Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3366-17
Province of San Luis

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GEOSCIENTIFIC MAPPING OF THE SIERRAS PAMPEANAS ARGENTINE-AUSTRALIAN COOPERATIVE PROJECT

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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SECTION I: GEOLOGY

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1. INTRODUCTION

1.1. LOCATION

The 3366-17 1:100 000 scale map area is located between latitude 32°40’-33°00’ S and longitude 65°00’-65°30’ W. The area includes the population centres of La Toma and Naschel. The main drainage is via Río Conlara which flows to the north and north-east.

1.2. NATURE OF WORK AND PREVIOUS INVESTIGATIONS

The mapping of the Sierras de San Luis and Comechingones was carried out in 1995 and 1996 under the Geoscientific Mapping of the Sierras Pampeanas Argentina - Australia Co-operative Project by geologists from the Australian Geological Survey Organisation and the Subsecretaria de Mineria, Argentina (Figures 1, 2). The mapping employed a multidisciplinary approach using 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. All geological maps were compiled on either published 1:20 000 scale topographic maps where available, or topographic bases produced at photo-scale from rectified Landsat images controlled by field GPS sites.

Topography, including cultural, hydrography and relief data were derived from existing 1:20 000 coverages where available. In areas where existing coverage was not available, culture and hydrography was derived from the rectified Landsat images, and the relief data was derived from the digital terrane model (DTM). Previous regional geological mapping of the Sierras de San Luis and Comechingones at a scale of 1:200 000 includes investigations by Pastore and Gonzalez (1954) of San Francisco (Hoja 23g), Pastore and Huidobro (1952) of Saladillo (Hoja 24g), and Sosic (1964) of Sierra del Morro (Hoja 24h).

More recent geological investigations have been of greater detail and have concentrated on the stratigraphy (e.g. Prozzi and Ramos, 1988; Ortiz Suárez and others, 1992), regional structure (e.g. González Bonorino, 1961; Criado Roqué and others, 1981; von Gosen and Prozzi, 1996), the complex igneous intrusive history (e.g. Zardini, 1966; Brogioni and Ribot, 1994; Llambías and others, 1996; Sato and others, 1996; Otamendi and others, 1996; Pinotti and others, 1996), Tertiary volcanism (e.g. Brogioni, 1988; 1990), and extensive studies on the numerous mineral deposits (e.g. Sabalúa and others, 1981; Llambías and Malvicini, 1982).

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Figure 1. Simplified regional geology of the southern Sierras Pampeanas, and location of the three project areas of the Geoscientific Mapping Project, including the San Luis area.

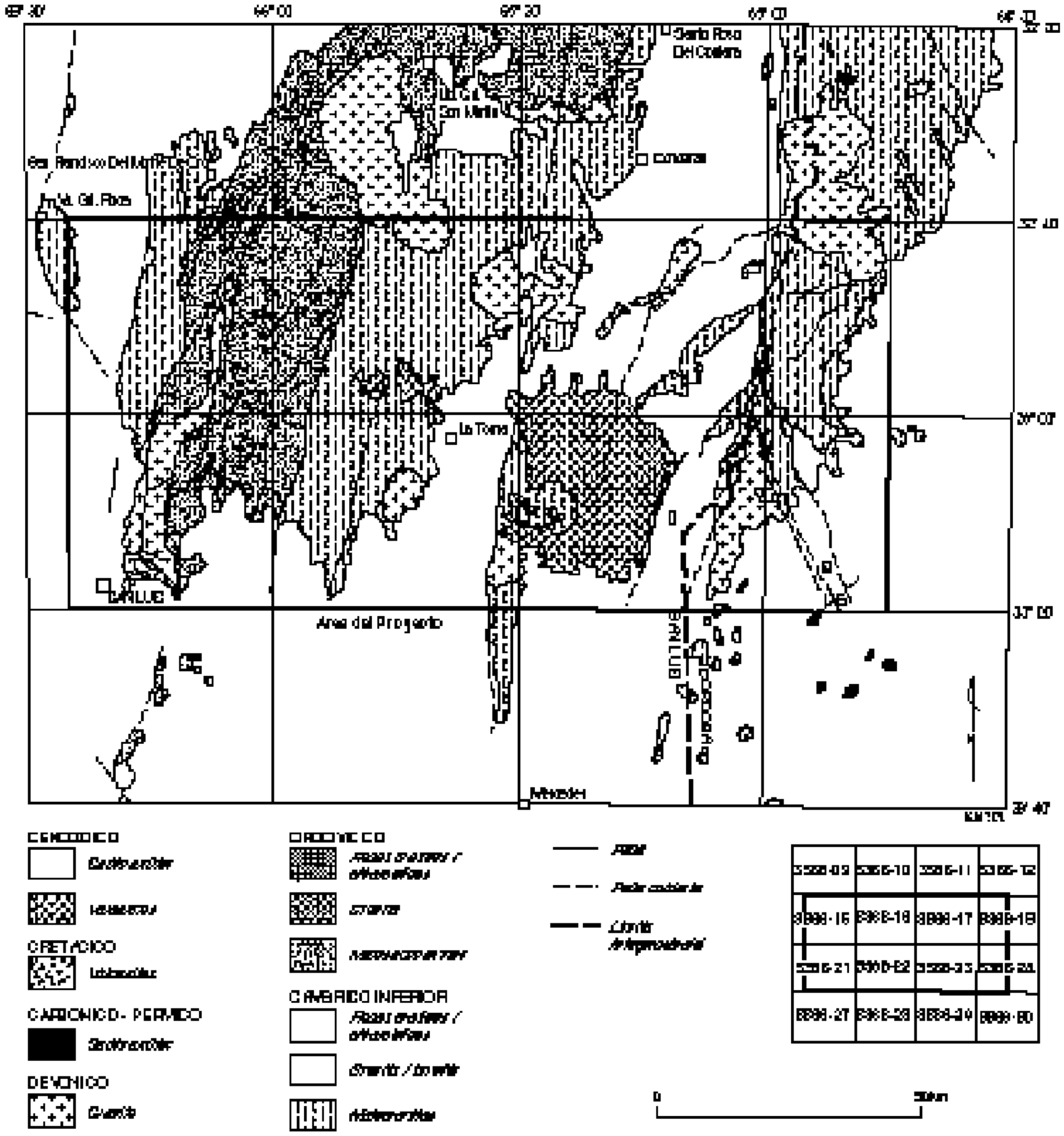

Figure 2. Location of the *Sierras de San Luis y Comechingones* 1:250,000 scale map area in San Luis and Córdoba Provinces with generalised geology. Locations of 1:100,000 scale map areas are indicated.

2. STRATIGRAPHY

2.1 GENERAL RELATIONS

The Sierras Pampeanas are a distinct morphotectonic province of early- to mid-Palaeozoic metamorphic, felsic and mafic rocks that form a series of block-tilted, north-south oriented ranges separated by intermontane basins. These 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 during 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, structural and metamorphic domains separated by major tectonic zones. There are two principal domains: an older, Cambrian domain, and a slightly younger, Ordovician domain. Both domains share a common geological history since early Devonian times.

