Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3366-15

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 3366-15 map area forms an east-west transect within San Luis Province; ~46km by ~40km between 32°40’-33°00’ S and 66°00’-66°30’ W. The area includes parts 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 covers the main range of the Sierras de San Luis and incorporates the minor population centres of La Carolina and Nogoli. The area is traversed by national route 146 and provincial routes 3, 38, 45 and 46. The main drainage is via Río Nogoli, Río Amieva, Río Claro and Río Grande.

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).

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

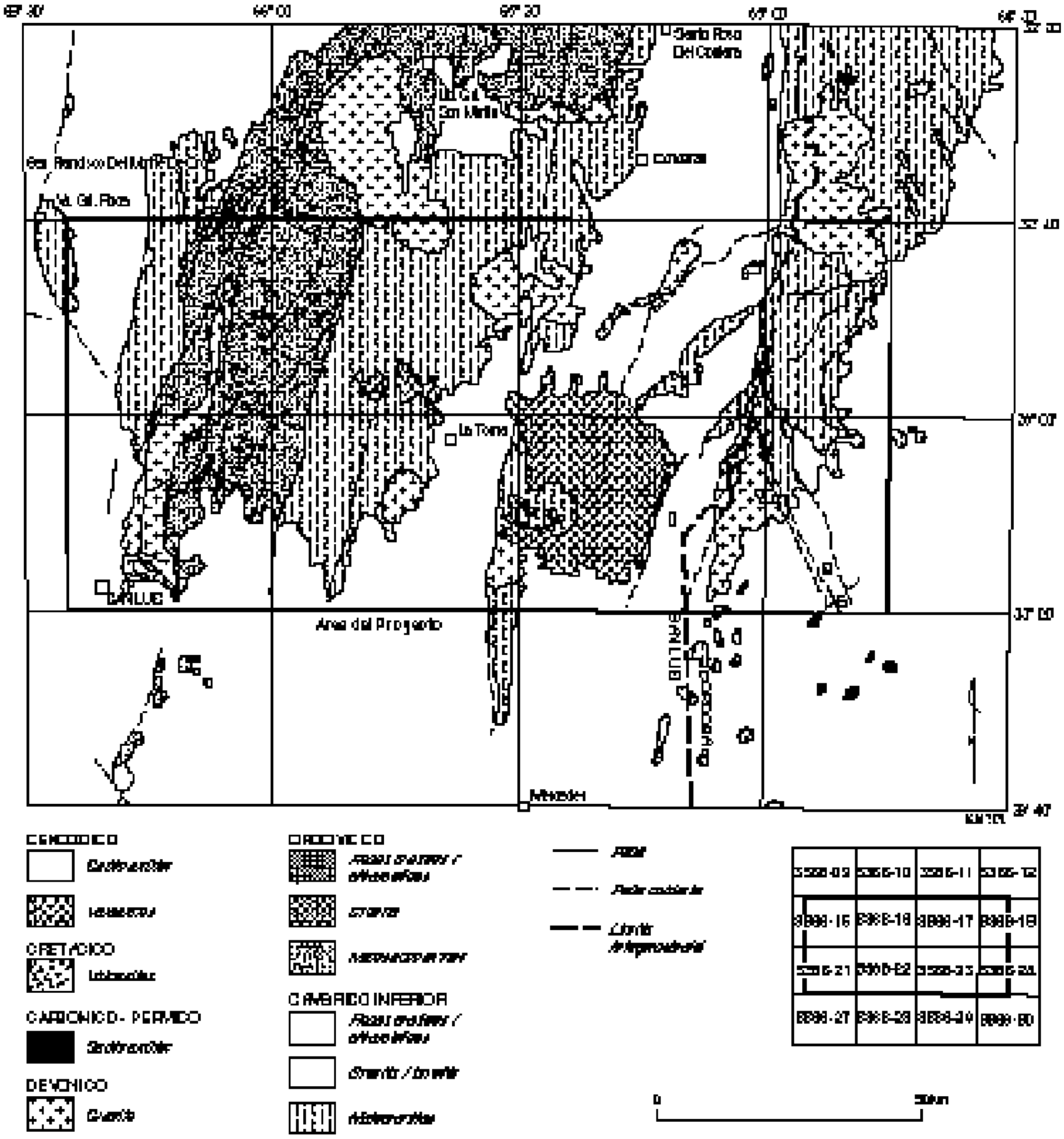

Figure 2. Location of the *Sierras de San Luis y Comechingones* 1:250,000 scale map area in San Luis and Córdoba Provinces with generalised geology. Locations of 1:100,000 scale map areas are indicated.

