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Provenance and tectonic setting of the protoliths of the Metamorphic Complexes of Sierra de San Luis

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RESUMEN. *Proveniencia y ambiente tectónico de los protolitos de las unidades metamórficas de la Sierra de San Luis*. Se presenta una caracterización de los protolitos metasedimentarios de tres unidades metamórficas de la Sierra de San Luis: el Complejo Metamórfico Pringles, la Formación San Luis y el Complejo Metamórfico Conlara sobre la base de la composición química (elementos mayoritarios y trazas). La elaboración de los datos químicos señala un predominio de pelitas en los protolitos de la Formación San Luis, en tanto que en el Complejo Metamórfico Conlara pueden identificarse grauvacas y pelitas y en el Complejo Metamórfico Pringles se observa predominio de grauvacas sobre pelitas. Los diagramas discriminantes de elementos mayoritarios tanto como las relaciones diagnósticas de elementos traza señalan consistentemente una fuente de composición de corteza superior para los protolitos de las tres unidades, excepto por un grupo de grauvacas del Complejo Conlara. Para las tres unidades es posible inferir la mezcla de dos fuentes detríticas: una de composición intermedia, andesítica y otra de composición ácida, ígnea o con material clástico maduro, reciclado. El escenario geodinámico más probable para la deposición de los protolitos de las unidades estudiadas habría sido un arco de islas continental o un margen continental activo, según surge de los distintos diagramas clasificatorios. En este contexto, una cuenca de retroarco podría explicar la naturaleza mixta del/las área/s fuente, con detritos provenientes tanto del antiguo basamento ascendido como del arco magmático. La cuenca habría evolucionado durante los tiempos cámbricos recibiendo aportes sedimentarios por el este desde el orógeno pampeano combinado probablemente con exposiciones de corteza más antigua y desde el oeste la fuente detrítica habría estado controlada por el margen continental activo.

Palabras clave: *Proveniencia, Marco tectónico, Protolitos rocas metámorficas, Margen de Gondwana, Paleozoico temprano*

ABSTRACT. A major and trace element based characterization of the metasedimentary protoliths of three metamorphic units of Sierra de San Luis (Pringles Metamorphic Complex, San Luis Formation and Conlara Metamorphic Complex) is presented. Geochemistry indicates a dominance of shales in the protoliths of San Luis Formation, whereas greywackes and shales made up the Conlara Metamorphic complex and mainly greywackes, the Pringles Metamorphic Complex. Both major element data and trace element ratios (i.e. Th/Sc, Th/U,) indicate a source with an average upper crustal composition for the protoliths of the Pringles Metamorphic Complex, the San Luis Formation and the shales of the Conlara Metamorphic complex. A component with less evolved signature may be inferred for the metagreywackes of the Conlara metamorphic Complex. Mixed sourced detritus are indicated for the three units with clastic material resulting mainly from both andesitic and acidic/recycled detritus. The overall data consistently suggest a continental island arc and/or active margin setting as the more probable geodynamic scenario for the deposition of the sedimentary precursors of the studied units. In this context, a back-arc setting can account for the mixed nature of the inferred source areas with uplifted old basement and arc-related detritus as the end members of the mixtures. The inferred back-arc basin would have evolved through the Cambrian receiving the sediments derived from the Pampean Orogen to the east combined with probably some old crust exposures and to the west the source might have been controlled by the active continental margin.

Key words: *Provenance, Tectonic setting, Protoliths metamorphic units, Gondwana margin, Early Paleozoic*

Introduction

Determining the source of detritus of clastic material in sedimentary and metasedimentary rocks can be performed through different techniques and studies. In addition to the more traditional methods of point counting various detrital components, the mineral chemistry and the geochronology of detrital constituents, the isotopic character of the rocks and minerals, and the trace element chemistry of the rocks are used to establish more details about the provenance of clastic material. It has been long recognized that the chemical composition of sedimentary rocks image the nature of the source region and this in turn is closely related to the plate tectonic setting. Moreover the evolution of crustal processes can be delineated through this chemical study (Bathia 1983; Roser and Korsch 1986, 1988; Floyd *et al.* 1991; Mc Lennan *et al.* 1993).

The provenance signatures can survive relatively high-grade metamorphism if no open system process has occurred (*i.e.* anatexis, metasomatism, veining, and so on). Ratios of low-solubility trace elements in generally reflect those of source rocks rather than the products of diagenesis or metamorphism (Cullers *et al.* 1975; Taylor and Mc Lennan 1985, Mc Lennan *et al.* 1990), making them valuable tools for provenance analysis.

Many trace elements are extremely insoluble in aqueous solutions, and tend, therefore, to be transferred from the source rock to the sediments without significant fractionation (Mc Lennan 1989; Nesbitt 1979; Bierlein 1995). Most hydrothermal fluids have very low concentrations of insoluble trace elements such as the rare earth elements (REEs); hence, alteration of whole-rock trace element patterns during hydrothermal alteration and metamorphism is generally ineffective (Bau 1991). The REEs, Th, Sc, Hf, and Co are the most suitable for provenance determination because of their relatively low mobility during weathering, transport, diagenesis (Girty *et al.* 1994) and metamorphism (Mc Lennan and Taylor 1991). REE distribution in shales and sandstones, in particular, has been used to characterize source terranes and tectonic setting (Taylor and McLennan 1985, Mc Lennan *et al.* 1990).

Detrital sediments may constitute the only record of a crust that was removed by erosion, covered with younger deposits or buried deeper in the crust (Condie *et al.* 1995).

The Sierra de San Luis defines a key location for the understanding of the Proterozoic to Palaeozoic evolution of the Sierras Pampeanas, since it marks the westernmost outcrops of the southern Sierras Pampeanas in close proximity to the Laurentian derived Western Sierras Pampeanas. The basement complex of the Eastern Sierras Pampeanas was inhomogeneously affected by three deformational events. Those are the Proterozoic to Cambrian Pampean cycle, the early Palaeozoic Famatinian cycle and the final Achalian cycle in the Devonian. The Sierra de San Luis comprises an Early Paleozoic metamorphic basement intruded by Ordovician to Devonian magmatic units. Although several authors have done regional or detailed studies on the magmatic, metamorphic, structural evolution and metalogenesis (Brogioni 1993. 2001; Delpino *et al.* 2001; González *et al.* 2002; Kilmurray and Dalla Salda 1977; Hack *et al.* 1991; Llambias *et al.* 1996, 1998; López de Luchi 1987, 1996; López de Luchi *et al,* 1999, 2001 a and b 2002 a and b; Ortiz Suárez 1988, 1996; Ortiz Suárez *et al,* 1992; Sims *et al.* 1997, 1998; Steenken *et al*. 2002; von Gosen 1998, von Gosen and Prozzi 1996, 1998 and references therein), few studies have been presented concerning the provenance and geodynamic setting of the protoliths of the metamorphic basement (Sims *et al.* 1997; López de Luchi *et al,* 1999; Brogioni, 2001; Cerredo and López de Luchi 2002).

Available radiometric ages for lower grade units, i.e the San Luis Formation are provided by some acidic metavolcanics interlayered in the phyllites that yielded a U-Pb age of 529 ± 12 Ma U-Pb zircon (upper intercept at the Concordia diagram) that is considered as the crystallization age of these rocks (Söllner *et al.* 2000). If these volcanic rocks are syn-sedimentary they imply a Cambrian age for the sedimentary pile that later evolves as San Luis Formation. Older magmatic units that were reported at present correspond to mafic rocks emplaced in the more central metamorphic complex. They yielded U-Pb SHRIMP ages ca. 480-484 Ma (Sims *et al.* 1997, 1998), therefore the sedimentation interval is comprised between 529-480 Ma, i.e it covers the arc-stage of the Famatinian cycle (Dalla Salda *et al*. 1998; Pankhurst *et al.* 1998, 2000 and references therein). Nevertheless, von Gosen *et al.* (2002) presented analytically weakly defined ages for the Paso del Rey Granite (~608 Ma) emplaced in the Pringles Metamorphic Complex and for the northern part of La Escalerilla pluton (~507 Ma) that is emplaced along the tectonic contact between the western sector of the San Luis Formation and the Pringles Metamorphic Complex.

