Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3366-16

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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CONTENTS

SECTION I: GEOLOGY

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1. INTRODUCTION

1.1 LOCATION AND ACCESS

The *3366-16* map area forms an east-west transect within San Luis Province; ~46km by ~40km between latitude 32°40’-33°00’ S and longitude 65°30’-66°00’ W. The area includes part of two 1:250 000 scale map sheets: San Francisco del Monte de Oro (3366-I), and Sierras de San Luis y Comechingones.

The area is contained within the Sierras de San Luis and covers the minor population centre of Paso Grande, and is traversed by provincial routes 2, 2A, 10, 22, 24, 38, 40 and 41. The main drainage is via Río Conlara, Río de la Cañada Honda, and Río Rosario.

1.2 NATURE OF WORK

The mapping of the Sierras de San Luis 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 and the Subsecretaría de Minería, Argentina (Figs. 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).

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.

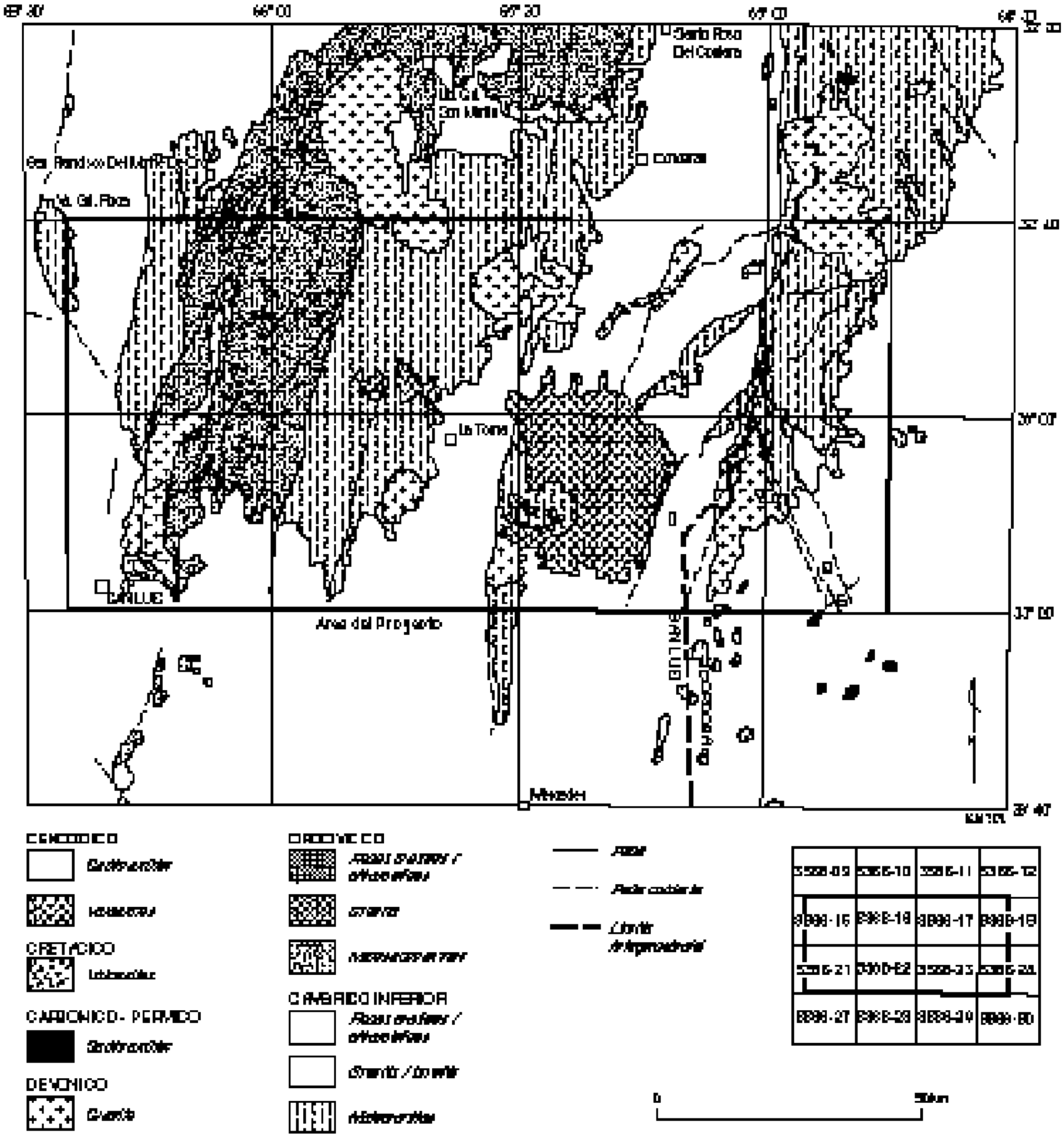

Figure 2. Location of the *Sierras de San Luis y Comechingones* 1:250,000 scale map area in San Luis and Córdoba Provinces with generalised geology. Locations of 1:100,000 scale map areas are indicated.

1.3 PREVIOUS INVESTIGATIONS

Previous regional geological mapping was at a scale of 1:200 000 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 & Ramos, 1988; Ortiz Suárez and others, 1992) , regional structure (e.g., González Bonorino, 1961; Criado Roqué and others, 1981; von Gosen & Prozzi, 1996), the complex igneous intrusive history (e.g., Zardini, 1966; Brogioni & Ribot, 1994; Llambías and others, 1996a, b; 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 & Malvicini, 1982).

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 *3366-16* consist of the Conlara Metamorphic Complexes. 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. The Cambrian domain is intruded by voluminous Early Devonian granites and both domains are partly covered by Neogene volcanics and Cainozoic continental deposits. A summary of the regional stratigraphy and age relations is shown in Table 1.

Table 1. Summary of the stratigraphy and age relations of the *Sierras de San Luis y Comechingones* (Sims and others, 1997). Age data and discussion of the various tectonic cycles are presented within the text. Some units are not represented on *3366-16*.

Tectonic Cycle	Age (Ma)	Deposition	Intrusion
Andean	present	Alluvial, aeolian and talus deposits.	
	1.9 – 9.5	Volcaniclastics	High-K, calc-alkaline to shoshinitic volcanism
Achalian	355 – 405		I- and S-type granite (e.g. Escalerilla, Renca, Achiras Igneous Complex)
Famatinian	470		Río de Molle monzonite Bemberg suite tonalites Tamboreo granodiorite
		San Luis Formation	
	490		Undifferentiated granitoids Mafic & ultramafic rocks
		Pringles Metamorphic Complex sediments	
Pampean	515 – 530		Undifferentiated granitoids Undifferentiated mafics
		Sediments of: • Nogoli Metamorphic Complex • Conlara Metamorphic Complex • Monte Guazú Metamorphic Complex	?Intrusives

2.2 PALAEOZOIC METAMORPHIC BASEMENT

2.2.1 INTRODUCTION

The metamorphic basement of 3366-16 consists of four main subdivisions that relate directly to the geological ages of the units. The first subdivision represents basement rocks of at least Cambrian age (the Conlara Metamorphic Complex) that were deformed and metamorphosed during the late Cambrian, Pampean Tectonic-Cycle. The second subdivision represents Cambro-Ordovician rocks of the Pringles Metamorphic Complex that were deposited prior to the onset of collisional tectonics associated with the Famatinian Tectonic Cycle. The third subdivision are the low-grade rocks of the San Luis formation. These rocks were deposited very late in the Famatinian Cycle, probably during a late extensional phase, and display little evidence of the intense effects of that tectonic event. They are, however, intruded by early Ordovician tonalites and granodiorites, and display contact metamorphic aureoles as a result of those intrusions. The fourth subdivision are represented by Devonian mylonite zones that 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 outcropping within the valley (Valle del río de 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 western margin of the Conlara Metamorphic Complex occur on 3366-16 and is defined by a major NNE trending magnetic lineament and mylonite zone (the Río Guzman Shear Zone) in the eastern Sierras de San Luis that seperates the Complex from the Ordovician San Luis Formation. A significant proportion of the Complex is covered by a thin mantle of unconsolidated Cainozoic deposits and palaeosols, however, good exposures occur within Río Rosario and Río Conlara

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 shoshinitic 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 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, and in the southern Sierra de Comechingones, contains minor interlayered tonalitic gneiss and banded ortho- and para-amphibolite. Within a kilometre of the Las Lajas Shear Zone in the southern Sierra de Comechingones, the schists are mylonitic and boudinaged, and chloritic alteration of biotite is common.

