Report on

1:100 000 Scale Geological and Metallogenic Maps
Sheet 3166-21 *Desiderio Tello*

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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GEOLOGY

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1. INTRODUCTION

1.1. LOCATION AND ACCESS

The 1:100 000 scale Desiderio Tello (3166-21) sheet covers the southeastern part of the Sierra de Chepes and the adjacent plain which are located in the southern part of the La Rioja Province (Figures 1, 2). The map area is bounded by latitudes 31°00’ S and 31°20’ S, and by longitudes 66°00’ W and 66°30’ W. The area falls in the northeastern part of the 1:250 000 scale Chepes (3166-III) sheet.

The area is easily accessible from Córdoba and La Rioja by Ruta Nacional 38 and Ruta Provincial 32, and from San Juan by Ruta Nacional 141 and Ruta Provincial 32. 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). Desiderio Tello, Santa Cruz, Chelcos, San Nicolas and Ambil are small population centres in the map area.

1.2. NATURE OF WORK AND PREVIOUS INVESTIGATIONS

Mapping of the Sierra de Chepes 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 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,

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.

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 (AGSO), and O. Cravero, J. Rios-Gomez and G. Vujovich (DNSG).

Although regional geological reconnaissance and specialist studies in the Sierra de Chepes and surrounding area have been carried out since 1873 (for example: Bodenbender, 1911 and 1912; Bracaccini, 1946 and 1948; Frengüelli, 1946, 1949 and 1950; Turner and de Alba, 1968), the first systematic mapping of the Sierra de Chepes was conducted by V. Ramos (Ramos, 1982). 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 Chepes. 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 reverse and normal 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 the Olta Metamorphic Complex (∈o) and form part of the Olta Metamorphic Complex, migmatite (∈oOmg) unit. 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 Olta Metamorphic Complex and 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 in the Santa Rita de Catuna 1:100 000 sheet immediately to the north), and covered by Carboniferous continental sediments and Cainozoic continental sediments.

2.2. CAMBRIAN BASEMENT

Olta Metamorphic Complex (∈o)

Distribution

The Olta Metamorphic Complex is exposed in elongate, northerly trending areas, up to 15 km long and 3 km wide. Olta Metamorphic Complex lithologies are also associated with the migmatite (Omg) of the Chepes Igneous Complex and form part of the Olta Metamorphic Complex, migmatite (∈oOmg) unit; however, the outcrops are small and contact relationships are complex, and therefore these rocks are unmappable at 1:100 000 scale.

Nomenclature, stratigraphic relations and age

The unit has been desribed as the Olta Formation by Furque (1968), Caminos (1979) and Ramos (1982). It is proposed in this report to change the name to Olta Metamorphic Complex, as the lithostratigraphy is mostly obliterated by metamorphism and tectonism. The mineral assemblages indicate metamorphic conditions ranging from greenschist facies to anatexis, and a variety of minor lithologies are included in addition to the widespread metasediments.

The intrusive contact between the Olta Metamorphic Complex and metaluminous granitoids of the Chepes Igneous Complex is sharp, and thermal aureoles are poorly developed. However, the country rock is commonly broken up with small to very large (few cms - 30 m), irregularly shaped fragments embedded in the granitoid. Most of the Olta Metamorphic Complex outcrops form steeply dipping screens between the intrusive bodies.

On the other hand, the contact between the Olta Metamorphic Complex and the migmatite (Omg) unit of the Chepes Igneous Complex is gradational and complex, and difficult, if not impossible, to locate at 1:100 000 scale.

A U-Pb age analysis on detrital zircon grains without metamorphic overgrowths obtained from a metasediment sample (A95PP111A; 66°32.50'W/33°63.96'S) yielded a minimum provenance age of about 545 Ma (Camacho and Ireland, 1997), and is interpreted to represent the maximum age of sedimentation. However, this age may have been affected by post depositional metamorphism causing Pb loss from an older population. 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 (Cordoba 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.

