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061.3: 553.495

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1979

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Nº 1	AÑO 1982

Reprint from

“VEIN-TYPE AND SIMILAR  
URANIUM DEPOSITS IN ROCKS  
YOUNGER THAN PROTEROZOIC”

## VEIN-TYPE AND SIMILAR URANIUM DEPOSITS OF ARGENTINA

### *Summary information*

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### Abstract

#### VEIN-TYPE AND SIMILAR URANIUM DEPOSITS OF ARGENTINA. SUMMARY INFORMATION.

Some vein-type and similar uranium deposits and occurrences are briefly described to show different models identified in Argentina. Practically all of them were formerly thought to be related to hydrothermal-magmatic processes, but at present few are considered to be so; some are classified as typically exogenous and opinions differ about the genesis of the remaining ones, especially because of a lack of sufficient research on the matter since this group of accumulations only contributes less than 10% to the entire uranium resources of Argentina. The typical vein-type ore bodies are small (including less than 200 t U) with grades varying from 0.1 to near 1% U. Other deposits, resolved as stockworks, could be from small to medium size (200 t U more than 2000 t U) with a uranium content from 0.7 to 0.03%, respectively. The mineralogical associations are variable, from complex ones in veins considered as magmatic-endogenous (with U, Ni, Co, Pb, Cu, Zn, etc.) to very simple ones in the exogenetic accumulations, which only comprise uranium minerals. The paragenetic studies available are not complete enough to define the possible relation of uranium with the other metals in the complex ores. The age of the mineralization has been defined in some cases, but not in others. There are examples of mineralizing processes occurring from Palaeozoic to very recent times. Some of the uranium deposits mentioned here have been exploited in the past; one of them will be re-opened very shortly; and a new one will be put into operation in 1981. The geological composition of Argentina is not favourable for uranium deposits related to the Proterozoic unconformity, and the best possibilities for finding interesting accumulations of vein and similar type are in the large Hercynian granitic environments which have outcrops that cover more than 150 000 km<sup>2</sup> (Pampean Hills and North Patagonian Massif).

### 1. BACKGROUND INFORMATION

Discarding old references on the identification of uranium mineralogical species, or on the presence of small uranium accumulations, the first and orientative occurrences were found in acidic pegmatites of the Córdoba Hills, in central Argentina. The subsequent search for uranium deposits during the period

1945–50 was orientated to this type of model and in this way the main pegmatites of the Pampean Hills (especially in Córdoba and San Luis provinces) were checked by the Dirección General de Fabricaciones Militares. Some of them provided small but rich uranium pockets (up to 50% U) where the uranium sometimes appeared as beautiful 1–3 cm cubic crystals of uraninite coated with “gummite” and yellow minerals (Friz et al. [1]; Stipanovic et al. [2]; Angelelli [3]).

In 1950, the control of the uranium activities in Argentina was transferred to the Comisión Nacional de Energía Atómica (CNEA), who started the search for radioactive mineral deposits in 1952, but also allowed private participation. Exploration at that time was mainly concentrated on the old mining hydrothermal districts.

The promulgation of the Law of Compulsory Nuclear Prospecting<sup>1</sup> forced the CNEA to check all Argentine mineral deposits to verify the possible presence of radioactive ores in each of them. This task was mainly carried out between 1957 and 1960, and numerous uranium and thorium occurrences were found, but were generally small and unworkable vein-type uranium accumulations.

But some more interesting occurrences were explored by the CNEA or private companies and a few proved suitable for further exploitation on a small scale, giving varying profits to their private operators (very good in the cases of the La Estela, San Sebastian and Santa Brigida mines, because of the high grade of the ores). The exhaustion of the richest parts of the ore bodies and the low prices of uranium brought about a total paralysation of all the mines in the second half of the ‘fifties.

Formerly, most of the above-mentioned uranium deposits and occurrences were related to endogenous-magmatic processes (Angelelli [3, 4]; Stipanovic et al. [2] etc.), even though the paragenetic studies were inadequate to support these ideas. This was especially valid for the complex uranium-nickel-copper associations.

The new orientation conferred by the CNEA on its exploration programmes after 1968 and the strong increase in uranium prices after 1973 partially renewed the interest for this type of uranium deposit in Argentina. A critical revision of the past information and new studies were carried out on some known occurrences and districts, which led to the development of new concepts about their metallogenesis.

Anyhow, these activities did not suffice to clarify pending metallogenic problems, because the main attention was given to the sandstone-type deposits, which contribute around 90% of the uranium resources of Argentina.

The location of the main deposits and occurrences mentioned in this paper is given in Fig. 1, and the purpose of this contribution is to offer some representative examples of extreme cases.

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<sup>1</sup> Included in the general Nuclear Minerals Act of 1956 and its Regulation of 1957.

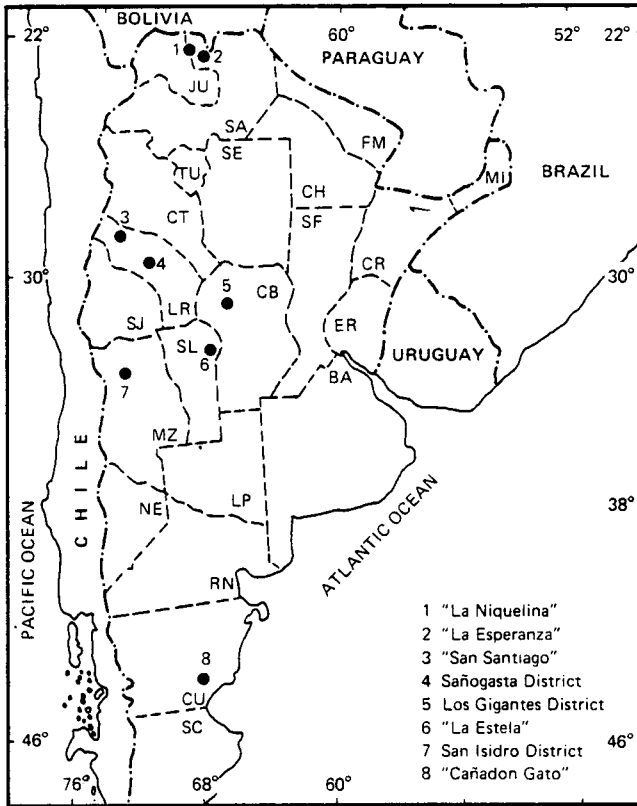


FIG.1. Location of the main vein-type and similar uranium deposits of Argentina.

Provinces: BA = Buenos Aires; CB = Córdoba; CH = Chaco; CR = Corrientes; CT = Catamarca; CU = Chubut; ER = Entre Rios; FM = Formosa; JU = Jujuy; LP = La Pampa; LR = La Rioja; MI = Misiones; MZ = Mendoza; NE = Neuquén; RN = Río Negro; SA = Salta; SC = Santa Cruz; SE = Santiago del Estero; SF = Santa Fe; SJ = San Juan; SL = San Luis; TU = Tucumán.

From an economic aspect (controlled by local conditions), the vein-type and similar uranium deposits of Argentina could be grouped as follows:

- (1) Small vein-type accumulations (less than 200 t U), commonly with a simple, or not too complex, mineralogical composition but with high-grade ores which allow exploitation, or would permit future production from ores still remaining in the mine under favourable price conditions (Sañogasta district).