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.

Felsic orthogneiss is interlayered with both the gneiss and schist and constitutes a relatively minor component of the Complex. The orthogneiss is strongly foliated and consists dominantly of equigranular quartz, feldspar and biotite with minor muscovite. The foliation in the orthogneiss appears to be contiguous with the earliest fabric in the enclosing rocks and suggests that the original granite was emplaced during either the early Cambrian Pampean orogeny or Cambro-Ordorvician Famatinian orogeny.

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 Los Morillos, Sierra del Morro and Sierra de la Estenzuela and have not been observed on 3366-16. Where they do occur, 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, these include wollastonite-flourite-scheelite veins in Sierra los Morillos, and pegmatitic epidote-feldspar-amphibole-biotite-pyrite-calcite-magnetite-quartz veins in Sierra de Yulto. The magnetic susceptibility of the marble is generally low ($<36 \times 10^{-5}$ SI) while the calc-silicate produced values up to 1231 ($\times 10^{-5}$) SI, and the late pegmatitic veins produced local values up to 3512 ($\times 10^{-5}$) 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 stongly lineated, are also common within the Complex and are typically found in NW or SW trending sets. Additionally, late aplite dykes occur in the southern Sierra de Comechingones.

2.2.3 CAMBRO-ORDOVICIAN

Pringles Metamorphic Complex (€Opgn, €Ope)

Pelitic and psammitic gneiss and schist, orthogneiss, amphibolite and pegmatite, minor calc-silicate

The Pringles Metamorphic Complex is exposed in the western portion of 3366-16 in a continuous north-south trending belt dissecting the Sierras de San Luis. This belt is fault bound to the east by the San Luis Formation and is well exposed in Río de la Cañada Honda.

The Pringles Metamorphic Complex comprises metasediments of probable late Cambrian - early Ordovician depositional age intruded by early Ordovician mafic and ultramafic rocks of the Las Aguilas Group (*c*. 480 Ma), and by numerous granite and pegmatite bodies. Analysis of zircon separates from felsic orthogneiss (A95JS079e) and monazite separates from pelitic gneiss (A95JS129c) within the Pringles Metamorphic Complex suggest that the rocks reached a metamorphic peak at about the time of emplacement of the Las Aquilas Group, and had cooled to about 600 °C by about 450 Ma (Sims and others, 1997). The peak metamorphic grade in the rocks reached granulite facies, particularly in the region of the Las Aguilas Group intrusions. A close temporal relationship between the age of the Las Aguilas Suite and the peak metamorphism as well as the close spatial relationship, suggests that the ultramafic and mafic rocks may have been the heat source of the metamorphism.

The most abundant rock-types in the Pringles Metamorphic Complex are pelitic and semipelitic gneiss and pelitic and semipelitic schist. The gneiss represents domains where peak (granulite-facies) metamorphic assemblages have been preserved, whereas the schist either represents domains of initially lower grade (amphibolite-facies) metamorphism or regions where subsequent deformation has been localised and resulted in a lower grade metamorphic overprint.

The gneiss contains quartz-feldspar-garnet-sillimanite-biotite-magnetite±cordierite ±spinel, is generally massive in outcrop and locally has a high magnetic susceptibility (maximum measured reading of 11371 x 10^{-5} SI). The gneiss generally contains a well developed mineral and compositional layering dipping steeply to the east with a near vertically plunging mineral lineation mostly defined by sillimanite ± biotite. Garnet is typically porphyritic, though locally it forms spectacular symplectic intergrowths with magnetite. Where cordierite is developed it occurs within leucosomes, intergrown with K-feldspar, that cross-cut the compositional layering but are generally flattened in the foliation plane and are elongate parallel to the extension lineation. In addition, cordierite-bearing pegmatites truncate the mineral fabric and are interpreted to represent the melt product of the leucosome forming reactions.

Pods of hornblende-plagioclase±orthopyroxene±clinopyroxene mafic gneiss are abundant within the gneiss and are typically strongly elongated parallel to the mineral lineation. Some mafic pods are partly boudinaged through internal conjugate fracture sets containing veins of plagioclase-orthopyroxene-clinopyroxene, and veins of the same composition as the cordierite-bearing pegmatites.

Within the gneiss, distinct belts of high-grade mylonite occur. These mylonites are of variable composition and locally contain cordierite- and sillimanite-stable assemblages and occasionally are overgrown by mm-scale, euhedral garnets with spiral inclusion trails. The mylonites are particularly well developed on the margins of the ultramafic bodies of the Las Aguilas Suite, which suggests that formation of the mylonites may be in part due to strain localisation along the contact between rheological contrasting rock-types. The mylonites contain a mineral and elongation lineation that is indistinguishable from that in the host gneiss, and generally have well developed shear-sense indicators such as S/C fabrics and winged porphyroclasts that consistently show an east over west displacement sense.

The boundary between gneiss and schist is transitional and is marked by numerous, thin, k-feldspar rich pegmatites that form either thin discontinuous veins or occur as dykes. The schist consists of a peak metamorphic assemblage of quartz-feldspar-garnet-biotite-sillimanite, is generally well layered and has a low magnetic susceptibility. A primary compositional layering that consists of alternating pelitic and semi-pelitic units is apparent in many areas of the schist that is not apparent in the higher grade regions of the complex.

Extensive tourmaline-apatite-garnet±beryl-bearing pegmatites occur within the schist and are associated with a number of S-type granite and leucogranite intrusions. These intrusions occur in distinct belts within which, a locally intense, moderate to shallow, dominantly east-dipping shear fabric is developed, with east-down shear sense on a moderately southeast plunging lineation. The shear fabric is mostly defined by muscovite-biotite±chlorite, while the lineation is locally defined by tourmaline. Many of the pegmatites are strongly folded and boudinaged in this shear fabric. Within the metasediments, the earlier, peak foliation was strongly folded and transposed, and texturally the peak sillimanite is largely replaced by coarse poikolitic muscovite+quartz, and fine folia of muscovite. In places, late radiating needles of tourmaline and coarse, unoriented porphyroblasts of muscoviteare grown on the secondary foliation plane.

Metre scale, elongate and zoned calc-silicate pods occur within both the gneiss and schist. These pods possibly represent boudins of originally thin and continuous, interlayered carbonate units, though the present lateral extent cannot be determined.

Orthogneiss comprises a relative minor component of the Complex, is extensively recrystallised and contains quartz-feldspar-garnet±biotite. Garnet is subhedral and poikiloblastic and contains abundant granular inclusions of well-rounded quartz and minor plagioclase.

2.2.4 ORDOVICIAN

San Luis Formation (Osl, Osls, Oslc)

Phyllite, schist, arenite, slate and metaconglomerate

The San Luis Formation (Prozzi & Ramos 1988) occurs in two elongate NNE trending belts in the Sierras de San Luis (Sims and others, 1997). The eastern belt, which is exposed on 3366-16, is generally less than 5 km wide and bound to the east by the Río Guzman Shear Zone and to the west by the Pringles Metamorphic Complex. It is truncated to the north by the Las Chacras batholith to the north of 3366-16 and passes under shallow cover to the south in 3366-22. The San Luis Formation is well exposed in Río de la Cañada Honda and along provincial route 41.

The age of the San Luis Formation (SLF) is tightly controlled by structural and stratigraphic constraints. The SLF unconformably overlies high-grade basement rocks of the Pringles Metamorphic Complex (metamorphosed at ~480 Ma) and is unaffected by the intense tectonism that has affected those rocks. However, the formation is intruded by the Tamboreo Granodiorite (472 ± 5 Ma), the Bemberg Suite tonalites (471 ± 5 Ma) and by a suite of aplitic to rhyolitic dykes that also cross-cut the Tamboreo Granodiorite (Sims and others, 1997). The contact of the SLF with the Pringles Metamorphic Complex and the Conlara Metamorphic Complex was strongly sheared during the Devonian, with kyanite, staurolite and garnet bearing assemblages (exposed on provincial route 2A) and minor quartz-feldspar-muscovite-kyanite-staurolite pegmatites locally developed within the SLF near the contacts

The majority of the SLF consists of medium- to thinly-bedded quartz arenite and phyllite in varying proportion, and include areas dominated by either lithology. Sedimentary structures, such as graded bedding, cross-bedding, channel and flame structures, are common in areas where there is a higher proportion of coarser grained beds. Most rock-types are quartz-rich, and significant carbonate occurs in the matrix of some coarser grained arenites.

