Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3163-19 COSQUIN

Province of Córdoba

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GEOSCIENTIFIC MAPPING OF THE SIERRAS PAMPEANAS ARGENTINA-AUSTRALIA COOPERATIVE PROJECT

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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by Peter G. Stuart-Smith

1. INTRODUCTION

1.1 LOCATION AND ACCESS

The Cosquin 1:100.000 Sheet area lies within the Córdoba Province, between 31^{o}00'-31^{o}20'S and 64^{o}00'-64^{o}30'W. The area is part of the Córdoba (3163-III)1:250 000 sheet area.

The region includes the central northern part of the Sierra Chica, one of several north-trending mountain ranges which traverse the northern part of the Córdoba Province. The Sierra Chica is drained by the easterly flowing Ríos La Granja, Ascochinga, and Santa Sabina.

Access to the region, from Córdoba city, is via El Manzano and Ruta Provincial 9 in the east. An unsealed road traverses the eastern flank of the Sierra Chica from El Manzano to La Cumbre (Jesús María sheet area).

1.2 NATURE OF WORK AND PREVIOUS INVESTIGATIONS

Mapping of the Cosquín area 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). Only the northern quarter of the sheet (between 31°00′ and 31°05′) was covered by the mapping program. The mapping employed a multidisciplinary approach using the newly acquired high-resolution airborne magnetic and gamma-ray spectrometric data, Landsat TM imagery, and 1:20 000 scale (approximate) black and white air photography.

The Cosquín geological map was compiled on topographic bases produced at photo-scale from rectified Landsat images controlled by field GPS sites. Relief data was obtained from the digital terrane model (DTM) acquired during the airborne geophysical survey.

Geologists involved in the fieldwork were P.G. Stuart-Smith (AGSO), and J.C. Candiani, H. Lopez, and R. Miró (DNSG) assisted with the fieldwork.

Much of the area was first mapped as undifferentiated metamorphic basement by early workers (e.g., Riman, 1918; Pastore, 1932; Pastore and Methol, 1953). Later workers (e.g., Michaut, 1986; Perez and others, 1996) recognised that many of the gneisses were originally intrusive granitic rocks, separating them from other (para) gneiss and marble. Perez and others mapped the granitoids east of the Carape Fault in the Sierra Chica, correlating them with the granitic batholith in the Sierra Norte.

2. STRATIGRAPHY

2.1. General relations

The Cosquín 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

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

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).

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 Río Guzman Shear Zone further south in the Province of San Luis. Only the Pampean domain is exposed in the Sierras Chica and Grande. The younger Famatinian domain is inferred to be present in the subsurface west of the Sierra.

In the area, basement consists of Early Cambrian metamorphic and igneous complexes intruded by Cambrian granitoids. The remnants of continental Cretaceous sediments and cap the summit of the Sierra Chica, and together with Tertiary, and Quaternary sediments occupy major valleys and intramontane areas, particularly in the east.

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

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

Table 2.1. Summary of stratigraphy and relationships in the Cosquín 1:100 000 sheet.

Age (Ma)	Unit	Description	Relations
CAINOZOIC QUATERNARY	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	Saldán Formation	Polymictic conglomerate, coarse-grained poorly sorted clastic sediments	Unconformably overlies metamorphic basement and granitic rocks
	Rosario Conglomerate	Polymictic conglomerate, lithic arenite, basalt	Unconformably overlies metamorphic basement and granitic rocks
CAMBRIAN	Cadonga Granite	Hornblende biotite monzogranite	Intrudes La Falda Complex. Faulted against El Manzano Formation
	Güiraldes Tonalite	Leuco-tonalite, leuco-granodiorite, leuco-monzogranite	Intrudes La Falda Complex
	Ascochinga Complex	Hornblende tonalite, biotite granodiorite, biotite granite	Faulted against El Manzano Formation.
	La Falda Complex	Banded pelitic gneiss, leuco-tonalitic ortho-gneiss, marble, and calc-silicate rocks	Faulted against El Manzano Formation. Intruded by Güiraldes Tonalite and Cadonga Granite
	El Manzano Formation	Pelitic gneiss, marble, calc-silicate rock, and amphibolite	Faulted against Ascochinga and La Falda Complexes.

2.2 EARLY PALAEOZOIC METAMORPHIC BASEMENT

El Manzano Formation (∈lm)

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

A one to three kilometre-wide fault-bounded belt of interlayered paragneiss, marble and amphibolite extends from El Manzano to north of Cerro Uritorco (in the Jesús María sheet area). This unit, here referred to as the El Manzano Formation, has previously been mapped by early workers (e.g., Riman, 1918; Pastore, 1932; Pastore and Methol, 1953) as part of undifferentiated basement metamorphics which are now subdivided into the El Manzano Formation and the La Falda Metamorphic Complex. The formation is distinguished from the metamorphic complex by the absence of tonalite and the greater abundance of marble and calc-silicate rocks. It is well-exposed particularly in the numerous marble quarries near El Manzano and north of Cadonga.

