Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3166-33 *Corral de Isaac*

Province of La Rioja

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GEOSCIENTIFIC MAPPING OF THE SIERRAS PAMPEANAS ARGENTINA-AUSTRALIA COOPERATIVE PROJECT

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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CONTENTS

GEOLOGY

ECONOMIC GEOLOGY

1. INTRODUCTION

2. METALLIC MINERAL DEPOSITS

    2.1 Au (-Cu-Ag) mineralisation

    Previous work and exploration in the sierras de Chepes, Las Minas and Ulapes
    Regional geological setting
    Au-Cu-Ag deposits of *Corral de Isaac (3166-33)*
    Mineralisation, alteration and paragenetic sequence, sierras de Las Minas, Chepes and Ulapes
    Genesis

    2.2 U occurrences

REFERENCES

ARGMIN database output sheets

GEOLOGY

By Peter Pieters and Patrick Lyons

1. INTRODUCTION

1.1. LOCATION AND ACCESS

The 1:100 000 scale Corral de Isaac (3166-33) sheet covers the southern part of the Sierra de Las Minas and the surrounding plain which fall mostly in the southern part of the La Rioja Province, and, in the extreme south, also in the San Luis Province (Figures 1, 2). The map area is bounded by latitudes 31°40’ S and 32°00’ S, and by longitudes 66°00’ W and 66°30’ W. The area occupies the southeast part of the 1:250 000 scale Chepes (3166-III) sheet.

The area is easily accessible from Córdoba by Ruta Nacional 38, Ruta Provincial 32 and Ruta Nacional 79, from La Rioja by Ruta Nacional 38 and Rutas Provinciales 27, 28 and 29, and from San Juan by Ruta Nacional 141 and Rutas Provinciale 29. The nearest regularly serviced airport is located at La Rioja.

The nearest major centre of population, logistics and commerce is Chepes on Ruta Nacional 141 located between the Sierra de Chepes and Sierra de Las Minas (outside the map area). Totoral, Corral de Isaac and Nueva Esperanza are small population centres in the area.

1.2. NATURE OF WORK AND PREVIOUS INVESTIGATIONS

Mapping of the Sierra de Las Minas was carried out in 1995 and 1996 under the Geoscientific Mapping of the Sierras Pampeanas Argentina - Australia Cooperative Project by geologists of the Australian Geological Survey Organisation (AGSO) and the Subsecretaría de Minería (DNSG). The mapping employed a multidisciplinary approach

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

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Figure 2. Location of the *Sierras de Las Minas, Chepes y Los Llanos* 1:250,000 scale map area in La Rioja and San Luis Provinces with generalised geology. Locations of 1:100,000 scale map areas are indicated.

using the newly acquired high-resolution airborne magnetic and gamma-ray spectrometric data, Landsat TM imagery, and 1:45 000 scale (approximate) black and white air photos. All geological maps were compiled on topographic bases produced at photo-scale from rectified Landsat images controlled by field GPS sites. Subsequently, the geological and topographic maps were scanned and digitised, and the data were transferred into GIS Arc/Info. From the GIS six 1:100 000 scale maps, combining geology and topography, were produced. Geologists involved in the fieldwork were P.E. Pieters and P. Lyons (AGSO), and O. Cravero, J. Rios-Gomez, G. Vujovich and O. González (DNSG).

Although regional geological reconnaissance and economic geology studies in the Sierra de Las Minas have been carried out since the early 1900's (Bodenbender, 1911 and 1912; Groeber, 1940; Mastrandrea, 1961; Jutorán and Kejner, 1965), the first systematic mapping of the Sierra de Las Minas was conducted in 1967 by R. Caminos (Caminos, 1979). A program of regional stream-sediment geochemistry (Cu, Pb, Zn) accompanied by geological observations and air photo interpretation was carried out in 1972 by the Subsecretaría de Estado de Minería (La Rioja) and led to the production of an unpublished series of 1:50 000 scale geological maps covering the entire area of the Sierra de Las Minas. From 1993 to 1995 the Metal Mining Agency of Japan and the Subsecretaría de Estado de Minería, financially sponsored by the Japan International Cooperation Agency (JICA), carried out a program of gold exploration including diamond drilling of ten holes in the Sierra de Las Minas (JICA, 1993, 1994 and 1995). Systematic mapping of the Chepes 1:250 000 sheet area is currently undertaken by the DNSG.

2. STRATIGRAPHY

2.1 REGIONAL RELATIONSHIPS

The Sierras Pampeanas are a distinct morphotectonic province of early to middle Paleozoic, low to high-grade metamorphic and felsic to mafic plutonic rocks that form a series of block-tilted, northerly oriented ranges separated by intermontane basins. The ranges are bounded by escarpments developed on moderate to steeply dipping normal and reverse faults developed during the Cainozoic Andean uplift (Caminos, 1979; Jordan and Allmendinger, 1986).

Recent geological and geophysical surveys conducted by the Cooperative Argentine-Australian Project in the Sierras Pampeanas show that the Paleozoic basement of the southern Sierras Pampeanas contains a number of distinct lithological and structural domains which are traversed by major shear zones. There are two principal domains: an Early Cambrian Pampean domain, and an early Ordovician Famatinian domain, which are juxtaposed in a complex way. Both domains share a common geological history since early Ordovician time.

In the map area, the Cambrian metasediments and meta-igneous rocks of the Pampean domain are exposed as small enclaves spatially associated with migmatitic rocks. The outcrops of metamorphics are not mappable at 1:100 000 scale, but the rocks are correlative with the Olta Metamorphic Complex which is widely exposed in the Sierras de Chepes and de Los Llanos north of the Sierra de Las Minas. However, a distinct aeromagnetic low indicates the presence of a 60 to 100 km wide, northerly trending tract of Olta Metamorphic Complex rocks beneath the alluvial plain in the eastern part of the map area. The Famatinian domain is represented by early Ordovician granitoid and minor mafic bodies, and in places migmatite of the Chepes Igneous Complex. The rocks of the Chepes Igneous Complex were subjected to compressive non-coaxial deformation and greenschist facies metamorphism in the late Ordovician. Subsequently, the domains were intruded by Devonian granites (not exposed but interpreted from airborne magnetics), and covered by Carboniferous continental sediments and Cainozoic continental sediments.

2.2 ORDOVICIAN IGNEOUS COMPLEX

Chepes Igneous Complex

Distribution

The Chepes Igneous Complex is by far the dominant basement unit (90% in area) exposed in the map area.

Nomenclature

Caminos (1979) and Ramos (1982) applied the name Chepes Formation for the unit. These authors recognised the following subdivisions:

- Normal facies,
- Migmatitic facies, and
- Porphyritic facies.

Because of the wide lithological variety, the gradational contacts between the lithological units and also the structural complexity it is proposed to change the name, in accordance with the International Stratigraphic Code, to Chepes Igneous Complex. The broad subdivisions of Caminos and Ramos were confirmed by this survey, but with more detailed information available the Chepes Igneous Complex has been subdivided into a range of unnamed informal units, one newly named but informal unit (Quemado norite), and the formal Asperezas Granite and Tuani Granite (Pieters and others, 1997). The following units are exposed in the map area:

- Quemado norite (On),
- Tonalite (Ot),
- Granodiorite (Ogd),
- Biotite granite (Ogr),
- Granitoid (Og),
- Tuani Granite (Otu),

- Asperezas Granite (Oa),
- Migmatite, granitoid, tonalite (Ox),

Stratigraphic relationships within the Chepes Igneous Complex

The order of emplacement of the various plutonic units and the formation of the migmatite of the Chepes Igneous Complex is poorly constrained as the contacts are commonly gradational and complex, and the late Ordovician phase of compressional deformation and metamorphism (see TECTONISM) has obscured the stratigraphic relationships. Furthermore, although isotopic dating indicated that the various magmatic pulses occurred in a relatively short time span of about 14-20 Ma, the resolution of the data was insufficient to discriminate the order of emplacement.

In the Sierra de Las Minas, the Asperezas Granite is emplaced with distinct contacts in the granodiorite (Ogd), biotite granite (Ogr) and granitoid (Og) units; however, in and south of the headwaters of the Rio Quemado its western contacts are gradational with the granite (Ogr) unit. The granodiorite (Ogd), granite (Ogr) and granitoid (Og) units, characterised by the widespread presence of biotite, hornblende, fine-grained mafic to intermediate xenoliths, paucity of primary muscovite and medium to high magnetic susceptibility, cover large areas in the map area. The outcrops are markedly elongate in a north-south direction. The contacts between these units are diffuse with complex compositional and textural changes over short distances (in the order of 100 m). The contacts between the tonalite (Ot) and Quemado norite (On), and between the tonalite (Ot) and surrounding granitoid (Og) and biotite granite (Ogr) are also gradational. However, the tonalite (Ot) and Quemado norite (On) have high high magnetic susceptibilities and a low radiometric response, and on both the radiometric and magnetic images these units form a distinct oval body. The rocks of these units are thought to be intermediate to mafic phases genetically related to the granodiorite, granite and granitoid units. The Tuani Granite, characterised by the presence of muscovite in addition to biotite has, like the Asperezas Granite, a very low magnetic susceptibility and a high radiometric response. The contact of the Tuani Granite with the granodiorite (Ogd) is based on geophysical characteristics. In the migmatite, granitoid, tonalite (Ox) unit the various rock types are not mappable at 1:100 000 scale; the contacts of the rock types are gradational, their distribution is complex, and their outcrops are small (< 200 m). The boundary of this unit is largely constrained by airborne geophysical data.

Geochronology

Camacho and Ireland (1997) obtained five U-Pb zircon crystallization ages for various rock types of the Chepes Igneous Complex in the Sierras de Las Minas, de Chepes and de Los Llanos. The data show that the various magmatic phases of the Chepes Igneous Complex were emplaced in a relatively short time span of about 14-20 Ma (Pieters and others, 1997). Zircon from a biotite-hornblende tonalite sample of the migmatite, granitoid, tonalite (Ox) unit, collected in the map area, gave a U-Pb crystallization age of 480±6 Ma, and zircon from a biotite monzogranite of the Asperezas Granite, exposed in the northern part of the Sierra de Las Minas (Ulapes (3166-27) 1:100 000 sheet) gave a U-Pb age of 490±7 Ma (Table 1).