- (2) Small vein-type accumulations with complex mineral associations, not favourable for exploitation despite their high-grade ores (complex metallurgy, small uranium resources for costly mill installations, non-favourable location, etc.), as in the La Niquelina and San Santiago mines.
- (3) Small vein-type accumulations with simple and favourable mineralogical associations, but not workable because of some unfavourable factors (small volumes, low-grade ores, bad locations, etc.), as, for example, the Cañadon Gato and the Soberanía deposits.
- (4) Small to medium size deposits of stockwork type included in granitic rocks, with good to low-grade ores (respectively) and suitable for exploitation under good price conditions, because of favourable locations, excellent acidic and coarse-grained gangue and cheap mining and processing operations (Los Gigantes, La Estela, etc.).

## 2. DEPOSITS WITH POSSIBLE HYDROTHERMAL-MAGMATIC ORIGIN

### 2.1. La Niquelina mine

This small deposit is located 300 km north of Salta City (in Salta province) in the Santa Victoria Hill in an environment of Cambrian quartzites and Ordovician dark shales, where vertical veins of some tens of metres long and up to one metre thick occur. Within a quartz-siderite gangue, mineralized pockets with pitchblende, niccolite, galena, sphalerite, chalcopryrite, pyrite, etc. occur (Tufiño [5]).

The pitchblende was formed at  $170 \pm 10$  Ma (Stipanivic and Linares [6]), and the deposit was classified as mesothermal (Lucero [7]).<sup>2</sup>

La Niquelina mine was formerly exploited for nickel, but after that for uranium and nickel in the second half of the 'fifties, when small but rich lots of niccolite and pitchblende were recovered.

The original ores were easily beneficiated with physical methods giving a uranium pre-concentrate (with more than 1% U) and a nickel pre-concentrate (with more than 15% Ni), both totalling around 150 t of pre-concentrates (in equal amounts). The final uranium and nickel recovery was not possible owing to technical problems (high arsenic content in both pre-concentrates).

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<sup>2</sup> Ma =  $10^6$  years.

## 2.2. La Esperanza mine (formerly named Chacabuco mine)

This old mine is located not so far from the above-mentioned La Niquelina deposit, in the same geostructural environment. During the Spanish colonization, this mine was exploited by the Jesuits to recover gold and silver.

The mineralized veins are settled in secondary faults perpendicular in relation to the main fault system of the region. The vein-gangue is composed of ankerite with a little calcite and quartz. Lead, zinc, copper and iron minerals are the dominant minerals in the upper levels, and uranium and cobalt minerals are subordinate, while at the lower levels the amount of uranium increases and other nickel minerals appear. Brodtkorb [8] has defined the following mineralizing sequence: First, pitchblende; second, sphalerite; third, ullmanite, tennantite and tetrahedrite; fourth, bornite, chalcopyrite, linneite and millerite; fifth, argentiferous galena.

Angelelli [4] has considered this deposit as epithermal (magmatic) and the uraninite was formed at  $271 \pm 15$  Ma (Stipanicic and Linares [6]).

## 2.3. San Santiago mine (formerly named La Solitaria mine)

This small deposit lies 280 km NW of Chilecito and 30 km E of Jagüe (La Rioja province) and has been worked intermittently on a small scale for over a 100 years to recover nickel.

The geological framework shows a Precambrian basement with pyritized quartzites, amphibolites, limestones and schists intruded by a Precambrian granite to which pegmatites, aplites, lamprophyres and quartz-veins are related (Barrionuevo [9], Diez [10], Belluco et al. [11]).

Within the pyritized quartzites and amphibolites, a subvertical vein was placed, which was 130 m long and between 0.30 and 0.60 m thick. In its contact with the vein, the wall-rocks show a strong hydrothermal alteration, resolved as pyritization [9–11].

Niccolite is the dominant mineral which can appear as small pockets, thin and long veinlets or in more important accumulations included in a calcite gangue with little quartz. Pitchblende and becquerelite appear as subordinate minerals as well as pyrite, chalcopyrite, magnesite, sphalerite and galena. In the weathered levels, autunite, zeunerite and annabergite occur. The pitchblende coats the niccolite pockets but also penetrates the niccolite bodies as thin veinlets [9–11].

Barrionuevo [9], Diez [10] and Angelelli [4] consider the whole mineralization at San Santiago to be mesothermal and related to the regional Precambrian granitic magmatism, but the uraninite of  $53 \pm 1$  Ma (Stipanicic and Linares [6]) to be posterior and independent of the nickel mineralization, and was referred to by Belluco et al. [11] as Tertiary hydrothermal process. The senior author (P.S.) does not discard the possibility of even an exogenetic origin with the uranium

leached from the granites and after that precipitated in the pre-existing nickeliferous veins during Tertiary times.

During the last exploration works carried out in 1952–53, around 75 t of uranium and nickel ores were recovered, with 1% U and 18% Ni. Despite these contents, the deposit is not economically workable because of its small size, discontinuity of the mineralization and unfavourable location (Barrionuevo [9]).

### 3. OTHER VEIN AND SIMILAR URANIUM DEPOSITS

#### 3.1. The Sañogasta District

Several uranium deposits and occurrences are known in the Sañogasta District, 35 km SW of Chilecito (La Rioja province). The more important ore bodies are those of San Sebastian and Santa Brigida.

The district is composed of Ordovician haematized schist and phyllites of low metamorphic grade, which are intruded by rhyolites, rhyodacites and quartz veins derived from Lower-Middle Devonian magmatites (granites, granodiorites, etc.) of which the granites have a high uranium content of around 10 ppm U (Lucero et al. [12]; Belluco et al. [11]; Berizzo and Valdiviezo [13]).

The subsequent erosion which followed the Middle Devonian orogeny produced a large crystalline peneplain over which Late Devonian, Carboniferous and Permian sediments were deposited (Berizzo and Valdiviezo [13]).

Vertical and sub-vertical veins of some tens of metres long (up to 60 m) and 0.50 to 8 m thick were settled within the Ordovician schists, or in contact with the schists and the Devonian granite. The veins are filled with calcite, violet fluorite and barite, and a mineralization of pitchblende, clarckite, pyrite, chalcopyrite, bornite, chalcocite and umanguite took place in the vein joints and cavities. "Gummite", uranophane, tyuyamunite, malachite, chrysocolla and azurite appear in the highest levels (Lucero et al. [12]; Berizzo and Valdiviezo [13]), but all the uranium was totally leached from the surficial levels up to a depth of 4–5 m.

The ore bodies of the Sañogasta District are sometimes disposed "en échelon" and they could be grouped in three main types [12, 13] as follows:

- (a) *Simple copper-uranium veins*, up to 50 m long and 0.50–3 m thick, well mineralized down to a depth of 35–50 m, while further downwards the uranium and copper mineralization decreases sharply. During some years of exploitation, rich lots with 1% U and 5% Cu were recovered from these simple veins and once 16 t of ore with 10% U were obtained.