The aim of this contribution is to characterize the tectonic setting and provenance of a part of the metamorphic complexes of the Sierra de San Luis based on major and minor elements. Contents of the metasedimentary rocks. Due to the difficulties of using methodologies inherent to sedimentary rocks for metamorphic rocks several approaches will be presented and discussed. This presentation is part of an ongoing study aimed to characterize the tectonic evolution of the Sierra de San Luis. In this paper we analyse the significance of provenance studies on a part of the metamorphic basement, i.e. on the Conlara and Pringles Metamorphic Complexes (Sims *et al,* 1997) and on the lower grade San Luis Fm. (Prozzi and Ramos 1988).

Geological setting

The mappable metamorphic units (Ortiz Suárez *et al.* 1992; Sims *et al.* 1997; von Gosen and Prozzi 1998 and references therein) are separated from west to east in the Western Basement Complex or Nogolí Metamorphic Complex, the Eastern Basement Complex or the gneisses of the Pringles Metamorphic Complex, the Mica-schists or the schists of the Pringles Metamorphic Complex, and the Conlara Metamorphic Complex. The San Luis Formation or Phyllite Group forms two parallel belts that separate the above mentioned units (Fig. 1). The most important map scale feature of the Sierra de San Luis is the NNE elongation of parallel belts of

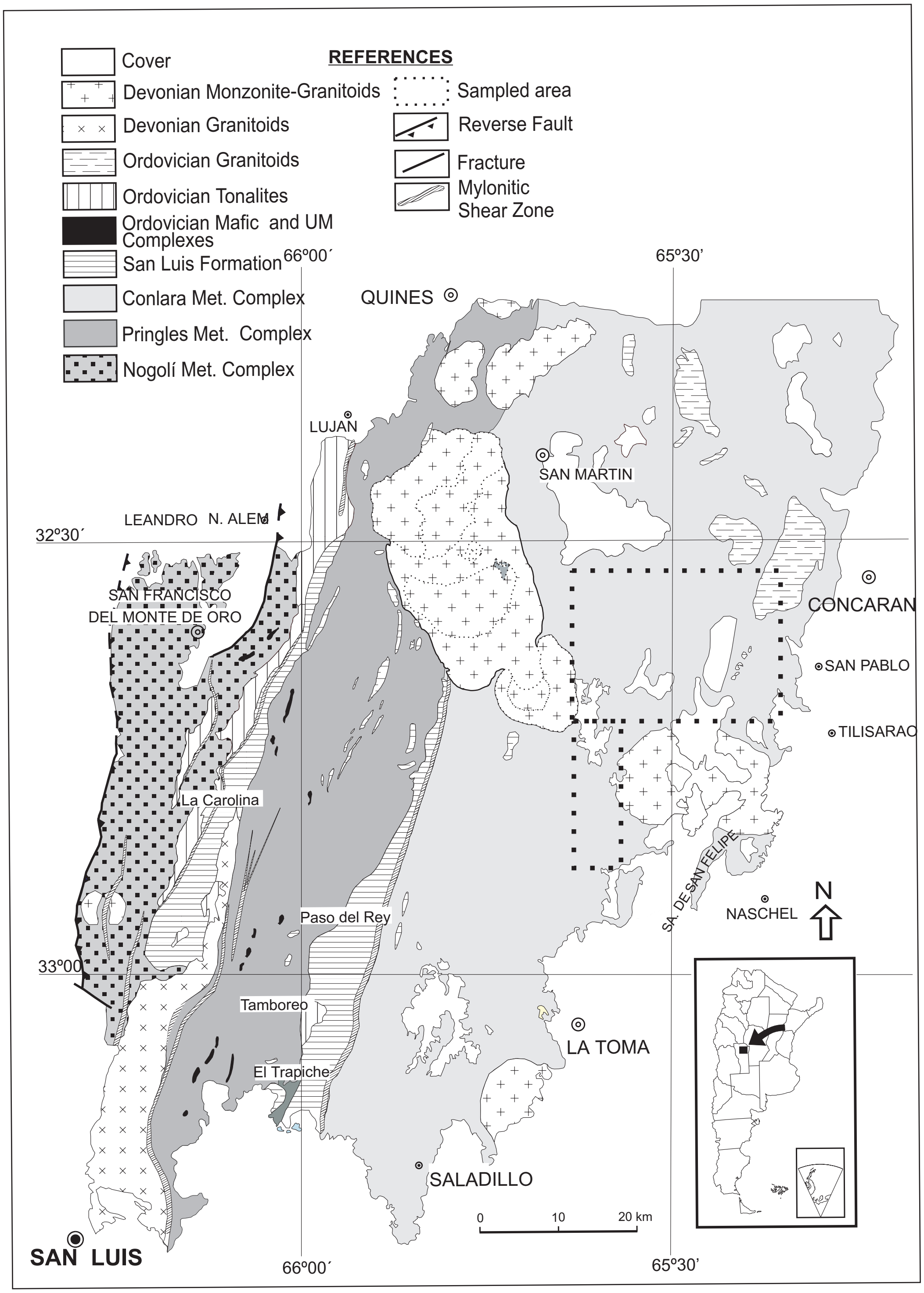

Figure 1: Geological sketch of the Sierra de San Luis modified after López de Luchi *et al.* (2001)

different metamorphic grade. 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 west central sector where granulite facies is present. The metamorphic rocks host granitoids and pegmatoids of Ordovician to Devonian age (Sims *et al.* 1997; 1998). Mafic to ultramafic complexes are emplaced in the higher metamorphic grade rocks of the Pringles and Nogolí Metamorphic Complexes (Delpino *et al.* 2001; Sims *et al.* 1997; González *et al.* 2002 and references therein).

The Nogoli Metamorphic Complex (not included in our analysis) is made up by felsic orthogneisses with minor mafic gneisses and is intruded by monzonites and granites (i.e. Río Claro granite, Sims *et al.* 1997, 1998). González *et al.* (2002) indicate that the metamorphic basement of the southwestern Sierra de San Luis is composed of a supracrustal association (metapelites, metaquartzites and mafic-ultramafic metavolcanic rocks with minor banded iron formations, marbles and calc-silicates and gneisses, migmatites and amphibolites).

The Pringles Metamorphic Complex is made up by gneisses, mica-schists, amphibolites and mafic complexes. The metamorphic grade of the Pringles Metamorphic Complex is considered by Hauzenberg *et al.* (2001) as ranging from greenschist facies to amphibolite facies (570-600 °C and 5-5.7 kbar), and locally to granulite facies in the vicinity of numerous mafic bodies (740-790 °C 5.7-6.4 kbar).

The San Luis Formation (Prozzi and Ramos 1988) consists of metaquartz-arenites and phyllites, minor black shales and scarce conglomerates. Acidic volcanic rocks are interlayered in this formation a feature that was already described by Hack *et al*. (1991) and von Gosen (1998).

The main rock types of the Conlara Metamorphic Complex are gneisses, migmatites, schists, banded schists and scarce amphibolites. Turmalinites, calc-silicatic rocks related with W mineralization and scarce and boudinated layers of amphibolites have been recognized (López de Luchi 1986; López de Luchi and Cerredo 2001). The western margin of the Conlara Metamorphic Complex is in contact with the San Luis Formation, a Devonian shear zone controls this limit (Sims *et al.* 1997). The assemblages in the Conlara Metamorphic Complex are characterized by the paucity of diagnostic paragenesis, in fact biotite (and rare relic garnet) is the only AFM phase present (López de Luchi and Cerredo 2001).

For the Nogolí Metamorphic Complex, González *et al.* (2002) calculated U-Pb monazite age of 458.2 ± 2.7 Ma (2s), with MSWD 0.26, for a sillimanite-garnet gneiss with remnant NW trending structures. Those ages were interpreted as an Early to Mid-Ordovician event related to the peak pressure and the formation of penetrative NNE trending structures. The possibility of a crystallization age as old as ~1.5 Ga for the mafic to ultramafic rocks, was pointed out by Sato *et al.* (2001) based on one Sm-Nd whole rock isochron.