1.3 PREVIOUS INVESTIGATIONS

Previous regional geological mapping was at a scale of 1:200 000 and included investigations by Pastore and Gonzalez (1954) of San Fransisco (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 the 3366-15 consist of the Nogoli Metamorphic Complex in the west of the map sheet. 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 Ordovician domain is intruded by a voluminous Early Devonian granite and is 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 3366-23.

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 the 3366-15 consists of three main subdivisions that relate directly to the geological ages of the units. The first subdivision represents basement rocks of at least Cambrian age (the Nogoli Metamorphic Complex) that was 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.

2.2.2 CAMBRIAN

Nogoli Metamorphic Complex (Ꞓn)

Felsic and mafic orthogneiss, paragneiss, monzonite and quartz-monzonite.

The Nogoli Metamorphic Complex represents the NW region of the Sierras de San Luis, in the region of the township of Nogoli, from which the name is derived. The complex is best exposed along the western escarpment of the Sierras de San Luis and within the deeply incised rios de la Quebrada, del Molle and Amieva. Additionally, a poorly outcropping region of basement rocks, largely defined from geophysical and satellite imagery, occurs to the northwest of the main San Luis Fault-escarpment and is tentatively included within the Nogoli Metamorphic Complex. The eastern boundary with the younger Pringles Metamorphic Complex is probably a tectonic contact but may represent an original terrane boundary, while the boundary with the Ordovician San Luis Formation is represented by a Tertiary thrust fault that may be a reactivated Devonian structure.

The Nogoli Metamorphic Complex comprises undifferentiated felsic and mafic orthogneiss of probable early Cambrian age, and pelitic gneiss of probable late Neoproterozoic to early

Cambrian age, though an older Proterozoic age for the metasediments could not be discounted at this stage. Felsic orthogneiss dominates with subordinate lenses and pods of mafic gneiss (dominantly amphibolite) that preserve complex and discordant, high-grade, structural fabrics. The basement gneiss is intruded by numerous co-magmatic monzonite and quartz-monzonite bodies that occur as both discrete mappable plutons (e.g., Río del Molle Monzonite) and as dykes at various scales. The aeromagnetic signature of the complex is relatively low with local anomalies probably related to amphibolite bodies or monzonite intrusions.

The strongly foliated felsic orthogneiss consists dominantly of recrystallised quartz, feldspar and biotite, with muscovite usually developed as a late retrograde phase. In some localities rare K-feldspar porphyroclasts are preserved within the felsic orthogneiss. Subordinate mafic gneiss occurs as layers and boudinaged pods within the felsic orthogneiss and pelitic gneiss, and consists of seriate hornblende, plagioclase, quartz and biotite, with retrograde epidote.

Minor outcrops (and extensive talus of very large boulders up to 15m diameter) consisting predominantly of high-grade pelitic gneiss occur within the Río Amieva. The metapelite consists of a peak metamorphic assemblage of quartz-feldspar-cordierite-sillimanite-biotite with a well developed gneissic fabric, and local spectacular, discordant networks of cordierite bearing leucosome cross-cutting the gneissosity. Additionally, numerous boudinaged pods of amphibolite occur within the gneissic fabric.

The earliest pervasive (concordant) gneissic fabric within the complex trends in a west to northwesterly direction. This early fabric is folded and partially retrogressed through muscovite replacing sillimanite, and is overprinted by subvertical to steeply east-dipping shear zones up to tens of metres in width that trend in a northerly direction. These latter zones, which have recrystallised and retrogressed the early high-grade assemblages, display multiple reactivation with contrasting shear-sense and range in metamorphic grade from amphibolite- to greenschist-facies. Mafic orthogneiss in one of these mylonite zones is characterised by an intense foliation defined by biotite, quartz ribbons and lineated hornblende, with the hornblende partially replaced by biotite, zoisite, clinozoisite and epidote. The latest (low-grade) mylonitic reactivation of these zones, with east-up shear-sense, is correlated with the pervasive Devonian deformation that is associated with the Achalian Tectonic-Cycle.

The Nogoli Metamorphic Complex is clearly distinguished from the Pringles Metamorphic Complex by the significant pre-Ordovician orthogneiss component and lower magnetic response (Hungerford and others, 1996), and probably represents at least an Early Cambrian terrane equivalent to the Conlara and Monte Guazú complexes further to the east.