- (b) *Composed stockworks*, with a central and rich copper-uranium body, similar to that mentioned in (a), but surrounded by an impregnation halo of 5 m or more (on both sides), where secondary uranium minerals and subordinate green-blue copper minerals occur, averaging a grade of 0.15–0.20% U (Figs 2 and 3).
- (c) *Simple stockworks without a central rich body*, mainly developed in very crushed and altered zones, with uranium yellow minerals with an average content of 0.25–0.40% U.

For some years, the San Sebastian and Santa Brigida mines produced 2500 t of ores with an average grade of 0.8% U (Friz et al. [1]), but, because only the richest parts of the deposit were exploited, materials with 0.1–0.3% U remained in the mine.

The whole Sañogasta copper-uranium mineralization was considered to be mesothermal and related to a Devonian magmatic phase by Angelelli [3, 4]. Lucero [7] also supported this origin but only for the step of the formation of the original vein mineralization, going on to accept a further exogenetic stage of uranium mineralization produced by underground waters which have leached the uranium from the original veins, later precipitating it. Belluco et al. [11] favour a pure exogenetic origin of the uranium veins.

The paragenetic studies are insufficient to define this problem, but the senior author (P.S.) prefers to support the following process, which is partially in agreement with that proposed by Berizzo and Valdiviezo [13]:

*First*, the original calcite and fluorite veins (forming the gangue) are endogenous and related to the Early-Middle Devonian magmatism. These veins also show continuity in depth (roots).

*Second*, the first uranium mineralization took place later on, because the uraninite was dated as being between  $305 \pm 10$  and  $316 \pm 30$  Ma, i.e. of Middle Carboniferous age (Stipanovic and Linares [6]). The uranium was formerly leached from the fertile Devonian granitic peneplains sculptured after the action of the Mid-Devonian diastrophism, after which it was deposited in favourable structures (joints, crushed zones, cavities) of the existing host calcite-fluorite veins, adopting a morphology of a vein or simple stockwork, rich in the upper levels, but with a strong impoverishment downwards.

*Third*, later on, and during different geological periods, the underground waters allowed a partial uranium mobilization, giving place to the formation of younger pitchblende veins (in reducing environments, with pyrite) as

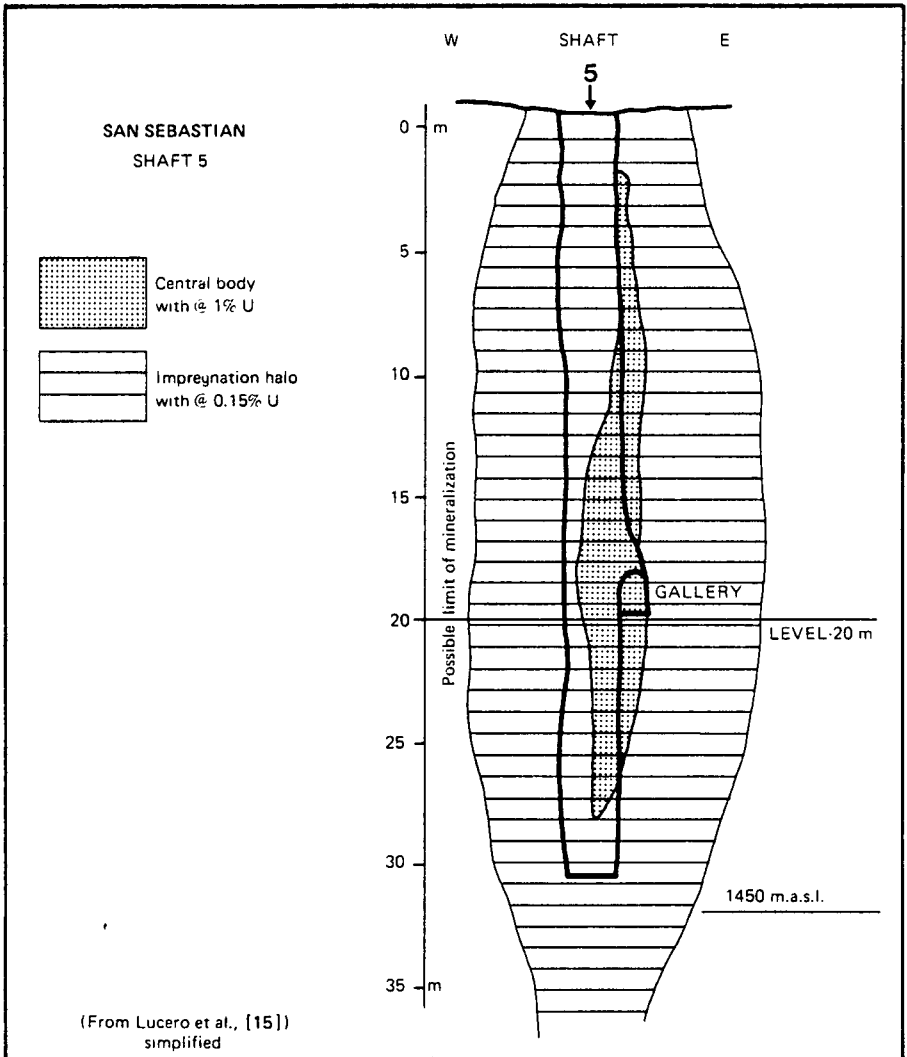


FIG.2. San Sebastian mine (La Rioja province). Vertical section of the vein along shaft No. 5.

well as of impregnation halos of yellow minerals in oxidizing zones outside the central veins. The new pitchblende veins were placed either in the joint and cavities of the original calcite-fluorite gangue, or inside the cracks of the old and partially altered uraninite veins, according to Schalamuck's studies (CNEA Lab.).

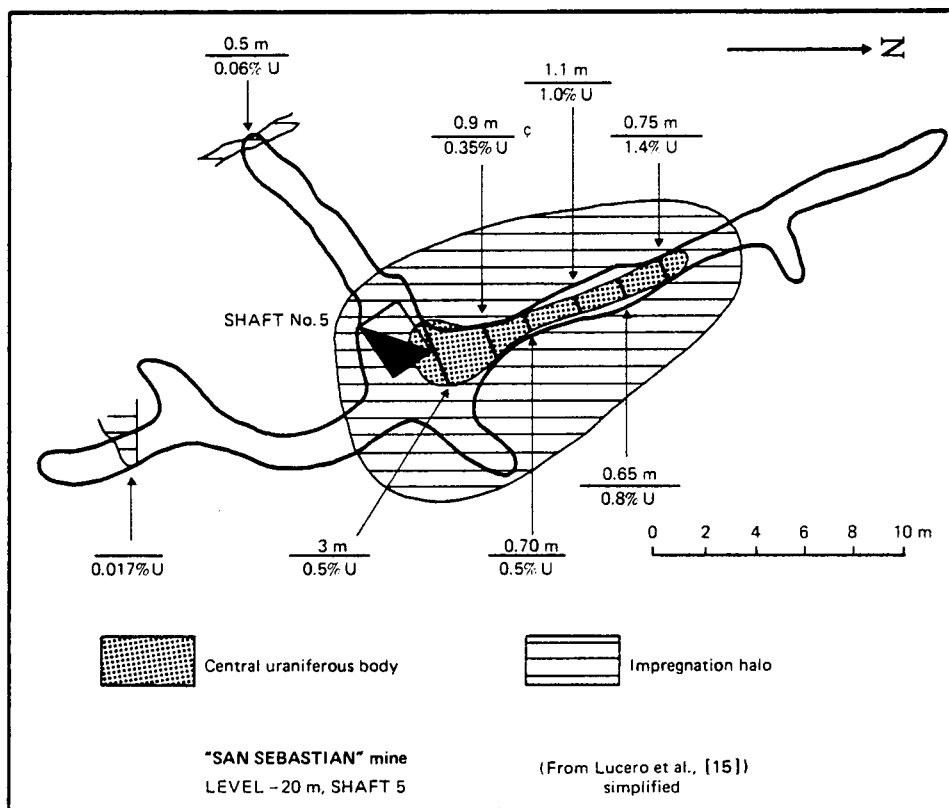


FIG.3. San Sebastian mine (La Rioja province). Mineralization at the -20 m level in shaft No. 5.

