Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3166-18

Province of Córdoba

Patrick Lyons and Roger G. Skirrow

GEOSCIENTIFIC MAPPING OF THE SIERRAS PAMPEANAS ARGENTINA-AUSTRALIA COOPERATIVE PROJECT

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

1997

CONTENTS

SECTION 1: GEOLOGY

1. INTRODUCTION 1

1.1 Location and access 1

1.2 Nature of work and previous investigations 1

2. STRATIGRAPHY 3

2.1 General relations 3

2.2 Early palaeozoic metamorphic basement 5
Marble (∈l) 5
Quilpo Formation (∈lq) 7
Cruz del Eje Metamorphic Complex (∈rgn, ∈rc) 8
La Falda Metamorphic Complex (∈gfn, ∈sgn) 9
Pichanas Metamorphic Complex and associated S-type granites (∈gnp, ∈gi1, ∈gi2, ∈c, ∈g) 11
Guamanes Shear Zone (Dmg, Og) 15

2.3 Plutonic rocks 16
La Fronda Tonalite (∈tf) 16
Capilla del Monte Granite (Dgm1, Dgm2) 17
Granite, unassigned (Dg) 18
Minor dyke rocks 18

2.4 Mesozoic 19
Rosario Conglomerate (Kr) 19
Los Terrones Conglomerate (Kt) 19

2.5 Cainozoic 20
Paleosol (Czc) 20
2.5.1 Quaternary 21

3. TECTONICS 21

3.1 Pampean Cycle: Early Cambrian deformation and metamorphism 22

3.2 Famatinian Cycle: Ordovician deformation and metamorphism 23

3.3 Achalian Cycle: Devonian deformation and metamorphism 24

3.4 Mesozoic faulting 25

3.5 Andian Cycle: reverse faulting 26

4. GEOLOGICAL HISTORY 26

4.1 Early Cambrian sedimentation 27

4.2 Pampean Cycle 27

4.3 Famatinian Cycle 28

4.4 Achalian Cycle 29

4.5 Carboniferous - Permian sedimentation 30

4.6 Mesozoic sedimentation and magmatism 31

4.7 Andean Cycle 31

SECTION 2: ECONOMIC GEOLOGY

1. INTRODUCTION 32

2. METALLIC MINERAL OCCURRENCES 33

2.1 Au deposits 33

2.2 W mineralisation: El Zinqui prospect 38

2.3 Cu occurrences 40

2.4 Fe mineralisation 42

2.5 Ag-Pb-Zn occurrences 42

3. NON-METALLIC MINERALS AND *ROCAS DE APLICACION* 42

3.1 Granite and Cordierite ornamental stone 42

3.2 Limestone, Marble 42

3.3 Fluorite, Clay, Ochre, Steatite, Garnet and Amphibolite 43

3.4 Mica, Quartz, Feldspar 43

BIBLIOGRAPHY 44

ARGMIN DATABASE OUTPUT SHEETS 51

SECTION 1: GEOLOGY

by Patrick Lyons

1. INTRODUCTION

1.1 LOCATION AND ACCESS

The 3166 -18 1:100 000 Sheet area lies within Córdoba Province, between 30°40’-31°00’S and 64°30’-65°00’W. The area is part of the 3163-II (Cruz del Eje)1:250 000 sheet area.

The region includes the central northern Sierra Grande which is drained by the north flowing Ríos Pintos, de La Candelaria, and Soto.

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, generally unsealed, connecting the centres of San Marcos Sierra, Canteras Quilpo, and Candelaria 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 3166-18 Sheet 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 airborne magnetic

Figure 1.1. Location and simplified geology of the Sierras septentrionales de Córdoba and location of 1:100 000 sheets.

and gamma-ray spectrometric data, Landsat TM imagery, and 1:20 000 scale (approximate) black and white air photography. The geological map was 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). More detailed work has been carried out Massabie (1982), and Caffe (1993), who mapped in the San Marcos Sierra-Quilpo area south of Cruz del Eje, Caminos and Cucchi (1990) and Martino (1993) who studied part of the Guamanes Shear Zone to the south of the sheet.

2. STRATIGRAPHY

2.1 GENERAL RELATIONS

The 3166-18 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).

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

Basement consists of Early Cambrian metamorphic and igneous complexes intruded by Cambrian, Ordovician, and Devonian granitoids. Mesozoic and Cainozoic cover units occupy major valleys and intramontane areas to the north and east.

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 Quilpo Formation, and in minor amount in the Cruz del Eje and La Falda Metamorphic Complexes. Details are given under the respective sections.

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

Age (Ma)	*Unit*	*Description*	*Relations*
QUATERNARY	Talus deposits.	Unconsolidated debris of granitic rocks derived from the Capilla del Monte Granite	Deposits along the fault scarp of Cerro Uritorco
	Alluvium	Unconsolidated clay, sand and gravel	Deposits along active river courses
	Fluvial fans	Unconsolidated bouldery gravels	Interfinger with alluvial deposits
TERTIARY TO QUATERNARY	Undifferentiated fluvial and aeolian deposits	Clay, sand, gravel, paleosol	Mantles older units.
	Fluvial fan deposits	Unconsolidated gravel	Raised deposits along base of Cainozoic fault scarps.
MESOZOIC	Los Terrones Conglomerate	Polymictic conglomerate, feldspathic lithic quartz arenite	Unconformably overlies metamorphic basement and granitic rocks
	Rosario Conglomerate	Polymictic conglomerate, lithic arenite, basalt	Unconformably overlies metamorphic basement and granitic rocks
DEVONIAN	Capilla del Monte Granite	Monzogranite	Intrudes La Falda Complex
	Unassigned granite	Granite	Intrudes La Falda and Cruz del Eje Complexes.
CAMBRIAN	La Falda Complex	Banded pelitic gneiss, leuco-tonalitic ortho-gneiss, marble, and calc-silicate rocks	Faulted against El Manzano Formation. Intruded by Guiraldes Tonalite and Capilla del Monte Granite
	Quilpo Formation	Marble, calc-silicate rocks, pelitic gneiss, amphibolite.	Concordant with La Falda Complex, structurally overlies Cruz del Eje Complex.
	Cruz del Eje Complex	Pelitic gneiss, minor quartzite, marble, amphibolite, calc silicate rocks.	Structurally beneath La Falda Complex(?).
	Guamanes Shear Zone	Sheared and mylonitised pelitic gneiss; boudinaged phyric granite.	Forms a division between Cruz del Eje and Pichanas Complexes and affected rocks of both.
	Pichanas Complex	Pelitic gneiss, quartzite, migmatite, S-type granite, minor marble and amphibolite.	Concordant(?) with Cruz del Eje Complex.
	La Fronda Tonalite	Tonalite	Intrudes Cruz del Eje Complex and Quilpo Formation.

Quilpo Formation (∈lq)

Pelitic gneiss, marble, calc-silicate rock, and amphibolite

A zone of mostly low gamma-ray spectrometric responses corresponds to a distinct belt of Cambrian metasedimentary and metamafic rocks, extending south-south east from the from the Canteras Quilpo area (about 20 km south east of Cruz del Eje) to south of Pampa de Olaen which is defined here as the Quilpo Formation. The area was mapped in detail by Massabie (1982) and Caffe (1993). Outcrop is generally excellent but mostly covered by low and dense vegetation.

The Quilpo Formation structurally overlies the adjacent Cruz del Eje Metamorphic Complex to the west and is possibly concordant. South of the Pampa de Olaen, converging structural trends indicate that the contact here is probably faulted in part, and to the east, the contact with the La Falda Metamorphic Complex is concordant. The central part of the belt is intruded by the La Fronda Tonalite. Locally contact metamorphism produced carbonate rocks to produce small amounts of grossular-wollastonite-diopside skarn (Caffe, 1993).

Zircons from a sample of gneiss taken from the eastern edge of the formation gave a U-PB age for peak metamorphism of about 529±8 Ma (Camacho and Ireland, 1997).

The formation is one of a number of fault-bounded, or partially fault bounded, semi-continuos carbonate-rich metasedimentary belts which traverse the southern Sierras Pampeanas. Like the El Manzano Formation in the Sierra Chica to the east, the Quilpo Formation comprises interlayered pelitic gneiss, marble, calc-silicate rocks, and amphibolite.

More than half the formation is composed of muscovite-biotite-K-feldspar-plagioclase-garnet ± sillimanite gneiss which shows well developed layering and locally grades into migmatite. Mineral lineations are absent or poorly developed and myrmekitic textures are common.

Calcitic *marble* (∈l), with dolomite content less than 2% (Di Fini, 1970), forms thick lenses, several of which are currently being exploited, particularly at Quilpo where dips are subhorizontal. Individual bodies are transposed and show a very complex history of ductile deformation characterised by disharmonic and interference folding.

