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## DISCOVERY OF THE SIERRA PINTADA URANIUM DISTRICT, MENDOZA PROVINCE, ARGENTINA

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*Presented by P. Stipanovic*

### Abstract

#### DISCOVERY OF THE SIERRA PINTADA URANIUM DISTRICT, MENDOZA PROVINCE, ARGENTINA.

Since 1956, uranium-bearing minerals have been known to exist in Sierra Pintada, Mendoza Province, Argentina. Based on paragenetic considerations, a first radiometric prospection was carried out, leading to the discovery of two groups of anomalies (Puesto Agua del Toro and Cuesta de los Terneros), such as vein-type deposits, with uraninite and 'yellow minerals' and one sandstone-type deposit (Puesto La Josefa), related to sediments with carbon trash. Many anomalies of both types have been found prior to 1959, but all of them turned out to be of small size and continuity. Some recent geological research and surveys in the area, and a reduced drilling programme carried out on selected anomalies, led to reinterpretation of the potential of the area. Furthermore, and as a result of an airborne radiometric prospection performed in mid-1968, numerous anomalies have been discovered. The main constellation of anomalies, along the flanks of the El Tigre Brachyanticline, occurs in sandstones of Permian age. Explored by 80 000 m of drilling, they have shown the existence of several peneconcordant lens-shaped ore bodies of economic size, with uranophane on the surface and prevailing uraninite and some brannerite, coffinite and davidite below the water table. Reserves exceed 20 000 tonnes of  $U_3O_8$ . A new regional programme with a 4-km drill-grid initiated in 1978 led to the discovery of new ore bodies which are at present being evaluated. The alternatives and discontinuities during the development of the district, the prospecting and exploration techniques employed, and the results achieved in the different stages of the operation are discussed in detail.

This case history attempts to illustrate the developing philosophy which was successfully applied in Sierra Pintada, with emphasis on the following points: (a) the need for adequate geological knowledge of the area; (b) the advantage of a massive survey (in this case, air survey); (c) the necessity for exploration (drilling) in order to define the anomalies and make their evaluation possible; and (d) the convenience of extending exploration when geology and control factors have been properly surveyed and recognized.

### 1. HISTORY OF THE SIERRA PINTADA DISTRICT

In 1956 the Comisión Nacional de Energía Atómica (CNEA) discovered several small radiometric anomalies in sandstones and volcanic rocks in the Sierra

Pintada District by surface reconnaissance prospecting. A ground follow-up and some limited mining operations carried out in the 1950s did not show any significant uranium occurrences, especially in the volcanics. In 1960, CNEA sponsored an airborne survey training programme, using the San Rafael Airport, and some irregular flights were made over northern and central Sierra Pintada, using Royal 118-B equipment with one-head 3 in. X 2 in. crystal.

No interest was shown in the discovery of two small anomalies in Permian sediments and the verification of two earlier recorded anomalies in travertine deposits in Las Peñas and Los Reyunos. However, the discovery of uranium ore bodies in sandstones, made in 1967 during a small-scale drilling programme, together with up-dated regional geological knowledge, made a new interpretation of the uraniumiferous possible potential and focused attention on the prospection of the Permian sandstones. A detailed radiometric airborne survey was therefore undertaken in 1968 at a line spacing of 250 m over an area of 3450 km<sup>2</sup>, and many new anomalies were located. Ground follow-up of these anomalies led to the discovery of uranium occurrences in the Cochicó Group sandstones on the western flank of the El Tigre Brachyanticline. These cover an area of 96 km<sup>2</sup>, of which 60 km<sup>2</sup> pertain to the 'Dr. Baulfes' and 'Los Reyunos' uranium mines.

The occurrences were systematically prospected by surface trenching, sampling and drilling during the period 1968–75. More than 600 boreholes, totalling about 60 000 m, were drilled. All the deposits were located at the top of the Atigradas Sandstone Member of the Los Reyunos Formation, in a very conspicuous stratigraphic position.

On the basis of a working hypothesis of the favourability of the Atigradas Sandstone Member and the existence of sporadic outcrops in Sierra Pintada, further geological surveys of reconnaissance drillings were initiated in 1978 on the eastern slope of the range, north of the El Tigre Brachyanticline. Two new deposits (Cerro Carrizalito and El Tigre Dam) and several positive holes were discovered.

## 2. LOCATION: GEOGRAPHICAL FEATURES

The Sierra Pintada uranium district is situated in Mendoza Province, Argentina, 25 km west of the city of San Rafael (population 90 000) and 250 km south of the city of Mendoza (population 500 000), the capital of the province (Fig. 1). The Sierra Pintada is a 100-km-long and 30 to 40-km-wide mountain range running north-to-south, which forms the northern part of a very conspicuous morphostructural unit, the San Rafael Block, with a core of Paleozoic and Triassic rocks, whose borders are partially covered by Tertiary continental strata and, more gradually, by Quaternary and Recent sediments.

The hilly environment, 800 to 2000 m.a.s.l., with a relief reflecting the faulted structure, is deeply cut by the perennial rivers Diamante and Atuel, fed



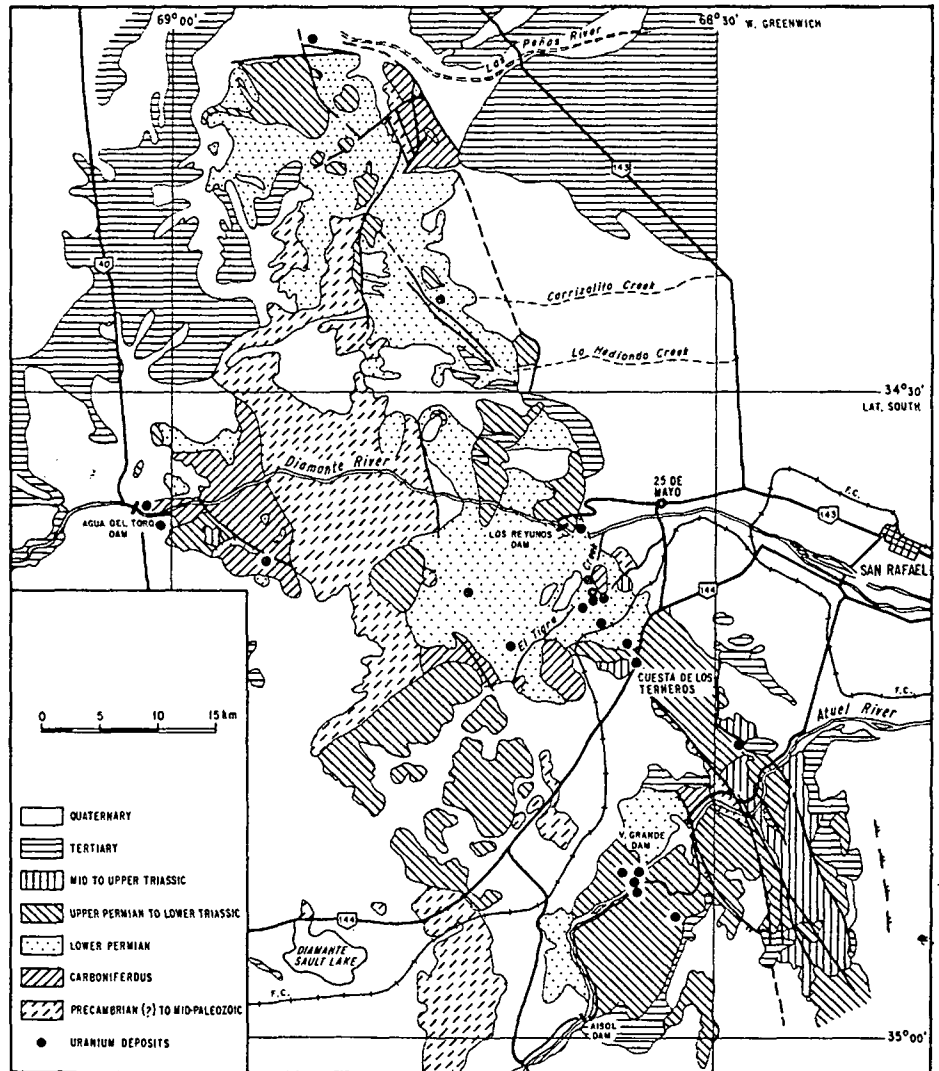


FIG.2. Sierra Pintada, regional geology.

by melting snow from the Cordillera de los Andes 200 km to the west. The region has a semi-arid climate, with an average summer temperature of 22°C and an average winter temperature of 7°C. Annual rainfall, supplemented by occasional snowfall, is 350 mm.

A number of local roads and tracks traverse the deposits, and a paved road links them with San Rafael and with other urban centres of the province. A railway line from San Rafael passes about 5 km to the east from the main ore bodies.

TABLE I. SIERRA PINTADA URANIUM-BEARING DEPOSITS:  
SIMPLIFIED STRATIGRAPHIC TABLE

AGES		FORMATIONS	LITHOLOGY AND FACIES	URANIUM SHOWS		
QUATERNARY		VARIOUS FORMATIONS	Continental sediments : alluvial, aeolian, piedmont , etc. Basaltic and andesitic lavas	<u>Yellow minerals</u> in travertines in Las Peñas and Los Reyunos		
TERTIARY	PLIOCENE	RIO SECO DEL ZAPALLO	Continental sediments.	Intercalated basaltic and andesitic flow		
	MIOCENE	AISOL	Continental sediments.			
MESOZOIC	TRIASSIC	PUESTO VIEJO	PENEPLANATION Continental sediments Ignimbrites. Intercalated basic to andesitic sills and dykes.			
	PERMIAN-	Co. CARRIZALITO GROUP	Co. CARRIZALITO	Acid facies.	Possible uranium source rocks.	
			AGUA DE LOS NOQUES	Dacitic facies.	Vein deposits "Rincón del Atuel"	
	TRIASSIC	QUEBRADA DEL PIMIENTO	Basaltic facies.			
	(?)		PUNTA DEL AGUA	Brick-red sandstones and conglomerates with pyroclastic and tuffaceous material predominating towards the top.	<u>Yellow minerals</u> "Los Enriques" deposit	
PALEOZOIC	PERMIAN	COCHICÓ GROUP	LOS REYUNOS DEPOSIT (EQUIV. TO AGUA DE LOS BURROS)	TOBA VIEJA GOROA MEMBER	Purplish-grey to violet lithic crystalline tuffs with calcareous sandstone key beds.	
			ARENISCAS ATIGRADAS MEMBER	Fine to coarse-grained orkotic sandstones, with parallel and cross-bedded stratification.	<u>Yellow minerals</u> with iron ochres on surface, uroninite under phreatic level. "Dr Baulies" and "Los Reyunos" deposits.	
			PSEPHITIC MEMBER	Red fonglomerates and conglomerates, alternating with yellow sandstones and pyroclastics.		
	CARBONIFEROUS	UPPER	Co. COLORADO (= BRECHA VERDE Fm)	Red and green conglomerates.		
LOWER		DEL IMPERIAL	Marine and continental sediments: conglomerates, quartzitic sandstones, siltstones and green and grey shales.	Granites Diorites Tonallites Anomalies in sandstones		
DEVONIAN		LA HORQUETA	Mainly marine sediments with different degrees of metamorphism: greywackes, quartzites, sericitic, argillites, mica, schists, etc.			
CAMBRO-ORDOVICIAN		PONON TREHUE	Marine limestones			
PRECAMBRIAN		Cº LA VENTANA	Metosediments and flysch facies intruded by granites and amphibolites			

A jet plane service is in operation between San Rafael and Buenos Aires. San Rafael is essentially a farming community with hospitals, a university and other facilities. Industrial development is rather limited. Near the main uranium deposits there is a small village, 25 de Mayo, located about 15 km from the site, which could be developed to provide housing during the exploitation of the mines.