Two main deformations affected the SLF during the Devonian compressional cycle. The first of these deformations (regional D3a) resulted in tight to isoclinal, upright to inclined folds with a well-developed, axial planar, slaty cleavage in most rock-types. The second deformation (regional D3b), resulted in the development of discrete shear zones, separated by domains of open refolding with a corresponding crenulation cleavage. Additionally, a very early foliation (?S2b) is also preserved in fine grained rocks in some areas. The regional metamorphic grade within the SLF is typically lower greenschist and the rocks are generally fine grained. In places though, a more schistose and coarser grained fabric is developed, which probably reflects slight variations in the metamorphic grade, during the Devonian compressional cycle. Local high-temperature metamorphic aureoles are also developed around Ordovician, granodioritic to tonalitic intrusives (von Gosen & Prozzi, 1996). The magnetic signature of the San Luis formation is generally low, however, local high magnetic responses are developed in the region of magnetite-bearing Devonian mylonites such as the Río Guzman Shear Zone.

Where axial planes of the two main Devonian deformation phases are sub-parallel and occur in transposed fine-grained rocks, slate is developed. The slate is dark-grey to green and consists predominantly of thinly bedded phyllites with minor thin quartzites. The phyllite consists predominantly of quartz, chlorite and sericite with minor organic carbon

(Prozzi and Ramos, 1988) and contain secondary euhedral crystals of calcite and pyrite. The thin quartzites consist predominantly of quartz, chlorite and minor muscovite with abundant secondary euhedral calcite and minor epidote. Both rock-types are cross-cut by thin veins of quartz±pyrite. The slate has been extensively quarried for building stone.

A distinctive, poorly-sorted, polymictic, conglomerate unit, named the Metaconglomerado Cañada Honda by Ortiz Suárez and others (1992), occurs within the SLF. The conglomerate is up to 100 m thick and is well exposed in Río de la Cañada Honda, in the eastern belt of the SLF. Additionally, Ortiz Suárez and others (1992) report the occurrence of a 100 m wide conglomerate unit that extends for about 2 km to the northwest of La Carolina within the western belt of the SLF. The conglomerate in the eastern belt consists predominantly of angular clasts of pebble- to cobble-sized, quartzite and phyllite, within a fine- to coarse-grained matrix. Some larger clasts preserve primary bedding features. Ortiz Suárez and others (1992) have also reported the occurrence of clasts of rhyolitic to dacitic metavolcanics. Interlayered with the conglomerate are discontinuos, thin to medium sandstone and mudstone beds displaying channel structures and graded bedding. The top of the unit grades through alternating conglomerate and thinly bedded quartzite into thickly bedded massive quartzite units. An anastomosing mylonitic foliation is developed within the conglomerate parallel to bedding and most of the smaller quartzite clasts are recrystallised and display extensive sub-grain development. A sub-parallel cleavage is also developed on the mylonitic foliation and has resulted in a fine crenulation surface.

2.2.5 DEVONIAN

Río Guzman Shear Zone (Dzmi)

The Río Guzman Shear Zone is a linear north-northeast trending, high-strain zone, traversing the Sierras de San Luis from the Las Chacras batholith in the north, to near Saladillo in the south. The zone, which is up to 3 km wide, is a major lineament on aeromagnetic imagery that can be traced further to the south, beneath a thin cover of Cainozoic sediments. The shear zone, named after the Río Guzman, which follows the shear zone for several kilometres, has not previously been described. Rocks within the shear zone are mostly well exposed.

The shear zone consists predominantly of steeply east-dipping mylonite that separates the high-grade, Cambrian Conlara Metamorphic Complex from the low-grade, Ordovician San Luis Formation and is largely contained within the low-grade rocks. The dominant assemblage in the mylonite consists of quartz-chlorite-sericite±magnetite with a variably developed subvertical stretching and mineral lineation. Relict (retrogressed) kyanite? with staurolite and garnet, within Conlara Metamorphic Complex rocks on the eastern margin of the zone, near Cerros Largos, however, suggests the shear zone may have initiated at higher pressures and have a long-lived history. Shear-sense indicators in the form of S-C fabrics and assymetric extensional shear bands are well developed and give east up displacement. The similarities of the kinematic indicators and metamorphic grade suggests a close temporal relationship with the Las Lajas Shear Zone in the Sierra de Comechingones.

Ar-Ar data from sericite in the mylonitic fabric, indicates a growth age between 360 and 350 Ma (Camacho & Ireland, 1997), which therefore constrains the minimum age of the greenschist-facies shearing. This age also provides maximum age for the Las Chacras Batholith, which truncates the shear zone to the north of *Sierras de San Luis y Comechingones*. Additionally, the shear zone has been intruded by a number of undeformed lamprophyre dykes, and has been partly reactivated as an east dipping thrust during the presently active, Tertiary Andean compression.

2.3 PALAEOZOIC IGNEOUS ROCKS

2.3.1 ORDOVICIAN INTRUSIVES

Las Aguilas Group (Ola)

Dunite, pyroxenite, hornblendite, amphibolite.

Mafic, ultramafic rocks and amphibolite are exposed in a series of discrete elongate bodies up to 3.5 km in outcrop length and up to 500 metres in outcrop width, in two NNE-SSW trending belts, within the Pringles Metamorphic Complex. Within 3366-16, mappable ultramafic and mafic units appear to be restricted to two small bodiesin the westernmost portion of the map sheet. Although the ultramafic rocks have a high magnetic reponse, individual bodies within the main belt are not readily distinguished in the aeromagnetics due to the high magnetic response of the enclosing pelitic gneiss. Additionally, numerous metre- to 100 metre-scale, moderately to highly magnetic, amphibolite bodies, representing either differentiated or metamorphosed equivalents of the ultramafic rocks, also occur within the Pringles Metamorphic Complex. These bodies are apparent in the aeromagnetics, particularly away from the region of granulite-facies gneiss, however, due to the small scale or lack of exposure they are not generally differentiated from the Pringles Metamorphic Complex.

The mafic and ultramafic rocks intruded into the Pringles Metamorphic Complex and are spatially and texturally associated with granulite-facies rocks. The margins of the larger bodies, and many of the smaller bodies, are extensively recrystallised with high-grade hornblende-pyroxene-bearing metamorphic assemblages. The recrystallised metabasic rocks are extensively boudinaged and contain a foliation parallel to that in the enclosing pelitic gneiss. Conversely, the cores of a number of the larger mafic bodies preserve relict igneous textures. For example, at Virorco, subhorizontal igneous layering is preserved while at Las Aguilas sub-vertical contacts occur between various intrusive phases. Furthermore, it is apparent that individual bodies are strongly elongate parallel to the stretching lineation in the enclosing gneiss. The implication being that the mafic, ultramafic and amphibolite rocks intruded synchronously with regional deformation.

The age of the Las Aguilas Suite has been constrained by U/Pb dating of zircon seperates from a felsic segregation in the ultramafic rocks at Las Aguilas. The zircons from this late crystallising phase provide an Early Ordovician age of 478 ± 6 Ma (Camacho & Ireland, 1997). Zircon rims from a spatially associated felsic orthogneiss at Las Aguilas produced a similar age of 484 ± 7 Ma (Camacho & Ireland, 1997).

The mafic and ultramafic rocks are composed of dunite, pyroxenite and hornblendite. Orthopyroxene is typically the most abundant primary mineral phase with subordinate olivine, plagioclase, clinopyroxene, spinel (chromite) and sulphide phases (pyrrhotite, pentlandite and chalcopyrite). Olivine is partially altered to serpentine, clinopyroxene is extensively replaced by clinoamphibole, and phlogopite is locally extensively developed associated with late deformation surfaces. Secondary sulphides include marcasite, covellite and pyrite.

The numerous bodies of amphibolite consist dominantly of hornblende and plagioclase with or without orthopyroxene and contain minor quartz and accessory phases (apatite, sphene, ilmenite and magnetite). Primary hornblende is variably replaced by biotite and secondary hornblende replaces orthopyroxene. Other secondary phases include epidote, zoisite, clinozoisite and calcite.