Lithology

The Olta Metamorphic Complex consists dominantly of psammitic and pelitic metasediments ranging from muscovite-biotite bearing quartzite to quartz-rich and mica-rich slate, phyllite and schist. Associated with the metasediments are minor micacaceous quartz-feldspar phyllite, schist and gneiss, hornblende-plagioclase schist and gneiss, and schistose to gneissic granitoid.

The metasediments are medium to dark grey, fine-grained, and characteristically show a parallel metamorphic segregation layering of felsic and mica-rich material ranging in thickness from a few millimetres to 2 cm, and a layer parallel foliation defined by subparallel aligned micas. Locally, a crude layering of 20 cm to 50 cm thick quartz-rich and mica-rich packages is tentatively interpreted to reflect sedimentary bedding. Where observed, the bedding structures are subparallel to the metamorphic layering.

Thin section study shows that the psammitic metasediments have a narrow compositional range comprising the following minerals: 70-85% quartz, 5-20% biotite, 5-15% muscovite, <5% opaques (mostly magnetite), in places <10% feldspar (both plagioclase and microcline), and rarely <2% clinozoisite/epidote and <2% apatite. Accessory microcrystalline zircon occurs in the biotite and is surrounded by pleochroic haloes; tourmaline is another common accessory mineral. The pelitic metasediments are similar and transitional to the psammitic metasediments; they contain 50-70% quartz and 25-40% micas.

The quartz is generally completely recrystallised to a polygonal granoblastic aggregate; only in one greenschist facies siltstone the quartz clasts are partly preserved although the grain margins are strongly abraded and the matrix is recrystallised to very fine biotite and white mica. The quartz (± feldspar) and micas are differentiated into parallel layers or lenses ranging in thickness from 0.5 mm to a few centimetres. However, mica also occurs scattered in the quartz (± feldspar) aggregates. In the layers, the biotite and muscovite occur as solitairy crystals and aggregated in folia which both tend to be orientated parallel to the layering. The metamorphic segregation layering and subparallel aligned micas define a distinct foliation (S1). However, throughout the rocks there are biotite and muscovite flakes randomly oriented, and cordierite porphyroblasts discordant or mimetic with respect to the S1 foliation.

Some rocks contain up to 5% porphyroblastic cordierite, and the assemblage cordierite - chlorite - biotite - muscovite in pelitic metasediments indicates low-pressure/high-temperature metamorphic conditions of the hornblende hornfels facies. Although porphyroblastic andalusite was not detected, the rare presence of this mineral is suggested by irregular patches of fine mica. In the Malanzán (3166-14) 1:100 000 sheet to the northwest, the assemblage cordierite - andalusite - K-feldspar was observed by Dahlquist and Baldo (1996) providing evidence that metamorphic conditions as high as the pyroxene hornfels facies were reached. Features indicating the onset of anatexis are widespread in the Olta Metamorphic Complex (and in the migmatite of the Chepes Igneous Complex); however, rocks typical of the sillimanite zone with which anatexis is commonly associated are extremely rare and metapelite with the assemblage sillimanite - K-feldspar was again only reported by Dahlquist and Baldo (1996).

With increasing amounts of feldspar the psammitic and pelitic metasediments grade into interlayered grey micacaceous quartz - feldspar metamorphics. These rocks are probably derived from feldspathic or volcaniclastic sediments, or felsic to intermediate volcanics. Compared to the psammitic and pelitic metasediments, the micaceous quartz - feldspar schist/gneiss is considerably lower in quartz (30-60%) and contains 30-60% feldspar (microcline and plagioclase). These rocks also carry 5-20% biotite, 5-35% muscovite and <2% opaques (mostly magnetite), and some contain up to 20% cordierite and <2% epidote/clinozoisite. The generally distinct foliation is defined by fine segregation layering of felsic minerals and mica, and layer parallel aligned micas.