The El Nihuil and Valle Grande dams on the Atuel River provide hydroelectric power (324 MW) and the Nihuil-Mendoza 132-kV power line crosses the centre of the uranium district. Two other dams on the Diamante River, which are in an advanced stage of construction (Agua del Toro and Los Reyunos), will double the present electricity output. A high-voltage line connects the Sierra Pintada main uranium deposit with the Los Coroneles power plant on the Diamante River. The El Tigre stream crosses the main ore body and will have to be diverted. It has a permanent flow of clear, slightly salty water of  $0.2$  to  $3.0 \text{ m}^3 \cdot \text{s}^{-1}$ , which rises during the summer rains into short floods of up to  $1000 \text{ m}^3 \cdot \text{s}^{-1}$ .

The main system of the Andes Mountains is seismically active, and nine earthquakes between 6.3 and 8.0 on the Richter Scale, with epicentres near Mendoza and San Juan, 250 and 400 km north of Sierra Pintada, respectively, have been recorded during the past 85 years. No earthquake has been recorded in the San Rafael and Sierra Pintada areas, but ripple effects or aftershocks of the large earthquakes further to the north are felt in the district.

### 3. REGIONAL GEOLOGY

In recent years an adequate geological background knowledge has been obtained. The area was totally covered by 1:200 000 regular geological surveys, and three quadrangles were published in 1956, 1964 and 1972, respectively. Special thesis papers and specific geological and photogeological surveys carried out by CNEA have contributed to a progressively increased understanding of the region (Fig. 2).

Table I shows a simplified geological scheme, and a brief description of the regional geology follows:

#### *Precambrian (?): Cerro La Ventana Formation*

It is considered that some amphibolites and granites, strongly tectonized and intruded by quartz veinlets, aplites and pegmatites, might pertain to this period.

#### *Cambro-Ordovician: Ponon Trehue Formation*

Reduced outcrops of whitish limestone overlying the above metamorphics and intrusives are assimilated to an old geosyncline in the Precordillera structural unit, 150 km northwards.

*Devonian: La Horqueta Group*

This is a complex sequence of clastic sediments, greywackes and pelites which crop out over large areas in a typical geosyncline flysch facies more than 1000 m thick. Metamorphism with sericitic and chloritic schists increases from south to north as a consequence of intrusions of granodiorites and diorites.

*Carboniferous: El Imperial Formation*

Unconformably overlying the La Horqueta Group are conglomerates, sandstones and shales, with marine episodes, into a regressive facies which varies in thickness from 100 to several hundred metres.

The Upper Carboniferous layer, which consists of red and green conglomerates, crops out in the western and southern slopes of Sierra Pintada. It is not present in the El Tigre Brachyanticline, where it has probably been removed by erosion from the Hercinian Orogeny, prior to the deposition of the Permian sediments.

*Permian: Cochicó Group*

This is integrated by a very heterogeneous sequence of clastic and pyroclastic sediments, with a wide distribution over the whole San Rafael Block. It is divided into two formations: Los Reyunos and Punta del Agua.

The sequence starts with red conglomerates and conglomerates alternating with yellow sandstones and pyroclastics, deposited on a very irregularly eroded surface. Fine to very coarse-grained arkosic sandstones follow, with parallel and cross-bedded stratification interbedded with tuffitic beds, presenting frequent lateral and vertical changes of facies. A combined fluvial-aeolian transport is assumed. These are the main uranium-bearing rocks.

Los Reyunos Formation culminates in a compact, purplish-grey to violet, lithic crystalline tuff with several calcareous sandstone key-beds. Punta del Agua Formation is a repeated sequence of brick-red sandstones and conglomerates, with pyroclastic and tuffaceous materials, which predominate towards the top.

*Upper Permian-Triassic: Cerro Carrizalito Group*

A very complex sedimentary-volcanic sequence overlies the Cochicó Group. It consists of a complete effusive cycle of basalts, followed by dacites and rhyolites. The volcanics cycle is interbedded and culminates with continental sediments of the Lower to Middle Triassic period.

*Tertiary-Quaternary*

After a peneplanation stage, during the Jurassic, Cretaceous and Lower Tertiary periods, thick Miocene and Pliocene continental clastic sediments were formed. Tertiary conglomerates, sandstones and tuffaceous sandstones are overlain by several Quaternary basaltic and andesitic flows and recent foothill deposits. Travertine deposits are also frequent.

**Structural scheme and geological history**

Sierra Pintada, as part of the San Rafael Block, is a well defined geological and structural regional unit, dominated by intense and repeated faulting. The predominant structural feature of the central uraniumiferous area is the 20-km-long El Tigre Brachyanticline, which stretches from the Diamante River in the north to Los Chañares in the south. It is traversed by a large number of faults, which vary in strike from NW-SE, through E-W to NE-SW.

The historical and geotectonic evolution is marked by:

(a) An Eopaleozoic geosyncline, flysch type, with intense folding and basic intrusives, reflecting variable metamorphism and deformation (Akadian-Bretonic Orogeny).

(b) A regressive sequence with peripheral molassic deposits and an uplift, with faulted structures during Carboniferous times (Asturian Orogeny). Some acid intrusions are related.

(c) Molassic deposits filling an active relief during the Permo-Triassic, with strong volcanism, a dominating folding and progressive block-faulting (Saalic Orogeny).

After the deposition of old Mid-Triassic sediments, a long period of peneplanation occurred up to the Miocene and it was assumed that this had a direct relation to the mobilization and deposition of uranium. Continental sediments coming from the western Andes covered the whole area during the Upper Tertiary, alternating with repeated episodes of vulcanism (mainly basaltic). At the end of the period, a great radio folding and a reactivation of faulting during the uplifting of the Andean Orogeny led to the complex and intricate fault-block structure of the pre-Tertiary rocks, affecting the continuity and spatial position of the uranium ore bodies. Tertiary sediments were totally eroded at the core of Sierra Pintada, and some fluvial terrace deposits, new basaltic volcanics and travertine deposits occurred during the Quaternary.

#### 4. FIRST-STAGE EXPLORATION (1956 -60)

##### 4.1. Ground prospection (1956–59)

At the beginning of this period, geological information was either scarce or not available. Nevertheless, numerous small occurrences of lead, silver, arsenic, fluorine, etc., and some paragenetic hypotheses prevailing at that time, led to the selection of the crystalline formations of this area for carrying out a reconnaissance ground prospection. A Precision Instrument 111-B, 1½ in. X 1 in. NaI(Tl) crystal scintillometer was utilized, with irregular grid itineraries, densified near the location of the ore deposits mentioned.

Puesto Agua del Toro was the first uranium discovery on the western flank of Sierra Pintada, in the Diamante River Valley. It is located in a brecciated fault, in the contact of an andesite with sandstones, tuffs and volcanic agglomerates, which were postulated as Triassic. The occurrence, consisting exclusively of yellow minerals, is 15 to 20 m long and 0.20 to 0.50 m thick, the grades varying from 0.1% to 0.2% U<sub>3</sub>O<sub>8</sub>. It was explored by trenches and edged near the surface. Not far away, at Puesto Agua de la Josefa, a second model of a punctual anomaly in sandstones with trash carbon was discovered (postulated at that time as pertaining to the Carboniferous period). In addition, high radioactive values in the acid effusives were proven.

At the same time, at La Cuesta de los Terneros, on the eastern slope of Sierra Pintada, 10 km south of El Tigre Brachyantocline, several anomalies of both models were found.

Priority was given to the more frequent occurrences, such as vein-type deposits, in relation to brecciated faults in Permo-Triassic effusive rocks. An exploratory effort was made, by means of a number of minor mining operations over selected anomalies, resulting in punctual and discontinuous bodies a few metres to 30 m long and 0.5 to 2 m thick. Uraninite and yellow minerals were related to a hydro-thermal process.

Despite the discovery of one occurrence, Los Chañares, in fluvial sandstones, in the contact with a rhyolite dyke, no effort was expended on the sedimentary model, and the real ore genesis was not properly interpreted at that time.

##### 4.2. Airborne prospection survey (1960)

An airborne radioactive prospecting programme was carried out, its main target being the training of personnel on this kind of survey, using some facilities offered by the San Rafael Airport with Cessnas 180 and 170, the property of the local Air Club. A Royal 118-B scintillometer, with one non-collimated head of 3 in. X 2 in. NaI(Tl) crystal was mounted.

The area was selected mainly because of its proximity to the La Cuesta de los Terneros anomalies.

The totally irregular survey, as rim or *chien de chasse* flight itineraries over some 1200 km<sup>2</sup>, in spite of the inadequate equipment and the excessive terrain clearance, led to the detection of two sandstone-type anomalies at Los Mesones and Los Caimanes, and two more anomalies in travertine deposits (Las Peñas and Los Reyunos). Unfortunately, the ground checking did not allow the potential mineralization of the sedimentary formations to be defined, and the district was abandoned.

