

Report on
1:100 000 Scale Geological and Metallogenic Maps
Sheet 3366-22
Province of San Luis

John P. Sims and Roger G. Skirrow

*GEOSCIENTIFIC MAPPING OF THE SIERRAS PAMPEANAS ARGENTINE-
AUSTRALIAN COOPERATIVE PROJECT*

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

1997

CONTENTS

	Page
SECTION I: GEOLOGY	1
1. INTRODUCTION	1
1.1 Location and access.....	1
1.2 Nature of work	1
1.3 Previous investigations.....	4
2. STRATIGRAPHY	5
2.1 General Relations	5
2.2 Palaeozoic Metamorphic Basement	7
2.2.1 Introduction.....	7
2.2.2 Cambrian	7
<i>Nogoli Metamorphic Complex</i>	7
2.2.3 Cambro-Ordovician	10
<i>Pringles Metamorphic Complex</i>	10
2.2.4 Ordovician	11
<i>San Luis Formation</i>	11
2.2.5 Devonian	13
<i>Río Guzman Shear Zone</i>	13
2.3 Palaeozoic Igneous Rocks	14
2.3.1 Ordovician Intrusives	14
<i>Undifferentiated granitoids and pegmatites</i>	14
<i>Tamboreo Granodiorite</i>	15
2.3.2 Devonian Intrusives	16
<i>San José del Morro Granite</i>	16
<i>Totora Granite</i>	16
2.3.3 Minor Dyke rocks	17
2.4 Tertiary volcanics	19
<i>San Luis Volcanic Group</i>	19
2.5 Cainozoic	21
<i>Unconsolidated cover</i>	21
2.6 Quarternary.....	22
<i>Unconsolidated deposits</i>	22
3. TECTONICS	23
3.1 Pampean Cycle.....	23
3.2 Famatinian Cycle.....	25
3.3 Achalian Cycle	26
3.4 Andean Cycle	29
4. GEOMORPHOLOGY	30
5. GEOLOGICAL HISTORY	31
5.1 Early Cambrian sedimentation	31
5.2 Pampean Cycle.....	32
5.3 Early Palaeozoic turbidite sedimentation.....	32

5.4 Famatinian Cycle.....	32
5.5 Achalian Cycle	33
5.6 Carboniferous - Permian sedimentation.....	34
5.7 Mesozoic sedimentation and magmatism	35
5.8 Andean Cycle	35
SECTION II: ECONOMIC GEOLOGY	36
1. INTRODUCTION.....	36
2. METALLIC MINERAL OCCURRENCES	38
2.1 W deposits of the La Florida - Pampa del Tamboreo districts	38
2.2 W deposits of the sierras de Los Morillos and Yulto	42
2.3 Pegmatite-hosted deposits of Be, Li	46
3. NON-METALLIC MINERAL OCCURRENCES	47
3.1 Mica, quartz, feldspar	47
BIBLIOGRAPHY.....	48
ARGMIN Database Output Sheets.....	59

SECTION I: GEOLOGY

by John P. Sims

1. INTRODUCTION

1.1 LOCATION AND ACCESS

The 3366-22 map area forms an east-west transect within San Luis Province; ~46km by 40km between latitude 32°00'-33°20' S and longitude 65°30'-66°00' W. The area includes parts of two 1:250 000 scale map sheets: San Luis (3366-III), and Sierras de San Luis y Comechingones.

The area covers the southeastern Sierras de San Luis and western sierras del Yulto and Los Morillos and incorporates the minor population centres of La Toma, Saladillo, and Juan Llerena. The area is traversed by national route 148 and provincial routes 2, 10, 17 and 41, with the main drainage via Río Quinto, Río Rosario, Río Guzman, Río de la Cañada Honda and Arroyo Saladillo.

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.

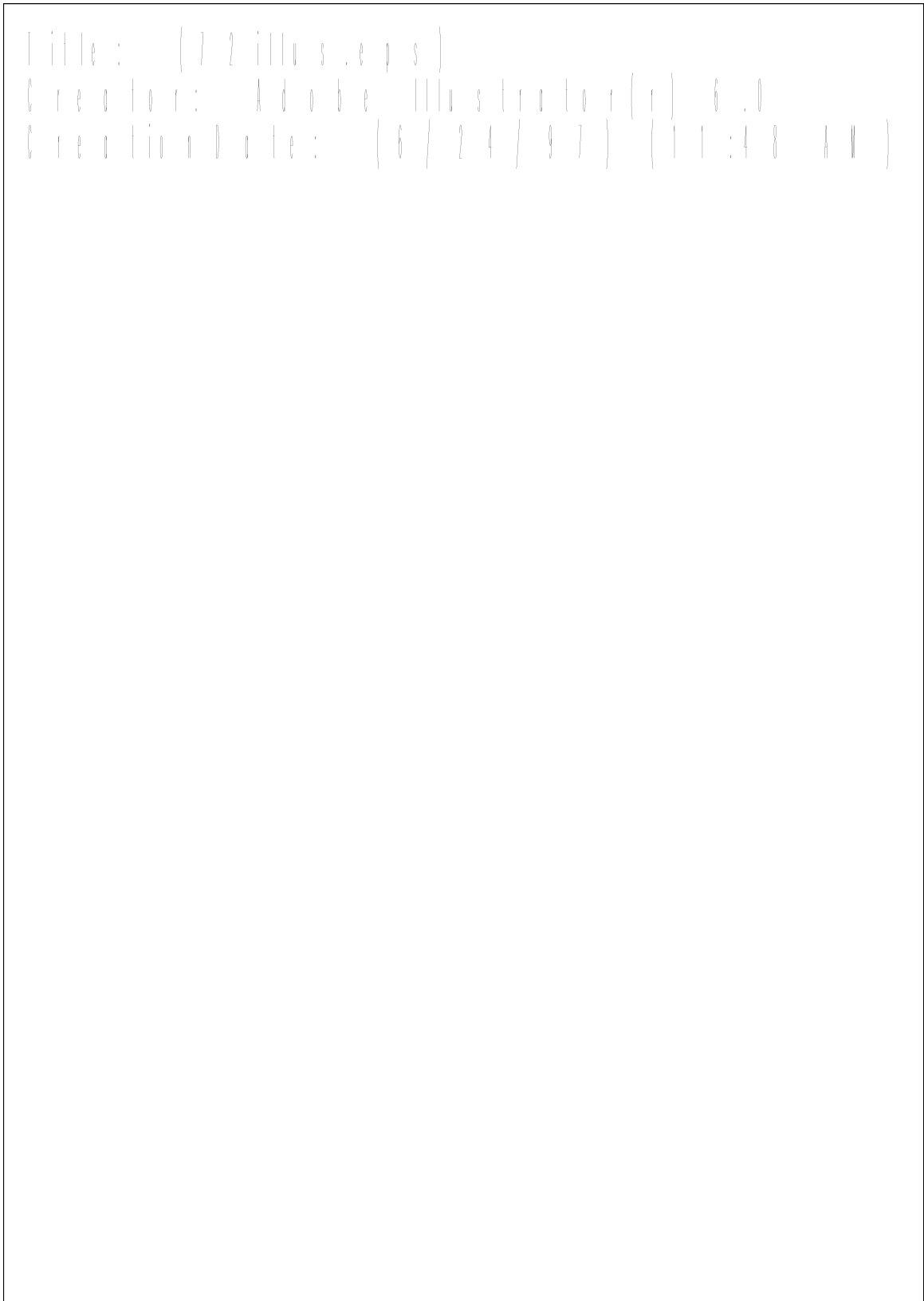


Figure 1. Simplified regional geology of the southern Sierras Pampeanas, and location of the three project areas of the Geoscientific Mapping Project, including the San Luis area.

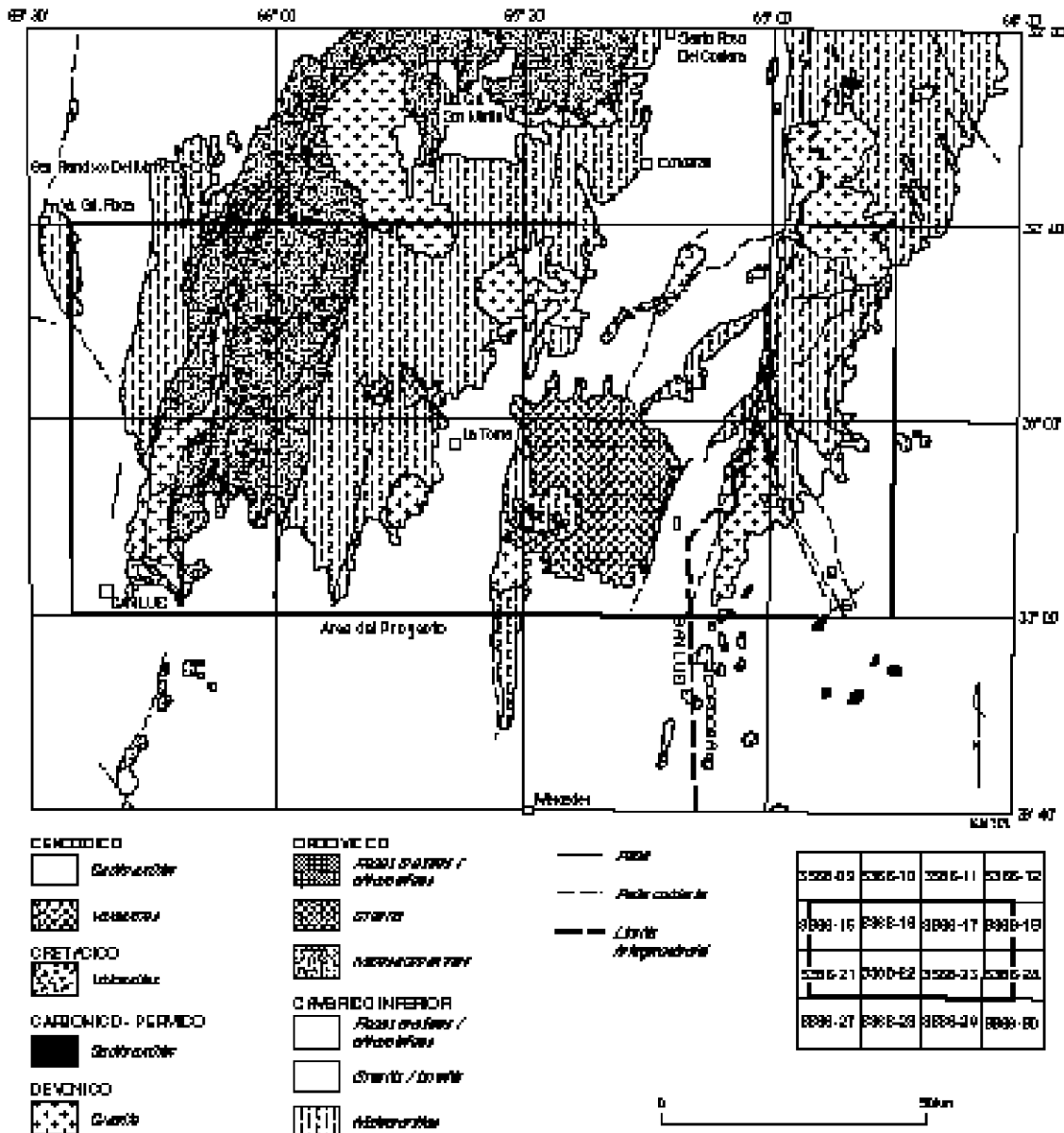


Figure 2. Location of the Sierras de San Luis y Comechingones 1:250,000 scale map area in San Luis and Córdoba Provinces with generalised geology. Locations of 1:100,000 scale map areas are indicated.