Rocks of the Cambrian domain in the Sierras de San Luis and Comechingones include the Monte Guazú and Conlara metamorphic complexes, in the east, and the Nogoli Metamorphic Complex in the west. The Ordovician domain consists of Cambro-Ordovician rocks of the Pringles Metamorphic Complex and the Early Ordovician San Luis Formation. Several granitic, tonalitic, mafic and ultramafic bodies dominantly intrude the Ordovician domain. Both domains are intruded by voluminous Early Devonian granites and are partly covered by Neogene volcanics and Cainozoic continental deposits.

2.2 PALAEOZOIC METAMORPHIC BASEMENT

2.2.1 INTRODUCTION

The metamorphic basement of the 3366-17 map area consists of the Cambrian Conlara Metamorphic Complex; granites, the Achiras Igneous Complex and the Las Lajas Shear Zone formed during the Achalian Tectonic Cycle.

2.2.2 CAMBRIAN

Conlara Metamorphic Complex (€cgn, €ce)

Pelitic and psammitic schist and gneiss; orthogneiss, minor calc-silicate and marble; pegmatite.

The Conlara Metamorphic Complex, comprises the majority of the basement cropping out within the valley of the Río Conlara between the Sierras de San Luis and Sierra de Comechingones. The Conlara Metamorphic Complex also incorporates the metamorphic part (the “Metamorfitas y Anatexitas India Muerta”) of a previously defined metamorphic-intrusive complex, the Achiras Complex (Otamendi and others, 1996), in the extreme south of the Sierra de Comechingones. The igneous part of the Achiras Complex of Otamendi and others (1996) has been redefined as the Achiras Igneous Complex.

The western margin of the Conlara Metamorphic Complex is defined by a major NNE trending magnetic lineament and mylonite zone (the Río Guzman Shear Zone; east of the 3366-17 map area) in the eastern Sierras de San Luis, that separates the Complex from the Ordovician San Luis Formation. A significant proportion of the Complex is covered by a thin mantle of unconsolidated Cainozoic deposits.

The Conlara Metamorphic Complex comprises dominantly late Neoproterozoic - Early Cambrian sediments intruded by Cambrian and/or early Ordovician granite and polymetamorphosed in the early-mid Palaeozoic. The thickness of the sedimentary sequence is unknown due to the generally shallow orientation of the main transposition foliation. The

Complex is intruded by a series of Devonian granites, which post-date the dominant structural and metamorphic episodes, and by Neogene calc-alkaline to shoshonitic volcanism. The Complex has a generally low magnetic signature and may be separated into regions that are comprised dominantly of gneiss, and areas comprised dominantly of schist.

Metapelitic and metapsammitic quartz-feldspar-biotite-muscovite-garnet-sillimanite ±tourmaline±chlorite schist is the most abundant rock type exposed in the Conlara Metamorphic Complex (approximately 50%). The schist contains a well-developed biotite-muscovite foliation that is openly folded at a meso- to macro-scopic scale with long, generally shallowly east-dipping limbs and short, shallowly west-dipping limbs. Strongly corroded sillimanite, biotite coronas on garnet, and coarse poikiloblasts of muscovite and quartz containing tightly crenulated inclusions of sillimanite, suggest that the dominant fabric is a low temperature overprint of an earlier higher-grade (amphibolite-facies) fabric. Biotite and muscovite define a generally east plunging mineral lineation while shear-sense indicators are well developed and show a dominantly east-up displacement that is consistent with the asymmetry of folding. An east-down shear-sense is locally preserved, however, particularly close to the western margin of the complex and where this fabric is associated with migmatitic shear bands and extensive pegmatites. In places, the schist contains a metamorphic differentiated layering that consists of alternating leucosome and millimetre-scale quartz-rich layers.

Metapelitic and metapsammitic quartz-feldspar-biotite±garnet±sillimanite gneiss is the next most abundant unit within the Conlara Metamorphic Complex (~40%). It is clearly distinguished from the schist by the paucity of muscovite in the foliation, and more massive outcrop style. Where secondary muscovite is developed, it is generally unoriented and a minor component of the mineral assemblage, or it is associated with discrete overprinting shear bands, where it is associated with biotite. Leucocratic and/or pegmatitic veins are common in this rock type and typically define the main foliation, which is tightly to isoclinally folded (and refolded) at a meso- to micro-scopic scale.

Calc-silicate and marble are intimately associated and are a minor constituent of the complex, they are restricted to a series of narrow layers and pods through Sierra de Yulto, Sierra del Morro and Sierra de la Estenzuela. Marble is subordinate and is predominantly calcite with minor quartz and diopside, while the calc-silicate assemblage includes hornblende, plagioclase, garnet, sphene, calcite and magnetite, with thin diopside coronas locally developed on garnet. Additionally, secondary veins crosscut the marble and calc-silicate and are associated with tungsten mineralisation and pegmatitic epidote-feldspar-amphibole-biotite-pyrite-calcite-magnetite-quartz veins in Sierra de Yulto. The magnetic susceptibility of the marble is generally low (<36 x 10^{-5} SI) while the calc-silicate produced values up to 1231 x 10^{-5} SI, and the late pegmatitic veins produced local values up to 3512 x 10^{-5} SI.

Various generations of quartz-feldspar-biotite±muscovite±tourmaline±garnet pegmatite also occur within the Conlara Metamorphic Complex. Early generations are strongly deformed and are elongate and boudinaged in the schist and gneiss. Later generations are somewhat less deformed and are spatially associated with Devonian granites. The magnetic susceptibility of the pegmatites is extremely low. Late-stage quartz-tourmaline dykes and veins that are generally strongly lineated, are also common within the Complex and are typically found in NW or SW trending sets.

2.2.3 DEVONIAN

Las Lajas Shear Zone (Dlmi)
Mylonitic schist, granite, marble, orthoamphibolite, pegmatite and serpentinite

The Las Lajas Shear Zone is a linear north-west-trending high strain zone, traversing the southern Sierra Comechingones. The zone, from 1-2 km wide, can be traced on aeromagnetic images further to the south-east towards Sampacho, beneath a thin cover of Cainozoic sediments. The shear zone, named after Estancia Las Lajas, has been described by Otamendi and others (1996) who differentiated two sub-units, the “Unidad Metamorfitas Loma Blanca” and the “Unidad Metamorfitas Monte Guazú”. The name Las Lajas Shear Zone is used here only for those rocks placed within the “Unidad Metamorfitas Loma Blanca”. The “Unidad Metamorfitas Monte Guazú” has been renamed the Monte Guazú Metamorphic Complex. Rocks in the shear zone are mostly well exposed within the numerous quarries located in marble lenses.

The shear zone is a mylonitic melange of metamorphic and intrusive rocks, and is faulted-bounded within the Conlara Metamorphic Complex. The main penetrative greenschist-facies mylonitic fabric cross-cuts the Achiras Igneous Complex (382 ± 6 Ma) and hence must be no older than Early Devonian in age. Pelitic schist predominates with lesser granite, marble, amphibolite, pegmatite and rare serpentinite.

Sillimanite-bearing feldspar-muscovite-biotite-quartz schist is the predominant rock type in the shear zone. The schist is more quartz-rich than gneiss in the Monte Guazú Metamorphic Complex but is indistinguishable from that of the enclosing Conlara Metamorphic Complex. The schist is typically finely-banded with an early amphibolite grade foliation defined by sillimanite and differentiated mica-rich folia, leucosome and minor quartzitic bands. This fabric is cut by variably developed mylonitic shear planes associated with recrystallised quartz ribbons and a retrograde greenschist overprint of chlorite, haematite and geothite. Pegmatite veins within the schist are boudinaged and S-C fabrics are locally defined by asymmetry of deformed leucosome clasts.