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 three areas in the Sierras de San Luis, between the Conlara Metamorphic Complex in the east and the Nogoli Metamorphic Complex in the west. The easternmost and largest outcropping region occurs in a continuous north-south belt dissecting the sierras and forms the eastern portion of 3366-15. This belt is fault bound to the west by the San Luis Formation and is well exposed in road cuttings beween Trapiche and La Carolina on Provincial route 9, and within Río Grande and Río de la Cañada Honda. The Pringles Metamorphic Complex is further exposed to the northwest of the Escalerilla Granite in two regions: the first of these is a small area in contact with the granite in the geographically high portion of the sierras, while the second region occurs further to the north in a deeply incised and poorly accessible area towards the township of San Fransisco del Monte de Oro.

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 (up to 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. Only the western belt is exposed in 3366-15, where it is no more than 3 km wide and passes through Carolina and extends discontinuosly southwards on both the eastern and western margins of Escalerilla Granite. The San Luis Formation is well exposed in low rolling hills west of Carolina and within Río Grande adjacent to Escalerilla Granite.

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 was strongly sheared during the Devonian, with kyanite, staurolite and garnet bearing assemblages 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. Black shales are locally associated with a dominantly fine-grained sequence southwest of Las Verbenas. 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 deformationsresulted in tight to isoclinal, upright to inclined folds with a well-developed, axial planar, slaty cleavage in most rock-types. The second deformation, resulted in the development of discrete shear zones, separated by domains of open refolding with a corresponding crenulation cleavage. Additionally, a very early foliation 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 (e.g. von Gosen & Prozzi, 1996). The magnetic signature of the San Luis formation is generally low in 3366-15.

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.

2.3 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. Mappable ultramafic and mafic units appear to be restricted to a number of intrusions within a belt approximately 5 km wide and approximately 50 km long within gneiss of the Pringles Metamorphic Complex, and to a small body just west of Escalerilla granite. 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 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.

Bemberg suite (Otb)

Granodiorite, Tonalite and Gabbro

A suite of intermediate to mafic intrusives called the Bemberg suite (Sims and others, 1997) are exposed in the Sierras de San Luis to the southwest of Carolina. The suite is wholey contained within the Ordovician San Luis Formation and consists of three main plutons, the Gasparillo, Las Verbenas and Bemberg tonalites, and a number of dykes and smaller unnamed plutons. Previous studies on these intrusives have been carried out by Sato and Llambías (1994), Sato and others (1996), Sanchez and others (1996) and Llambías and others (1996b). Sato and Llambías (1994) have previously classified these plutons as "granitoides pre-cinemáticos".

The Bemberg suite intrudes low-grade rocks of the San Luis Formation and have produced a contact aureole within those rocks defined by cordierite (von Gosen & Prozzi, 1996). Llambías and others (1996b) have described pendants of early high-grade gneiss within the western margin of the Gasparillo Tonalite, while the Las Verbenas Tonalite is cross-cut by the early Devonian Escalerilla Granite. U/Pb geochronology of zircon separates from the Bemberg Tonalite has produced an early Ordovician age of 468 ± 6 Ma (Camacho & Ireland, 1997).

The Bemberg suite are dominantly tonalites but consist of multiple intrusive phases that range from granodiorite to gabbro in composition and include minor dykes of granitic composition (Sanchez and others, 1996; Sato and others, 1996). The tonalites are comprised dominantly of plagioclase, quartz, biotite and hornblende, and subordinate epidote (Sanchez and others, 1996). K-feldspar comprises less than 2% and accessory phases include titanite, apatite, allanite and magnetite (Sato and others, 1996; Llambías and others, 1996b). The average magnetic susceptibility of the tonalites is 28 x 10^{-5} SI.

The Bemberg suite are affected by regional tectonism in the Devonian (Achalian Tectonic Cycle), and Sato and others (1996) report an irregularly developed metamorphic foliation as well as brittle and ductile shear zones developed within the intrusives.

Río del Molle Monzonite (Omzm)

The Río del Molle Monzonite is an elongate, composite body approximately 3km long and 1.5km in width that is exposed in Río del Molle east of the township of Nogoli. The intrusion consists of various comagmatic phases of monzonite and quartz-monzonite

This body contain numerous discordant xenoliths and rafts of the basement gneiss. Although there are no isotopic constraints for the monzonite, the regional structural relations and apparent continuity of this belt with the Sierra de las Minas, in La Rioja province, where early Ordovician ages have been derived for various granitic to tonalitic intrusives (Pankhurst and others, 1996; Pieters and others, 1997; Camacho & Ireland, 1997), suggests an early Ordovician emplacement age.