The wide distribution of other exogenetic occurrences in the same geological environment, contained in different host rocks, also favours the above-mentioned exogenetic origin for the Sañogasta uranium deposits.

### 3.2. Uranium deposits in the Palaeozoic granitic environment of the Pampean Hills

#### 3.2.1. Background information

A large and composed "granitic" batholith was intruded in metamorphic rocks of the Late Precambrian (gneisses, schists, marbles, etc.). This batholith extends over more than 120 000 km<sup>2</sup> through several provinces, but the more important outcrops are those of the San Luis and Córdoba provinces where their

morphological expression constitutes the system of the Pampean Hills (or Central Hills) divided into partial mountain chains (Córdoba Hill, San Luis Hill, Comechingones Hill, etc.).

Within this “granitic” environment, the following different types of uranium deposit and occurrence are known:

- (a) In acidic Palaeozoic pegmatites;
- (b) Vein and stockwork deposits in granitoids;
- (c) Uraniferous palaeocalcretes (Late Eocene);
- (d) Recent uraniumiferous calcretes.

The genetic process which led to the formation of uraniumiferous pegmatites is well known and not discussed here. But, on the other hand, no total agreement exists on an explanation of the metallogenesis of some of the uranium veins and stockworks mentioned in (b), and in this regard a similar problem exists to that connected with the French and Portuguese uranium deposits included in the Hercynian granitoids.

In this connection, the following main genetic models are supported by the Argentinian geologists:

- (i) Typically magmatic-hydrothermal (epithermal);
- (ii) Endogenous-hydrothermal (epithermal), but possibly related to episensitization processes; and
- (iii) Typically exogenetic, with the uranium leached at different times from large granitic peneplains of different ages and after that deposited under favourable chemical-physical conditions either in crystalline or in sedimentary rocks.

Outside the theoretical point of view on the subject, the problem is of special economic and practical significance, because of the following aspects:

The possible uranium potential of the whole granitic environment of the Pampean Hills would be very different according to the validity of one of the three above-mentioned mineralizing models, with an increasing favourability from the first to the third one;

The orientation of the future detailed exploration programme over the above-mentioned large areas would also vary according to the valid metallogenetic model;

Should the third possibility turn out to be the correct one, the corresponding process also would be valid to explain the formation of the calcrete deposits (Eocene to Recent), favouring largely the uraniumiferous potential of the whole area.

Two different examples of vein-type and similar uranium deposits included in the granitic Pampean Hills are mentioned.

### 3.2.2. *The crystalline environment of the Pampean Hills*

The granitic batholith of the Pampean Hills was intruded in Precambrian metamorphic rocks and is mainly composed of granites, granodiorites, porphyric granites, etc., of different ages, ranging from Lower Cambrian to Triassic, but most are of Hercynian age (Stipanovic and Linares [6]).

A large number of pegmatites and aplites have been intruded either in the granitoids or in the metamorphites, and the acidic pegmatites commonly show interesting pockets of uraninite, columbite, tantalite, etc. (Angelelli [4]; Lucero [7]).

The entire crystalline environment of the Pampean Hills has undergone different stages of peneplanitization resulting from erosion which followed the action of the main diastrophic phases. Among them, the more important in relation to some uranium deposits are the Intersenonian and some Tertiary phases, which allowed the sculpture of very large peneplains, extending over thousands of square kilometres, from which the uranium was able to be leached at different opportunities when favourable climatic and morphological conditions prevailed (conditions mentioned by Stipanovic [14]).

The crystalline rocks of the Pampean Hills have also suffered a strong fracturing produced by different tectonic movements and some of these fracturing systems have played an important role in the control of the uranium accumulations (Lucero [7], Lucero et al. [12]).

A main tectonic phase, compressive in character, has originated a NNW-SSE (with tendency to N-S) large-scale fault system of regional scope (upthrust), which created the horst-graben structure of the Pampean Hills, with fault scarps of 1000 metres or more [7, 12].

In joining with the above-mentioned large faults, a secondary NW-SE fault system produced some wedge-shaped and strongly fractured zones in which several uranium deposits and occurrences are located (Fig.4), such as those of Los Europeos, Schlagintweit, La Morenita and Cerro Aspero (Lucero et al. [15], Nicolli et al. [16]). Another fracturing system, with W-E direction and tensional character has also contributed to the control of other uranium occurrences, as that of La Estela (Lucero et al. [12, 15]).

The uranium content of the different granitoids of the Pampean Hills is variable, from around 4 ppm U in the standard granites up to 6–9 ppm U in the “fertile” granites, which commonly are those with potassium feldspars of perthitic-microcline type, sub-hedral biotite (as dominant ferromagnesian component), and apatite, zircon and rutile as accessory minerals. The apatite, normally very frequent, is commonly uraniferous and fluorescent (Lucero et al. [15]).

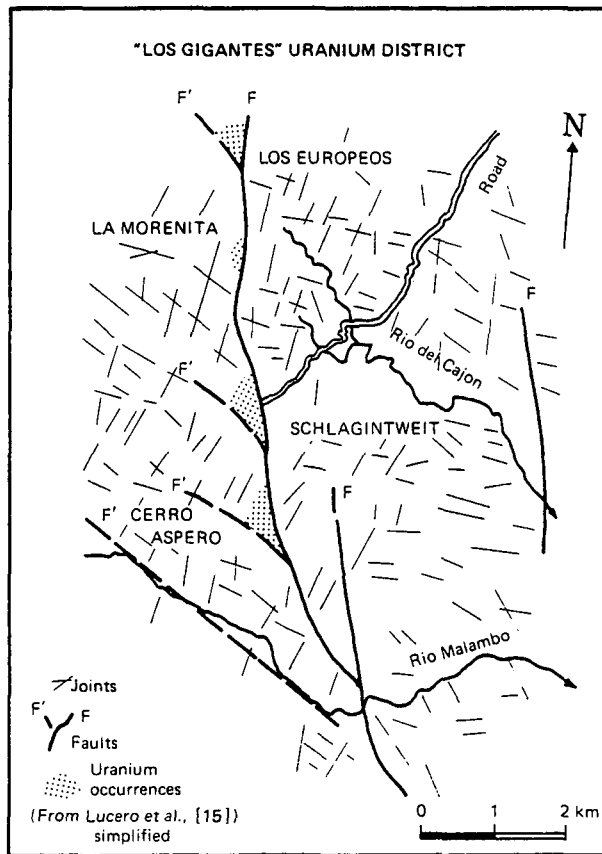


FIG.4. *Los Gigantes District (Córdoba province). Location of the uranium occurrences controlled by structural factors.*

In some limited areas, related to convergent tectonic structures, the granitic rocks show clear signals of episyenitization (see below).

