Report on
1:100 000 Scale Geological and Metallogenic Maps Sheet 3166-17
Province of Córdoba

Patrick Lyons and Roger G. Skirrow

GEOSCIENTIFIC MAPPING OF THE SIERRAS PAMPEANAS ARGENTINA-AUSTRALIA COOPERATIVE PROJECT

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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SECTION 1:GEOLOGY

by Patrick Lyons

1. INTRODUCTION

1.1 LOCATION AND ACCESS

The 3166 -17 1:100 000 Sheet area lies within Córdoba Province, between 30°40'-31°00'S and 65°00'-65°30'W. The area is part of the 3163-II (Cruz del Eje)1:250 000 sheet area.

The region includes the western Sierra Grande which is drained by the north flowing Ríos Pichanas and Guasapampa.

Access to the region, from Córdoba city, is via Ruta Nacional 38 which connects the main population centres of La Cumbre, Capilla del Monte, Cruz del Eje, and Villa de Soto. A number of secondary roads connecting the centres of La Higuera, Ciénaga del Coro, La Playa (all south of the sheet area), Agua de Ramón, and Paso Viejo to the main centres afford good access to most of the rock types in the sheet area.

1.2 NATURE OF WORK AND PREVIOUS INVESTIGATIONS

Mapping of the Sierras septentrionales de Córdoba was carried out in 1995 and 1996 under the Geoscientific Mapping of the Sierras Pampeanas Argentina - Australia Cooperative Project by geologists from the Australian Geological Survey Organisation (AGSO) and the Subsecretaria de Mineria (DNSG) (Figure 1.1). The mapping employed a multidisciplinary approach using the newly acquired high-resolution
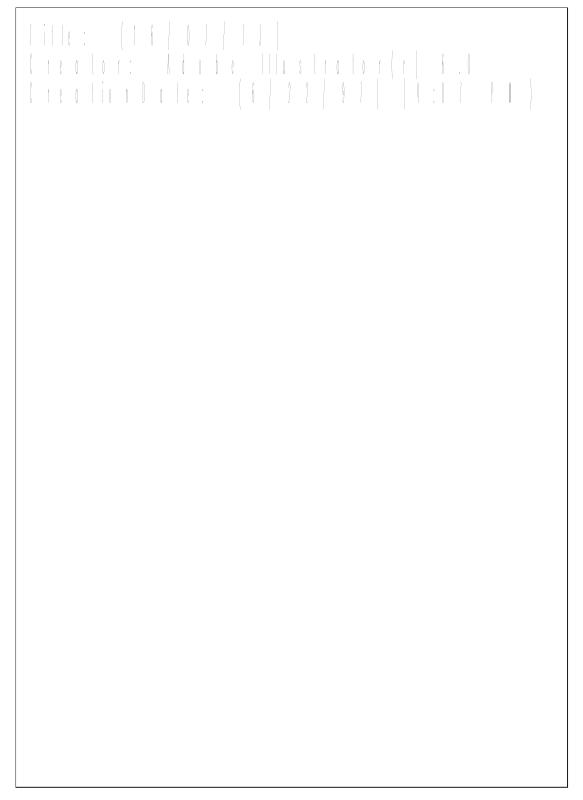
Figure 1.1. Location and simplified geology of the Sierras septentrionales de Córdoba and location of 1:100 000 sheets.

airborne magnetic and gamma-ray spectrometric data, Landsat TM imagery, and 1:20 000 scale (approximate) black and white air photography. All geological maps were compiled on topographic bases produced at photo-scale from rectified Landsat images controlled by field GPS sites. Geologists involved in the fieldwork were P. Lyons, and P.G. Stuart-Smith (AGSO), and J.C. Canadiani, H. Lopez, and R. Miro (DNSG). P. Espejo, M. Viruel, D. Martos (DNSG) and B. Torres (Secretaría de Minería de la Provincia de Córdoba) assisted with the fieldwork.

The area was first mapped as undifferentiated metamorphic basement by early workers (e.g., Pastore, 1932). Much of the Sierra Grande was mapped by Olsacher between 1961 and 1964 (Lucero Michaut and Olsacher, 1981). Lapidus and Rossi (1959) studied tungsten mineralisation near Agua de Ramón.

2. STRATIGRAPHY

2.1 GENERAL RELATIONS

The 3166-17 Sheet area is part of the southern Sierras Pampeanas, a distinct morphotectonic province of early to mid Palaeozoic metamorphic, felsic and mafic rocks, forming a series of block-tilted, north-south oriented ranges separated by intermontane basins (Figure 2.1). The ranges are bounded by escarpments developed on moderate to steeply dipping reverse faults developed during the Cainozoic Andean uplift (Jordan and Allmendinger, 1986).

Basement consists of Early Cambrian metamorphic and igneous complexes intruded by Cambrian, Ordovician, and Devonian granitoids. The remnants of an extensive Carbo-Permian fluvio-lacustrine sequence (González and Aceñolaza, 1972) occur in a graben

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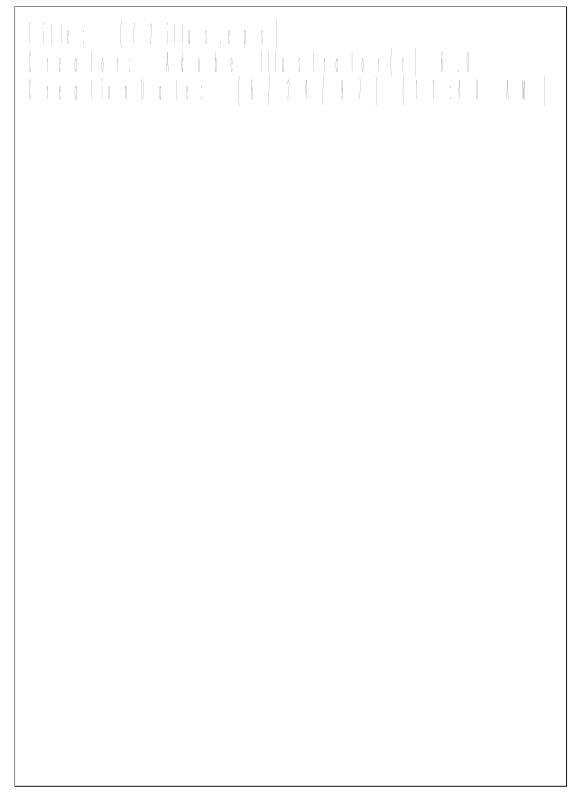CreationDate: (6/24/97) (11:48 AM)

Figure 2.1. Location of the three project areas of the Argentina-Australia Cooperative Project and simplified regional geology of the southern Sierras Pampeanas.

valley in the north west of the map area and continental Cainozoic and Quaternary cover occupies major valleys and intramontane areas to the north, east and west.

