TEMPORAL CONSTRAINTS ON THE POLYPHASE EVOLUTION OF THE SIERRA DE SAN LUIS. PRELIMINARY REPORT BASED ON BIOTITE AND MUSCOVITE COOLING AGES

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INTRODUCTION

The Sierra de San Luis (Eastern Sierras Pampeanas) comprises an Early Paleozoic metamorphic basement intruded by Ordovician-Devonian granitoids. Ductile deformation and granite intrusions can not be younger than the Late Carboniferous as indicated by the continental basins of this age. Metamorphic belts with different peak metamorphic conditions, composition and structural evolution, a profuse development of leucosomes, pegmatoids and aplites, granitic plutons and mafic rocks that are emplaced at different stages of the polyphasic deformation of their host, characterize the basement of San Luis. This magmatic, metamorphic and structural evolution could provide an insight into the tectonic evolution of the western margin of Gondwana. New cooling ages for granites, pegmatites and one mica-schist are presented as part of an ongoing geochronological study that will cover the geochronology together with thermobarometric calculations on the granites and their country rocks.

Several authors have done regional or detailed studies on the magmatic, metamorphic and structural evolution or metalogenesis in the Sierra de San Luis (cf. Criado Roque *et al.*, 1981, Ortiz Suárez *et al.*, 1992, López de Luchi, 1996, Dalla Salda *et al*., 1998. Llambias *et al.*, 1998, Sims *et al.*, 1997, 1998, von Gösen, 1998, von Gösen and Prozzi, 1996, 1998, López de Luchi *et al.*, 2000, Hauzenberger *et al.*, 2001 and references therein). Although those studies have contributed to a general geological background there are still basic questions that remain open. The timing of the different events, the clear separation between the pre-Famatinian and Famatinian deformation, the relation between granites/metamorphic evolution/ regional deformation on the basis of the analysis of contacts, microstructures and facies are far to be answered.

BASEMENT GEOLOGY AND TECTONIC MODELS

Three main polyphase deformed metamorphic rocks make up the Sierra de San Luis, gneisses, schists and phyllites together with amphibolites, calc-silicatic rocks and rare marbles. Peak metamorphic conditions are equivalent to the amphibolite facies except for both the phyllites that were equilibrated at lower grade and restricted areas in the central west sector where granulite facies is present. The metamorphic rocks are country rocks for granitoids and pegmatoids that show coupling or decoupling of their internal structure in relation with the pervasive regional deformation. Mafic to ultramafic complexes are emplaced in the higher metamorphic grade rocks. Diverse characterization and formational names have been reported for the metamorphic basement, therefore map versions of the Sierra are variable regarding the extent or contact-relations between the units. In spite of this, the most important map scale feature of the Sierra de San Luis is the NNE elongation of parallel belts of different metamorphic grade and/or structural level. This spatial distribution is shown by at least the major part of the pegmatites and solid-state foliated granites whereas the mainly magmatic foliated batholiths show both trends, parallel and cross-cutting the regional orientation. The mappable metamorphic rocks (Ortiz Suárez *et al.*, 1992; Sims *et al.*, 1997, von Gösen and Prozzi, 1998 and references therein) are separated from west to east in the Western Basement Complex or Nogolí Metamorphic Complex (NMC), the Eastern Basement Complex or the gneisses of the Pringles Metamorphic Complex (PMC), the Mica-schists or the schists of the Pringles Metamorphic Complex, and the Conlara Metamorphic Complex (CMC). The San Luis Formation or Phyllite Group forms two parallel belts that separate the above mentioned units (Figure 1).