On the other hand, the "fertile" granites also offer another characteristic pattern – they show an advanced alteration and disaggregation, produced either by their own composition or by a strong weathering process which was favoured by the crushing tectonics of the concerned areas.

### 3.2.3. *Los Gigantes District*

Several uranium occurrences are known in Los Gigantes District, about 80 km W of Córdoba City (Córdoba province) of which the more important are

those of Los Europeos, La Morenita, Cerro Aspero and Schlagintweit, but especially the latter (Fig 4).

All these occurrences outcrop and are located in the wedge-shaped crushed granitic bodies produced in the joining of some of the NNW-SSE and NW-SE faults mentioned above (Lucero et al. [15]).

The more important ore body (Schlagintweit) has a surficial extension of 600 m by 300 m and the mineralization is limited to 40–50 m in depth, according to the drilling exploration.

Two main factors have controlled the uranium mineralization – one is structural in character because the mineralization is limited to the more crushed and tectonized areas included in the above-mentioned wedge-shaped zones, where alteration is also more advanced. The other factor is chemical in character – the uranium has been preferentially concentrated where the phosphatic content is also high. Autunite and meta-autunite are the dominant minerals, but also beta-uranophane and phosphuranyllite are present in small quantities (Lucero et al. [15]; Nicolli et al. [16]), all of them coating cracks, joints, fractures and grains of the host rocks. The mineralization is exclusively monomineral and there is not any kind of gangue [15, 16]. Downwards, where the granite is less altered and fractured, the mineralization is limited to fine veinlets of pitchblende and finally it disappears in depths [15, 16].

Recent studies demonstrated that the “fertile” granites were strongly leached in recent times by surficial waters, and the mobilized uranium has been preferentially concentrated where the two above-mentioned factors were present (physical and chemical factors). As a result of this leaching process, a very strong disequilibrium was found in the “fertile” granitic environment, where the average ratio between U total and eU is only 0.13 for the whole district, but still smaller for these granites at present showing a low U total content [15, 16].

The uranium mineralization at Los Gigantes District was considered as typically exogenetic and very young, possibly produced during Quaternary and Recent times [15, 16].

The Schlagintweit ore body was explored on the surface by trenches and by means of galleries and 10 000 m of drilling in depth. More than 2000 t U were proved to have an average grade of 250–300 ppm U. Another 2500 t U were defined as possible additional resources.

Despite the low grade of the ores, the Schlagintweit deposit will be put into production because of the favourable uranium leaching conditions (low sulphuric consumption in heap leaching) and cheap mining exploitation (surficial open pit).

Westwards of Los Gigantes District, a very promising occurrence was recently discovered in the same geological environment with more favourable grade ores.

The uranium potential of the whole granitic environment of the Pampean Hills (120 000 km<sup>2</sup>) in relation to deposits of a similar type to those of Los Gigantes appears to be excellent, but this favourability also could be applied to

the North Patagonian Massif, which shows a similar composition, with abundant Hercynian granitic rocks.

#### 3.2.4. *La Estela mine (formerly La Marquesa mine)*

Several uranium occurrences are known in the western slope of the Comechingones Hill, the more important of which is that of La Estela mine, located 190 km NNW of San Luis City (San Luis province).

From this deposit more than 3000 t uranium ores were extracted sporadically during the 'fifties, with an average grade of 0.5% U (Friz et al. [1]). It is estimated that more than 150 t U remained in the mine, with an average grade of around 0.1% U.

The country rock of the uraniferous district is a two-mica granite with microcline, orthoclase and oligoclase and xenomorphic quartz. The biotite is commonly altered (chloritized) and the more frequent accessory minerals are apatite, zircon and rutile (Lucero et al. [15]). In the area of emplacement of the ore body, the granite was episyenitized, in coincidence with convergent tectonic structures, and the quartz was partially or totally removed, possibly by alkaline solutions. In these episyenitized zones, the uranium content can be 100 times higher than in the nearby standard and not altered granites [15].

The La Estela uraniferous stockwork is included within a 30–40 m brecciated zone which was produced by a W-E tensional fault, but the original ore body, as well as its host rocks were later strongly disturbed by post-mineral faulting as indicated in Fig.5 [15].

The uraniferous ore body has 270 m in W-E direction parallel to the main faulted zone, and is between 7 and 15 m thick in the upper levels. Downwards, the uranium mineralization was certified up to 130 m deep showing a tendency to adopt a more defined vein-type pattern with small but rich pitchblende veinlets [15].

In the upper levels of the stockwork, the uranium remobilization and reprecipitation seem to have been frequent, and uranophane and autunite appear coating the joints, fractures and grains of the crushed host rocks but also forming impregnation halos inside the strongly altered wall-rocks (mainly kaolinized and, in minor scale, sericitized). In the proper La Estela mine, violet stink-fluorite, partially quartz, is also present in the uranium ore body and this fluorite was considered to be the paragenetic gangue for the uranium mineralization (Lucero et al. [15]).

The uranium mineralizing process of the La Estela was assumed to be typically epithermal with magmatic roots by Angelelli [3, 4], Lucero [7], Lucero et al. [12, 15] and Stipanagic et al. [2], and related to an igneous process produced at  $23 \pm 1$  Ma (Stipanagic and Linares [6]).

At present, the senior author (P.S.) is of the opinion that the above-mentioned metallogenetic concept merits some review according to new information available