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 terrain model (DTM).

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 Francisco (Hoja 23g), Pastore and Huidobro (1952) of Saladillo (Hoja 24g), and Sosic (1964) of Sierra del Morro (Hoja 24h).

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

2. STRATIGRAPHY

2.1 GENERAL RELATIONS

The Sierras Pampeanas are a distinct morphotectonic province of early- to mid-Palaeozoic metamorphic, felsic and mafic rocks that form a series of block-tilted, north-south oriented ranges separated by intermontane basins. These ranges are bounded by escarpments developed on moderate to steeply dipping reverse faults developed during the Cainozoic Andean uplift (Jordan and Allmendinger, 1986).

Recent geological and geophysical surveys conducted during the Cooperative Argentine-Australia Project in the Sierras Pampeanas show that the Paleozoic basement of the southern Sierras Pampeanas contains of a number of distinct lithological, structural and metamorphic domains separated by major tectonic zones. There are two principal domains: an older, Cambrian domain, and a slightly younger, Ordovician domain. Both domains share a common geological history since early Devonian times.

Rocks of the Cambrian domain in 3366-22 consist of the Conlara Metamorphic Complex. The Ordovician domain consists of Cambro-Ordovician rocks of the Pringles Metamorphic Complex and the Early Ordovician San Luis Formation. Several granitic, tonalitic, mafic and ultramafic bodies dominantly intrude the Ordovician domain. The Cambrian domain are intruded by voluminous Early Devonian granites and is partly covered by Neogene volcanoclastics. Both the Cambrian and Ordovician domains are partly covered by Cainozoic continental deposits. A summary of the 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 3366-22.

Tectonic Cycle	Age (Ma)	Deposition	Intrusion
Andean	present	Alluvial, aeolian and talus deposits.	High-K, calc-alkaline to shoshonitic volcanism
	1.9	} Volcaniclastics	
	9.5		
Achalian	355		I- and S-type granite (e.g. Escalerilla, Renca, Achiras Igneous Complex)
	405		
Famatinian	470	San Luis Formation	Río de Molle monzonite Bemberg suite tonalites Tamboreo granodiorite
	490		Undifferentiated granitoids Mafic & ultramafic rocks
			Pringles Metamorphic Complex sediments
Pampean	515		Undifferentiated granitoids Undifferentiated mafics
	530		
		Sediments of: <ul style="list-style-type: none"> • Nogoli Metamorphic Complex • Conlara Metamorphic Complex • Monte Guazú Metamorphic Complex 	?Intrusives

2.2 PALAEOZOIC METAMORPHIC BASEMENT

2.2.1 INTRODUCTION

The metamorphic basement of 3366-22 consists of four main subdivisions that relate directly to the geological ages of the units. The first subdivision represents basement rocks of at least Cambrian age (Conlara Metamorphic Complex) that were deformed and metamorphosed during the late Cambrian, Pampean Tectonic-Cycle. The second subdivision represents Cambro-Ordovician rocks of the Pringles Metamorphic Complex that were deposited prior to the onset of collisional tectonics associated with the Famatinian Tectonic Cycle. The third subdivision are the low-grade rocks of the San Luis formation. These rocks were deposited very late in the Famatinian Cycle, probably during a late extensional phase, and display little evidence of the intense effects of that tectonic event. They are, however, intruded by early Ordovician tonalites and granodiorites, and display contact metamorphic aureoles as a result of those intrusions. The fourth subdivision are represented by Devonian mylonite zones that formed during the Achalian Tectonic Cycle.

2.2.2 CAMBRIAN

Conlara Metamorphic Complex (€cgn, €ce)

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

The Conlara Metamorphic Complex, comprises the majority of the basement outcropping within the valley (Valle del río de Conlara) between the Sierras de San Luis and Sierra de Comechingones. The Conlara Metamorphic Complex also incorporates the metamorphic part (the “Metamorfitas y Anatexítas India Muerta”) of a previously defined metamorphic-intrusive complex, the Achiras Complex (Otamendi and others, 1996), in the extreme south of the Sierra de Comechingones.

The western margin of the Conlara Metamorphic Complex is defined by a major NNE trending magnetic lineament and mylonite zone (the Guzman Shear Zone) in the eastern Sierras de San Luis, that separates the Complex from the Ordovician San Luis Formation.

A significant proportion of the Complex is covered by a thin mantle of unconsolidated Cainozoic deposits, however, good exposures occur within Río Quinto, Río Rosario, Sierra del Yulto and Sierra Los Morillos.

The Conlara Metamorphic Complex comprises dominantly late Neoproterozoic - early Cambrian sediments intruded by Cambrian and/or early Ordovician granite and polymetamorphosed in the early-mid Palaeozoic. The thickness of the sedimentary sequence is unknown due to the generally shallow orientation of the main transposition foliation. The Complex is intruded by a series of Devonian granites, which post-date the dominant structural and metamorphic episodes, and by Neogene calc-alkaline to shoshonitic volcanism. The Complex has a generally low magnetic signature and may be separated into regions that are comprised dominantly of gneiss, and areas comprised dominantly of schist.

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

In places, the schist contains a metamorphic differentiated layering that consists of alternating leucosome and millimetre-scale quartz-rich layers, and in the southern Sierra de Comechingones, contains minor interlayered tonalitic gneiss and banded ortho- and para-amphibolite. Within a kilometre of the Las Lajas Shear Zone in the southern Sierra de Comechingones, the schists are mylonitic and boudinaged, and chloritic alteration of biotite is common.

Metapelitic and metapsammitic quartz-feldspar-biotite \pm garnet \pm sillimanite gneiss is the next most abundant unit within the Conlara Metamorphic Complex (~40%). It is clearly

distinguished from the schist by the paucity of muscovite in the foliation, and more massive outcrop style. Where secondary muscovite is developed, it is generally unoriented and a minor component of the mineral assemblage, or it is associated with discrete overprinting shear bands, where it is associated with biotite. Leucocratic and/or pegmatitic veins are common in this rock type and typically define the main foliation, which is tightly to isoclinally folded (and refolded) at a meso- to micro-scopic scale.

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

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

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

2.2.3 CAMBRO-ORDOVICIAN

Pringles Metamorphic Complex (€Opgn, €Ope)

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

The Pringles Metamorphic Complex is exposed in the Sierras de San Luis, in three areas 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. On 3366-22, the Pringles Metamorphic Complex only occurs in the northwestern most portion of the sheet, and is fault bound to the east by the San Luis Formation.

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 Aguilas Group, and had cooled to about 600 °C by about 450 Ma (Sims and others, 1997). The peak metamorphic grade in the rocks reached granulite facies, particularly in the region of the Las Aguilas Group intrusions. A close temporal relationship between the age of the Las Aguilas Suite and the peak metamorphism as well as the close spatial relationship, suggests that the ultramafic and mafic rocks may have been the heat source of the metamorphism.

The most abundant rock-types in the Pringles Metamorphic Complex are pelitic and semipelitic gneiss and pelitic and semipelitic schist. The gneiss represents domains where peak (granulite-facies) metamorphic assemblages have been preserved, whereas the schist either represents domains of initially lower grade (amphibolite-facies) metamorphism or regions where subsequent deformation has been localised and resulted in a lower grade metamorphic overprint. Only the schist is represented on 3366-22.

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 poikilitic muscovite+quartz, and fine folia of muscovite. In places, late radiating needles of tourmaline and coarse, unoriented porphyroblasts of muscovite are grown on the secondary foliation plane.

2.2.4 ORDOVICIAN

San Luis Formation (Osl, Osls, Oslc)

Phyllite, schist, arenite, slate and metaconglomerate

The San Luis Formation (Prozzi and Ramos 1988) occurs in two elongate NNE trending belts in the Sierras de San Luis. The eastern belt is less than 5 km wide and bound to the east by the Río Guzman Shear Zone and to the west by the Pringles Metamorphic Complex. It is truncated to the north by the Las Chacras batholith and passes under shallow cover to the south. The western belt is no more than 3 km wide and passes through Carolina and extends discontinuously southwards on both the eastern and western margins of Escalerilla Granite (Sims and others, 1997). On 3366-22, the San Luis Formation is well exposed in Río de la Cañada Honda, in Río Quinto below Embalse La Florida.

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; Sims and others, 1997) and by a suite of aplitic to rhyolitic dykes that also cross-cut the Tamboreo

Granodiorite. The contact of the SLF with the Pringles Metamorphic Complex and the Conlara Metamorphic Complex was strongly sheared during the Devonian, with kyanite, staurolite and garnet bearing assemblages and minor quartz-feldspar-muscovite-kyanite-staurolite pegmatites locally developed within the SLF near the contacts (Sims and others, 1997).