The El Manzano Formation is faulted against the Ascochinga Igneous Complex to the east and the Güiraldes Tonalite, Cadonga Granite and La Falda Metamorphic Complex to the west, except where concordant contacts are inferred with the La Falda Metamorphic Complex 2 km north of Cadonga. Both the La Falda Metamorphic Complex and the El Manzano Formation share a common structural and metamorphic history and are interpreted as Early Cambrian in age.

The dominant lithology is *para-gneiss* which comprises about half the unit, and is interlayered with marble and calc-silicate rocks, and minor amphibolite. The gneiss, derived from a pelitic protolith, is typically a dark grey muscovite-biotite-quartz K-feldspar banded rock with minor sillimanite. A penetrative gneissic foliation is defined by mineralogically differentiated bands of micas and medium- to coarse-grained granoblastic quartz and feldspar leucosome.

Marble and *calc-silicate rocks* crop out as low strike ridges. They are normally banded white, green, grey or pink and form layers up to 2 m thick. Medium- to coarse-grained granoblastic calcite-dolomite is the most common mineral present with varying amounts of chondrodite, scapolite, grossular, clinozoisite, diopside, titanite, plagioclase, K-feldspar, quartz, and apatite. Banding parallels a weak to strong gneissic foliation marked by aligned silicate minerals (where present) and probably represents tectonically transposed lenses formed during the Pampean medium- to high-grade deformation event.

Amphibolite bands, up to 10 m across, are commonly interlayered with marble and calc-silicate rocks. They are a dark green, foliated and banded rock composed essentially of hornblende, plagioclase and quartz with minor secondary epidote and chlorite.

The El Manzano Formation is the northernmost of a number of similar faulted-bounded belts of marble-rich sequences which occur throughout the Sierras de Córdoba. Other examples are: the Quilpo Formation west of Sierra San Marcos; and in the Sierra Comechingones where the southernmost of these is distinguished as the Las Lajas Metamorphic Complex. Like the latter complex (Stuart-Smith 1997b), the El Manzano Formation was probably fault-emplaced during either the Ordovician Famatinian or the Devonian Achalian deformation event. These units may represent originally separate sequences or dismembered parts of a once continuous sedimentary package of platform carbonates and pelites, and possible mafic rocks deposited during the Early Cambrian.

La Falda Metamorphic Complex (∈fgn, ∈sgn)

Banded pelitic gneiss, leuco-tonalitic ortho-gneiss, marble and calc-silicate rocks

The La Falda Metamorphic Complex lies between two separate north to north-west-trending largely fault-bounded carbonate-rich metamorphic units of the El Manzano Formation in the Sierra Chica and the Quilpo Formation to the west of the sheet area, near San Marcos Sierra. Several granitic plutons and smaller bodies intrude the complex and include the ?Cambrian Güiraldes Tonalite in the sheet area. In the west, 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 Formation by the presence of tonalite and a smaller proportion carbonate rocks but shares 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 Güiraldes Tonalite in the Sierra Chica.

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 sub-units based on the predominance of either pelitic gneiss or ortho-gneiss. The ortho-gneiss dominated portion, mapped as the San Marcos Formation by Massabie (1982) west of Capilla del Monte, is not present in the sheet area.

Grey *banded muscovite-biotite-feldspar-quartz-garnet ±sillimanite gneiss* is the predominant rock type. Feldspar contents range from 10% to 20% with plagioclase predominating over K-feldspar. The rock is typically gneissic and 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.

Buff to pale *grey medium-grained equigranular muscovite-biotite leuco-tonalitic ortho-gneiss* forms 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 Famatinian 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.

Ascochinga Igneous Complex (∈at, ∈agd, ∈ag1)
hornblende tonalite, biotite granodiorite, and biotite granite

East of the Carape Fault, in the Sierra Chica, deformed Early Cambrian granitic rocks and minor metamorphics are distinguished as the Ascochinga Igneous Complex. The complex was first mapped as undifferentiated metamorphic basement by early workers (e.g., Riman, 1918; Pastore, 1932; Pastore and Methol, 1953). Later workers (e.g., Michaut, 1986; Perez and others, 1996) recognised that many of the gneisses were originally intrusive granitic rocks, separating them from other paragneiss and marble. Perez and others mapped the granitoids east of the Carape Fault as either "Pluton Ascochinga" or "Pluton Estancia Veija" and correlated them with the granitic batholith in the Sierra Norte. Here both units of Perez and others have been incorporated into the Ascochinga Igneous Complex, which is subdivided into seven informal sub-units based on the dominance of a particular lithology (Stuart-Smith, 1997a). All the phases described by Perez and others are recognised, in addition to a foliated granite sub-unit and an interlayered para- ortho-gneiss sub-unit which broadly corresponds to the "Pluton Estancia Veija" as mapped by Perez and others (1996). Only the southern extremity of the complex is exposed in the Cosquín sheet area.