Recent geological and geophysical surveys conducted as part of the Cooperative Argentine-Australia project in the Sierras Pampeanas show that the Paleozoic basement of the southern Sierras Pampeanas contains of a number of distinct lithological and structural domains separated by major tectonic zones. There are two principal domains: a Cambrian Pampean domain, and the Ordovician Famatinian domain to the west. Both domains have shared a common geological history since early Ordovician times. The boundary between the domains is broadly coincident with a regional change in the gravity near the western flank of the Sierras de Córdoba (Miranda and Introcaso, 1996) and is marked by the Guzman Fault further south in the Province of San Luis. Only the Pampean domain is exposed in the Sierras septentrionales de Córdoba. However, the younger Famatinian domain is inferred to be present in the subsurface west of the Sierra Grande.

A summary of stratigraphy and relations is given in Table 2.1.

2.2 EARLY PALAEOZOIC METAMORPHIC BASEMENT

Marble (∈l)

Minor marble units are found throughout the sheet area but mappable outcrop is principally found in the Pichanas Metamorphic Complex in the south of the sheet area near the Río Pichanas and Arroyo Ciénaga del Coro. Details are given under the respective sections.

Pichanas Metamorphic Complex and associated S-type granites (∈gnp, ∈gno, ∈gnt, ∈gnh, ∈eb, ∈gi1, ∈g)
Paragneiss, quartzite, schist, migmatite, associated S-type granite, minor marble and amphibolite

The Pichanas Metamorphic Complex is the most extensive unit in the sheet area. Its name derives from the Río Pichanas. It is primarily composed of cordierite and garnet paragneiss and migmatite with minor marble and amphibolite units. In places, high T metamorphism resulted in local melting which produced a number S-type granite

The Pichanas Metamorphic Complex shares a common deformational and metamorphic history with the Cruz del Eje Metamorphic Complex to the west (Sheets 3166-18, 3166-24) and a Th-Pb age determined from monazite gave 526±11 Ma as the age for peak amphibolite grade metamorphism (Camacho and Ireland, 1997).

Metapelitic paragneisses with minor marble and amphibolite (∈gnp, ∈gno) form the dominant units in the complex. They grade into migmatite in places. They contain medium- to high-grade assemblages of quartz (25% to 40%), K-feldspar (25% to 35%), biotite (10% to 30%), plagioclase (5% to 10%), muscovite (5% to 10%) and minor garnet, cordierite, and sillimanite. Retrograde effects are evident by muscovite replacement of sillimanite and K-feldspar and chlorite replacement of cordierite and garnet. They are identified by the relative proportions of cordierite and garnet; cordierite is greater than garnet in ∈gnp and garnet is greater than cordierite in ∈gno. However, the boundary between the two is gradational. This may reflect bulk compositional differences or facies changes in the original sedimentary pile. On radiometric images a broad distinction can be made as the garnetiferous unit gives higher uranium and thorium counts.

A unit known as in earlier works as the Tuclame Formation (∈gnt),e.g., Lucero Michaut and Olsacher (1981), crops out extensively south of Paso Viejo and as a narrow north-west trending belt, about 1 km to 2 km wide, extending from west of the Río Pichanas to the Tasa Cuna Valley.

Table 2.1 . Summary of stratigraphy and relationships in the 3166-18 1:100 000 Sheet.

Age (Ma)	Unit	Description	Relations
CAINOZOIC QUATERNARY	Talus deposits.	Unconsolidated debris of basement material	Deposits along the fault scarps Sierras Serrezuela and Guaspampa
	Alluvium	Unconsolidated clay, sand and gravel	Deposits along active river courses
CAINOZOIC	Undifferentiated fluvial and aeolian deposits	Clay, sand, gravel, paleosol	Mantles older units.
MESOZOIC TERTIARY	La Playa Formation	Travertine	
CARBO-PERMIAN	Tas-Cuna Formation	Shale, sandstone, conglomerate	Remanant preserved in graben.
DEVONIAN	La Playa Aplopegmatite	Granite	Intrudes La Playa Granodiorite and Pichanas Formation.
	La Playa Granodiorite	Granodiorite	Intrudes Pichanas Complex.
	Esmeralda Granodiorite	Granodiorite	Intrudes Pichanas Complex.
	Unassigned granite	Leucogranite	Intrudes Pichanas Complex .
CAMBRIAN	Pichanas Complex	Pelitic gneiss, quartzite, migmatite, S-type granite, minor marble and amphibolite.	Concordant(?) with Cruz del Eje Complex.

Although structurally complex, it appears to be concordant with the cordierite dominant paragneiss except for the north east side of the aformentioned belt which is separated by a faulted informally called the Dos Pozos mylonite-cataclasite zone. The zone is about 100m wide, sub-vertical, and kinematic indicators show a north-east side up movement. Whether this is the only movement on the fault is not known. The fault does not offset Early-Mid Devonian mineralisation which transects it.

It comprises a sequence of non magnetic (magnetic susceptibilities <20×10-5 SI) *quartz-rich meta psammitic and minor pelitic gneiss* which are typically banded on a centimetre scale. The banding consists of alternating quartzo-feldspathic layers with thinner

micaceous-rich layers. Major mineral constituents are quartz (40% to 70%), biotite (15% to 30%), muscovite (5% to 25%), plagioclase (10% to 25%), K-feldspar (<30%), and sillimanite (< 10%) which is mostly retrogressed to muscovite. Accessory phases include tourmaline, apatite, rutile, and zircon. The presence of migmatite pods, derived from partial melting of pelitic units within the original sedimentary pile, indicates that peak metamorphism was at least amphibolite facies. It is similar to rocks within the Cruz del Eje Formation (∈rc) and the Conlara Complex in an Luis Province and the Olta Complex in La Rioja Province. As a possible correlation may be made it has not been formally separated here.

This unit preserves a complex Pampean progressive deformation history, involving up to three folding events, which are not apparent in the gneisses and migmatites of other units in the Sierras septentrionales. In places, the banding is clearly a differentiated crenulation cleavage and in lower grade parts it may also represent original bedding.

*Quartz, K-feldspar, biotite, plagioclase, ±chlorite, ±sillimanite, ±cordierite g*neiss (∈gnh) crops out over a small area extending from the north eastern margin of the La Playa Granodiorite to a point about 3 km north of Agua de Ramón. Due to poor access through the unit it is relatively unknown but may be distinguished by slightly elevated biotite contents compared to the cordierite and garnet gneisses to the east, and zones of granodioritic composition which may be orthogneiss.   The unit has a distinct radiometric signature with elevated K and Th responses relative to adjacent units, which may be due to a concentration of pegmatite or the presence of metasomatism related to mylonitisation apparent on its western margin where kinematic indicators indicate east over west movement with a component of sinistral displacement. The regional gneissic foliation generally trends north-south but is locally east-west in the area about a kilometre north of Agua de Ramón.

Quartz, muscovite, biotite, ±K-feldspar, ±cordierite, ±garnet schist (∈eb) crops out in the far north of the Sierra de Guasapampa and as small scattered exposures and inliers west of the escarpment. It covers an area of about 12 km^2. Previously the schist was mapped as tonalitic biotite gneiss (Lucero Michaut and Olsacher, 1981). The indistinct

contact with the gneiss to the south and may represent a slight change in grade or an original sedimentary facies variation.