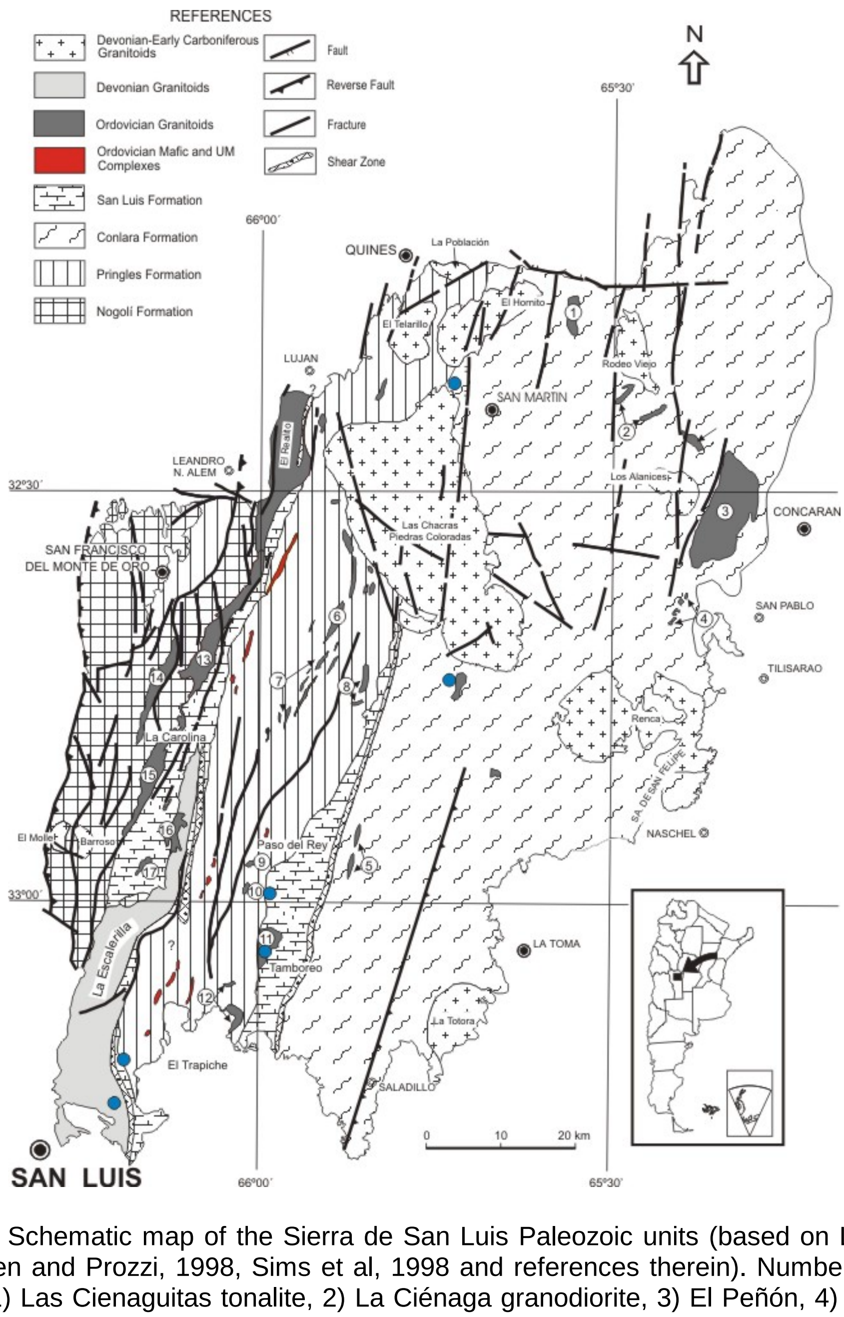

Figure 1: Schematic map of the Sierra de San Luis Paleozoic units (based on López de Luchi 1993, von Gösen and Prozzi, 1998, Sims et al, 1998 and references therein). Numbers indicate plutons as follows: 1) Las Cienaguitas tonalite, 2) La Ciénaga granodiorite, 3) El Peñón, 4) La Tapera granite, 5) Río de La Carpa granite, 6) Cruz de Caña granite, 7) Cerros Largos granite, 8) La Capilla granite, 9) Paso del Rey (north), 10) Paso del Rey (south), 11) Tamboreo tonalite/granodiorite, 12) La Florida granite, 13) San Miguel granodiorite, 14) Río Claro granite, 15) Gasparillo tonalite, 16) Las Verbenas tonalite, 17) Bemberg tonalite. Blue dot indicate sampled localities.