Outcrop of the complex is good west of the El Manzano-La Granja road, but is poorer farther to the east where is onlapped by Mesozoic and younger sedimentary cover. Subdivision of the complex is based mainly on interpretation of aeromagnetic and gamma-ray spectrometric patterns, consequently most boundaries within the complex are approximate. In the field, contacts between sub-units are often gradational. Aeromagnetic anomalies also indicate continuity of the complex to the east of National Route 9 and with the Sierra Norte to the north, which contains all the main granitoid phases recognised in the Ascochinga Igneous Complex (R. Miró personal communication, 1996).

Relationships between the Ascochinga Igneous Complex and other Paleozoic units are poorly known. To the north, in the Jesús Maria sheet area, granitoid units within the complex intrude minor bodies of para- and ortho-gneiss with contacts mostly concordant to the differentiated metamorphic fabrics. However, they display only variably developed foliations indicating late syntectonic emplacement with respect to the S1 fabrics in paragneiss. Minor dykes of undeformed pegmatite, aplite and lamprophyre intrude the complex. Contacts with other basement units are fault-bounded. The western extent of the complex is limited by the east-dipping Carape Fault where it is thrust over the El Manzano Formation to the west. In the east, unconsolidated Mesozoic and Cainozoic sediments onlap basement rocks.

The age of the Ascochinga Igneous Complex is interpreted as Early Cambrian, based on a U-Pb zircon dating of granite from the Sierra Norte which yielded an age around 514 Ma (U-Pb zircon unpublished data) This age is consistent with ages of about 515 Ma to 520 Ma for the El Pilón Granite (Rapela and others, 1995; Camacho and Ireland, 1997) near Villa de Soto and about 530 Ma for peak M1 metamorphism in the Sierras de Córdoba (Camacho and Ireland, 1997). This deformation, metamorphism and magmatism defines the Pampean Cycle in the Sierras Pampeanas.

Of the seven phases recognised in the Ascochinga Igneous Complex, only three are present in the Cosquín sheet area. These are: hornblende tonalite, biotite granodiorite and biotite granite.

Grey medium- to coarse-grained biotite hornblende tonalite, (∈at), is the principal lithology, forming the bulk of the pluton. Although mostly tonalitic in composition, the rock ranges through granodiorite, monzogranite, monzonite and monzodiorite. Perez and others (1996) recognised three facies: the “Facies tonalitica hornblendifera, tonalita biotita, and tonalita porfiritica”. However, these facies could not be mapped during the current program as contacts between them are gradational and their distribution could not be distinguished on either aerial photographs, Landsat TM images, or on the basis of magnetic and gamma-ray spectrometric properties. Textures vary from equigranular to seriate with minor pink K-feldspar crystals up to 2 cm across. Biotite contents range from 5 to 15% with hornblende up to 25%. Titanite, zircon, apatite, allanite and magnetite are common accessories. A characteristic of this phase is its high magnetic susceptibility, mostly greater than 500 x 10^{-5} SI units, and the abundance of mafic-rich xenoliths and enclaves (diorite and amphibolite) and biotite/hornblende schlieren. A variably developed gneissic foliation dips moderately to the east and is defined by aligned biotite and hornblende. Primary quartz and feldspar grains are deformed with some recrystallised polygonal mosaic development The foliation becomes a penetrative mylonitic foliation within 500 m of the Carape Fault where it forms shear planes with a steeply pitching mineral lineation. All rocks show minor late epidote, sericite and carbonate alteration of plagioclase and marginal chloritisation of biotite. Haematite is present in late fractures.

Buff to grey *biotite granodiorite,* (∈agd), occurs in two north-trending bodies surrounded by hornblende tonalite, east of the Carape Fault. The granodiorite is medium- to coarse-grained, and equigranular to rarely seriate with pink microcline subhedra up to 2 cm across. Titanite, apatite, allanite and magnetite are accessory minerals and rare hornblende may be present. The granodiorite is distinguished from the main phase by the lack of hornblende and mafic xenoliths and a lower magnetite content (magnetic susceptibilities are less than 100 x 10^{-5} SI units). The slightly higher potassium content of the rock compared with the overall more tonalitic main phase, is reflected in gamma-ray spectrometric images and was one of the main criteria used to map the full extent of the sub-unit. The phase corresponds to the “Facies granodioritica” distinguished by Perez and others (1996).