#### 4.3. Comments on the results of the 1956–60 period

The inadequate survey prospection, the scarcity of geological information on a regional basis, and the erroneous priority given to the vein-type deposits, led to a ten-year delay in developing the Sierra Pintada uranium district. The negative results were based on:

- (a) Lack of flexibility in evaluating the metallogenetic models;
- (b) The tendency to sacrifice general prospecting targets by premature development of early findings;
- (c) Inadequate equipment and surveying techniques in airborne prospection;
- (d) Hesitation (or impossibility, because of budgetary problems) in exploring by drilling in some conspicuous occurrences (subsequently, at Los Mesones and Los Chañares, some interesting ore bodies were revealed);
- (e) The limitation of prospection to excessively restricted environments without prior regional analysis.

### 5. SECOND-STAGE EXPLORATION (1967–75)

#### 5.1. Prior reconnaissance and geological reinterpretation

During the 1960s some CNEA personnel received training, including visits to the principal uranium-developed countries. At the same time, geological knowledge of Sierra Pintada was advancing considerably. Three regular geological quadrangles at a 1:200 000 scale and several theses led to a better understanding of this complex morphostructural unit.

Late in 1967, a preliminary analysis of existing background data on uranium within the framework of the local geology and known world uranium deposit models led to the selection of representative anomalies and, profiting from CNEA's recently acquired capacity to improve drilling, 30 to 50-m-deep holes were bored in each of them.

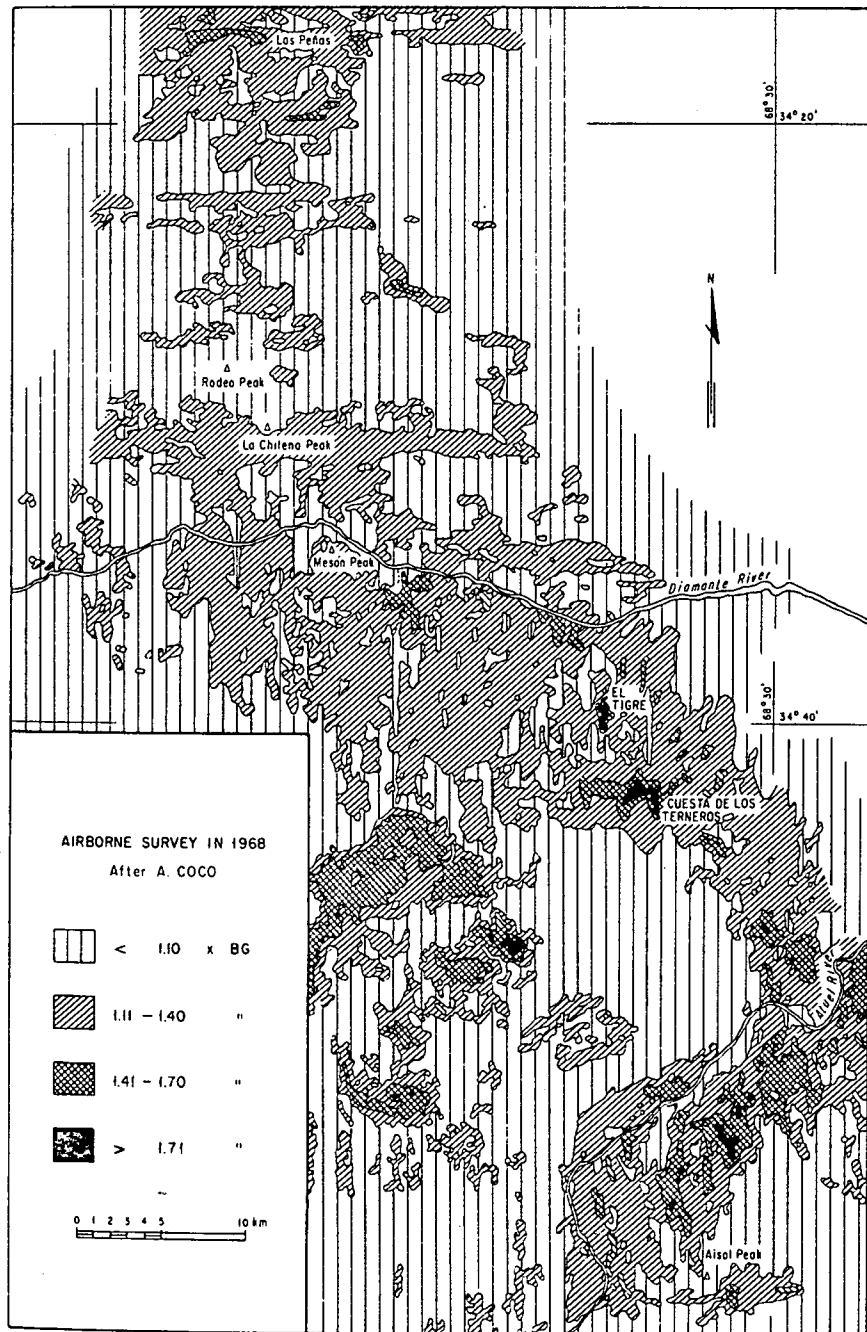


FIG.3. Sierra Pintada, gamma total isocontour map.

Results were entirely positive in Los Chañares, where mineralization was verified in fluvial Permian sandstones with evident sedimentary control – thickness of up to 4 m and grades varying from 0.1% to 0.2%  $U_3O_8$ .

After a final reinterpretation of all the available uranium data, and with the support of new geological mapping, an airborne prospecting survey was programmed to cover the Permian Cochicó Group outcrops and especially the Atigradas Sandstones Member over an area of 3000 km<sup>2</sup>.

### 5.2. Total gamma airborne survey (mid-1968)

The main equipment, technical specifications and operating conditions were as follows:

Conventional cartographic maps at a scale of 1:100 000 were used for the flights, and enlarged copies at a scale of 1:50 000 were used for data plotting.

Aircraft: A Cessna 180-B.

Scintillometer: MP-10 equipment made by CNEA was used, consisting of one-head 5 in. X 2 in. NaI(Tl) crystal, with a lead collimator, with scales of 250, 500, 1000, 3000 and 10 000 cps and time constants of 0.5, 1 and 1.5 seconds.

Radio-altimeter: AN/APN 1.

The strip camera was a continuous French Cameflex, model S, with 35-mm film.

Synchronized recorders, in tandem, with fiducial mark devices: two Esterline Angus.

Line flight intervals were 250 m at a terrain clearance of less than 100 m. Flight directions were in general normal to main structures, except over El Tigre Brachyanticline, where topographical conditions made it compulsory to adopt N-S strike directions.

Data recovery from records was punctual, at every 250 m, and was plotted after manual clearance correction at the 100-m base level.

Contour maps were made at intervals of BG X values of 1.10, 1.40, 1.70 and over 1.70 (Fig. 3).

Operative costs, including airborne photography at 1:20 000 scale over El Tigre Brachyanticline area was US \$6.60/km<sup>2</sup>, at 1968 values.

In these conditions, 270 hours were flown in 135 days and on 649 lines, covering a 3450 km<sup>2</sup> surface. The results, notably effective, can be summarized as follows:

- (a) All the later anomalies were detected;
- (b) The constellation of the El Tigre Brachyanticline anomalies was clearly defined; and
- (c) Some very valuable geological data were obtained.

### 5.3. Ground-checking (late 1968)

The definition of the airborne radioactive anomalies of the El Tigre Group had been proven from the very beginning, so, before elaborating the isocontour maps and final interpretation, a classical geological survey mapping with selected detailed cross-sections at a 1:10 000 scale was therefore launched (Fig. 4). Simultaneously, another working group started the ground-checking of some principal anomalies, using the French scintillometer SPP 2.

As a result of the clear stratigraphic control, and owing to topographic limitations, a regular grid prospecting was exceptionally used, and the checking had to be done by means of cross-sections 10 to 25 m apart between lines, with readings at every metre. In addition, for the follow-up of the ore bodies in covered areas, such as La Terraza, by radon prospecting, the French EPP 10 emanometer had to be used. The method proved suitable for extending the known ore bodies or main faults. However, no results were obtained over the virgin sectors.

Geochemistry applied from the very beginning to water, soils and stream samples did not give positive results even in the neighbourhood of the main out-cropping ore body.

Adequate knowledge of the El Tigre Brachyanticline mineralized area was obtained by means of the ground-checking, the specific geological survey and the interpretation of photographs taken during the airborne survey.

Late in 1968, more than 15 proven occurrences were located and their stratigraphic positions and lithostratigraphic controls defined. All occurrences were located in the uppermost sequence of the then redefined 'Areniscas Atigradas Member' of the Los Reyunos Formation in the Permian-Triassic Cochicó Group (see Table I).

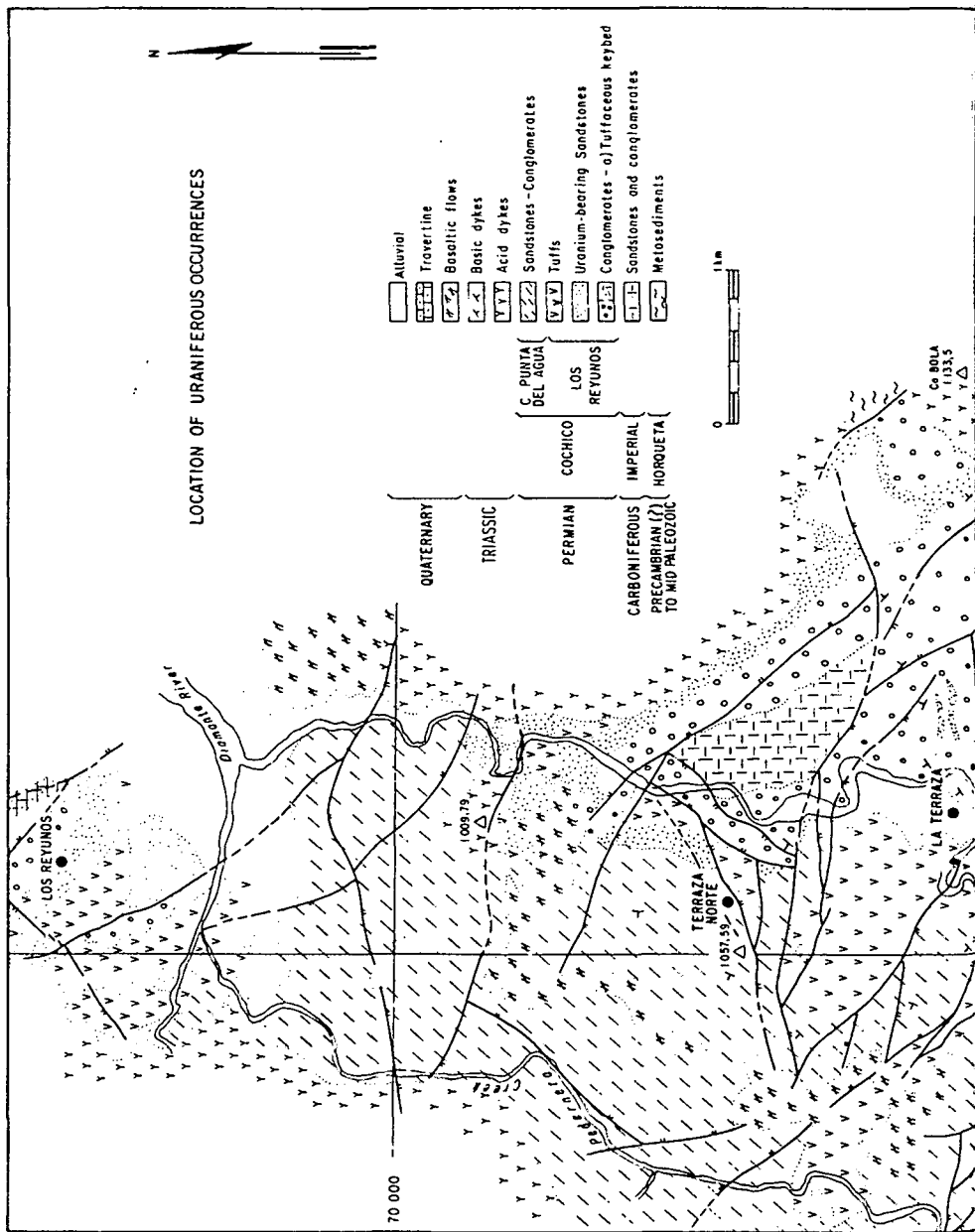
During the same period, six drill-holes were bored in the El Tigre I front and the continuity of the mineralization was proven, with thicknesses varying between 4 and 18 m and with grades varying between 0.09 and 0.19  $U_3O_8$ .