The metamorphic evolution of the Pringles Complex would be entirely Ordovician as it is constrained by dating of felsic and mafic rocks. Specifically for the garnet-sillimanite gneiss, Sims *et al.* (1998) calculated an U-Pb age of 452 ± 12 Ma in monacite and an U-Pb age of 460 Ma in zircon rims. Dating of igneous rocks that intrude the complex yielded U-Pb SHRIMP zircon ages of 484 ±7 Ma in orthogneisses and 478 ± 6 Ma in a felsic segregation in the mafic complexes rocks. Therefore the metamorphism would be bracketed between *c.* 480-450 Ma. Regional cooling of the Complex is constrained by muscovite ages of 444 ± 9.0 Ma (López de Luchi *et al.* 2002). Nevertheless von Gosen and Prozzi (1998) mentioned the possibility of having older deformational events in this Complex based on the comparison with The West Basement Complex or Nogolí Metamorphic Complex but lacking age constraint.

The San Luis Formation shows a low-grade metamorphic overprint, that was considered to be Ordovician or Devonian (see Sims *et al.* 1997; von Gosen and Prozzi, 1998). At present, the only available age for the sedimentation of the protoliths of the San Luis Fm is a conventional zircon age for metavolcanic interlayers in the phyllites that yielded 529 ± 12 Ma (Söllner *et al*. 2000), i.e. Middle Cambrian, coeval the granulite facies metamorphism in the nearby Sierras de Córdoba and with the inferred collision of the Pampean Terrane (Rapela *et al*. 1998). Von Gosen and Prozzi (1998) described some volcanic dykes that could have intruded the phyllites.

Age constraints for the Conlara Complex are at present mainly restricted to cooling ages calculated on muscovite and biotite of pegmatites. K/Ar muscovite ages calculated for tourmaline bearing pegmatites indicate 430 ± 10.4 and 421.5 ± 9.9 Ma pegmatitic event. Regional cooling at biotite closure temperature took place between 380-360 Ma (López de Luchi *et al*. 2002).

López de Luchi (1986) first characterized the metaclastic sequences of the Conlara Metamorphic Complex as dominated by greywackes. A recent geochemical study (López de Luchi *et al.* 1999) of these metaclastic rocks showed that the protoliths were mainly greywackes, semipelites and subordinated pelites with Al_2O_3/SiO_2 from 0.175 to 0.28, $Al_2O_3/CaO+Na_2O$ from 2.2 to 3.4 for Fe_2O_3t + MgO between 4.5-7.5 which together with REE patterns that show significative Eu-anomalies, moderate LREE enrichment and absence of HREE depletion are typical for various Phanaerozoic active margin settings. In La-Th-Sc discrimination diagrams they plot in the continental island arc field (López de Luchi *et al.* 1999). Brogioni (2001) considered, on the basis of a major element study of the schists and gneisses of the Pringles Metamorphic Complex, that their protoliths were mainly greywackes deposited in an active continental setting.

Cerredo and López de Luchi (2002) proposed that an active margin of Cambrian age is strictly valid for the tectonic setting of the protoliths of the San Luis Formation as this unit shows the lower metamorphic overprint without evidence of open-system behaviour during metamorphism.

Samples and analytical techniques

The metamorphic rocks that were studied comprised schist, some gneisses and phyllites that correspond to metagreywackes and metapelites. In the Conlara Metamorphic Complex metamorphic assemblages correspond to quartz-andesine/oligoclase-biotite± muscovite ±garnet±tourmaline and scarce chlorite. Schist exhibit a medium- to coarse-grained granoblastic-lepidoblastic texture with a conspicuous biotite±muscovite foliation that is affected by at least two folding phases (López de Luchi and Cerredo 2001).

Metasedimentary rocks of the Pringles Metamorphic Complex comprise biotite garnet gneisses with a medium- to coarse-grained granoblastic-lepidoblastic texture. They are composed of the mineral assemblage quartz+oligoclase/andesine+biotite+garnet with apatite, zircon, rutile and magnetite as accessory minerals. They have a gneissic fabric given by the alternation of less foliated quartzo-feldspathic-rich and strongly foliated biotite-rich domains. Garnet is associated with the biotite –rich layers. Locally it is possible to recognize the preservation of primary centimeter-scale sedimentary bedding that is defined either by the interlayering of quatzitic layers or by varying biotite/plagioclase ratios. The gneissic foliation is overprinted by a continuous schistosity in D3 high-strain domains. Muscovite and fibrolite commonly appear in these highly strained gneisses.

Metapelites of the San Luis Formation are composed of quartz+chlorite+sericite/muscovite and show a well developed axial plane slaty cleavage.

Around 54 whole rock major and trace elements data are presented (Table 1, 2). This study is based on our own collection of samples of the Conlara Metamorphic Complex that were selected considering no visible evidence of veining or open-system behaviour. New whole rock major and minor element chemical data for the Conlara Metamorphic Complex are presented (Table 1). New determinations were performed on samples up to 10 k that were screened for alteration in hand specimens and thin sections. Samples were broken using iron hammer and further reduced using an iron platted jaw crusher and subsequently agate mills. Major elements were analysed by wet methods at the former LAQUIGE. Minor elements were performed at ActLab with research resolution for trace elements. Method comprised X-ray fluorescence spectrometry and ICP/MS for trace elements and (XRF) for major elements.

Our own chemical data on the metasedimentary rocks of the Conlara Metamorphic Complex were combined with whole rock published analysis (Methods mostly correspond to XRF for major and some trace-elements or by a combination of XRF with ICP/MS) and plotted on provenance and several tectonic discrimination diagrams. The whole data set was recalculated to an anhydrous base. Data of the Pringles and Conlara Metamorphic Complexes and San Luis Formation were taken from Hack *et al.(* 1991); Delakowitz *et al. (*1991); Sims *et al. (*1997); and Brogioni (2001).

Results

Chemical characterization

The whole new data set is presented in Table 1. The range of chemical compositions of the metasedimentary rocks of each unit are reported in Table 2. General geochemical features of the samples are those of the average sandstones and shales of Turekian and Wedephol (1961). According to the diagrams of Herron (1986) the rocks are mainly classified as greywackes and shales (Fig. 2). Samples of the Pringles Metamorphic Complex that are located in the field of the shales correspond to the high-grade metamorphic sector of the Pringles Complex (see Sims *et al.* for coordinates of the location). Three samples of the Pringles Metamorphic Complex are located in the field of the litharenite and one classifies as arkose. It must be taken into account that in spite of using classification schema with elements with different geochemical behaviour, like that of Fonteilles (1976) that uses alkalis against Al_2O_3 (López de Luchi 1986), there is a generally good agreement between the different classifications. The difference in mobility of Na and K during diagenesis and later metamorphism does not seem to have strongly influenced the analysed rocks.

The trace element abundances in sedimentary rocks have been employed to trace the composition of the upper continental crust (Fig. 3,a,b). Elements considered more useful are REEs, Th and Ni, Y, Sc, Cr. Contents (Table 1) show a considerable scatter for the Conlara Metamorphic Complex.

Y/Ni shows the lowest values for the metashales of both San Luis Formation and Conlara Metamorphic Complex but absolute mean values are lower for this last unit. (Table 2)

Th/U is 3.8 for the upper continental crust (McLennan *et al.* 1990). As U is readily oxidized and lost to the oceans and to ore deposits, Th/U may be useful for interpreting recycling histories (McLennan *et al.* 1990 and references therein). Th/U is similar for the shales of the San Luis Formation and the Conlara Metamorphic Complex, 2.67-6.33 and 2.6-8 respectively. Metagreywackes of all the units exhibit a wider span with values up to 16 for the Conlara Metamorphic Complex (Fig. 3b). No correlation exist between SiO_2 content and Th/U.