Massive pink medium- to coarse-grained *biotite granite,* (∈agl)**,** occupies the eastern part of the complex. This granite is the least deformed and most felsic phase of the complex and may be the youngest, as it intrudes the more mafic phases to the north in the Jesús María sheet area. The granite is mostly equigranular and coarse-grained with seriate and porphyritic textures in some medium-grained varieties. In the latter, pink microcline feldspar forms phenocrysts up to 1 cm across. Common accessory minerals include apatite, zircon, magnetite and garnet. Compositionally the granite lies across the syenogranite, monzogranite and quartz syenite fields. Minor fine-grained muscovite is present as rare primary grains and as an alteration mineral intergrown with haematite and epidote marginal to biotite grains. Very weak sericite and epidote alteration is also ubiquitous. Magnetic susceptibilities are low ($<100 \times 10^{-5}$ SI units). Its peraluminous composition indicates a different source to all other granitoids in the complex which were derived from igneous sources.

The Ascochinga Igneous Complex is an Early Cambrian meta-intrusive complex comprising rocks of a diverse chemical character and origin, including tholeiitic mafic enclaves, peraluminous granite, and metaluminous tonalite, granodiorite and granite. These latter rocks are the most extensive units, forming a fractionated composite batholith which is contiguous with the compositionally and texturally similar granitoids to the north in the Sierra Norte (Perez and others, 1996; Lira and others, 1996). They are interpreted to have formed in a continental magmatic arc setting (Lira and others, 1996). Major and trace element geochemistry shows that the granitoids are typically medium-K calc-alkaline with FeO*/MgO ~ 2, La/Yb ~ 10, and have slight depletion of MREE and small to absent negative Eu-anomalies (Rapela and Pankhurst, 1996). Initial 87Sr/86Sr ratios are mostly in the range 0.708 to 0.711, with Ndt -4 to -5, indicating involvement of older crust (Rapela and Pankhurst, 1996).

2.3 PLUTONIC ROCKS

Cadonga Granite **(∈gx)**
Hornblende biotite monzogranite

Grey fine-grained equigranular granitic rocks cropping out in the south in the vicinity of Cadonga have been mapped by Pérez and others (1996) as "Pluton Candonga". They mapped an undifferentiated body of hornblende tonalite, biotite tonalite and granodiorite and noted that it intruded adjacent metamorphic rocks. Only the northern portion of the body, here referred to as the Cadonga Granite, crops out in the area, covering less than 15 km^2.

The granite contains numerous subconcordant enclaves of biotite schist, gneiss and amphibolite, most probably derived from the adjacent La Falda Complex. In detail, the contact with these rocks is intricate and intrusive with the granite truncating all metamorphic fabrics. The main body of the granite is massive. To the north and west, the pluton is separated from the Güiraldes Tonalite, by a screen of La Falda Metamorphic Complex metamorphics; contacts are inferred to be concordant and intrusive. These relationships indicate that the granite probably forms a series of intrusions parallel to the main metamorphic layering of the enclosing La Falda Metamorphic Complex. The granite is faulted against the El Manzano Formation to the east, and about 2 km east of Cadonga it forms a series of faulted mylonitic blocks overlying the El Manzano Formation. The age of the Cadonga Granite is not known, but, an Early Cambrian age is interpreted based on correlation with other granites in the Sierras Chica and Sierra Norte.

The three granitoid types described by Perez and others (1996) were not found in the area. The northern part of the pluton *comprises grey fine- to medium-grained equigranular hornblende biotite monzogranite* with common accessory magnetite, allanite, titanite, apatite. The rock is moderately magnetic with a mean magnetic susceptibility of about 300 x 10^{-5} SI units. Most minerals show evidence of some strain with very weak chlorite, sericite and epidote alteration. The granite is metaluminous, medium-K calc-alkaline and oxidised.

Güiraldes Tonalite (∈tg)

Leuco-tonalite, leuco-granodiorite and leuco-monzogranite

Leuco-granitoids cropping out along the Sierra Chica between La Falda and Cadonga are included in the Güiraldes Tonalite. The unit includes parts of the "Pluton Güiraldes" and the "Tonalita La Cumbre" of Pérez and others (1996). There are no distinct compositional or relational differences between the plutons mapped by Pérez and others. Saieg (referred to by Pérez and others, page 501) described the contact between the two as transitional. The limit of the Güiraldes Tonalite is poorly defined, owing to intricate intrusive contacts and numerous enclaves of the surrounding La Falda Metamorphic Complex. There is no magnetic (magnetic susceptibilities are low: about 20×10^{-5} SI units) or gamma-ray spectrometric contrast between the granite and the complex. The tonalite may well represent a larger body of the intrusive tonalites found within the La Falda Metamorphic Complex, correlating with rocks west of Capilla del Monte mapped as the San Marcos Formation by Massabie (1982).