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

Two main deformations affected the SLF during the Devonian compressional cycle. The first of these deformations resulted 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. The magnetic signature of the San Luis formation is generally low, however, local high magnetic responses are developed in the region of magnetite-bearing Devonian mylonites such as the Río Guzman Shear Zone.

Where axial planes of the two main Devonian deformation phases are sub-parallel and occur in transposed fine-grained rocks, slate is developed. The slate is dark-grey to green and consists predominantly of thinly bedded phyllites with minor thin quartzites. The phyllite consists predominantly of quartz, chlorite and sericite with minor organic carbon (Prozzi and Ramos, 1988) and contain secondary euhedral crystals of calcite and pyrite. The thin quartzites consist predominantly of quartz, chlorite and minor muscovite with abundant secondary euhedral calcite and minor epidote. Both rock-types are cross-cut by thin veins of quartz±pyrite. The slate has been extensively quarried for building stone.

A distinctive, poorly-sorted, polymictic, conglomerate unit, named the Metaconglomerado Cañada Honda by Ortiz Suárez and others (1992), occurs within the SLF. The conglomerate is up to 100 m thick and is well exposed in Río de la Cañada Honda. The conglomerate 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 discontinuous, thin to medium sandstone and mudstone beds displaying channel structures and graded bedding. The top of the unit grades through alternating conglomerate and thinly bedded quartzite into thickly bedded massive quartzite units. An anastomosing mylonitic foliation is developed within the conglomerate parallel to bedding and most of the smaller quartzite clasts are recrystallised and display extensive sub-grain development. A sub-parallel cleavage is also developed on the mylonitic foliation and has resulted in a fine crenulation surface.

2.2.5 DEVONIAN

Río Guzman Shear Zone (Dzmi)

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

The shear zone consists predominantly of steeply east-dipping mylonite that separates the high-grade, Cambrian Conlara Metamorphic Complex from the low-grade, Ordovician San Luis Formation and is largely contained within the low-grade rocks. The dominant assemblage in the mylonite consists of quartz-chlorite-sericite±magnetite with a variably developed subvertical stretching and mineral lineation. Relict (retrogressed) kyanite? with staurolite and garnet, within Conlara Metamorphic Complex rocks on the eastern margin of the zone, near Cerros Largos, however, suggests the shear zone may have initiated at higher pressures and have a long-lived history (Sims and others, 1997). Shear-sense indicators in the form of S-C fabrics and asymmetric extensional shear bands are well developed and give

east up displacement. The similarities of the kinematic indicators and metamorphic grade suggests a close temporal relationship with the Las Lajas Shear Zone in the Sierra de Comechingones.

Ar-Ar data from sericite in the mylonitic fabric, indicates a growth age between 360 and 350 Ma (Camacho and Ireland, 1997), which therefore constrains the minimum age of the greenschist-facies shearing. Additionally, the shear zone has been intruded by a number of undeformed lamprophyre dykes, and has been partly reactivated as an east dipping thrust during the presently active, Tertiary Andean compression.

2.3 PALAEOZOIC IGNEOUS ROCKS

2.3.1 ORDOVICIAN INTRUSIVES

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. On 3366-22, this unit is dominantly represented by extensive pegmatites that occur in the the northwestern portion of the sheet.

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 greenschist-facies conditions.

Tamboreo Granodiorite (Ogdt)

The Tamboreo Granodiorite forms a slightly elevated plateau ~3 km wide by ~6km long, called Pampa del Tamboreo, which is ~5km to the northeast of Embalse La Florida. Detailed studies of the pluton have been carried out by Zardini (1966) and Sato and others (1996). These previous studies referred to this pluton as the Tamboreo Tonalite.

The granodiorite intrudes the San Luis Formation and has a distinct metamorphic aureole on the eastern margin. The western margin, however, is strongly sheared and in contact with schist of the Pringles Metamorphic Complex. The granodiorite is intruded by north-south trending aplitic to rhyolitic dykes. U/Pb geochronology of zircon separates has produced an early Ordovician age of 470 ± 5 Ma (Camacho and Ireland, 1997).

The granodiorite is grey to pink in outcrop, and contains a low proportion of mafic xenoliths, which are elongate parallel to a locally well-developed foliation (Sato and others, 1996) defined by biotite. K-feldspar proportions range from 1.5% (Sato and others, 1996) to 25% (Sims and others, 1996), which suggests that there is either a strong compositional zonation within the pluton or multiple phases with a range of compositions. Biotite (up to 25%) is the main mafic mineral along with minor epidote. Minor phases include calcite, chlorite, titanite, apatite, allanite and zircon. Recrystallised feldspars and secondary phases including zoisite and muscovite, suggests that deformation of the pluton occurred under upper-greenschist facies metamorphic conditions. The maximum recorded

magnetic susceptibility was 25×10^{-5} SI. The composition and age of the pluton suggest it is closely related to the Bemberg Suite tonalites (Sims and others, 1997)

2.3.2 DEVONIAN INTRUSIVES

San José del Morro Granite (Dgm)

The San José del Morro granite is exposed over approximately 60 km² in the north of the Sierra de Yulto. Aeromagnetic images show the pluton is semi-ovoid in shape and more extensive than is outcropping. To the west of the exposed area, approximately 40 km² is covered by fault bounded Cainozoic sediments.

The granite intrudes the Conlara Metamorphic Complex and K/Ar ages indicate that the granite was emplaced between 390-360 Ma (Lema, 1980). The granite is strongly foliated on the NW margin and generally has a moderately well developed mineral alignment.

The granite is moderately magnetic, pink to red, strongly jointed and consists of equigranular and porphyritic phases. Compositionally the granite ranges from monzogranite to syenogranite and has a metaluminous character (Quenardelle, 1993) The granite consists of predominantly porphyritic K-feldspar (microcline), plagioclase, quartz, with abundant biotite and minor titanite. Quenardelle (1993) also reports trace apatite, magnetite, ilmenite and zircon. Locally, the granite contains numerous mafic enclaves and xenoliths of the country rock. A number of large rafts of basement rock, suggest the pluton may be only shallowly exposed. Numerous pegmatites and aplite dykes intrude the country rock on the margin of the granite and cross-cut the large basement rafts. Additionally, minor, shallowly worked, skarn mineralisation occurs in calc-silicate and marble units adjacent to the pluton.

Totora Granite (Dgtl, Dgte, Dgti)

The Totora Granite is a semi circular pluton, approximately 10 km in diameter that crops out in the southeastern Sierras de San Luis between the townships of Saladillo and La Toma. The granite forms a slightly elevated plateau with a well exposed margin and is also

well exposed in low platforms along provincial route 20. The name of the granite derives from the small town of La Totorá which is located on the pluton.

The granite intrudes the basement rocks of the Conlara Metamorphic Complex and truncates the main structural fabric in those rocks. Aeromagnetic data suggests that the granite continues under shallow cover to the southeast. Though there is no isotopic data for this pluton, the shape and magnetic zonation of the pluton and the absence of a marked tectonic overprint suggests that this granite is Devonian in age.

The pluton is grey to pink in outcrop and consists predominantly of K-feldspar, quartz and plagioclase, with minor mafic enclaves. Photographic and magnetic imagery as well as petrography, suggests the granite consists of three phases: a main, coarse- to very coarse-grained, sub-equigranular phase that is moderately magnetic (average magnetic susceptibility of 972×10^{-5} SI) and strongly jointed in outcrop, a thin leucocratic border phase that occurs on the western margin and is not jointed, and an inner porphyritic and slightly-less-magnetic phase (average magnetic susceptibility of 721×10^{-5} SI). Biotite comprises approximately 5% of the total rock in the main and inner phase and is partially replaced by chlorite, while accessory phases include magnetite, sphene and garnet. The K-feldspar is microcline and is partially replaced by muscovite, while plagioclase displays myrmekitic grain boundaries. The inner phase of the pluton contains significantly more plagioclase than the main phase (20% c.f. 10%) and is also weakly foliated.

2.3.3 MINOR DYKE ROCKS

Pegmatite (peg)

Numerous pegmatite dykes intrude the basement of 3366-22. There are essentially four main subdivisions:

1. Pegmatites emplaced during M1 metamorphic peak in the Middle Cambrian, at around 530-515 Ma. These are restricted to within the Conlara Metamorphic Complex on 3366-22.
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 prior to 460Ma, and associated with the undifferentiated Ordovician granites.
4. Pegmatites emplaced during the Devonian, and associated with the extensive granite bodies.

Aplite

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

Lamprophyre

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

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

2.4 TERTIARY VOLCANICS

San Luis Volcanic Group (Tvp)

Pyroclastic and epiclastic volcanic deposits

A series of volcanic centres occur in a northwest-southeast trending belt of approximately 90 km length through central and western *Sierras de San Luis y Comechingones*. The volcanic centres include Sierra del Morro in the southeast, cerros Rosario and Tiporco, Cerros Largos, Cañada Honda, and La Carolina in the northwest, and range from late Miocene (~9.5 Ma) to Pliocene (~1.9 Ma) in age. The geology, petrography and geochemistry of the volcanics have been examined by Brogioni (1987b, 1990). A general description of the volcanic centres is presented in **Table 2**. Only minor volcanoclastic deposits occur on 3366-22.

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

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

Volcanic centre (<i>dating location</i>)	Age (Ma) (K/Ar)	Rock-types and general description
La Carolina (<i>Tres Cerritos</i>)	8.2 ± 0.4 ³	Range of volcanic plugs and domes, minor pyroclastic deposits and subvolcanic breccias.
(<i>C° Tomolasta</i>)	7.5 ± 0.4 ²	Extensive alteration of host rocks. Basement deeply eroded (~300m?). NW trending faults
(<i>C° Pan de Azucar</i>) (<i>not specified</i>)	7.3 ± 0.4 ² 6.3 ± 0.3 ³	
Cañada Honda (<i>Diente Verde</i>)	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. Paleoa 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. Paleoa landsurface readily apparent, however, much of the pyroclastic material has been removed. Ring faults around basement dome
Sierra del Morro (<i>not specified</i>)	6.4 ± 0.6 ¹	Range of volcanic plugs and domes, breccia pipes and dykes mostly contained within domed (~700m) basement rocks with a central collapsed(?) caldera.
(<i>not specified</i>)	2.6 ± 0.6 ¹	Palaeo landsurface readily apparent with thick cover of pyroclastic and epiclastic material preserved on the north, east and south flanks.
(<i>not specified</i>)	1.9 ± 0.2 ¹	Western flank deeply dissected (~200m) adjacent to Los Morillos fault escarpment. 'Box' faults around basement dome.