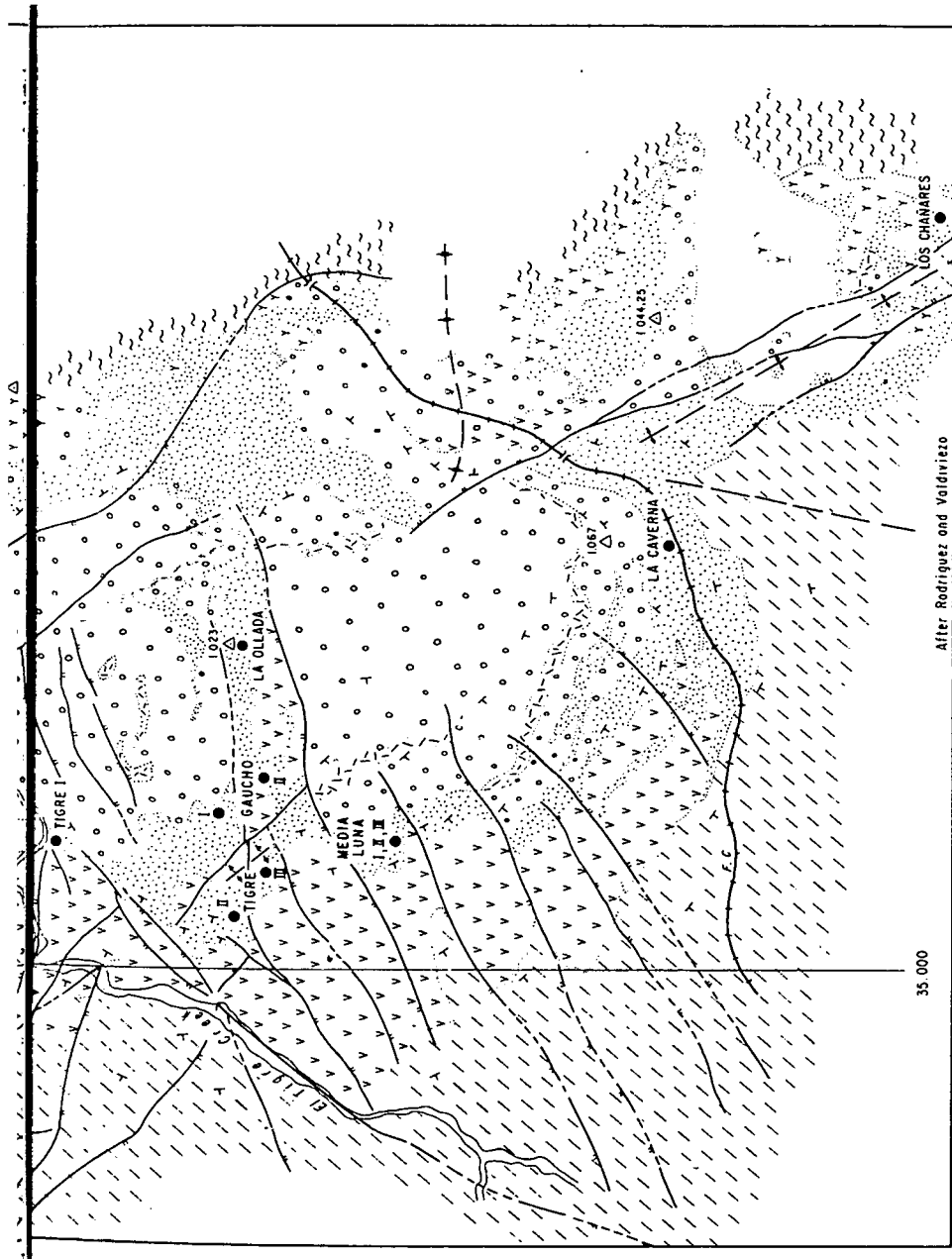
Subsequently, a programme was initiated for implementing a topo-geological survey at a scale of 1:1000 which would cover the whole mineralized area (5000 X 6000 m) and serve as support of development activities and drill-hole locations.

### 5.4. Exploratory operations

A total of 600 holes were drilled in the El Tigre area (about 60 000 m). Except for the main ore body (El Tigre I-La Terraza), the grid was rather irregular (50 m to more than 100 m), starting at the discovery sites.

The main ore body, which is divided by faults into three blocks, was recognized by the almost regular grid (50 m apart – this being established by





After Rodriguez and Valdivieso

FIG. 4. Geology of the El Tigre Brachyanticline area.

geostatistical methods). Taking into account the existing topographical problems, it was possible to bore 241 drill-holes totalling 23 628 m and distributed as follows:

Block A:	131 holes	11 800 m
Block B:	58 holes	5 634 m
Block C:	52 holes	6 194 m

Of these, 133 drill-holes were completely cored, 103 were cored only in the mineralized interval, in NX and BX diameters with excellent core recovery (average 90%), and five holes with cuttings recovery. Further, and in order to obtain suitable samples for hydrometallurgical assays, a 320-m gallery was excavated in Block A and a 35-m shaft and 206-m gallery in Block B. In addition to the core recovery, all the drill-holes were logged with GM Sensor Equipment. The radioactivity/grade correlation was positive.

Total expenditure during the exploration stage amounted to approximately 5 million US \$ at 1974 values. A problem that still persists is the high cost of drilling, which is about four to five times higher than in the USA, and the contractor's explanation of this cost is not acceptable to CNEA.

## 5.5. The constellation of the El Tigre uranium deposits

### 5.5.1. Local geology

The Permian-Triassic Cochicó Group (consisting of sediments with repeated intercalations of tuffs and varied pyroclastics) lies unconformably over the above-mentioned Precambrian(?) to Carboniferous basement. The group is subdivided into the Los Reyunos Deposit Formation (Permian) and the Punta del Agua Formation (Uppermost Permian to Mid-Triassic).

#### (a) *Los Reyunos Deposit Formation*

This consists of a transgressive filling which overlies an irregular relief imposed by the Hercynian Orogeny over the former basement. It comprises:

##### (i) *The Psephitic Member*

The Psephitic Member consists of polymictic fanglomerates and conglomerates which are composed of angular blocks and pebbles embedded in a distinctive red arenaceous matrix. It contains small intercalations of cross-bedded yellowish sandstone and two pyroclastic beds, the lower one agglomeradic and the upper tuffaceous.

*(ii) The Areniscas Atigradas Member*

This member, which is 70 to 100 m thick, consists of a cross-bedding of fine to medium grained calcareous feldspathic argillaceous sandstone, with a thin bed of tuffite (key-bed) commonly developed about 50 m above its base (Fig. 5). The fresh sandstone varies in colour from dark greenish-grey to greenish-gray and is occasionally reddish owing to staining by iron oxides. Thin beds of coarser-grained, less argillaceous sandstone are common.

The most abundant constituent is quartz, occurring as poorly sorted subangular to subrounded grains which frequently show bipyramidal crystal outlines characteristic of phenocrysts in porphyritic rhyolites. Rounding of these grains may be due to reabsorption by the groundmass of the host rock, rather than to sedimentation processes. The feldspar grains are predominantly plagioclases, varying from albite to oligoclase in composition, and usually have a high degree of alteration to kaolinite. The matrix, which constitutes up to 20% of the rock, consists of clay minerals, fine-grained sericite, chlorite and interstitially precipitated calcite. The latter also occurs as an alteration product of feldspar, often completely replacing pre-existing grains.