The Güiraldes Tonalite forms an irregular-shaped body enclosed by the La Falda Metamorphic Complex. This body is displaced and faulted against the El Manzano Formation to the east, the latter forming a continuous faulted belt thrust over units to the west. The contact with the La Falda Metamorphic Complex in the south is also sheared where it is interlayered with gneiss and amphibolite. Enclaves of marble, amphibolite and gneiss, up to 1 km across, are common throughout. In several quarries east of Villa Gardino, massive marble enclaves, are well exposed with intrusive tonalite and pegmatite veins. The latter are associated with minor skarn development. Intrusive contacts with the La Falda Metamorphic Complex are exposed to the north in the Jesús Maria sheet area and are described by Stuart-Smith (1997).

The dominant lithology is a pale grey to pink, *medium- to coarse-grained, muscovite biotite equigranular leuco-tonalite* with lesser *leuco-granodiorite and leuco-monzogranite*. Apatite is a common accessory phase and rare garnet is present in highly fractionated phases near contacts. A weak, but pervasive, NNW-trending foliation is widely developed particularly along pluton margins. The foliation is moderately to steeply dipping (60°-85°) and is axial planar to broad regional tight folds. The foliation comprises weakly aligned deformed primary muscovite and biotite primary grains, with minor secondary sericite folia and weak chlorite epidote alteration of biotite. Plagioclase subhedra are typically deformed and quartz is strained with sutured grain-boundaries and some ribbon aggregates. This low-grade metamorphic fabric is the same as that present in the Ascochinga Igneous Complex and is probably Early Ordovician (Famatinian) in age.

The granitoids comprising the Güiraldes Tonalite are strongly peraluminous with ASI > 1.1 (S-type of Chappell and White, 1974), low K_2O and HFSE contents (~1%), initial 87Sr/86Sr of 0.7065 and a εNdt of about -4 (Rapela and Pankhurst, 1996). Pérez and others (1996) interpreted the pluton to be related to the metaluminous granites of the Ascochinga Igneous Complex and interpreted them as forming in a magmatic arc setting. Rapela and Pankhurst suggested their genesis involved high-pressure melting of primitive mafic rocks that had undergone relatively recent depletion in lithophile element content.

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).

In the Sierra Chica numerous folded muscovite-quartz- K-feldspar pegmatite dykes, up to 10 m wide, are associated with the latest stages of Early Cambrian felsic (tonalitic) magmatism in the region, post-dating the medium-grade Pampean deformation and earlier metaluminous granitic intrusion. These occur particularly along the western margin of the Ascochinga Igneous Complex and throughout the Güiraldes Tonalite and immediately adjacent to the La Falda Metamorphic Complex metamorphics (within two kilometres). The pegmatites are folded and deformed by regional F2 open folds and the S2 foliation (?Famatinian) and are localised, in low-strain zones associated with the folds, indicating syn-tectonic emplacement. K-Ar dating of muscovite from one such pegmatite west of La Falda (in the adjacent sheet area), from the neck of an F2 boudin of tonalitic orthogneiss, yields a minimum age of 428 Ma (Camacho, 1997).

Lamprophyre

Minor lamprophyre (vogesite) dykes, up to 1 m wide, intrude the Ascochinga Igneous Complex south of Jesús María township, 1 km west of Colonia Caroya. The dykes are exposed in a quarry and are extensively altered to carbonate, chlorite and epidote. Typically, they have chilled margins and contact rocks are intensely fractured, with closely spaced joints parallel to dyke margins.

The dykes are part of a regional set which trends northwesterly and northeasterly, parallel to faults and joints developed at the close of the Devonian Achalian deformation. The age of the dykes is not known. Similar dykes in the Sierras Comechingones postdate Early Devonian thrusts and are late Paleozoic to Mesozoic in age (Stuart-Smith, 1997b). Toselli and others (1996) interpret similar lamprophyre dykes, intruding the Granito Ñuñorco in the western Sierras Pampeanas, to be related to the late Devonian/early Carboniferous “Chánica Orogeny” (correlated with the final phase of the Achalian Cycle).

2.4 MESOZOIC

Cretaceous sedimentary rocks are widespread along the eastern and western margins of the Sierra Chica. In the region, these units include the Rosario Conglomerate near La Falda and the Saldán Formation east of the Sierra Chica. 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 and the La Calera Fault along the eastern margin of the range (Kay and Ramos, 1996). Both half-grabens were inverted with bounding faults reactivated during Cainozoic Andean uplift to form the present-day morphology.

Rosario Conglomerate (Kr)

Polymictic conglomerate and lithic arenite

Remnants of valley-fill *polymictic conglomerates and poorly sorted lithic arenite* referred to as the Rosario Conglomerate (Piovano, 1996) form small isolated cappings unconformably resting on The La Falda Metamorphic Complex and Güiraldes Tonalite along the western scarp and summit of the Sierra Chica east of La Falda. Farther to the north, near Estancia El Rosario in the Jesús María sheet area a nepheline basalt flow, intercalated with the sediments (Gordillo and Lencias, 1967), yields a total rock K-Ar age of 119 ± 10 Ma (Gonzalez and Toselli, 1975).