Calc-silicate rocks have a granoblastic texture and contain minor tremolite, K-feldspar, clinozoisite, muscovite, biotite, quartz, and diopside.

Interlayered boudinaged *amphibolite* bodies, up to tens of metres thick and a kilometre in length, generally form strike ridges. Although very difficult to distinguish on aerial photographs, they have low gamma-ray spectrometric responses and magnetic signatures characterised by a moderate to strong narrow, elongate anomalies (average magnetic susceptibilities of 400×10-5 SI), which allow concentrations of the unit to be identified on regional magnetic images. They are fine- to medium-grained rocks, commonly banded, and principally composed of prismatic to sub-prismatic hornblende or actinolite (50-70%) and plagioclase (25-30%). Common minor and accessory minerals and alteration products include quartz, epidote, carbonate, diopside, magnetite, and titanite. Geochemical analyses suggest some amphibolite bodies may be after high Mg protoliths. Throughout the Sierras de Córdoba the common association of amphibolite with marble suggests the possibility that they are para-amphibolites.

Cruz del Eje Metamorphic Complex (∈rgn, ∈rc)
Quartz feldspar biotite garnet gneiss, migmatite, amphibolite; garnet quartzite

The Cruz del Eje Metamorphic Complex, together with the Quilpo Formation, occupies the region between the Río Candelaria and the Río Pintos in the central part of the map sheet. It is divided into two units, the Cruz del Eje Formation (∈rgn) and minor quartzite (∈rc).

The formation is principally composed of quartz-feldspar-biotite ± garnet gneiss with locally developed migmatite, and minor carbonate rocks and amphibolite. Marble, calcsilicate and amphibolite rich portions of the complex have been distinguished on the map and possibly represent equivalents of the Quilpo Formation.

There are no isotopic age determinations for the unit. However, an Early Cambrian age is interpreted as the unit shares the same regional deformational and metamorphic history as the Quilpo Formation.

Gneiss and *migmatite* are composed of quartz (30% - 70%), plagioclase (10% to 40%), K-feldspar (<25%), biotite (<10%), and up to 5 % garnet. Minor cordierite and chlorite are also present, and zircon, apatite, titanite, epidote, sericite, haematite, and carbonate are common accessory minerals. Sillimanite (and retrograde muscovite) may also be present where gneiss is interlayered with marble. Mineralogically and geochemically, the gneiss is similar to that within the Pichanas Metamorphic Complex but overall, has lower mica and K-feldspar contents.. Near Embalse Cruz del Eje and Canteras Quilpo, outcrops of garnetiferous quartzite (∈rc), deformed into steep-sided ovoid domes and basins, are similar to metapsammitic units in the within the Pichanas Metamorphic Complex. Geophysically, the Cruz del Eje Metamorphic Complex is distinguished from the Pichanas Metamorphic Complex by its relatively higher thorium gamma-ray spectrometric response and moderately stronger magnetic anomalies.

La Falda Metamorphic Complex (∈gfn, ∈sgn)
Paragneiss intercalated with orthogneiss, minor marble and calc-silicates

The La Falda Metamorphic Complex lies between two separate north to northwest-trending largely fault-bounded carbonate-rich metamorphic units of the El Manzano Formation in the Sierra Chica and the Quilpo Formation in the west near San Marcos Sierra. Several granitic plutons and smaller bodies intrude the complex and include the ?Cambrian Cadonga Granite and Güiraldes Tonalite in the east and the Devonian Capilla del Monte Granite in the north. Further to the north and along the Punilla Valley, the unit is covered by unconsolidated Quaternary coarse clastic deposits, and in the central and southern parts of the Sierra Chica, remnant deposits of the Cretaceous Rosario Conglomerate unconformably overlie parts of the complex.

The La Falda Metamorphic Complex is distinguished from the El Manzano and Quilpo Formations by the presence of tonalite and a smaller proportion carbonate rocks but shared a common structural and metamorphic history and is, thus, Early Cambrian. Numerous aplite and muscovite - quartz - K-feldspar pegmatite dykes, up to 10 m wide, intrude the unit. These occur particularly within 2 km of the Guiraldes Tonalite in the Sierra Chica and between Capilla del Monte and La Falda where they are probably associated with numerous unnamed granitic intrusive bodies. Magnetic anomalies indicate that these small granite bodies may apophyses of a single body at shallow depth.

The complex consists mostly of pelitic gneiss with about 20% interlayered leucotonalitic ortho-gneiss and very minor marble and calc-silicate rocks. Rare amphibolite boudins probably represent meta-mafic dyke rocks. The complex is subdivided into two subunits based on the predominance of either pelitic gneiss or ortho-gneiss. The orthogneiss dominant unit was mapped and named the San Marcos Formation by Massabie (1982).

The grey *banded muscovite-biotite-feldspar-quartz-garnet ±sillimanite gneiss* (∈fgn) is the predominant rock type in the complex. Cordierite porphyroblasts occur in contact surrounding the Capilla del Monte Granite. Feldspar contents range from 10% to 20% with plagioclase predominating over K-feldspar. The rock is typically gneissic and is migmatitic in places with leucosome bands of quartz-feldspar. The rock is interpreted as a meta pelite and is indistinguishable from pelitic gneiss in the El Manzano Formation and the Quilpo Formation.

A second unit (∈sgn), Massabie's San Marcos Formation, is dominated by grey *medium-grained equigranular muscovite-biotite leuco-tonalitic ortho-gneiss* lenses within pelitic gneiss, ranging from less than a metre to several metres wide. Quartz contents are uniformly high (40%-45%) with some variation in proportional feldspar content. Zircon is the only common accessory phase. Locally, their composition is a leuco-monzogranite. In places, the ortho-gneiss truncates the main S1 metamorphic differentiated fabric, enclosing rotated enclaves of pelitic gneiss. Both the pelitic and ortho- gneisses are isoclinally folded by F2 with the ortho-gneiss extended within the S2 foliation plane. Biotite folia within the ortho-gneiss are continuos with S2 and S1 foliations in the pelitic gneiss. These relationships indicate that the ortho-gneiss originally intruded the pelitic gneiss at the close of the Early Cambrian Pampean deformation (D1) prior to the Early Ordovician Famantinian deformation (D2).

Very minor *marble and calc-silicate rocks* are interlayered with pelitic gneiss. They are composed of recrystallised calcite-dolomite with common grossular, quartz and epidote.

Pichanas Metamorphic Complex and associated S-type granites (∈gnp, ∈gi1, ∈gi2, ∈c, ∈g)

Paragneiss, migmatite, associated S-type granite, cordierite rock, minor marble and amphibolite

The Pichanas Metamorphic Complex is the most extensive unit in the region, cropping out over a wide area between the Río Soto and the Sierra de Guasapampa, the western most part of the Sierra Grande. 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 bodies, the most well known being the ‘El Pilón’ body.

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

Metapelite with minor marble and amphibolite (∈gnp) forms the dominant unit in the complex. It grades into migmatite in places. It contains 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.

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, a distance of about 6 km. However, here it is shown to be 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. Only the eastern part occurs on the 3166-18 Sheet. It consists of three units, a K-feldspar phyric granite (∈gi1), an equigranular leucogranite (∈gi2), and enclaves of cordierite-biotite rock (∈c).

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. The largest body contains a relatively minor amount of cordierite restite. Analyses of Rb-Sr and Sm-Nd isotopes indicate that all three units are cogenetic products of ultra metamorphism (Rapela and others, 1995).

The dominant unit (∈gi1) 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.

The equigranular phase (∈gi2) is a small body which crops out over an area of about 3 km2 centred about 13 km due south of Villa de Soto where it is quarried at Cantera Santa Clara for dimension stone. It corresponds to the leucomonzogranite of Rapela and others (1995).

Mapping and radiometrics show the granite occupies the centre of the larger body of the phyric granite and Rapela and others (1995) consider it represents the melt product of the reaction which gave rise to the cordierite rock (discussed below). It is pale pink to pink-brown medium to coarse grained equigranular leucogranite principally composed of K-feldspar, quartz, up to 5% biotite, partly altered to chlorite, and up to 5% plagioclase. Sillimanite makes up about 2% and often occurs as rims around K-feldspar grains. Grains of K-feldspar often show myrmekitic textures and sometimes form phenocrysts up to 2 cm long.. Muscovite forms up to 1% of the rock. Minor garnet is seen in hand specimen but may not be present in a thin section cut from a randomly picked sample. Rapela and others (1995) report the presence of cordierite which is possibly found in greatest concentrations closest to the cordierite rocks at Orcoyana and Cerro Negro. There are trace amounts of magnetite (or ilmenite), zircon, and monazite also. This unit is geochemically similar to the phyric phase but has slightly elevated SiO_2 and K_2O contents and significantly lower (two thirds mean or less) total Fe, MgO, CaO, Ba, Sr, Th, Zr, Cr, and Ni contents. Magnetic susceptibility is low, about 10×10-5 SI, and total count (70 cps) and potassium response (6 cps) are sufficiently higher than background to give an identifiable response on radiometric images.