Table 1. U-Pb zircon dating by Camacho and Ireland (1997).

Sample	Latitude (S)	Longitude (W)	Unit	Rock type	Age (Ma)
A95PP 183A	31°40.72’	66°19.31’	migmatite, granitoid, tonalite (Ox)	biotite-hornblende tonalite	480±6
A95PP 159A	31°26.98’	66°17.49’	Asperezas Granite (Oa)	biotite monzogranite	490±7

Geochemistry

The narrow range of crystallization ages (491-477 Ma), geochemical characteristics (Pieters and others, 1997) and the contact relationships in the field indicate that the units of the Chepes Igneous Complex in the Sierras de Las Minas, Chepes and de Los Llanos were emplaced during one major magmatic event in the early Ordovician, and that they belong to the same igneous suite (or batholith).

The SiO_2 concentrations of the granite, granodiorite and tonalite samples from the three sierras range from 60% to 78%, and of the norite/gabbro from 43% to 45%. Binary plots of the concentrations of the major element oxides against SiO_2 concentrations display well defined linear trends. The rocks are alkalic to calc-alkaline, and most are metaluminous although close to and partly straddling the boundary of the peraluminous field.

On an AFM ternary diagram the data follow a coherent and decidedly calc-alkaline trend. A Na_2O-K_2O-CaO ternary plot shows similar ties to the calc-alkaline trend for these oxides as defined by Nockolds and Allen (1953). The Na_2O-K_2O-CaO ternary plot also demonstrates that the larger part of the samples are granodiorite with smaller numbers plotting in the monzo- and syenogranite fields, and the tonalite field.

The samples plot dominantly as volcanic-arc granites (VAG) on Nb against Y and Rb against Nb+Y diagrams after Pearce and others (1984). The low TiO_2 concentrations of the samples, without exception <1%, are also consistent with other arc-derived rocks (Green, 1980).

Quemado norite (On) of the Chepes Igneous Complex

Distribution

In the map area the unit crops out in the drainage of the Rio del Quemado.

Nomenclature

Ramos (1982) reported on the occurrence of mafic plutonic rocks in the Sierra de Chepes, and assigned this unit as an informal subdivision to the ‘Chepes Formation’. The unit is distinct and mappable at 1:100 000 scale, and therefore it is proposed to introduce the name Quemado norite. The name is after the Rio del Quemado; in the drainage of this river the unit is well exposed and easily accessible by vehicle track.

Lithology

Mapping of this unit was restricted to the marginal zones where it is in contact with granitoid. Although medium to locally coarse-grained norite, gabbro and diorite are the characteristic rock types, the rocks in the marginal zone are more variable in composition as well as texture. Where the unit is in contact with granitoid, the compositions of the rocks range from norite/gabbro to quartz diorite and tonalite, and the colour index, grain size and proportion of constituent minerals are highly variable. Compositional and textural (grainsize) layering is common; the layers range in thickness from 4 to 15 cm.

In thin section the norite and gabbro consist of plagioclase, orthopyroxene and clinopyroxene with variable amounts of hornblende and very little (<2%) biotite; magnetite is a common accessory. Hornblende commonly forms large, skeletal, poikilitic, optically continuous crystals with enclosed rounded plagioclase, ortho- and clinopyroxene. Replacement of pyroxenes and hornblende by secondary amphibole varies from marginal to pervasive. Other secondary minerals are epidote/clinozoisite, chlorite, actinolite, sericite, and where quartz is present it is recrystallised to a fine polygonal granoblastic aggregate. The nature of the secondary minerals indicates that the rocks were subjected to greenschist metamorphism.

The magnetic susceptibility of the mafic rocks varies from 500 to 5500 x 10^{-5} SI, and in the Rio del Quemado drainage the outcrop area is located in a 10 km long, north-south elongate zone characterised by a strong aeromagnetic signature and very low radiometric signature.

Remarks

From the field observations it is not clear whether the mafic rocks intrude the granitoid/tonalite as discrete bodies (for example sills) or if they form synplutonic mafic bodies emplaced in partially crystallised felsic/intermediate magma.

Tonalite unit (Ot) of the Chepes Igneous Complex

Distribution

The exposure of this unit is restricted to a north-northeast trending, oval-shaped body in the drainage of the Rio El Quemado. However, tonalite is a minor to rare but widespread component of the migmatite, granitoid, tonalite (Ox) unit, and the granodiorite (Ogd) and granitoid (Og) units of the Chepes Igneous Complex; in these units it is unmappable at 1:100 000 scale. The unit, together with the Quemado norite which it encloses, is characterised by a very high aeromagnetic signature and a low radiometric response, and on airphotos and Landsat TM images it stands out by a relatively dark tone.

Nomenclature

Caminos (1979) included this unit in the ‘normal facies of the Chepes Formation’ consisting of massive granodiorite and tonalite. The ‘Chepes Formation’ is replaced by the Chepes Igneous Complex which, in the map area, is subdivided into eight units.

Lithology

Although grey, fine to medium-grained tonalite is the characteristic rock type of this unit, it is closely accompanied by, and gradational to, granodiorite. Locally granodiorite makes up about 50% of the outcrop.

The main rock-forming minerals of the tonalite are plagioclase (30-45%), quartz (10-40%), biotite (5-20%), and hornblende (0-35%). The minor constituents include magnetite (<5%), muscovite (<5%), primary epidote (<1%), allanite (<1%), titanite (<1%), and locally orthopyroxene (<1%). The plagioclase tends to be relatively coarse and is commonly tabular subhedral; it shows normal zoning with the composition varying from oligoclase to labradorite. Biotite and hornblende are commonly subhedral. Primary epidote and allanite tend to be interstitial. Where observed the orthopyroxene mantles magnetite.

The rocks are affected by deformation and greenschist facies regional metamorphism. The quartz is recrystallised to a fine, polygonal granoblastic matrix commonly forming parallel aligned ribbons. The plagioclase, particularly in the cores, is altered to very fine or microcrystalline epidote/clinozoisite and sericite; biotite is variably replaced by chlorite and epidote/clinozoisite. A weakly to moderately developed foliation is defined by quartz ribbons and trails of recrystallised biotite. In places, fine-grained biotite tails trail from medium-grained biotite.

The magnetic susceptibility of the tonalite is moderate to high, ranging from 300 to 1500 x 10^{-5} SI.

Granodiorite (Ogd) of the Chepes Igneous Complex

Distribution

This unnamed granodiorite is exposed both east and west of the Asperezas Granite and biotite granite (Ogr) unit in the eastern part of the Sierra de Las Minas. Because of the gradational character of the boundaries between the granodiorite (Ogd), biotite granite (Ogr) and granitoid (Og) the distribution of these units is based, for a large part, on their geophysical properties.

Like in the granite country the topography is hilly with low to moderate relief with broad flat-topped or rounded ridges. The rocks are exposed as tors, boulders, pavements and irregular sheets.

Nomenclature, stratigraphic relations and age

Caminos (1979) and Ramos (1982) included this unit in the ‘normal facies of the Chepes

Formation' consisting of massive granodiorite and tonalite. The 'Chepes Formation' is replaced by the Chepes Igneous Complex which, in the map area, is subdivided into eight units.

Lithology

The rocks are mainly light grey passing to medium grey where they contain relatively high amounts of biotite, and some of the granites are light pink to greyish pink.

The main rock type is granodiorite containing 5 to 20% biotite and in places up to 5% hornblende; on a regional scale the composition grades into monzogranite and tonalite. Compositional and, to a lesser degree, textural changes at outcrop scale range from abrupt to gradational, and show in the field as igneous banding of biotite ± hornblende bearing phases and felsic (with or witout K-feldspar) phases, the occurrence of biotite-rich schlieren in more felsic granodiorite, and irregular shaped enclaves of granite or tonalite in granodiorite.

Xenoliths are widespread and in places they make up 20 to 30 % of the rock. The composition is microdiorite or micro quartz diorite containing 20% to 60% biotite and commonly also hornblende (<10%). Some xenoliths contain fine to medium-grained feldspar phenocrysts. The size of the xenoliths is up to 100 cm with the most common sizes varying between 5 and 20 cm. Most contacts with the host rock are sharp but gradational contacts were also observed. In zones of high strain, for example along the western margin of the Sierra de Las Minas, the xenoliths are flattened, predominantly about a northerly strike. Enclaves of migmatite in the granodiorite are rare, for example, at locality A95RS054 (31°58.37'W/66º19.30'S; Dos Buhos mine) in the southernmost part of the Sierra de Las Minas.

The typical granodiorite is made up of quartz (15-30 %), plagioclase (30-50 %), K-feldspar (10-25 %), biotite (10-15 %), hornblende (<10 %), and accessory magnetite and zircon. The quartz is recrystallised to aggregates with polygonal granoblastic textures and/or deformed to grains with strained extinction and sutured boundaries. The plagioclase forms subhedral grains and commonly shows normal zoning; particularly in the cores it is altered to microcrystalline epidote/clinozoisite, fine epidote, sericite and minor to fine muscovite. The K-feldspar, dominantly microcline, is relatively coarse, anhedral and little altered to kaolinite. The biotite and hornblende occur mostly as single crystals but also in clusters; the biotite is variably replaced by chlorite, epidote and sphene, and the hornblende by secondary amphibole. A minor but characteristic phase is made up of primary epidote and allanite. In places the epidote is nucleated on the allanite. The accessory primary epidote is difficult to recognise from the widespread secondary epidote; however, the secondary epidote is usually more pleochroic, intergrown with clinozoisite, and closely associated with plagioclase and biotite which it replaces. Titanite and zircon are common accessories; zircon commonly occurs in the biotite surrounded by pleochroic haloes.