Pink to buff medium-grained recrystallised equigranular leucogranite comprises about a third of the unit, forming concordant sheets interlayered with schist and other rocks within the shear zone. Foliated metamorphic muscovite and rare relict primary biotite together with bands of granoblastic polygonal quartz and feldspar define a well-developed moderate east-dipping mylonitic foliation with a quartz-muscovite mineral lineation. S-C fabrics are common. Rare idioblastic garnet is present in places, showing sericitic alteration. The granite is indistinguishable to that in the Achiras Igneous Complex.

Lenses of white to grey banded marble, up to 500†m thick and 5500 m long, make up about 20% of the unit, and occur throughout the entire length of the exposed shear zone. The marble is typically strongly mylonitised with a prominent lineation.

Minor orthoamphibolite lenses (~5%) occur throughout the shear zone, interlayered with schist and marble. The amphibolite is a fine-grained, banded, dark green to black rock consisting mostly of prismatic hornblende, quartz and plagioclase. Bands of recrystallised quartz, carbonate, plagioclase and epidote define a penetrative greenschist facies mylonitic foliation with lineated quartz.

Semi-concordant pegmatite veins comprise up to 5% of the shear zone, forming boudinaged lenses or deformed veins intruding all other rock types. They are mostly white to buff in colour and contain up to 6% muscovite and trace amounts of biotite, garnet or tourmaline. A penetrative mylonitic foliation, defined by recrystallised granoblastic polygonal bands of quartz and deformed muscovite folia, contains a quartz-mica mineral elongation lineation.

Rare massive serpentinite crops out in a tectonised lens, about 50 m long, in the northern-most exposed portion of the shear zone. The rock consists of mesh-textured serpentine, carbonate, talc and magnetite with minor relict olivine and metamorphic prismatic tremolite. This is the only known occurrence of an ultramafic rock in the southern Sierra de Comechingones, however, these rocks are more common to the north of the Cerro-Aspero Batholith where they have been interpreted as dismembered ophiolites incorporated during the Pampean Cycle (Escayola and others, 1993; Martino and others, 1995).

2.3 PALAEOZOIC IGNEOUS ROCKS

2.3.1 INTRODUCTION

In the Sierras de San Luis and Comechingones Palaeozoic igneous rocks were emplaced during three main tectonic cycles. The oldest igneous rocks were emplaced during the Cambrian (Pampean Cycle) and occur as highly deformed bodies within the Early Palaeozoic basement complexes. These are mostly represented by metagabbros, amphibolites and tonalitic orthogneisses within the Monte Guazú Metamorphic Complex. There are no geochronological data and very little geochemical data available for these rocks. The oldest dated rocks were emplaced during the Ordovician (Famatinian Cycle) and consist of ultramafic and mafic rocks, amphibolites, tonalites, granodiorites, and highly fractionated granites and pegmatites. These do not occur in the map area, however. The most significant phase of intrusion, however, occurred during the Devonian-Carboniferous (Achalian Cycle) when a series of major granite batholiths were emplaced.

2.3.2 DEVONIAN INTRUSIVES

Numerous Devonian granites and related pegmatites occur in Sierras de San Luis and Comechingones. The granites are generally distinct plutons with a marked aeromagnetic signature. The granites can be divided into two separate groups, concordant granites and discordant granites. Within the map area the Achiras Igneous Complex is a concordant granite. The majority of the remaining plutons could be considered as discordant. The concordant granites intruded as sheets or as highly elongated bodies and generally contain a well developed mineral fabric either due to subsequent deformation or flow banding. The discordant granites are sub-circular, zoned plutons that show little evidence of tectonic overprint (e.g. Renca Granite).

U-Pb zircon analysis shows that ages of the concordant and discordant granites are within error which suggests that the intrusion of the concordant granites may be controlled by some form of a large-scale, crustal structure.

Uspara Granite (Cerro Aspero Batholith) (Dgu)

Previously unmapped granite crops out semi-continuously along the base of the Comechingones range for about 12 km south of Papagayos. The granite also forms low exposures along Route 1 in the San Luis Province in the vicinity of Arroyo Uspara, after which the granite is named. The granite is non-magnetic (magnetic susceptibility <10 x 10^{-5} SI), and aeromagnetic anomalies indicate that it is considerably more extensive in the shallow subsurface over much of the plain, as far south as La Estanzuela and to about 10 km west of Papagayos.

The pluton is a grey to pale pink, medium-grained, equigranular to weakly seriate leucogranite. Primary muscovite and biotite are equally abundant and comprise together about 5% of the rock. Anhedral quartz forms scattered phenocrysts up to 1 cm across. Patches and veins of muscovite-tourmaline-feldspar quartz pegmatite are common. There are no chemical or isotopic data available.

The relationship with adjacent units is not known. Along the base of the Comechingones the granite is highly altered (kaolinised and chloritised), brecciated and cut by numerous moderately east-dipping faults. Kaolinite has been extracted from several quarries located in the area. These faults form part of the 1-2 km wide Cainozoic reverse fault zone along which the present ranges have been uplifted. Towards the top of the fault scarp, the granite contact with the overlying Monte Guazú Metamorphic Complex dips shallowly to the east and is inferred to be intrusive. At Papagayos the Comechingones Granite truncates the northern extent of the Uspara Granite. The contact, not exposed between the two plutons, is interpreted to be either faulted or intrusive. The lack of any high grade deformation fabrics (primary biotite is undeformed and shows only very weak haematite alteration) and the spatial relationship of the granite to the Cerro Aspero Batholith, suggests it may be part of the Devonian batholithic suite, possibly an earlier peraluminous phase which is intruded by the later Comechingones Granite.

Renca Granite (Dgre, Dgrp)

The Renca Granite is a generally well exposed pluton, nearly elliptical in plan, with a long axis of about 25 km oriented WNW-ESE, and a short axis about 13 km long. The village of Renca lies just on its eastern margin. This batholith has been well studied. See López de Luchi (1996) for references.

It is a dual phase ‘ring’ granite which intruded the metasedimentary Conlara Metamorphic Complex. The ring structure of the Renca Granite is clearly seen on the magnetic and, to a lesser extent, radiometric images. López de Luchi (1996) inferred a late Devonian to Carboniferous age based on Rb-Sr data obtained from the Las Chacras-Piedras Coloradas batholith (Brogioni, 1991). Recent U-Pb zircon data (Camacho and Ireland, 1997) give a crystallisation age of 393 ± 5 Ma.

The outer ring, about 2 km to 5 km thick, is a coarse-grained, K-feldspar phyric, biotite granite/monzogranite and the core is an equigranular, medium-grained, two-mica granite. About the north end of the Dique San Félipe the equigranular phase has been partially haematised during later alteration. The phyric outer phase contains K-feldspar phenocrysts about 5 cm to 10 cm long in a groundmass of grains up to 1 cm. It contains about 40% K-feldspar, 30% quartz, 15% biotite, and 10% muscovite. Accessory phases include titanite, apatite, magnetite, zircon, and allanite as well as secondary chlorite and epidote. The equigranular core phase contains about 30% quartz, 25% K-feldspar, 15% plagioclase, 10% muscovite, and 10% biotite and accessory zircon, and apatite as well as chlorite replacing biotite.