Undifferentiated granitoids and pegmatite (Ogu, Opeg)

S-type leucogranite, granite, granodiorite, tonalite and pegmatite

This unit includes a distinctive suite of S-type granite, leucogranite and pegmatite that occur in an elongate NNE trending belt that passes through Embalse La Florida to the east of Trapiche. This group of rocks, which has previously been described as “granitoides sin-cinemáticos” by Ortiz Suárez and others (1992) and Llambías and others (1996a), is well exposed from Embalse La Florida through Paso del Rey and within Río Grande east of Siete Cajoles.

Structural constraints on the “granitoides sin-cinemáticos” suggest that the granites and pegmatites intruded a high-grade (amphibolite facies) basement. Previous geochronology by Linares (1959) and Llambías and others (1991) indicates that the pegmatites associated with these rocks were emplaced prior to 460 Ma.

The undifferentiated granitoids comprise various phases of leucogranite, granite (including Paso del Rey, Cruz de Caña and Cerros Largos granites) granodiorite and pegmatite. The granite is typically leucocratic and equigranular, containing quartz-feldspar-biotite-muscovite±garnet. The associated pegmatites are extremely coarse grained, feldspar-quartz-muscovite-tourmaline-garnet-apatite bearing varieties that are typically compositionally zoned.

The “granitoides sin-cinemáticos” are spatially associated with zones of extensional deformation developed late in the Famatinian tectonic cycle. They are spatially associated with pervasive retrogression of the high-grade assemblages within the Pringles Metamorphic Complex and development of a muscovite-tourmaline-bearing assemblages at the expense of sillimanite-biotite-bearing assemblages. Complex interference folds defined by pegmatites of this suite suggests multiple deformation episodes. Llambías and others (1996a) have estimated that the initial deformation within the granites developed under amphibolite-facies conditions, whilst open refolding is consistent with the initial upright folding of the San Luis formation under greenshist-facies conditions.

2.3.3 DEVONIAN INTRUSIVES

Renca Granite (Dgre, Dgrp)

The Renca Granite is a generally well exposed pluton that is 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, 1993). However, Halpern and others (1970) obtained a Rb-Sr date of 415±25 Ma for the Renca Granite and recent U-Pb zircon data (Camacho and Ireland, 1997) give a magmatic crystallisation age of 393±5 Ma.

The outer ring, which is about 2 to 5 km in outcrop thickness, 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. 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.

Las Chacras Granite (Batolito de Las Chacras-Piedras Coloradas) (Dgc)

The Las Chacras Batholith consists of multiple phases of circular granite that are exposed over an area greater than 500 km^2, in the central north of the Sierras de San Luis. However, less than 5 km^2 of the southern most pluton is exposed on 336-16. The Batholith derives its name from the township of Las Chacras which is located on the batholith. Detailed studies of the batholith have been made by by Brogioni (1987a & 1991), who incorporates the Potrerillos granite and the Las Chacras batholith as the Batolito de Las Chacras-Piedras Coloradas. The granite has positive relief is well exposed in platforms and low bouldery hills.

The Las Chacras granite on 3366-16 is undeformed and intrudes the Conlara Metamorphic Complex. K/Ar isotopic ages for the batholith, from amphibole and biotite respectively, range from 336 ± 17 Ma to 320 ± 16 Ma (Brogioni, 1987a), and must be considered as minimum ages. A maximum age for the batholith is provided by an argon-argon age of 350-360 Ma (Camacho, 1997) for the Río Guzman Shear Zone that the batholith truncates. Similarities with Devonian plutons such as Renca Granite, suggest the batholith must have been emplaced in the Devonian or early Carboniferous.

Portrerillos Granite (Batolito de Las Chacras-Piedras Coloradas) (Dgpi, Dgpe)

The Potrerillos granite is an ovoid pluton with a maximum diameter of approximately 12 km exposed between the townships of Renca and Las Chacras in the central north of 3366-16. The name of the pluton is derived from the small community of Potrerillos, which is situated on the exposed pluton. The pluton has positive relief compared to the country rock (Conlara Metamorphic Complex) and is hence very well exposed in low bouldery hills that form the Sierrita de las Piedras Coloradas. It has previously been described as the Potrerillos Stock of the Batolito de Las Chacras-Piedras Coloradas by Brogioni (1987a, 1991).

The Potrerillos granite is undeformed and intrudes the Conlara Metamorphic Complex and the outer phases of the Las Chacras Batholith. An isotopic (K/Ar biotite) age of 335 ± 17 Ma has been reported (Brogioni, 1987a), which must be considered as a minimum age. The marked similarity of the aeromagnetic signature of this pluton to that of the Renca granite, strongly suggests that the Potrerillos granite is no older than Devonian in age and assocated with the Achalian tectonic cycle.

Aeromagnetic data, suggests the Potrerillos granite is either strongly zoned or consists of a non-magnetic core-phase and a moderately magnetic rim phase that is approximately 2.5

km wide. Measured magnetic susceptibilities of the central phase are low, and average 8 x 10^{-5} SI. The Potrerillos granite has a high radiometric signature.

This coarse grained, porphyritic and strongly jointed granite is deep pink to red in outcrop. It consists of approximately 40% very coarse, porphyritic k-feldspar, with up to 30% quartz, 10-15% plagioclase and up to 15 % biotite. K-feldspar contains inclusions of biotite, plagioclase and quartz, and matrix plagioclase displays myrmekitic textures. Quartz is slightly recrystallised. Accessory phases include allanite, zircon, apatite and magnetite, while secondary phases include muscovite replacing plagioclase and chlorite replacing biotite.

The Potrerillos granite is quarried for building stone in the Cantera Los Aquilchuchos "Granito Rojo Dragon".

2.3.4 MINOR DYKE ROCKS

Pegmatite (peg)

Numerous pegmatite dykes intrude the basement rocks of 3366-16. There are essentially four mainsubdivisions:

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

2. Pegmatites emplaced during the M2 metamorphic peak in the early Ordovician at around 480 Ma. These are largely restricted to within the Pringles Metamorphic Complex .

3. Pegmatites emplaced post-M2in the mid Ordovician at around 460Ma, and associated with the undifferentiated Ordovician granites.

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

Aplite

A group of thin aplite dykes that are wholly contained within the San Luis Formation and intrusives within those rocks, occur in the Sierras de San Luis. These dykes are up to 5 km in length and no more than 3 m in width. They cross-cut the Tamboreo granodiorite (to the south of 3366-16), which has been dated at 472 ± 5 Ma (Camacho & Ireland, 1997), and are folded and recrystallised. A minimum age for for the dykes is provided by Devonian ages for the deformation of the San Luis formation. The dykes consist of medium-grained phenocrysts of quartz, feldspar, garnet and muscovite, in a fine grained recrystallised matrix, with minor secondary zoisite. Limited geochemistry from Sato and others (1996) indicates that the dykes are granitic in composition. Brodtkorb and others (1984) have interpreted some of these dykes, that occur within the San Luis Formation as metavolcanics.

Lamprophyre

A number of thin lamprophyre (minette) dykes have also been observed within and adjacent to the Río Guzman Shear Zone in the Sierras de San Luis. These dykes are no more than 1 m in width and consist almost entirely of medium-grained biotite. Within the shear zone, the dykes have intruded parallel to the mylonitic foliation but are not deformed.

The precise age of the dykes is not known, however, they clearly postdate Late Devonian thrusts and therefore must be late Paleozoic or Mesozoic in age. Toselli and others (1996) interpret similar lamprophyre dykes, intruding the Granito Ñuñorco in the western Sierras Pampeanas, to be related to the late Devonian/upper Carboniferous "Chánica Orogeny".

2.4 TERTIARY VOLCANICS

San Luis Volcanic Group (Tva, Tvp, Tvb, Tt)
Intrusive plugs, domes, breccia pipes and dykes, lava, pyroclastic deposits, epiclastic volcanic deposits and hydrothermal deposits

A series of volcanic centres occur in a northwest-southeast trending belt of approximately 90 km length through central and western *Sierras de San Luis y Comechingones*. The volcanic centres include Sierra del Morro in the southeast, cerros Rosario and Tiporco, Cerros Largos, Cañada Honda, and La Carolina in the northwest. The geology, petrography and geochemistry of the volcanics have been examined by Brogioni (1987b, 1990). A general description of the volcanic centres is presented in **Table 2**. The volcanic centres of Cañada Honda, Cerros Largos, Cerro Tiporco and Cerros Rosario are represented on 3366-16.