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.

2.5 CAINOZOIC

Unconsolidated cover (Czu, Czg, Czc, Czd)

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

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

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

Raised fluvial and colluvial fan deposits of unconsolidated gravels (labelled Czg) form low, wooded, dissected hills at the base of many of the main Cainozoic fault scarps. The most extensive of these occur along the western scarp of the Sierras de San Luis. These deposits are correlated with similar Pleistocene (Quaternary level 1 subdivision of Massabie, 1982) deposits in the Capilla del Monte area of Córdoba. Increased erosion and

exposure of Miocene-Pliocene volcanic plugs from east to west places a lower age constraint on the earliest uplift and hence the maximum age of the fans at mid-Pliocene.

2.6 QUATERNARY

Unconsolidated deposits (Qa, Qg, Qs, Qt)

Active alluvial deposits, fans, gravels, talus.

Holocene (Santa Cruz, 1978) to Recent alluvial deposits of clay, sand and gravel along active river courses and adjacent terraces and overbank deposits (labelled Qa) dissect the undifferentiated Cainozoic 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 were 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 (Cordillo, 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 $< \sim 7$ Kbars at temperatures of no more than $\sim 750^{\circ}\text{C}$ (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 Stuart-Smith, 1997), give an age of ~ 530 Ma (Camacho and Ireland, 1997). Late Pampean granites in Córdoba give ages of ~ 515 - 520 Ma (Camacho and Ireland, 1997; Rapela and Pankhurst, 1996; AGSO-Subsecretaría de Minería Argentina, unpublished data).

3.2 FAMATINIAN CYCLE: ORDOVICIAN DEFORMATION AND METAMORPHISM

Formation of a basin, in which the sedimentary protolith to the Pringles Metamorphic Complex was deposited, possibly marks the initiation of a subduction complex to the west of the Sierras de San Luis in the late Cambrian. Numerous intrusives within the La Rioja area that were emplaced around 490-480 Ma (Camacho and 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 and 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 \pm 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 degrees 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 Achaian 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 Achaian 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 and Prozzi, 1996)

At least 4 distinct styles of deformation are recognised within the Achaian 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 and 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 contemporaneous folding and crenulation of the earlier mylonitic fabric

Overprinting the strike-slip shear-zones are a number of major low-grade shear-zones that traverse 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 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 and Prozzi, 1996) affect all the basement units in the Sierras de San Luis and the Sierra de Comechingones, in places displacing the S3 mylonitic foliations and related folds. The faults are rarely exposed, but are prominent on aerial photographs and Landsat images. Some of the faults are also delineated on magnetic images as low magnetic zones owing to magnetite destruction. 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 (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. ¹⁴C 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 Felipe, and del Yulto. The Sierra del Morro is a broad cone of uplifted basement resulting from the intrusion of the volcanic centre.

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

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

5. GEOLOGICAL HISTORY

The *Sierras de San Luis 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 and Ireland, 1997) and the geological relationships, indicate that there are two principal domains in the southern Sierras Pampeanas: an older Cambrian domain, and a younger 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 - Subsecretaría 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 Cambrian basement during a widespread deformational,

metamorphic and magmatic event known as the “Ciclo orogénico Famatiniano” (Aceñolaza and 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 and 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 Carboniferous. 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 (González and 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 and Ramos, 1996), formed minor dykes or extruded as basalt flows intercalated with the sediments. These extrusive occur to the north of *Sierras de San Luis 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 and González, 1990).

5.8 ANDEAN CYCLE

During the Cainozoic, in the Sierras de San Luis and Valle de Río Conlara dominantly andesitic lavas extruded, doming basement rocks and forming volcanic edifices with extensive pyroclastic aprons. This magmatism, which is dated between 9.5 Ma and 1.9 Ma was probably related to an extensional phase following the development of flat subduction of the Nazca plate (Smalley and others, 1993) in the mid-Miocene. The cessation of magmatism is marked by the commencement of east-west compression that resulted in inversion of the Cretaceous basins (Schmidt, 1993) and block thrusting of the basement rocks, forming north-south oriented ranges, separated by intermontane basins. The ranges are bounded by escarpments developed on moderate to steeply-dipping reverse faults (Jordan and Allmendinger, 1986; Martino and others, 1995; Costa, 1996), many of which show a reactivated and long-lived history. Costa interpreted most significant movement in the region to have occurred during the Late Pliocene-Pleistocene with further movement continuing during the Quaternary.

SECTION II: ECONOMIC GEOLOGY

By Roger G. Skirrow

1. INTRODUCTION

The 3366-22 1:100 000 map area of San Luis contains a range of metallic and industrial mineral occurrences, including W in the La Florida, Pampa del Tamboreo, sierras de Los Morrillos and Yulto districts, and widespread deposits of Be, Li, mica, feldspar and quartz. One alluvial(?) Au occurrence is also present near the Río de la Cañada Honda.

Geological and resource data on mineral occurrences have been compiled in a database (ARGMIN, in MicroSoft Access; Skirrow and Trudu, 1997) using a combination of data from the literature and field data. The principal deposits in most mining districts of the 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 and Skirrow, 1996), stable isotopes of oxygen, hydrogen and sulfur (Lyons and Skirrow, 1996), as well as $^{40}\text{Ar}/^{39}\text{Ar}$ radiometric age dating (Camacho, 1997). Geographic coordinates were measured by GPS (locational accuracy $\pm 50\text{m}$), 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 $\pm 200\text{ m}$. 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 $\pm 3000\text{m}$). 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 $\pm 400\text{m}$.

Mineral occurrence data are presented in the 1:100 000 scale Metallogenic Map. Output data sheets from the ARGMIN database are appended to this report. Details on the geology

and grade-tonnage data, where available, for specific mineral deposits may be found in the database. A 1:250 000 Metallogenic Map for the sierras de San Luis and Comechingones regions 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). Mineral potential maps for specific deposit types are also included in the Metallogenic Atlas for the Sierras Pampeanas project (Skirrow and Johnston, 1997). A geographic information system (GIS) for the project includes all geology, geophysics and metallogenic coverages (Butrovski, 1997).

2. METALLIC MINERAL OCCURRENCES

2.1 W DEPOSITS OF THE LA FLORIDA - PAMPA DEL TAMBOREO DISTRICTS

Three main styles of W mineralisation are present in the sierras de San Luis and Comechingones regions: (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) includes deposits in the La Florida - Pampa del Tamboreo - Santo Domingo belt of the eastern Sierras de San Luis, and deposits in the Pancanta district south of La Carolina (Sheet 3366-15). Wolframite-quartz veins of style (ii) are evidently restricted to the La Carolina - San Román district. 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.

The La Florida and Pampa del Tamboreo W districts form part of a 25 km long belt of W mineralisation between La Florida and Santo Domingo on Sheet 3366-16 (Skirrow, 1997a). Although some of the main deposits have been located by GPS and many others have been located on airphotographs and their geographical coordinates measured, a 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).

Regional setting: The regional geology and structure of the La Florida - Pampa del Tamboreo - Santo Domingo region is complex (Sims and others, 1997). The Río Guzman Shear Zone marks the boundary between the early Ordovician San Luis Formation to the west and the Cambrian Conlara Metamorphic Complex to the east. The San Luis Formation is a sequence of metapelites, metapsammities and metaconglomerates that were deposited during and after Famatinian extension. Two main belts of San Luis Formation

occur to the west of the Río Guzman Shear Zone, and represent thrust slices that developed during compressive deformation in the Devonian (Sims and others, 1997). The western of these two belts was dismembered by emplacement of the Escalerilla granite in the Devonian (U-Pb zircon age of 404 ± 5 Ma, Camacho and Ireland, 1997). Tungsten deposits of styles (i) and (ii) are distributed preferentially in the San Luis Formation.

A zone of D_3 shears separate the San Luis Formation from metapsammites and metapelites of the Pringles Metamorphic Complex to the west, whose tectonic and metamorphic history differs from that of the younger San Luis Formation. These quartzo-feldspathic metasediments were initially metamorphosed to medium grade during D_1 in the early Ordovician, then intruded by extensive granitoids and tourmaline-bearing pegmatites during D_2 extension.

Regional low grade retrogression accompanied D_2 , resulting in widespread muscovite±tourmaline development in schists. Following deposition of the San Luis Formation late- to post- D_2 , the Pampa del Tamboreo granodiorite was emplaced at 470 ± 5 Ma (Camacho and Ireland, 1997), producing a contact metamorphic aureole in the San Luis Formation. The Pampa del Tamboreo granodiorite and the San Luis Formation were intruded by numerous plagioclase-quartz porphyritic rhyolite dykes. The metasedimentary and igneous rocks were intensely deformed and metamorphosed to low grade during the Devonian D_{3-4} compressive events, with strain generally localised in and near shear zones. Although no Devonian granites are known to crop out in the the La Florida - Santo Domingo region, a broad zone of low aeromagnetic response occurs near La Florida and may represent a Devonian granite in the subsurface.

Geology: The geology and genesis of W deposits in the La Florida - Pampa del Tamboreo - Santo Domingo belt have been discussed by numerous workers, including Monchablon (1956), Stoll (1963a, b), Ambrosini and others (1981), Leveratto and Malvicini (1982), Carotti and others (1985), Brodtkorb and others (1984, 1985), Hack and others (1991), Fernandez and others (1991) and Ramos (1990, 1992).

The principal features that are shared by many of the W deposits in the La Florida - Pampa del Tamboreo - Santo Domingo belt are as follows.