The mineral assemblage is characteristic of medium to high grade pelitic schist, and has a muscovite content of about 30%. The schistosity, with common intrafolial folds is sub-horizontal to gently east dipping. A moderate to steeply east-dipping, crenulation cleavage is developed in places and steepens in the east near the Río de Guasapampa where it becomes more penetrative with a corresponding increase in metamorphic grade.

Bodies of S-type granite associated with Early Cambrian high grade metamorphism occur throughout the Pichanas Metamorphic Complex. The most well known of these, and its cogenetic cordierite, has been previously named the El Pilón Granite or El Pilón Formation (Lucero Michaut and Olsacher, 1981) as its distribution was formerly recognised only over a small area between La Represa and Los Simbolitos (3166-18 Sheet) a distance of about 6 km. However, it is the main body of a discontinuous belt about 20 km long, which crops out as small hills and turtle backs between Los Simbolitos and Embalse Pichanas. Concordant and discordant contacts with the surrounding meta-pelites, and numerous enclaves of the same, provide field evidence that these granite bodies are voluminous accumulations of partial melt products generated during high-T metamorphism of the pelites.

On this sheet the K-feldspar phyric granite($\in$gi1) is the only assigned S-type granite. It is a pink to deep pink, *phyric to megaphyric, K-feldspar biotite granite* with minor muscovite, sillimanite, chlorite, after biotite, and cordierite and trace amounts of plagioclase and zircon. K-feldspar laths often display a local flow alignment, and make up about 40% to 45% of the granite. Biotite contents are about 15% to 20%. The radiometric response is high with total counts around 90 cps to 95 cps and potassium around 6.5 cps which gives a clearly identifiable response on radiometric images. Magnetic susceptibility is low, generally about 10×10-5 SI.

Recent isotopic age data obtained for the S-type granites are summarised in Table 2.2. Although recent U-Pb zircon data (Camacho and Ireland, 1997) are approximate, due to

some Pb loss, there is broad agreement with Rb-Sr ages obtained by Rapela and others (1995).

Table 2.2. Isotopic ages of S-type granite from the Pichanas Metamorphic Complex. 1. Rapela and others (1995) 2. Camacho and Ireland (1997).

Rock type	Age (Ma)	Method	Ref.	Comment
Granite	520±5	Rb-Sr	1	Leucogranite (and cordierite rock)
Granite	ca 527	U-Pb	2	Phyric granite
Granite	ca 514	U-Pb	2	Leucogranite

Some lead loss at about 480 Ma (Camacho and Ireland, 1997) may be due to the Ordovician Famatinian event.

Small bodies of unassigned granite ($\in$g), interpreted from aerial photographs and radiometric images, occur as part of a broad belt trending NW-SE from an area about 3 km east of Tosno to area about 8 km west of La Higuera and as smaller isolated pods around the main body.

Limited field evidence suggests they are porphyritic to equigranular, ranging in composition from granite to granodiorite. They contain numerous enclaves of schist and gneiss derived from meta-pelites and typically form intrusive, elongate to equidimensional, bodies which are concordant to sub-cordant with the regional fabric of the enclosing metamorphic rocks. They probably originated as melt products derived during high-T regional metamorphism of the metasediments. There are no isotopic age determinations, however, an Early Cambrian age is interpreted as the age of the peak regional metamorphism in the area is about 530 Ma (Camacho and Ireland, 1997). The main body, which has similar field relationships to country rock as the undifferentiated bodies, crystallised at about 520 Ma (Rapela and others 1995; this report). These ages are consistent with an origin as anatectic melt products (cf. Fitzsimmons and others, 1996).

2.3 PLUTONIC ROCKS

Esmeralda Granodiorite (Dgr)

The Esmeralda Granodiorite is a small body, covering about 3 km^2, immediately east of Agua de Ramón. It is well exposed and easy access is afforded by disused roads connecting the W deposits which it hosts. It is named after the Mina Esmeralda which is the largest of these deposits.

It is equigranular, medium grained, weakly foliated, and contains quartz, K-feldspar, plagioclase, biotite, muscovite, both primary and secondary, and minor to trace sericite, chlorite, epidote, and zircon. Lapidus and Rossi (1959) report the presence of apatite. Limited whole rock geochemistry indicate it is a granodiorite, albeit that it has an elevated SiO$_2$ content which may be due to silicification related to mineralisation. The foliation is parallel to the steep NNE striking regional foliation. Magnetic susceptibility is low, less than 10×10-5 SI, and the radiometric response is weak. Magnetic images suggest the western margin of the granodiorite is fault bounded. There are no isotopic age data for the Esmeralda Granodiorite, however, there is a possible genetic relationship between the granodiorite and W mineralisation. The 40Ar-39Ar dating of muscovites from cross cutting tungsten bearing veins gave ages between 360 Ma and 368 Ma (Camacho, 1997).

La Playa Aplo-pegmatite (Dgp1)

This is a high K granite which occupies a small area on the east of the La Playa Granodiorite which it intrudes and appears to be genetically related to the prominent aplo-pegmatites found within it. Although a dominantly medium grained rock, it contains substantial patches of very course grained pegmatitic material. Modal analyses (R. Miró, pers. comm.) show it contains about 35% to 40% quartz, 30% to 40% plagioclase, 20% to 30% K-feldspar, 2% to 7% muscovite, and 2% to 6% biotite. Minor and trace minerals include garnet, epidote, apatite, rutile, and zircon. There are no isotopic data but the close spatial association and intrusive relationship with the La Playa Granodiorite suggest a Devonian age.

La Playa Granodiorite (Dgp2)

This granite crops out immediately west of La Playa and covers an area of about 30 km2. It is a white to light grey, equigranular, medium grained, biotite bearing granodiorite which intruded rocks of the Pichanas complex and Totora Huasi Gneiss. Gomez (via R. Miró, pers. comm.) gives modal analyses of about 35% quartz, 35% plagioclase, 12% microcline, and 15% biotite, including secondary chlorite, and accessory muscovite, primary and secondary, epidote, sericite, and zircon. It is intruded by prominent aplo-pegmatite dykes genetically related to Dgap. There are no age data for the La Playa Granodiorite, but similarities between its major and trace element geochemistry and that of the Esmeralda Granodiorite and their spatial proximity suggests a Devonian age.

Granite, unassigned (Dg)

A small body of leucogranite about 7 km south of Embalse Pichanas crops out as small bosses over an area of less than 5 ha. It is a white, equigranular, medium grained granite similar in hand specimen to the La Playa Granodiorite (Dgp2) containing K-feldspar, quartz, plagioclase, muscovite, and minor biotite and chlorite. It also has similar magnetic and radiometric responses to the La Playa Granodiorite and is possibly an apophysis of a genetically related body. There are no geochemical or isotopic data but the above superficial similarities suggest it is the same age as the La Playa body.