La/Th in the metasandstones ranges from 1.8 to 3.5 the latter value for the Conlara Metamorphic Complex. Values for La/Th above 2 are typical for turbidites deposited in continental island arc (McLennan *et al.* 1990). On the other hand, Bathia and Crook (1986) indicated that continental margins present values between 1.77 to 2.36, the highest for the continental island arc. Values higher than 3 may reflect some basic detritus because the oceanic island arc setting is characterized by La/Th around 4.

Th/Sc shows values from around 1 up to 4 for the

Table 1: Major and minor element contents of the metaclastic rocks of the Conlara Metamorphic Complex.

Sample	Shale		Greywacke										
	155	19.4	L1	Y3	C2	Y2	152	MR10	R8	59	19-2	103 REP	LR5
SiO_2	61.51	63.83	68.19	68.51	68.63	68.87	71.58	71.85	72.33	72.69	72.78	73.08	73.17
TiO_2	1.04	0.81	0.92	0.72	0.81	0.67	0.72	0.63	0.46	0.59	0.71	0.65	0.77
Al_2O_3	17.41	16.96	14.09	14.59	14.22	14.51	12.77	12.95	14.22	13.05	12.69	13.23	13.28
Fe_2O_3	3.13	2.97	1.76	2.47	2.11	2.25	0.57	0.97	1.11	0.85	2.02	0.82	1.91
FeO	2.70	3.98	3.67	2.33	3.06	3.03	3.54	2.71	2.41	3.37	2.35	3.60	2.20
MnO	0.10	0.09	0.14	0.08	0.10	0.09	0.07	0.07	0.08	0.05	0.09	0.06	0.08
MgO	1.84	3.57	2.74	3.05	2.45	2.72	2.61	2.14	1.57	1.82	1.85	1.88	1.64
CaO	3.38	1.24	2.17	1.90	1.73	1.65	2.75	3.56	2.29	2.09	2.14	2.12	1.77
Na_2O	3.67	1.43	3.05	2.66	3.57	2.91	2.82	2.86	3.07	2.94	2.22	2.69	2.24
K_2O	4.97	4.93	3.10	3.51	3.12	3.13	2.38	2.03	2.20	2.41	2.89	1.69	2.77
P_2O_5	0.25	0.17	0.17	0.17	0.18	0.16	0.19	0.23	0.27	0.15	0.26	0.19	0.16
Ba	375						414	314	327	483	436	308	328
Rb	288	211	378	201	180	236	100	106	109	154	121	103	103
Sr	316	88	140	166	166	140	183	184	209	187	165	182	203
Pb	25						10	12	10	16	14	11	12
Th	16						10	13	7	14	15	13	11
U	5						2	3	2	3	4	3	2
Zr	319						315	372	190	331	428	380	330
Nb	15						7	9	7	9	9	9	7
Y	35						36	40	38	33	39	38	36
Sc	12						12		9	11	11	11	11
V	116						88	80	68	69	77	79	92
Cr	117						192	256	61	200	63	253	55
Ni	15						18	16	29	15	15	18	16
Cu	29						10	39	16	10	22	35	10
Zn	61						67	55	46	62	71	43	56
Ga	25						16	15	18	15	17	15	17
Co	14						12	12	11	10	11	11	11
Ge	2						2	2	2	2	2	2	2
As	5						5	5	5	5	5	5	5
Mo	2						2	4	2	3	2	4	2
Ag	1						1	1	1	1	1	1	1
Sn	6						3	2	2	3	3	2	3
Sb	1						1	1	1	1	1	1	1
Cs	19						6	10	36	9	20	10	13
Hf	8						8	9	5	9	11	10	8
Ta	1						1	1	1	1	1	1	1
W	1						2	3	1	2	2	2	4
Tl	2						1	1	1	1	1	1	1
Br	6	7	6	6	6	6	5	4	4	5	5	5	4
I	8	11	9	9	8	8	7	6	5	6	6	7	6
B	7	3	5	5	5	5	6	6	5	5	4	5	4
La	65						35	40	23	28	44	39	32
Ce	155						73	83	51	66	91	81	69
Pr	19						9	10	6	8	11	10	9
Nd	71						36	38	23	32	41	38	33
Sm	12						8	8	5	7	8	8	7
Eu	3						2	2	1	1	2	2	1
Gd	9						7	7	5	6	7	7	6
Tb	1						1	1	1	1	1	1	1
Dy	6						6	7	6	6	6	6	6
Ho	1						1	1	1	1	1	1	1
Er	4						4	4	4	4	4	4	4
Tm	1						1	1	1	1	1	1	1
Yb	3						3	4	4	3	4	4	3
Lu	0						1	1	1	1	1	1	0

Major elements are expressed in % weight, minor elements in ppm.Analytical techniques are presented in the text. Location of the samples are indicated in Figure 1.

Table 2: Range of major and minor element contents of the metaclastic rocks of the eastern and central belt of the Sierra de San Luis.

	San Luis Formation		Conlara Met. Complex		Pringles Met. Complex	
	shale	greywacke	shale	greywacke	shale	greywacke
SIO_2	60.44-64.95	69.27-77.86	51.38-63.83	61.51-73.17	61.22-67.61	65.75-79.25
TIO_2	0.56-0.81	0.47-0.58	0.87-1.07	0.46-1.04	0.5-1.03	0.17-0.76
AL_2O_3	16.27-18.08	10.69-14.39	16.96-20.22	12.07-15.76	15.36-17.63	8.36-16.55
Fe_2O_{3t}	4.76-7.08	3.06-3.44	6.52-10.99	3.95-5.84	4.05-10.32	1.67-4.67
MnO	0.1-0.23	0.02-0.04	0.09-0.22	0.05-0.1	0.09-0.22	0.04-0.12
MgO	1.75-2.89	1.03-1.35	3.44-4.26	1.64-3.31	1.5-3.9	0.13-1.9
CaO	0.28-5.73	0.52-2.08	0.81-1.6	0.31-3.68	0.78-4.77	0.03-4.57
Na_2O	1.47-2.63	1.58-3.78	1.55-2.69	1.66-3.57	1.18-3.00	0.48-4.2
K_2O	2.64-4.77	2.58-2.83	3.62-5.76	1.69-4.3	1.19-2.45	1.29-4.23
P_2O_5	0.11-0.25	0.12	0.15-0.21	0.14-0.27	0.06-0.15	0.01-0.21
Ba	390-570	275-335	475-900	328-650	280-640	80-727
Rb	104-242	110-144	141-218	100-378	54-126	14-211
Sr	70-226	55-231	86-168	71-209	91-253	44-248
Pb	14-32	16-28	18-26	10_43	16	18
Th	16-19	13-19	16	9_16	22-31	15
U	4	3	4	3	1	4
Zr	131-182	186-198	158-214	132-428	232-245	50-373
Nb	6_18	14	14-22	9_17	8_16	6_18
Y	27-38	25	25-33	25-40	20	21-36
La	28-34	26-36	24-30	22-44	20-48	20-77
Ce	60-95	55-85	55-70	50-91	110	25-194
Sc	22	13	22-36	9_22	9	14
V	94-157	48-150	120-196	77-118	40-126	40-102
Mn	735-1480	110-360	875-1500	520-600	585-575	305-525
Cr	68-89	30-48	86-142	50-256	6-102	10_76
Ni	18-38	11	42-70	15-38	2_50	4_43
Cu	2_27	18	8_96	2_39	4	9
Zn	90-274	84	124-188	43-124	76-194	56-128
Ga	23	15	24-33	16-23	17-34	16-23
Co	14			10-12.10	44	14-37
Zr/Th	8.84-10.63	10.42-14.31	10.88-17.83	8.35-30.22	7.48-11.27	11.63-16.47
Th/Sc	1.51-2.15	0.91-1.82	0.67-1.71	0.33-1.94	1.95-4.14	0.88-1.5
Th/U	2.67-6.33	4.75-13.00	2.6-8.0	3.64-6.00		3.4-9
La/Y	0.97-1.31	1.08-1.44	0.85-1.87	0.62-1.31	2.00-2.67	0.97-1.62
La/Sc	1.17-1.70	2.25-2.60	0.78-1.36	1.57-3.00	4.80-5.75	2.13-3.25
Zr/Sc	6.17-8.5	12.38-18.6	6.21-10.64	6.00-38.95	23.2-31.00	12.00-27.75
Y/Ni	0.73-1.6	1.33-6.25	0.47-0.64	0.68-2.61	0.35-11.5	1.00-8.75
Cr/V	0.41-0.79	0.32-0.63	0.71-0.8	0.6-3.22	0.15-0.81	0.65-0.78
La/Th	1.68-2.13	1.89-2.00	1.56-2.00	2.01-3.46	1.55-2.09	1.86-2.00
$(La/Yb)_N$				3.9-8.39		
$(Gd/Yb)_N$				1.05-1.69		
Eu/Eu*				0.60-0.73		