The medium to dark green hornblende - plagioclase schist or gneiss are thought to represent disrupted dykes and other small intrusive bodies emplaced in the metasedimentary sequence, and/or volcanic intercalations of intermediate composition. The compositions and textures of hornblende-plagioclase schist or gneiss and schistose or gneissic granitoid vary considerably depending on the degree of metamorphism and deformation, and the nature of the protoliths ranging from granite to mafic rich quartz - diorite. The rocks contain 25-55% quartz, 0-55% feldspar (plagioclase and microcline), 0-20% biotite, 0-20% muscovite and 0-65% hornblende; minor constituents are magnetite (<5%) and sphene (<2%). Amphibolite was not observed. The weakly to moderately well developed foliation is defined by lenticular quartz segregations, subparallel aligned mica and occasionally hornblende crystals and biotite folia. The mineral assemblage hornblende-plagioclase indicates metamorphic conditions of the hornblende hornfels facies.

The medium grey schistose or gneissic granitoid represent metamorphosed and deformed felsic to intermediate intrusive rocks which were mostly disrupted prior to or during the main phase of metamorphism. In places, these rocks are difficult to recognise from deformed and metamorphosed granitoids of the Chepes Igneous Complex.

The main foliation (S1) has a northwesterly to northeasterly strike with dips ranging from shallow to steep to the east as well as the west. The rare occurrence of remnants of isoclinal fold hinges contained within the foliation (intrafolial folds) suggests deformation by layer parallel folding. The main foliation is locally deformed by open to tight microscopic to mesoscopic folds which are accompanied by a more or less well developed axial-plane or crenulation cleavage (S1').

The S1 and S1' fabrics are regionally deformed by a phase of shearing associated with east-west compression of late Ordovician age. The layering is disrupted and boudinaged, and locally the foliation is rotated into paralellism with vertical to steeply dipping shear planes. During this phase of deformation the rocks were also affected by retrogressive metamorphism with the formation of epidote/clinozoisite, chlorite and white mica, and the recrystallization of quartz. In zones of higher strain, where mylonite is developed, the S1 and S1' foliations are mostly obliterated by the shearing. The northerly aligned outcrop areas of the Olta Metamorphic Complex tend to coincide with mylonite zones, possibly because they form zones of weakness as screens between the relatively resistant bodies of plutonic rocks of the Chepes Igneous Complex. In these mylonite zones the Olta Metamorphic Complex lithologies are commonly tectonically intermixed with the plutonic rocks.

The Olta Metamorphic Complex is generally characterised by low aeromagnetic anomalies and radiometric response. The majority of the psammitic and pelitic metasediments have a magnetic susceptibilty lower than 40 x 10^{-5} SI; however, some rocks are relatively rich in magnetite (5%) raising the magnetic susceptibilty up to 300 x 10^{-5} SI. The meta-igneous rocks have a wide range of magnetic susceptibilties, up to 2000 x 10^{-5} SI.

2.3. CAMBRIAN BASEMENT/ ORDOVICIAN IGNEOUS COMPLEX

Olta Metamorphic Complex, migmatite (∈oOmg)

Distribution

In the map area, the large terrain of migmatite (Omg) of the Chepes Igneous Complex contains northerly trending, elongate areas, up to 9 km long by 2 km wide, which are underlain by Olta Metamorphic Complex lithologies and migmatite in proportions which may vary between 25% and 75%. Granite, granodiorite and tonalite make up a minor part (<5%) of the unit. The outcrop areas have been mapped based on evidence from fieldwork, and interpretation of Landsat TM imagery, airphotos and also airborne magnetics and radiometrics.

Nomenclature, stratigraphic relations and age

The unit is poorly defined and is a mixture of lithologies which could not be differentiated at 1:100 000 scale. The contact with the surrounding migmatite of the Chepes Igneous Complex is complex and transitional.

The age of deposition of the Olta Metamorphic Complex lithologies is Early Cambrian, and the age of the migmatite is early Ordovician, as discussed in separate sections on these units.

Lithology

The lithologies of the Olta Metamorphic Complex, migmatite unit are described in separate sections elsewhere in this report.