Saldán Formation Ks

Polymictic conglomerate and coarse-grained poorly sorted clastic sediments

Low rounded hills of *polymictic conglomerate* and *coarse-grained poorly sorted clastic sediments* onlapping metamorphic and plutonic basement rocks along the eastern flank of the Sierra Chica and on the plains between the Sierra Chica and National Route 9, are mapped as the Saldán Formation. The formation, as mapped, almost certainly contains areas of reworked undifferentiated Cainozoic gravels which could not be readily separated during the mapping program. The formation was deposited as a coalesced fluvial fan, up to 250 m thick, sourced locally from the Sierra Chica (Santa Cruz, 1978). Synsedimentary basaltic volcanism, correlated with the Early Cretaceous “Groupo volcaniclástico de El Pungo”, is indicated by a high volcanic component in the upper part of the unit (Piovano, 1996). Basalt clasts give a K-Ar total rock age of 100.5 ± 2.8 Ma (Piovano, 1996), similar to that obtained for basalt flows near Estancia El Rosario in the Rosario Conglomerate.

2.5 CAINOZOIC

2.5.1 Tertiary to Quaternary

Undifferentiated deposits (Czu)

The most extensive Cainozoic unit 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 which covers and preserve pre-existing topographic relief between the main Pampean ranges. The loess comprises mostly friable illite and silt. Material was derived from both the metamorphic-igneous basement rocks and a volcanic-pyroclastic source (Santa Cruz, 1978).

Fluvial fan deposits (Czg)

Raised *fluvial fan deposits of unconsolidated gravels* form low wooded dissected hills along the eastern flank of the Sierra Chica. Based on correlations with the Punilla Valley these deposits are possibly Pleistocene in age, correlating with the "level 1" deposits of Massabie (1982).

2.5.2 Quaternary

Fluvial fan deposits (Qg)

Holocene (Santa Cruz, 1978) to Recent *fluvial fan deposits of unconsolidated bouldery gravels* interfinger downslope with finer-grained alluvial deposits (Qa) along the base of the Punilla Fault scarp on the western flank of the Sierra Chica. Massabie (1982) included these deposits in his Level II subdivision of Quaternary units in the Capilla del Monte area.

Alluvial deposits (Qa)

Holocene (Santa Cruz, 1978) to Recent *alluvial deposits of clay, sand and gravel* are present along active river courses and adjacent terraces. The unit correlates with the Level III Quaternary unit of Massabie (1982) in the Capilla del Monte area. The most extensive deposits are associated with the Río La Granja east of the Colonia Caroya.

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 Metamorphic Complex and pelitic and carbonate metasediments of the El Manzano 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, trending mostly NNW, and dipping steeply to the east.

Quartzite units in the La Falda Metamorphic Complex in the adjacent sheet area, west of La Falda, preserve an earlier differentiated cleavage of spaced biotite-rich folia which are truncated by leucosome veinlets and the differentiated S1 gneissic foliation. This is not observed in the Cosquín sheet area.

Sillimanite-garnet assemblages in pelitic gneiss indicate M1 metamorphism was at least upper amphibolite facies and abundant muscovite-pegmatites and leucosome (forming subconcordant lenses with S1), suggest limited partial melting took place. Estimates of peak metamorphic conditions for the Sierra Chica are mostly about 6 Kb, and 700°C to 800 °C (e.g., Pérez and others, 1996). Uranium-lead dating of zircon rims and monazite grains which grew during the peak metamorphic event (M1) in both the Pichanas and Cruz del Eje

Metamorphic Complexes ,to the west, give an age of about 530 Ma, interpreted here as the age of the M1/D1 event of the Pampean Cycle.

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.

Within metasedimentary gneissic units of the El Manzano Formation and 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 La Falda Metamorphic Complex which intruded as subconcordant intrusions after S1, are folded with limbs commonly boudinaged.

In areas of penetrative S2 development, particularly in the west, 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 (about 100°). This lineation is perpendicular to long axes of boudinaged tonalitic layers, indicating a broadly coaxial deformation. Lower amphibolite/upper greenschist facies metamorphism (M2) is indicated.

Within granitoids of the Ascochinga Igneous Complex a variably developed gneissic foliation, defined by aligned biotite and hornblende, dips moderately to the east. Primary quartz and feldspar grains are deformed with some recrystallised polygonal mosaic development. The foliation becomes a penetrative mylonitic foliation within 500 m of the Carape Fault where it forms shear planes with a steeply pitching mineral elongation lineation. Shear zone fabrics indicate reverse movement with the Ascochinga Igneous

Complex thrust over the El Manzano Formation to the west. The moderate easterly dip of the Fault is also reflected by magnetic anomalies along the entire length of the zone.