Both phases are peraluminous with ASI around 1.1. Magnetic susceptibilities vary from about 100 x 10^{-5} to 1000 x 10^{-5} SI for the ring phase, and are less than 10 x 10^{-5} SI for the core phase.

Tilisarao Granite (Dgsi, Dgse)

The Tilisarao Granite is a large foot-shaped body, 25 km long and 5 - 10 km wide, discernible on magnetic images but is only partially exposed in the westernmost part of the Sierra de Tilisarao. From magnetic imagery, the granite consists of a large non-magnetic core surrounded by a narrow, moderately magnetic, rim about 1 - 2 km wide. The core facies is a peraluminous granodiorite containing about 30% quartz, 25% plagioclase, 20% K-feldspar, 15% biotite, 5% hornblende and minor titanite, allanite and garnet. Accessory minerals are zircon, apatite, magnetite, with secondary chlorite and epidote. The granite has a seriate texture with grains ranging between 1 mm and 10 mm. The rim facies has not been examined. Limited geochemical data suggest the Tilisarao Granite is related to the suite of Devonian granites.

Los Cerrillos Granite (Dgl)

The exposed portion of the Los Cerrillos Granite forms most of the Sierra de Tilisarao. It is a medium grained, equigranular, quartz, K-feldspar, biotite, minor muscovite granite with abundant K-feldspar-quartz- muscovite pegmatite dykes. In general, it is well exposed except for small area near its centre where it is predominantly subcrop with more resistant pegmatite veins well eminent and clearly visible on aerial photographs. Pegmatite veins are vertical to sub-vertical with dominant NW and NE strikes. No geochemical or age data are available but stratigraphic relationships and K-Ar dates obtained from pegmatites intruding the granite (Rinaldi and Linares, 1973; reported in Fernandez Lima and others, 1981) suggest it is at least mid Devonian.

Achiras Igneous Complex (Dag, Dagl)

Interlayered granite, leucogranite

An intrusive complex, defined as the Achiras Igneous Complex, forms the extreme south of the Sierras Comechingones centred on the town of Achiras. This complex comprises the intrusive part (the “Granito Los Nogales”) of what was previously termed the Achiras Complex by Otamendi and others (1996). Outcrop of the complex is good but becomes poorer south of Provincial Route 1 where elevation is lower and topography more undulating. Aeromagnetic anomalies, however, indicate that the complex extends under thin unconsolidated Cainozoic sediments, to the south and south-west.

The intrusive complex comprises a stratified, subconcordant granite suite. The unit consists mainly of two different granite types, a coarse seriate strongly magnetic granite and a non magnetic equigranular leucogranite-granite. Late-stage aplite and tourmaline-garnet-muscovite-bearing pegmatite dykes are common. The granites form sheet-like bodies which display mostly concordant but intrusive contacts, postdating earlier, differentiated, high-grade metamorphic fabrics within the metamorphic. U-Pb zircon age determinations of the magnetic granite yield a crystallisation age of 382 ± 6 Ma (Camacho and Ireland, 1997). This contrasts with previous authors (e.g. Fagiano and others, 1992; Nullo and others, 1992) who interpreted an Early Ordovician age for the granite, correlating it with the syn-D2 granitic group of Rapela and others (1990).

The complex is structurally stratified from dominantly magnetic, seriate granite at the base, through to dominantly leucogranite/granite at the top. These two informal sub-units are entirely gradational and represent only a change in proportion of the constituent rock types. The lower sub-unit was previously mapped as “Granito Los Nogales” (Fagiano and others, 1992; Nullo and others, 1992), while Otamendi and others (1966) used the term “Granito Los Nogales” for granites in both the sub-units.

Pink, coarse-grained, seriate biotite-granite is the predominant rock (90%) in the southernmost and structurally lowest of the sub-units, forming only a minor component of the overlying granite-leucogranite dominated sub-unit. The granite is distinguished by its strongly magnetic character (magnetic susceptibilities about 500-1500 x 10^{-5} SI) and the presence of rare hornblende and common, pink, perthitic microcline crystals, which are up to 5 cm across. Apatite, magnetite and lesser pyrite are accessories. In places, weakly aligned biotite and pegmatite bands define flow banding. Xenoliths of pelitic gneiss, amphibolite and tonalite are common as concordant enclaves parallel to flow banding.

Flow-banded, pink to grey, medium- to coarse-grained, equigranular biotite-granite to leucogranite forms about 70% of the upper sub-unit and is a minor constituent in the remainder of the complex. The granite is equigranular with a ubiquitous flow-banded fabric evident by aligned biotite, concordant pegmatitic bands and patches, and schlieren and lenses of pelitic gneiss. Zircon, apatite, and rare garnet are accessory phases. Muscovite is a minor primary constituent but is more abundant as a secondary mineral in zones adjacent to the Las Lajas Shear Zone where the granite has a mylonitic fabric. In these areas biotite is replaced by chlorite and quartz and muscovite form a ENE-dipping mineral lineation on a muscovite-rich mylonitic foliation. Very weak carbonate, epidote, sericitic and haematitic alteration is widespread. Small fibrous aggregates of sillimanite with muscovite reaction rims are present near contacts with gneiss and possibly represent minor contamination of intrusive margins with host pelitic gneiss.

Interlayered grey banded, feldspar-biotite-quartz (±garnet±muscovite) gneiss and (±garnet±sillimanite±feldspar) muscovite-biotite-quartz schist occur throughout the complex as concordant enclaves and xenoliths within the layered seriate granite and granite-leucogranite intrusions.

Geochemically both the seriate granite and equigranular granite-leucogranite form a fractionated suite, the latter the most fractionated (Figures 27, 28, 29). They have similar major and trace element trends to other Devonian granites, and are peraluminous with an ASI of about 1.1. However, they differ in that they show little enrichment in Rb, Y, U with fractionation compared to other granites of the same age and are mostly less oxidised.

The granites have been interpreted as products of local anatexisis (Fagiano and others, 1992; Nullo and others, 1992; Otamendi and others, 1996) with emplacement conditions estimated at 700°C and 3 Kb (Fagiano and others, 1992). This interpretation has been largely based on the interpretation of a tectonic origin for biotite alignment in the granites and a correlation with the principal second deformation phase (D2) of Dalla Salda (1984).

It is clear from this study that the alignment of biotite is a product of magma flow and that the granite truncates both D1 and D2 fabrics and is only affected by greenschist facies deformation. The granites probably represent products of a fractionated granitic magma, derived from metasedimentary sources, which intruded the Early Cambrian metamorphic rocks at mid/upper crustal levels during the Early Devonian as a series of multiple injections during progressive mylonitisation and eventual truncation by a greenschist facies high-strain zone, differentiated as the Las Lajas Shear Zone.

A major swarm of pegmatites is spatially associated with the Achiras Igneous Complex. The pegmatites occur as either semiconcordant veins intruding both granitic and gneissic rocks, or as discordant, mostly NW- and NNW-trending tourmaline-bearing veins. The concordant variety form part of the layered granite complex and represent highly fractionated melts injected during multiple granite intrusion. The discordant variety are more common and more widely distributed than the earlier pegmatites. They are spatially associated with the Las Lajas Shear Zone and concentrated within the basement hanging-wall. In places, they crosscut folds formed during the mylonite formation, and in others, they are strongly mylonitised. These relationships indicate that the discordant pegmatites intruded during thrusting on the Las Lajas Shear Zone and represent the final products of felsic magmatism in this region.