- Scheelite is the primary ore mineral
- The W mineralisation is associated with quartz veinlet networks or is disseminated
- Host rocks are part of the low grade metamorphic rocks of the San Luis Formation, except for some of the westernmost deposits in the belt (Los Cocos district, Sheet 3366-21)
- Deposits occur within or in proximity (<1 km) to zones of intense D₃ deformation
- Scheelite commonly occurs in feldspathic rock types such as plagioclase-quartz porphyry to aplitic bodies and meta-arkosic rocks
- Quartz veinlet networks are most intensely developed in relatively competent units where they are in contact with less competent rocks, for example metapsammite, quartzite or felsic porphyry/aplite within phyllite or metapelitic schist
- The mined zones are broadly confined to particular compositional layers but locally transgress layering
- Veins and veinlet networks are deformed and vein minerals are recrystallised
- Sulfides and oxides are very low in abundance; pyrite, arsenopyrite, and ilmenite altered to rutile, occur at La Teodolina (Sheet 3366-16; Ramos, 1992; Brodtkorb and others, 1985), and pyrite is widespread (e.g. Carotti and others, 1985)
- Tourmaline and white mica commonly are very abundant in proximity to the quartz veinlet systems with scheelite mineralisation; calcsilicates such as epidote and titanite as well as apatite, fluorite and carbonate occur in veins and wall rocks with scheelite in some deposits (Brodtkorb and others, 1985; Carotti and others, 1985; Hack and others, 1991), and scapolite, hornblende and garnet were reported in scheelite-bearing quartzite host rocks in the Los Cocos district (Stoll, 1963a; Brodtkorb and others, 1985)
- Biotite is very abundant in mineralised zones of some but not all deposits (e.g. La Teodolina), and is partially chloritised

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

- Felsic dykes (some previously interpreted as felsic volcanics, Brodtkorb and others, 1984) cutting the compositional layering in the San Luis Formation (e.g. at El Araucano, Sheet 3366-16) are mineralised with quartz-scheelite veins; these dykes are of identical texture and mineralogy to a dyke that intrudes the Pampa del Tamboreo

granodiorite at Puesto Tito (Sheet 3366-21, 6342000N, 3500000E). A maximum age of 470 ± 5 Ma is therefore suggested for the formation of quartz-scheelite veinlets.

- Relatively thin, fine to medium grained, feldspathic bands are present in the San Luis Formation (e.g. at La Riojita, Sheet 3366-16), and although they could represent metavolcanics, they are texturally distinct from the prominent porphyritic felsic bodies which at least in some cases are certainly dykes.
- Quartz veins containing scheelite at Fortuna (Sheet 3366-22) cross cut the Pampa del Tamboreo granodiorite, but xenoliths of biotite schist in the granodiorite are mineralised at Donosa (Sheet 3366-22; Brodtkorb and others, 1985).
- Intense D_{3-4} deformation has resulted in transposition of compositional layering in large parts of the San Luis Formation, so that many of the porphyritic felsic bands are parallel to both the main foliation and to compositional layering in the metasediments.
- Mineralised zones in some deposits are confined to structures interpreted to have formed during D_{3-4} , such as F_{3-4} fold hinges and F_{3-4} axial planes (e.g. Los Cocos).
- Scheelite porphyroblasts in biotite schist at La Teodolina are wrapped by the main foliation which is a crenulation cleavage. Ramos (1992) suggested the scheelite porphyroblasts predated the crenulation cleavage; our observations concur with this conclusion, but we propose that the scheelite overgrew the earlier slaty cleavage. La Teodolina is situated within the D_{3-4} shear zone at the western contact of the San Luis Formation. Both foliations in this area are believed to have formed during D_{3-4} progressive deformation and low grade metamorphism, in the Devonian (Sims and others, 1997), implying a Devonian age of scheelite growth at La Teodolina.
- Scheelite occurs in tourmaline-bearing pegmatites (e.g. La Teodolina, Ramos, 1992; and in mylonitic quartz-feldspar-tourmaline pegmatite at General Joffre, Sheet 3366-22), but the timing of pegmatite emplacement and of the scheelite in the pegmatites is not known.

Genesis: Previous interpretations of the timing and origin of W mineralisation in the La Florida - Pampa del Tamboreo - Santo Domingo belt may be grouped into two main hypotheses.

1. The W was syngenetic, associated with felsic volcanism, and was remobilised during deformation and metamorphism (Brodtkorb and Brodtkorb, 1975, 1979; Brodtkorb and others, 1985; Fernandez and others, 1991; Hack and others, 1991).

2. The W was epigenetic-syn deformational and formed from pneumatolitic or hydrothermal fluids related to granites (Stoll, 1963a, b; Carotti and others, 1985). Smith and González (1947) noted that scheelite postdated aplite dykes at the Santo Domingo deposit.

An alternative hypothesis suggested by Skirrow (1997a) is that W was introduced by hydrothermal fluids into the San Luis Formation and schists immediately to the west no earlier than ~470 Ma and most likely during the early Devonian, synchronous with D₃ compressive deformation. The major controls on localisation of scheelite were the presence of D₃ structures such as shear zones and folds, particularly where there were significant competency contrasts between compositional layers. In the resultant dilational sites (felsic porphyry bodies, quartzites, granitoid contacts, etc), quartz±tourmaline±calcsilicate±fluorite vein networks developed. Scheelite precipitated preferentially in 'chemical traps': these consisted of calcic host rocks such as feldspar porphyry bodies, meta-arkosic layers and amphibole-bearing contact metamorphic zones (e.g. at the Pampa del Tamboreo granodiorite).

2.2 W DEPOSITS OF THE SIERRAS DE LOS MORILLOS AND YULTO

The geology of W deposits of the sierras del Los Morillos, Morro and Yulto have been discussed in numerous unpublished reports and publications. Some of the relatively recent publications include: review/synthesis papers by Brodtkorb and Brodtkorb (1975, 1977, 1979); summary by Angelelli (1984); regional geology, petrography and genesis of the deposits by Llambías and Malvicini (1982) and Delakowitz and others (1991); and a review/synthesis by Brodtkorb and Pezzutti (1991). References to the older literature including studies of individual deposits may be found in these publications. Geochemistry of the host rocks was presented by Delakowitz and others (1991), while K-Ar dating results for minerals from five samples of the host rocks were given by Llambías and Malvicini (1982).

Regional setting: Three main districts of W deposits are present in the region of Sheet 3366-22: the Sierra de Los Morillos (or 'Faja Los Morillos', Llambías and Malvicini, 1982), which includes the most important mines; Sierra de Yulto and the Sierra del Morro

(constituting the 'Faja Oriental'). The first two districts occur principally within Sheet 3366-22. The region forms part of the late Neoproterozoic to early Cambrian Conlara Metamorphic Complex and comprises mainly metapelitic, metapsammitic and metacarbonate rocks and associated amphibolitic rocks that were polymetamorphosed and deformed in the early Paleozoic (Sims and others, 1997). Biotite-muscovite±sillimanite±garnet banded gneiss and schist, foliated migmatite and massive migmatite are the principal metamorphic rock types in the W districts (Llambías and Malvinini, 1982). Leucotonalitic pegmatites and aplite occur subparallel to parallel with the foliation in the medium grade metamorphic rocks. Mylonite and other shear fabrics are common, and generally trend N-S. Zones of dolomitic and calcitic marble up to 5 m thick and amphibolite up to 4 m thick occur in the three abovementioned W districts where, in association with calcsilicate rocks ('tactites'), they host scheelite mineralisation. Intense multiphase deformation has resulted in complex distributions of the marble-amphibolite zones (e.g. at El Morro No. 1, Smith and González, 1947; also Delakowitz and others, 1991).

The San José del Morro granite was emplaced in the central part of the region (eastern part of Sheet 3366-22), and has a K-Ar radiometric age of 365 ± 15 to 380 ± 20 Ma (for biotite; Lema, 1980). Numerous granitic pegmatites containing K-feldspar, plagioclase, quartz and muscovite cut the earlier foliation-parallel tonalitic pegmatites, and are themselves cut by the San José del Morro granite (Llambías and Malvinini, 1982). Some of the granitic pegmatites contain accessory beryl, apatite, fluorite and tourmaline. Aplite is associated with the San José del Morro granite. Extensions of the San José del Morro granite under Cainozoic cover rocks and subsurface within Paleozoic basement have been interpreted from aeromagnetic imagery. Additionally, several other large bodies concealed beneath Cainozoic cover rocks and/or subsurface within Paleozoic basement have been identified from aeromagnetics and may represent Devonian granites.

Geology: Three types of W mineralisation have been defined: (i) disseminated scheelite hosted by calcsilicate rocks; (ii) wolframite and scheelite in quartz veins; and (iii) non-economic scheelite and minor wolframite in granitic pegmatites where they cross cut calcsilicate zones (Llambías and Malvicini, 1982).

(i) Disseminated scheelite in calcsilicate rocks. Calcsilicate rocks ('tactites') occur as zones within and at the contacts of marble or amphibolitic rocks with gneiss. Contacts with the enclosing rocks are commonly gradational. The calcsilicate rocks contain assemblages typical of skarns (Meinert, 1993) and consist of combinations of tremolite-actinolite, biotite/phlogopite, hornblende, epidote, clinozoisite, feldspar, calcite, dolomite, muscovite, and accessory quartz, titanite, magnetite, pyrite, pyrrhotite, fluorite, apatite, chlorite, ilmenite and beryl (Llambías and Malvicini, 1982; Delakowitz and others, 1991). Chalcopyrite, sphalerite, molybdenite, aikinite, bismuthinite and sulfosalts are present in some areas. In the Loma Blanca deposit minor garnet occurs with epidote in alteration patches that overprint banded amphibole-phlogopite/biotite rock. Minor to trace disseminated diopside and vesuvianite and veins of wollastonite occur in marble at Loma Blanca, and at Don José veins containing wollastonite, fluorite and scheelite cross cut marble (J. Sims and M. Marcoux, pers. comm., 1996). Paragenetically later, unoriented, talc, tremolite (replacing diopside), epidote-clinozoisite and chlorite (replacing wollastonite) suggest the presence of a retrograde hydration stage that post-dated both the amphibolite facies regional metamorphism and later high temperature metamorphism at Loma Blanca.