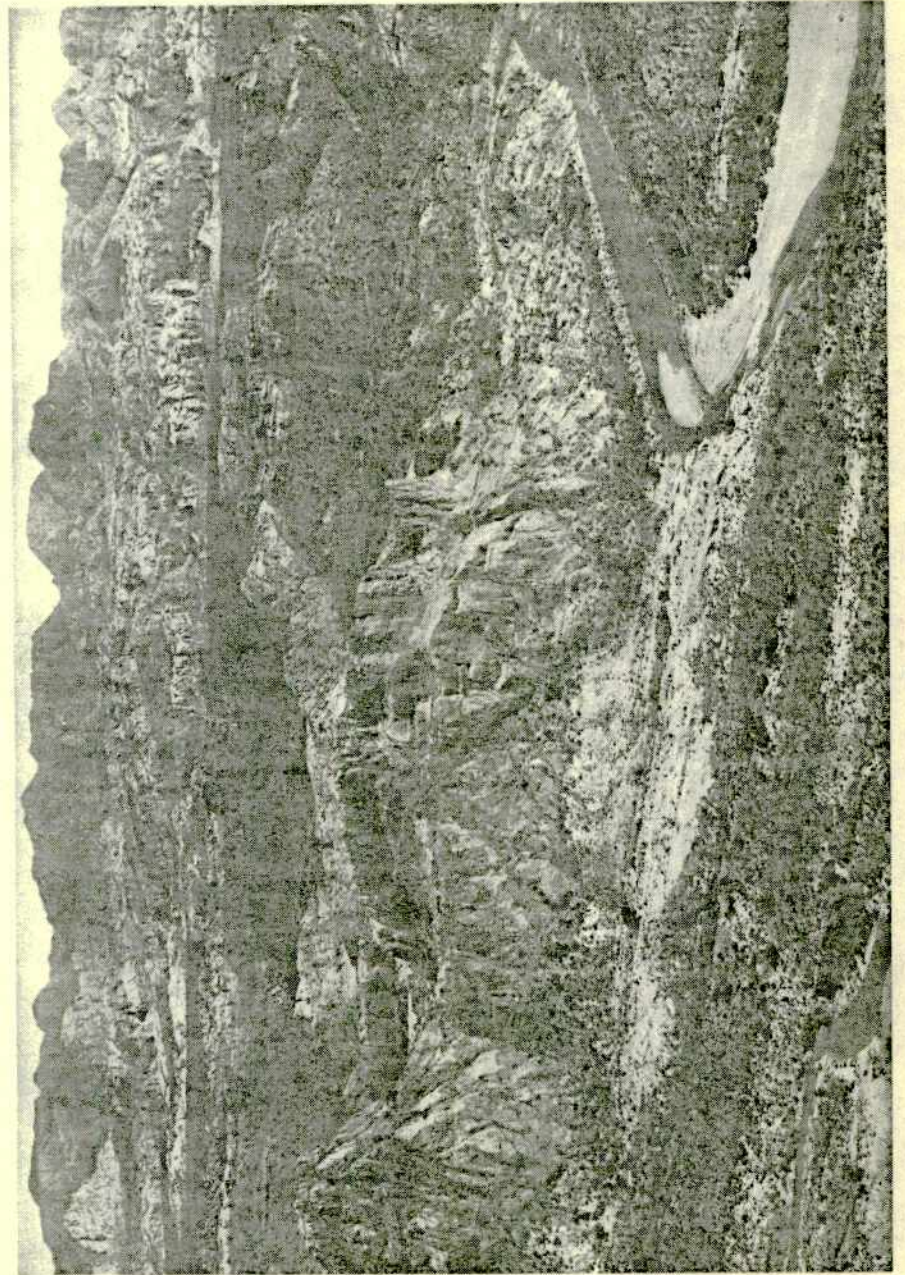
The Atigradas Sandstone includes two preferential stratigraphic levels to host the uraniferous bodies. The main, or upper, position occurs in the sandstone above the tuffite, but subsidiary ore bodies are developed in the sandstone sequence below the tuffite.

The contact between the Atigradas Sandstone and the underlying Psephitic Member is characterized by interfingerings in the peripheral zones of the El Tigre structure.

Small-scale planar cross-bedding, indicating deposition from the south-west, has been observed at the southern extremity of Tigre I. A shallow water depositional environment is postulated, followed by minor scouring, together with an accumulation of aeolian sands, prior to the deposition of the overlying Toba (tuff) Vieja Gorda Member, both of them into a desertic climate.

*(iii) The Toba Vieja Gorda Member*

This member is estimated to be up to 200 m thick. It is a purplish-grey to violet lithic tuff made up of quartz, feldspar, biotite and other mafic minerals. It also contains lapilli and xenoliths of the Devonian La Horqueta Formation. A reddish agglomerate a few metres thick, containing two to three thin beds of white tuffite, occurs between 80 and 110 m above the base of the tuff. An erosional surface marks its top.



*FIG. 5. El Tigre I ore body.*

(b) *The Punta del Agua Formation*

This formation was deposited over the Toba Vieja Gorda Member on a rugged erosional surface. It occurs westwards from the western limits of the El Tigre-La Terraza ore body and north of it. The basal part consists of brick-red sandy conglomerates with intercalations of pale yellow and pink sandstones; the upper part is a sequence of coarse-grained clastic sediments interbedded with pyroclastic rocks and lavas. Its thickness is estimated at several hundred metres.

(c) *Local structural pattern*

The El Tigre Brachyantoclinal corresponds to a former closed anticline, superimposed by several diastrophic cycles leading to the present fault-block structure. The deformation process started with a disharmonic folding (anticlinorium), which affected the Psephitic Member, and a smooth anticline acting rather symmetrically over the subsequent formations. The uranium-bearing Areniscas Atigradas Member participates in this last deformation.

This compressive tectonism was followed by several fracturing cycles which contributed to the complex faulting of the periclinal system in relation to the anticlinorium structure, with a parallel east-west strike on the western slope of the structure. Stratigraphic throws vary widely, reaching up to 70 m.

5.5.2. *Main ore bodies*

(a) *Tigre I-La Terraza*

This ore body crops out in the central-western flank of the El Tigre Brachyantoclinal. Two peneconcordant ore bodies were outlined by means of diamond drilling surveys in the Areniscas Atigradas Member. The upper (or main) ore body covers an area of about 1800 m from north to south and about 600 m from east to west. The lower ore body covers a surface of 800 X 250 m.

The upper ore body top is generally 10 to 20 m below the overlying Toba Vieja Gorda Member and the lower contact may extend right down to the tuffite key-bed. It varies in thickness from a cut-off of 0.04% to a maximum of 30 m and an average of 10 m. The ore body crops out, or sub-outcrops, beneath a thin overburden cover in the east and pinches out abruptly to less than 0.35 m thickness in the south and west. In the north-west and north, its boundaries have not been defined and it may continue below the 800 m.a.s.l. altitude. The lower ore body is located below the tuffite key-bed, usually about 10 to 15 m below the upper ore body in Block C and about 20 m in Block A. Its average thickness in the delineated blocks is about 5 m, petering out to below 0.5 m along the edges.

The vertical value distribution corresponds to a well-shaped, lenticular habit of higher-grade zones which cannot be individually correlated over large distances. The average grade, at a 0.04%  $U_3O_8$  cut-off, is 0.125% for the main body and 0.09%  $U_3O_8$  for the lower one.

Two east-west transverse normal faults divide the deposit into three main blocks, referred to as A, B and C, from south to north. The major fault of the zone, which separates Blocks A and B, has a southward downthrow of approximately 70 m. The faults between Blocks B and C have a total southward down displacement of about 50 m. The 'loss of ground' caused by these faults is up to 80 m wide (which accounts for the division into separate blocks).

In addition, there are numerous normal faults with steeper dips and north-west, south-west and west trends. The first two sets are generally more significant, with displacements of up to 35 m. The majority of these faults have downthrows to the south-west, south and south-east. The most notable exception is the north-eastern fault (exposed in the open pit), which has a downthrow of 30 m to the north-west. No reverse faults have yet been recognized.

The main ore body dip varies between 12° and 35°. It has a general dip which varies between 20° and 30° to the north-west in Block A and towards the north-north-west in Blocks B and C.

The present interpretation of the distribution and spatial position of the mineralization has been attained through 23 east-west cross-sections and 160 correlation sections between drill holes.

*(b) Tigre II-III and Media Luna I-II-III*

This is the second most important uranium ore body in the District and occurs about 1.2 km south of Tigre I. It is about 1000 m long by 300 m wide, extending from Tigre II in the north to Media Luna III in the south. The mineralized beds, occurring 25 to 30 m below the Toba Vieja Gorda Member, crop out in the east and dip to the west at 18° to 20°. The total mineralized thickness varies from 2 to 20 m, averaging about 8 m. The grade, at a cut-off of 0.04%, is 0.096%  $U_3O_8$ .

*(c) Los Gauchos I-II*

Gaicho I and II occur in the uppermost part of the Areniscas Atigradas Member, dipping 20° to the west-north-west. They are a lens-shaped body, covered by an eroded relic of tuffs, 15 to 20 m thick and located south-west from Tigre I-La Terraza, extending about 200 × 250 m. They consist of three peneconcordant beds, each of them 1 to 2 m thick, separated by thin, low-grade ore intercalations. They have been explored by means of 60 drill-holes (2500-m drillings), the average grade being 0.1%  $U_3O_8$ .

(d) *La Terraza Norte*

This deposit is located close to the Tigre I-La Terraza ore body, from which it is probably separated by a barren zone of faulted discontinuity. Reconnaissance drilling initiated in 1978 proved the existence of this 7-m-thick 'blind' body with a grade of 0.09%  $U_3O_8$ . Its outline has not yet been defined or delineated, but it may well be a natural extension of the main ore body.

Isolated holes made it possible to recognize mineralization 6 km northwards in a similar position.

(e) *Other deposits at El Tigre Brachyanticline*

A constellation of small ore bodies: Gaucho III-IV, La Ollada, La Caverna and Los Chañares, crop out south-east of Tigre I. The bodies are several tenths of a metre wide, with thicknesses of up to 2 m and ore grades of less than 0.1%  $U_3O_8$ . Exploration is now in progress to define their importance.

## 5.6. Deposits removed from the main area

La Pintada Anticline deposits are located 6 km west-south-west from the El Tigre Brachyanticline and in the same stratigraphic position. They comprise several lenses over an area of 500 X 200 m, with a similar type of mineralization. Not far from these deposits, the Los Enriques deposit occurs in similar sandstones.

A group of five radioactive anomalies with yellow uranium minerals has been found at Pantanito, 30 km west from El Tigre in the same Permian sediments. Work has not yet been initiated.

On the western slope of North Sierra Pintada, at Carrizalito, 20 km north of the El Tigre deposit, uranium occurrences crop out along hundreds of metres, with a content of up to 0.05%  $U_3O_8$ . An isolated hole (4 m thick and with a similar grade) cuts the mineralization 300 m to the east at a depth of 100 m.

At Rincón del Atuel, on the eastern slope of Sierra Pintada, a vein-type deposit occurs in Triassic effusives of the Cerro Carrizalito Group. It crops out along 400 m and has been intersected by about ten drillings up to 50 m deep. The ore bodies appear discontinuous, up to 2 m thick and with up to 0.1%  $U_3O_8$  grades.

A group of occurrences of a type which is not yet well known has been located in some Triassic effusives and sediments south-east of the area (Las Abejas, La Rinconada, El Totem, Los Buitres and El Nihuil), some of them with a very marked radioactive disequilibrium. They have not yet been explored.

A summary of the results, ages of the host rocks and types of occurrences is given in Table II.