Major elements are expressed in % weight, minor elements in ppm. Analytical techniques are presented in the text. Location of the samples are presented in Sims *et al*. (1997), Brogioni (2001) and in Figure 1. Ranges are calculated on the basis of 10 samples of the San Luis Formation (Sims *et al*. 1997, Hack *et al*. 1991), 25 for the Conlara Metamorphic Complex (Sims *et al*. 1997, Cerredo and López de Luchi 2002) and our new data and 19 samples of the Pringles Metamorphic Complex (Sims *et al*. 1997, Brogioni 2001).

Pringles Metamorphic Complex and for the San Luis Formation whereas the Conlara Metamorphic Complex shows the lowest values 0.33-1.94 for the metagreywackes and 0.67-1.71 for the metashales (Fig. 3a).

La/Sc shows the higher values for the Pringles Metamorphic Complex shales and is mostly comparable in the rest of the units. Zr/Sc show higher values for the Pringles Metamorphic Complex and the metagreywackes of the Conlara complex. Within each of the units, this ratio attains higher values for the metagreywackes in the case of San Luis Formation and Conlara Complex whereas shales of Pringles Metamorphic Complex present higher values and less variation (Table 2).

Ti/Zr is comparable for all the units but it does not exhibit a correlation with Cr, Sc or V (Table 2).

In the Conlara Metamorphic Complex, the metagreywackes can be separated in two groups, one that shows

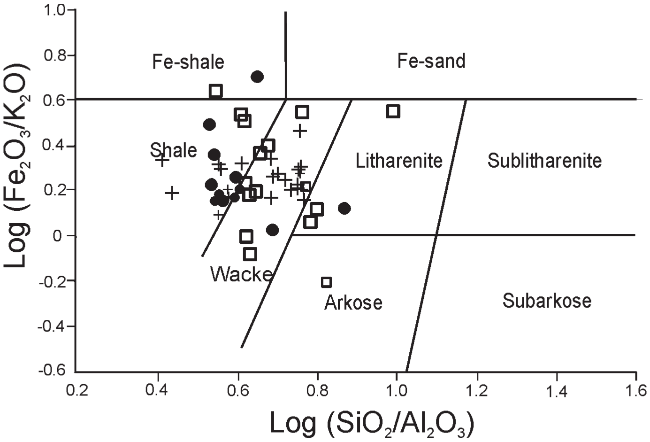

Figure 2: Chemical classification of the metaclastic rocks of the eastern and central belts of the Sierra de San Luis based on the log SiO_2/Al_2O_3vs. log (Fe_2O_3t/K_2O) of Herron (1986).
Symbols: filled circle San Luis Formation, cross: Conlara Metamorphic Complex, empty squares: Pringles Metamorphic Complex.

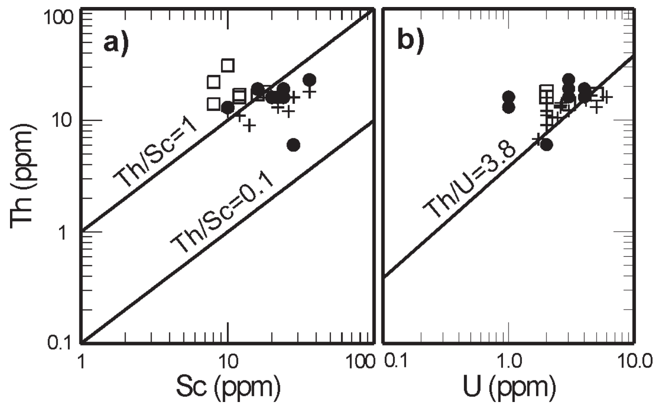

Figure 3: a, Th *vs* Sc and **b,** Th *vs* U diagrams for the metasedimentary rocks of San Luis Fm. and Pringles and Conlara metamorphic complexes (modified after Mc Lennan *et al.* 1990) Symbols as in figure 2.

the contents of Cr above 200 ppm and the lowest values for Ni, Th/Sc, Ti/Zr and the higher Zr/Sc, and La/Sc. The other with low Cr posses similar Th/Sc, La / Sc and Zr/Sc but higher Ti/Zr. Metashales exhibit intermediate values for Cr, higher Th/Sc, Ni, TiO_2, MgO, Fe_2O_{3T} and lower Zr/Sc and La /Sc (Table 1, 2 and Fig. 3 a).

The metagreywackes of the Pringles Metamorphic Complex are characterized by low Cr, high Th/Sc (above 0.9), Zr/Sc and two groups can be distinguished one with higher Ti/Zr, Sc and V.

Complete REE data are only available for the some metasandstones of Conlara Metamorphic Complex. Only La and Ce were reported in the literature for the rest of the units. Values for Eu/Eu* (Taylor and Mc Lennan 1985) cover the span from 0.57-0.79 which fits well within the reported range of sandstones from turbidites (McLennan *et al.* 1990). Two correlations are shown when this ratio is plot against Th/Sc (Fig. 4a). Gd_N/Yb_N is below 2 an indication of the minor importance of garnet fractionation in the sources of the protoliths of the Conlara Metamorphic Complex (Fig. 4b).

Interpretation of the results must be based on the combination of several chemical evidences because some trace element like La, Th, Y and Cr concentrations can be affected by fractionation during the different sedimentary processeses.

Provenance

In order to characterize the provenance, the major element based diagram of Roser and Korsch (1988) is used because this bivariate plot uses parameters that are largely independent of grain-size effects (sandstone-mudstone). The discriminant functions of the diagram use Al_2O_3, TiO_2, Fe_2O_{3T}, MgO, CaO, Na_2O, and K_2O contents as variables. This discriminant diagram is useful for characterising bulk provenance in metamorphic terranes where recrystallisation has obscured or destroyed original detrital mineralogy. These functions discriminate among four sedimentary provenances: mafic, P1: ocean island arc; intermediate, P2: mature island arc; felsic, P3: active continental margin; and recycled, P4: granitic–gneissic or sedimentary source. Provenance discrimination diagrams based only on major elements are somewhat unreliable because of the mobilization of these components during weathering and alteration (Roser and Korsch 1988).

Notwithstanding this difficulty, in this diagram (Fig. 5) we can observe some differences between the different analyzed samples. The majority of the Conlara Metamorphic Complex samples plot on the P3 and P4 fields. P3 would indicate a provenance from active continental margins whereas P4 indicate recycled continental sources associated with a passive continental margin, intracratonic sedimentary basins, and recycled orogenic provinces. Only three samples plot in the P2 field. The San Luis Formation occupies fields similar to the Conlara Metamorphic Complex. The samples of the Pringles Metamorphic Complex show a bimodal distribution in the P2, mature island arc provenance and P4 fields.