(ii) Wolframite and scheelite in quartz veins. Although quartz vein hosted W mineralisation represents only 5-7% of total W production for the region, it is widespread in the sierras del Los Morillos and Yulto, and is significant from a genetic viewpoint. The veins consist of quartz, muscovite, tourmaline, fluorite, apatite, epidote, beryl, and accessory titanite, scheelite, wolframite, pyrite, chalcopyrite, sphalerite, bismuthinite, cassiterite, magnetite, hematite, rutile and ilmenite (Llambías and Malvicini, 1982). Tourmaline is ubiquitous in the veins except at the large Loma Blanca deposit, where quartz veins cutting marble contain abundant coarse muscovite, fluorite, apatite and scheelite. In another exposure at Loma Blanca quartz-feldspar pegmatite dykes have offshoot veins of quartz-feldspar that follow the relict banding in the biotite/phlogopite-amphibole rock. Further from the main dykes these thin pegmatites grade into quartz-only veins, and an aureole of unoriented tremolite/actinolite-epidote alteration is developed adjacent to these veins/pegmatites, overprinting unoriented biotite/phlogopite and amphibole in the host rock. The calcsilicate alteration is identical to that in scheelite-mineralised zones. These relationships and vein mineralogy suggest the veins and

associated calcsilicate alteration formed at temperatures transitional between pegmatitic and hydrothermal conditions. The veins and associated hydrous alteration postdate the regional deformation and overprint the banding in biotite/phlogopite-amphibole rock.

(iii) Non-economic scheelite and minor wolframite in granitic pegmatites where they cross cut calcsilicate zones. This association of W with pegmatites, along with the common presence of apatite, beryl and fluorite in pegmatites, calcsilicate rocks and quartz veins, was cited by Llambías and Malvicini (1982) as evidence for a genetic association of W with pegmatitic fluids.

Genesis: Evidence is presented by Skirrow (1997a) in support of introduction of at least some W at temperatures of $>500^{\circ}\text{C}$. Hydrothermal muscovite within the quartz-fluorite-scheelite veins at Loma Blanca has been dated by the $^{40}\text{Ar}/^{39}\text{Ar}$ method at 363 ± 1 Ma (i.e. early Devonian; Camacho, 1997). This age is considered to closely represent the time of introduction of W in the vein structures and, by implication, into the calcsilicate zones where textures indicate post-deformational formation of hydrothermal alteration assemblages.

Our studies corroborate the epigenetic timing of W deposition suggested by Llambías and Malvicini (1982) and Malvicini and others (1991) although they proposed a Famatinian (Ordovician-Silurian) age of W mineralisation. It is further suggested there is a temporal and spatial association of W mineralisation with Achalian granites, and that the calcsilicate-associated W mineralisation of the El Morro region shares several key characteristics of tungsten skarn deposits (Skirrow, 1997a). The apparent stratabound nature of the W mineralisation associated with calcsilicate rocks in the El Morro region was cited by Brodtkorb and Brodtkorb (1975, 1977, 1979), Delakowitz and others (1991), and Brodtkorb and Pezzutti (1991) as evidence for a syngenetic volcanic-exhalative origin of the tungsten. Genetic models are further discussed by Skirrow (1997a).

2.3 PEGMATITE-HOSTED DEPOSITS OF BE, LI

Pegmatites in sheet 3366-22 host a number of occurrences of Be, Li and industrial minerals (e.g. mica, feldspar, quartz, 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, 1994) described muscovite-rich K-feldspar-quartz pegmatites from other regions of the Sierras Pampeanas (type 2 of Herrera, 1968; transitional between muscovite and rare element classes of Cerný, 1991, according to Galliski, 1993, 1994). These are a major economic source of muscovite, and relatively small examples may be present in the sierras de San Luis (e.g. López, 1984) but their tectonic-magmatic setting and genetic relationships to other pegmatite types within the map area are not well constrained.

Pegmatites of the rare element class of Cerný (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 and Sosa, 1991). Internal zoning, dimensions, geometry and parageneses are described in the cited references.

In Sheet 3366-22 the documented Be occurrences are situated in the Conlara Metamorphic Complex and San Luis Formation, and are members of the rare element class of Cerný (1991) or types 3 and 4 of Herrera (1968). They are most likely related to Famatinian and/or Achalian magmatic and tectonic processes. One reported occurrence of Li is present, within the San Luis Formation.

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

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. Many of those mined only for muscovite, quartz or feldspar probably are members of the muscovite or primitive rare element classes of pegmatites, and formed during the Pampean or early Famatinian extensional tectonism. Some pegmatites mined for Be as well as muscovite, quartz or feldspar may be members of the rare element class of pegmatites.

BIBLIOGRAPHY

- ACENOLAZA, F.G., y TOSELLI, A.J., 1976. Consideraciones estratigráficas y tectónicas sobre el Paleozóico inferior del Noroeste Argentino. Memoria, II Congreso Latinoamericano de Geología, 2, 755-764.
- AMBROSINI, G.L., GONZALEZ, R., QUARTINO, B.J. y RINALDI, C.A., 1981. Mineralización de wolfram en el faldeo oriental de la Sierra de San Luis. VIII Congreso Geológico Argentino, Actas, IV: 623-630.
- ANGELELLI, V., 1984. Yacimientos Metalíferos de la República Argentina I, II. Comisión de Investigaciones Científicas, Provincia de Buenos Aires.
- ANGELELLI, V., y RINALDI, C.A., 1965. Reseña acerca de la estructura, mineralización y aprovechamiento de nuestras pegmatitas
- ARCIDIACONO, E.C., 1974. Contribución al conocimiento de columbita-tantalitas de las provincias de Córdoba y San Luis. Asoc. Geol. Argent., Rev., 29(2): 171-184.
- ASTINI, R.A., 1996. Las fases diastróficas del Paleozóico medio en La Precordillera del oeste Argentino - evidencias estratigráficas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 509-526.
- BRODTKORB, M.K. DE y BRODTKORB, A., 1975 (published in 1980). Especulaciones sobre un origen singenético-sedimentario de la scheelita presente en las metamorfitas del nordeste de la Provincia de San Luis. VI Congreso Geológico Argentino, Bahía Blanca, 1975, Actas 3: 37-50.
- BRODTKORB, M.K. DE y BRODTKORB, A., 1977. Strata-bound scheelite deposits in the Precambrian basement of San Luis (Argentina). In: KLEMM,
- BRODTKORB, M.K. DE y BRODTKORB, A., 1979. Consideraciones genéticas de la scheelita presente en las metamorfitas de la provincia de San Luis. Asociación Geológica Argentina, Revista, 34(2): 131-140.
- BRODTKORB, M.K. y PEZZUTTI, N., 1991. Yacimientos scheelíticos en rocas calcosilicáticas asociadas a anfibolitas, Provincias de San Luis y Córdoba. In: BRODTKORB, M.K. (ed.), Geología de yacimientos de wolframio de las provincias de San Luis y Córdoba, Argentina. Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata, 1, 169-184.

- BRODTKORB, M.K., DE, PEZZUTTI, N., y BRODTKORB, A., 1985. La franja con mineralización scheelítica entre el dique La Florida y Paso del Rey, Provincia de San Luis. Asociación Geológica Argentina, Revista, XL (1-2): 51-59.
- BRODTKORB, M.K., DE, PEZZUTTI, N.E., y DALLA SALDA, L.H., 1984. Presencia de vulcanismo ácido en el Precámbrico de la Provincia de San Luis. Noveno Congreso Geológico Argentino, Actas, 2: 181-190.
- BROGIONI, N. y RIBOT, A., 1994. Petrología de los cuerpos La Melada y La Gruta, faja máfica-ultramáfica del borde oriental de la Sierra de San Luis. Asociación Geológica Argentina, Revista, 49: 269-283.
- BROGIONI, N., 1987a. El Batolito de Las Chacras-Piedras Coloradas, Provincia de San Luis. Geología y edad. X Congreso Geológico Argentina, 4, 115-118.
- BROGIONI, N., 1987b. Petrología del vulcanismo Mio-Plioceno de la Provincia de San Luis. Revista del Museo de La Plata, Tomo 10 (83), 71-100.
- BROGIONI, N., 1988. Caracteres geológicos y clasificación de los domos volcánicos Mio-Pliocenos de San Luis. Revista del Museo de La Plata, Tomo 10 (84): 101-112.
- BROGIONI, N., 1990. Geología y petrografía del vulcanismo Mio-Plioceno de la Provincia de San Luis. Revista del Museo de La Plata, Tomo 10 (90): 197-214.
- BUTROVSKI, D., 1997. Geographic Information System (GIS) for the Sierras Pampeanas Mapping Project, Argentina. Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report. Arc/Info GIS.
- CAMACHO, A. and IRELAND, T.R., 1997. U-Pb Geochronology: Final report. Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- CAMACHO, A., 1997. ^{40}Ar - ^{39}Ar and Rb-Sr Geochronology: Final report. Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- CAROTTI, M., CONDE, S.A.R., MALLAVIABARRENA, M., y RINALDI, C.A., 1985. Características de los yacimientos de scheelita de La Pampa del Tamboreo, Provincia de San Luis. Actas del Noveno Congreso Geológico Argentino, Bariloche, 1984, 9(7): 220-230.
- CERNY, P., 1991a. Rare-element granitic pegmatites. Part I: Anatomy and internal evolution of pegmatite deposits. Geoscience Canada, 18 (2): 49-67.