TABLE II. AGE OF HOST ROCKS AND TYPES OF OCCURRENCES OF SIERRA PINTADA URANIUM DEPOSITS

TYPE	AGE	DEPOSIT	TYPE	AGE	DEPOSIT
⊕	P	Many orebodies in the El Tigre Brachyanticline	⊕	P	Cerro Carrizalito
⊕	P	La Pintada	⊕	Q	Las Peñas
⊕	P	Pantanito	⊞	Ṛ	Many orebodies at Cuesta de los Terneros
⊕	P	Punta del Agua	⊞	Ṛ	Arroyo El Alumbre
⊕	P	Los Enriques	⊞	Ṛ	Las Abejas
⊕	P	La Josefa	⊞	Ṛ	La Rinconada
⊞	P-Ṛ	Agua del Toro	⊞	Ṛ	El Totem
⊞	Ṛ	Rincón de Abajo	⊕	C	Puesto Aleguino
⊞	Ṛ	Pircas del Mesón	⊕	C	Central No. 1 Nihuil Dam
⊕	P	Los Reyunos	⊕	P	Nihuil
⊕	Q	Don Manuel	⊕	P	Cañadón Generoso
⊕	Q	Saladillo Grande	⊞	Ṛ	Rincón del Atuel
⊕	Sedimentary-type deposits			C	Carboniferous
⊞	Vein-type deposits			P	Permian
				Ṛ	Triassic
				Q	Quaternary

### 5.7. Ore mineralogy

The bodies are typical peneconcordant lenses ranging from a few to hundreds of metres in size and up to 20 m thick. A cloud of similarly shaped, variable stratiform bodies occurs in the main lenses, either isolated or joined in irregular chains, which expand along the north-south strike of the structure. The host-rock lithological units are made up of 'arkoses' or feldspathic sandstones, fine to medium grained, yellow on the surface and greenish-grey in the depth.

The sandstones consist of quartz, acid plagioclases and potassic feldspars, with minor lithic volcanic glass, paraectinites, etc. Apatite and zircon are rather scarce. Sericitization, calcification and kaolinization of the feldspars are marked.

The calcite content of the ore is an important factor in uranium extraction and for this reason the weighed average  $\text{CaCO}_3$  was sampled and analysed regularly in most boreholes. The main value of the  $\text{CaCO}_3$  content is about 6.5% in the El Tigre I-La Terraza ore body and 5% in the El Tigre III and Media Luna deposits.

In the thin, highly mineralized and coarser-grained beds, black pitchblende is present interstitially in layers or patches; brannerite, coffinite, liebigite and davidite are also present, but have not been identified macroscopically. Yellow uranophane occurs near the surface as a thin film along the cleavage and joint planes in the sandstone.

Pitchblende grains of 1 to 12  $\mu\text{m}$  in size, or in veinlets 0.2 to 1.5 mm thick, occur:

- (a) Interstitially and as fracture fillings in quartz and feldspar grains;
- (b) Intimately associated with  $\gamma\text{Fe}_2\text{O}_3$  and iron-rich chloritic material in the matrix; and
- (c) Associated with structures suggestive of a cellular type of organic matter.

The pitchblende has a microcrystalline texture and presents an X-ray diffraction pattern similar to uraninite but contains no thorium.

The presence of coffinite, brannerite, davidite and liebigite was confirmed by X-ray diffraction analysis. Brannerite is frequently either completely or partially enclosed as a thin film over anastase and leucoxene. Microprobe scans have indicated that uranium is frequently found finely disseminated on the leucoxene grains. Brannerite grains may be pseudomorphous after anastase.

There is an irregular vertical distribution of values of the uranium minerals. In general, however, higher contents tend to occur in the central part of the ore bodies, with a relatively abrupt decrease towards the top, and a more gradual one towards the edges and the base of the lenses. Deep below, some pyrite occurs, 2 to 5 mm in diameter, which rapidly evolves near the surface into hematite and limonite. Trash carbon has also been checked with grades of about 0.1% C.

To summarize, the ore in the Sierra Pintada district is practically monometallic.

## 5.8. Ore genesis

The following hypothesis for ore genesis is supported:

The uranium is derived from Permian-Triassic acid effusives which poured out to the south or south-west of the Sierra Pintada uranium district. During peneplanation, possibly during the Upper Mesozoic and Lower Tertiary periods, the uranium was leached and mobilized in aqueous solutions in which the presence of  $\text{CO}_2$  led to the formation of stable, complex specimens, such as UDC or UTC, together with Ca, Fe, etc., which migrated to the Areniscas Atigradas Member.

The precipitation of uranyl ion was generated by the presence of oxygen in the aquiferous and hydrated ferric oxides, such as the  $\alpha$  and  $\gamma$  varieties, controlled by the  $\text{CO}_2$  pressure.

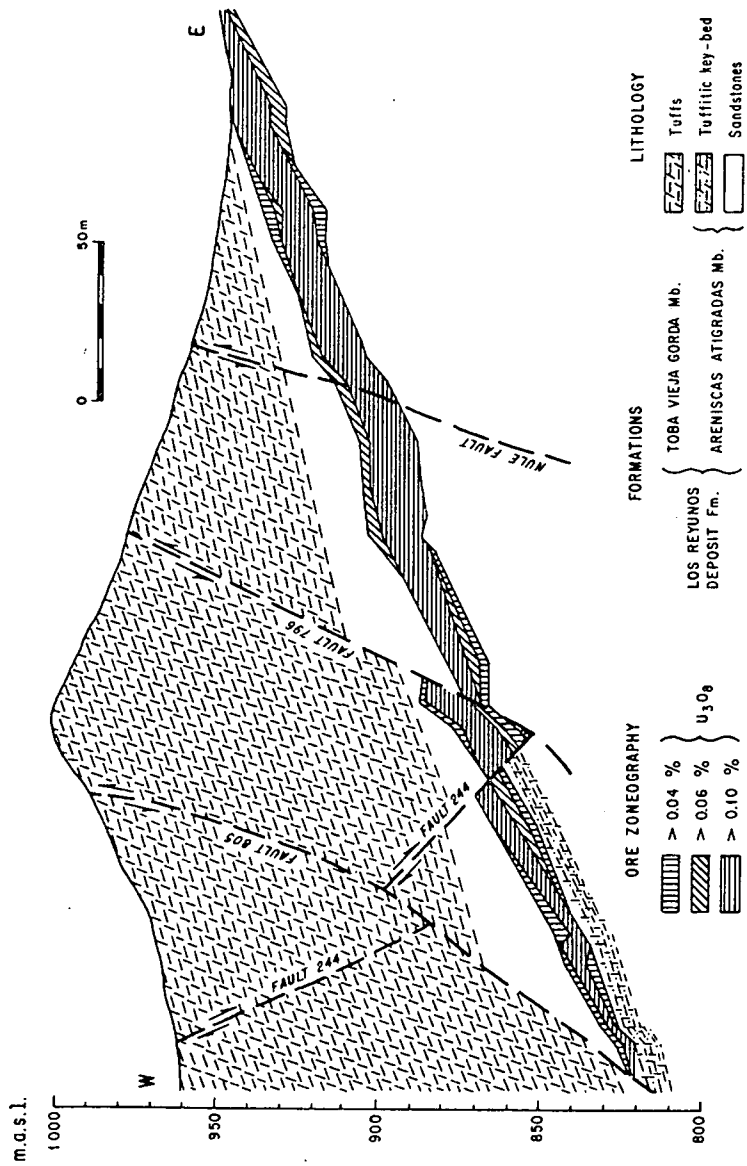


FIG. 6. Tigre I-La Terraza ore body, transverse cross-section.

Intimate association with the  $\gamma$  Fe<sub>2</sub>O<sub>3</sub> iron-rich chlorite in the matrix of the sandstone suggests that its precipitation could also be influenced by the presence of Fe and by variations in the Eh values. Higher mineralization in the upper part of the paleo-aquifer level, red, reddish-brown and red-violet in colour, corresponds to the location of the  $\gamma$  Fe<sub>2</sub>O<sub>3</sub> variety, where bacteria find a more favourable environment for reducing uranium. Minor participation in the uranium fixation is attributed to the action of organic matter due to the scarce content of carbon trash which corresponds to the arid depositional environment of the sediments.

#### 5.9. Ore reserves

The ore reserves estimate is based on the drilling exploration data. Although a regular 50-m grid was the aim, the rugged relief made this impossible. Spacing between boreholes is therefore less than 70 m, the borehole sheets serving as the basis for estimating the ore reserves. Co-ordinates, collar elevation, lithology, graphical representation of total  $\gamma$ -logs, sampling data and uranium values were obtained by this method. In addition, the CaCO<sub>3</sub> content is given for the whole or a part of the mineralized zones in a number of boreholes.

The following sampling procedure was used:

(a) All cores were radiometrically scanned to select the mineralized zone, which was then split into samples varying in length according to the radioactivity level, but generally about 1 m long. These samples were analysed radiometrically; in a large number of boreholes, values of over 0.05% U<sub>3</sub>O<sub>8</sub> were checked through chemical analysis.

(b) When chemical analysis was not carried out systematically, it was carried out at regular intervals to check calibration standards. The correspondence of radiometrically and chemically determined values is excellent for all the boreholes, and there is no evidence of disequilibrium. The thorium content of the ore is relatively low, and consequently its effect on radiometric analysis is minimal.

(c) Radiometric and chemical analyses of drill cores made it possible to determine the mineral grade and it was necessary in a few cases – mainly at the beginning of the drilling – to take into account the radioactivity/grade correlation for the purpose of the estimates.

(d) Estimates of volumes were based on the structural interpretation made on topographical and geological profiles (Figs 6 and 7) and on plants and zoneo-graphical profiles.

(e) Thickness has been corrected for each borehole intercept on the basis of the average dip calculated for each section of the deposit. In the same way, the surface of influence of each borehole intercept was corrected to calculate the blocks.