The strained plagioclase and microcline, recrystallization of quartz, commonly present foliation and shearing, flattened xenoliths and the assemblage of secondary minerals indicate regional scale contemporaneous compressive deformation and greenschist facies metamorphism.

Biotite granite unit (Ogr) of the Chepes Igneous Complex

Distribution

The biotite granite unit is exposed in the eastern part of the Sierra de Las Minas. The outcrop areas are generally elongated north-south.

The topography of the granite country is typically hilly with low to moderate relief and flat-topped or rounded ridges, and the rocks form tors, boulders, pavements and irregular sheets.

Nomenclature and stratigraphic relations

Caminos (1979) and Ramos (1982) included this unit in the ‘normal facies of the Chepes Formation’ described as massive granodiorite and tonalite. The ‘Chepes Formation’ is replaced by the Chepes Igneous Complex which, in the map area, is subdivided into eight units.

The unit is transitional to the the granodiorite (Ogd) and granitoid (Og) units, and the contact with the Asperezas Granite (Oa) varies from distinct to gradational. Fieldwork data, in combination with airphoto and Landsat image interpretation, only poorly constrain the boundaries. However, the airborne radiometric and magnetic signatures of the units are more distinct and the position of the boundaries is mainly based on their geophysics.

Lithology

The most common rock type is monzogranite which is light pink to light grey, fine to medium-grained, equigranular to seriate with relatively coarse K-feldspar, and homogeneous. In places it grades into, or is cut by veins or dykes of, leucogranite and aplite (partly Asperezas Granite). Granodiorite lithologies were also observed. The monzogranite contains 2-15% biotite. Xenoliths are only locally common; they are round to oval with sharp as well as gradational boundaries and up to 6 cm long, and invariably consist of biotite microdiorite or micro quartz diorite containing up 30-60% biotite.

The rocks are deformed and metamorphosed in a similar manner as the Asperezas Granite.

Granitoid unit (Og) of the Chepes Igneous Complex

Distribution

This composite unit is a widely distributed throughout the Sierra de Las Minas.

Nomenclature and stratigraphic relations

The granitoid unit consists of 25-75% granodiorite and 25-75% biotite granite, and minor tonalite and leucogranite; these rock types could not be differentiated at 1:100 000 scale into separate units by field mapping, and interpretation of airphotos, Landsat TM and airborne geophysics.

The contact with the migmatite, granitoid, tonalite unit (Ox) is locally sharp but mostly gradational. In places the unit is intruded by the Asperezas Granite.

Lithology

The rock types making up this unit are described in separate sections on the granodiorite (Ogd) unit and the biotite granite (Ogr) unit.

Tuani Granite (Ot) of the Chepes Igneous Complex

Distribution

The muscovite-biotite granite of the Tuani Granite occupies small outcrop areas in the extreme south of the Sierra de Las Minas (southeast of Corral de Isaac) and in the subdued hills which occur south of the hilly basement country east of the prominent escarpment bounding the Sierra de Las Minas.

Nomenclature, stratigraphic relations and age

The name Tuani Monzogranite was introduced by Dahlquist and Baldo (1996), and the name Tuani Granite by Pankhurst and others (1996). The unit is as yet not formally defined, and the usage of the name Tuani Granite is preferred in this report.

Lithology

The typical lithologies of this unit are white to light pink, fine to medium-grained and equigranular to seriate muscovite-biotite monzogranite. The rocks consist of the following minerals: quartz (15-50%), K-feldspar (microcline) (15-30%), plagioclase (albite-oligoclase) (0-30%), muscovite (5-15%), biotite (0-15%). Like the other units of the Chepes Igneous Complex, the granite has been subjected to deformation and regional greenschist metamorphism.

Asperezas Granite (Oa) of the Chepes Igneous Complex

Distribution

Leucogranite of the Asperezas Granite crops out mostly in the eastern part of the Sierra de Las Minas as commonly north-south elongate bodies ranging in size from up to 50 m thick dykes to stock-size bodies up to 8 km long and 2 km wide. The granite bodies stand out in the landscape as relatively resistant, light pink to white ridges which are almost bare of vegetation. The outcrops form rugged tors and irregular surfaces. On airphotos and Landsat images the unit is very conspicuous because of its light tones.

Nomenclature and stratigraphic relations

The name Asperezas Granite was formalised by Caminos (1968).

The contacts with biotite granite (Ogr), granodiorite (Ogd) and granitoid (Og) units vary from gradual to abrupt. In the southern part of the Sierra de Las Minas, where the Asperezas Granite grades westward into the biotite granite the boundary is poorly defined and the position is only approximate. On the other hand, the eastern contact with the granodiorite unit is sharp.

Lithology

The leucogranite is light pink to white, fine to coarse-grained, seriate with relatively coarse K-feldspar, and homogeneous. Xenoliths are rare and very small (0.5-2cm across), and consist of biotite-rich microdiorite to quartz diorite. The unit is cut by pegmatite and aplite veins, and locally grades into pegmatitic granite and fine-grained granite or aplite. The pegmatite phase probably represents the final stage of differentiation by fractional crystallization of the magma which also produced the Asperezas Granite.

The typical rock type is leucocratic monzogranite composed of 30-60% K-feldspar (mostly microcline; rarely orthoclase), 10-30% Na-rich plagioclase, 20-50% quartz, <5% biotite and accessory zircon. The microcline is anhedral and perthitic, relatively fresh, and in places is deformed by kinking. The plagioclase is an- to subhedral and commonly more or less replaced by sericite and epidote/clinozoisite in the form of very fine crystals as well as microcrystalline aggregate. Most of the quartz is recrystallised to a fine polygonal granoblastic aggregate. Brown biotite occurs in single crystals and in small, subparallel oriented aggregates, and is altered to chlorite along the cleavage and margins. Fine muscovite is a minor (<2%) secondary mineral associated with feldspar and biotite.

The rocks are variably deformed and the assemblage of secondary minerals indicates that they have been subjected to greenschist facies metamorphism. The northerly trend of the elongate bodies parallels the trend of a commonly present discontinuous, spaced foliation, and the trend of brittle-ductile shear zones within and along contacts of the bodies. The foliation is steep to vertical, and defined by lenses of recrystallised quartz, biotite folia or streaks and platy K-feldspar.

The magnetic susceptibility of the unit is typically low and varies between 0 and 70 x 10^{-5} SI. On the other hand, the radiometric response is high compared to that of the other plutonic units of the Chepes Igneous Complex.

Remarks

The contact relationships, geochemistry and U-Pb zircon dating indicate that the Asperezas Granite forms a late crystallization phase genetically associated with the granite, granodiorite and granitoid units of the Chepes Igneous Complex.

Migmatite, granitoid, tonalite unit (Ox) of the Chepes Igneous Complex

Distribution

Exposures of this unit are confined to the central western part of the Sierra de Las Minas.

Nomenclature and stratigraphic relations

This unit consists of various plutonic lithologies and migmatite which are not separable at 1:100 000 scale, because of the small outcrop areas and complex contact relationships.

The boundaries with the granitoid unit (Og) and granodiorite unit (Ogd) are gradational and poorly defined, and their positions are mostly constrained by geophysics.

Lithology

The proportion of migmatite in the unit varies from 10% to 20%, the proportion of granitoid from 50% to 80%, and the proportion of tonalite from 10% to 30%. The distribution of these rock types varies considerably from place to place over distances as short as 50 m.

A common migmatite type is stromatic migmatite (Mehnert, 1968) where neosome and paleosome are more or less distinctly layered and have contrasting compositions. The layers are less than 5 mm to 50 cm thick and discontinuous with lenticular to pinch-and-swell forms. The layering commonly trends about north-south. At a more advanced stage of migmatisation the rock becomes a schlieren or nebulitic migmatite. In these migmatites the boundaries between the paleosome and neosome are irregular and diffuse, and these phases can only be recognised by the slightly different proportions of their mineral contents. The schlieren have irregular and whispy forms but their long dimensions still follow the regional structural trend. At this stage the migmatite merges into magmatic granitoid.

The paleosome of the migmatite is composed of psammitic, pelitic and feldspathic metasediments (including 2-mica phyllite, schist and gneiss), schistose and gneissic granitoid, and minor hornblende-plagioclase schist and gneiss. With advanced migmatisation the paleosome and neosome lithologies become progressively more homogeneous eventually forming granitoid in which the original planar fabric elements are only preserved as schlieren. The paleosome of the migmatite commonly contains equant porphyroblasts of plagioclase or K-feldspar. Feldspar porphyroblasts are even noticable in nebulitic and schlieren migmatite or granitoid where migmatisation has reached an advanced stage of homogenization. Scattered, equidimensional milky to grey quartz segregations measuring 4-10 cm across are a typical feature closely associated with the migmatite complex.

The neosome comprises two types of leucosome: fine to medium-grained muscovite-biotite monzo- or syenogranite and muscovite-bearing pegmatite, and granodiorite. The plagioclase is an- to subhedral, equidimensional and shows very little compositional zoning. The K-feldspar (microcline) is anhedral, relatively coarse and occasionally poikilitic. The quartz commonly occurs in irregular aggregates. The leucosomes are commonly separated from the paleosome by a melanosome forming a thin selvedge of dark grey to black biotite-feldspar-quartz rock which in places also contains hornblende or cordierite. The biotite forms parallel streaky aggregates aligned about the same trend as the layering. The contact with the paleosome is gradational and with leucosome abrupt. The neosome rocks form discontinuous, lenticular bodies up to 50 cm thick. With advanced migmatism the paleosome and neosome become progressively more disrupted, intermingled and intermixed, and eventually it is impossible to differentiate the two phases.

The migmatite lithologies are closely associated with granitoids ranging in composition from monzo- or syenogranite through granodiorite to tonalite. The contacts between the migmatite and granitoids are both sharp and diffuse or gradational, and in places it is not clear whether the granitoids represent an advanced stage of migmatisation or that they form magmatic bodies derived from lower crustal levels.