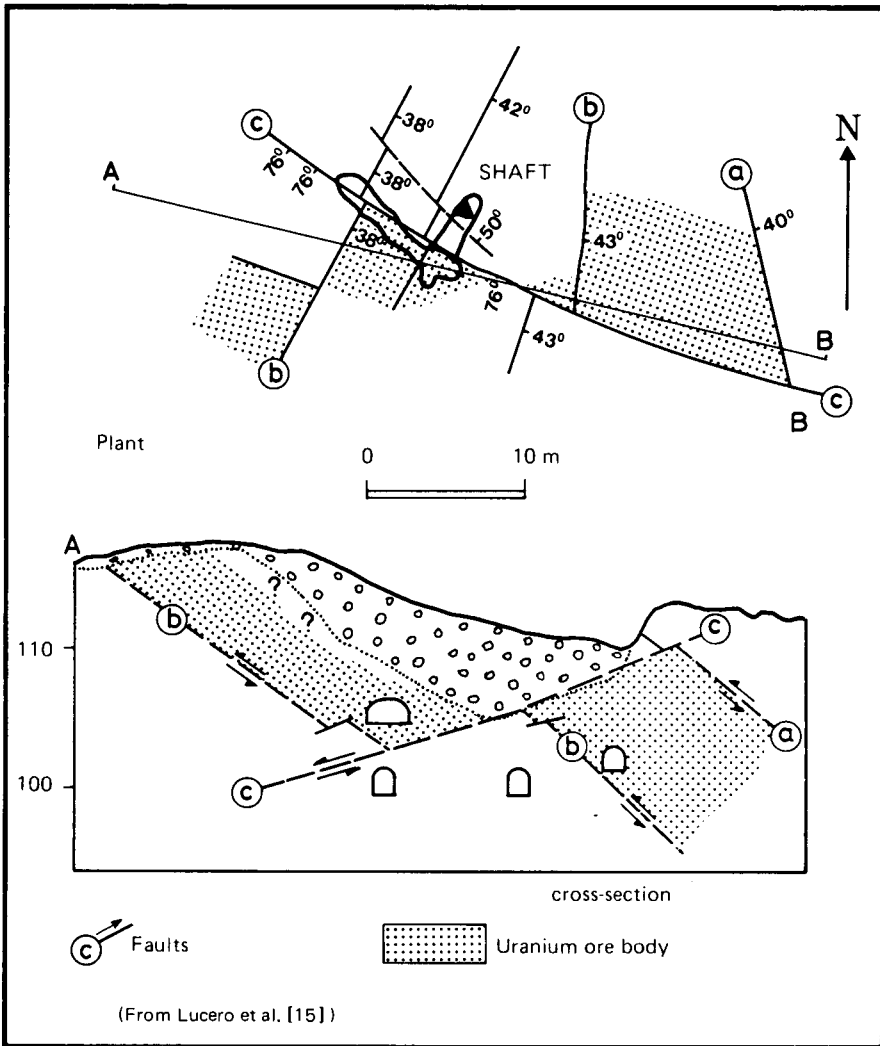


FIG.5. La Estela mine (San Luis province). Fracturing of the uranium stockwork by post-mineral faults.

about the mineralizing processes which controlled the formation of other uranium occurrences in the whole crystalline environment of the Pampean Hills. In this regard he believes that some factors favour a typical exogenetic explanation for La Estela.

- (a) The uranium contained in the fertile granites of the Pampean Hills is easily leachable and the leaching process could have taken place at any time when the geomorphological (peneplain) and climatic conditions were favourable. The example provided by Nicolli et al. [16] is self-explanatory in this regard.
- (b) The process of episyenitization with a strong differential enrichment of uranium in the de-quartzified granites also favours the exogenetic processes.
- (c) In the northern slope of the Comechingones Hill, where La Estela mine is located, are also fertile and episyenitized granites from which the uranium was already leached and transported to the adjacent Conlara Valley, where it appears in the underground waters (Nicolli et al. [17, 18]).
- (d) The Early Miocene antiquity of La Estela uraninite only indicates its age but not its magmatic origin. This uraninite could have been produced by exogenetic solutions transporting uranium previously extracted from the nearby fertile granitic environments.
- (e) The apparently closed paragenetic relation between the uranium and the stink-fluoritic gangue has never been proved by definitive research on the matter and this association could be only fortuitous. On the contrary, and according to available descriptions, all the uranium minerals (black or yellow) seem to be younger than the fluorite because they coat the fluorite grains and fragments, whose joints and fractures are also invaded by the uranium minerals. It also must be mentioned that during the first years of exploiting La Estela mine (then named La Marquesa), the *only product extracted* was a light-coloured and non-uraniferous fluorite. The present stink-fluorite could be only the result of the radioactive action produced by the uranium minerals over some veins of standard light fluorite.
- (f) In a drilling core sample from La Estela, exhibited at the CNEA Office in Córdoba, a beautiful uraninite vein, 2–3 mm thick, appears introduced into the granitic host rock where the fluorite gangue is practically absent.

### 3.3. San Isidro District

This district, comprising three small uranium occurrences (Soberanía, Independencia and Papagayos) lies 20 km W of Mendoza City (Mendoza province).

They were exploited for a short time during the 'fifties, producing more than 1200 t of ores with an average grade of 0.2% U. The activities were stopped because of the cost of mining production and the low uranium prices of that time (Friz et al. [1]).

Closely related to a main fault, which put Triassic and Tertiary continental sediments in tectonic contact (Figs 6 and 7), three mineralized sectors were defined in connection with sub-vertical quartz veins 0.10–0.30 m thick. The individual uraniferous bodies had an extension between 20 and 80 m along the strike and all together totalized 350 m of mineralization in horizontal development (Belluco et al. [19]).

The uranium mineralization decreased between 30 and 60 m and practically disappears downwards, despite the continuation of the quartz-vein-gangue. The uranium content in the veins was between 0.1 and 0.7% U with an average of 0.2% U.

The original quartz veins which filled tensional fissures were disturbed by posterior movements, acquiring a brecciated pattern with cataclastic structure (Belluco [20]).

Below a depth of 15–20 m uranium is present as pitchblende, but above this level as schroeckingerite, uranophane and meta-autunite. In all cases, the uranium minerals (black and yellow) coat the breccia fragments or the cataclastic joints of the quartz veins. Small amounts of copper, iron, manganese, silver, vanadium and molybdenum are present. The yellow uranium minerals also penetrated into the clays and sandstones of the wall-rocks [20].

Belluco [20] supports a hydrothermal magmatic origin for the whole mineralizing process at San Isidro, related to nearby Tertiary andesitic intrusions, but recognizes that (a) both the black and yellow uranium minerals, together with the manganese, appear at later times, replacing the quartz or coating the quartz fragments or penetrating into the quartz cracks; (b) the gangue materials of the veins belong to two generations – the first one which produced the original quartz vein, and the second, when opal, calcite and gypsum were introduced into the small cavities of the veins, or have cemented the quartz grains.

Angelelli [4] has accepted the hydrothermal magmatic origin for the uranium occurrences of the San Isidro District, and later on so did Lucero [7], despite the fact that previously Belluco [19] changed his former position (see above) in favour of an exogenetic model, with the uranium leached from the nearby fertile granites outcropping at Cacheuta and precipitated by descending waters in the San Isidro faulted zones.

The senior author (P.S.) agrees with Belluco's 1974 opinion, especially because the granites and rhyolites of Cacheuta show not only a high content of labile uranium, but also a clear indication of its mobilization and immediate precipitation, producing many surficial uranium occurrences (Belluco et al. [19]). The uranium precipitation at San Isidro took place at 20 Ma, during Miocene times.