2.3.3 MINOR DYKE ROCKS

Pegmatite (peg)

Numerous pegmatite dykes occur within the map area. There are essentially two main subdivisions:

1. Pegmatites emplaced during M1 metamorphic peaking the Middle Cambrian, at around 530-515 Ma. These are restricted to within the Conlara Metamorphic Complex.

2. Pegmatites emplaced during the Devonian, and associated with the extensive granite bodies.

2.4 TERTIARY VOLCANICS

San Luis Volcanic Group (Tvp)

Intrusive plugs, domes, breccia pipes and dykes, lava, pyroclastic deposits, epiclastic volcanic deposits and hydrothermal deposits

A series of volcanic centres occur in a north-west trending belt of approximately 90 km length through central and western Sierras de San Luis and Comechingones. The volcanic centres include Sierra del Morro in the south-east, Cerros Rosario and Tiporco, Cerros Largos, Cañada Honda, and La Carolina in the north-west. The geology, petrography and geochemistry of the volcanics have been examined by Brogioni (1987, 1990).

The volcanic rocks, called here the San Luis Volcanic Group, range from late Miocene (~9.5 Ma) to Pliocene (~1.9 Ma) in age and are intrusive into the Conlara and Pringles metamorphic complexes and the San Luis Formation. Associated pyroclastic and epiclastic deposits form aprons around the volcanic centres and have been variously reworked or eroded. The intrusive volcanic rocks have a high reversely magnetised signature and highly potassic radiometric signature. Magnetic susceptibilities of the intrusive volcanics are generally in the range of 1000 – 3000 x 10^{-5} SI, while the pyroclastics are generally in the range of 400 – 800 x 10^{-5} SI. The volcanic rocks fall within the calc-alkaline to shoshonitic series.

Epiclastic deposits (Tvp) form a well preserved apron around Sierra del Morro (south of the map area) where they form resistant radial fans with inverted relief around the main basement dome.

2.5 CAINOZOIC

Unconsolidated cover (Czu)
Loess, alluvial deposits, etc.

Unconsolidated alluvial, colluvial and aeolian deposits, as well as palaeosols, overly the basement rocks in Sierras de San Luis and Comechingones and are interspersed with some of the volcaniclastic deposits. The most extensive Cainozoic unit (Czu) is an intercalated sequence of undifferentiated Tertiary to Quaternary fluvial and aeolian deposits and paleosols that cover a large part of the Pampean region. In areas of low lying relief, these deposits cover all older units and forms a mantle or rarely dune fields between the main Pampean ranges. The undifferentiated Cainozoic deposits comprise mostly friable illite and silt, with material derived from both the metamorphic-igneous basement rocks and a volcanic-pyroclastic source (Strasser and others, 1996).

2.6 QUATERNARY

Unconsolidated deposits (Qa, Qg)
Active alluvial deposits, fans, gravels.

Holocene (Santa Cruz, 1978) to Recent alluvial deposits of clay, sand and gravel along active river courses and adjacent terraces and overbank deposits (Qa) dissect the undifferentiated Cainozoic units. Active fan deposits (Qg) occur along the base of the fault scarps bordering the Sierra de Comechingones.

3. TECTONICS

Three major deformation, metamorphic and magmatic events have affected the basement rocks of Sierras de San Luis and Comechingones. The three tectonic events are termed here the (Early Cambrian) Pampean Cycle, the (early Ordovician) Famatinian Cycle, and the (Devonian) Achalian Cycle. Rocks of the Conlara Metamorphic Complex preserve evidence of the Pampean and Famatinian events. Devonian magmatism and deformation are preserved in the Achiras Igneous Complex and the Las Lajas Shear Zone. The map area was also affected by reverse faulting and block-tilting during the Cainozoic Andean Cycle.

3.1 PAMPEAN CYCLE: EARLY CAMBRIAN DEFORMATION AND METAMORPHISM

The oldest preserved structural feature in Sierras de San Luis and Comechingones is a medium- to high-grade metamorphic differentiated foliation which is well-preserved in pelitic gneiss and amphibolite of the Monte Guazú, Conlara and Nogoli metamorphic complexes. The foliation (S1), which is variably developed, is typically a penetrative gneissic foliation in pelitic gneiss, defined by leucosome lenses and a mineralogical layering defined by biotite, quartz and sillimanite with a lineation (L1) defined by sillimanite and quartz. In tonalitic orthogneiss, aligned biotite forms S1 folia, with a weak biotite and quartz lineation. In amphibolite and calc-silicate rocks the foliation forms strongly differentiated mineralogical bands with aligned hornblende. Throughout most of the Monte Guazú Metamorphic Complex the S1 foliation, trends NNW and dips ~45° to the east. The trend of the S1 foliation in the Conlara and Nogoli metamorphic complexes is generally similar, however, the dip of the foliation is more variable due to locally intense reworking during subsequent events. No kinematic indicators where observed.

Sillimanite-garnet assemblages in pelitic gneiss indicate M1 metamorphism was at least amphibolite facies and abundant muscovite-pegmatites, and leucosome (forming subconcordant lenses with S1) suggest limited partial melting took place. Pressure-temperature (P–T) estimates of peak metamorphic conditions for rocks of the Monte Guazú Metamorphic Complex in the Sierra de Comechingones range from 6.1 to 9.5 Kb, at 700 to 800 °C

(Gordillo, 1984; Martino and others, 1994; Cerredo, 1996). No P–T estimates exist for the Conlara or Nogoli metamorphic complexes, however, peak metamorphic assemblages in the Nogoli Metamorphic Complex of cordierite-garnet-sillimanite in pelitic rocks, and an apparent scarcity of orthopyroxene in metamafic rocks, suggests pressures of <~7 Kb at temperatures of no more than ~750°C (e.g. Grant, 1985; Spear, 1981, 1993).

No isotopic data exist from Sierras de San Luis and Comechingones to constrain the age of the Pampean Cycle. However, U-Pb dating of zircon and monazite from Córdoba (Sierras de Septentrionales), which grew during M1 (Lyons and others, 1997), give an age of ~530 Ma (Camacho and Ireland, 1997). Late Pampean granites in Córdoba give ages of ~515-520 Ma (Camacho and Ireland, 1997; Rapela and Pankhurst, 1996; AGSO-Subsectretaría de Minería Argentina, unpublished data).

3.2 FAMATINIAN CYCLE: ORDOVICIAN DEFORMATION AND METAMORPHISM

Evidence of Famatinian metamorphism and compressional deformation is preserved in gneiss and schist of the Conlara Metamorphic Complex, in particular in the rocks structurally beneath the Las Lajas Shear Zone. A schistosity parallel to S1 forms the main penetrative structure. All S1 fabrics are rotated into parallelism forming a new S2 foliation with a pronounced mineral lineation (L2) of biotite, muscovite and quartz. Lower amphibolite/upper greenschist facies metamorphism (M2) is indicated. Quartz-feldspar leucosome, formed during M1, are deformed into asymmetrical clasts indicating westward-directed thrusting. In places, the schistosity is axial plane to relict isoclinal folds (F2) which plunge parallel to the lineation.