The main structural fabric in the migmatite is a generally northerly trending foliation defined by the compositional layering, and parallel alignment of biotite and of elongate aggregates or streaks of biotite with or without hornblende. This foliation parallels and is mostly, if not all, controlled by the structural fabric of the metamorphics of the paleosome.

The migmatite, granitoid and tonalite lithologies are altered and deformed under greenschist-facies conditions. Plagioclase is partly altered to sericite, secondary muscovite and epidote/clinozoisite, biotite to chlorite, epidote/clinozoisite and titanite, and quartz is recrystallized to granoblastic-polygonal aggregates. The rocks are locally disrupted by shearing and cut by a spaced foliation, both about a northerly trend, and in zones of high strain they are transformed into mylonite. The spaced foliation is defined by reoriented biotite and by aggregates, lenses and ribbons of recrystallised quartz.

Dykes of up to 1.5 m thick micro quartz diorite or granodiorite locally cut the migmatite, granitoid and tonalite; these dykes are particularly noticeable in the Callana gold district.

The other rock types making up this unit are described in separate sections on the granitoid (Og) and tonalite (Ot) units.

2.3. ORDOVICIAN PEGMATITE, APLITE AND MICROGRANITE DYKES

Distribution

Pegmatite, aplite and microgranite dykes, veins and pods occur throughout the Sierra de Las Minas but are much less common than in the Sierras de Chepes and de Los Llanos. The larger dykes are mostly spatially associated with the Asperezas Granite. The dykes and veins are shown on the map with the standard dyke map symbol.

Nomenclature and age

This unit is informal and unnamed as it comprises two and possibly three phases of emplacement of felsic rocks, which, at the present stage of mapping, only locally can be differentiated. The dykes, veins and pods were emplaced in the early Ordovician accompanying migmatisation, as late crystallization products during the magmatic cycle of the Chepes Igneous Complex, and possibly also in the late Ordovician during regional compressive deformation.

Lithology

A distinct phase of pegmatite, aplite and microgranite emplacement is associated with the migmatite of the migmatite, granitoid. The rocks occur in discontinuous and irregular shaped veins and pods, most commonly 4-10 cm thick. Generally, the veins follow the northerly structural trend of the migmatite lithologies; locally they are folded. The rocks consist of quartz, albite/oligoclase and K-feldspar with minor muscovite, and accessory biotite. In the pegmatite the feldspar forms the coarse phase. Because of the small size of the bodies this phase is not represented on the map.

Another phase of dykes and veins is attributed to advanced differentiation by fractional crystallization of granitic magma which probably also produced the various granites, in particular the Asperezas Granite. The rocks intrude all lithologies of the Chepes Igneous Complex, and also are incorporated in the Ulapes mylonite. Generally, the dykes and veins have a northerly to northwesterly trend, and are affected by shear deformation. In the central eastern part of the Sierra de Las Minas the bodies reach a thickness up to 50 m and a length of 2 km. Boudinageing and tight folding were observed in outcrops as well as on airphotos. The rocks are composed of quartz, albite/oligoclase and K-feldspar with minor muscovite, accessory biotite, and locally contain tourmaline.

The origin of the remaining dykes and veins is uncertain. The orientations of the bodies vary greatly, although northerly and westerly trends are most common. In addition to quartz, albite/oligoclase, K-feldspar, minor muscovite and accessory biotite the pegmatite also contains locally tourmaline. Many bodies show a more or less well defined zoning, particularly in texture. Except for minor macroscopic open folding, and locally shearing and faulting the rocks are relatively little deformed. The rocks may have been emplaced during the waning stages of the late Ordovician phase of east-west compressive deformation; however, no other felsic magmatism has been recorded from that time in the region. In other parts of the southern Sierras Pampeanas pegmatites are genetically related to the Devonian Achala Granite Complex (Morteani and others, 1995), but in the Sierra de Las Minas there is no field and aeromagnetic evidence that the Devonian granite plutons, concealed beneath the alluvial plains adjacent to the sierras, are accompanied by pegmatites and other highly differentiated rocks. On the other hand, these dykes and veins may also have been derived from the felsic magma which produced the granites of the Chepes Igneous Complex, but they were only slightly affected by deformation as they are located in zones of low strain.

2.4. ORDOVICIAN ULAPES MYLONITE

Distribution

The Ulapes mylonite was mapped as a lithological unit along almost the entire eastern margin of the Sierra de Las Minas where it is exposed in a 200-1000 m wide zone.

Nomenclature and age

Caminos (1979) was the first author to report on the presence of mylonite along the eastern margin of the Sierra de Las Minas. The mylonite forms a distinct lithological unit which is mappable at 1:100 000 scale. In this report it is proposed to designate the unit as the Ulapes mylonite. The type area nominated is immediately west of Ulapes where the mylonite is well exposed and easily accessible.

^{40}Ar-^{39}Ar dating of muscovite from sample A95PP192B (66°20.36'W/31°06.15'S; Desiderio Tello (3166-21) 1:100 000 sheet), consisting of mylonitised granite, gave a total fusion age of 454±1 Ma and a step heating age of 450-462 Ma, which are interpreted as the age range (late Ordovician) of the shearing deformation. The secondary muscovite, interpreted to have grown in greenschist-facies conditions during shearing, is subparallel to the stretching lineation in the shear fabric.

Lithology

The mylonite is typically associated with northerly trending straight to curved and sinuous, ductile shear zones which cut the basement rocks at intervals of 5-15 km. The shear zones are up to about 1 km wide, and aeromagnetics indicates that these structures are also present beneath the alluvial sediments of the plains east and west of the Sierra de Las Minas. The mylonite passes gradually, at a high angle to the northerly trend of shear fabrics, into weakly to moderately deformed wall rock from which it was derived. The wall rock consists mostly of granite, granodiorite, tonalite and migmatite of the Chepes Igneous Complex. Towards the shear zone the strain gradient is accompanied by an increasing intensity of shear foliation (S2), and veins, layering and foliation in the wall rock are displaced and rotated into parallellism to the shear fabric in the zone.

The mylonite is intercalated with protomylonite and ultramylonite indicating strongly variable strain conditions within the shear zones. The ultramylonite forms discontinuous and lenticular, up to 15 cm thick, dark grey layers of fine-grained homogeneous rock in which the original igneous and metamorphic fabrics are completely destroyed. The protomylonite is gradational with the mylonite and occurs in layers up to several metres thick; the proportion of protomylonite increases towards the margins of the shear zones. The protolith of the protomylonite is easily recognisable. The mylonite zones developed under greenschist-facies metamorphic conditions as indicated by the widespread occurrence of muscovite and biotite grown parallel to the mylonitic foliation, and the absence of high-grade metamorphic minerals such as garnet and sillimanite or pseudomorphs of these minerals.

2.5. DEVONIAN GRANITE

Devonian granite is not exposed in the Sierra de Las Minas. However, an aeromagnetic domain of oval-shaped and zoned, stock to pluton-size structures suggest the presence of Devonian granite beneath the alluvial plains west of the central western margin of the Sierra de Las Minas. In other parts of the southern Sierras de Pampeanas, Devonian granites display similar aeromagnetic signatures (Sims and others, 1997; Stuart-Smith and others, 1997). Magnetic modelling indicates that the interpreted granite bodies occur at depths between 300 and 600 m below the alluvial plain (Hungerford and others, 1996).

^{40}Ar-^{39}Ar isotopic dating of sericite associated with sericite - pyrite ± chlorite hydrothermal alteration and mesothermal Au ± Cu bearing quartz veins in brittle-ductile shear zones gave an crystallization age range of 389-393 Ma (Camacho, 1997). These results conform with the occurrence of a regional Early Devonian Au, Ag, Pb, Zn, W, Cu metallogenic event in the southern Sierras Pampeanas (see Skirrow; ECONOMIC GEOLOGY in this report). The concealed Devonian granite bodies in the map area may have provided the heat source that induced the convective circulation of hydrothermal fluids.

2.6. CARBONIFEROUS SEDIMENTS

Malanzán Formation (Cm)

Distribution

The distribution of the Carboniferous Malanzán Formation is largely controlled by a graben structure in the southern part of the map area which cuts the basement rocks about an east-west structural trend. The valley associated with the graben interrupts the Sierra de Las Minas in the extreme south. Because of their topographically low position in the fault-controlled valleys the sediments escaped complete erosion.

Nomenclature, stratigraphic relationships and age

The name Malanzán Formation was introduced by Furque (1968) although the sediments had been studied in detail by Bracaccini already in 1946 in the area of Malanzán (Malanzán (3166-14) 1:100 000 sheet). The formation belongs to the Paganzo Group which was introduced by Azcuy and Morelli (1970).

The Malanzán Formation rests unconformably on the basement of the Chepes Igneous Complexes. The unit is unconformably overlain by Cainozoic terrestrial sediments.

Plant fossils indicate a Late Carboniferous age for the Malanzán Formation (Archangelsky and Leguizamón, 1971; Azcuy, 1975a, b; Frengüelli, 1946; Bracaccini, 1948.

Lithology

The Malanzán Formation was deposited in the Paganzo Basin, a large cratonic basin which covered the west and central areas of Argentina (Gonzále and Aceñolaza, 1972; Gamundi and others, 1990). Sedimentation in this basin started in the Early Carboniferous and continued up into the Triassic. The environment of deposition was dominantly continental, and a thin interval of shallow marine Carboniferous sediments was deposited during a short-lived transgression from the west. To the west the Paganzo Basin passes into basins with dominantly marine-facies sediments which are interpreted to have formed in a back-arc tectonic setting (Gamundi and others, 1990). Tuff beds have been recorded to occur in the Permian sequence of the continental sediments.

The Malanzán Formation consists of a basal polymictic conglomerate followed by grey, green and brown fine to coarse sandstone and mudstone with sparse intercalations of conglomerate. The mudstone and fine sandstone are commonly carbonaceous and contain plant remains. The sandstone is commonly feldspathic and in places arkosic. The sediments were deposited in a fluviatile channel and floodplain, and lacustrine environments. The maximum thickness of the unit is about 600 m.