2.4. ORDOVICIAN IGNEOUS COMPLEX

Chepes Igneous Complex

Distribution

The Chepes Igneous Complex is the dominant basement unit 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:

- Migmatite (Ogm),
- Granodiorite (Ogd),
- Biotite granite (Ogr),
- Granitoid (Og),
- Porphyritic granitoid (Ogp), and
- Asperezas Granite (Oa).

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.

The Asperezas Granite is emplaced with mostly distinct contacts in the porphyritic granitoid (Ogp) unit. The porphyritic granitoid (Ogp) forms relatively distinct, large plutons which are intruded with sharp contacts in the Olta Metamorphic Complex (∈o). The unit also intrudes the migmatite (Omg) unit, but the boundary is less well defined. The granite (Ogr) and granitoid (Og) units occur in outcrops which are markedly elongate in a north-south direction. The contact between these units is diffuse with complex compositional and textural changes over short distances (in the order of 100 m). The granodiorite (Ogd) is only exposed in the extreme northern part of the Sierra de Las Minas in the south of the map area. The boundary of the migmatite (Omg) unit is generally poorly defined and 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). The results of the zircon U-Pb analyses are summarised in Table 1.

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

Sample	**Latitude (S)**	**Longitude (W)**	**Unit**	**Rock type**	**Age (Ma)**
A95PP 076A	30°57.98’	66°40.74’	granitoid (Og)	biotite-hornblende granodorite	491±6
A95PP 114A	31°06.38’	66°31.85’	Chepes Igneous Complex, undivided (Oc)	biotite granodiorite	477±7
A95PP 116A	31°11.08’	66°31.66’	porphyritic granitoid (Ogp)	biotite monzogranite	485±7
A95PP	31°26.98’	66°17.49’	Asperezas	biotite	490±7

159A			Granite (Oa)	monzogranite	
A95PP 183A	31°40.72’	66°19.31’	migmatite, granitoid, tonalite (Ox)	biotite-hornblende tonalite	480±6

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).

Migmatite (Omg) of the Chepes Igneous Complex

Distribution

This unit is widely exposed in the map area.

Lithology

The unit is made up of a multitude of rock types which mainly form part of the migmatite complex (including remnants of the Olta Metamorphic Complex), while the remainder comprises granitoids and minor intermediate plutonic rocks which are thought to have been emplaced at the time of the migmatisation process. The proportion of migmatite in the unit is at least 50% and commonly between 60% and 70%. The distribution of the various rock types varies considerably from place to place over distances as short as 50 m. The outcrop area of the different rock types is commonly irregular and too small to be mapped at 1:100 000 scale. However, in places with sparse or no vegetation, some of the migmatite phases, and associated granitoids and Olta Metamorphic Complex metasediments, may be recognised on 1:45 000 scale black and white air photos by tonal differences.

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 tends to parallel the northerly structural trend of the Olta Metamorphic Complex metamorphics. 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. These rock types have been described in the section on the Olta Metamorphic Complex, although in the migmatite they tend to be slightly higher-grade and coarser, and the proportion of the psammitic and pelitic metasediments is less than the total of the other rock types. 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, and locally also relatively coarse anhedral cordierite. Feldspar porphyroblasts are even noticable in nebulitic and schlieren migmatite or granotoid 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 granitoid bodies which were observed range in size and shape from irregular enclaves 1 to 30 m across to dykes and stocks.

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 and cordierite. This foliation parallels and is mostly, if not all, controlled by the structural fabric of the metamorphics of the Olta Metamorphic Complex. The migmatite layering is only locally deformed by isolated disharmonious or rootless folds, and as there is no evidence of a linear or planar shape fabric formed under medium to high-grade metamorphic conditions it is thought that the metamorphic-magmatic event took place in a passive tectonic setting. The mineral assemblages of the metamorphics of the Olta Metamorphic Complex and migmatite indicate a tectonic setting of low-pressure metamorphism.

The migmatite and granitoid 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.

Granodiorite (Ogd) of the Chepes Igneous Complex

Distribution

This unnamed granodiorite is only exposed in the northern part of the Sierra de Las Minas in the extreme south of the map area.