The cordierite rock (∈c) crops outs as small hills near Arroyo Orcoyana and Cerro Negro where it is quarried at Canteras Tamain and Cerro Negro. It is enclosed by the leucogranite. Individual out crops are ovoid, about 150 m long and 10 m wide, and are described by Gordillo (1974) and Rapela and others (1995). Contacts are sharp or faulted with occasional screens of biotite paragneiss. Faulted contacts are cataclastic and contain material derived from both the cordierite-biotite rock and the leucogranite and host minor Cu mineralisation. The cordierite rock occurs in both massive and orbicular varieties and contains small enclaves derived from the regional paragneiss. It is interpreted to be a residue product of the ultra metamorphism of pelites.

The massive form is a blue-grey gneiss, which weathers to a distinct yellow brown colour, is generally a massive coarse grained granoblastic rock. The separate orbicular variety contains ovoid orbicules up to 20 cm long with cordierite rich rims and biotite-sillimanite rich cores. Quartz, K-feldspar, and plagioclase fill the spaces between orbicules. In general, cordierite makes up about 70% to 80% of the rock. As well as biotite (5% - 35%), quartz (5% - 10%), sillimanite (3% - 10%), and plagioclase (1% - 5%), the rock also contains minor muscovite, K-feldspar, and apatite. Biotite is partly altered to chlorite. Geochemical analyses carried out on four samples are reported by Gordillo (1974) and give mean SiO_2, Al_2O_3, FeO, and MgO contents of 49%, 30%, 7%, and 8%, respectively. Magnetic and radiometric responses are weak.

Rapela and others (1995) suggest the cordierite-biotite rock is the solid product of the low pressure partial melting of pelites described by the reaction,

biotite + sillimanite + plagioclase + quartz $\rightarrow$ *cordierite + K-feldspar + melt.*

Excess biotite and sillimanite occupy the cores in the orbicular variety which may be due to an excess of these minerals in the first place, or that melt, which occupies the spaces between orbicules, unable to be removed, inhibited the reaction from going to completion.

Recent isotopic age data 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).

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

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

Small bodies of unassigned granite (∈g) are interpreted from aerial photographs. 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).

Guamanes Shear Zone (Dmg, Og)

Quartz, feldspar, biotite,±garnet,±sillimanite gneiss, amphibolite, phyric granite, mylonite

The north to north-west trending Guamanes Shear Zone, Dmg, dips moderately to steeply east and comprises a belt of mylonitised Early Cambrian rocks of the Pichanas and Cruz del Eje Metamorphic Complexes, and Palaeozoic phyric granite and pegmatite. The belt here is the northern continuation of the Guamanes Shear Zone, named and described by Martino (1993). Previous authors (e.g., Bodenbender, 1905; Olsacher, 1960; Bonalumi and Gigena, 1982; Caminos and Cucchi, 1990) described the mylonitic rocks within the belt as phyllites, micaceous quartzites, “metaquartzites” or laminated schists. Bonalumi and Gigena (1984) identified it as a belt of “tectonised schists”.

In addition, bodies of phyric granite (Og) mapped as granodiorite by Caminos and Cucchi (1990), form boudinaged and dismembered bodies.

The Guamanes Shear Zone preserves a long history of repeated episodes of ductile shearing producing a range of mylonitic rocks, including ultramylonite. Although shearing may have initiated during the Early Cambrian Pampean deformation, Ar-Ar isotopic age determinations of biotite and muscovites which grew during the last event yield Devonian ages of about 360 Ma with indicated temperature conditions of about 300° (Camacho, 1997). Movement during the Devonian, clearly shown by kinematic indicators in mylonites was east over west thrusting. This movement largely overprints previous fabrics. Therefore, the Guamanes Shear Zone has been accorded a Devonian age.

There are no age data for the phyric granite bodies. However, they intruded prior to Devonian thrusting and strain was largely localised around their margins, although they were dismembered and stretched in the direction of movement. They were possibly emplaced during the Ordovician Famatinian extensional event around 470 Ma (Sims and others, 1997) prior to tourmaline-bearing pegmatite intrusion and have, thus, been given and Ordovician age.

2.3 PLUTONIC ROCKS

La Fronda Tonalite (∈tf)

The La Fronda Tonalite crops out in an area south of Canteras Quilpo and west of the Río Pintos. It covers an area of about 25 km^2. It is intruded into the gneisses, marbles, and amphibolites of the Cruz del Eje Metamorphic Complex and the Quilpo Formation. Roof pendants of country rock are found over the southern part of the out crop. Further references and a fuller description, including limited major element whole rock geochemistry, are found in Caffe (1993). According to Rapela and Pankhurst (1996) the La Fronda Tonalite has a similar geochemical and isotopic signature to the Güiraldes Tonalite. It is a white, equigranular, coarse grained, quartz, plagioclase, K-feldspar, muscovite (primary and secondary) tonalite with some trondhjemitic geochemical affinities. Grainsize varies from about 2 mm to 10 mm, often with large crenulated muscovite phenocrysts. Minor and accessory minerals are biotite, monazite, zircon, and apatite. It also contains secondary epidote, sericite, and chlorite. Minor garnet-wollastonite skarns occur at the north end of the out crop where it intruded into marbles of the Quilpo Formation. Analyses of isotopic data by Rapela and Pankhurst (1996) indicate the tonalite is derived from high pressure partial melting, during the Cambrian, of mafic rocks.

Capilla del Monte Granite (Dgm1, Dgm2)

The Capilla del Monte Granite, named by Rimnan (1918), has been described by Massabie (1982) and Murra and Baldo (1996). The granite is well exposed as bare pavements in the Punilla Valley near Capilla del Monte and as rocky crags on the summit of Cerro Uritorco. Talus slopes mantle the mountain's steep western flank and Late Tertiary to Quaternary gravel fans cover much of the pluton at its base. Magnetic anomaly patterns indicate that the granite forms a roughly circular pluton, about 10 km across.

The granite intrudes Cambrian metamorphic rocks of the La Falda Metamorphic Complex and the El Manzano Formation to the east with smooth discordant contacts. The eastern portion of the contact at Cerro Uritorco dips shallowly eastwards with embayments and outliers of metamorphics forming a thin capping over parts of the pluton. The granite post-dates both the Pampean and Famatinian deformations but has some development of the conjugate northwest - northeast-trending fracture set which characterises the later part of the Devonian Achalian deformation. K-Ar age determinations indicate a minium age of 345±10 Ma for the pluton (Massabie, 1982), however, as ages up to about 380 Ma are reported (see Linares and Gonzalez, 1990, for references) a Devonian rather than Carboniferous age is likely.

The pluton is a massive *pink coarse-grained biotite muscovite monzogranite*. Two textural varieties are distinguished, a dominantly equigranular phase (Dgm1) and a porphyritic border phase (Dgm2). Where porphyritic, microcline forms phenocrysts up to 7 cm across. Zircon and apatite are accessory phases. Murra and Baldo (1996) describe three varieties of granite based mostly on the proportion of quartz and potassic feldspar. At the base of Cerro Uritorco, where the unit is cut by numerous steep east-dipping Cainozoic faults, the granite is fractured with common haematite and fluorite alteration.

Granite, unassigned (Dg)

Undifferentiated undeformed granites occur throughout the Sierras de Cuniputo and Perchel, east of the Río Pintos Exposures cover small areas, however, magnetic anomalies indicate that they are probably apophyses to much larger plutons at shallow depths. The proximity of the granites east of the Río Pintos to the Capilla del Monte Granite and their similar magnetic and gamma-ray spectrometric signatures suggests they are part of a Devonian suite which may also be genetically related to pegmatite dyke swarms present in the area.

Minor dyke rocks

Pegmatite

Several generations of pegmatite dykes intrude basement metamorphics and granitic rocks. The oldest are form small deformed pods, less than a metre wide. These pegmatites are probably the product of partial melting during Cambrian M1 metamorphism (Pampean).

Between Capilla del Monte and La Falda undeformed subvertical, mostly north-trending pegmatite dykes area associated with numerous unnamed, possibly Devonian, granitic intrusive bodies. Magnetic anomalies indicate that these small granite bodies may be joined at shallow depth and underlie much of the La Falda Metamorphic Complex in the vicinity.