- CERREDO, M., 1996. Metamorphic evolution of high grade metapelites of Sierra de Comechingones, Córdoba, Argentina. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 531.
- COSTA, C.H. and VITA-FINZI, C., 1996. Late Holocene faulting in the southeast Sierras Pampeanas of Argentina. *Geology*, 24, 1127-1130.
- COSTA, C.H., 1996. Analisis neotectónico en las sierras de San Luis y Comechingones: problemas y methods. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 285-300.
- COSTA, C.H., MURILLO, M.V., VITA-FINZI, C. and GARDINI, C.E., 1994. Quarternary folding and perspectives for paleoseismological studies in the southeastern Sierras Pampeanas, Argentina. In Prentice, C. Schwartz, D. and Yeats, R. (editors), Workshop on paleoseismology, U.S. Geological Survey Open-File Report, 94-568, 39-40.
- CREA, 1996. Mineral resources database, Departamento Pringles. Microsoft Access / ArViewII platform. Gobierno de Provincia de San Luis.
- CRIADO ROQUE, P., MOMBRU, C. y RAMOS, V.A., 1981. Estructura y interpretación tectónica. In: Geología y recursos naturales de la Provincia de San Luis (edited by Yrigoyen, M), VIII Congreso Geológico Argentino Relat., 155-192.
- DALLA SALDA, L., 1987. Basement tectonics of the southern Pampean ranges, Argentina. *Tectonics*, 6, 249-260
- DALLA SALDA, L., LOPEZ DE LUCHI, M., CINGOLANI, C., and VARELA, R., 1996. A Laurentia-Gondwana fit: Lower Paleozoic tectonics and granitoids. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 435-440.
- DALLA SALDA, L.H., CINGOLANI, C., and VARELA, R., 1992. Early Paleozoic orogenic belt of the Andes in southwestern South america: result of Laurentia-Gondwana collision? *Geology*, 20, 617-620.
- DALZIEL, I.W.D., DALLA SALDA, L.H. and GAHAGAN, L.M., 1994. Paleozoic Laurentia-Gondwana interaction and the origin of the Appalachian-Andean mountain System. *Geological Society of America Bulletin*, 106: 243-252.
- DALZIEL, I.W.D., DALLA SALDA, L.H., CINGOLANI, C. and PALMER, P., 1996. The Argentine Precordillera: a Laurentian terrane? Penrose Conference Report, GSA Today, February 1996: 16-18.

- DELAKOWITZ, B., HULL, R., BRODTKORB, M.K. DE y BRODTKORB, A., 1991. Geología génesis de yacimientos scheelíticos en la Sierra del Morro Oeste, Provincia de San Luis. En: BRODTKORB, M.K. de (Ed.), Geología de yacimientos de wolfrámio de las Provincias de San Luis y Córdoba. Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata, 1: 49-96.
- DEMANGE, M., BALDO, E.G., and MARTINO, R.D., 1993. Structural evolution of the Sierras de Córdoba (Argentina). Second ISAG, Oxford (UK), 21, 513-516.
- ESCAYOLA, M.P., RAME, G.A., Y KRAEMER, P.E., 1996. Caracterización y significado geotectónico de las fajas ultramáficas de las Sierras Pampeanas de Córdoba. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas III: 421-438.
- FERNANDEZ, R.R., PEZZUTTI, N., y BRODTKORB, M.K. DE, 1991. Geología, petrografía y yacimientos entre Pampa de Tamboreo - Paso del Rey - Santo Domingo, Provincia de San Luis. Publication del Instituto de Recursos Minerales, Universidad de La Plata, 1: 153-170.
- GALLISKI, M.A., 1993. La Provincia Pegmatítica Pampeana. I: Tipología y distribución de sus distritos económicos. Asociación Geológica Argentina, Revista, 49: 99-112.
- GALLISKI, M.A., 1994. La Provincia Pegmatítica Pampeana. II: Metalogénesis de sus distritos económicos. Asociación Geológica Argentina, Revista, 49: 113-122.
- GONZALE, R.R. y ACENOLAZA, F.G. 1972. La cuenca de deposición neopaleozóica-mesozóica del oeste argentino. Fundación e Instituto Miguel Lillo, Tucumán, Miscelánea. 40: 629-643.
- GONZALEZ BONORINO, F., 1961. Petrología de algunos cuerpos básicos de San Luis y las granulitas asociadas. Asociación Geológica Argentina, Revista, XVI(1-2): 61-106.
- GORDILLO, C.E., 1984. Migmatites cordieríticas de la Sierra de Córdoba; condiciones físicas de la migmatización. Academia Nacional de Ciencias; Miscelánea 68, 40p, Córdoba
- GRANT, J.A. 1985. Phase equilibria in low-pressure partial melting of pelitic rocks. American Journal of Science, 285, 409-435.
- HACK, M., BRODTKORB, M.K. DE, HÖLL, R., y BRODTKORB, A., 1991. Geología y consideraciones genéticas de los yacimientos scheelíticos entre el dique La Florida y Pampa de Tamboreo, Provincia de San Luis. Publicación del Instituto de Recursos Minerales, Universidad de La Plata, 1: 113-152.
- HERRERA, A.O., 1963. Las pegmatitas de la Sierra de San Luis: Estructura interna, mineralogía y génesis. Asociación Geológica Argentina, Revista, 18(1-2): 43-71.

- HERRERA, A.O., 1965. Evolución geoquímica de las pegmatitas zonales de los principales distritos Argentinos. Asociación Geológica Argentina, Revista, 20: 2.
- HERRERA, A.O., 1968. Geochemical evolution of zoned pegmatites of Argentina, Economic Geology, 63: 13-29.
- JORDAN, T.E. and ALLMENDINGER, R.W. 1986. The Sierras Pampeanas of Argentina: A modern analogue of Rocky Mountain foreland deformation. American Journal of Science, 286: 737-764.
- KAY, S.M. AND RAMOS, V., 1996. El magmatismo crecácico de las Sierras de Córdoba y sus implicancias tectónicas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas III: 453-464.
- KRAEMER, P., ESCAYOLA, M.P., y MARTINO, R.D., 1995. Hipótesis sobre la evolución tectónica neoproterozoica de las Sierras Pampeanas de Córdoba (30°40' - 32°40'), Argentina. Revista de la Asociación Geológica Argentina, 50, 47-59.
- KRAEMER, P., ESCAYOLA, M.P., y SFRAGULLA, J., 1996. Dominios tectónicos y mineralización en el basamento de las Sierras Pampeanas de Córdoba. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 239-248.
- LEMA, H. 1980. Geología de los afloramientos del arroyo Peñas Blancas, sierra de Yulto, Provincia de San Luis. Revista de la Asociación Geológica Argentina, 35, 147-150.
- LEVERATTO, M.A. y MALVICINI, L., 1982. Geología y génesis del yacimiento de wolfrámio El Duraznito, San Luis. Asociación Geológica Argentina, Revista, 37: 369-383.
- LINARES, E. y GONZALES, R.R., 1990. Catalogo de edades radiométricas de la Republica Argentina. Años 1957 - 1987. Publicaciones especiales de la Asociación Geológica Argentina, Serie "B" (Didáctica y Complementaria). N° 19. 627pp.
- LINARES, E., 1959. Los métodos geochronológicos y algunas edades de minerales de la Argentina, obtenidas por medio de la relación plomo-uranio. Asociación Geológica Argentina, Revista, 14: 181-217.
- LLAMBIAS, E.J. y MALVICINI, L., 1982. Geología y génesis de los yacimientos de tungsteno de las Sierras del Morro, Los Morrillos y Yulto, Provincia de San Luis. Asociación Geológica Argentina, Revista, 37: 100-143.
- LLAMBIAS, E.J., CINGOLANI, C., VARELA, R., PROZZI, C., ORTIZ SUAREZ, A., TOSELLI, A. y SAAVEDRA, J., 1991. Leucogranodioritas sin-cinemáticas ordovícicas en la Sierra de San Luis. VI Congreso Geológico Chileno Resúmenes Expandidos. 187-191.

- LLAMBIAS, E.J., QUENARDELLE, S., SUAREZ, A.O., y PROZZI, C., 1996a. Granitoides sin-cinemáticos de la Sierra Central de San Luis. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas III: 487-496.
- LLAMBIAS, E.J., SATO, A.M., PROZZI, C. y SANCHEZ, V., 1996b. Los pendants de gneises en el plutón Gasparillo: Evidencia de un metamorfismo pre-Famatiniano en las Sierras de San Luis. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 369-376.
- LOPEZ, M.G., 1984. Relaciones petrológicas entre pegmatitas y sus cajas en la región de Tilisarao-Renca, Provincia de San Luis. Asociación Geológica Argentina, Revista, 39(1-2): 131-143.
- LYONS, P., SKIRROW, R.G. and STUART-SMITH, P.G., 1997. Report on Geology and Metallogeny of the "Sierras Septentrionales de Córdoba" 1:250 000 map sheet, Province of Córdoba. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- LYONS, P., STUART-SMITH, P.G., SIMS, J.P., PIETERS, P., SKIRROW, R.G. and CAMACHO, A., 1996. Whole Rock Geochemistry Report Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- MALVICINI, L., ORTIZ SUAREZ, A., SOSA, G.M., ULACCO, H. y RAMOS, G., 1991. El ciclo metalogenético Precámbrico-Paleozóico de la Sierra de San Luis, República Argentina. 6 Congreso Geológico Chileno, Resúmenes Ampliados, 101-105.
- MARTINO, R., KRAEMER, P., ESCAYOLA, M., GIAMBASTIANI, M., y ARNOSIO, M., 1995. Transect de Las Sierras Pampeanas de Córdoba a los 32° S. Revista de la Asociación Geológica Argentina, 50, 60-77.
- MARTINO, R.D., SIMPSON, C., and LAW, R.D., 1994. Ductile thrusting in Pampean ranges: its relationships with the Oculoyic deformation and tectonic significance. IGCP Projects 319/376, Novia Scotia, Abstracts.
- MASSABIE, A.C., 1982. Geología de los Alrededores de Capilla del Monte y San Marcos, Provincia de Córdoba. Revista de la Asociación Geológica Argentina, 37: 153-173.
- MEINERT, L.D., 1993. Igneous petrogenesis and skarn deposits. In: KIRKHAM, R.V., SINCLAIR, W.D., THORPE, R.I. and DUKE, J.M. (eds), Mineral Deposit Modeling. Geological Association of Canada Special Paper 40, 569-584.
- MONCHABLON, A., 1956. Yacimientos de wolfrámio de la Provincia de San Luis, Dirección Nacional de Geología y Minería, Buenos Aires, inedito.