Minor dyke rocks

Pegmatite
Several generations of pegmatite dykes intrude basement metamorphics and granitic rocks. The oldest form small deformed pods, less than a metre wide. These pegmatites

are probably the product of partial melting during Cambrian M1 metamorphism (Pampean).

Pegmatite dykes swarms are common in quartzite units (∈gnt) of the Pichanas Formation.

Ridge forming pegmatites related to the La Playa Aplopegmatite intruded the La Playa Granodiorite.

Lamprophyre

Lapidus and Rossi (1959) report west to north-west dipping lamprophyre dykes intruded into basement gneiss in the vicinity of the Mina El Carmen tungsten deposit near Agua de Ramón. They are cut by late Devonian tungsten bearing veins.

2.4 PALAEOZOIC

Tasa Cuna Formation (C-Ptc)
Fluvio-lacustrine sediments

Remnants of Carbo-Permian fluvio-lacustrine sediments of the Panganzo Formation, in this locality termed the Tasa Cuna Formation, (González and Aceñolaza, 1972) are preserved in the graben of the Tasa Cuna Valley between the Sierra de Serrezuela and the Sierra de Ciénaga del Coro. Another outlier is found about 10 km north of La Playa near Totora Huasi. The formation comprises a fluvio-lacustrine sequence of siltstones (in places carbonaceous), sandstones, and lithic conglomerates. Beds are locally tilted

up to 20°. At one location (30.83753° S, 65.34294° W) near the south west end of the Arroyo Agua de Ramón, steep westerly dipping siltstones provide evidence that deposition occurred prior to graben formation.

2.5 CAINOZOIC

2.5.1 Tertiary

La Playa Formation (Tpp)
Travertine

The Pliocene La Playa Formation (Olsacher, 1960) occurs as small out crops in the vicinity north and south of La Playa. Possibly related to Cainozoic volcanism (Lucero Michaut and Olsacher, 1981), it consists of light grey, fine-grained calcite with occasional layers of carbonaceous material and lithic fragments deposited in a lacustrine environment. Fossils of plant stems and fresh water molluscs are common.
Small cavities are lined with fine-grained crystalline quartz.

2.5.2 Tertiary to Quaternary

An extensive Cainozoic sequence (Czu) of *undifferentiated Tertiary to Quaternary fluvial and aeolian deposits and paleosols* which cover a large part of the Pampean region. The upper loess portion of the unit has been mapped in the area east of the Sierra Chica as the ?Upper Pleistocene "Formación General Paz" by Santa Cruz (1978). Strasser and others (1996) correlated similar deposits in the San Luis region with Late Pleistocene and Holocene units in the Buenos Aires Province.

The unit is dominated by pinkish loess which covers all older units forming a mantle or rarely dune fields which cover and preserve pre-existing topographic relief between the

main Pampean ranges. Present river courses and associated deposits locally dissect the deposits.

The loess deposits comprise mostly friable illite and silt. Material was derived from both the metamorphic-igneous basement rocks and a volcanic-pyroclastic source (Santa Cruz, 1978).

2.5.3 Quaternary

Holocene (Santa Cruz, 1978) to Recent *alluvial deposits of clay, sand and gravel* (Qa) occur along active river courses and adjacent terraces. The most extensive deposits are associated with the Ríos Soto and Pichanas in the north.

Minor Recent *talus deposits* (Qt) of granitic debris, derived from basement rocks, occur on the western slopes of the Sierra Serrezuela and Sierra Guasapampa. The steep slopes are all reverse fault scarps formed during the Cainozoic Andean Cycle.

3. TECTONICS

Three major deformation/metamorphic and magmatic events have affected basement rocks: the Early Cambrian Pampean Cycle, the Early Ordovician Famatinian Cycle and the Devonian Achalian Cycle. Faulting and block-tilting occurred during the Mesozoic and later Cainozoic Andean Cycle.

3.1 PAMPEAN CYCLE: EARLY CAMBRIAN DEFORMATION AND METAMORPHISM

No original sedimentary structures, such as bedding, are unequivocally recognised in the metamorphic rocks. In general, the earliest surface (S1) is a penetrative gneissic foliation in pelitic gneiss, defined by leucosome lenses and bands and foliated muscovite-biotite-rich bands. In amphibolite and calc-silicate rocks the foliation forms strongly differentiated mineralogical bands with aligned hornblende. Throughout most of the region the S1 foliation forms the dominant trends on aerial photographs and satellite imagery.

Sillimanite-garnet assemblages in pelitic gneiss indicate M1 metamorphism was at least upper amphibolite facies and abundant muscovite-pegmatites and leucosome (forming subconcordant lenses with S1), suggest limited partial melting took place. Estimates of peak metamorphic conditions for the Sierra Chica are mostly about 6 Kb, and 700°C to 800°C (see Table 3.1). Uranium-lead dating of zircon rims and monazite grains which grew during the peak metamorphic event (M1) in both the Pichanas and Cruz del Eje Metamorphic Complexes, give an age of about 530 Ma, interpreted here as the age of the M1/D1 event of the Pampean Cycle.

In the Sierra Grande there are, broadly, two principal orientations of the D1 high grade fabric (local S3 or S4 ?), steeply dipping to the south west and north-north east. However, in the Sierra de Guasapampa the fabric is upright or dips steeply to the west. This fabric is tightly to isoclinally folded at meso-scale. Limited data show the plunge of meso-scale fold hinges unevenly distributed about a girdle oriented steeply to the

Table 3.1. M1 Metamorphism - estimated peak conditions in the southern Sierras Pampeanas

Location	Temperature(°C)	Pressure (Kb)	Reference
Sierras de Córdoba	700 - 750	6.1 - 6.4	Toselli & others, 1992
Sierra Chica	500 - 700	4 - 6	Pérez & others, 1996
Sierra del Cuniputo-Totoralejo	700 - 800	6 - 8	Murra & Baldo, 1996
Sierras Comechingones	700 - 750	6.1 - 6.4	Cordillo, 1984
Sierra Chica de Córdoba	820	5.7	Baldo & Casquet, 1996
Sierras Comechingones	760-800	8.5-9.5	Cerredo, 1996
San Carlos	650-700	4.5-5	Demange & others, 1993
Sierras Comechingones/ Chicas	800	8	Martino & others, 1994
Guamanes Belt	700	6	Martino & Simpson, 1993

north west. This suggests that the fabric was produced during regional ductile shearing, however, shear sense indicators are absent.

3.2 FAMATINIAN CYCLE: ORDOVICIAN DEFORMATION AND METAMORPHISM

Widespread isoclinal folding and thrusting, at lower amphibolite/upper greenschist facies conditions, throughout the region is attributed to the Early Ordovician Famatinian Cycle. Metamorphic conditions produced chlorite from garnet and cordierite, and muscovite from sillimanite.

In areas of penetrative S2 development all planar D1 fabric elements are rotated into parallelism with the S2 foliation with a pronounced mineral lineation (L2) of biotite, muscovite and quartz, which plunges shallowly to the east (~ 100°). This lineation is perpendicular to long axes of boudinaged tonalitic layers, indicating a broadly coaxial deformation.