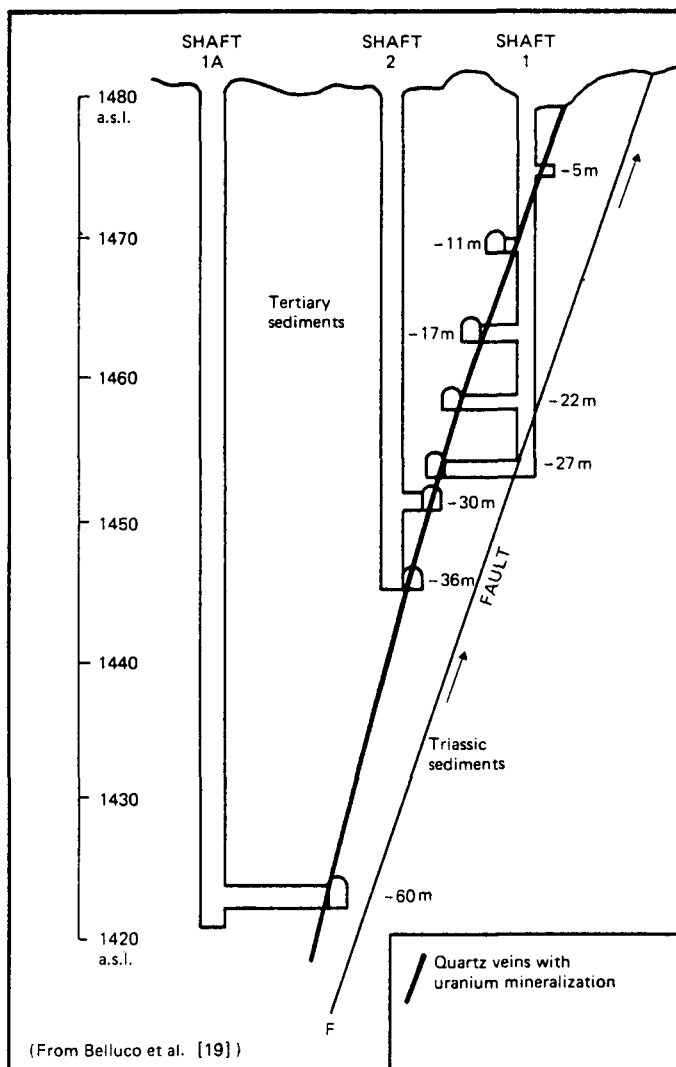


FIG.6. Soberania mine (Mendoza province). Relation of the uraniferous quartz veins with a main fault (see Fig.7, cross-section A-A').

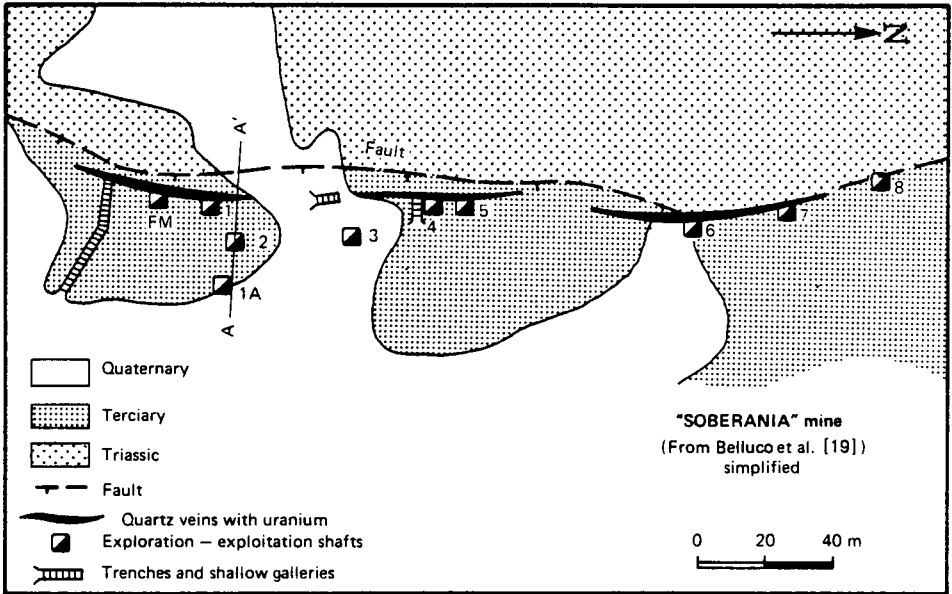


FIG. 7. Soberania mine (Mendoza province). Vertical section A-A' (see Fig. 6).

### 3.4. Cañadon Gato

This small deposit lies 70 km WNW of Comodoro Rivadavia City (Chubut province). The country rocks are Palaeocene subhorizontal beds of sandstones, glauconitic sandstones, mudstones and abundant pyroclastic tuffs which have a high uranium content (commonly over 20 ppm U). The sediments, mainly of continental deposition, are soft, not well cemented, of variegated but light colours. Montmorillonite elongate balls (5–10 cm) are included in some fine-grained sandstones, following the stratification (Olsen [21], Friz et al. [1], Stipanovic et al. [2]).

Within the above-mentioned sedimentary environment, tensional open fissures have allowed the ejection of basaltic materials (forming basaltic dykes) as well as the violent ejection of acidic pyroclastic materials (forming pyroclastic dykes), which dragged rocks from the substratum but also basaltic blocks [1, 2, 21].

At Cañadon Gato, an 8-km-long vertical to sub-vertical fissure is present, its thickness varying from a few centimetres to 45 m in some wide "bulbs", where the pyroclastic dykes got a diastem pattern (Fig. 8). Commonly the acidic tuffs of the dykes are altered in montmorillonite. Small amounts of oil and asphalt are expelled through the fissure [1, 2, 21].