Outcrops of the monzonite and quartz-monzonite are typically rich in porphyritic K-feldspar (up to 50% in quartz-monzonite) and plagioclase. Quartz comprises less than 10% of modal abundance and the major mafic phases are biotite (10-30%) and hornblende (2-25%). Accessory phases include primary epidote, aegirine-augite, zoisite, sphene and allanite, and the more mafic phases of the suite contain minor sulphides (dominantly chalcopyrite). Magnetic susceptibilty is generally low, being less than 91 x 10^{-5} SI in monzonite and less than 22 x 10^{-5} SI in quartz-monzonite, though local anomalous readings do occur adjacent to visible sulphides. Geochemically, the Nogoli Suite are in the range of ~50-60% SiO_2 and is oxidised. Trace elements Ba, Sr, Zr, Ce, La are particularly high and Rb is low (Sims and others, 1997). Deformation and metamorphosism under amphibolite-facies conditions has heterogeneously recrystallised these intrusions and folded and crenulated the earlier fabrics within the xenoliths.

2.3.2 DEVONIAN INTRUSIVES

Escalerilla Granite (Dge)

The Escalerilla granite is a large elongate granite with positive relief that forms the main range of the Sierras de San Luis. The granite varies from less than 1 km, to around 8 km in width along an outcrop length of approximately 55 km. The northernmost extent of the granite is exposed at Carolina. Numerous roads, *ríos* and *arroyos* cross the granite along its entire length.

The granite intrudes basement rocks of the Pringles Metamorphic Complex and the San Luis Formation as well as the Las Verbenas tonalite, and contains xenoliths and rafts of all three rock-types. The granite truncates the main structural fabric within the Pringles Metamorphic Complex and is cross-cut by numerous veins and dykes of pegmatite and granite. U/Pb zircon geochronology of zircon separates indicates the Escalerilla granite crystallised at 403 ± 6 Ma (Camacho & Ireland, 1997).

The granite is grey to pink and contains up to 30% porphyritic K-feldspar and 25% plagioclase. Biotite comprises up to 10% and muscovite up to 5% of the total rock and accesory phases include sphene, epidote, apatite, clinozoisite and ilmenite. The pluton is non-magnetic.

Quartz (<30%) and biotite are extensively recrystallised and define a mylonitic foliation that is associated with a least two different styles of deformation. The dominant and pervasive fabric is steeply east dipping with a steeply plunging mineral lineation defined by biotite and muscovite with a shear-sense of east over west. K-feldspar porphyroclasts are mechanically rotated in the foliation and are weakly aligned with the lineation. The sub-ordinate mylonitic foliation is generally north trending and is strongly partitioned within the granite, it is sub-vertical in orientation with a sub-horizontal mineral lineation defined by biotite. K-feldspar is partially recrystallised within these shear zones. Various shear-sense indicators show a sinistral displacement sense.

2.3.3 MINOR DYKE ROCKS

Pegmatite (peg)

Numerous pegmatite dykes intrude the basement of 3366-15. There are essentially four main subdivisions:

1. Pegmatites emplaced during M1 metamorphic peakin the Middle Cambrian, at around 530-515 Ma. These are restricted to within the Nogoli Metamorphic Complex on this mapsheet.

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-M2 in 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.

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* (Sims and others, 1997) 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 (1987, 1990). Only the volcanic centres of La Carolina and Cañada Honda are represented on 3366-15. A general description of the volcanic centres is presented in **Table 1**.

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 1. 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 *(Tres Cerritos)* *(C° Tomolasta)* *(C° Pan de Azucar)* *(not specified)*	 8.2 ± 0.4[3] 7.5 ± 0.4[2] 7.3 ± 0.4[2] 6.3 ± 0.3[3]	Range of volcanic plugs and domes, minor pyroclastic deposits and subvolcanic breccias. Extensive alteration of host rocks. Basement deeply eroded (~300m?). NW trending faults
Cañada Honda *(Diente Verde)*	 9.5 ± 0.5[2]	Range of volcanic plugs and domes. Extensive alteration of host rocks. Basement deeply eroded (~200m?)
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 *(not specified)* *(not specified)* *(not specified)*	 6.4 ± 0.6[1] 2.6 ± 0.6[1] 1.9 ± 0.2[1]	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.