2.7. CAINOZOIC SEDIMENTS

Los Llanos Formation (Tpl)

Distribution

The Los Llanos Formation is exposed in isolated, low but steeply dissected hilly areas immediately west of the southern part of the Sierra de Las Minas. The unit is covered by and in places difficult to differentiate from alluvial terrace and dissected alluvial fan deposits (Czd), and alluvial plain, palaeosoil and eolian deposits (Czu). In general, the Los Llanos Formation is slightly more deformed by gently tilting than the subhorizontal Czd and Czu units, and it is also more closely dissected.

Nomenclature, stratigraphic relationships and age

The unit was first described by Bodenbender (1911) as the Los Llanos Beds (Estratos de Los Llanos); Caminos (1979) revised this name to the Los Llanos Formation. The unit lies unconfomable on the basement of the Chepes Igneous Complexes, and is overlain conformably or with an erosive contact by the Czd and Czu units. Based on mammalian fossils the age of the unit is early Pliocene (Pascual and others, 1965).

Lithology

The unit consists of poorly sorted, polymictic sandstone and pebble to boulder conglomerate with rare discontinuous beds of sandy mudstone. The rocks are commonly white to light grey. The sandstone is quartz-rich and in places feldspathic. The subangular to subrounded pebbles of the conglomerate consist mostly of various quartz types and minor granitoid. Calcareous cement is present in places, and is partly replaced by silica. Large-scale trough cross-bedding occurs widespread. Based on drilling the maximum thickness is at least 290 m. The unit was deposited in an alluvial fan environment, and the fans probably flanked the sierras in the early stages of uplift.

Alluvial, eolian and paeosoil deposits in intermonane basins (Cza)

This unit is restricted to small intermontane basins in the higher parts of the Sierra de Chepes. The basins are thought to be remnants of an old erosion surface where partly preserved soils (age unknown) are overlain by fluviatile poorly to moderately consolidated silt and sand and fine eolian (possibly loess) deposits.

Eolian deposits (Cze)

Sandy to silty eolian sediments overlie the alluvial plain in the southeast corner of the map area. On the Landsat TM this unit is characterised by parallel discontinuous dunes.

Alluvial plain, paleosoil and eolian deposits (Czu)

This unit occurs widespread in the map area underlying the vast plain which surrounds the sierras. Only near the sierras the plain is eroded and dissected by streams debouching from the uplands forming escarpments up to 10 m high. The alluvial plain sediments consist mainly of poorly to moderately consolidated sand with minor gravel and silt, and paleosoils indicating periods of non-deposition. The sandy to silty eolian deposits are thin and locally overlie the plain.

Alluvial deposits (Qa)

Sand, silt and minor gravel are deposited by intermittent streams flowing from the sierras onto the surrounding plains. The streams are mostly anastomising, have formed broad but very shallow valleys which become rapidly narrower away from the sierras, and eventually peter out on the sandy plain.

Alluvial fan and talus deposits (Qg)

Gravel, sand and silt are deposited in alluvial fan and talus deposits along the margins of the sierras. The deposits are most extensive where they are coalesced to bajadas flanking fault-controlled escarpments along the eastern margin of the Sierra de Las Minas.

3. TECTONICS

Three major deformation/metamorphic and magmatic events have affected the basement rocks:

- the Cambrian Pampean cycle,
- the Ordovician Famatinian cycle, and
- the Devonian Achalian cycle.

Faulting, tilting and uplift occurred during the Cainozoic associated with the Andean cycle.

3.1 PAMPEAN CYCLE

Deformation and metamorphism of the Pampean cycle (D1 and M1) were only reported from the metasediments and meta igneous rocks of the paleosomes associated with migmatite of the migmatite, granitoid, tonalite (Ox) unit. The main deformational/metamorphic fabric (S1) is defined by parallel metamorphic segregation layering of felsic minerals (quartz, plagioclase and K-feldspar) and mica (biotite and muscovite). The layers range in thickness from a few mms to 2 cm, and are commonly lensoid and anastomising. A layer parallel foliation is defined by subparallel aligned micas. The S1 foliation strikes between northeast and northwest with steep dips to the east as well as the west. The paleosomes of metamorphics are the only remnants of the Pampean basement in the map area, but farther north in the Sierras de Chepes and de Los Llanos this basement is more widely exposed as the Olta Metamorphic Complex (Pieters and others, 1997).

3.2. FAMATINIAN CYCLE

During the Famatinian cycle the terrane of metasediments and meta-igneous rocks of the Olta Metamorphic Complex was intruded by granitoids and minor intermediate to mafic plutonic rocks. As result of the high heat flow the country rocks of the Olta Metamorphic Complex underwent low-pressure/high temperature thermal metamorphism and migmatisation (M2). The mineral assemblages of the metamorphic rocks of the paleosomes in the migmatites were formed during this phase of metamorphism, and overprint the older, lower grade assemblages (M1) while preserving largely the older deformational fabric (S1).

There is no unequivocal field evidence of deformational structures which are associated with this phase of magmatism and thermal metamorphism.

Subsequent to the magmatism and low-pressure/high temperature thermal metamorphism the rocks of the Chepes Igneous Complex were subjected to regional, east-west, non-coaxial compressional deformation (D2) at greenschist facies metamorphic conditions (M3). Throughout the Sierras de Las Minas the igneous fabric in the rocks of the Chepes Igneous Complex is rotated and recrystallized into parallellism by a moderately to steeply easterly-dipping, weakly to strongly penetrative shear fabric associated with westerly-directed thrusting, development of mylonite in high-strain zones, and retrogressive greenschist facies metamorphism. A weakly to moderately well developed mineral lineation of biotite, muscovite and quartz aggregates occurs widespread, and plunges generally moderately to steeply to the east. Zones of high strain are focussed in northerly-trending, curved or sinuous, and up to 1 km wide and up to 80 km long mylonitic shear zones (Ulapes mylonite). Aeromagnetics indicates the presence of similar structures beneath the Cainozoic sediments of the plain, and on a regional scale the shear zones are spaced at intervals varying from a few kilometers to 15 km. Geophysical modeling suggests that most shear zones dip to the east (Hungerford and Pieters, 1996). The westerly-directed shear movement was determined from S-C fabric, extension of originally parallel veins, asymmetric feldspar porphyroclasts, and fragmented rigid grains with antithetic slip between the fragments.

^{40}Ar- ^{39}Ar isotopic dating of muscovite of mylonitised granite sample from the Desiderio Tello (3166-21) 1:100 000 sheet gave an age range of 450 to 462 Ma (late Ordovician) which is interpreted to represent the age of shearing (Camacho, 1997).

3.3. ACHALIAN CYCLE

During the early stage of the Achalian cycle, felsic magmatism, resulting in the emplacement of granite plutons, took place over a large part of the southern Sierras Pampeanas. Most of the plutons are exposed east of the map area in the Cordoba and San Luis Provinces, but aeromagnetics has shown that plutons belonging to this cycle may be present concealed beneath the Cainozoic sediments of the plain west of the Sierra de Las Minas. U-Pb zircon dating of the granites from the sierras of Cordoba and San Luis Provinces brackets the crystallization of the felsic magma over a 20 Ma period from 400 Ma to 380 Ma (Camacho and Ireland, 1997).

During the late stage of the Achalian cycle, east-west compression produced a regionally widespread conjugate system of rectilinear brittle-ductile, vertical, northwest- and northeast-trending strike-slip faults. In the Sierra de Las Minas this fault system is particularly well developed, and is accompanied by easterly trending extensional faults. Some north-south trending reverse faults possibly also belong to the system. Kinematic indicators (such as the displacement and deflection of veins, dykes, xenoliths and older (S2) foliation, and S-C fabric) show that the northwest structures are sinistral strike-slip faults, and the northeast structures dextral faults. In the Sierra de Las Minas the northwest-trending and to a lesser degree the northeast-trending shear faults are clearly marked as linear valleys on air photos and Landsat TM, and as demagnetized lineaments on aeromagnetic images. The structures are topographically recessive and supergene alteration has oxidized the magnetite to hematite/limonite. From fieldwork it is known that the shear zones are commonly 1-3 m and at the most 6 m wide; a maximum width of 10 m was recorded by the Metal Mining Agency of Japan (JICA, 1993). The dominance of the northwest-trending structures, in number as well as extent, suggests that the conjugate fault system (and east-west compression) is associated with a northwest-oriented sinistral wrench zone in which movement was mostly concentrated on the synthetic northwest shear faults. The brittle-ductile shear zones were progressively deformed by at least two phases of brittle deformation resulting in fracturing and brecciation of the shear fabric and quartz veins enclosed by the shear zones.

In the Sierra de Las Minas the shear faults, in particular the northwest-trensing set, are commonly associated with sericite - pyrite ± chlorite alteration and quartz vein-type Au ± Cu mineralisation, the result of mesothermal hydrothermal activity. ^{40}Ar-^{39}Ar isotopic dating of sericite associated with the hydrothermal alteration gave an crystallization age range of 389-393 Ma (Camacho, 1997). Granites emplaced during the late stages of the Achalian cycle of felsic magmatism possibly provided the heat source for the convective circulation of hydrothermal fluids.