3.3 ACHALIAN CYCLE: DEVONIAN DEFORMATION AND RETROGRESSION

Throughout much of the region, the medium- to high-grade Pampean (D1) and Famatinian (D2) fabric elements are mostly rotated into parallelism by a shallowly- to moderately-dipping, penetrative shear fabric associated with a prolonged collisional episode, termed here the Achalian Cycle. This episode is marked by the development of mylonite in high-strain zones and pervasive, retrogressive greenschist-facies metamorphism and the emplacement of voluminous granite plutons. To varying degrees, the deformation affects all basement rocks, and is probably the most significant single tectonic episode in the region.

Deformation during the Achalian Cycle involved repeated partitioning of strain between zones of thrusting and zones of strike slip displacement, with repeated overprinting relationships. Domains between shearing were folded and refolded; in some places producing basin and dome interference folds. Strain was focussed in the north-west-trending Las Lajas Shear Zone, which truncates the Conlara Metamorphic Complex, north of Achiras.

At least three distinct styles of Achalian Cycle deformation are recognised within the map area. These styles are in part an effect of the partitioning of strain but also an effect of changing stress or metamorphic conditions in the terrane through the tectonic cycle.

1. *Pervasive mylonitic foliation and tight to isoclinal folding.*

The earliest structural element is a pervasive mylonitic foliation associated with thrusting under upper greenschist-facies conditions. In the Conlara Metamorphic Complex, this forms a pervasive fabric defined by biotite that rotates the earlier Pampean and Famatinian fabrics into parallelism. A maximum age for this early fabric forming event is provided by a 403 ± 6 Ma age (U/Pb zircon; Camacho and Ireland, 1997) for the Escalerilla granite which is affected by the early tectonism.

Within the mylonite fabric, quartz is recrystallised to ribbons, biotite is deformed and locally replaced by chlorite, haematite and geothite, and M1 sillimanite is altered to fine muscovite aggregates. A mineral lineation (L3) or slickenline plunges down-dip to the ENE and is defined by aligned muscovite, chlorite, quartz and rotated relict biotite.

Sheath folds are also present, in places, plunging parallel to L3. Kinematic indicators including, asymmetric mantled porphyroclasts and S-C fabrics all indicate westward-directed thrusting.

2. *Thrusting at low-grade in discrete shear zones with contemporaneous folding and crenulation of the earlier mylonitic fabric.*

Overprinting the strike-slip shear-zones are a number of major low-grade shear-zones that traverse the Sierras de Comechingones (Las Lajas Shear Zone). These shear zones are up to several kilometres in width, and contain greenschist-facies mineral fabrics that show east-up shear-sense on an easterly plunging lineation, parallel to the early L3 fabric. A regional crenulation cleavage associated with north-south trending open folding is considered to be have developed contemporaneously between the main shear-zones.

In leucogranite within the Las Lajas Shear Zone, foliated metamorphic muscovite, rare relict primary biotite, and bands of granoblastic polygonal quartz and feldspar define the mylonitic foliation. S-C fabrics are also common with a quartz-muscovite mineral lineation. Idioblastic garnet where present is altered to sericite.. In ortho-amphibolite, bands of recrystallised quartz, carbonate, plagioclase and epidote define a penetrative greenschist facies mylonitic foliation, and in pegmatite, S3 is present as recrystallised granoblastic polygonal bands of quartz and deformed muscovite folia.

The mylonitic fabric of the Las Lajas Shear Zone extends up to 1 km into the structurally underlying parts of the Conlara Metamorphic Complex. In areas further south (and structurally deeper), the main penetrative fabric is the medium-grade S2 foliation along which the Early Devonian subcordant granite sheets of the Achiras Igneous Complex were intruded. These layered granites are essentially undeformed, containing no penetrative tectonic foliations, and together with the metamorphics are folded about shallow N- to E-plunging regional open inclined to overturned macroscopic folds and mesoscopic chevron folding (F3). A weak axial plane crenulation (S3b) dips moderately to steeply (40-85) to ENE.

3. Brittle-ductile strike-slip faulting typically in conjugate sets trending NW and SW
A complex system of rectilinear brittle vertical WNW- and ENE-trending strike-slip faults, breccia zones and fractures (von Gosen and Prozzi, 1996) affect all the basement units in the Sierras de San Luis and the Sierra de Comechingones, in places displacing the S3 mylonitic foliations and related folds. The faults are rarely exposed, but are prominent on aerial photographs and Landsat images. Some of the faults are also delineated on magnetic images as low magnetic zones owing to magnetite destruction

The orientation and conjugate relationship of the WNW- and NE-trending strike-slip faults, breccia zones and fractures indicates 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).

3.4 ANDEAN CYCLE: REVERSE FAULTING

Tectonism associated with the collision of the Nazca and South American plates resulted in a period of extensional deformation in the Sierras Pampeanas region during the Neogene, followed by compression from the late Neogene through to the present. The extensional phase resulted in the development of a number of small north-west trending basins. The best examples of these occur in the southernmost Sierras de San Luis in the area of Potrero de los Funes and San Luis, where small segments of the uplifted basin sediments are preserved. Also during this period, high-K calc-alkaline to shoshonitic volcanics were emplaced in a ~80 km belt, parallel to the extensional basins, from Sierra del Morro to La Carolina,.

A marked change in the regional stress field occurred after the mid-Pliocene, coincident with the cessation of volcanism. Since that time, the Sierras Pampeanas region has been in a compressional regime and the Sierras de San Luis and Sierra de Comechingones are examples of the uplift on basement thrusts formed during this period (e.g. Costa and Vita-Frinzi, 1996). The ranges slope gently to the east and are bounded to the west by escarpments developed on low to moderate angle, east dipping, reverse faults. In the Sierra Comechingones, a major north-south fault zone, the Comechingones Fault (Costa and others, 1994), extends along the base of the western escarpment, and can be traced on aeromagnetic images to the south of La Punilla, beneath a veneer of Cainozoic sediments. Carbon 14 ages suggest the fault was active as recently as ~1000 years ago (Costa and Vita-Frinzi, 1996). Immediately south of Papagayos, the main fault zone, which is possibly up to 2 km wide, is exposed in kaolinite quarries within the Uspara Granite. Exposures of the granite are intensely brecciated, altered to chlorite and kaolin and cut by gouge zones dipping 45° to the south-east. The vertical component of displacement decreases to the south and is probably taken up by a number of fault splays such as that which borders the Sierra de la Estanzeula.

4. GEOMORPHOLOGY

The uplift during the Late Cainozoic of peneplanated crystalline basement on reverse faults, generally trending north-south, produced a series of tilt blocks throughout the Sierras Pampeanas (Jordan and Allmendinger, 1986). The asymmetry of the basement blocks is produced by the formation of steep escarpments on the bounding fault side and gentle slopes, the dissected peneplanated surface, on the other. Broad flat valleys between major blocks are depositional centres filled with a variety of Cainozoic and Quaternary sediments including aeolian, fluvial, and lacustrine material.