The chemical composition of sedimentary rocks is influenced by hydraulic sorting and reworking. These processes lead to the concentration of weathering-resistant phases commonly zircon. Enrichment of Zr is therefore an indication of reworking. Th and Sc are incompatible and compatible, respectively, in igneous differentiation processes. Th/Sc indicates the degree of igneous differentiation (McLennan *et al.* 1990, 1993). The Th/Sc ratio of sedimentary rocks reflects the average provenance and is particularly sensitive to overall

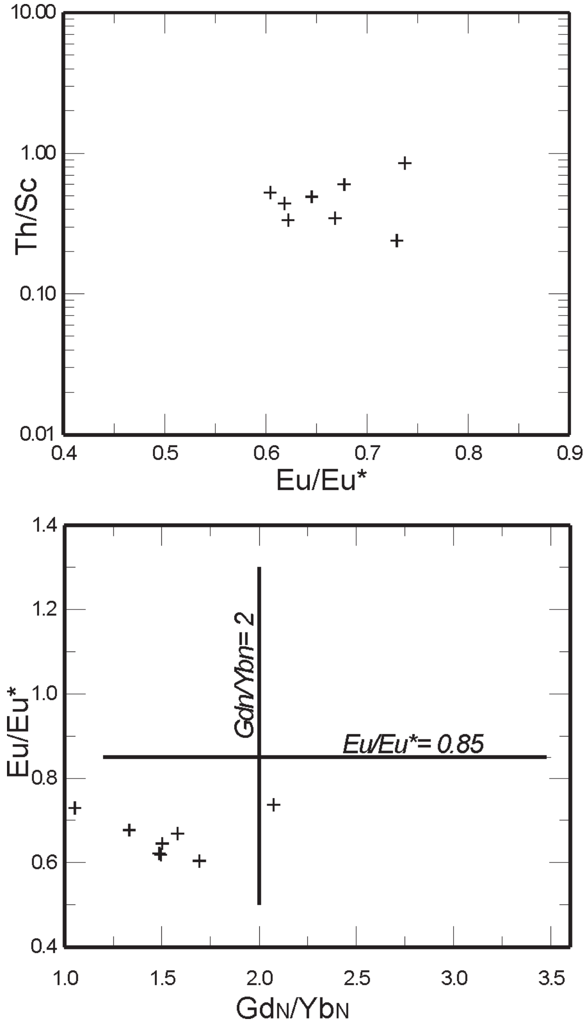

Figure 4: a, Th/Sc *vs* Eu/Eu* and **b,** Eu/Eu**vs* Gd_N/Yb_N plots of the metasedimentary rocks from the Conlara Metamorphic Complex. Normalization factors from Taylor and Mc Lennan (1985). Symbols as in figure 2.

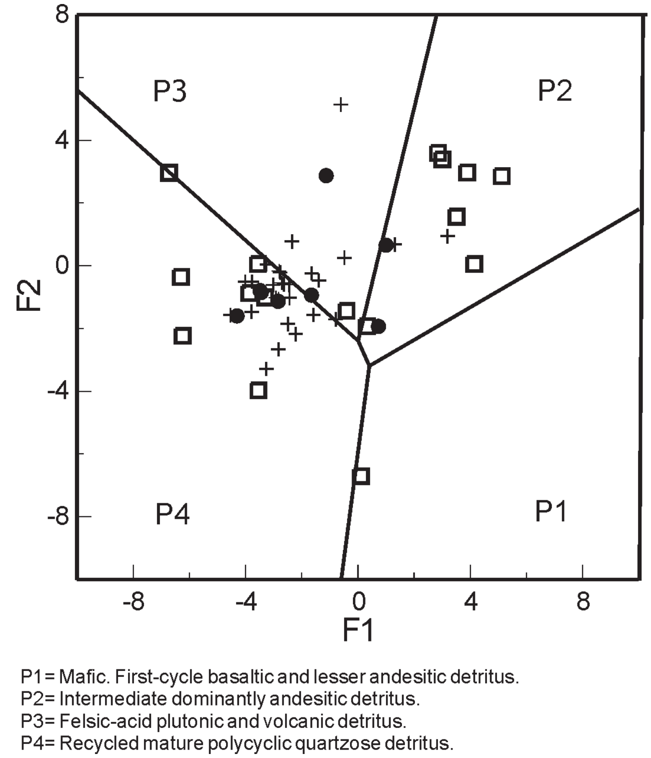

Figure 5: Plot of the metaclastic sequences of the Sierra de San Luis in the discriminant function diagram for the provenance signature of sandstone-mudstone suites based on major element chemistry (modified after Roser and Korsch 1988). Symbols as in figure 2.

bulk composition. Samples from active margins generally have lower Th/Sc ratios than passive margin samples, indicating variable but generally more mafic composition of the provenance (Mc Lennan *et al.* 1990).

Samples from the phyllites and from the Conlara Metamorphic Complex display a negative slope in the Th/Sc *vs* Zr/Sc diagram (Fig. 6) whereas those of the Pringles Metamorphic Complex are displaced towards higher values of both parameters but except for two samples they define an equivalent trend that always is above 1 for Th/Sc. The typical value for Th/Sc for the upper crust is 1 (Taylor and McLennan 1985). Samples for the Conlara Metamorphic Complex exhibit two groups one with values above 1 and Zr/Sc <10 and another values of Th/Sc pretty below 1 and higher Zr/Sc. Most of the phyllites and the samples of the Pringles Metamorphic Complex show values from 0.9 to 2.15 for Th/Sc and therefore reflect input from fairly evolved crustal igneous sources. Th/Sc ratios less than 0.8 are an indication of sources other than typical continental crust, *i.e.* for instance mafic sources, and probably reflect an input from mature or recycled sources if coupled with higher Zr/Sc.

An additional evidence of the paucity of mafic sources for the metamorphic rocks under study is provided by the TiO_2 *vs* Ni (Fig. 7a) which indicates that the magmatic protoliths of the metasedimentary pile were largely derived from acidic to acid/intermediate magmatic compositions.

Chemical characterization of the units indicate that Conlara Metamorphic Complex may exhibit some mafic input based on both the low Th/Sc and high Cr content of one of the groups of metasandstones. In a plot of this ratio against Cr this last group is seen as completely separated from the rest of the whole data set. In addition shales tend to exhibit higher Cr and Th/Sc than the corresponding metagreywackes in the case of the Conlara Metamorphic Complex. Given the general enrichment and coherent behaviour of MgO, Ni, and Cr and the lowest values for Th/Sc compared to average greywacke, an ultramafic component in the Conlara Metamorphic Complex is examined.

Ultramafic source rocks are characterized by low Y/Ni (< 0.5) and high Cr/V (>10), whereas felsic source rocks plot with lower Cr/V and higher Y/Ni ratios

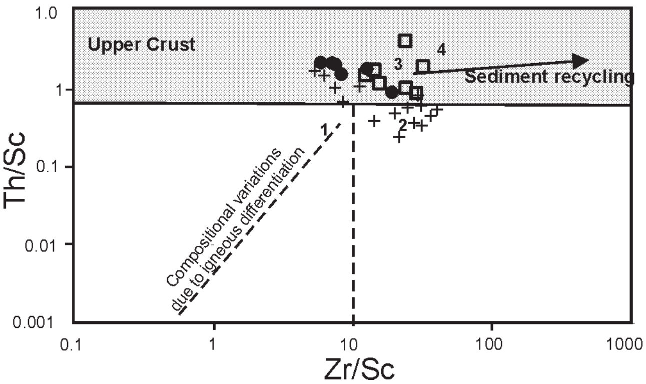

Figure 6: Plot of the metaclastic sequences of the Sierra de San Luis in the Th/Sc vs. Zr/Sc diagram after McLennan *et al.* (1993), reflecting reworking through Zr/Sc and upper crust felsic input through Th/Sc. Note the similar Zr/Sc for the metagreywackes of the Pringles and Conlara complexes and the different Th/Sc. Metashales of both San Luis Fm and Conlara Complex plot in the same sector of the diagram. Numbers identify the mean values for 1,OIA, 2,CIA, 3, ACM and 4, PM following Bathia and Crook (1986). Symbols as in figure 2.

(Hiscott 1984; Dinelli *et al*. 1999). Metasandstones of the Conlara Metamorphic Complex with high Cr shows higher Cr/V (around 2.6) but this value is well below the mafic signature. This distinction is also evident in the Cr *vs*. Th/Sc plot (Fig. 7b) in which except for this last group no correlation exists between Th/Sc and Cr which suggests that mafic sources are ruled out for most of the units in accordance with the information provided by comparison between TiO_2 and Ni (Fig 7 a). Therefore in most of the sequences enrichment in Ni, Cr and Mg may result from a combination of provenance and secondary processes more than with a mafic source.