2.4 MESOZOIC

Minor amounts of Cretaceous sediment occur in the east of the sheet area (although relatively widespread on the adjacent Jesús María 1:100 000 Sheet. The continental redbed deposits were deposited in Early Cretaceous half-grabens developed adjacent to the Punilla Fault along the western scarp of the Sierra Chica (Kay and Ramos, 1996

Rosario Conglomerate (Kr)
Polymictic conglomerates, lithic arenite and nepheline basalt

A small amount of the remnants of valley-fill *polymictic conglomerates and poorly sorted lithic arenite* (Kr) referred to as the Rosario Conglomerate (Piovano, 1996) occurs on the 3166-18 Sheet. This unit forms small isolated cappings unconformably resting on metamorphic and granitic basement along the western scarp and summit of the Sierra Chica south of Cerro Uritorco (see Jesús María 1:100 000 Sheet).

Los Terrones Conglomerate (Kt)
Polymictic conglomerate and feldspathic lithic quartz arenite

Deposits of *polymictic conglomerate* and *feldspathic lithic quartz arenite* are poorly represented on this sheet but more extensive on the Jesús María sheet to the east.
The sediments form remanent continental fan deposits with clasts in the basal conglomerates up to 3 m across. Regular variation in clast size defines a crude stratification of medium to thick beds. The rocks unconformably overlie metamorphic basement forming a gently north-dipping (10°) sequence in the north, and are locally deformed adjacent to reactivated basement faults.

The Cretaceous age for the deposits is inferred by regional correlations with similar continental redbed deposits (Gordillo and Lencinas, 1970; Massabie, 1982).

2.5 CAINOZOIC

The most extensive Cainozoic unit (Czu) is an intercalated sequence 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).

Raised *fluvial fan deposits of unconsolidated gravels* (Czg) form low wooded dissected hills at the base of many of the main Cainozoic fault scarps. In the sierras septentrionales de Córdoba the most extensive of these occur in the Punilla Valley, in the east of the sheet area, where they overlie the central portion of the Capilla del Monte Granite. These deposits correspond to the level 1 subdivision of Massabie (1982) who interpreted a Pleistocene age.

Paleosol (Czc)

Along the Punilla Valley and in the Sierra Grande, *paleosols* (Czc), commonly with a hardpan of calcrete, form thin (a few metres thick) remnant cappings over basement rocks. They are best exposed along the gently sloping eastern flanks of the ranges where they are overlain by intercalated Tertiary to Quaternary fan deposits bordering the Punilla Fault scarp. The most extensive palaeosol development occurs on the Pampa de Olaen west of the Punilla Valley. The age of the deposits is not known. Their formation predates the last significant uplift which probably took place during the Late Pliocene-Pleistocene (Costa, 1996)

2.5.1 Quaternary

Holocene (Santa Cruz, 1978) to Recent *fluvial fan deposits of unconsolidated bouldery gravels* (Qg) interfinger downslope with finer-grained Qa alluvial deposits. The fan deposits occur along the base of the Punilla Fault scarp and at the base of the Sierra San Marcos. Massabie (1982) mapped the deposits as Level II in his subdivision of Quaternary units in the Capilla del Monte area.

Holocene (Santa Cruz, 1978) to Recent *alluvial deposits of clay, sand and gravel* (Qa) occur along active river courses and adjacent terraces. The unit includes the Level III Quaternary unit of Massabie (1982) in the Capilla del Monte area.

Minor Recent *talus deposits* (Qt) of granitic debris, derived from basement rocks, occur along some of the reverse fault scarps formed during the Cainozoic Andean Cycle (see Tectonics)

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. Regionally, the oldest preserved structure is a medium-grade metamorphic differentiated foliation which is well-preserved in pelitic gneiss of the La Falda, Cruz del Eje, and Pichanas Metamorphic Complex and pelitic and carbonate metasediments of the Quilpo Formation. This foliation (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.

Quartzite units in the La Falda Metamorphic Complex preserve an earlier differentiated cleavage of spaced biotite-rich folia which are truncated by leucosome veinlets and the differentiated S1 gneissic foliation. This cleavage may either represent an earlier surface, obliterated by the S1 foliation during peak metamorphic conditions, or it may have formed early during progressive deformation and S1 development.

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, to the east of the sheet area, 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 Cruz del Eje Metamorphic Complex and Pichanas Metamorphic Complex (316-17 1:100 000 Sheet), gives an age of about 530 Ma, interpreted here as the age of the M1/D1 event of the Pampean Cycle.

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

In the Sierra Grande there are, broadly, two principal orientations of the D1 high grade fabric (S3 or S4 ?), steeply dipping to the south west and north-north east. 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 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.

Within metasedimentary gneissic units of the La Falda Metamorphic Complex, an S2 foliation, subparallel to S1, is axial plane to macroscopic and mesoscopic isoclinal F2 folds. Tonalitic bodies within the complex which intruded as subconcordant intrusions after S1, are folded with commonly boudinaged limbs.

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 predate the final Devonian compression and may have intruded during the Famatinian extensional regime.

3.3 ACHALIAN CYCLE: DEVONIAN DEFORMATION AND METAMORPHISM

Throughout much of the region, medium-grade D1 and D2 fabric elements are locally rotated into parallelism by a shallow- to moderately- ENE-dipping penetrative D3 shear fabric associated with westerly-directed thrusting, development of mylonite in high-strain zones and retrogressive greenschist facies metamorphism (M3). To varying degrees, this deformation affects all basement rocks in the region, including Early Devonian granites. Zones of high-strain were focussed in two mylonite zones, one west of the Sierras San Marcos passing west of La Falda within the western margin of the La Falda Metamorphic Complex and the parts of the Quilpo Formation, and the other, in the north to northwest-trending Guamanes Shear Zone, which separates the Pichanas and Cruz del Eje Metamorphic Complexes. Within the zones, an S3 mylonitic foliation is well defined. The foliation is axial planar to tight F3 folds which become open in areas of low-strain. In these areas the S3 foliation is a crenulation cleavage and folds have wavelengths up to 1 km.

In granitoids of the Ascochinga Igneous Complex minor, but ubiquitous, late epidote, sericite and carbonate alteration of plagioclase and marginal alteration of biotite to either chlorite or intergrown muscovite, haematite and epidote are possibly related to Achalian retrogression (M3). Haematite, present in late fractures may also be of this age or associated with younger Mesozoic or Cainozoic faulting.

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 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 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 MESOZOIC FAULTING

The Punilla Fault is interpreted to have initiated as Early Cretaceous east-dipping extensional faults (Sanchez and others, 1995) active during deposition of the Early Cretaceous continental deposits such as the Los Terrones and Rosario Conglomerates.

The Punilla Fault is well exposed along the dissected western scarp of the Sierra Chica. The fault is not a discrete fault, rather it is a 2 to 3 km wide fault zone comprising brecciated rocks cut by zones of intense shearing. Within the zone, basement rocks, including the Devonian Capilla del Monte Granite, are brecciated and broken into a melange: pelitic gneiss is converted to chlorite schist and granitic orthogneiss is fractured and sheared with locally intense haematite-chlorite-epidote alteration. Locally, quartz veins cut the shear planes. Shear planes with steeply pitching slickenlines dip steeply to moderately (75°) to the east. This deformation can be attributed to Early Cretaceous deformation (or older) as both the Los Terrones and Rosario Conglomerates are relatively undeformed, unconformably overlying the fault rocks.

3.5 ANDIAN CYCLE: REVERSE FAULTING

The Sierras Chica, San Marcos and de 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 such as the Punilla Fault, which extends along the full length of the Sierra Chica. Many of the faults are 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 Grande area forms 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 paragneisses which comprise parts of the La Falda, Cruz del Eje, and Pinchanas Metamorphic Complexes. Carbonate-rich metasediments also occur within the complexes and as a major unit, the Quilpo Formation. 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 540Ma (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).

At the closing stages of the Pampean Cycle, an extensive phase of felsic magmatism is evident by widespread subconcordant intrusion of granite and granodiorite (see Ascoghinga Igneous Complex on Jesús María 1:100 000 Sheet). There are no radiometric dates on these intrusions, however, in the Sierra Norte, similar intrusions in a northern extension of the are dated at about 514 Ma.

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). A compressive deformation (D1 in the Famatinian domain, D2 in the Pampean domain), at mostly upper amphibolite facies, was accompanied by the development of kilometre-scale east-dipping ductile shear-zones with, orthogonal westerly-directed thrust movement (e.g., Martino, 1993; Martino and others, 1994). The Guamanes Shear Zone was probably active during this event.

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

Compression was closely followed, possibly in the one continuos event, by extensional deformation (D2 in the Famatinian domain) at greenschist-facies (Sims and others, 1997). 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. This phase of magmatism corresponds to the G2 granites of Rapela and others (1992). U-Pb dating of zircons from granites in both the Sierras de San Luis and the Sierras de Chepes (to the north in La Rioja) indicate crystallisation ages of about 470 Ma (Camacho and Ireland, 1997). Apart from the presence of, granitic intrusives and pegmatites veins in the Guamanes Shear Zone there is little evidence for extensional structures or magmatism associated with this event in the map region.