The volcanic rocks, called the San Luis Volcanic Group (Sims and others, 1997), 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.

Table 2. Volcanic centres, age and general descriptions. References for age determinations: [1] Ramos and others (1991); [2] Urbina and others (1995); [3] Sruoga and others (1996).

Volcanic centre *(dating location)*	**Age (Ma)** (K/Ar)	**Rock-types and general description**
La Carolina		Range of volcanic plugs and domes, minor pyroclastic deposits and subvolcanic breccias. Extensive alteration of host rocks. Basement deeply eroded (~300m?). NW trending faults
(Tres Cerritos)	8.2 ± 0.4[3]	
(C° Tomolasta)	7.5 ± 0.4[2]	
(C° Pan de Azucar)	7.3 ± 0.4[2]	
(not specified)	6.3 ± 0.3[3]	
Cañada Honda		Range of volcanic plugs and domes. Extensive alteration of host rocks. Basement deeply eroded (~200m?)
(Diente Verde)	9.5 ± 0.5[2]	
Cerros Largos		Volcanic domes. Tuff mostly preserved in topographic low (?diatreme) to SW of volcanic domes. Basement eroded (~100m?)
Tiporco		Single isolated volcanic dome in raised (~50m) basement ring. Travertine and subsurface veins of calcareous onyx encircle the volcanic centre. Paleao landsurface readily apparent, however, much of the pyroclastic material has been removed
Cerros del Rosario	2.6 ± 0.6[1]	Range of volcanic plugs and domes partly centred in raised (~200m) basement ring. Paleao landsurface readily apparent, however, much of the pyroclastic material has been removed. Ring faults around basement dome
Sierra del Morro		Range of volcanic plugs and domes, breccia pipes and dykes mostly contained within domed (~700m) basement rocks with a central collapsed(?) caldera. Palaeo landsurface readily apparent with thick cover of pyroclastic and epiclastic material preserved on the north, east and south flanks. Western flank deeply dissected (~200m) adjacent to Los Morillos fault escarpment. 'Box' faults around basement dome.
(not specified)	6.4 ± 0.6[1]	
(not specified)	2.6 ± 0.6[1]	
(not specified)	1.9 ± 0.2[1]	

The volcanic rocks (labelled Tva) include plugs, domes, dykes, sills and minor lavas and range in composition from basaltic andesite to dacite. Brogioni (1987b) also reports rocks of latitic to trachytic composition. Chemically the volcanic rocks fall within the calc-alkaline to shosonitic series.

Sub-volcanic breccia pipes and dykes (labelled Tvb) are well exposed within the central caldera of Sierra del Morro and on the southern flanks of Cerro Rosario. The breccia pipes form hard resistant topography and consist of unoriented, welded, angular fragments of both volcanic and country rock, ranging in size from microscopic to metre scale. The breccia dykes are poorly outcropping and consist dominantly of well layered fragmental volcanic material.

Pyroclastic and epiclastic deposits (labelled Tvp) are well preserved, particularly in the region of Sierra del Morro and Cerros del Rosario. The pyroclastic deposits are generally cream to grey, well bedded, and are hard to friable. The beds may range from centimetres to metres in thickness and consist of a combination of pumice, ash and lithic fragments. The beds include ground surge deposits, ash fall tuff and fragmental tuff. Welded pyroclastic breccia was also observed adjacent to Cerro Tiporco. Bombs of both basement and volcanic material are common in the pyroclastics. Epiclastic deposits are well developed in the region of Sierra del Morro, where they form resistant radial fans with inverted relief around the main basement dome.

Hydrothermal deposits including calcareous onyx and travertine (labelled Tt) occur distributed about Cerro Tiporco. The calcareous onyx, which is exposed within quarries such as *Santa Isabela*, forms veins of various thickness (generally < 2m) that intrude basement schist and are interlayered in places with pyroclastic deposits. The veins consist of green to brown carbonate with local, vuggy porosity and late aragonite and flourite crystallisation. The travertine generally forms a rigid cap rock (probably a palaeo-landsurface) that is well presesrved to the NW of Cerro Tiporco where it is deeply dissected and now form the caps of hills. The travertine seems to be in part, basal to the volcaniclastics.

2.5 CAINOZOIC

Unconsolidated cover (Czu, Czg, Czc, Czd)

Loess, alluvial deposits, fans, gravels, caliche,channel deposits etc.

Unconsolidated alluvial, colluvial and aeolian deposits, as well as palaeosols, overly the basement rocks in Sierras de San Luis y Comechingones and are interspersed with some of the volcaniclastic deposits. The most extensive Cainozoic unit (labelled Czu) is an intercalted 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 Cainoizoic 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). Strasser and others (1996) have correlated the stratigraphically younger deposits in the San Luis region with Late Pleistocene and Holocene units in the Buenos Aires Province.

In places, paleosols (labelled Czc), typically with a hardpan of calcrete, form thin (a few metres thick) remnant cappings over basement rocks. They are best exposed along the gently sloping eastern flanks of the Sierras de Comechingones and in the easternmost Sierras de San Luis where they are overlain by intercalated Tertiary to Quaternary fluvial and aeolian deposits. The age of the deposits is not known. Their formation predates the last significant uplift which probably took place during the Late Pliocene-Pleistocene (Costa, 1996).

Raised fluvial and colluvial fan deposits of unconsolidated gravels (labelled Czg) form low, wooded, dissected hills at the base of many of the main Cainozoic fault scarps. The most extensive of these occur along the western scarp of the Sierras de San Luis. These deposits are correlated with similar Pleistocene (Quaternary level 1 subdivision of Massabie, 1982) deposits in the Capilla del Monte area of Córdoba. Increased erosion and exposure of Miocene-Pliocene volcanic plugs from east to west places a lower age constraint on the earliest uplift and hence the maximum age of the fans at mid-Pliocene.

2.6 QUATERNARY

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

Holocene (Santa Cruz, 1978) to Recent alluvial deposits of clay, sand and gravel along active river courses and adjacent terraces and overbank deposits (labelled Qa) dissect the undifferentiated Cainoizoic units. The most extensive of these deposits are associated with the Río Rosario in the south, several rivers draining east from the Sierra Comechingones and west from the Sierras de San Luis, and are also common in numerous minor drainages within the Sierras de San Luis. Bodies of fluvial channel deposits of mainly sand and minor gravel within the presently active channels (labelled Qs) are best developed within the Río Rosario. Active fan deposits (labelled Qg) occur along the base of the fault scarps bordering the Sierra de Comechingones and San Luis. And minor Recent talus deposits (labelled Qt) occur along the exhumed, steeply dipping contacts of the Comechingones and Alpa Corral granites in the northeast, and also occur around many of the highly resistant volcanic plugs of the San Luis Volcanic Group.

3. TECTONICS

Three major deformation, metamorphic and magmatic events have affected the basement rocks of *Sierras de San Luis y Comechingones* (Table 1). Rocks of the Monte Guazú, Conlara and Nogoli metamorphic complexes preserve evidence of the earliest event, while the latter two are present within the rocks of the Pringles Metamorphic Complex. The San Luis Formation only shows effects of the latest event. The three tectonic events are termed here the (Early Cambrian) Pampean Cycle, the (early Ordovician) Famatinian Cycle, and the (Devonian) Achalian Cycle. All regions were 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 y 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 calcsilicate 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 Kbars at temperatures of no more than ~750°C (e.g. Grant, 1985; Spear, 1981, 1993).

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

3.2 FAMATINIAN CYCLE: ORDOVICIAN DEFORMATION AND METAMORPHISM

Formation of a basin, in which the sedimentary protolith to the Pringles Metamorphic Complex was deposited, possibly marks the initiation of a subduction complex to the west of the Sierras de San Luis in the late Cambrian. Numerous intrusives within the La Rioja area that were emplaced around 490-480 Ma (Camacho & Ireland, 1997) probably represent the core of the associated volcanic arc (Pieters and others, 1997). Correlatives of these intrusives within *Sierras de San Luis y Comechingones,* are represented by monzonites and quartz-monzonites (e.g., the Río del Molle Monzonite) emplaced into the Nogoli Metamorphic Complex. The back-arc basin had closed, however, by the early Ordovician, when the Cambro-Ordovician rocks were strongly deformed and intruded by syn-kinematic mafic and ultramafic rocks of the Las Aguilas Group (LAG) at ~480 Ma (Camacho & Ireland, 1997).