At a regional perspective, the Sierra has been included in the Famatinian belt (Dalla salda et al, 1998 and references therein). At present no clear record of Cambrian arc-related magmatism has been recognized. The metamorphic belts were considered of different ages and/or tectonic evolution (see Sims *et al.*, 1997). The Conlara Metamorphic Complex was considered to be the result of a Cambrian metamorphic event. The Pringles Metamorphic Complex shows peak metamorphic conditions at 450 Ma whereas the Western Nogoli Metamorphic Complex. is considered as being Cambrian, Proterozoic or Ordovician. The Phyllites (in part San Luis Fm.) are considered to be Ordovician or Devonian (see Sims *et al.*, 1997, von Gösen and Prozzi, 1998). The only available age for the sedimentation of the protholiths of the San Luis Fm is a U-Pb zircon age from acid metavolcanics interlayering in the phyllites that yielded 529±12 Ma (Söllner *et al.*, 2000), i.e. Middle Cambrian, coeval with the inferred collision of the Pampean Terrane. Ages of oldest granitoids of the Sierra are Ordovician (Table 1).

Some hypothesis on the tectonic evolution of the Proto-Andean margin of Gondwana could be extended to San Luis. Sims *et al.* (1997) considered an Early Cambrian (540 Ma) passive margin developed during the intracontinental rifting and break-up of Gondwana. This is followed by the Pampean Cycle: D1 is interpreted as the first in a series of compressive events associated with convergence on the Pacific margin of Gondwana. At the closing stages of this cycle, felsic magmatism was developed during an extensional collapse. They considered that there is no evidence for subduction at this stage. The Famatinian Cycle was due to the initiation of subduction and formation of a magmatic arc that was closed by the Precordillera collision (470 Ma). This collision resulted in the amalgamation of the Cambro-Ordovician back-arc (Pringles Metamorphic Complex) and the Cambrian basement (Conlara and Nogoli Metamorphic Complex). Following the Famatinian cycle, extensional tectonism was accompained by S-type granites and pegmatites. The extensional tectonic controlled the basin for the protholiths of the San Luis Metamorphic Complex Igneous activity culminated at 470 Ma in the emplacement of granitoids in the San Luis Fm. Collision related magmatism would have ceased by the Mid Caradocian (c. 450 Ma). The last event is the Achalian orogeny. Early Devonian deformation of the Ordovician cover sequence and the older crystalline basement together with the development of a magmatic arc, are the result of the resumption of the convergence on the western margin of Gondwana. Compression would result from the amalgamation of Chilenia. This hypothesis differs from previous interpretations of the tectonic evolution of San Luis basement. It proposes an Ordovician sedimentation in an extensional setting, a Devonian magmatic arc and compression. Von Gösen and Prozzi (1998) considered that there is no evidence for any Cambrian compression in Sierras de San Luis. They considered a Proterozoic evolution for the Western Basement Complex (partially the Nogoli Metamorphic Complex.) that constitutes the basement for a Cambrian passive margin sequence. During the Famatinian cycle a magmatic arc was developed. The mafic and ultramafic rocks in the Eastern Basement Complex (the gneisses of Pringles Metamorphic Complex) intruded the metasediments during the early Ordovician synchronously with regional deformation at the onset of the arc magmatism. The timing of the compressive deformation would be Mid-Late Ordovician. After the intrusion of La Escalerilla Granite (403 Ma, U-Pb Zircon age, Sims et al, 1997)WNW-ESE compression led to folding of the cover sediments and was accomodated by the formation of mylonites leading to the uplift of different blocks. Oblique reverse faulting with a sinistral component in the western part of the sierra, a strike-slip reactivation of the former block boundaries and displacement of the Phyllite Group over the Micaschists are related to a Devonian compression. Post- Famatinian deformation and metamorphism (von Gösen and Prozzi, 1998) are assumed to have been related to the colliding Precordillera (Cuyania).

METHODOLOGY

Reported sampling sites include those in which crystallization ages are known in the case of the foliated granites, together with localities where the relationship between the pegmatoids and the foliation either of the country rocks or the solid-state foliated granites was established. Table 1 present our results together with the published ages of the sites.

Age data are discussed in relation with the field evidences. Deformational phases are labelled D1 and D2 without a direct correlation with the reported Famatinian deformations that have been defined on a different basis. At present we consider that D1 would be roughly equivalent to the Famatinian deformation whereas D2 might correspond to a transpressional deformational event (von Gösen and Prozzi, 1998).