Tectonic setting

Bathia (1983) proposed a discrimination diagram for the tectonic setting of sandstones based upon a bivariate plot of discriminant functions of major elements analysis of 69 Paleozoic sandstones. Bathia and Crook (1986) assigned the sedimentary basins to four tectonic settings: oceanic-island arc, continental island arc, active continental margins and passive continental margins. The plotting of the samples of the three units show a considerable overlap and are concentrated in the continental island arc and the active continental margin fields. The oceanic-island arc setting corresponds to basins developed on thick continental crust or thin continental margins whereas the latter correspond to Andean-type basins developed on or adjacent to thick continental margins. In any case the tectonic setting is related with an active margin.

In the diagram shown in Fig. 8, most of the samples fall into the active continental margin, except for four samples of Pringles Metamorphic Complex and one of

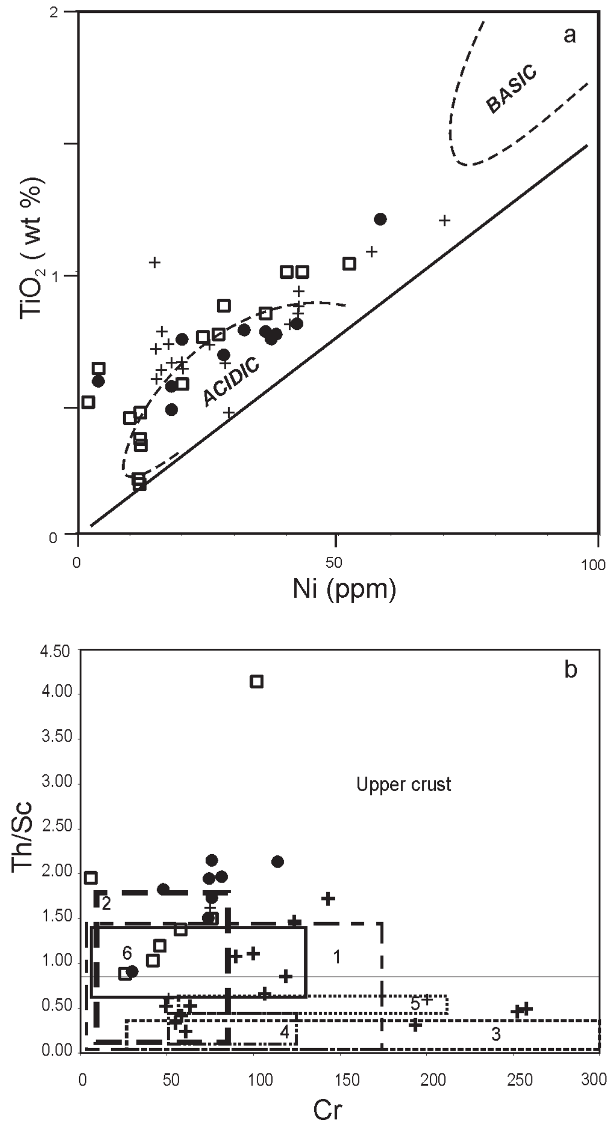

Figure 7: a, TiO_2 vs. Ni and **b,** Th/Sc vs. Cr for the metasedimentary rocks of San Luis Fm. and Pringles and Conlara metamorphic complexes. **a,** fields for acidic and basic source materials after Floyd *et al.* (1989), **b,** boxes were prepared with the data of Mc Lennan et al, (1990) for greywackes and mudstones of modern sedimentary basins: 1: back- arc, 2: continental arc, 3: fore-arc, 4: strike-slip; 5: continental-collision, 6: trailing-edge. This diagram is useful to separate the different signature of the samples under study but the overlap of the different basins render it less distinctive for the tectonic setting. Note that for contnent of Cr below 100, samples of the Conlara Complex show the lowest Th/Sc.

the phyllites that plot in the passive margin field. The former corresponds to the group that plot in the P4 field in Fig 5. Trace element ratios such as La/Th, La/Sc, Ti/Zr, have been used to discriminate turbidites from different tectonic settings (Bhatia and Crook 1986). In a plot of La *vs*. Th, samples from the Conlara and Pringles Metamorphic Complexes are grouped in the field of continental island arc and in the limit between this field and that of the continental margin plus passive margins (Fig. 9a). In the ternary plot of La–Th–

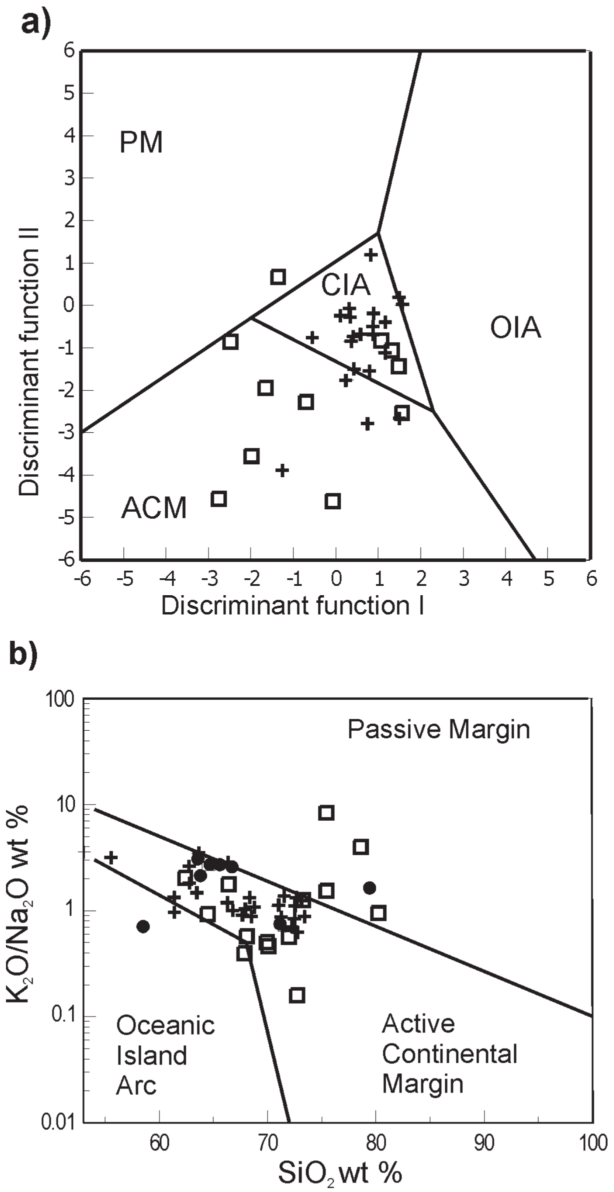

Figure 8: Plot for the tectonic setting of the metaclastic sequences of the Sierra de San Luis in **a,** K_2O/Na_2O *vs.* SiO_2 discriminant plot of tectonic setting for sandstone-mudstone suites (modified after Roser and Korsch, 1986); **b,** Discriminant function diagram (modified after Bathia, 1983) for the metasandstones of the Conlara and Pringles metamorphic complexes. Symbols as in figura 2.

Sc, the samples of the Conlara and Pringles Metamorphic Complexes fall in the field of continental island arcs (Fig. 9b). The ratios of Ti/Zr vs La/Sc are also useful to discriminate different tectonic settings. Most of the samples plot in the continental island arc field with a trend similar to the recent deep sea turbidites from and deposited at continental arc margins (McLennan *et al.* 1990).

In Fig 7b compositional span for rocks of basins with known tectonic setting are included. The degree of overlapping of the different type of sedimentary basins is considerable. Taking into account the above mentioned inferred tectonic setting, samples of Conlara Metamorphic Complex mostly plot in the area of back-arc basins whereas the rest are located in the area of continental margins or above it for a part of the metashales of the San Luis Formation. It is worth to mention that the high metagreywackes of the Conlara Metamorphic Complex plot close to the fore-arc area which would imply more basic detritus.