Compressional phase

The peak metamorphic assemblages in the Pringles Metamorphic Complex, which formed under granulite facies conditions during the Famatinian Cycle, are spatially located in an elongate belt around the LAG. The pelitic rocks contain a gneissic fabric defined by sillimanite and biotite (S1 in the Pringles Metamorphic Complex but regional S2), with lenses and pods of cordierite- and garnet-bearing leucosomes. The gneissic layering trends N-NNE and dips mostly steeply to the east, and sillimanite and biotite laths define a steeply plunging mineral lineation. A number of discrete mylonite zones are formed within the complex, these are generally less than 20-30 m wide and parallel the gneissic layering. High-grade assemblages involving sillimanite and locally cordierite in the mylonites and a stretching lineation parallel to that in the gneiss suggest they formed synchronously. The mylonites are particularly well developed along the margins of the ultramafic bodies. Shear sense indicators both in the gneissic layering and in the mylonites and give an east-up displacement sense.

In gneiss and schist of the Conlara Metamorphic Complex 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.

Extensional phase

By ~470 Ma the compressional regime had ceased and the terrane was in extension, resulting in deposition of the San Luis Formation (SLF). This was followed subsequently by intrusion of the Tamboreo Granodiorite and tonalites of the Bemberg Suite, which produced metamorphic aureoles in the cover rocks.

The extensional structures developed under greenschist-facies conditions, and deformation was partitioned into domains of shearing with a shallow to steep, east to southeasterly dipping lineation and domains of open to tight folding of the older structural surfaces in the basement rocks. Shear fabrics defined by muscovite ± biotite predominate, with a lineation locally defined by tourmaline. Shear sense indicators give an east-down displacement sense. Numerous pegmatites and (fractionated) granites intruded synchronously with the deformation and show varying degress of folding and dynamic recrystallisation. A U-Pb uraninite age of ~460 Ma has been derived from one of these pegmatites (Linares, 1959).

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 the Achalian Cycle (Sims and others, 1997). 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 the most significant single tectonic episode in the region.

Deformation in 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 a number of major mylonite zones, in particular, in the northwest-trending Las Lajas Shear Zone, which truncates the Conlara Metamorphic Complex, north of Achiras; and in the north-northeast trending Río Guzman Shear Zone, which separates the Conlara Metamorphic Complex from the San Luis Formation. Additionally, a number of significant mylonite zones developed, including one along the eastern flank of the Sierra de Comechingones, passing through Las Albahacas, and a complex zone that follows the eastern contact of the Escalerilla Granite in the Sierras de San Luis. These deformations have been previously incorporated within the Famatinian Cycle (e.g. von Gosen & Prozzi, 1996)

At least 4 distinct styles of deformation are recognised within the Achalian Cycle (Sims and others, 1997). 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. Interference with flat-lying folds in both the Pringles and Conlara metamorphic complexes produced open basin and dome fold-interference patterns. In the early Ordovician San Luis Formation, tight to isoclinal folds are developed in bedding with an axial planar slaty cleavage (S1 in the SLF but regional S3) developed between major shear zones. A maximum age for this early fabric forming event is provided by a 403 ± 6 Ma age (U/Pb zircon; Camacho & Ireland, 1997) for the Escalerilla granite which is affected by the early tectonism. Kinematic indicators including asymmetric mantled porphyroclasts and S-C fabrics all indicate westward-directed thrusting.

2. Ductile strike-slip shearing

Discrete sinistral shear-zones up to 50m wide are developed in a number of areas within the Sierras de San Luis. The shear zones contain a mylonitic fabric with a sub-horizontal mineral and elongation lineation and well developed shear sense indicators. Argon-argon dating (Camacho, 1997) suggests that a change in the regional stress field corresponding to development of ductile strike-slip shearing may have occurred in the Middle Devonian (Sims and others, 1997).

3. *Thrusting at low-grade in discrete shear zones with contemporaeous 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 both the Sierras de San Luis (Río Guzman Shear Zone) and the Sierras de Comechingones (Las Lajas Shear Zone and Las Albahacas 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.

4. 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 & 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. Within the Sierras de San Luis, where exposed, these faults typically consist of narrow zones (<1 m wide) of brittle-ductile mylonite and minor ultramylonite. Fault mineral assemblages include quartz, sericite, epidote, hematite, goethite and chlorite.

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. Ar-Ar ages of hydrothermal white micas in the fault zones, in places associated with Au mineralised quartz veins, indicate that this stage began about 385 Ma, peaked at 370 Ma and continued until 355 Ma (Camacho, 1997; Skirrow, 1997b, c).

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 southeast – northwest trending basins. 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 that have 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. ^{14}C ages suggest the fault was active as recently as c. 1000 years ago (Costa and Vita-Frinzi, 1996).

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 emplacement 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 y 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 & 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 Cambro–Ordovician domain. Both domains share a common tectonic history since early Devonian times.

5.1 EARLY CAMBRIAN SEDIMENTATION

The oldest rocks in the region form a structurally thick sequence of pelitic and lesser psammitic gniesses 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 y Comechingones* but are less extensive than in interpreted extensions of the same domains in northern Córdoba (Lyons and others, 1997), where they form semi-continuous belts. These metasediments are interpreted as being deposited on a passive margin, developed during intracontinental rifting and breakup of Laurentia from Gondwana in Eocambrian times at about 540 Ma (Dalziel and others, 1994).

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). 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).

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 although similar intrusions in the Sierra Norte - Ascochinga area in Córdoba have been dated at ~515 Ma (AGSO - Subsecretaria de Minería, unpublished U-Pb zircon data).

5.3 EARLY PALAEOZOIC TUBIDITE 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 Cambrain basement during a widespread deformational, metamorphic and magmatic event known as the “Ciclo orogénico Famatiniano” (Aceñolaza & Toselli, 1976), Famatinian Orogen (eg. Dalla Salda and others, 1992) or “Ciclo Famatiniano” (Dalla Salda, 1987). The compressive deformation (D1 in the Cambro-Ordovician rocks, D2 in the Cambrian rocks), which occurred at mostly upper amphibolite facies and locally at granulite-facies, was accompanied by the development of kilometre-scale east-dipping ductile shear-zones with orthogonal, westerly-directed, thrust movement. A number of mafic/ultramafic bodies (the Las Aguilas Group) that intruded the sedimentary protolith to the Pringles Metamorphic Complex were involved in the deformation and represent a significant mantle-derived heat source contributing to the high temperature metamorphic conditions.

The high-grade metamorphic episode during the Famatinian cycle was closely followed by extensional tectonism under upper-greenschist-facies conditions accompanied by emplacement of S-type granite and pegmatite (undifferentiated granitoids and pegmatite). Extensional tectonism and granite emplacement were restricted to discrete belts and resulted in pervasive retrogression within those belts of the high-grade metamorphic assemblages. The low-grade San Luis Formation was probably deposited during this extensional phase. Igneous activity culminated at ~470 Ma in the emplacement of granodioritic to tonalitic intrusives (Tamboreo Granodiorite & Bemberg Suite) that are spatially restricted to within the San Luis Formation. U-Pb monazite data (Camacho and Ireland, 1997) from the Pringles Metamorphic Complex and U-Pb uraninite data (Linares, 1959) from pegmatites suggest the terrain had cooled through 600°C by ~450-460 Ma.

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 intruded into the metamorphics discontinuously during and after shear zone development. Some of the shear zones (e.g. the Las Lajas Complex) were the locus of multiply injected subconcordant granite and later pegmatite intrusion. In other areas, circular, zoned, and fractionated plutons, commonly coalesced to form 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 until ~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 Sierras Grandes. 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 & Aceñolaza, 1972) were deposited during the Carboniferous and Permian times. These sediments, which are not represented in *Sierras de San Luis y Comechingones* 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 & 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 y 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 & 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 commensement 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.

SECTON II: ECONOMIC GEOLOGY

By Roger G. Skirrow

1. INTRODUCTION

The 3366-16 1:100 000 map area of San Luis contains a wide range of metallic and industrial mineral occurrences, including W in the Santo Domingo - Paso del Rey districts, Au±W±Sb in the Santo Domingo and El Duraznito districts, Cu in the Cañada Honda - Diente Verde area, aluvial Au, and Be, Li, Nb, and Ta in several districts. The sheet area also contains important deposits of onyx, travertine, slate, mica, quartz, feldspar and various building stones.