Table 1: Selected ages for the basement of Sierra de San Luis. In bold ages calculated presented and discussed in this paper. References: (1) Sims et *al.*, 1997; (2) López de Luchi et *al.*, 2000, (3), Linares and González, 1990; (4), Sims et *al.*, 1998; (5) González and Sato, 2000. * Uraninite, ** monazite.

Metamorphic unit	Sample and/or locality	Rock type	U-Pb Zr Ages (Ma)	K/Ar Ms Ages (Ma)	Ar/Ar Ms Ages (Ma)	K/Ar Bt Ages (Ma)
CMC	AH 24 La Canada	Pegmatite pre S2		**430±10,4**		
	AH25	Ms overgrowth of S2		**396, 7±8,2**		
	AH27 NE Huertita dam	Folded Pegmatite		**421,5±9,9**		
	Renca batholith	Renca porphyric	393±5(1)			382±17(2)
	3km WSaladillo	Granite				392±15(3)
	Guzman shear zone	Mylonite			351-362(4)	
Micaschists PMC schists	AH8 S Paso del Rey	Pegmatite (cut a foliated granite)		**444,5±9,0**		
	AH7 S Paso del Rey	Ms of a boudinated pegmatite		**398,2±9,2**		
	Paso del Rey	Pegmatites	455-462*(2)			
Micaschists (or San Luis Metamorphic Complex)	AH2 SE La Escalerilla	Bt-Ms-Qz schists Ms predates Bt-Ms foliation		**394,5±8,3**		
	SE La Escalerilla	Mylonitized NNW pegmatite			374±0,6(4)	
	NE contact of L.Escalerilla	Mylonite in pegmatite			366±2(4)	
		La Escalerilla	403±5(1)			**397,0±10,4** **398,5±9,2**
Phyllites	AH 6 Tamboreo	tonalite	470±5(1)			**364,7±9,7**
Phyllites (west L.Esc.)	Bemberg	tonalite	468±6(1)			
PMC Gneiss		Orthogneiss	484±7(4)			
	Las Àguilas	Felsic seggreg in pyroxenite	478±6(4)			
		Gneiss	451±10(4)**			
NMC	El Molle pluton	monzonite				380±7(5)
	El Barroso	Mylonite				364±7(5)

RESULTS AND DISCUSSION

To elucidate the cooling history of the Sierra de San Luis K/Ar age determinations were performed on Muscovite and Biotite samples. At present we accept the interpretation of Sims *et al* (1998) for the only available monazite age (equivalent to an U-Pb age on zircon rims), as indicating peak-metamorphic conditions(>750^{0}C) for the gneiss of Pringles Metamorphic Complex. Closure temperatures for biotite (300 ± 50°C) and muscovite (350 ± 50°C) are considered according to Purdy and Jäger (1976).

K/Ar Muscovite ages calculated for tourmaline bearing pegmatites of the Conlara Metamorphic Complex (Bt-Ms schists) indicate an older 430±10,4 and 421.5± 9,9 Ma pegmatitic event that corresponds to layers that are parallel to an S1 foliation and are folded together with the country rock. Therefore, the S1 surface correspond to a deformation pre-430Ma/421Ma. Foliated biotite granites located at the south of Las Chacras batholith, show Ms blast overgrowths, the K/Ar Ms cooling age of them is 396.7±8.2 Ma. These granites are intruded syn –kinematically in relation to a folding phase that affects D1 structures, i.e a second deformation D2, that would be pre 396 Ma and post 430/421Ma since the older reported pegmatites are folded.

Crystallization age for the Renca batholith is 393 ± 5 Ma (U-Pb SHRIMP, Sims et al, 1997). The pluton intruded the Bt-Ms schist and cut the F2 folds. Cooling age for a foliated granite of the Conlara Metamorphic Complex, located farther to the south (3km west of Saladillo) yielded a K/Ar Bt age 392±15Ma (Linares and González, 1990).

In the mica-schist located on the road from Tamboreo to Paso del Rey, Ms age on a folded pegmatite that cuts both the country rock and a foliated granite is 444±9.0 Ma, therefore foliation development and deformation is pre-444 Ma. Although this last muscovite age is similar, within error, to the oldest that was calculated in the Conlara Metamorphic Complex, the pegmatite post-dated an S1 surface in both the metamorphic and the granitic rocks. Folding of the pegmatite is accompained by the development of an S2 foliation. In this area, Ms age on a boudinated pegmatite, yielded 398±9.2 Ma, which indicates a second pegmatitic event, that is parallel to the S2 foliation and was subsequently deformed.