3.4 ANDEAN CYCLE

The Sierra de Las Minas is a westerly tilted fault block bounded in the east by a continuous escarpment with heights above the adjacent plain which vary from 100 to 200 m in the north to 50 to 100 m in the south. It is generally thought that the escarpment is developed on a late Cainozoic listric reverse borderfault (Jordan and Allmendinger, 1986). However, during this survey no unequivocal field evidence was found to ascertain the nature of faulting. Along the entire escarpment occur regular, moderately to steeply-dipping triangular facets which appear to have formed on east-dipping planar fault scarps dissected by erosion. If so, the escarpment would represent a normal fault. Another argument for young extensional faulting in the Sierra de Las Minas is the presence of westerly and/or northerly trending graben structures, which are bounded by escarpments with similar geomorphic expression as the border escarpment. The graben structures are up to 2 km wide, and also cut the basement beneath the Cainozoic sediments of the plain, as indicated by the aeromagnetics. On the other hand, in a compressional tectonic regime the east-west oriented grabens may have formed at a high angle to the north-south oriented minimum principal stress, and the narrow, north-south oriented graben structure in northeast Sierra de Las Minas may have developed on tension fractures associated with arching of the basement rocks during east-west compression. Jordan and Allmendinger (1986) discussed the occurrence of two broad and northerly plunging arched structures developed in crystalline basement underlying the two northern conical projections of the Sierra de Los Llanos (Chamical (3166-I) 1:250 000 sheet), about 85 km north of the Sierra de Las Minas.

In other parts of the southern Sierras Pampeanas is outcrop evidence of young (Quaternary) reverse faulting (for example Sims and others, 1997), and focal mechanism solutions of earth quakes in the Sierras Pampeanas indicate moderate-angle reverse faulting at mid to lower crustal depths (Jordan and Allmendinger (1986).

4. GEOMORPHOLOGY

The two main geomorphological units in the map area are the mountain range (sierra) of the Sierra de Las Minas and the plains. The Sierra is north-south elongate, and in the north it is separated from the Sierra de Chepes by an irregular, wide and roughly east-west oriented valley which partly is controlled by faulting. In the extreme south, the Sierra is dissected by another transverse fault-controlled valley. The greatest heights occur in the east (up to 910 m in the map area) where the Sierra is bounded by a steep, up to 300 m high escarpment. The height of the summit surface decreases gradually in westward direction until it dips very gently beneath the alluvial sediments of the plain.

On a regional scale the Sierra de Las Minas forms a sloping plateau as the summit surface forms a distinct plane of accordance that slopes consistently in one direction. The plateau surface is interpreted to represent a peneplain of unknown age which was uplifted and tilted in Cainozoic time.

All streams in the map area are intermittent, and in the sierra many streams are poorly adjusted as result of subrecent tectonic movements. The drainage in the sierras is partly subsequent and partly consequent. The drainage pattern is commonly rectangular to angulate where it is controlled by faults and fractures, and in places the stream courses are marked by abrupt changes in gradient (waterfalls and rapids) and are anomalous as result of stream piracy.

The plains surrounding the Sierra de Las Minas dip away very gently and gradually from the uplands, and in the topographic lows between the main north-south elongate sierras in the Sierras de Pampeanas occur in places large salt lakes, for example the Pampa de Las Salinas between the southern end of the Sierra de Las Minas and the Sierra de La Huerta (outside the map area). However, surrounding the Sierra de Las Minas the plain is eroded and dissected by streams debouching from the uplands which has resulted in an up to 6 km wide, gently dipping and low-relief topographic depression. In many places the margin of the plain is expressed by an up to 10 m high scarp, but in other places headward erosion is gradual. A minor, secondary consequent drainage has developed from the margin of the plain towards the trunk rivers in the depressions. The main (trunk) rivers have incised wedge-shaped indentations in the plain and eventually peter out on the plain.

5. GEOLOGICAL HISTORY

5.1 CAMBRIAN

The oldest rocks in the map area are metasediments and meta-igneous rocks which occur as paleosomes associated with the migmatite of the migmatite, granitoid, tonalite (Ox) unit of the Chepes Igneous Complex. The metamorpic rocks are remnants of the Olta Metamorphic Complex which is exposed in the Sierras de Chepes and de Los Llanos. The metasediments are interpreted as being deposited on the passive margin of western Gondwana, developed during intracontinental rifting and break-up of Laurentia from Gondwana and opening of the Iapetus ocean in Early Cambrian time at about 540 Ma (Dalziel and others, 1994).

The age of sedimentation of the Olta Metamorphic Complex metasediments is based on indirect isotopic age control. A U-Pb age analysis on single-crystal zircon grains yielded a minimum provenance age of around 540 Ma (Camacho and Ireland, 1997), and is interpreted to represent the maximum age of sedimentation. The metasediments of the Olta Metamorphic Complex are tentatively correlated with the Tuclame Formation (Stuart-Smith and others, 1997) exposed in the 3166-17 1:100 000 sheet area (Córdoba Province). Zircon and monazite U-Pb metamorphic ages of around 530 Ma for a migmatitic rock of the Tuclame Formation (Camacho and Ireland, 1997) provide the minimum age limit of sedimentation.

Following sedimentation and minor magmatic activity the newly formed western margin of the Gondwana continent was subjected to compressive deformation and regional metamorphism of the Pampean cycle. The sediments, together with felsic to mafic volcanic and plutonic rocks were deformed by a roughly east-west oriented compressive event (D1) and regionally metamorphosed at greenschist facies conditions (M1) to form phyllite, schist and locally gneiss. Based on the U-Pb ages of the Tuclame Formation (see above), the age of the Pampean cycle is about 530 Ma (Early Cambrian).

5.2 EARLY ORDOVICIAN

In the early Ordovician, closure of the Iapetus ocean (Niocaill and others, 1997) and eastward subduction beneath the western margin of Gondwana (Pampean terrane) were accompanied by the formation of a large continental margin magmatic arc. During this early phase of the Famatinian cycle the dominantly calc-alkaline granitoids and minor intermediate and mafic plutonic rocks of the Chepes Igneous Complex were emplaced in the area of the Sierras de Las Minas, de Chepes and de Los Llanos. These rocks represent the infrastructure of the magmatic arc, and because of the high heatflow the country rock of the Olta Metamorphic Complex (Pampean terrane) was subjected to low pressure/high temperature metamorphism and migmatisation (M2) overprinting the earlier phase of regional metamorphism (M1). U-Pb dating of zircons of the granitoids of the Chepes Igneous Complex yielded crystallizaton ages ranging from 491 to 477 Ma (early Ordovician).

5.3 LATE ORDOVICIAN

During this time the Pampean terrane and continental margin magmatic arc underwent east-west, non-coaxial compressive deformation (D2) at greenschist facies regional metamorphic conditions (M3). A weakly to strongly penetrative north to north-northwest trending foliation has affected the rocks of both the Olta Metamorphic and Chepes Igneous Complexes, and retrogressive metamorphism occurred widespread. In zones of high strain, up to 1 km wide, mylonitic shear zones were formed within and bounding the sierras, but also, as indicated by airborne geophysics, in the basement rocks underlying the plains. The ductile shear zones are mostly east dipping and kinematic indicators show orthogonal, westerly directed thrust movement.

^{40}Ar-^{39}Ar dating of muscovite from mylonitised granite exposed in the southeast part of the Sierra de Chepes gave a total fusion age of 454±1 Ma and a step heating age of 450-462 Ma (Camacho, 1997), which are interpreted as the age range (late Ordovician) of the shearing deformation. In the area of the Sierras de Las Minas, de Chepes and de Los Llanos there is no evidence of deformation, magmatism and metamorphism during the time interval of about 30 Ma separating the formation of the continental margin magmatic arc and the regional east-west compressive deformation.

In a number of tectonic interpretations of the Sierras Pampeanas it was suggested that in the final stage of the Famatinian cycle (orogeny), at about 450 Ma and contemporaneously with the Taconic orogeny in North America, the Precordilleran terrane amalgamated with western Gondwana (for example, Martino and others, 1994; Astini and others, 1996; Toselli and others, 1996; Dalla Salda and others, 1992; Van der Voo, 1993). The age of the regional east-west compressive deformation in the Sierras de Las Minas, de Chepes and de Los Llanos is in agreement with this major collision event.

5.4 DEVONIAN

Peraluminous to slightly peralkaline and zoned granite plutons occur widespread east of the map area in the sierras of Cordoba and San Luis Provinces. The granite bodies were emplaced in country rock of the Pampean and Famatinian terranes during and after compressive deformation dominated by orthogonal westerly-directed thrusting and the development of regional ductile shear zones at greenschist facies metamorphic conditions. This phase of felsic magmatism and deformation belongs to the Achalian cycle. In the map area is no outcrop evidence of felsic magmatism and deformation, but airborne magnetics suggests the presence of zoned granite bodies concealed beneath Cainozoic sediments in the plain west of the Sierra de las Minas and east of the southeast part of the Sierra de Los Llanos. U-Pb zircon dating of the granites from the sierras of Cordoba and San Luis Provinces brackets the crystallization of the felsic magma over a 20 Ma period from 400 Ma to 380 Ma (Camacho and Ireland, 1997).

During the later stage of the Achalian cycle east-west compression produced a regionally widespread conjugate system of rectilinear brittle-ductile, vertical, northwest- and northeast-trending strike-slip faults and fractures. The orientation and conjugate relationship of the faults indicate a continuation of the east-west compressive tectonic regime. In the Sierra de Las Minas this fault system is particularly well developed, and is associated with sericite - pyrite ± chlorite alteration and quartz vein-type Au ± Cu mineralisation, the result of mesothermal hydrothermal activity. ^{40}Ar-^{39}Ar isotopic dating of sericite associated with the hydrothermal alteration gave an crystallization age range of 389-393 Ma (Camacho, 1997). These results conform with the occurrence of a regional Early Devonian Au, Ag, Pb, Zn, W, Cu metallogenic event in the southern Sierras Pampeanas (see Skirrow; ECONOMIC GEOLOGY in this report). Granites emplaced during the Achalian felsic magmatic phase possibly provided the heat source for the convective circulation of hydrothermal fluids.

5.5 PERMO-CARBONIFEROUS

Following peneplanation of the Cambrian to Devonian basement, continental sediments with rare marine incursions (from the west) were deposited in the Paganzo Basin, a large cratonic basin which covered the west and central areas of Argentina (Gonzále and Aceñolaza, 1972;

Gamundi and others, 1990). Sedimentation in this basin started in the early Carboniferous and continued up into the Triassic. To the west the Paganzo Basin passes into basins with dominantly marine-facies sediments which are interpreted to have formed in a back-arc tectonic setting (Gamundi and others, 1990). Tuff beds have been recorded to occur in the Permian sequence of continental sediments. In the area of the Sierras de Las Minas, de Chepes and de Los Llanos only remnants of late Carboniferous and Early Permian sediments of the Paganzo Group are preserved in graben structures.