The region encompassing the sheet area is comprised of three main physiographic domains: the Sierras de San Luis in the west, the Sierra de Comechingones in the east, and the Conlara Valley in the centre which includes a number of minor ranges and the uplifted basement around the volcanic centre of Sierra del Morro. The principal faults along which uplift occurred are the San Luis and Comechingones Faults which dip to the east. The fault scarps are on the western side of the main sierras and the dissected peneplanated surfaces slope to the east. The broad depositional basin of the Conlara Valley contains the smaller tilt blocks of the Sierras de La Estanzuela, de Tilisarao, del Portezuelo, San Félipe, and del Yulto. The Sierra del Morro is a broad cone of uplifted basement resulting from the intrusion of the volcanic centre.

The Conlara Valley is filled with Cainozoic alluvial, aeolian, and volcanogenic deposits which preserve an earlier Cainozoic surface evidenced by the presence of palaeo-channels found away from present day watercourses. The intermontane deposits in the west of the sheet area are characterised by Quaternary gravels shed from the Sierras de San Luis.

The main drainage from the Sierras de San Luis is via the Río Quinto to the south east, which flows in to the Conlara Valley, and the Río Chorillos to the south west. The Sierras de Comechingones are drained by the east-south east flowing Río Cuarto. The Conlara Valley is drained by the north-north east flowing Río Conlara and the southward flowing Río Rosario.

5. GEOLOGICAL HISTORY

The Sierras de San Luis and Comechingones area forms part of the southern Sierras Pampeanas, comprising basement ranges of Neoproterozoic to early Palaeozoic metamorphic rocks and Palaeozoic granitoids, separated by intermontane 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 that 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 (e.g. Camacho and Ireland, 1997) and the geological relationships indicate that there are two principal domains in the southern Sierras Pampeanas: an older Cambrian domain, and a younger Ordovician domain. Both domains share a common tectonic history since early Ordovician times.

5.1 EARLY CAMBRIAN SEDIMENTATION

The oldest rocks in the region form a structurally thick sequence of pelitic and lesser psammitic gneisses which comprise the Valle de la Río Conlara and the Sierra de Comechingones (Conlara and Monte Guazú metamorphic complexes), as well as an orthogneiss dominated terrane with minor pelitic gneiss (the Nogoli Metamorphic Complex) in the western Sierras de San Luis. No original sedimentary structures, such as bedding, can be recognised in these metamorphic rocks. Minor marbles are common in the eastern complexes of the Sierras de San Luis and Comechingones but are less extensive than in interpreted extensions of the same domains in northern Cordoba (Lyons and others, 1997), where they form semicontinuous belts. 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). Uranium-lead dating of detrital zircons in paragneisses from Córdoba (Quilpo Formation and Pichanas Metamorphic Complex; Lyons and others, 1997) show a 500–600 Ma Gondwana signature common to Cambro-Ordovician sediments previously described from Australia, New Zealand and west Antarctica (Camacho and Ireland, 1997). 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). This formation was interpreted by Dallas Salda and others (1992) to be related to the rift-drift transition during post-collisional Gondwana-Laurentia breakup.

5.2 PAMPEAN CYCLE

Early Cambrian deformation, metamorphism, mafic and felsic intrusion

Following intrusion of 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. Uranium-lead dating of zircon rims and monazite formed during this metamorphic event (M1) in Córdoba give an age of ~530 Ma **(**Lyons and others, 1997; Camacho and Ireland, 1997). 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 tonalite, granodiorite and granite within the Monte Guazú Metamorphic Complex. There are no radiometric dates on these intrusions, however, in the Sierra Norte - Ascochinga area in Córdoba, similar intrusions, dated at ~515 Ma (AGSO-Subsecretaria de Mineria Argentina, unpublished data), form a complex with minor xenoliths and enclaves of dioritic rocks.

5.3 EARLY PALAEOZOIC TURBIDITE SEDIMENTATION

Continental and arc derived pelitic turbidites were deposited in a probable back arc basin setting along the Pampean margin in the early Palaeozoic. Remnants of this back arc basin form the protoliths to the Pringles Metamorphic Complex in the Sierras de San Luis.

5.4 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 Cambro-Ordovician back arc (Pringles Metamorphic Complex) and the Cambrian basement 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 Cambro-Ordovician rocks, D2 in the Cambrian rocks) at mostly upper amphibolite facies, though locally, granulite-facies was accompanied by the development of kilometre-scale east-dipping ductile shear-zones with, orthogonal westerly-directed thrust movement. Dalla Salda (1987) and Toselli and others (1992) ascribed this deformation (in the Córdoba region) to the D2 domain. Primary structures were mostly overprinted, although original graded beds and turbidite sequences are still recognisable in places within the Cambro-Ordovician, Pringles Metamorphic Complex. A number of mafic/ultramafic bodies (the Las Aguilas Group) which intruded the sediments were involved in the deformation and represent a significant mantle-derived heat source contributing to the high temperature metamorphic conditions. In the Cambrian basement, the earlier D1 fabrics were openly to tightly folded and locally recrystallised to form a new foliation (S2).

The high-grade metamorphic episode during the Famatinian cycle was closely followed by extensional tectonism under upper-greenschist-facies conditions. However, the extensional phase does not appear to have affected the rocks of the Conlara Metamorphic Complex.

5.5 ACHALIAN CYCLE

Early Devonian deformation, metamorphism and granite intrusion

Resumption of convergence on the western margin of Gondwana in the mid Palaeozoic is evidenced by a widespread compressive deformation of the Ordovician cover sequence (San Luis Formation) and older crystalline basement, and the development of an Early Devonian magmatic arc. The deformation was dominated by orthogonal westerly-directed thrusting, with a component of sinistral shearing, both at greenschist facies, and the development of regionally extensive ductile and brittle-ductile, conjugate shear-zones. Locally, outside the principal shear zones, the basement and cover rocks were open to isoclinally folded and refolded with an axial planar crenulation surface developed in places. Dalla Salda (1987) defined this deformation as D3, placing it in the “Ciclo Famatiniano”, however, U-Pb and Ar-Ar data (Camacho and Ireland, 1997; Camacho, 1997) indicate this is a discrete event separated from the Famatinian cycle by at least 60 Ma.

Peraluminous to slightly peralkaline felsic melts, generated from partial melting of MgO depleted crustal rocks (Dalla Salda and others, 1995) intruded into the metamorphics discontinuously during and after shear zone development. Some of the shear zones (e.g. La Lajas Complex) were the locus of multiply injected subconcordant granite and later pegmatite intrusion. In other areas, circular, zoned, and fractionated plutons, commonly coalesced forming batholiths, and crosscut early, greenschist-facies shear-zones. Uranium-lead zircon dating of the granites suggests that initial plutonism was around 404 Ma (Camacho and Ireland, 1997). Ar-Ar ages from greenschist-facies mylonite zones and brittle-ductile strike-slip faults and fractures suggests that deformation continued through till ~355 Ma (Camacho, 1997), however, granite intrusion may have continued into the Caboniferous. The Achalian Cycle derives its name from the Achala Batholith, the largest of the Devonian Batholiths in the southern Sierras Pampeanas, which is exposed north of the Sierra de Comechingones 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 terrane.

5.6 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 times. These sediments, which are not represented in map area, may have covered much of the crystalline basement, however, only remnant outcrops of the group are now preserved in narrow (<2 km wide) grabens. These grabens, possibly initiated during syn-sedimentary extensional faulting, were active after the cessation of sedimentation and prior to the Andean Cycle deformation. It is possible that these late-Palaeozoic sediments were first deposited in basins controlled by a regional wrench tectonic regime late in the Achalian cycle.