The mica-schist south of La Escalerilla Granite show an heterogeneous Bt-Ms mylonitic foliation that postdated muscovite blastesis of an older foliation. K/Ar age on the muscovite that overgrows the penetrative foliation yielded 394.5±8,3Ma. The timing of this mylonitization is more difficult to be constrained because the mylonitic foliation is defined by minerals of an equivalent closure temperature. Then, the Ms age provides the time in which the system crosses the around 400^0C isotherm.

K/Ar Bt ages for La Escalerrila Granite are the oldest (397.0±10.4/398.5±9.2 Ma). A zircon age for La Escalerilla (403 ± 5 Ma) is given by Sims *et al.* (1997). The pluton exhibits a conspicuos high temperature solid state deformation that would bracket a ductile deformation between 403-398 Ma, i.e around 400 Ma an important ductile event that could have facilitated the ascent of La Escalerilla pluton, was active in Sierra de San Luis. If this age is correlated with the cooling ages of both the younger pegmatites of the Conlara Metamorphic Complex and the Ms overgrowth of the micaschists of Pringles Fm, a Devonian deformation could be responsible for S2 development, pegmatite intrusions and the emplacement of La Escalerilla Granite

If the Ar/Ar ages of 374±0.6 and 366±2 Ma on muscovite and/or sericite of in sheared pegmatites are considered, the shearing event would be younger then the above mentioned 400 Ma deformation. This shearing could be heteregeneous because at present no trace of this younger deformation is recognized in the Renca batholith which on the basis of its biotite cooling age of 385±10 Ma would be below 300^0C by this time (López de Luchi et *al.*,2000).

Biotite cooling age of 364.7±9.2 Ma for the Tamboreo pluton is the youngest that has been reported for the solid-state foliated granites and it is coincident within error to previous Bt age of 360±15 Ma (Linares and González, 1990). Tamboreo (SHRIMP Zircon age of 470±5 Ma) exhibits low-temperature solid state deformation probably overprinting a higher temperature foliation. The cooling rate will be extremely low, which seems difficult to reconcile with the proposed emplacement in unconsolidated sediments that were later transformed into phyllites. At present the only available time constraint for the phyllites, is the 529±12 Ma U-Pb zircon (upper intercept at the Concordia diagram) age on metavolcanic interlayered in the primitive sedimentary pile (Söllner *et al.*, 2000).

Sims *et al.* (1997) reported U-Pb SHRIMP crystallization ages between 484± 7 and 478± 6 Ma for orthogneisses and a felsic segregation in the mafic-ultramafic complexes in Pringles Metamorphic Complex respectively together with a metamorphic monazite U-Pb age of 451±10 Ma for a sillimanite-garnet gneiss. Mafic complexes are foliated and retrograded therefore its emplacement could be considered as predating one deformation. Therefore, the observed D1 in our study could be bracketed between 470-430 Ma. Between 480-450 Ma temperatures were higher than 750°C (Rubatto *et al.*, 2001), as indicated by the monazite age, which could allow melting in the crust, being responsible for pegmatites and peraluminous granites.

A c.a.380 Ma Bt cooling age for a monzonitic pluton that is comparable with the Devonian batholiths in Conlara Metamorphic Complex was reported (González and Sato, 2000) together with a Sm/ Nd whole rock isochron age of 1502 ± 95 Ma for mafic and ultramafic rocks in association with supracrustal sequences (Sato *et al.*, 2001).

We can constrain a D1 prior to around 440-420 Ma followed by another deformation that would be bracketed between that time and 398-396. Subsequently a new foliation seems to develop locally at least probably in connection with the shear zones, that discontinously affects the metamorphic sequence. No evidences at present exist to indicate separate post-Cambrian evolutions for the gneiss of Pringles Metamorphic Complex, the micaschists of the Pringles Metamorphic Complex and Conlara Metamorphic Complex. Coeval magmatic and deformational events together with cooling would point to a common cooling history.

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