The age of this deformation is poorly constrained in the Sierra Septentrionales de Córdoba. K-Ar and Rb-Sr dating of muscovite from a pegmatite, which was emplaced syn-D2, yields a minimum age of about 428 Ma (Camacho, 1997). The deformation (D2) is interpreted here as part of the Early Ordovician Famatinian Cycle which is dated in the Sierras de San Luis at 490 Ma (Camacho, 1997)

Sims and others (1997) have identified a *compressional* and an *extensional* phase of the Famatinian event in Sierras de San Luis. However, no evidence for a widespread extensional regime has been found in the sierras septentrionales de Córdoba. Boudinaged phyric granites in the Guamanes Shear Zone (Sheet 3166-18, 24) predate the final Devonian compression and may have intruded during the Famatinian extensional regime.

3.3 ACHALIAN CYCLE: DEVONIAN DEFORMATION AND METAMORPHISM

A complex system of rectilinear brittle subvertical sinistral NW- and dextral NE-trending strike-slip faults, breccia zones, fractures and kink zones (S4) affect all the basement units in the Sierras Septentrionales de Córdoba, crosscutting the S3 foliation where present. Regional faults are rarely exposed, but are prominent on aerial photographs and Landsat images. Some of the faults are also delineated on magnetic images as zones of demagnetisation.

The orientation and conjugate relationship of the WNW- and NE-trending strike-slip faults, breccia zones and fractures indicates a possible continuation of the east-west compressive regime that accompanied S3 and S4 development. This fracture system is developed throughout the Sierras Pampeanas, and in Córdoba and La Rioja Provinces where muscovite Ar-Ar ages of micas from quartz veins indicate that this stage began about 385 Ma, peaked at 370 Ma and continued until 355 Ma (Camacho, 1997). These faults zones therefore represent the final stage of the Achalian Cycle.

3.4 ANDIAN CYCLE: REVERSE FAULTING

The Sierras de Serrezuela and Guasapampa are examples of basement tilt blocks formed by east-west compression during the Cainozoic Andean uplift (Jordan and Allmendinger, 1986). The ranges slope gently to the east and are bounded to the west by escarpments developed on moderate to steep east-dipping reverse faults. Many of the faults are probably reactivated Palaeozoic or Mesozoic structures. Quaternary faulting effects are limited to characteristic haematitic zones of fault gouge up to 5 m wide which dip 30-55° to the east, crosscutting older and mostly steeper fault fabrics.

4. GEOLOGICAL HISTORY

The Sierras Septentrionales de Córdoba area form part of the southern Sierras Pampeanas, comprising basement ranges of early Palaeozoic metamorphic rocks and Palaeozoic granitoids, separated by intermontane Mesozoic and Cainozoic sediments. The basement rocks form a series of north-trending lithological and structural domains separated by major mid-crustal shear zones. These domains have been variously interpreted to form (originally) part of an ensialic mobile belt (e.g. Dalla Salda, 1987) or as terranes which either accreted or developed on a western convergent margin of the Río Plata craton (e.g. Ramos, 1988; Demange and others, 1993; Escayola and others, 1996, Kraemer and others, 1995, 1996). Recent geochronological studies indicate that their are two principal domains in the southern Sierras Pampeanas: an older Cambrian Pampean domain, and a younger Ordovician Famatinian domain to the west, not exposed in the map area. Both domains share a common geological history since early Ordovician times. The boundary between the domains is broadly coincident with a regional change in the gravity on western flank of the Sierras de Córdoba (Miranda and Introcaso, 1996) and is marked by the Guzman Fault in San Luis.

4.1 EARLY CAMBRIAN SEDIMENTATION

The oldest rocks in the region form a structurally thick sequence parageneisses of the Pinchanas Metamorphic Complex. These metasediments are interpreted as being deposited on a passive margin, developed during intracontinental rifting and break up of Laurentia from Gondwana in Eocambrian times at about 540 Ma (Dalziel and others 1994) in a tectonic environment similar to that envisaged by Dalla Salda and others (1994?). Lithological similarities and comparable ages indicate that the metasediments may be correlatives of the Early Cambrian (Aceñolaza and Toselli, 1981) Puncoviscana Formation in the northern Sierras Pampeanas as postulated by Willner and Miller (1986).

4.2 PAMPEAN CYCLE

Early Cambrian deformation, metamorphism, mafic and felsic intrusion

Following intrusion of rare tholeiitic mafic dykes, the sediments were deformed at mid-crustal levels by a compressive event (D1) and metamorphosed at mostly upper amphibolite facies and locally, granulite-facies to form banded gneiss and locally migmatites. Mafic dykes were converted to amphibolite and extensively boudinaged. Muscovite-pegmatites formed subconcordant lenses. Estimates of peak metamorphic conditions for the area are mostly about 6 Kb, and 700°C to 800°C. A penetrative differentiated foliation formed as the last, and possibly second or even third fabric, in a progressive westerly-directed thrusting event, which is evident in the rocks by the presence of mylonite and a ubiquitous east-plunging mineral lineation, commonly sillimanite. Uranium-lead dating of zircon rims formed during this metamorphic event (M1) in Córdoba give an age of about 530 Ma (Camacho and Ireland, 1997). In the map region this event includes both the D1 and D2 domains of Dalla Salda (1987) and has been previously termed the "Ciclo orogénico Pampeano" (Aceñolaza and Toselli, 1976) or "Ciclo Pampeano" (Dalla Salda, 1987, Toselli and others, 1992). The deformation is interpreted as the first in a series of deformation events associated with convergence on the newly created Pacific Gondwana margin formed after final amalgamation of the supercontinent (e.g., Dalzeil and others, 1994).

4.3 FAMATINIAN CYCLE

Early Ordovician Deformation, metamorphism, mafic and felsic intrusion

During the Ordovician, closure of the Iapetus Ocean and collision of the Precordillera with the Pampean margin of the Gondwana craton (Dalla Salda and others, 1992, 1996, Dalziel and others, 1996) resulted in amalgamation of the accretionary wedge and the Pampean domain during a widespread deformational, metamorphic and magmatic event known as the "Ciclo orogénico Famatiniano" (Aceñolaza and Toselli, 1976), Famatinian Orogen (e.g., Dalla Salda and others, 1992) or "Ciclo Famatiniano" (Dalla Salda, 1987). Earlier D1 fabrics were tightly folded with local axial plane crenulation cleavage, subparallel to the higher grade differentiated D1 fabric.

Dalla Salda (1987) and Toselli and others (1992) ascribed this deformation to the D2 domain. Zircons which grew during this event yield an age of about 480 Ma dating the timing of peak metamorphism in the Famatinian domain in San Luis.

Compression was followed closely, possibly in the one continuos event, by extensional deformation (D2 in the Famatinian domain) at amphibolite- to greenschist-facies. This deformation was mostly confined to the already established ductile shear-zones and was accompanied by retrogression of higher grade metamorphic assemblages and by intrusion of numerous granitic to tonalitic bodies and tourmaline-bearing pegmatites. It is not known whether the extensional phase affected the Pichanas Meyamorphic Complex in the 3166-17 Sheet area.