The volcanic rocks (labelled Tva) include plugs, domes, dykes, sills and minor lavas and range in composition from basaltic andesite to dacite. Brogioni (1987) also reports rocks of latitic to trachytic composition. Chemically the volcanic rocks fall within the calc-alkaline to shosonitic series (Sims and others, 1997).

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.

The more deeply eroded volcanic centres in the northwest, are associated with significant epithermal alteration and minor (to date) precious metal (Au-Ag) mineralisation. These deposits are covered in more detail in the Economic Geology section.

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* (Sims and others, 1997) 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.

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, 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.

SECTION II: ECONOMIC GEOLOGY

By Roger G. Skirrow

1. INTRODUCTION

The 3366-15 1:100 000 map area contains a wide range of metallic and industrial mineral occurrences, including Au (Ag, Pb, Zn) in the La Carolina district, W in the Pancanta and San Román districts, and Be, Li, Nb, Ta and Sn in several districts.

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: SAN ROMÁN - PANCANTA W BELT

Numerous W occurrences are present in the 3366-15 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 represented in the 3366-15 map sheet by deposits in the Pancanta district south of La Carolina. Wolframite-quartz veins of style (ii) are evidently restricted to the La Carolina - San Román district. 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. Type (iii) calcsilicate-associated scheelite occurrences are confined to mainly the Conlara Metamorphic Complex to the east of the Río Guzman Shear Zone where calcsilicate rocks, metacarbonates and amphibolites are intercalated with metapelitic rocks. The major districts of style (iii) W mineralisation are situated in the sierras del Morro, Los Morillos, Yulto and La Estanzuela.

Regional setting: Two belts of the San Luis Formation occur to the west of the Río Guzman Shear Zone (Sims and others, 1997), and represent thrust slices that developed during compressive deformation in the Devonian. The San Román - Pancanta W belt is located in the western of the two thrust slices of San Luis Formation, which is separated from the early Devonian Escalerilla granite by a major D_3 shear zone (Sims and others, 1997).

Geology: W mineralisation of the Pancanta district consists of quartz-scheelite veins up to 0.6 m wide hosted by granitoid (Angelelli, 1984) and metasedimentary schists of the San Luis Formation. Some quartz-scheelite veins occur near lamprophyre dykes that intrude the granitoid, and are associated with tourmaline and epidote alteration (Angelelli, 1984). Descriptions in the literature suggest the W in the Pancanta district is of style (i).

W mineralisation in the San Román district 2 km south of La Carolina comprises large tabular to lens shaped quartz veins up to 2 m wide with wolframite and scheelite (style (ii)). The veins are hosted by sheared metapelitic and metapsammitic rocks of the San Luis Formation, within ~300 m of the Escalerilla granite. Intense shearing of host rocks and quartz veins along the western contact zone of the granite has resulted in transposition of compositional layering in the metasediments into parallelism with the veins and with the main shear foliation. Boudinaged quartz veins and granite blocks with quartz pressure shadows near Galeria A (see Fig. 130, Angelelli, 1984) indicate shearing was synchronous or postdated granite and vein emplacement. Reverse movement on the shear zone here was west-over-east, as indicated by assymetric shear bands in the metasediments. Minor quartz veins within the margin of the granite are of unknown genetic relationship to the W-bearing veins but probably formed during shearing.

In addition to wolframite and scheelite, the recrystallised saccharoidal quartz veins contain minor white mica, tourmaline, pyrite, chalcopyrite, native bismuth and other bismuth(?) minerals. Hydrothermal alteration of the host rocks within 1-2 m of veins consists of tourmaline and white mica. Tourmaline forms a lineation which pitches in the same orientation as biotite in the sheared metasediments, suggesting hydrothermal alteration was pre- or more likely syn-shearing.

Genesis: Given the early Devonian age of the Escalerilla granite (Sims and others, 1997), and spatial and possible temporal association of the veins in the San Román and Pancanta districts with D_3 shearing (Sims and others, 1997), it is likely that the W veins were emplaced in the early Devonian D_3 compressive deformation, and may be genetically related to the Achalian Escalerilla granite. The association with granite was recognised by Malvicini and others (1991) but the Escalerilla granite was believed to have been Famatinian.

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

Pegmatites in sheet 3366-15 host a number of significant sources of Be, Li, Nb, Ta, Sn and industrial minerals (e.g. feldspar, quartz, mica, etc.).