The age of this deformation is poorly constrained in the Sierra Chica. Muscovite K-Ar and Rb-Sr dates from a syn D2 pegmatite intruding La Falda Metamorphic Complex rocks west of La Falda, 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).

3.3 ACHALIAN CYCLE

Devonian deformation and metamorphism

Throughout much of the southern Sierras Pampeanas, 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. 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 north-west-trending Guamanes Thrust Zone. In the sheet area the main features of this deformation are localised brittle-ductile thrusting, fracture zones and widespread retrogressive mineral assemblages.

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 the basement units in the Sierra Chica, crosscutting the S3 foliation where present. Regional faults are rarely exposed, but are prominent on aerial photographs and Landsat images. Some of the faults are also delineated on magnetic images as zones of demagnetisation.

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

3.4 MESOZOIC FAULTING

The Punilla and La Calera Faults are interpreted to have initiated as Early Cretaceous east-dipping extensional faults (Sanchez and others, 1995) which were active during deposition of the Early Cretaceous continental deposits such as the Rosario Conglomerate and the Saldán Formation.

The Punilla Fault is well exposed along the dissected western scarp of the Sierra Chica, near La Falda. 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 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 the Rosario Conglomerate is relatively undeformed and is inferred to unconformably overlies the fault rocks.

3.5 ANDEAN CYCLE

Reverse faulting

The Sierras Chica, is an example of a basement tilt block which formed by east-west compression during the Cainozoic Andean uplift (Jordan and Allmendinger, 1986). The range slopes gently to the east and is bounded to the west by an escarpment developed on the moderate to steep east-dipping Punilla Fault, a reverse fault which extends along the full length of the Sierra Chica. The fault is a reactivated Mesozoic extensional structure. 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 melange and steeper fault fabrics.

Another major north-trending Quaternary fault is also interpreted in the subsurface east of the Sierra Chica. Aeromagnetic patterns indicate a 1 km wide zone of alteration passing immediately west of the Jesús Maria Fault. In the area, exposed granitoids close to the interpreted fault are extensively haematised and fractured. Minor haematitic gouge zones, faults and fractures are also exposed in granite quarries between Colonia Caroya and Jesús Maria township to the north.

In the Sierras Comechingones to the south, Costa (1996) interpreted the last and most significant movement on similar faults in the region during the Late Pliocene-Pleistocene with some movement continuing during the Quaternary.

4. GEOLOGICAL HISTORY

The Cosquín sheet 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 together with U-Pb isotopic age determinations, 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 Río Guzman Shear Zone in San Luis Province.
The geological history of the Cosquín sheet area is summarised in Table 4.1.

4.1 EARLY CAMBRIAN SEDIMENTATION

The oldest rocks in the region form a structurally thick sequence of para-gneisses and carbonate-rich metasediments of the La Falda Metamorphic Complex and El Manzano 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 540 Ma (Dalziel and others 1994) in a tectonic environment similar to that envisaged by Dalla Salda and others (1994). Lithological similarities and comparable ages indicate that the metasediments may be correlatives of the Early Cambrian

(Aceñolaza and Toselli, 1981) Puncoviscana Formation in the northern Sierras Pampeanas as postulated by Willner and Miller (1986).

4.2 PAMPEAN CYCLE

Early Cambrian deformation, metamorphism, mafic and felsic intrusion

In the Early Cambrian the sediments were deformed at mid-crustal levels by a compressive event (D1) and metamorphosed at mostly upper amphibolite facies to form banded gneiss and locally migmatites. 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. Uranium-lead dating of zircon rims formed during this metamorphic event (M1) in Sierras de Córdoba give an age of ~ 530 Ma (Camacho and Ireland, 1997). In the map area 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., Dalziel and others, 1994).

Table 4.1. Summary of the geological history of the Cosquín sheet area. Age data and discussion of the various tectonic cycles are presented within the text. The ages of the Pampean Tectonic Cycle are derived from Lyons and Stuart-Smith (1997).

Tectonic Cycle	Age (Ma)	Deposition	Deformation	Intrusion
Andean	Cainozoic	Alluvial, aeolian and talus deposits.	Reverse faulting, block tilting	
	Cretaceous	Conglomerate, arenite	Normal faulting on the Punilla and Calera Faults	

Achalian	~355		NW & NE conjugate strike-slip faulting	Lamprophyre dykes
			Thrusting, local mylonitic foliation (S3), retrogressive greenschist facies	
	404			
Famatinian	~490		Mylonitic S2 foliation isoclinal F2 folding, thrusting on the Carape Fault. Lower amphibolite/ upper greenschist facies	
Pampean	515		Differentiated S1 foliation, amphibolite facies	Tonalite, granite and granodiorite
	530			(Ascochinga Complex, Cadonga Granite, Güiraldes Tonalite, La Falda Complex)
	?540	Pelitic and carbonate sediments of the El Manzano Formation and La Falda Complex		

At the closing stages of the Pampean Cycle, an extensive phase of felsic magmatism is evident by widespread subconcordant intrusion of tonalite, granodiorite and granite (La Falda Metamorphic Complex, Ascochinga Igneous Complex, Güiraldes Tonalite, Cadonga Granite). There are no radiometric dates on these intrusions, however, in the Sierra Norte, similar intrusions in a northern extension of the Ascochinga Igneous Complex are dated about 514 Ma.