4.4 ACHALIAN CYCLE

Early Devonian granite intrusion and deformation

Mid Palaeozoic resumption of convergence on the western margin of Gondwanaland is evidenced by a widespread compressive deformation in the Famatinian (D2) and Pampean domains (D3), and the development of an Early Devonian magmatic arc. The deformation was dominated by orthogonal westerly-directed thrusting and the development of regionally extensive ductile shear zones with intensive greenschist facies retrogressive fabrics. Locally, outside the principal shear zones, the metamorphic rocks were open to isoclinally folded with an axial crenulation developed in places. Dalla Salda (1987) defined this deformation as D3, placing it in the "Ciclo Famatiniano".

Peraluminous to slightly peralkaline felsic melts, generated from partial melting of MgO depleted crustal rocks (Dalla Salda and others, 1995) intruded the metamorphics discontinuously during and after shear zone development.). U-Pb zircon dating of these

granites in the southern Sierras Pampeanas brackets crystallisation of the felsic magmas and shear zone formation over a 20 Ma period between 404 Ma and 384 Ma. The Achalian Cycle derives its name from the Achala Batholith, the largest of the Devonian batholiths in the southern Sierras Pampeanas, which is exposed south of the map area in the Sierra Grande. The cycle probably corresponds to the "Fase Precordilleránica" (Astini, 1996) in the precordillera west of the Sierras Pampeanas where it is related to the amalgamation of the Chilena domain.

The final stages of the Achalian Cycle were the province-wide development of a complex system of rectilinear brittle-ductile vertical NW- and NE-trending strike-slip faults and fractures. The orientation and conjugate relationship of the fractures indicates a continuation of the east-west compressive regime. Locally, the structures are associated with vein-type Au±Cu mineralisation, the result of mesothermal activity interpreted to be associated with the waning stages of magmatic arc activity as the centre of magmatic activity migrated westward (Ramos and others, 1986). Muscovite Ar-Ar ages indicate that this stage began about 385 Ma, peaked at 370 Ma and continued until 355 Ma (Camacho, 1997). Toselli, Durand, Rossi de Toselli and Saavedra, (1996) attribute development of the fracture system to a 355 Ma old "Chánica Orogeny".

4.5 CARBONIFEROUS - PERMIAN SEDIMENTATION

Following peneplanation, and later marine transgression, fluvio-lacustrine and shallow-marine sediments of the Paganzo Group (Gonzále and Aceñolaza, 1972) were deposited during the Carboniferous and Permian. The sediments may have covered much of the crystalline basement, however, only remnant outcrops of the group are now preserved in narrow (<2 km wide) grabens. These grabens, possibly initiated during syn-sedimentary extensional faulting, were active after the cessation of sedimentation and prior to the Andean Cycle deformation. It is possible that the late-Palaeozoic sediments were first deposited in basins controlled by the regional wrench tectonic regime.

4.6 ANDEAN CYCLE

East-west compression during the Cainozoic Andean uplift resulted in Neogene inversion of the Cretaceous basins (Schmidt, 1993) and block tilting of basement rocks, forming north-south oriented ranges separated by intermontane basins. The ranges are bounded by escarpments developed on moderate to steeply-dipping reverse faults (Jordan and Allmendinger, 1986; Martino and others, 1995; Costa, 1996), many of which show repeated reactivation. Costa interpreted the last and most significant movement in the region took place during the Late Pliocene-Pleistocene with some movement continuing during the Quaternary.

SECTION 2: ECONOMIC GEOLOGY

by Roger G. Skirrow

1. INTRODUCTION

The Sheet 3166-17 area contains a wide range of metallic and industrial mineral occurrences, including Ag-Pb-Zn±Au in the El Guaico district, and W in the Aguas de Ramón district. The region is well known for its production of high quality dimension stone.

In the Geoscientific Mapping of Sierras Pampeanas Cooperative Project the principal metallic deposits in all main mining districts of the map area were investigated in the field, and geological observations were entered into the ARGROC and ARGMIN databases (Skirrow and Trudu, 1997). ARGMIN is a Microsoft Access database that was initially developed jointly by AGSO and the Subsecretaría de Minería in ORACLE, based on OZMIN (Ewers and Ryburn, 1993). Additional geological and resource data from the literature on mineral occurrences have been compiled in ARGMIN. Petrography of ore and host rock samples (thin sections and polished thin sections) was recorded in a petrographic database (Sims and others, 1996), and selected samples for ore genesis studies were analysed for whole rock geochemistry (Lyons and others, 1996; Lyons and Skirrow, 1996), stable isotopes of oxygen, hydrogen and sulfur (Lyons and Skirrow, 1986), as well as $^{40}Ar/^{39}Ar$ radiometric age dating (Camacho, 1997). Geographic coordinates were measured by GPS (locational accuracy 50m), whereas those occurrences not visited in the field were generally located on aerial photographs and their geographic coordinates digitised. The locational accuracy for photo-located occurrences is ±200 m. The locations of remaining occurrences are taken from various published sources, which in some cases allow only very approximate geographic coordinates to be estimated (e.g., 3 km for U deposits).

Mineral occurrence data as well as non-metallic mineral and dimension stone occurrences are shown on the 1:100 000 scale metallogenic map accompanying this report. Output data sheets from the ARGMIN database are appended to the report. Details of the geology and grade-tonnage data, where available, for individual metallic mineral occurrences may be found in the database. The 1:250 000 scale Metallogenic Map for the Sierras Septentrionales de Córdoba (Skirrow, 1997) shows the mineral occurrences in relation to 'prospectivity domains' or areas of mineral potential. These domains are defined on the basis of 'metallogenic models' for each mineral deposit style, as discussed by Skirrow in Lyons and others (1997) and which were developed from the observations and interpretations presented in the following sections. For further datasets of mineral potential, the reader is referred to the *Atlas Metalogenético* (1:400 000 scale) for the Sierras Pampeanas mapping project (Skirrow and Johnston, 1997) and project GIS (Butrovski, 1997) in which metallogenetic models for the principal styles of metallic mineralisation are presented as separate coverages.

2. METALLIC MINERAL DEPOSITS

2.2 AG-PB-ZN DEPOSITS

2.2.1 El Guaico Ag-Pb-Zn (V, Au) district

The El Guaico (- Los Pozos) Ag-Pb-Zn (V-Au) district covers an area with a diameter of about 10 km, centred approximately 10 km NW of La Higuera and 22 km SW of Villa de Soto. The deposits were worked intermittently between the 1880s and the 1970s. The geology of the district and its metallic deposits was most recently described by Sureda (1978), Lucero Michaut and Olascher (1981) and Candiani (1995). An evaluation of resources at the Rara Fortuna deposit was undertaken by Candiani and others (1988), and the geochemistry of mine mullock was investigated by Torres and Leynaud (1994). Individually, the worked deposits are relatively small and range from resources of approximately 100 000 tonnes at 280 g/t Ag, 1.7 % Pb, 2.6 % Zn (Rara

Fortuna, Candiani and others, 1988) to occurrences of a few tonnes. The district is also known for the occurrence of secondary vanadium minerals in association with the veins, such as vanadinite, brackebuschite and descloizite (Sureda, 1978). Manganese occurrences shown on the 1:750 000 map of Ricci (1974) in the vicinity of the El Guaico district may, in reality, correspond to Ag-Pb-Zn deposits as Sureda (1978) described secondary manganese minerals from the deposits.