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, 1993) described muscovite-rich K-feldspar-quartz pegmatites from other regions of the Sierras Pampeanas (type 2 of Herrera, 1968; transitional between muscovite and rare element classes of Cerný (1991) according to Galliski, 1993, 1994). These are a major economic source of muscovite, and 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 (1991) (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). Several of the Sn-enriched pegmatites occur in sheet 3366-15. 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).

2.3 EPITHERMAL AU-AG (-PB-ZN) MINERALISATION OF THE LA CAROLINA DISTRICT

The La Carolina district in the Sierra de San Luis has been mined intermittently for Au, Pb and Zn since the 1880's, from primary hydrothermal mineralisation hosted mainly by Tertiary volcanic rocks and from alluvial deposits. The principal exploited primary precious and base metal mineralisation occurs at the La Carolina (Esperanza), La Estancia and La Rica mines. More recently, numerous prospects were delineated in a ~20 square kilometre area in the La Carolina district during exploration by the Dirección Nacional de Fabricaciones Militares between 1986 and 1988. Subsequent exploration until 1990 was carried out by Carolina SAM, an association of Dirección Nacional de Fabricaciones Militares with Minera Mincorp (Anglo American and Perez Compang) (Beninato and others, 1994). During this period 65 diamond drill holes, 570 percussion holes, trench and soil geochemical sampling and geological mapping were completed. Diamond drill hole intersections included 9m @ 4g/t Au (La Ilusión) and 6m @ 2.5 g/t Au, 122 g/t Ag, 0.3% Pb, 0.5% Zn (Cerro Mogote).

Regional setting: Regional geology of the basement in the La Carolina district has been previously discussed by numerous workers (see Sims and others, 1997), including Pastore and Gonzalez (1954), Kilmurray and Villar (1981), Ortiz Suárez and others, (1992), Bassi (1992) and von Gosen and Prozzi (1996). A regional zone of mylonitic shears trending NNE through the vicinity of La Carolina separate greenschist facies metasediments of the San Luis Formation in the west from older amphibolite facies metasedimentary biotite±muscovite±garnet±graphite schists, gneisses and migmatites in the east. Intense penetrative deformation fabrics in metapsammites and metapelites of the San Luis Formation were generated during the Devonian D_3 and D_4 compressive events (Achalian cycle), whereas fabrics in the amphibolite facies rocks developed initially in the early Ordovician during D_1 and D_2 (Famatinian cycle), and were overprinted by the Devonian deformation (Sims and others, 1997). Pegmatites and minor amphibolite zones occur within the schist, gneiss and migmatite. The 403±6 Ma Escalerilla granite (Camacho & Ireland, 1997) extends from La Carolina southwards for >45 km.

Calcalkaline to shoshonitic, intermediate to felsic, volcanic rocks of the La Carolina district form the northwestern part of an ~80 km linear Miocene-Pliocene volcanic belt that extends southeastwards to the Sierra del Morro (Llambías & Brogioni, 1981; Brogioni, 1987, 1988, 1990; Ramos and others, 1991). Nine K-Ar radiometric dates ranging from 9.5±0.5 Ma to 1.9±0.2 Ma were reported by Ramos and others (1991), Urbina and others (1995) and Sruoga and others (1996). The available dates indicate that between ~9.5-6.3 Ma andesite to trachyte were erupted in the northwestern (La Carolina - Cañada Honda) and southeastern (El Morro) parts of the belt, while andesitic volcanism occurred in the central Cerros de Rosaria area. Younger andesitic to trachyandesitic volcanism (2.6-1.9 Ma) occurred in the central and southeastern parts of the belt.

Geology: Volcanic rocks of the La Carolina to Sierra del Morro belt comprise domes, lava flows, dykes, and volcaniclastic rocks including breccias, lapillistones and tuffs (Brogioni, 1987, 1990; Urbina and others, 1995; Sruoga and others, 1996). Several volcaniclastic breccia facies have been described: autoclastic, hydrothermal, 'explosion' and pyroclastic. The 'explosion' breccias are believed to have resulted from phreatomagmatic activity that preceded dome emplacement (Sruoga and others, 1996). The presence of possible base-surge deposits (Brogioni, 1990; Sruoga and others, 1996) together with 'explosion' breccias led Sruoga and others (1996) to suggest a maar-diatreme environment of volcanism in the La Carolina area. Hydrothermal breccias are spatially associated with both the domes and 'explosion' breccias, and they commonly occur in arc-shaped lenses (Sruoga and others, 1996). The arcs may represent segments of subcircular fracture systems. A diatreme model had previously been applied to gold exploration in the district by the Dirección Nacional de Fabricaciones Militares, and at least three diatremes up to 2 km diameter were identified (Beninato and others, 1994). However, some of the diagnostic features of a maar-diatreme environment such as intra-maar deposits and well defined annular fracture systems are not clearly evident, and may have been removed or obscured by erosion.