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 mostly manifest in the Sierra de Las Minas in La Rioja province. 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 and others (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. Although the sediments may have covered much of the crystalline basement there are no remnant outcrops of the group are now preserved on the 3166-18 sheet. Elsewhere there are sediments 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 MESOZOIC SEDIMENTATION AND MAGMATISM

During the Early Cretaceous, extensional faulting, including probable reactivation of some basement faults along the eastern margin of the southern Sierras Pampeanas, accompanied local deposition of continental clastics in half grabens.

4.7 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 3166-18 area contains the northern segment of the Candelaria Au district, as well as the San Ignacio Au deposits, the El Zinqui W prospect and several Cu and Fe occurrences. The region is also well endowed in dimension stone including marble from the Canteras de Quilpo.

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, 1996), 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 OCCURRENCES

2.1 AU DEPOSITS

2.1.1 Candelaria Au district

The northern portion of the Candelaria Au district, situated on Sheet 3166-18, includes deposits in the Clementina (Matilde) and El Patacón areas. The central sector of the Candelaria district is situated on Sheet 3166-24 to the south, and includes the Puigari-Monserrat, La Bragada and Paso de La Quinta deposits. A summary of the general characteristics of the mineralisation in the Candelaria district is presented below.

Regional setting: The Candelaria district is located about 20 km southeast of Villa de Soto. The district comprises more than 25 identified small Au-quartz vein deposits and occurrences, and numerous un-named workings that were operated mainly up to the

1930s. They lie within a belt that trends north-south for about 16 km in the vicinity of the Río Candelaria and extends a further about 5 km south of the Sheet 3166-24 area (Caminos and Cucchi, 1990).

Regional and district geology was discussed by Lucero and Olascher (1981), Bonalumi and Gigena (1984) and Caminos and Cucchi (1990). Economic assessments of resources have been carried out by Zolezzi and others (1988), Anonymous (1987), Torres and Miró (1986), Anonymous (1989) and Deantonio (1994a). Martos and others(1994) briefly described the occurrences. A resource of 60 000 tonnes at 20 g/t Au was estimated for the Puigari-Monserrat deposits by Zolezzi and others (1988).

The Au mineralisation is located principally within a 4-7 km wide north-south striking Guamanes Shear Zone, a zone of sheared gneiss that contains numerous zones of mylonite and ultra-mylonite. Several deposits occur in quartz-biotite-feldspar±garnet gneiss (Cruz del Eje Metamorphic Complex) to the east of the shear zone, including some of the larger deposits in the district such as Puigari-Monserrat. Elongate Ordovician(?) granite stocks up to 1 km wide and 4 km long, and numerous associated tourmaline-bearing pegmatites, occur within the shear zone, and contain the shear fabric. Mylonite zones are characteristically chlorite-haematite altered and overprint a biotite shear fabric in the gneiss. Movement on the steeply east-dipping mylonite zones was generally east side up, and represents reactivation of the shear zone.

A swarm of undeformed porphyritic hornblende andesite dykes occurs within the Guamanes Shear Zone west of Paso de La Quinta and Oro Grueso (Sheet 3166-24). The dykes are inferred to be post-Devonian to Tertiary in age.

Geology: Gold occurs in single and multiple quartz veins striking 330°-030° and dipping 20°-45° to the east. Vein thicknesses range up to 1m, or so, and typically show pinch-and-swell morphology. *En echelon* arrays of gash-shaped, gently sigmoidal, veins are present in places. Although the host gneisses contain well-developed foliations, intense shearing adjacent to veins is generally not present (cf. Au deposits of Sierra de las Minas, La Rioja). The high angle between quartz veins and the gneissic foliation, and the vein morphology and orientation, indicate that the veins probably formed in zones of subvertical extension within the Guamanes Shear Zone (Fig. 1). An exception to this style of Au deposit occurs at Paso de La Quinta (see below, and Sheet 3166-24).

Most quartz veins consist of massive, milky white, recrystallised quartz with uncommon cavities lined with subhedral quartz. Minor pyrite and trace amounts of sphalerite, galena, chalcopyrite, and arsenopyrite (Anonymous, 1989) occur in association with this subhedral quartz. The margins of some quartz veins are brecciated in brittle faults. Hematitic-goethitic fracturing of the early quartz is widespread and appears to be associated with the brecciation.

Hydrothermal alteration consists of intense sericitisation of host rocks within about 1m of major veins, and of wall rock remnants within veins. At the Puigari-Monserrat deposit the quartz-biotite-feldspar-muscovite±garnet gneiss host rock was pervasively altered to chlorite and haematite with carbonate veinlets; the chlorite is inferred to occur in a distal position relative to proximal sericitic alteration, and the pervasive hematisation may be synchronous with both the haematitic fracturing of vein quartz and the regional mylonitisation with which chlorite-haematite alteration is associated.

Gold mineralisation occurs in two principal textural styles with sulfides in the primary ore zones and as coarser free Au in near-surface secondary ore zones (<40m depth; Anonymous, 1989). Grain sizes of up to 200 microns were reported by Anonymous (1989). Gold grades appear to be highly variable. For example at Puigari-Monserrat, 0.3-1.8 m wide channel samples across veins indicated that grades of 0.2-2 g/t Au are common but sporadic samples contained 15-70 g/t Au (Zolezzi and others, 1988).

Hydrothermally altered zones associated with Au mineralisation exhibit a pronounced depletion in magnetic susceptibility compared with gneissic host units. This relatively local, deposit-scale, signature is clearly related to haematisation which occurred late in the paragenetic sequence. The Guamanes Shear Zone that hosts most of the Au deposits of the Candelaria district displays a low aeromagnetic response, particularly in its eastern parts, with higher response along the eastern contact (Fig. 1). Some of the Au deposits are located close to NW and NE trending magnetic lineaments where they intersect the eastern margin of the N-S trending Guamanes Shear Zone.

At the Paso de La Quinta prospect in the southern part of the Candelaria district (Sheet 3166-24), a contrasting style of Au mineralisation is present. Cropping out as a prominent N-S trending ridge, the 3-7m wide and >1600m strike length siliceous zone consists of crystalline quartz and chalcedony vein networks, silicified mylonite and breccia. The siliceous zone appears to dip subvertically, in contrast to the shallow dips of other vein Au deposits of the district. In contrast to other deposits in the Candelaria district, there is no evidence of extensive recrystallisation of silica vein minerals. Alteration of fine-grained mylonite host rocks consists of intense chlorite-sericite-pyrite. Reported maximum grades are 160 g/t Au and 460 g/t Ag, and a resource of 1 000 000 tonnes of ore was estimated by Deantonio (1994a), although no average grade was quoted.

Genesis: Hydrothermal sericite from the Puigari-Monserrat and La Bragada deposits give $^{40}Ar/^{39}Ar$ ages of about 376-378 Ma (Camacho, 1997). This age represents initial white mica alteration, with subsequent cooling over the next 12-20 Ma. Alteration and, by implication, Au mineralisation in the Candelaria district either postdated Achalian magmatism by at least around 7 Ma (Camacho, 1997), or temporally overlapped emplacement of Achalian granite. Stable isotopic studies suggest that the hydrothermal ore fluids could have evolved from meteoric waters reacting with metasedimentary rocks, although small magmatic or metamorphic water input to the ore fluids cannot be excluded (Lyons and others, 1997)

The quartz-Au veins formed initially in a brittle-ductile deformational regime, possibly synchronous with reverse movement on mylonite structures within the Guamanes Shear Zone. Later fracturing, faulting and brecciation of the vein systems and associated hematite±chlorite alteration suggest a change in pressure, temperature and/or strain rate conditions. Some remobilisation of Au may have occurred at this time.

The Au deposits of the Candelaria district are interpreted here to be members of the broad class of structurally-controlled mesothermal lode Au deposits found in regionally metamorphosed orogenic terranes. Martos and others (1994) grouped the Candelaria Au deposits with the ‘low-sulfide Au-quartz veins’ model of Cox and Singer (1986). One deposit, Paso de La Quinta, is notably different from other Au deposits of the Candelaria in its structural style, mineralogy and geochemistry, and may have formed at relatively shallow crustal levels (Lyons and others, 1997).

2.1.2 San Ignacio Au

The San Ignacio Au deposits comprise four principal quartz veins about 1 km NNW of San Ignacio in the Valle de Punilla, Sierras de Córdoba. These deposits were worked until the 1930s. Evaluation of resources and mining viability was carried out by Miró and Torres (1987) and Deantonio (1994b). A resource of 170 000 tonnes at 10.2 g/t Au was estimated by Miró and Torres (1987). The regional geology was discussed by Pastore and Methol (1953), and the deposit geology was described by Rigal (1934) and Miró and Torres (1987).