- ORTIZ SUAREZ, A., PROZZI, C. y LLAMBIAS, E.J., 1992. Geología de la parte sur de la Sierra de San Luis y granitoides asociados, Argentina. *Estudios Geológicos*, España, 48(5-6): 269-277.
- ORTIZ SUAREZ, A.E. y SOSA, G.M., 1991. Relaciones genéticas entre las pegmatitas portadores de estaño y metamorfitas asociadas en la zona de La Carolina / San Francisco del Monte de Oro, Provincia de San Luis. *Asociación Geológica Argentina, Revista*, XLVI(3-4): 339-343.
- OTAMENDI, J.E., NULLO, F.E., FAGIANO, M. y ARAGON, E., 1996. Dos Terrenos Metamórficos y estructurales en el extremo sur de la Sierra de Comechingones, Córdoba-San Luis: Algunas implicancias tectónicas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 249-266.
- OYARZABAL, J.C. y GALLISKI, M.A., 1993. Geología del yacimiento San Luis: Un caso de yuxtaposición de tipologías diferentes en pegmatitas de clase elementos raras. XII Congreso Geológico Argentino, Actas, V: 167-174.
- PASTORE, F. y GONZALES, R.L., 1954. Descripción geológica de la Hoja 23g, San Francisco (San Luis). *Dirrección Nacional de Minería, República Argentina*, 80, 62p.
- PASTORE, F. y RUIZ HUIDOBRO, O.J., 1952. Descripción geológica de la Hoja 24g, Saladillo (San Luis). *Dirrección Nacional de Minería, República Argentina*, 78, 63p.
- PIETERS, P., SKIRROW, R.G. and LYONS, P., 1997. Report on Geology and Metallogeny of the Sierras de Las Minas, Chepes and Los Llanos 1:250 000 map sheet, Province of La Rioja. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- PINOTTI, L.P., CONIGLIO, J.E., y LLAMBIAS, E.J., 1996. Características geológico-estructurales del Plutón Alpa-Corral, 32°8' - 32°47'S y 64°55' - 64°45'W, Sierras Pampeanas de Córdoba, Argentina. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas III: 477-486.
- PROZZI, C.R. y RAMOS, G. 1988. La Formación San Luis. I Jornadas de trabajo de Sierras Pampeanas, San Luis.
- QUENARDELLE, S.M., 1993. Caracterización geológica-petroológica del granito San José del Morro, Provincia de San Luis. XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos, Actas IV:61-67.
- RAMOS, G.A., 1990. Estudios preliminares sobre el control estructural en la mina de scheelita 'La Teodolina', Provincia de San Luis, Argentina. Decimo Primer Congreso Geológico Argentino, San Juan, 1990, Actas, 1: 357-360.

- RAMOS, G.A., 1992. Caracteres estructurales de algunas manifestaciones de scheelita en la zona de la Mina 'La Teodolina', San Luis, Argentina. In: BRODTKORB, M.K. DE y SCHALAMUK, I.B. (eds.), I Reunión de mineralogía y metalogenía, La Plata, 1991. Instituto de Recursos Minerales, Universidad Nacional de La Plata, No. 2: 237-247.
- RAMOS, V., 1988. Late Proterozoic - Early Paleozoic of South America - a collisional history. *Episodes*, 11(3): 168-174.
- RAMOS, V., MUNIZAGA, F. y KAY, S. MAHLBERG, 1991. El magmatismo Cenozóico a los 33°S de latitud: Geocronología y relaciones tectónicas. 6 Congreso Geológico Chileno, 1: 892-896.
- RAPELA, C.W., and PANKHURST, R.J., 1996. The Cambrian plutonism of the Sierras de Cordoba: pre-Famatinian subduction? and crustal melting. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 491.
- RICCI, S.M., 1971. Provincia de San Luis - Mapa Minero, Escala 1:750 000. Ministerio de Industria y Minería, Subsecretaría de Minería, Dirección Nacional de Promoción Minera.
- SABALUA, J., CHABERT, M., y SANTAMARIA, G., 1981. Mineralización de sulfuros de hierro, cobre y níquel, en el cuerpo basico de Las Aguilas, Provincia de San Luis. VIII Congreso Geológico Argentino, San Luis, Actas, IV: 497-507.
- SANTA CRUZ, J.N., 1978. Aspectos sedimentológicos de las formaciones aflorantes al este de la Sierra Chica, Provincia de Córdoba, Republica Argentina. *Asociación Geológica Argentina, revista*, 36: 232-244.
- SATO, A.M., ORTIZ SUAREZ, A., LLAMBIAS, E.J., CAVAROZZI, C.E., SANCHEZ, V., VARELA, R., y PROZZI C., 1996. Los plutones pre-Ocloyicos del sur de la Sierra de San Luis: Arco magmático al inicio del ciclo Famatiniano. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 259-272.
- SCHMIDT, C., 1993. Neogene inversion of two Cretaceous basins, Sierras Pampeanas, Argentina. Geological Society of America, 1993 Annual Meeting, Boston, Abstracts, 233.
- SIMS, J., SKIRROW, R.G., STUART-SMITH, P.G. and LYONS, P., 1997. Report on Geology and Metallogeny of the "Sierras de San Luis y Comechingones" 1:250 000 map sheet, Provinces of San Luis and Córdoba. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.

- SIMS, J.P., STUART-SMITH, P.G., LYONS, P., PIETERS, P., SKIRROW, R.G. and CAMACHO, A., 1996. Petrography Report. Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- SKIRROW, R.G., 1997a. Economic Geology of the Sierras de San Luis and Comechingones 1:250 000 map sheet. *In*: SIMS, J., SKIRROW, R.G., STUART-SMITH, P.G. and LYONS, P., 1997, Report on Geology and Metallogeny of the "Sierras de San Luis y Comechingones" 1:250 000 map sheet, Provinces of San Luis and Córdoba. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- SKIRROW, R.G., 1997b. Economic Geology of the Sierras Septentrionales de Córdoba 1:250 000 map sheet. *In*: LYONS, P., SKIRROW, R.G. and STUART-SMITH, P.G., 1997, Report on Geology and Metallogeny of the "Sierras Septentrionales de Córdoba" 1:250 000 map sheet, Province of Córdoba. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- SKIRROW, R.G., 1997c. Economic Geology of the Sierras de Las Minas, Chepes and Los Llanos 1:250 000 map sheet. *In*: PIETERS, P., SKIRROW, R.G. and LYONS, P., 1997, Report on Geology and Metallogeny of the Sierras de Las Minas, Chepes and Los Llanos 1:250 000 map sheet, Province of La Rioja. Geoscientific Mapping of the Sierras Pampeanas Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- SKIRROW, R.G. and JOHNSTON, A.I., 1997. Atlas Metalogenético de las Sierras Pampeanas, República Argentina. Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report.
- SKIRROW, R.G. and TRUDU, A., 1997. ARGMIN: A mineral deposit database for the Sierras Pampeanas, Republic of Argentina. Geoscientific mapping of the Sierras Pampeanas, Argentine-Australian Cooperative Project, Australian Geological Survey Organisation, unpublished report. Database in Microsoft Access and Oracle.
- SMALLEY, R. Jr., PUJOL, J., REGNEIR, M., CHIU, J.M., CHATELAIN, J.L., ISACKS, B.L., ARAUJO, M. and PUEBLA, N., 1993., Basement seismicity beneath the Andean Precordillera thin-skinned thrust belt and implications for crustal and lithospheric behaviour. *Tectonics*, 12, 63-76.
- SMITH, W.C. and GONZALES, E.M., 1947. Tungsten investigations in the Republic of Argentina, 1942-43, U.S. Geological Survey Bulletin, 954-A:1-37.

- SOSA, G.M., 1991. Pegmatitas portadoras de estaño de la Provincia de San Luis: Su geología, mineralogía y génesis. Primero Reunión de Mineralogía y Metalogenia, La Plata, Instituto de Recursos Minerales, Universidad Nacional de La Plata, Actas, (2): 379-392.
- SOSA, G.M., 1990. Relaciones entre las pegmatitas portadores de estaño y las portadoras de niobio-tantalito de la Provincia de San Luis. Decimo Primer Congreso Geológico Argentino, San Juan, 1990, Actas, 1: 366-368.
- SOSA, G.M., 1993. Pegmatita estannífera compleja mina 'Victor Hugo', Provincia de San Luis. XII Congreso Geológico Argentino, Actas, V: 159-166.
- SOSIC, M., 1964. Descripción geológica de la Hoja 24 h - Sierra del Morro, San Luis-Córdoba. Dirección Nacional Geología y Minería, Buenos Aires, 95, 44p
- SPEAR, F.S., 1981. An experimental study of hornblende stability and compositional variability in amphibolite. American Journal of Science, 281, 697-734.
- SPEAR, F.S., 1993. Metamorphic phase equilibria and pressure-temperature-time paths. Mineralogical Society of America, Monograph. 799pp.
- SRUOGA, P., URBINA, N. y MALVICINI, L., 1996. El volcanismo Terciario y los depósitos hidrotermales (Au, Cu) asociados en La Carolina y Diente Verde, San Luis, Argentina. XIII Congreso Geológico Argentino, Actas I: 89-100.
- STOLL, W.C., 1963a. Los yacimientos de scheelita de Cerro Los Cocos (Provincia de San Luis), Asociación Geológica Argentina, Revista, 18(3-4): 116-120.
- STOLL, W.C., 1963b. La geología del tungsteno en Argentina. Asociación Geológica Argentina, Revista, 18(1-2): 96-106.
- STRASSER, E.N., TOGNETTI, G.C., CHIESA, J.O. y PRADO, J.L., 1996. Estratigrafía y sedimentología de los depósitos eólicos del pleistoceno tardío y Holoceno en el sector sur de la sierra de San Luis. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas IV: 73-83.
- TOSELLI, A.J., DURAND, F.R., ROSSI DE TOSELLI, J.N., y SAAVEDRA, J., 1996. Esquema de evolución geotectónica y magmática eopaleozóica del Sistema de Famatina y sectores de Sierras Pampeanas. XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas V: 443-462.
- URBINA, N., SRUOGA, P. y MALVICINI, L., 1995. El volcanismo Mioceno y la mineralización aurífera asociada en La Carolina y Diente Verde, Provincia de San Luis, Argentina, Set de diskettes del IX Congreso Latinoamericano de Geología, Caracas, Venezuela.

VON GOSEN, W. and PROZZI, C., 1996. Geology, structure and metamorphism in the area south of La Carolina (Sierra de San Luis, Argentina). XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, Actas II: 301-314.

ZARDINI, R., 1966. Composición, estructura y origen de la Pampa del Tamboreo (provincia de San Luis). Acta Geológica Lilloana, 8, 50-73

ARGMIN

MINERAL DEPOSIT DATABASE

OUTPUT DATA SHEETS