Alteration and mineralisation: Currently known primary precious and base metal mineralisation and hydrothermal alteration zones are restricted to the La Carolina - Cañada Honda area. Hydrothermal alteration of volcanics and to a lesser extent metamorphic basement rocks in an area totalling at least 9 km^2 was mapped by Bassi (1992), the Dirección Nacional de Fabricaciones Militares (Beninato and others, 1994), Urbina and others (1995) and Sruoga and others (1996). Alteration types reported in these studies, and confirmed in the present work, include: argillic, sericite-pyrite, silicification, and propylitic (chlorite-carbonate-hematite±epidote±pyrite). In addition, sericite-adularia was reported by Urbina and others (1995), and minor alunite occurs the La Rica deposit (Malvicini & Urbina, 1995). Alteration assemblages appear to be zoned around precious-base metal mineralisation in the La Carolina district, as follows (see Table 1):

- Distal, propylitic, chlorite-carbonate-hematite±montmorillonite±mixed layer clay zones (e.g. alteration of latite, Cerro Tomalasta, A95RS088), which may or may not be directly related to mineralisation.
- Argillic (illitic±mixed layer clay) and sericite±pyrite zones up to several hundred metres wide (e.g. alteration zone south of historical La Luisa mine, A95RS110).
- Core zones up to a few metres wide consisting of silica-pyrite±illite±sericite± calcite± adularia±pyrophyllite±alunite±jarosite, and containing Au, Ag, Pb and Zn mineralisation (e.g La Estancia, A95RS105; Cerro Mogote, A95RS113).

Metamorphic muscovite, garnet and graphite are partially preserved in these alteration assemblages (e.g. La Estancia, La Rica).

Table 1. X-ray diffraction (XRD) results for hydrothermally altered samples from the La Carolina district, Sierras de San Luis.

Occurrence	**Sample number**	**Alteration & mineralisation**	**Diagnostic minerals detected by XRD**
La Carolina Au	A95RS084B, 099B	Argillic; disseminated pyrite & Cu minerals	illite (*whph 0.3, #I=250); sericite or muscovite (whph 0.13); chalcanthite; possible jarosite; feldspar
La Estancia Au-Ag-Pb-Zn	A95RS105B	Silicification; argillic; disseminated pyrite, sphalerite, galena;	illite (whph 0.38 & 0.52, I=200); possible feldspar; possible pyrophyllite; possible jarosite; calcite
Cerro Mogote Au	A95RS113	Silicification with disseminated sphalerite, galena	illite-sericite/muscovite (whph 0.27, I=500); alunite; pyrophyllite
Cerro Tomolasta	A95RS088B	Propylitic and argillic; no mineralisation	illite (whph 0.29, I=60); mixed layer clay; kaolinite; calcite; hematite; chlorite
La Luisa	A95RS110	Argillic	sericite or muscovite (whph 0.17 & 0.12, I=350); mixed layer clay (whph 0.53, I=110); K-feldspar; possible jarosite

*whph: width at half peak height; together with peak intensity (I), the whph is related to crystallinity of the mica and hence to its temperature of formation - broader peaks representing lower temperatures
#I: peak intensity

Zones of intense argillic and sericitic alteration occur in the following settings:

1. In association with ‘explosion’ and hydrothermal breccias, within inferred diatreme structures (Dirección Nacional de Fabricaciones Militares, Beninato and others, 1994; Urbina and others, 1995; Sruoga and others, 1996);
2. At the intersections of NW- and NNE-trending fracture zones in metamorphic basement, e.g. (Bassi, 1992), for example at La Estancia the mineralisation occurs in a WNW trending Tertiary(?) fault zone cutting a NNE-trending silicified pre-Tertiary mylonite zone;
3. In annular zones encompassing volcanic centres (e.g. Diente Verde, Sruoga and others, 1996);
4. spatially associated with breccia dykes in volcanics and basement metamorphics (e.g. La Carolina, La Rica, La Luisa).