Regional setting: The regional setting of the vein system is within Cambrian medium to high grade paragneiss, marble, amphibolite and orthogneiss of the Complejo La Falda, which was intruded by Devonian granite stocks. The Au deposits lie within a 1-2 km wide major NW-trending lineament characterised by low magnetic susceptibility that overprints Devonian granites in the region. The lineament may be a member of the prominent set of widely distributed NW and NE- trending structures in the southern Sierras Pampeanas. In La Rioja some of these lineaments are shear zones of early Devonian age (Skirrow, 1997).

Geology: The quartz veins are hosted by massive to foliated muscovite-rich granite and biotite gneiss with N-S trending, shallow to steep, east dipping foliation. Aplite, pegmatite and amphibolite dykes crop out in the mine area. Four principal quartz veins trend NE-SW and E-W; dips are steeply NW and S, respectively. Veins are 15-50 cm wide, and display pinch-and-swell, *en echelon* and sigmoidal morphologies. Brecciation is common in places. Earliest quartz is massive to weakly banded, medium-grained, milky white, partly recrystallised and contains rare cavities. Pyrite and other sulfides appear to be associated with this phase of quartz. Subsequent fracturing resulted in networks of clearer grey quartz cutting the milky quartz.

Gold was reported to occur as disseminations in association with pyrite (Rigal, 1934; Pastore and Methol, 1953). Average grades from sampling of workings are 6-14 g/t (Miró and Torres, 1987). These authors also noted the occurrence of galena, chalcopyrite, bornite, cerussite, vanadinite, descloizite and rare wolframite. Goethite is common as a secondary alteration product of sulfides.

Hydrothermal alteration consists of localised sericitisation with minor pyrite adjacent to quartz veins and of host rock remnants within veins and breccias.

Genesis: Vein morphology, textures, paragenesis and alteration in the San Ignacio Au deposits show strong resemblance to mesothermal lode Au mineralisation in the Candelaria district, although vein dips are steeper at San Ignacio and imply subhorizontal extension directions.

Argon-argon dating of sericite alteration at San Ignacio can be interpreted to represent initial white mica alteration at around 370 Ma (Camacho, 1997). This age compares with interpreted ages of 376-378 Ma for initial sericitic alteration and Au mineralisation in the Candelaria district.

A model of quartz-Au vein formation related to regional faulting during the Devonian is proposed. The occurrence of Au mineralisation within a radius of 2-3 km from Devonian granite stocks, and the location of Au within the regional NW-trending lineament transecting the belt of Devonian granites, are considered significant regional factors in localising vein formation.

2.2 W MINERALISATION: EL ZINQUI PROSPECT

Regional setting: Tungsten mineralisation of the El Zinqui area is situated about 3 km west of Capilla del Monte at the western margin of the Valle de Punilla. The geology and economic potential of the deposits were investigated in 1985-86 in a joint project between the Agencia de Promoción Minera de Carlos Paz del Banco Nacional de Desarrollo, the Misión Alemana de Cooperación Técnico Minera, and the Departamento de Servícios Técnicos de Apoyo (BANADE, 1986). The deposits were also mentioned by Brodtkorb and Pezzutti (1991). Numerous shallow exploratory pits and trenches are present over an area of approximately 1 km^2. A resource of 271 000 tonnes at 0.46% WO_3 was estimated by BANADE (1986). Scheelite mineralisation at El Zinqui is associated with calcsilicate rocks of the La Falda Complex that was intruded by the Devonian Granito Capilla del Monte and numerous smaller Devonian(?) stocks. These granites form a 10 km wide belt extending more than 25 km southwards from Capilla del Monte to Pampa de Oleán. A major belt of marble and amphibolite, intruded by the Cambrian(?) Tonalita La Fronda, occurs 5-10 km west of El Zinqui.

Geology: The metamorphic rocks in the El Zinqui area consist of quartz-plagioclase-biotite-muscovite gneiss, abundant pegmatite dykes and banded amphibolite. Pegmatites composed of quartz, K-feldspar, muscovite and minor garnet are intensely sheared (mylonitic in places), and are transposed parallel to the regional N-S striking gneissic foliation. Internal mm-scale banding in the amphibolite bodies, which range in thickness up to 7 m, parallels the foliation in the adjacent gneisses and pegmatites. Two phases of folding and several fault orientations were described in the BANADE (1986) report. These have resulted in highly variable foliation orientations and a complex distribution of amphibolite outcrops and associated calcsilicate-scheelite zones.

Calcsilicate zones occur principally within the banded amphibolites, but also occur in the pegmatites. In all observed cases the calcsilicates form unfoliated medium- to coarse-grained aggregates that are texture-destructive, and clearly cross cut the banding in amphibolite. The discordant calcsilicate patches are up to a few metres wide and are commonly internally zoned from outermost amphibole through epidote±garnet to core zones of diopside-quartz. Preliminary petrographic studies indicate that the diopside-quartz assemblage was replaced by tremolite/actinolite-carbonate-chlorite. Other volumetrically minor minerals present are carbonate, pyrite, sphalerite, chalcopyrite, biotite and muscovite. Subhedral, growth-zoned, undeformed scheelite commonly occurs with sulfides in disseminated patches within the calcsilicate zones. The scheelite is interpreted to have formed synchronously with the calcsilicate assemblages which overprinted the banded amphibolites and pegmatites.

Genesis: The calcsilicate assemblages, ore minerals and the paragenetic sequence are similar to those described in some W-skarns (Meinert, 1993; Cox and Singer, 1986). The diopside-quartz, garnet and scheelite-forming stages correspond to prograde skarn development, which commonly occurs at 350°-550°C (Meinert, 1993), whereas the hydrous assemblages probably developed as part of a later retrograde stage at lower temperatures. The undeformed textures of calcsilicates and scheelite at El Zinqui and the location of mineralisation within a belt of Devonian granites are consistent with scheelite formation during the Devonian metallogenic phase (Lyons and others, 1997).

2.3 CU OCCURRENCES

A small number of occurrences of Cu mineralisation are known in the region, including those located in the northern Sierra Grande near Pampa de Oleán (‘Cucchicorral’) and 3 to 4 km SSE of San Marcos Sierra (‘Cunuputu’).

2.3.1 Cuchicorral Cu

Cu mineralisation at Cucchicorral (Pastore and Methol, 1953) is situated at the western margin of the Pampa de Oleán, 10 km W of La Cumbre. The regional host sequence comprises Cambrian medium- to high- grade paragneiss, marble, amphibolite and orthogneiss of the La Falda Complex, Complejo Cruz del Eje and El Manzano Formation that were intruded by numerous Devonian(?) granite stocks. A distinctive magnetic zone (about 10 ×7 km) of relatively short wavelength - high amplitude anomalies in the Cucchicorral area corresponds in part to a N- to NE-trending belt of amphibolite and marble, although several prominent anomalies lie under cover in the

Pampa de Oleán. The sources of these concealed anomalies are unknown. At least four granite stocks crop out within a radius of 2 km of Cucchicorral.

Workings at Cucchicorral consist of an approximately 40 m decline along the faulted contact between a pink granite dyke and biotite-rich quartz-feldspar augen gneiss, and a nearby shallow pit. Cu carbonates are confined to the limonitic fault zone of a few tens of centimetres width. Pastore and Methol (1953) reported the presence of chalcopyrite, pyrite and magnetite. Other rock types in the vicinity include abundant deformed aplite and pegmatite dykes, and banded amphibolite. Additionally, calcsilicate zones up to a few metres diameter and consisting of coarse grained, unfoliated, aggregates of epidote, weakly-strained quartz, and fibrous actinolite-tremolite occur within amphibolite.

Although the worked Cu mineralisation is hosted by a minor fault zone in gneiss and granite, the nearby amphibolite host rocks and alteration assemblages, textures and fabrics resemble those at the El Zinqui skarn W prospect near Capilla del Monte, where chalcopyrite is a minor ore mineral. The spatial association of Cu mineralisation at Cucchicorral with the calcsilicate alteration zones suggests they may both be the products of hydrothermal fluid reaction with chemically and structurally favourable host rocks. Furthermore, the late timing of alteration in relation to deformation, and proximity to numerous Devonian(?) intrusions, are consistent with alteration and Cu mineralisation during the Devonian metallogenic phase.