Regional setting: The quartz-sulfide veins occur in a range of medium- to high-grade Cambrian metamorphic rock types of the Complejo Pichanas, including banded quartz-feldspar-biotite-muscovite schist and massive to foliated gneiss and migmatite , and granitoid bodies interpreted as melt generated during the high grade Cambrian metamorphism. The schist occurs in a NW-trending belt, about 1 km wide, that passes through the centre of the district, and is bounded to the NE by the Dos Pozos mylonite and cataclasite zone. Parts of this zone are haematite-chlorite altered, whereas in other areas the schist-gneiss contact zone is occupied by sheared pegmatite. The structure may represent a mylonite developed at biotite-stable conditions that was reactivated, at least once, under low grade and brittle conditions.

A set of NE-trending faults and lineaments, that are prominent regional features in Landsat TM imagery and in aerial photographs, cut the metamorphic rocks but do not appear to be offset by the Dos Pozos mylonite-cataclasite. Northwest-trending faults and lineaments (subparallel to the strike of foliation) also are present in the district, including the Dos Pozos mylonite-cataclasite. Horizontal offsets on the NE faults are at most a few metres to tens of metres. Both orientations of faults, particularly the NW set, are common throughout the southern Sierras Pampeanas and typically show low magnetic response. A small stock of non-magnetic Devonian(?)crops out 11 km SSW of Rara Fortuna at Coro de Mesa. This intrusion may be more extensive in the subsurface, as suggested by the presence of two sub-circular structures about 5 km in diameter identified in Landsat TM imagery (Candiani and others, 1988), one of which encompasses the exposed granite. In addition, a 5 km diameter subcircular zone of slightly enhanced magnetic response within regionally less magnetic rocks is located in the central-north part of the El Guaico district. This has been interpreted as a possible

granite at depth within the metamorphic rocks (see Sheet 3166-17 and 1:250 000 scale Interpretación Aeromagnetica and Hoja Geológica maps).

Geology: The Ag-Pb-Zn quartz vein deposits strike in one of two principal orientations: NE and to a lesser extent NW. Many of the NE-oriented veins lie within the regionally extensive lineaments and faults of the same strike. It is notable that several of the main deposits occur adjacent to the contact between the schist and gneiss/migmatite of the Complejo Pichanas. For example, Veta Rica Sur, Eufemia, San Carlos and Rara Fortuna are hosted by gneiss/migmatite and the vein systems terminate at or near the contact with schist, whereas the schist-hosted Garibaldi, La Víbora, Asunción and Ana María vein systems terminate southwestwards at or near the gneiss/migmatite contact. At Eufemia the veins transect the contact, indicating relatively late emplacement of veins with respect to movement on the schist-gneiss/migmatite contact. In general the host rocks adjacent to veins do not show evidence of extensive shearing, and the vertical to subvertical veins formed in extensional structures. However, at San Carlos weakly developed S-C structures indicate subhorizontal dextral movement, and at Santo Domingo a steep stretching lineation suggests subvertical movement at the vein margin. The competency contrast between schist and gneiss/migmatite units may have played an important role in localising vein formation through the development of dilatant zones near the contact during shearing on the Dos Pozos structure.

The mineralised vein systems have typical strike lengths of 150-700 m and consist of single or multiple veins and vein networks with widths of 0.2 to 1 m and rarely reaching 2.4 m (Rara Fortuna). Veins are generally tabular with minor pinch-and-swell, and high length-to-width ratios.

Similar vein textures and fabrics were observed in a number of the major deposits. The veins have undergone negligible post-depositional deformation or recrystallisation, and textures are very well preserved. Three main paragenetic stages have been identified in the present investigation This largely corroborates the detailed mineralogical observations of Sureda (1978).

1.   The initial and principal stage of extension was synchronous with infilling with coarse, white, subhedral and euhedral, coarse to fine grained, growth-zoned, crustiform and comb textured quartz in mm- to cm-scale bands parallel to vein walls.   These textures are indicative of open space filling. Vein networks in wall rocks and breccias within veins also formed at this stage.   Pyrite, arsenopyrite, sphalerite, galena and sulfosalts of Ag, Pb, Sb and Sn (Sureda, 1978) formed in bands parallel to crustiform quartz and interstitial to euhedral quartz.   In some deposits, coarse sulfides may have replaced wall rock fragments in quartz vein stockworks (e.g., San Carlos, Eufemia). Sphalerite is generally deep orange in thin section, suggesting relatively high FeS contents.

2.   A second stage of fracturing resulted in ramifying veinlet networks of clear to grey, subhedral to euhedral, growth-zoned quartz cutting the older banded quartz.   An assemblage of sulfides similar to that of the first paragenetic stage formed in these veinlet networks.   It is possible that in some deposits minor chalcedonic quartz also precipitated in the second phase (Sureda, 1978; this study).

3.   Re-opening of vein structures and chalcedony deposition represents the third main paragenetic stage.   In the southwestern part of the El Guaico district, several important Ag-Pb-Zn deposits contain vein-like zones of colloform banded chalcedonic quartz and microcrystalline haematite.   The chalcedony veins cut assemblages of stages 1 and 2, but chalcedony also forms rare intergrowths with stage 2 quartz.   No sulfides were observed in chalcedony in the deposits investigated, although Sureda (1978) included argentite and several Cu sulfides in an opaline-forming supergene stage. Secondary vanadium minerals, carbonates of Cu and Pb, and oxides of manganese and iron formed during this stage (Sureda, 1978) and/or later.   Primary vanadium minerals have not been identified conclusively.

Silver occurs primarily in argentite and in sulfosalts of As, Sb and Pb, and rarely as the native metal (Sureda, 1978).   At the Rara Fortuna mine Ag distribution closely correlates with Pb (Candiani and others 1978).   Native gold was observed by Sureda (1978) in several deposits.   Taken together with Au values of up to 0.41 g/t from

mullock (Torres and Leynaud, 1994), these observations indicate that anomalous Au occurs in the south-central part of the district between Santo Domingo and La Víbora.

Calcite occurs widely in the district as a minor secondary mineral. Primary or hypogene calcite in crustiform bands and nodules from two deposits was described by Sureda (1978).