At the La Carolina, La Rica and La Luisa Au-Ag-Pb-Zn workings, the intense argillic and sericitic alteration with pyrite is centred on heterolithic breccia dykes (10's of cm to >5m wide) that are composed of angular, unsorted, metamorphic wall rock and unvesiculated volcanic clasts in a comminuted rock matrix. The breccia dykes and spatially associated alteration follow pre-existing foliation and compositional layering orientation in metamorphic wall rocks (e.g. La Carolina, A95RS084, 099), or cross cut this orientation (e.g. La Rica, A95RS108). The dykes are interpreted to have formed by phreatomagmatic processes, and may have been permeable zones through which hydrothermal fluids were focussed. The dykes are overprinted by the argillic, sericitic, pyritic and silicic alteration. The 'hydrothermal' breccias described by Urbina and others 1995) and Sruoga and others (1996) have similar clast makeup and fabrics (e.g. Cerro Mogote) to the breccia dykes at La Carolina and La Rica, but are intensely silicified. They may be either true hydrothermal breccias or phreatomagmatic (diatreme-related?) breccias that have been overprinted by intense hydrothermal alteration and mineralisation which was focussed on these permeable zones.

Precious and base metal mineralisation consists of free gold and/or electrum associated with pyrite, sphalerite, galena, marcasite, chalcopyrite, wurtzite, tennantite-tetrahedrite, arsenopyrite, pyrrhotite, and pearcite-polybasite (Bassi, 1992; Malvicini & Urbina, 1995; Urbina and others, 1995). Trace enargite was reported at La Rica by Malvicini and Urbina (1995). The precious and base metal minerals at La Estancia, La Rica and Cerro Mogote occur in subvertical, massive to finely banded and brecciated, fine-grained, quartz-pyrite-clay replacement zones of a few centimetres to metres in width. Common vughy domains are filled with fine grained euhedral quartz and sulfides. Contacts of siliceous mineralised zones with less silicified, argillic-sericite altered breccia and metamorphic rocks are gradational. According to Bassi (1992) gold at the La Carolina deposit occurs in a "vein-like body in the west wall of a lenticular quartzite horizon". Observations in the present study suggest that intense argillic and sericite-pyrite alteration is associated with a 10 m wide breccia dyke; 'quartzite' and a 'vein-like' mineralised zone were not identified in surface workings. The altered breccia dyke contains disseminated Cu sulfate (7525 ppm Cu) and anomalous Au, Zn and Pb (A95RS084B).

Genesis: It is widely accepted that the hypogene Au-Ag mineralisation of the La Carolina district formed contemporaneously with Mio-Pliocene volcanism. The predominace of sericitic alteration and presence of adularia in some mineralised zones led Malvicini and Urbina (1995), Urbina and others (1995) and Sruoga and others (1996) to conclude that the epithermal mineralisation was of the sericite-adularia or low sulfidation type. However, in recognition of the (minor) alunite and enargite in some deposits, and reported ‘sinter’, these authors suggested a hot spring environment of mineralisation. The disseminated style of Au mineralisation in narrow siliceous pyritic replacement zones and presence of pyrophyllite (Table 1) are also indicative of extremely acid, relatively high temperature conditions (probably >270°C). These mineral assemblages, including enargite, are similar to those of high sulfidation epithermal systems, and it is probable they are the product of reaction of magmatic volatiles (e.g. SO_2, CO_2) with groundwaters (Sillitoe, 1993). Influx of such magmatic fluids is supported by oxygen isotope compositions of quartz in the mineralised zones (Skirrow, 1997a). Low sulfidation epithermal veins, by contrast, are conventionally interpreted to have formed from fluids of meteoric origin (e.g. Field & Fifarek, 1985). These observations may be reconciled in an alternative genetic model involving:

1. early, relatively deep epithermal, high temperature, high sulfidation style alteration (and Au, Ag mineralisation?) in narrow zones associated with phreatomagmatic activity,
2. erosion of the upper parts of the hydrothermal systems,
3. overprinting by broad zones of lower temperature, adularia-calcite bearing alteration (and Pb-Zn±Au, Ag mineralisation?) in a shallower epithermal setting.

2.4 ALLUVIAL AU OF THE LA CAROLINA DISTRICT

The La Carolina district and particularly the Cañada Honda area, is well known for its alluvial gold deposits, some of which are currently being exploited. The deposits 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.

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ARGMIN

MINERAL DEPOSIT DATABASE

OUTPUT DATA SHEETS