2.3.2 Cunuputu Cu

The Cunuputu Cu occurrence is located within a broad zone of very low aeromagnetic response that includes the Complejo La Falda and part of the Granito Capilla del Monte 4-5 km to the east. Elevated aeromagnetic responses along the western and southwestern margins of the granite may correspond to a relatively magnetic phase of the intrusion or hornfels and/or magnetite-bearing hydrothermal alteration.

Pastore and Methol (1953) described a zone of chalcopyrite, pyrite, chalcocite and magnetite mineralisation up to 1 m wide, and of unknown length, within small amphibolite and diorite bodies, hosted by quartzo-feldspathic gneiss of the Complejo La Falda. Epidote, calcite and chlorite replacing amphibole, together with magnetite, probably represent hydrothermal alteration of similar style to that documented at the Cucchicorral Cu and El Zinqui W occurrences.

2.4 Fe MINERALISATION

Several minor occurrences of Fe mineralisation are known in northern Sierras de Córdoba, most notably 15 km from San Marcos Sierra near 'La Fronda'. At La Fronda (location uncertain) magnetite-rich amphibolite up to 0.9 m width occurs in a sequence of gneiss, marble and schist of the El Manzano Formation (Angelelli, 1984).

2.5 Ag-Pb-Zn OCCURRENCES

Two Ag-Pb-Zn occurrences were shown on the 1:750 000 scale map of Ricci (1974) in the Complejo La Falda. According to the locations given (accuracy ±3 km), they appear to be situated within or close to a major NW-trending aeromagnetic lineament and fault zone that transects Devonian granites. It is interesting to note that mesothermal lode Au at San Ignacio also occurs close to this lineament.

3. NON-METALLIC MINERALS AND *ROCAS DE APLICACION*

3.1 GRANITE AND CORDIERITE ORNAMENTAL STONE

The Sheet 3166-18 area is well known for its production of *rocas de aplicación*, including several types of granite (e.g., quarries at La Fronda), and cordierite rock in the El Pilón district (Pastore and Methol, 1953; Lucero Michaut and Olascher, 1981).

3.2 LIMESTONE, MARBLE

A large number of deposits of limestone, dolomite and marble are present in Sheet 3166-18. Some of the larger worked deposits occur in belts of intensely deformed early Cambrian metacarbonate-amphibolite rocks, including the Quilpo (Formación Quilpo) and Candelaria districts (Pastore and Methol, 1953; Lucero Michaut and Olascher, 1981).

3.3 FLUORITE, CLAY, OCHRE, STEATITE, GARNET AND AMPHIBOLITE

Several worked occurrences of fluorite, clay, ochres, steatite, garnet, amphibolite were shown on the maps of Ricci (1974), Pastore and Methol (1953) and Lucero Michaut and Olascher (1981), and on the 1995 Mapa Geológica de la Provincia de Córdoba (1:500 000 scale).

3.4 MICA, QUARTZ, FELDSPAR

Numerous relatively small pegmatite bodies have been worked for muscovite, quartz and feldspar and occur widely throughout the region (Ricci, 1974).

BIBLIOGRAPHY

ACENOLAZA, F.G., y TOSELLI, A.J., 1976. Consideraciones estratigraficas y tectonicas sobre el Paleozoico inferior del Noroeste Argentino. Memoria, II Congreso Latinoamericano de Geología, 2, 755-764.

ACENOLAZA, F.G., y TOSELLI, A.J., 1981. Geología de Noroeste Argentino. Publicacíon especial Fac. Ci. Nat. UNT, Tucumán, 1287, 212 p

ANGELELLI, V., 1984. Yacimientos Metalíferos de la Republica Argentina I, II, Comisión de Investigaciones Científicas, Provincia de Buenos Aires.

ANONYMOUS, 1987. Evaluación económica de las minas La Bragada y Puigari, Secretaría de Minería de la Nación, Centro de Exploración Córdoba, 17 p.

ANONYMOUS, 1989. Informe sobre Mina La Bragada, Secretaría de Minería de la Nación, Centro de Exploración Córdoba, 89-3, 26 p.

ASTINI, R.A., 1996. Las fases diastroficas del Paleozoico medio en La Precordillera del oeste Argentino - evidencias estratigraficas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 509-526.

BANADE, 1986. Informe sobre el yacimiento 'El Zinqui', Departamento de Punilla, Provincia de Córdoba, Banco Nacional de Desarrollo, 18 p y figs.

BODENBENDER, G., 1905. La Sierra de Córdoba, constitución geológia y productos naturales de aplicación. Ministero de Agricultura de la Nación. Buenos Aires (Sección Geología 2): 1-146.

BONALUMI, A.A. y GIGENA, A.A., 1982. Plan Oro, Tomo1, Informe Interno, Dirección Gen. Ind. Prom. Ind. Min. Cba. 150p. Córdoba ,unpublished report.

BONALUMI, A.A. y GIGENA, A.A., 1984. Observaciones metalogenéticas de un distrito aurífero del Noroeste de la Provincia de Córdoba. IX Congreso Geológico Argentino, Buenos Aires, Actas, 7: 231-244.

BRODTKORB, M.K. DE y PEZZUTTI, N., 1991. Yacimientos scheelíticos en rocas calcosilicáticas asociadas a anfibolitas, Provincias de San Luis y Córdoba. In: BRODTKORB, M.K. DE (ed.), Geología de yacimientos de wolfamio de las provincias de San Luis y Córdoba, Argentina. Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata, 1: 169-184.

BUTROVSKI, D., 1997. Geographic Information System (GIS) for the Sierras Pampeanas Mapping Project, Argentina. Australian Geological Survey Organisation, Arc/Info GIS.

CAFFE, P.J., 1993. Petrologia y estructura del area comprendida entre laocalidades de Pintos y Quilpo Sud, departementos Punilla y Cruz del Eje, Pcia. de Córdoba. Unpublished Bsc thesis, University of Córdoba, Argentina.

CAMACHO, A., 1997. ^{40}Ar-^{39}Ar and Rb-Sr geochronology, final report. Geoscientific mapping of the Sierras Pampeans, Argentine-Australia Cooperative Project, Australian Geological Survey Organisation,unpublished report.

CAMACHO, A. and IRELAND, T.R., 1997. U-Pb geochronology, final report. Geoscientific mapping of the Sierras Pampeans, Argentine-Australia Cooperative Project, Australian Geological Survey Organisation, unpublished report.

CAMINOS, R. y CUCCHI, R.J., 1990. Levantamiento geológico-estructural de la región situada entre Villa de Soto y La Candelaria, Provincia de Córdoba. Dirección Nacional de Minería y Geología, 38 p.

COSTA, C.H., 1996. Analysis neotectonico en las sierras de San Luis y Comechingones: problemas y methods. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 285-300.

COX, D.P. and SINGER, D.A., 1986. Mineral deposits models, U.S. Geol. Surv. Bull., 1693, 379 p.

DALLA SALDA, L.H, 1987. Basement tectonics of the southern Pampean ranges, Argentina. Tectonics, 6: 249-260

DALLA SALDA, L.H., CINGOLANI, C., VARELA, R., and LOPEZ DE LUCHI, M., 1995. The Famatinian Orogenic Belt in South-western South America: granites and metamorphism: an Appalachian similitude?. IX Congreso Latinoamericano de Geología, Caracas, Resumenes.

DEANTONIO, M., 1994a. Proyecto de exploración de un prospecto de oro y plata denominada 'Paso de la Quinta' - Provincia de Córdoba. Actas del Encuentra Internacional de Minería, I: 161.

DEANTONIO, M., 1994b. Proyecto estudio de factibilidad de exploitación de las minas de ore del grupo 'San Ignacio'. Actas del Encuentra Internacional de Minería, I: 171-174.

DI FINI, A., 1970. Mármoles de Córdoba. Boletin de la Asociación Geológica de Córdoba, V 1, no 1, pp 33-50.

EWERS, G.R. and RYBURN, R.J., 1993. User’s guide to the OZMIN mineral deposit database. Australian Geological Survey Organisation, Record 1993/94, 69p.

FITZSIMMONS, I.C.W., KINNY, P.D., and HARLEY, S.L., 1996. Timescales of Pan-African metamorphism, melting and exhumation at Brattstrand Bluffs, east Antarctica. Evolution of Metamorphic Belts, Geological Society of Australia, Abstract volume 42.

GONZALE, R.R. y ACENOLAZA, F.G. 1972. La cuenca de deposición neopaleozóica-mesozóica del oeste argentino. Fundación e Instituto Miguel Lillo, Tucamán, Miscelánea, 40: 629-643.

GORDILLO, C.E., 1974. Las rocas cordieríticas de Orcoyana y Cerro Negro - Soto (Córdoba). Boletin de la Asociación Geológica de Córdoba, volume 2, no 3-4, p 90-100.

GORDILLO, C.E. y LENCINAS, A., 1970. Geologia de Córdoba. Boletin Asociación Geológica de Córdoba. I (1).