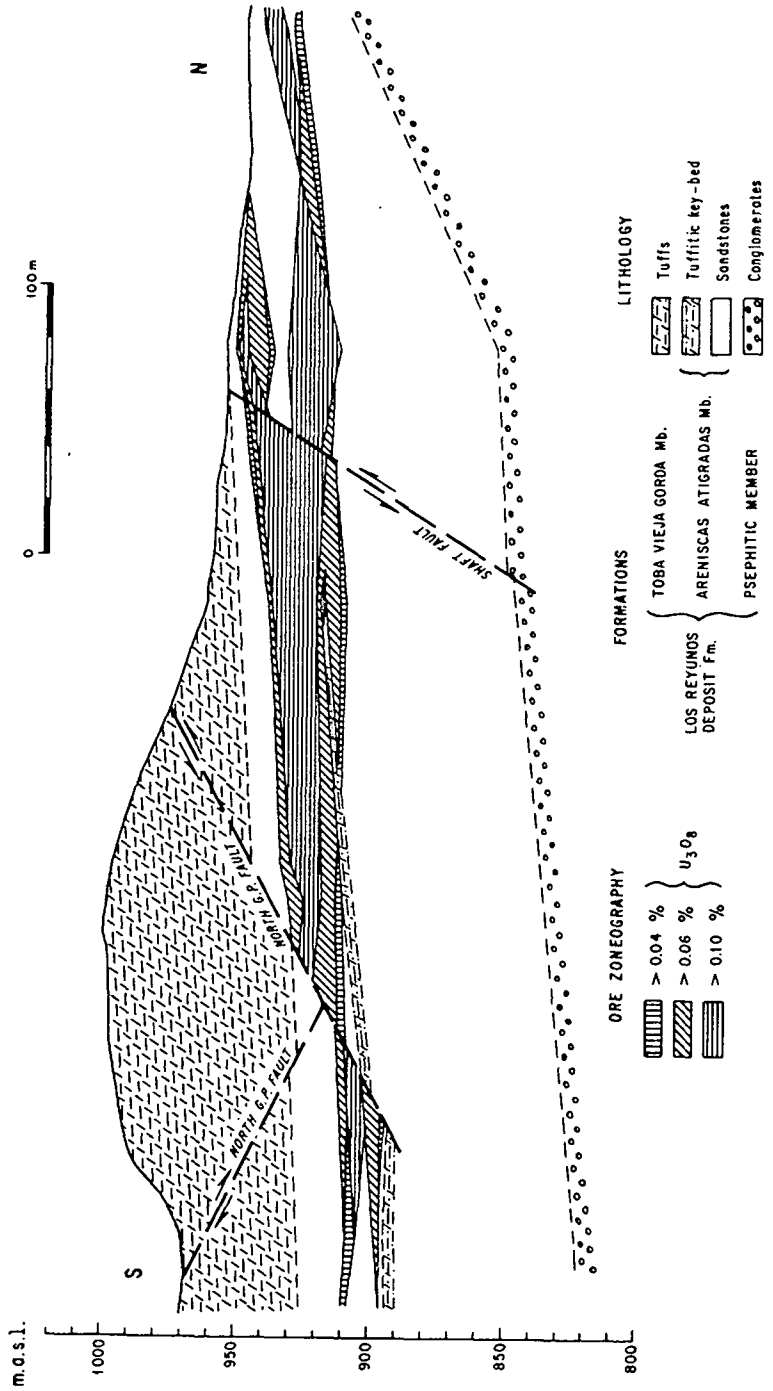


FIG. 7. Tigrera ore body, longitudinal cross-section.

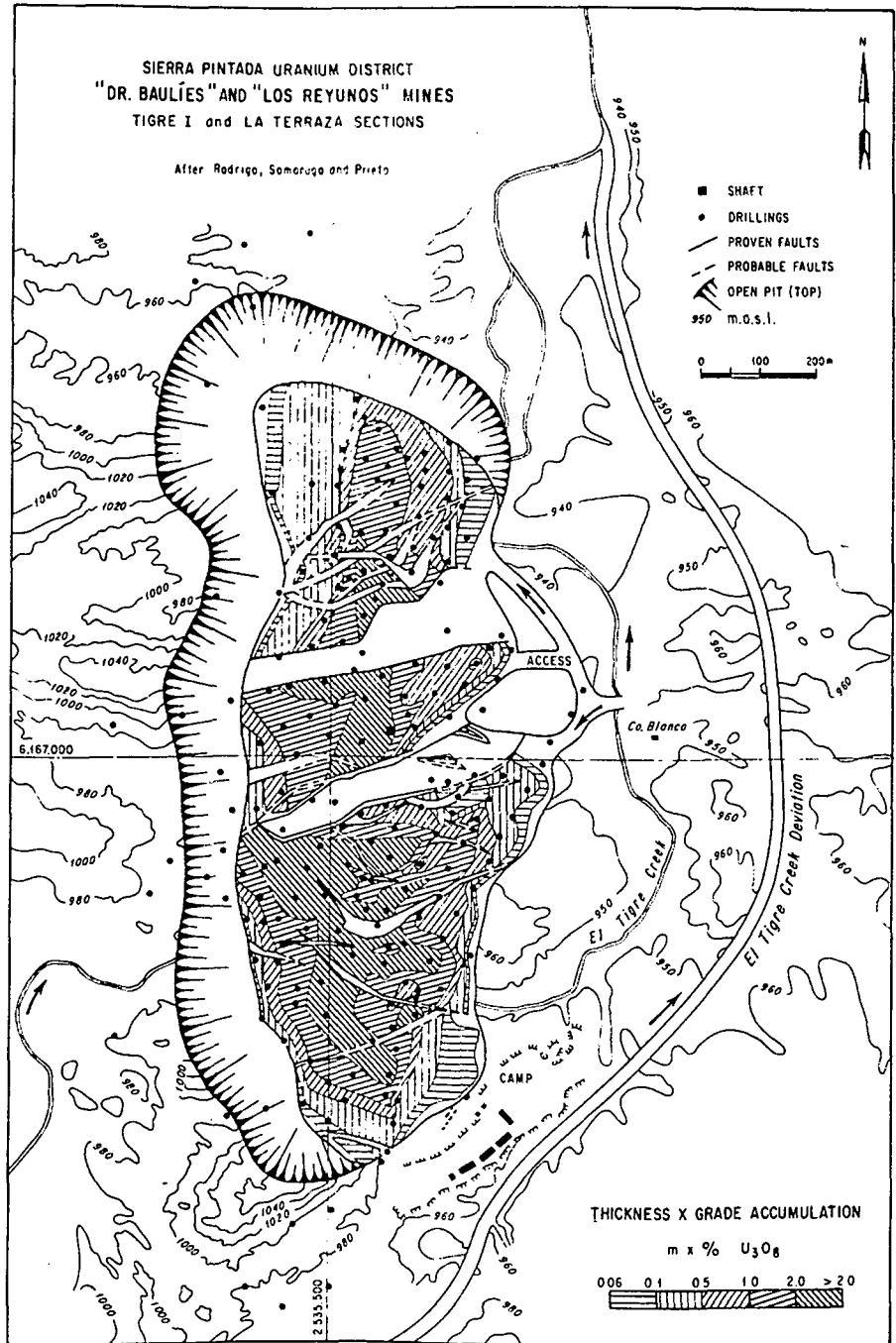


FIG. 8. Tigre I-La Terraza, ore zoneography and open-pit scheme.

TABLE III. SIERRA PINTADA DISTRICT: URANIUM ORE RESERVES (t U<sub>3</sub>O<sub>8</sub>)\*

OCCURRENCES	REASONABLY ASSURED RESOURCES	ESTIMATED ADDITIONAL RESOURCES	TOTAL
Tigre I - La Terraza	16 000	-	16 000
La Terraza North	800	500	1 300
Tigre III	1 000	500	1 500
Media Luna I-II-III	1 400	500	1 900
El Gaucho I-II-III-IV	300	200	500
Los Chañares**	100	200	300
Minor ore bodies at El Tigre**	500	1 000	1 500
La Pintada**	100	200	300
Cerro Carrizalito**	100	500	600
Positive isolated holes**	300	3 000	3 300
TOTAL	20 600	6 600	27 200

\* In the range of US \$90–95/kg U<sub>3</sub>O<sub>8</sub> (equiv. US \$40–43/lb U<sub>3</sub>O<sub>8</sub>).

\*\* With preliminary exploration.

The calculations of ore reserves are based on geostatistical concepts applied in:

- (a) Estimates of thickness and ore grade in the sections of borehole intercepts without drill cores;
- (b) Correction of grade assigned to each block;
- (c) Calculation of accuracy for each block and of global accuracy;
- (d) Classification of mineral categories according to the French nomenclature.

Sampling of each borehole was performed on fractions of different thicknesses, determined according to intervals of radiometric values (normally 1 m or less). The calculation of thickness and grade for each borehole intercept was made by selecting fractions according to a chosen cut-off grade. Where cores were missing, both parameters were determined by the statistical correlation of radiometry and grade which made it possible to build up the corresponding curve based on borehole cores through chemical analysis.

To define the average grade of each block, the Matheron Corrector was used for correcting the grade of the borehole centred in the block. This method made it possible to avoid over- or under-evaluation of the blocks, the area of influence being subject to the reconnaissance grid which was assigned, and the accuracy of the estimate then calculated. Once the accuracy had been established, the accuracy of the metal obtained by multiplying the product of the thickness by the grade tonnage of each block was classified into Reserves, Resources and Perspectives. Blocks with an accuracy level of 68% probability, which did not exceed a value of 50%, were classified as Reserves; those exceeding this value were considered to be Resources and those which were devoid of accuracy or whose values were higher than 100% were classified as Perspectives. The cut-off grades used were 0.04, 0.06 and 0.1%  $U_3O_8$  on first estimates. Recently, a cut-off of 0.03%  $U_3O_8$  was added.

Calculations of ore reserves for the Tigre I-La Terraza ore body were also made by Golden Associates by means of computers and taking into account the open-pit preliminary design. Estimate differences are within the normal margin of error for ore reserve calculations.

A zoneography of the economic ore body and a preliminary scheme for open-pit exploitation are shown in Fig. 8.

Estimated reserves at the end of 1979, based on the NEA-IAEA classification, are shown in Table III.

## 6. THIRD STAGE OF DEVELOPMENT (LATE 1977 UP TO THE PRESENT TIME)

### 6.1. Exploration

In spite of the positive results obtained during the second stage, the development of the regional potential of Sierra Pintada virtually stopped for a period of two years.

A new programme was conceived in mid-1977 based on the geological aspects and the assumption that the Areniscas Atigradas Member is often present with no significant outcrops. The main targets include the follow-up of its paleogeography, regional distribution and composition. Three potential uraniferous areas were postulated:

North-east Sierra Pintada, from El Tigre north towards the Carrizalito and the Las Peñas occurrences;

The central western slope of Sierra Pintada, centred in the Agua de La Josefa and Pantanito group of anomalies; and

The south Sierra Pintada, south of the El Nihuil Dam, with several types of occurrence.

Two photogeological studies were carried out: the first over 3200 km<sup>2</sup> at a scale of 1:20 000 and the second over 66 000 km<sup>2</sup> at a scale of 1:500 000, using Landsat imagery.