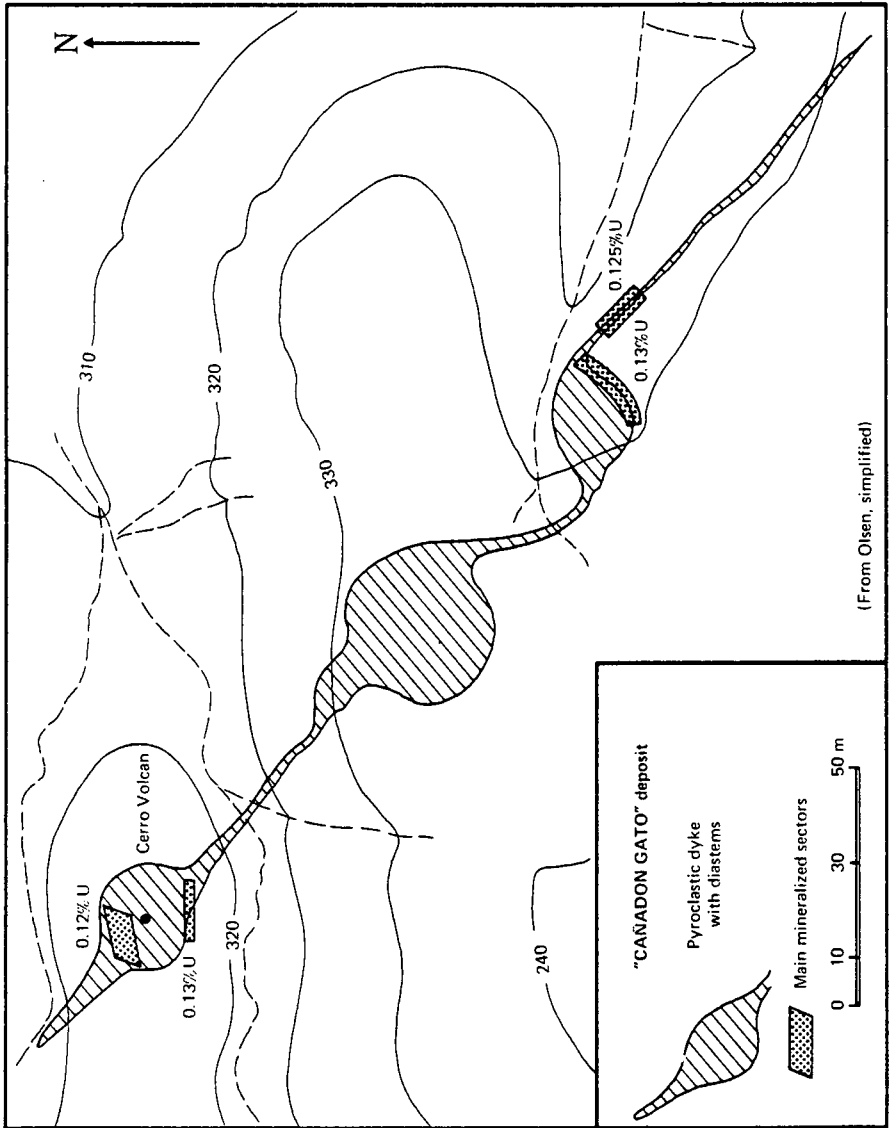


FIG. 8. Cañadón Gato deposit (Chubut province). Morphology of the pyroclastic dyke with diastems bearing uranium accumulations.

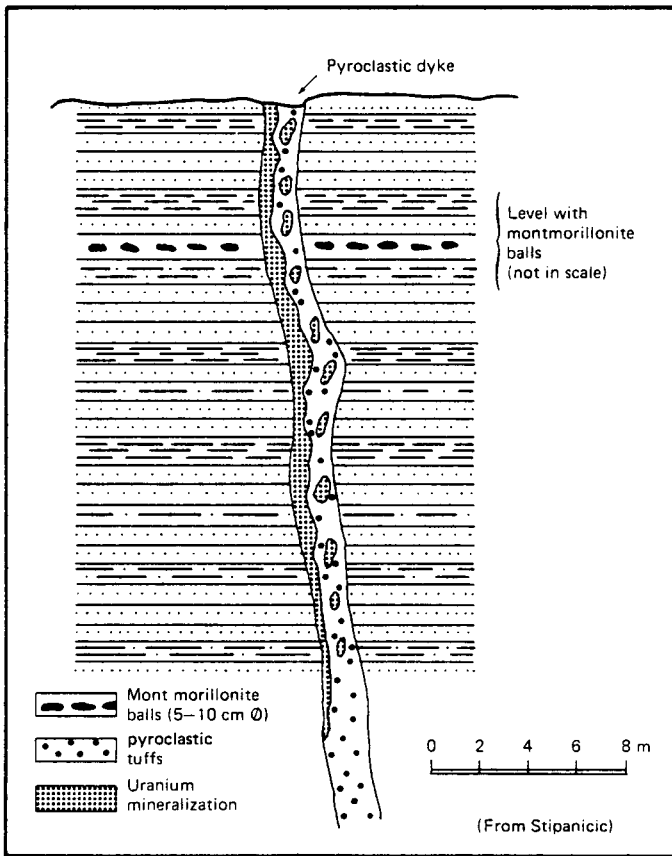


FIG.9. *Cañadón Gato deposit (Chubut province). Distribution of the uranium mineralization in the pyroclastic dykes and surrounding sediments.*

The uranium mineralization is present exclusively as yellow minerals (meta-autunite and meta-torbernite), which appear in the pyroclastic dyke (commonly on the walls) then adopting a vein-type pattern, and also as adsorbed by the montmorillonite balls included in the Palaeocene sediments (Fig.9).

The mineralization extends 350 m along the strike of the dyke but disappears at a depth of between 20 and 35 m. The thickness of the mineralized sector varies between 1 m (in the dykes) and several metres (in the "bulbs"). The average grade of the deposit is 0.13% U [1, 2, 21].

In the surrounding sediments the uranium appears highly concentrated by the montmorillonite balls up to a distance of 10 to 20 m from the dyke, and also impregnates the fine-grained host sandstones, but with a low grade.

The Cañadon Gato deposit was considered as typically exogenetic. The uranium was leached from the high radioactive Tertiary tuffs and the fertile solutions have found an impervious wall in the pyroclastic dyke, which favoured the further uranium adsorption by montmorillonitic materials of the dykes and clay-balls as well as by oil and asphalt [1, 2, 21].

#### 4. CONCLUSIONS

- 4.1. The discussion and elucidation of the genesis of the vein-type and similar deposits and occurrences of Argentina involve not only an academic point of view but also practical and economic interest.
- 4.2. At the beginning of the uranium exploration, almost all the known uranium accumulations of this type were considered to be hydrothermal-magmatic in origin and, consequently, the search for new similar deposits was only directed towards geological environments where hydrothermal-magmatic processes took place, which represented a considerable regional geological limitation.
- 4.3. The evolution of universal ideas on the matter, and the importance of new local data, led to a re-interpretation of the genesis of several Argentine vein-type and similar uranium occurrences.
- 4.4. As a result of this revision, at present only few of the numerous uranium accumulations mentioned above are considered as having magmatic-hydrothermal roots while others are interpreted as purely exogenetic. In a third group remain the uranium deposits and occurrences with a still not well-defined metallogeny, but the idea that they should have a pure magmatic origin has been practically discarded; opinions vary between an exogenetic position and those which support a vinculation with episyenitization processes.
- 4.5. The last two cases both largely favoured the uranium possibilities of extended areas of the Argentine territory; this is especially valid for the Hercynian granitic environments whose outcrops cover more than 150 000 km<sup>2</sup> in the central provinces of Argentina, as well as in the north Patagonian Massif.
- 4.6. The planning and location of new uranium exploration programmes will be considerably aided by the application of new metallogenetic concepts.

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## DISCUSSION

C. TEDESCO: We notice that in Argentina vein-like deposits may be related to different host rocks and various geological environments. Which prospecting methods led to their discovery? Were they sometimes discovered by chance while other types of deposit were being sought?

P. STIPANICIC: One vein-type deposit (Cañadon Gato) was discovered by geological considerations because several subsurface radioactive anomalies were known in gamma-logs of oil fields of Comodoro Rivadana (Asbest) and the corresponding levels were surveyed in the field. One vein-type deposit (Los Europeos) was discovered by chance.

Some uranium vein-type occurrences were discovered when radiometric checking other mineral deposits (San Santiago, Niquelina). Still other uranium vein-type deposits were discovered during the implementation of CNEA regular radiometric surveys (Schlagintweit and others) or by ground radiometric surveys carried out by private companies (Cachenta, Soberiano, etc.).

Up to now practically all the discoveries by ground surveys, were orientated by previous geological and structural analyses and the subsequent selection of favourable areas.

According to our experience, small or thin vein deposits are very difficult to discover by airborne survey which by contrast is effective when the accumulation is of the disseminated type, despite its possible low grade.

Geochemistry was effective for defining anomalous areas where later on uranium vein-type occurrences were found by radiometric ground surveys (Comechinquos Hills in San Luis).

Emanometry was effective in the exploration of buried sedimentary uranium deposits, but it was hardly ever applied in the search for vein-type deposits because on many occasions crystalline rocks were outcropping.

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