JORDAN, T.E. AND ALLMENDINGER, R.W. 1986. The Sierras Pampeanas of Argentina: A modern analogue of Rocky Mountain foreland deformation. American Journal of Science, 286: 737-764.

KAY, S.M. y RAMOS, V.A., 1996. El magmatismo Cretacico de Las Sierras de Córdoba y sus implicancias tectonicas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas III: 453-464

LUCERO MICHAUT, H.N. y OLASCHER, J., 1981. Descripción Geológica de la Hoja 19h, Cruz del Eje, Provincia de Córdoba (Escala 1:200 000). Servicio Geológico Nacional, Boletín, 179, 96 p.

LYONS, P. and SKIRROW, R.G., 1996. Whole rock and stable isotope geochemistry - Final Report. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.

LYONS, P, SKIRROW, R.G. and STUART-SMITH, P.G. 1997. . Report on Geology and Metallogeny of the Sierras septentrionales de Córdoba, 1:250 000 map sheet, Province of Córdoba. Geoscientific Mapping of the Sierras Pampeanas, Argentina-Australia Cooperative Project, Australian Geological Survey Organisation, unpublished report.

LYONS, P., STUART-SMITH, P.G., SIMS, J.P., PIETERS, P., SKIRROW, R.G. and CAMACHO, A., 1996. Whole Rock Geochemistry Report. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report, June 1996.

MARTINO, R.D., 1993. La faja de deformación “Guamanes”: petrografía, estructura interna y significado tectónico, Sierra Grade de Córdoba. Revista de la Asociación Geológia Argentina, 48 (1): 21-32.

MARTINO, R., KRAEMER, P., ESCAYOLA, M., GIAMBASTIANI, M., and ARNOSIO, M., 1995. Transect de Las Sierras Pampeanas de Córdoba a los 32° S. Revista de la Asociacíon Geológica Argentina, 50: 60-77.

MARTINO, R.D., SIMPSON, C., and LAW, R.D., 1994. Ductile thrusting in Pampean ranges: its relationships with the Ocloyic deformation and tectonic significance.GCP Projects 319/376, Novia Scotia, Abstracts.

MARTOS, D.E., PETRELLI, H.A., CANDIANI, J.C. y MIRÓ, R.C., 1994. Modelos de yacimientos auríferos de la Provincia de Córdoba. Secretaría de Minería de la Nación, Actas del Encuentra Internacional de Minería, I: 37-48.

MASSABIE, A.C., 1982. Geologia de los Alfrededores de Capilla del Monte y San Marcos, Provincia de Córdoba. Revista de la Asociacíon Geológica Argentina, 37: 153-173.

MEINERT, L.D., 1993. Igneous petrogenesis and skarn deposits. In: KIRKHAM, R.V., SINCLAIR, W.D., THORPE, R.I. & DUKE, J.M. (eds), Mineral Deposit Modeling. Geological Association of Canada Special Paper 40: 569-584.

MIRANDA, S. y INTROCASO, A., 1996. Cartas gravimetricas y comportamiento isostatico areal de las Sierras de Córdoba - Rep. Argentina. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 405-417.

MIRÓ, R.C., y TORRES, B., 1987. Proyecto 'San Ignacio'. Etapa: Formulación, Secretaría de Minería de la Nación, Dirección Nacional de Minería y Geología, Región Centro. Centro de Exploración Córdoba.

MURRA, J.A. y BALDO, E.G., 1996. El granito de Capilla del Monte y su encajonante ígneo-metamórfico, Sierras Pampeanas de Córdoba. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas III: 499-505.

OLSACHER, J., 1960. Descripción geológica de la hoja 20h, Los Gigantes, Provincia de Córdoba. Drrección Nacional de Geología y Minería. Buenos Aires. Bull. 90.

PASTORE, F., 1932. Descripcion de la Hoja Geologica 20I, Córdoba. Ministerio Agricultura, Direccion de Mineria y Geologia, Boletin, 36, 67pp.

PASTORE, F. y METHOL, E., 1953. Descripcion de la Hoja Geologica 19I, Capilla del Monte. Ministerio Industria Cometcio, Direccion Nacional de Mineria, Boletin 79.

PIOVANO, E.L. 1966. Correlación de la Formación Saldán (Cretácico temprano) con otras secuencias de las Sierras Pampeanas y de las cuencas Chacoparanense y de Paraná. Revista de la Asociación Geológica Argentina, 51: 29-36.

RAMOS, V.A., JORDAN, T.E., ALLMENDINGER, R.W., MPODOZIS, C., KAY, S., CORTES, J.M., and PALMA, M.A., 1986. Paleozoic terranes of the Central Argentine-Chilean Andes. Tectonics, 5: 855-880.

RAPELA, C.W., PANKHURST, R.J., BALDO, E., and SAAVEDRA, J., 1995. Cordieritites in S-type granites: Restites following low pressure, high degree partial melting of metapelites. The Origin of Granites and Related Rocks, Third Hutton Symposium Abstracts. US Geological Survey Circular 1129.

RAPELA, C.W., SAAVEDRA, J., TOSELLI, A., AND PELLITERO, E, 1996. Eventos magmaticos fuertemente peraluminosos en las Sierras Pampeanas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 337-353

RICCI, S.M., 1974. Provincia de Córdoba - Mapa Minero, Escala 1 : 750,000, Ministero de Indústria y Minería, Subsecretería de Minería, Dirección Nacional de Promoción Minera.

RIGAL, R., 1934. La mina de oro de San Ignacio, en la Provincia de Córdoba. Dirección Minas y Geología, Publicación No. 104, Buenos Aires.

RIMAN, E., 1918. Estudio geologico de la Sierra Chica entre Ongamira y Dolores. Acadamia Nacional de Ciences de Córdoba, Boletin 22, 129-199.

SANTA CRUZ, J.N., 1978. Aspectos sedimentologicos de las formaciones aflorantes al este de la Sierra Chica, Provincia de Córdoba, Republica Argentina. Asociación Geológica Argentina, revista, 36: 232-244.

SCHMIDT, C., 1993. Neogene inversion of two Cretaceous basins, Sierras Pampeanas, Argentina. Geological Society of America, 1993 Annual Meeting, Boston, Abstracts, 233.

SIMS, J.P., STUART-SMITH, P.G, LYONS, P. y SKIRROW, R., 1997. Sierras de San Luis y Comechigones (Informe 1:250.000 Hoja geológia). Servicio Geologico Minero Argentino - Australian Geological Survey Organisation, unpublished report.

SIMS, J.P., STUART-SMITH, P.G., LYONS, P., PIETERS, P., SKIRROW, R.G. and CAMACHO, A., 1996. Petrography Report. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report, June 1996.

SKIRROW, R.G. y JOHNSTON, A.I., 1997. Atlas Metalogenético de las Sierras Pampeanas, República Argentina. Australian Geological Survey Organisation, Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project.

SKIRROW, R.G. and TRUDU, A., 1997. ARGMIN: a mineral deposit database for the Sierras Pampeanas, Republic of Argentina. Australian Geological Survey Organisation, Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project. Database in Microsoft Access and Oracle.

STRASSER, E.N., TOGNELLI, G.C., CHIESA, J.O. y PRADO, J.L., 1996. Estratigrafia y sedimentologia de los depositos eolicos del pleistoceno tardio y Holoceno en el sector sur de la sierra de San Luis. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas IV: 73-83.

TORRES DE DIGIUSTO, M.B. y MIRÓ, R.C., 1986. Proyecto: Mina Clementina y Matilde, Secretaría de Minería de la Nación, Centro de Exploración Córdoba, 13 p.

TOSELLI, A.J., DALLA SALDA, L. y CAMINOS, R., 1992. Evolucíon metamórfica del Paleozoic Inferior de Argentina. In J.G. Gutiérrez Marco, J Saavedra and I. Rábano (Eds), Paleozoico Inferior de Ibero-América. Universidad de Extremadura.

TOSELLI, A.J., DURAND, F.R., ROSSI DE TOSELLI, J.N. y SAAVEDRA, J., 1996. Esquema de evolucion geotectonica y magmatica eopaleozoica del Sistema de Famatina y sectores de Sierras Pampeanas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 443-462.

WILLNER, A.P., and MILLER, H., 1986. Structural division and evolution of the lower Paleozoic basement in the NW Argentine Andes. Zentralblat fur Geologie und Paläontologie, I, 1245-1255.

ZOLEZZI, R.E., MIRÓ, R.C. y PETRELLI, H., 1988. Perfil del Proyecto Puigari-Monserrat, Secretaría de Minería, Dirección Nacional de Minería y Geología, Centro de Exploración Córdoba, 19 p.

ARGMIN

DATABASE OUTPUT SHEETS