5.6 CAINOZOIC

During the Cainozoic the peneplained Paleozoic basement and preserved overlying sediments of the Sierras Pampeanas were deformed into north-south oriented, elongate fault blocks forming the present characteristic topography of rugged sierras separated by broad intermontane basins.

The Sierras de Las Minas, de Chepes and de Los Llanos were uplifted and tilted by reverse faults which in places have reactivated Paleozoic mylonitic shear zones. Locally these Sierras are traversed by graben structures parallel as well as transverse to the regional north-south structural grain. The Pliocene Los Llanos Formation is the oldest exposed alluvial fan deposit possibly related to the uplift, and Jordan and Allmendinger (1986) reasoned that the faulting is not older than 10 Ma.

ECONOMIC GEOLOGY

By Roger G. Skirrow

1. INTRODUCTION

The ***Corral de Isaac (3166-33)*** map area contains some of the most significant deposits of Au-Cu-Ag in the sierras de Las Minas, Ulapes and Chepes region, as well as a number of minor U occurrences. The principal Au-Cu-Ag deposits are situated in the Las Callanas district, with subsidiary mineralisation near San Isidro (Grupo Sur, Grupo Norte), Vallecito, Dos Buhos (Provincia de San Luis), La Pirca and several other minor occurrences.

In the Geoscientific Mapping of Sierras Pampeanas Cooperative Project the principal metallic deposits in all main mining districts of the map area were investigated in the field, and geological observations were entered into the ARGROC and ARGMIN databases (Skirrow & Trudu, 1997). ARGMIN is a Microsoft Access database that was initially developed jointly by AGSO and the Secretaría de Minería in ORACLE, based on OZMIN (Ewers & Ryburn, 1993). Additional geological and resource data from the literature on mineral occurrences have been compiled in ARGMIN. Petrography of ore and host rock samples (thin sections and polished thin sections) was recorded in a petrographic database (Sims et al., 1996), and selected samples for ore genesis studies were analysed for whole rock geochemistry (Lyons et al., 1996; Lyons & Skirrow, 1996), stable isotopes of oxygen, hydrogen and sulfur (Lyons & Skirrow, 1986), as well as ^{40}Ar/^{39}Ar radiometric age dating (Camacho, 1997). Geographic coordinates of mineral occurrences were obtained by GPS in this and a previous study of the Sierra de las Minas (accuracy ±50m). The locations of remaining occurrences are taken from various published sources, which in some cases allow only very approximate geographic coordinates to be estimated (e.g . ±3km for U deposits).

Mineral occcurrence data as well as non-metallic mineral and dimension stone occurrences are shown on the 1:100 000 scale metallogenic map accompanying this report. Output data sheets from the ARGMIN database are appended to the report. Details of the geology and grade-tonnage data, where available, for individual metallic mineral occurrences may be found in the database. The 1:250 000 scale Metallogenic Map for the Sierras de Chepes, Las Minas and Los Llanos shows the mineral occurrences in relation to 'prospectivity domains' or areas of mineral potential. These domains are defined on the basis of 'metallogenic models' for each mineral deposit style, which were developed from the observations and interpretations presented in the following sections. For further datasets of mineral potential, the reader is referred to the *Atlas Metalogenético* (1:400 000 scale) for the Sierras Pampeanas mapping project (Skirrow and Johnston, 1997), and project GIS (Butrovski, 1997) in which metallogenetic models for the principal styles of metallic mineralisation are presented as separate coverages.

2. METALLIC MINERAL DEPOSITS

2.1 AU (-CU-AG) MINERALISATION

Previous work and exploration in the sierras de Chepes, Las Minas and Ulapes

Quartz vein systems hosting Au, Cu and Ag mineralisation occur widely throughout the sierras de Las Minas and Ulapes and to a lesser extent in the Sierra de Chepes. This style of mineralisation is represented in ***Corral de Isaac (3166-33)*** most notably by deposits in the Las Callanas and San Isidro districts as well as in the Vallecito, Dos Buhos and La Pirca deposits. Mines in the sierras were initially worked towards the end of the last century, and small scale mining activity continued intermittently until ~1990 (El Espinillo II). Previous work on the regional geology is discussed by Pieters et al. (1997). The geology of the Au, Ag and Cu mineral deposits and their workings were briefly described by Caminos (1979), Ramos (1982) and Angelelli (1984). Economic and geological evaluations of the occurrences were carried out by Mastandrea (1961), Sarudiansky (1988, 1990), Marcos (1987, 1988, 1989) and Cravero and Ríos (1988). Mapping of several occurrences in the

Sierra de Chepes was carried out by the Secretaría de Minería de la Nación in 1988-89. A synthesis of the geology and mineralogy of the Au deposits was presented by Ríos et al. (1992), while fluid inclusion and multi-element geochemical data were given by Cravero et al. (1995). A program of regional stream sediment geochemistry (Cu, Pb, Zn) was undertaken by the Secretaría de Minería de la Nación in the 1980's (?), and the results are currently being recompiled at the Subsecretaría de Minería.

Most recently a project carried out over three years by the Metal Mining Agency of Japan and the Secretaría de Estado de Minería was completed on Au-Ag exploration in the sierras de Las Minas and Ulapes (JICA/MMAJ, 1993, 1994, 1995). No work was carried out in the Sierra de Chepes.

Regional geological setting

Most Au-Cu-Ag deposits of the sierras de Las Minas, Ulapes and Chepes are hosted by granodioritic to granitic plutonic complexes of the Chepes Igneous Complex which were emplaced, metamorphosed to amphibolite facies, and deformed in a compressive tectonic setting in the early Ordovician (Pieters et al., 1997). Older, possibly early Cambrian, pelitic and psammitic metasediments and metamorphosed feldspathic (volcanic?) rocks of the Olta Metamorphic Complex host a small number of Au-Cu-Ag occurrences in the Sierra de Chepes (e.g. Porongo deposit, ***3166-14***). Rocks of the Olta Metamorphic Complex occur as generally irregularly shaped bodies and enclaves of phyllite, schist, gneiss and migmatite, and contain varying proportions of quartz, muscovite, biotite, feldspar and cordierite. Contacts with the Chepes Igneous Complex range from sharp to gradational or tectonic. Small bodies of fine-grained plagioclase-hornblende schists within the Olta Metamorphic Complex are relatively common throughout the sierras.

Major mylonite zones of up to several kilometres width developed during the late Ordovician deformation. Kinematic indicators suggest that the biotite-muscovite shear fabric was associated with westerly-directed movement on moderately to steeply easterly-dipping surfaces.

Several inferred granitoids with similar aeromagnetic signatures to Devonian granites in the San Luis map area occur under shallow cover in the extreme northeast of the La Rioja area, and also to the west of the Sierras de Las Minas (Hungerford et al., 1996).

Au-Cu-Ag deposits of *Corral de Isaac (3166-33)*

The geology, mine workings, vein dimensions and orientations and mineralogy for many of the Au-Cu-Ag occurrences in ***Corral de Isaac (3166-33)*** were described by Caminos (1972) and JICA/MMAJ (1993). The geology is summarised below. Further discussion of the geology and genesis for these and other deposits of the sierras de Las Minas, Chepes and Ulapes is presented by Skirrow (1997).

The Las Callanas district comprises six main vein systems. Although a variety of rock types are present in the district, the principal host to mineralisation is foliated granodiorite of the Chepes Igneous Complex. Other rock types of significance in outcrop and diamond drill core are: medium grained amphibole-feldspar metabasite, which is intruded by granodiorite dyklets; quartz - K-feldspar granite dykes that intrude the granodiorite; and fine grained metabasite. Mineralised quartz extension veins and shear veins occur within intensely foliated zones that strike approximately NW and dip generally steeply. Veins consist of quartz, goethite, hematite, pyrite, malachite, chrysocolla, chalcedony, native gold, chalcopyrite (in diamond drill core), and locally abundant galena, brown and white carbonates, anglesite and cerussite (e.g. Mina San Pedro or La Callana III). Textures and paragenetic sequences are similar to those described for Au-Cu-Ag deposits elsewhere in the sierras de Las Minas, Ulapes and Chepes (see below). The sheared and fractured host rocks are hydrothermally altered adjacent to quartz and carbonate veins to assemblages including sericite-pyrite, hematite±carbonate and in places epidote (particularly in metabasite rocks). As described below and in Skirrow (1997) shear fabrics including S-C fabrics and stretching lineations are variably developed in the Las Callanas district and indicate generally sinistral subhorizontal movement on the mineralised structures in this district.

The San Isidro district includes the Grupo Sur and Grupo Norte mineralisation. The Grupo Sur area contains quartz vein networks and silicified zones up to 3m wide within foliated and fractured granodiorite and quartz - K-feldspar aplite dykes of the Asperezas granite, both members of the Chepes Igneous Complex. The quartz veins and associated hematitic and sericitic alteration overprint these Ordovician igneous rocks. Mineralised quartz vein systems contain goethite, hematite, malachite, chrysocolla, pyrite, chalcedonic silica and native gold. Exposure of the Grupo Norte mineralisation is very limited in strike length and width (up to 20cm) associated with fracturing and faulting in granodiorite. The principal veined and fractured zone of mineralisation strikes roughly east-west; shear fabrics are poorly developed at Grupo Sur.

The Vallecito deposit comprises a principal quartz vein 1-2 m wide, hosted by granodiorite of the Chepes Igneous Complex. The vein system and associated narrow shear zone strikes approximately NW. Numerous shallow trenches have been recently excavated across the mineralised zone. The main vein consists of massive greyish quartz with abundant goethitic and hematitic fractures, and paragenetically late bands and veins of jasper, chalcedony and silica - Fe-oxide breccia. Malachite, anglesite or cerussite, galena and native gold are present in the vein; galena is intergrown with early coarse quartz. The granodiorite host rock is intensely sericitised adjacent to veins. This hydrothermal sericite was dated by the Ar-Ar method, revealing an age of 382-393 Ma (Camacho, 1997; Skirrow, 1997).