Geological and resource data on mineral occurrences have been compiled in a database (ARGMIN, in MicroSoft Access; Skirrow & Trudu, 1997) using a combination of data from the literature and field data. The principal deposits in most mining districts of the map 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 & Skirrow, 1996), stable isotopes of oxygen, hydrogen and sulfur (Lyons & & 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). Locational and commodity data for a number of mineral deposits in Departamento Pringles were derived from the CREA (1996) mineral deposit database. The positional accuracy of occurrences from this data source is estimated as ±400m.

Mineral occcurrence 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, 1997a). 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: SANTO DOMINGO - PASO DEL REY DISTRICTS

Numerous W occurrences are present in the 3366-16 map area, ranging from mines with extensive surficial and underground workings to small pits and shafts. Although some of the principal deposits have been located by GPS and many others have been located on airphotographs and their geographical coordinates measured, a large number of 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 or by GPS (if any).
In the Sierras de San Luis and Comechingones 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 calcsilicate rocks. Minor wolframite and scheelite also occur in pegmatites. Style (i) is the principal W deposit type represented in the 3366-16 map sheet. Both styles (i) and (ii) are distributed preferentially in the San Luis Formation, a sequence of early Ordovician metapelites, metapsammites and metaconglomerates that were deposited during and after Famatinian extensional deformation, and that were intruded by felsic dykes.

The W deposits in the Santo Domingo - Paso del Rey districts form part of a belt of deposits extending approximately 25 km between Santo Domingo and La Florida to the south. The geology and genesis of W deposits in this belt have been discussed by numerous workers, including Monchablon (1956), Stoll (1963a, b), Ambrosini and others (1981), Leveratto and Malvicini (1982), Carotti and others (1985), Brodtkorb and others (1984, 1985), Hack and others (1991), Fernandez and others (1991) and Ramos (1990, 1992).

Regional setting: The regional geology and structure of the Santo Domingo - Paso del Rey - La Florida region is complex (Sims and others, 1997). The Río Guzman Shear Zone marks the boundary between the Ordovician San Luis Formation to the west and the

Cambrian Conlara Metamorphic Complex to the east. A zone of D_3 shears separate the San Luis Formation from metapsammites and metapelites of the Pringles Metamorphic Complex to the west, whose tectonic and metamorphic history differs from that of the younger San Luis Formation. These quartzo-feldspathic metasediments were initially metamorphosed to medium grade during D_1 in the early Ordovician, then intruded by extensive granitoids and tourmaline-bearing pegmatites during D_2 extension. Regional low grade retrogression accompanied D_2, resulting in widespread muscovite±tourmaline development in schists. Following deposition of the San Luis Formation late- to post-D_2, the Pampa del Tamboreo granodiorite (see Hoja Geológica 3366-21) was emplaced at 470±5 Ma (Camacho & Ireland, 1997), producing a contact metamorphic aureole in the San Luis Formation. This granodiorite and the San Luis Formation were subsequently intruded by numerous plagioclase-quartz porphyritic rhyolite dykes. The metasedimentary and igneous rocks were intensely deformed and metamorphosed to low grade during the Devonian $D_{3\text{-}4}$ compressive events, with strain generally localised in and near shear zones.

Geology: The principal features that are shared by many of the W deposits in the - Santo Domingo - Paso del Rey - La Florida belt are as follows.

- Scheelite is the primary ore mineral
- The W mineralisation is associated with quartz veinlet networks or is disseminated
- Host rocks are part of the low grade metamorphic rocks of the San Luis Formation, except for some of the westernmost deposits in the belt (Los Cocos district, Sheet 3366-21)
- Deposits occur within or in proximity (<1 km) to zones of intense D_3 deformation
- Scheelite commonly occurs in feldspathic rock types such as plagioclase-quartz porphyry to aplitic bodies and meta-arkosic rocks
- Quartz veinlet networks are most intensely developed in relatively competant units where they are in contact with less competant rocks, for example metapsammite, quartzite or felsic porphyry/aplite within phyllite or metapelitic schist
- The mined zones are broadly confined to particular compositional layers but locally transgress layering
- Veins and veinlet networks are deformed and vein minerals are recystallised

- Sulfides and oxides are very low in abundance; pyrite, arsenopyrite, and ilmenite altered to rutile, occur at La Teodolina (Ramos, 1992; Brodtkorb and others, 1985), and pyrite is widespread (e.g. Carotti and others, 1985)
- Tourmaline and white mica commonly are very abundant in proximity to the quartz veinlet systems with scheelite mineralisation; calcsilicates such as epidote and titanite as well as apatite, fluorite and carbonate occur in veins and wall rocks with scheelite in some deposits (Brodtkorb and others, 1985; Carotti and others, 1985; Hack and others, 1991), and scapolite, hornblende and garnet were reported in scheelite-bearing quartzite host rocks in the Los Cocos district (Stoll, 1963a; Brodtkorb and others, 1985)
- Biotite is very abundant in mineralised zones of some but not all deposits (e.g. La Teodolina), and is partially chloritised

Other critical observations of relevance in understanding the timing and depositional controls of the W deposits are as follows.

1. Felsic dykes (some previously interpreted as felsic volcanics, Brodtkorb and others, 1984) cutting the compositional layering in the San Luis Formation (e.g. at El Araucano) are mineralised with quartz-scheelite veins; these dykes are of identical texture and mineralogy to a dyke that intrudes the Pampa del Tamboreo granodiorite at Puesto Tito (Sheet 3366-21). A maximum age of 470±5 Ma is therefore suggested for the formation of quartz-scheelite veinlets.
2. Relatively thin, fine to medium grained, feldspathic bands are present in the San Luis Formation (e.g. at La Riojita), and although they could represent metavolcanics, they are texturally distinct from the prominant porphyritic felsic bodies which at least in some cases are certainly dykes.
3. Quartz veins containing scheelite at Fortuna cross cut the Pampa del Tamboreo granodiorite, but xenoliths of biotite schist in the granodiorite are mineralised at Donosa (Sheet 3366-22; Brodtkorb and others, 1985).
4. Intense D_{3-4} deformation has resulted in transposition of compositional layering in large parts of the San Luis Formation, so that many of the porphyritic felsic bands are parallel to both the main foliation and to compositional layering in the metasediments.
5. Mineralised zones in some deposits are confined to structures interpreted to have formed during D_{3-4}, such as F_{3-4} fold hinges and F_{3-4} axial planes (e.g. Los Cocos).

6. Scheelite porphyroblasts in biotite schist at La Teodolina are wrapped by the main foliation which is a crenulation cleavage. Ramos (1992) suggested the scheelite porphyroblasts predated the crenulation cleavage; our observations concur with this conclusion, but we propose that the scheelite overgrew the earlier slatey cleavage. La Teodolina is situated within the D_{3-4} shear zone at the western contact of the San Luis Formation. Both foliations in this area are believed to have formed during D_{3-4} progressive deformation and low grade metamorphism, in the Devonian (Sims and others, 1997), implying a Devonian age of scheelite growth at La Teodolina.
7. Scheelite occurs in tourmaline-bearing pegmatites (e.g. La Teodolina, Ramos, 1992; and in mylonitic quartz-feldspar-tourmaline pegmatite at General Joffre), but the timing of pegmatite emplacement and of the scheelite in the pegmatites is not known.

Genesis: Previous interpretations of the timing and origin of W mineralisation in the La Florida - Pampa del Tamboreo - Santo Domingo belt may be grouped into two main hypotheses. (a) The W was syngenetic, associated with felsic volcanism, and was remobilised during deformation and metamorphism (Brodtkorb & Brodtkorb, 1975, 1979; Brodtkorb and others, 1985; Fernandez and others, 1991; Hack and others, 1991). (b) The W was epigenetic-syndeformational and formed from pneumatolitic or hydrothermal fluids related to granites (Stoll, 1963a,b; Carotti and others, 1985). Smith and González (1947) noted that scheelite postdated aplite dykes at the Santo Domingo deposit.