Visible hydrothermal alteration is restricted to within 1-2 m of veins and to wall rock fragments within veins, and consists of sericite ± pyrite replacement of host rock. Chloritisation may be present at some deposits (e.g., Asunción). Wall rock alteration is associated with the two earlier paragenetic stages.   Mass balance calculations on sericite-pyrite altered versus least altered schistose wall rock at Garibaldi indicate net gains of K, Si, Fe, S and the ore metals, and losses of Na, Ca and Mg. Elements that were essentially immobile during alteration were Al, Ti, Zr and HREE.

Genesis: An hypabyssal to shallow-mesothermal, relatively low temperature, environment of deposition is indicated for paragenetic stages 1 and 2 (Lyons and others, 1997).   The third paragenetic stage of chalcedony ± haematite deposition occurred during introduction of relatively cool, oxidised fluids, possibly at shallower crustal levels than stages 1 and 2..

Argon-argon dating of sericite hydrothermal alteration associated with typical Ag-Pb-Zn mineralisation at El Guaico (Rara Fortuna; Camacho, 1997) indicates an early Devonian age of 386±4 Ma. This step heating age is considered to represent the period of sericitic alteration and Ag-Pb-Zn mineralisation, and is significantly older than the K-Ar age of 340±10 Ma for sericite at Rara Fortuna reported by Sureda (1978). The base-precious metal mineralisation at El Guaico formed early during the Devonian metallogenic phase in the southern Sierras Pampeanas that includes Au±Cu deposits in the Sierra de las Minas (La Rioja), Au in the Candelaria district and W mineralisation at Aguas de Ramón and Sierra del Morro of Provincia de San Luis (Lyons and others, 1997).

The geological and geochemical characteristics of Ag-Pb-Zn veins of the El Guaico district are similar to those of the 'polymetallic veins' model of Cox and Singer (1986), which are typically associated with high-level felsic intrusions.

2.2 W DEPOSITS

2.2.1 Aguas de Ramón W district

Regional setting: The Aguas de Ramón W district is situated 50 km ESE of Villa de Soto, near the Río Guasapampa. The district comprises three zones of W mineralisation distributed over an area measuring 3 km from north to south, with a total of more than 20 main veins and numerous subsidiary veins. The district geology and W deposits were described in detail by Lapidus and Rossi (1959) and a summary was given by Lucero Michaut and Olascher (1981).

Cambrian metamorphic rocks of the Pichanas Complex in the Aguas de Ramón district include quartz-plagioclase-biotite-muscovite banded migmatite, minor amphibolite and marble, and metamorphosed pegmatite and aplite. The metamorphic rocks were intruded by lamprophyre dykes and by the Devonian(?) Granodiorita Esmeralda pluton, which contains a distinct tectonic foliation parallel to the regional NNE trending foliation.

Geology: Lapidus and Rossi (1959) distinguished two types of W mineralisation: (i) quartz-muscovite-tourmaline veins with wolframite, scheelite and sulfides; and (ii) minor metasomatic replacement mineralisation consisting of disseminated scheelite in small amphibolite-marble bodies (<60 m long). Mineralised amphibolite typically consists of hornblende/actinolite, plagioclase, biotite, epidote, apatite, Fe-oxides, calcite and scheelite (Lapidus and Rossi, 1959).

Resources estimated by Lapidus and Rossi (1959) include 22 876 tonnes at 0.94% WO_3 (Mina Esmeralda) and 10 071 tonnes at 2.15% WO_3 (Mina El Carmen).

Vein sets of type (i) mineralisation strike predominantly 090±20°; those in the northern zone dip 30-45° S whereas in the central and southern zones the veins dip 38-60° S and 52-88° S, respectively. The vein sets in each zone display a convex-northward morphology, and *en echelon* distributions are present. Exploited veins are <800 m long and are typically 0.15-0.5 m wide. The Granodiorita Esmeralda is the principal host rock in the southern and central zones, whereas migmatites of the Pichanas Complex host veins in the northern zone. The veins formed by extension perpendicular to the foliation in the metamorphic rocks and the granodiorite.

The veins are typically zoned from coarse-grained muscovite at the margins through coarse, milky white, recrystallised quartz with disseminated sulfides and wolframite in places, to a central fine-grained tourmaline zone. Several generations of veins are present, each with similar internal zonation, or containing only some of the main vein minerals. For example, planar tourmaline veins in late faults cut mineralised quartz-muscovite-tourmaline veins. Rare chalcedonic quartz is present with the late tourmaline in Veta Santa Rita at Mina Esmeralda. Other vein minerals include scheelite (replacing wolframite), pyrite, chalcopyrite, sphalerite, calcite, bismuthinite, fluorite, apatite and ferrocalcite. Lapidus and Rossi (1959) suggested the sulfides postdated quartz-tourmaline-wolframite. A variety of Fe, W and Bi oxides and carbonates of Cu developed during supergene oxidation of the mineralisation.

Well developed hydrothermal alteration occurs adjacent to veins, particularly in the granodiorite. The alteration consists of bleached aureoles up to 0.5 m wide consisting of pervasive sericitisation and silicification. Lapidus and Rossi (1959) described chloritisation of biotite and calcite±epidote alteration of plagioclase in altered granodiorite.

Genesis: Coarse-grained hydrothermal muscovite from the margin of a quartz-tourmaline vein at Mina Esmeralda gave an $^{40}Ar/^{39}Ar$ step heating plateau age of 366±1 Ma (Camacho, 1997). The W mineralisation is considered to have formed during the early Devonian metallogenic phase that occurred throughout the southern Sierras Pampeanas, and which overlapped with the period of felsic magmatic activity (Lyons

and others, 1997). Based on stable isotope analysis, the W-bearing hydrothermal fluids were probably of evolved meteoric water origin, with or without a small component of magmatic fluid. The Aguas de Ramón mineralisation corresponds closely to the 'W veins' model of Cox and Singer (1986).

2.3 BE DEPOSITS

Several minor Be occurrences are present within the map area, particularly in the sierras de Guasapampa and Serrezuela where Lucero and Olascher (1981) mentioned beryl-pegmatites at the San Antonio, La Inés and Carlito occurrences. The deposits measure up to 200 m in length and 6 m in width.

3. NON-METALLIC MINERALS

3.1 MICA, QUARTZ, FELDSPAR

Numerous relatively small pegmatite bodies have been worked for muscovite, quartz and feldspar and occur widely throughout the region (Ricci, 1974). Lucero Michaut and Olascher (1981) noted a large body of quartz at Loma Negra, 6 km SSE of Serrezuela.

3.2 LIMESTONE, MARBLE AND TRAVERTINE

Several deposits of limestone, dolomite and marble are present in the Sheet 3166-17 area.

Small bodies of travertine carbonate occur near La Playa in the southwestern part of the map area (Lucero Michaut and Olascher, 1981). The travertine probably represents low

temperature hydrothermal activity associated with Miocene-Pliocene volcanism in the Pocho region to the south.

3.3 GRANITE AND CORDIERITE ORNAMENTAL STONE

High quality granite is quarried at Cantera Rumi Huasi. This distinctive K-feldspar porphyritic granite is inferred to be Cambrian in age.

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