At the Dos Buhos deposit in the extreme south of the Sierra de Las Minas (Provincia de San Luis) 12 *labores* (shaft, declines, pits) are distributed along a NE trending zone of quartz veins and shearing roughly 1 km long. The host rock to quartz veins at all but the most northeasternmost workings is a fine-medium grained, dark grey, biotite-muscovite gneiss containing K-feldspar phenocrysts or porphyroclasts, abundant mafic xenoliths or clasts, and sparse rounded quartz segregations or clasts up to 5 cm length. Magnetic susceptibility in this rock type is highly variable from zero to 1800 SI units. At the northeastern limit of labores the host rock is medium grained granodiorite (magnetic susceptibility 300-2000 SI units) containing mafic xenoliths with magnetic susceptibility up to 5000 SI units. Lens- and gash-shaped quartz veins reach a maximum thickness of ~1m in near-surface exposures and contain goethite, hematite (rare coarsely crystalline) and minor chrysocolla. Shear fabrics and intense sericitic±hematitic alteration are developed within ~1m of the vein systems.

Mineralised quartz veins at the La Pirca deposit occur within granodiorite to the east of the escarpment along the Ulapes shear zone. Quartz - K-feldspar dykes of the Asperazas granite are also present in the mine area. Well developed NE-striking shear fabrics and intense sericitic, silicic and chloritic alteration occur in a zone of roughly east-west trending quartz veining. The gash-shaped quartz veins contain goethite, hematite, chlorite, minor chrysocolla and malachite and native gold.

The Ortiz occurrence, also situated to the east of the Sierra de Las Minas escarpment, is hosted by a variety of igneous rocks of the Chepes Igneous Complex including K-feldspar porphyritic and equigranular granodiorite, Asperezas granite dykes, and small areas of microdiorite. Quartz veins are massive to regularly banded (5-10 mm) with partings of goethite-hematite. Malachite, pyrite and native gold are associated with Fe-oxides. A single shallow pit exposes parts of the vein system. Shearing and sericitic alteration are poorly developed in surface exposures at Ortiz.

Geochemistry of Au-Cu-Ag deposits in ***Corral de Isaac (3166-33)*** are presented in Table 3.

Table 2. Au geochemistry - statistics for sierras de Las Minas, ***Corral de Isaac (3166-33)***

Deposit	Average g/t	Maximum g/t	Standard deviation	Number of samples	Data source
Brava	1.0	5.3	1.9	13	1
Callana III	6.0	40.4	10.5	15	1
SE Callana IV	0.6	4.2	1.2	22	1
SE Callana V	4.6	87.3	16.8	27	1
Callana VII	0.0	0.3	0.1	25	1
Cerco Quemada	0.4	1.0	0.4	5	1
Chilca	1.8	7.1	3.6	4	1
El Puerto	12.7	34.8	14.9	8	3; 6; 5
Grupo Norte	7.5	25.7	9.9	14	1; 4
Grupo Sur	3.3	13.6	4.4	20	1
La Pirca	23.0	142.5	46.1	9	1
P. los Arces	0.1	0.1	0.0	5	1
Río Noquis	0.3	3.5	1.0	11	1
San Rafael	0.0	0.1	0.0	5	1
Senda Compuesta	1.4	6.5	2.2	9	1
V. Ortiz	3.9	16.1	6.2	6	1
Vallecito	5.7	131.0	26.2	25	1
W El Retarmo	0.4	1.3	0.6	4	1

Data sources:
1. JICA/MMAJ (1993)
2. YAMIRI - Secretaría de Estado de Minería
3. Secretaría de Estado de Minería, 1989 (J. Ríos Gómez)
4. Marcos (1988)
5. Cravero et al. (1995)
6. J. Ríos Gómez, pers. comm. (1995)

Mineralisation, alteration and paragenetic sequence, sierras de Las Minas, Chepes and Ulapes

Similarities in structural setting, vein mineralogy, alteration, textures, geochemistry and paragenetic sequences in more than 15 observed Au-Cu-Ag occurrences in the sierras de Las Minas, Ulapes and Chepes allow the deposits to be discussed as a group. Based on observations of surface exposures and diamond drill core, together with petrographic examination of polished thin sections and previous work, a generalised paragenetic sequence for the Au-Cu-Ag deposits is proposed in Table 1. It should be noted that not all stages are represented in all deposits.

Two textural and compositional types of gold are present: early fine grained electrum closely associated with pyrite, with fineness as low as 640 (JICA/MMAJ, 1993; Cravero et al., 1995), and later coarse gold associated with hematite, goethite, chalcedony, opal, chrysocolla, malachite, and other supergene phases with fineness of greater than 950 (Cravero et al., 1995). Coarse late gold is readily observed in hand specimen and is interpreted to have formed during oxidation in Stages 2 and 3 from remobilisation of Stage 1 Au (Ríos et al., 1992; Cravero et al., 1995).

Relatively narrow zones (<3 m) of sericite-pyrite and hematitic hydrothermal alteration are well developed around some vein systems, whereas distal chlorite±epidote±carbonate alteration is generally weak (Las Callanas district; La Pirca) or absent. Pervasive silicification and development of quartz vein stockworks are uncommon (e.g. San Isidro - Grupo Sur). Sericite-pyrite and hematitic alteration and quartz veins show uniformly very low magnetic susceptibility, matching the low aeromagnetic responses for the linear shear zones hosting mineralisation. However, the aeromagnetic lows appear to be significantly broader than the zones measured at surface.

Genesis

The Au (Cu, Ag) deposits of the sierras de Las Minas, Ulapes and Chepes are considered to be members of the broad class of structurally-controlled mesothermal lode Au deposits found in orogenic terranes (including ‘low-sulfide Au-quartz veins of Cox & Singer, 1986). However, the La Rioja deposits are relatively Cu±Pb-rich variants compared to ‘typical’ mesothermal lode Au deposits. The elevated Cu±Pb contents, moderate to high salinities of some fluids involved in vein formation, and similarity of calculated fluid oxygen-hydrogen isotopic compositions with magmatic waters, collectively point to a contribution of fluids and/or metals from igneous rocks (Skirrow, 1997). Early Devonian granitoids, such as that inferred from aeromagnetic imagery under cover rocks to the west of the Sierra de Las Minas, are possible candidates for sources of fluid and/or metals and/or heat energy.

A striking feature of the aeromagnetic imagery in particularly the sierras de Las Minas and Ulapes is the pattern of NW and NE trending lineaments and zones of very low magnetic response. In outcropping areas some magnetic low lineaments correspond to mineralised shear and fracture zones, and have been traced under cover to the east and west of the exposed basement (Hungerford et al., 1996). Similar zones are much less common in the Sierra de Chepes. Dating by the $^{40}Ar/^{39}Ar$ method of white mica hydrothermal alteration associated with Au-Cu-Ag mineralisation within the NW trending structures suggests that both alteration and shearing in conjugate NW and NE structures occurred in the early Devonian (Skirrow, 1997).

Structural observations indicate consistent region-wide kinematic and geometrical relationships in shear zones hosting mineralised quartz veins (Skirrow, 1997). Movement on NW trending shear zones was sinistral with subhorizontal (strike-slip) displacements, whereas movement on NE trending shears was dextral, again with strike-slip displacements. The orientations and morphologies of quartz veins are consistent with their formation syntectonically in extensional domains within the shear zones. The NW and NE trending shear zones and contained quartz veins are proposed to have formed as a conjugate set within a region of E-W compression and N-S extension (Skirrow, 1997).

2.2 U OCCURRENCES

Several U occurrences are listed in ***Corral de Isaac (3166-33)***, mainly in the San Isidro Au-Cu-Ag district. It is possible these U occurrences are associated with Au-Cu-Ag mineralisation; however, no U minerals were identified at these deposits in the present study.

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Table 3. Generalised paragenetic stages, alteration and textures for Au-Cu-Ag deposits, Sierras de Las Minas and Chepes

Stage	Vein mineral assemblage	Wall rock alteration relative to vein	Vein textures	Deformation
1. hypogene, (~300°C)	milky white quartz, carbonate, pyrite, chalcopyrite, galena, sphalerite, Au (electrum)	proximal (<3m): sericite-pyrite (sericitisation of feldspar) distal: chlorite±epidote (chloritisation of biotite)	massive, deformed, anhedral to subhedral milky quartz; disseminated fine grained pyrite; cavity-filling chalcopyrite & other sulfides; disseminated anhedral white±brown carbonate; Au-Ag with/in pyrite?	S-C fabrics in altered wall rocks; extensional quartz veins
2a. hypogene to deep-supergene, low temp., oxidised	hematite, carbonate, clear grey quartz and recystallised quartz, Au	proximal and distal: hematite (extremely fine grained, disseminated)	anastomosing seams/fractures of fine hematite & thin veins of fine grained hematite-carbonate (brown); networks of fine clear grey quartz in older quartz; coarse Au with Fe-oxide	fracturing, brecciation of stage 1 quartz
2b. supergene oxidation	chalcedony-hematite (jasper), goethite, clear quartz, Au, malachite, chrysocolla, covellite, tenorite, cuprite, anglesite, cerrusite	proximal: hematite, goethite	finely banded chalcedony; microbreccia veinlets of jasper cutting earlier quartz; cavity infilling by goethite, fine specular hematite; clear euhedral quartz; coarse Au	brittle fracturing along vein structures
3. weather-ing	clay, limonite, goethite, malachite, chrysocolla, covellite, tenorite, cuprite, anglesite, cerrusite		fine grained replacement of silicates, sulfides, carbonates, oxides; coarse Au with Cu phases	no deformation

ARGMIN

MINERAL DEPOSIT DATABASE

OUTPUT DATA SHEETS