An alternative hypothesis, discussed in detail by Skirrow (1997a), is that W was introduced by hydrothermal fluids into the San Luis Formation and schists immediately to the west no earlier than ~470 Ma and most likely during the early Devonian, synchronous with D_3 compressive deformation. The major controls on localisation of scheelite were the presence of D_3 structures such as shear zones and folds, particularly where there were significant competancy contrasts between compositional layers. In the resultant dilational sites (felsic porphyry bodies, quartzites, granitoid contacts, etc), quartz±tourmaline±calcsilicate±fluorite vein networks developed. Scheelite precipitated preferentially in ‘chemical traps’: these consisted of calcic host rocks such as feldspar porphyry bodies, meta-arkosic layers and amphibole-bearing contact metamorphic zones (e.g. at the Pampa del Tamboreo granodiorite).

2.2 W DEPOSITS OF THE PASO GRANDE - VILLA PRAGA REGION

Several W deposits in the Villa Praga area (e.g. Cerrito Blanco, Piedras Coloradas) are hosted by the Devonian Las Chacras granite, and consist of quartz-wolframite veins (Angelelli, 1984). This relationship indicates either syn- or post-Devonian W vein formation. W deposits in the Paso Grande area are hosted by the Cambrian Conlara Metamorphic Complex.

2.3 SHEAR-ASSOCIATED AU AND W-AU QUARTZ VEIN DEPOSITS OF THE SANTO DOMINGO AND EL DURAZNITO DISTRICTS

Several small Au±W deposits are known from the Santo Domingo and El Duraznito districts in the Paso del Rey region. The geological setting of this region was summarised above, and the geology of the deposits was described by Angelelli (1984), Leveratto and Malvicini (1982) and Fernandez and others (1991).

Geology: The El Duraznito W (-Au) deposit occurs within a few hundred metres of the terrane boundary between the Conlara Metamorphic Complex to the east and San Luis Formation in the west. Leveratto and Malvicini (1982) described the host rocks to the vein system as fine grained quartz-muscovite schists and mylonitic. The veins are commonly 30-50 cm wide and form a zone ~150 m in width. The main paragenetic and structural stages are as follows.

1. Tourmaline veins trending 005-015° and dipping steeply east, and alteration of host rock
2. Quartz veining with similar orientation to tourmaline veins, accompanied by minor tourmaline, muscovite, rutile, pyrite and chalcopyrite
3. Brecciation of earlier veins, and infilling by quartz±scheelite
4. Quartz veining trending 015-030° and inclined 55-75° west, and containing wolframite, scheelite, native gold, bismuthinite, chalcopyrite, native bismuth, sphalerite, bismuth sulfosalts, pyrite, pyrrhotite, beryl, rutile and siderite
5. Cataclastic deformation

Hydrothermal alteration consists of carbonate, pyrite, quartz and feldspar(?) replacement of schist adjacent to veins. Leveratto and Malvicini (1982) interpreted both alteration and cataclastic deformation to have postdated the vein systems. Alternatively, the hydrothermal alteration may have been synchronous with quartz-W-Au-Bi vein formation, occurring during ductile deformation which produced boudinage of veins and mylonitic fabrics in host rocks.

The small Santo Domingo Au deposit occurs within a belt of quartz-scheelite vein deposits in a high strain zone in the San Luis Formation. Quartz veins between 0.2 and 1.2 m wide and vein networks are hosted by metapsammite and phyllite, and are subparallel to the mylonitic foliation. Veins show pinch-and-swell and gash shaped morphologies, and are interpreted to have formed synchronously with the mylonite. Zones of bleached and ferruginous (after pyrite?), argillic and/or sericitic altered wall rock in the vicinity of the quartz-pyrite-gold veins may be related to vein formation, or alternatively may have postdated vein formation. Relatively late, brittle, hematitic fault zones occur within the mylonitic metasediments. Gold has been reported in a number of other quartz-scheelite vein deposits in the Santo Domingo district (Fernandez and others, 1991), and antimony occurs in economic quantities in some of the Au-W occurrences (Rossello, 1987).

Genesis: The structural history of the Santo Domingo - El Duraznito area is complex, and the terrane boundary shear zone may have been reactivated many times between the early Ordovician and the Tertiary. Nevertheless, the principal mylonite fabrics in the San Luis Formation of the Santo Domingo district are interpreted to have formed during the Devonian D_3 compressive deformation (Sims and others, 1997). Scheelite at El Duraznito was suggested by Leveratto and Malvicini (1982) to have formed during regional metamorphism. We infer this metamorphism to have been the low grade event that accompanied D_3 deformation in the early Devonian. The structural style is similar to those of Au-quartz vein deposits in the Sierra de Las Minas (La Rioja) and the Candelaria district (Córdoba). It is therefore proposed that Au±W±Sb mineralisation associated with quartz veins in the Santo Domingo - El Duraznito formed syn-D_3, possibly during the early Devonian metallogenic event. The association of Au with W, B, Be, Bi and Sb is suggestive of a magmatic component in the ore fluids. Remobilisation of syngenetic volcanic-related Au, Sb and W during subsequent deformation events has also been suggested (Malvicini and others, 1991).

2.4 PEGMATITE-HOSTED DEPOSITS OF BE, TA, NB

Pegmatites in sheet 3366-16 host a number of significant sources of mainly Be and industrial minerals (e.g. mica, feldspar, quartz, etc.), with several Nb and Ta occurrences in the southwestern part of the sheet area.

The earliest pegmatites in the sierras de San Luis 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 Pringles Metamorphic Complex.

Herrera (1968) and Galliski (1993, 1994) 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 relatively small 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 (1991a) (types 3 and 4 of Herrera, 1968) are widely represented in the sierras de San Luis. 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 & Sosa, 1991). Internal zoning, dimensions, geometry and parageneses are described in the cited references.

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

2.5 PORPHYRY-STYLE CU (-AU) MINERALISATION OF THE DIENTE VERDE AREA

Quartz vein stockworks containing chalcopyrite, pyrite, pyrrhotite, magnetite, electrum, bornite, tennantite and supergene oxidation products occur in 9.5±0.5 Ma andesitic monolithic volcanic breccia at Diente Verde (Brogioni, 1990; Urbina and others, 1995; Sruoga and others, 1996). The occurrence has been worked for Cu from several small pits, but there is little evidence of recent exploration. The stockwork is exposed over an area of a few tens of metres diameter centrally within a cone-like volcanic edifice. Hydrothermal alteration is limited in the crater but an extensive zone of bleached argillic/sericitic altered volcanic breccia and lapilli tuff encompasses the volcanic edifice.

2.6 ALLUVIAL AU

Several well known aluvial Au districts occur in the 3366-16 sheet area, particularly on the Río de La Carpa. The aluvial Au deposits of the La Carolina, Cañada Honda (Sheet 3366-15) and Río de La Carpa districts were described by Bassi (1948, 1992), Rossello and Barboso (1988), and Rossello and Castro (1995), amongst others. Rosello and Castro (1995) proposed two types of gold placer deposits: Pleistocene-Holocene colluvial-alluvial deposits, and modern alluvial deposits that formed by reworking of the earlier placer deposits. The source of gold is presumed to be epithermal mineralisation associated with Miocene-Pliocene volcanism.

3. NON-METALLIC MINERAL OCCURRENCES

3.1 MICA, QUARTZ, FELDSPAR

Numerous pegmatite bodies have been worked for muscovite, quartz and feldspar and occur widely in the map area. As noted above, most of those mined for muscovite probably are members of the muscovite or primitive rare element classes of pegmatites, and formed during the early Famatinian extensional tectonism.

3.2 ONYX, TRAVERTINE

Travertine and calcareous onyx (calcite) and aragonite deposits (e.g. Cantera Santa Isabel) occur near Cerro Tiporco, 18 km NW of La Toma. The onyx occurs as mantos and veins hosted by Miocene to Pliocene epiclastic sediments and volcanics (Lacreu, 1990, 1992, 1995). An epigenetic (Pliocene) hydrothermal origin for the onyx was proposed by Lacreu (1990, 1992, 1995). Oxygen and carbon isotope analyses of carbonates from Santa Isabel and travertines were reported by Lacreu (1995).

Pliocene to Pleistocene travertine occurs in ten mapped bodies within 5 km of Cerro Tiporco, and represent low temperature hydrothermal activity associated with Miocene-Pliocene volcanism (Lacreu, 1990, 1992, 1995).

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ARGMIN

MINERAL DEPOSIT DATABASE

OUTPUT DATA SHEETS