The granitoids are mostly medium-K calc-alkaline (Pérez and others, 1996) varieties, interpreted to be indicative of a continental magmatic arc setting (Pérez and others, 1996; Lira and others, 1996). Some peraluminous granites are also present: these possibly evolved from high P melting of primitive material that had undergone recent depletion of lithophile element content, with initial $^{87}Sr/^{86}Sr$ ratios indicating some involvement of older crust (Rapela and Pankhurst, 1996).

4.3 FAMATINIAN CYCLE

Early Ordovician Deformation and metamorphism

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 an 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). Throughout the southern Sierras Pampeanas 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 Ascochinga Igneous Complex was probably thrust over the El Manzano Formation at this time. In the Sierra Chica and elsewhere in the Pampean domain earlier D1 fabrics were tightly folded with local axial plane crenulation cleavage, subparallel to the higher grade differentiated D1 fabric.

Dalla Salda (1987) and Toselli and others (1992) ascribed this deformation to the D2 domain. Zircons which grew during this event yield an age of about 490 Ma dating the timing of peak metamorphism in the Famatinian Terrane in San Luis (Camacho and Ireland, 1997). Within the Cosquín sheet there is little evidence for the younger extensional deformation or magmatism that also characterised this event in the Famatinian terrane to the west.

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. 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 in adjoining sheet areas. 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 probably corresponds to the “Fase Precordilleránica” (Astini, 1996) in the precordillera west of the Sierras Pampeanas where it is related to the amalgamation of the Chilena domain.

The final stages of the Achalian Cycle were the province-wide development of a complex system of rectilinear brittle-ductile vertical NW- and NE-trending strike-slip faults and fractures. The orientation and conjugate relationship of the fractures indicates a continuation of the east-west compressive regime. Locally, in other areas 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 and Ireland, 1997). Toselli, Durand, Rossi de Toselli and Saavedra, (1996) attribute development of the fracture system to a 355 Ma old "Chánica Orogeny".

4.5 MESOZOIC SEDIMENTATION AND MAGMATISM

During the Early Cretaceous, extensional faulting, including probable reactivation of the Punilla and La Calera Faults, accompanied local deposition of continental clastics (Rosario Conglomerate and Sáldan Formation) in half grabens. Mafic magmas, generated by partial melting (<2%) of garnet-bearing OIB-like mantle (Kay and Ramos, 1996), formed minor dykes or extruded as basalt flows intercalated with the sediments in the Jesús Maria sheet area to the north. Age determinations on the mafic rocks range from 150 Ma to 56 Ma (Linares and González, 1990).

4.6 ANDEAN CYCLE

East-west compression during the Cainozoic Andean uplift resulted in Neogene inversion of the Cretaceous basins ,Schmidt, 1993) and block tilting of basement rocks, forming north-south oriented ranges (e.g., Sierra Chica) 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 (e.g., La Punilla and La Calera Faults). 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 3163-19 (Cosquín) area contains few metallic mineral occurrences, with only single occurrences of Fe-Ti and Ni presently known. However, the region is well endowed in dimension stone including marble from the El Manzano Formation.

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 occcurrence 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

No significant metallic mineral deposits are known from the Sheet 3163-19 area. An Fe-Ti occurrence is described below. No descriptions or accurate locations are available for the occurrences of Ni shown on the 1:750 000 scale map of Ricci (1974).

2.1 FE-TI MINERALISATION

Ti-Fe mineralisation occurs at 'Isola Valentina' 10 km E of Huerta Grande (Angelelli, 1984; location uncertain and host stratigraphic unit name not known). Mineralisation consists of ilmenite and haematite-magnetite in quartz vein zones, and as disseminations in granite/pegmatite textured bodies within metasedimentary rocks

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

3.1 LIMESTONE, MARBLE

A large number of deposits of limestone, dolomite and marble are present in the region. Some of the larger worked deposits occur in belts of intensely deformed early Cambrian metacarbonate-amphibolite rocks, including deposits in the El Manzano Formation in the Sierra Chica.

3.2 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 Olsacher (1981), and on the 1995 Mapa Geológica de la Provincia de Córdoba (1:500 000 scale).

3.3 MICA, QUARTZ, FELDSPAR

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

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