Simultaneously, a geological ground survey was launched in north-east Sierra Pintada with checks of selected locations and the performance of detailed cross-sections. At the end of 1979, about 230 km had been completed at a scale of 1:2500. Interest was focused on the Areniscas Atigradas Member, on the sandstone carboniferous El Imperial Formation and on some sedimentary sequences of the Triassic which are considered to be excellent host rocks.

The acid effusives have also been considered as possible uranium sources (see Table 1).

A preliminary scheme concerning these, mostly buried, formations was completed at the end of 1977, taking into account the considerable doubts concerning their structural position conditioned by the complex block-faulting of Sierra Pintada. Subsequently, a drilling programme was initiated on a 4-to-6-km grid, with an average depth of 350 m, for the sole purpose of obtaining sound geological knowledge. A Gerhart Owen Widco Logger, Model 3500 PSL, was used for total  $\gamma$ , resistivity and self-potential for cutting recovery and multilogging. Results were entirely satisfactory, the existence of the Areniscas Atigradas Member at accessible depths having been proven in many localities. Four holes intersected uranium ore with grades of up to 0.1% U<sub>3</sub>O<sub>8</sub>. Many others gave positive anomalies (0.02 to 0.03% U<sub>3</sub>O<sub>8</sub>).

A second 10 000-m drilling programme was initiated late in 1979 over an area of 5 × 2 km north from the El Tigre I-La Terraza up to the Diamante River, on a 400-m grid, chosen because of the size of the known economic ore bodies in the district. A few drill-holes were completed by the end of 1979. One of them intersected an ore body at the El Tigre Dam in the Diamante River which was 1.60 m thick and had a grade of 0.1% U<sub>3</sub>O<sub>8</sub>. The remainder were anomalous, with contents varying from 70 to 300 ppm U<sub>3</sub>O<sub>8</sub>. The programme is being implemented, and a new one involving some 20 000 m is to be initiated as soon as possible.

The results obtained raise reasonable hopes for future development. The existence of very favourable host rocks and the mobilization and fixation of uranium have now been proven without any doubt and with an excellent continuity, within a triangle of 45 km base (El Tigre-La Pintada-Pantanito-Agua de La Josefa) and 50 km height (up to the north of Carrizalito).

## 6.2. Mining and milling programmes

Following some minor mining exploitations, a programme was initiated early in 1978 at the El Tigre III ore body. A pit was opened which will produce 200 000 tonnes of ore per year, the third part of which, with a grade of 0.1% U<sub>3</sub>O<sub>8</sub>, is being sent to the old Malargüe Mill, and the remainder, with a grade of 0.07%

U<sub>3</sub>O<sub>8</sub>, is processed locally by heap-leaching methods in a plant which started operating in September 1979.

The geological concept of the deposit was satisfactorily proven during this operation.

A major programme to exploit El Tigre I-La Terraza, by subcontracting the engineering, erection and operation of the mine and mill (on the basis of an agreement to purchase a fixed volume of yellow cake of up to 700 t U<sub>3</sub>O<sub>8</sub> per year) is now in the final stage of negotiations. The complex is expected to start operating early in 1983.

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## DISCUSSION

P. BARRETTO: From 1969 to 1975 you carried out exploratory work in the Sierra Pintada area and used several techniques: airborne surveys, emanometric surveys and geochemistry. Which of these really indicated the interesting items to follow up? What were your experience and results in other areas?

P. STIPANICIC: The first good indication of the area's favourability was based on geological considerations. Before 1968 some airborne surveys which were carried out with lines that were too wide and irregularly spaced did not give good results, owing to the highly radioactive background prevailing in the area. The 1968 detailed airborne survey, with a grid of 250 m, gave an excellent result because the Permian sandstone bearing the uranium mineralization is covered by a thick (up to 200 m) piroclastic tuff with high radioactivity. When lines too widely spaced were used, the highly radioactive background of the tuff masked the anomalies corresponding to the outcrops of some ore bodies, but with a 250-m regular grid, the major part of the uranium outcrops, including those of small volume, could be located by airborne survey, the remaining being discovered by radiometric prospecting on foot. The altitude of flights was around 100 m. Classical emanometry gave good results in Argentina. Many years ago (1953–56) we used the old laboratory instruments, the Ambron ionization chamber, which gave us good results for defining and following the continuation of the buried uranium bodies in Cosquín, Córdoba. After that, we used the French emanometers (by sniffers), also with excellent results, as in Paso de Indios (Chubut). In Sierra Pintada, the method proved useful for extending the known ore bodies or main

results. Geochemical surveys were not very successful in Argentina (including the Sierra Pintada District).

P. BARRETTO: What was the direction of flights at Sierra Pintada?

P. STIPANICIC: Normally, crossing the structure with few parallel lines, when topographic conditions obliged us to do so, or for control.

F. SCOTT: Did the faults limit the mineralizing process? What is the thickness of the ore bodies?

P. STIPANICIC: They are of typical stratiform type and lenticular shape. Faulting is later than the mineralizing process and only produced the division of the ore bodies in blocks. The maximum thickness of the main ore body (Tigre I-La Terraza) is 30 m for a cut-off of 0.04%  $U_3O_8$ , and the average thickness is around 10 m.

H. FUCHS: Is there any clear relation between the tuff with abnormal uranium content and the mineralization at Sierra Pintada?

P. STIPANICIC: I presented a paper on this kind of problem during the IAEA Panel on Uranium Exploration Geology in Vienna in 1970. According to my idea, which was followed by other geologists, many of the sandstone-type uranium deposits of Argentina are closely related to the presence or availability of large peneplanized areas sculptured in fertile uranium sources, such as granites, acidic tuffs, etc. Peneplanation and adequate climatic conditions have favoured uranium leaching from the igneous source rocks and the uranium was afterwards deposited in any kind of host rocks offering favourable chemical and physical characteristics. The morphology of the resulting ore body could therefore be variable, stratiform, vein-type, etc. In the Sierra Pintada geological environment, Devonian, Carboniferous, Permian and Triassic are very rich in granites, granodiorites, andesites, rhyolites, tuffs, etc., and all this variety of uranium source rocks was peneplanized in more than one stage. The first large peneplanation occurred between the Middle Permian and Lower Triassic; another great stage of peneplanation was recorded at the end of the Upper Triassic as well as during several stages in Tertiary times. The uranium could have been leached from these peneplains at different geological times. In my opinion, the more important factors are the availability of large igneous and peneplanized outcrops and the presence of favourable host rocks. I believe that the uranium of the Sierra Pintada ore bodies was mainly extracted from the Permian-Triassic tuffs.

H. FUCHS: In north-eastern Australia (Queensland) we have a similar geological framework, with tuffs on top of the Permian sandstone, but there we have indications that mineralization probably came with the younger volcanic acid tuffs and the uranium mineralization in the sandstone originated by apophysis of the tuffs. In your example, it seems that it was just the erosional surface which allowed the uranium extraction from the source rocks.

P. STIPANICIC: I would like to emphasize the factor just mentioned: large peneplanized crystalline surface, presence of favourable host rocks and climatic

conditions could meteorize the outcropping source rocks, allowing the uranium leaching *at any time*. In Argentina, with a surface close to 3 million km<sup>2</sup>, there are some good examples. In the central part of the country there is a mesocraton composed of granites, granodiorites, syenites, etc., varying in age from Ordovician to Triassic, but the majority are of Hercynian age. Large peneplanized surfaces were sculptured from Late Cretaceous times (Laramic diastrophism) but also immediately after important Tertiary diastrophic phases. Within this crystalline environment, which covered a surface of more than 100 000 km<sup>2</sup>, one can find exogenic uranium deposits of different types, formed during different times, but always related to some peneplanized igneous source area, from where the uranium was leached. Thus the Cosquin stratiform uranium deposits (Punilla Valley, Córdoba Province) are included in Eocene sediments and were formed using the products coming from the crystalline Laramic peneplain. But in the same geological environment, the uranium deposits of Los Gigantes district were formed by uranium leached in recent times from the source rocks of a young peneplain (Upper Tertiary) and precipitated as ore shots in the same tectonized granites, in the joint of two main fault systems. Moreover, the same superficial and recent uranium solutions were able to form small accumulations of calcrete type (San Luis).

J. DARDEL: What are the accessory minerals?

P. STIPANICIC: The mineralogy is very simple: uraninite is the prevailing mineral with subordinate brannerite and coffinite. The relationship of uranium mineralization with carbonaceous materials does not seem to be clear, owing to the scarcity of the latter. In shallow levels there is a relation to the content of some colloidal iron-oxides ( $\gamma$  Fe<sub>2</sub>O<sub>3</sub>).

D.A. PORTER: Uraninite is below the water table; but what is the mineralization above the water table?

P. STIPANICIC: Above the water table, uranophane.

D.A. PORTER: What is the control of the mineralization?

P. STIPANICIC: I don't know if Messrs Rodrigo and Belluco have a good answer to your question, because, to my knowledge, there is not a well proven explanation of the control of the mineralization. There is no clear paleo-channel control; there is no clear redox-front control, in spite of the fact that some geologists are in favour of this idea. There is no clear relation to lithological changes, because porosity and permeability seem to be similar elsewhere. The only objective indication is the apparent control by some iron-oxides.

D.A. PORTER: What is the age of the mineralization?

P. STIPANICIC: I am not sure, but from geological considerations I believe it could be Tertiary. During Tertiary times there were large peneplanized surfaces of acidic igneous rocks. Climatic conditions from Tertiary times until now did not change much (except during the Quaternary) and we have proved in some uranium districts that in very recent times a large amount of uranium was leached from tuff during a very short period of time. In the Atuel Canyon, a few km

south-west of Sierra Pintada, a Permian-Triassic tuff shows very high radioactive value, which in some cases reached up to 3000 and 4000 cps (SPP2), but corresponding chemical analyses only indicated between 30 and 50 ppm U. Dr. Nicolli carried out a very interesting study on the subject (using the Mössbauer effect) and he proved that practically all the uranium contained in the tuff was leached in the last million years, or, more possibly, in the past half million years. For all these reasons, I believe that the uranium mineralization in the Sierra Pintada district could be Tertiary.

M. MATOLÍN: What kind of emanometric prospecting was used? What type of sampling and depth of sampling?

P. STIPANICIC: For the particular case of Sierra Pintada, emanometry by sniffers was used, and the air samples were normally taken between 0.50 m and less than 1 m. According to my information, trace-tracks (or similar methods) were not very successful in some testing areas.