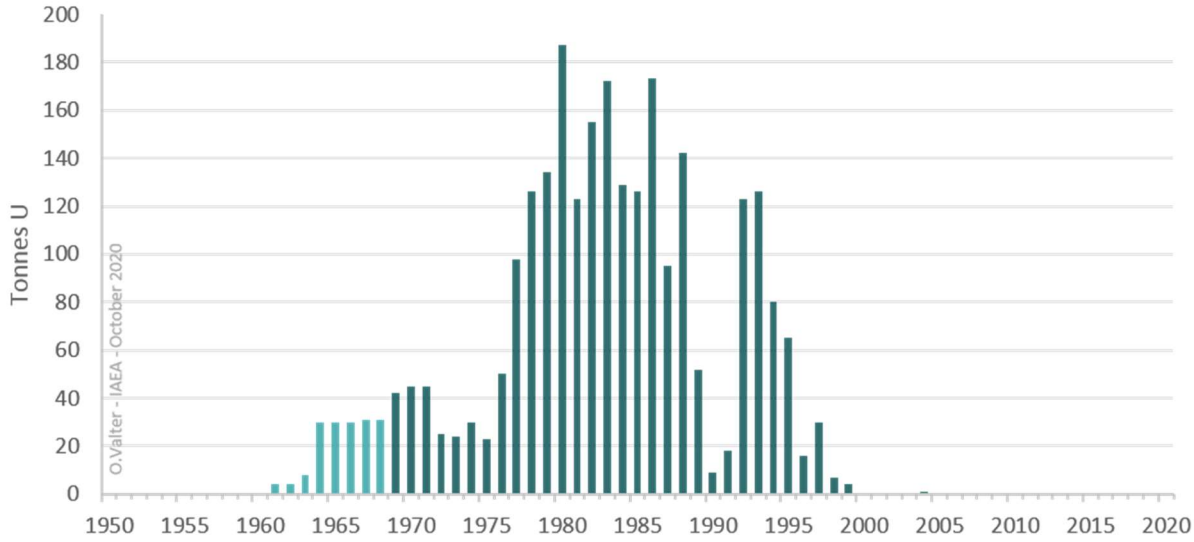

FIG. 5. Historical uranium production in Argentina (Data in light green are from the Red Book Retrospective, in dark green from Red Books).

Cumulative national production to 1997 from open pit and at a conventional mill by heap leaching at seven mines was 2643 tU from sandstone deposits including treatment of mine water and restoration of the environment [9, 13, 24].

Environmental activities

The European Union project entitled Innovative Strategies for the Preservation of Water Quality in the Mining Areas of Latin America conducted hydrogeochemical investigations to establish baseline values preceding mining operations of the Cerro Solo uranium–molybdenum deposit.

In 2009, an ongoing project to apprise the Sierra Pintada feasibility study emphasised improving surface and subsurface monitoring of water and conducting investigations on management of mining waste and mill tailings as short-term objectives.

The World Bank was considering a grant to remediate past mines and production plants for uranium [13].

Employment in the uranium industry

In 2002–2005, the uranium production industry hired 60 persons, and in recent years (2006–2008), the number of persons employed in the uranium production industry had risen to 133. This number was expected to increase to 140 by 2009. By way of comparison, in 1989, employment stood at 700, which then decreased each year.

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