5.7 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. 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. These extrusive occur to the north of Sierras de San Luis and Comechingones in both the Sierras de San Luis and the Sierras de Córdoba. Age determinations on the mafic rocks range from 150 Ma to 56 Ma (Linares and González, 1990).

5.8 ANDEAN CYCLE

During the Cainozoic, in the Sierras de San Luis and Valle de Río Conlara dominantly andesitic lavas extruded, doming basement rocks and forming volcanic edifices with extensive pyroclastic aprons. This magmatism, which is dated between 9.5 Ma and 1.9 Ma was probably related to an extensional phase following the development of flat subduction of the Nazca plate (Smalley and others, 1993) in the mid-Miocene. The cessation of magmatism is marked by the commencement of east-west compression that resulted in inversion of the Cretaceous basins (Schmidt, 1993) and block thrusting of the 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 a reactivated and long-lived history. Costa interpreted most significant movement in the region to have occurred during the Late Pliocene-Pleistocene with further movement continuing during the Quaternary.

SECTION II: ECONOMIC GEOLOGY

by Roger G. Skirrow

1. INTRODUCTION

The 3366-17 1:100 000 map area contains several significant districts of W deposits as well as Be, Li, Nb and Ta mineralisation and mica, quartz and feldspar resources.

Geological and resource data on mineral occurrences have been compiled in a database (ARGMIN, in MicroSoft Access; Skirrow and Trudu, 1997) using a combination of data from the literature and field data. The principal deposits in most mining districts of the Sierras de San Luis and Comechingones study area were investigated in the field, with observations subsequently entered into the ARGROC and ARGMIN databases. 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 airphotographs and their geographic coordinates digitised. The locational accuracy for photo-located occurrences is ±200 m. The locations of remaining occurrences are taken from the original data sources, which in some cases allow only very approximate geographic coordinates to be estimated (up to ±3000m).

Mineral occurrence data are presented in the 1:100 000 scale Metallogenic Map. Output data sheets from the ARGMIN database are appended to this report. Details on the geology and grade-tonnage data for specific mineral deposits may be found in the database. A 1:250 000 Metallogenic Map for the Sierras de San Luis and Comechingones shows the mineral occurrences in relation to prospectivity domains (Skirrow, 1997). The genesis of mineral deposits, metallogeny of the region and discussion of mineral prospectivity are presented in the Economic Geology section of the Report on 1:250 000 scale Geology of the Sierras de San Luis and Comechingones (Sims and others, 1997). The principal geological, geophysical and metallogenic model coverages from the GIS of the Sierras Pampeanas (Butrovski, 1997) are presented in summary format (1:400 000 scale) in the *Atlas Metalogenético* (Skirrow and Johnston, 1997).

2. METALLIC MINERAL OCCURRENCES

2.1 W DEPOSITS: SIERRA DE LA ESTANZUELA, AND OTHER W OCCURRENCES OF THE CONLARA METAMORPHIC COMPLEX

Numerous W occurrences are present in the 3366-17 map area, ranging from mines with extensive surficial and underground workings to small pits and shafts. Although many of the deposits have been located on airphotographs and their geographical coordinates measured, the occurrences necessarily have been grouped because of lack of accurate locational data. Groupings are based on those given in the data source (e.g. Ricci, 1971); such groups of occurrences have been assigned the coordinates of principal deposits in the group that have been located on airphotographs.

In the Sierras de San Luis and Comechingones region three main styles of W mineralisation are present: (i) scheelite associated with quartz veinlets in generally low grade metasedimentary sequences, (ii) wolframite with minor sulfides in large quartz veins, and (iii) scheelite associated with calc-silicate rocks. Minor wolframite and scheelite also occur in pegmatites. Type (iii) calc-silicate-associated scheelite occurrences are confined to mainly the Conlara Metamorphic Complex to the east of the Río Guzman Shear Zone where calc-silicate rocks, metacarbonates and amphibolites are intercalated with metapelitic rocks. The major districts of style (iii) W mineralisation are situated in the Sierras del Morro, Los Morillos, Yulto and La Estanzuela, the last of which lies within sheet 3366-17.

Tungsten deposits of the Sierra de La Estanzuela were described by Monchablon (1956) and Angelelli (1984), and the regional geology has been discussed by Fernandez Lima and others (1981) and in the present project (Sims, Lyons, these Notes). Other W mineralisation in the Conlara Metamorphic Complex include the Sierra San Felipe district and isolated deposits between Paso Grande and Villa Praga (Sheet 3366-16). The geological settings, association of scheelite with carbonate±amphibolitic host rock types and presence of pegmatites described by Monchablon (1956), Brodtkorb and Brodtkorb (1977) and Angelelli (1984) in the Sierras de La Estanzuela and San Felipe (e.g. at ‘La Chiquita’) districts are similar to those of the Sierras del Morro, Los Morrillos and Yulto. It is therefore likely they formed by similar Devonian magmatic-hydrothermal processes to those suggested for the El Morro W deposits (Sims and others, 1997).

2.2 PEGMATITE-HOSTED DEPOSITS OF BE, LI, TA, NB

Pegmatites in sheet 3366-17 host a number of significant sources of Be, Li, Nb and Ta, and industrial minerals (e.g. mica, feldspar, quartz, etc.).

The earliest pegmatites in the Sierras de San Luis and Comechingones regions are interpreted to represent the melt products of the leucosome-forming reactions during high grade (upper amphibolite and granulite facies) metamorphism in both the Pampean and Famatinian cycles (see Sims and others, 1997). These generally small unmineralised garnet-bearing quartz-K-feldspar± plagioclase±biotite pegmatites are common in the Conlara and Pringles Metamorphic Complexes.

Herrera (1968) and Galliski (1993, 1993) described muscovite-rich K-feldspar-quartz pegmatites from other regions of the Sierras Pampeanas (type 2 of Herrera, 1968; transitional between muscovite and rare element classes of Cerný, 1991, according to Galliski, 1993, 1994). These are a major economic source of muscovite, and examples may be present in the Sierras de San Luis (e.g. López, 1984), but their tectonic-magmatic setting and genetic relationships to other pegmatite types within the map area are not well constrained.

Pegmatites of the rare element class of Cerný (1991) (types 3 and 4 of Herrera, 1968) are widely represented in the Sierras de San Luis and Comechingones regions, and also occur in sheet 3366-17 within the Conlara Metamorphic Complex. The deposits have been described by many workers including Herrera (1963, 1965, 1968), Angelelli and Rinaldi (1965), Arcidiácono (1974), Ortiz Suárez and Sosa (1991), Sosa (1990, 1991, 1993), Oyarzábal and Galliski (1993), and Galliski (1993, 1994). Examples of the beryl, complex (spodumene subtype) and albite-spodumene types of Cerný (1991) have been recognised (Galliski, 1993), including cassiterite-bearing pegmatites (Sosa, 1990, 1991, 1993; Ortiz Suárez and Sosa, 1991). Internal zoning, dimensions, geometry and paragenesis are described in the cited references.

The timing, tectonic setting and magmatic affiliations of pegmatite types in the Sierras de San Luis and Comechingones regions are discussed in Sims and others (1997).

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ARGMIN

MINERAL DEPOSIT DATABASE

OUTPUT DATA SHEETS