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.

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 along and nearby the southeastern margin of the Sierra de Chepes, and in the northern 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.

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 exposed along the southeastern margin of the Sierra de Chepes.

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.

Lithology

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

Porphyritic granitoid unit (Ogp) of the Chepes Igneous Complex

Distribution

The porphyritic granitoid is exposed in kidney to oval-shaped plutons in the Sierra de Chepes. The long dimension of the largest pluton is 17 km.

Lithology

Although medium to coarse-grained, porphyritic biotite granodiorite is the most typical rock type, the unit covers a wide range in composition and texture. The granodiorite grades into monzogranite as well as tonalite, and in addition to porphyritic textures the rocks are also commonly seriate and equigranular. The phenocrysts consist of alkali-feldspar. The mineral assemblages are similar to those of the granodiorite, biotite granite and tonalite units except that the presence of hornblende is less common. The effects of deformation and regional greenschist metamorphism are the same as for the other units of the Chepes Igneous Complex.

Asperezas Granite (Oa) of the Chepes Igneous Complex

Distribution

Leucogranite of the Asperezas Granite crops out in north-south elongate bodies intruded in the porphyritic granitoid (Opg) and migmatite (Omg) units. 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 conspicuous because of its light tones.

Nomenclature

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

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.

2.5. ORDOVICIAN PEGMATITE, APLITE AND MICROGRANITE DYKES

Distribution

Pegmatite, aplite and microgranite dykes, veins and pods occur in swarms and solitary throughout the Sierras de Chepes. The dykes and veins are shown on the map with the standard dyke map symbol, except in the southeast part of the Sierra de Chepes, west of Ambil, where the dykes are up to 100 m wide and form mappable units (Op) at 1:100 000 scale.

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 mylonite of shear zones. 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.

2.6. CARBONIFEROUS SEDIMENTS

Malanzán Formation (Cm)

Distribution

The distribution of the Carboniferous Malanzán Formation in the map area is restricted to a few small outcrops along the southeastern margin of the Sierra de Chepes.

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

In the map area 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 100 m.

2.7 CAINOZOIC SEDIMENTS

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 terrace and dissected alluvial fan deposits (Czd)

These deposits are located nearby or onlap the basement rocks and also the Permo-Carboniferous sediments exposed in the sierras. The poorly to moderately consolidated sand, gravel and silt were deposited in alluvial fans which are younger than and locally overlie partly eroded Czu deposits.

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 east of the Sierra de Los Llanos (Santa Rita de Catuna (3166-15) 1:100 000 sheet). 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 Chepes this fault system is poorly to moderately well developed, and is accompanied by easterly trending extensional faults. Some north-south trending reverse faults possibly also belong to the system.

3.4 ANDEAN CYCLE

During the Cainozoic the peneplained Paleozoic basement was uplifted in north-south oriented, elongate fault blocks forming the present-day characteristic topography of rugged sierras separated by flat intermontane basins. It is generally thought that the sierras were uplifted and tilted by late Cainozoic listric reverse faults (Jordan and Allmendinger, 1986). However, during this survey no unequivocal field evidence was found to ascertain the nature of faulting. Along many escarpments bounding the sierras 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 escarpments would represent normal faults. 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 a few kilometers 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 structures (for example 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 (north of the map area).

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 ranges (sierras) of the Sierra de Chepes and Sierra de Las Minas (in the extreme south), and the plains. The Sierra de Chepes is separated from the Sierra de Las Minas by an irregular, wide and roughly east-west oriented valley which partly is controlled by faulting. In the map area the drainage is to the southeast and the Sierra de Chepes gradually becomes higher in reverse direction; he greatest height of 1250 m occurs in the extreme northeast in the headwaters of the Rio Grande.

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

The plain adjacent to the Sierra de Chepes dips 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 Chepes 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 20 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.

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

There are no known metallic mineral deposits in Desiderio Tello (3166-21).

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MINERAL DEPOSIT DATABASE

OUTPUT DATA SHEETS