As REE data are only available for the metagreywackes of the Conlara Metamorphic Complex, the Eu/Eu* is compared with La_N/Yb_N (Fig.10). Samples plot in the area of overlapping between continental arc, back-arc and trailing edge basins. The four metagreywackes with high Cr content, plot far from the area of the fore-arc basins and the La_N/Yb_N seems to be diagnostic for continental arcs.

Discussion

In this work, the application of geochemical criteria to the study of a new data set of the Conlara Metamorphic Complex integrated with previously published data for the rest of the metamorphic units of the Sierra de San Luis, provide significant insights and additional constraints concerning the discrimination, provenance, and tectonic setting of the protoliths of the metamorphic sequences. Interpretation of provenance and tectonic setting must be made cautiously, because specific tectonic settings do not necessarily produce rocks with unique geochemical signatures (McLennan *et al.* 1990; Bahlburg 1998). Significant major element changes due to long-lasting weathering of the source area may provide ambiguous results on major element compositions. Although it is difficult to deduce the sedimentary provenance simply from the geochemistry of metasediments we have use several ratio of mobile and inmobile trace-elements and major elements in order to analyze if any systematic characterization of each units can be performed. Parameters for provenance and tectonic setting must be referred clearly to the lithology because there are differences in chemistry that rely on the grain size of a sediment.

Chemical classification of the metamorphic units indicate that Conlara Metamorphic Complex is made up by greywackes and shales whereas the Pringles Metamorphic Complex is mainly composed of metagreywackes (Fig. 2). The San Luis Formation is dominated by shales. Samples that plot as shales in the case of the Pringles Metamorphic Complex are located in the area that corresponds to the granulite facies metamorphism therefore these results must be used with caution due the possibility of extraction of mobile components out of the metamorphic rocks independently of any sedimentary process.

Th/Sc ratio may provide an indication of the involvement of recycled *vs.* more primitive composition of the source area. The Conlara Metamorphic Complex is the

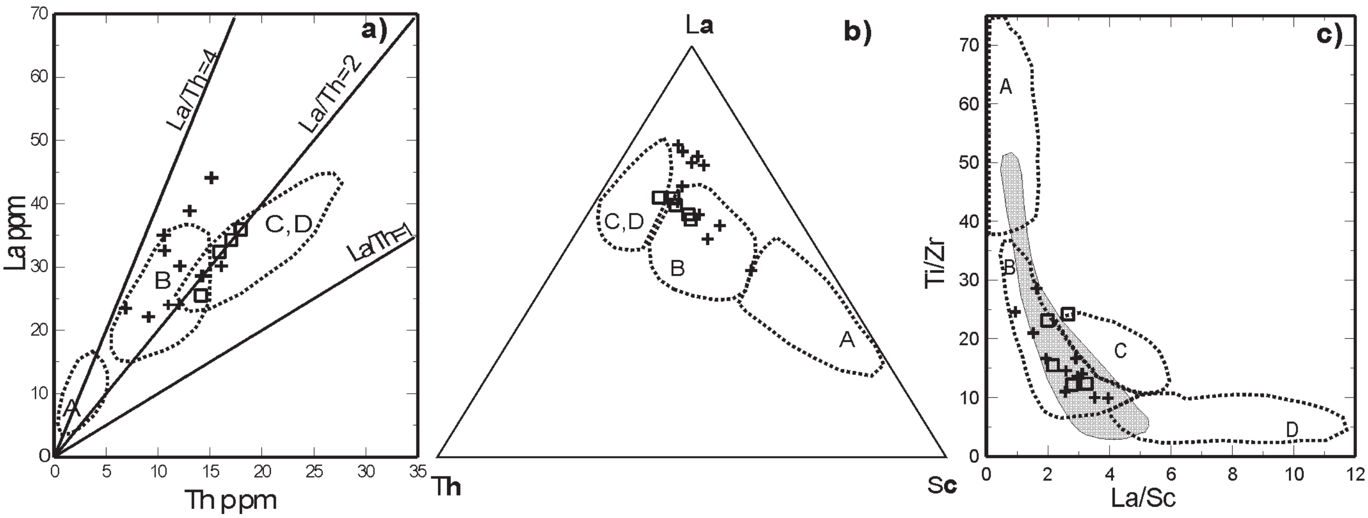

Figure 9: a, La *vs* Th plot, **b,** La-Th-Sc diagram and **c,** La/Sc *versus* Ti/Zr portrayal of the of the metasandstones of the Conlara and Pringles metamorphic complexes. Outlined fields (after Bathia and Crook 1986) are: A - oceanic island arc, B – continental island arc, C – Active continental margin, D – passive margin; shaded area corresponds to the field of recent deep sea turbidites derived from and deposited at a continental arc margin (data from McLennan *et al.* 1990, after Bahlburg 1998). Samples are mostly located in the field B. Symbols as in Fig.2

only unit that presents values below 0.8, the limit for the upper crustal composition (McLennan *et al.* 1990). Therefore a group of metamorphic rocks of this complex may sample a more basic source than the rest. All the units exhibit a wide span of Th/U with values well above the 3.8 that is considered as diagnostic of the upper crust (McLennan *et al.* 1990). Values higher than 3.8 rule out fore-arc basins but are no diagnostic of a particular setting.

REE for the Conlara Metamorphic Complex shows a moderately negative Eu anomaly associated with low Gd_N/Yb_N. Shales of this complex exhibit the lowest values for this last ratio and the smaller Eu anomaly. All these results are typical for the recent turbidites (McLennan *et al.* 1990)

Provenance analysis indicate that mixed sources controlled the protoliths of the metamorphic units (Fig. 5, 6, 7). Major elements indicate a predominance of felsic or recycled sources for the Conlara Metamorphic Complex and the San Luis Formation whereas most of the greywackes of the Pringles Metamorphic Complex plot in the field of dominantly andesitic detritus (Fig. 5). Shales of this last complex plot in the field of recycled provenance. As the F1 parameter is sensitive to the content of Na_2O, CaO and Al_2O_3 increasing plagioclase content may misplace the samples in the P2 field (Fig. 5).

Minor-element were used in order to further check the composition of the sources. The source area of the units except for a group of the Conlara Metamorphic Complex had a typical upper crustal composition (Fig. 6). Metashales of Conlara and San Luis Formation present upper crustal signature. Sandstones of Pringles and Conlara Metamorphic Complexes differ in Th/Sc both showing higher Zr/Sc ratios. Whereas the former show upper crustal signature (upper crust igneous sources, silicic and intermediate magmatic precursors) and moderate reworking, the meaning of lower Th/Sc of the metasandstones of Conlara Metamorphic Complex is less clear. The samples of the Conlara Metamorphic Complex that plot in the P2 field (Fig. 5) exhibit the higher Cr content and lower Th/Sc, a likely indication of more mafic sources. The rest of the data do not indicate mafic sources because they plot in the field of acidic sources (Fig. 7a) and Y/Ni shows values similar to that of the granitoids with low Cr/V (Table 1).

There is a tendency for some metashale samples of both the Conlara and Pringles Metamorphic Complexes to higher values of TiO_2 and Ni which is derived from the intrinsic compositional differences between shales and greywackes

Most of the inferences about the tectonic setting of the metagreywackes point to a continental island arc with a tendency for the Pringles Metamorphic Complex to active continental margins (Fig. 8, 9a, b, c). Following Bathia (1983) continental island arcs correspond to the sedimentary basins adjacent to island arcs formed on a well developed continental crust or on thin continental margins (detached and non-contracted type arc-trench systems, respectively). Arcs are continental fragments, detached from the mainland. Sediments are deposited in inter-arc, back-arc and fore-arc basins and are mainly derived from felsic volcanic rocks. Back-arc basins formed on the continental side of the island arc are included in this setting. Active continental margins include sedimentary basins of the Andean type thick continental margins and the strike-slip types. These basins are developed on or adjacent to a thick continental crust composed of rocks of older fold belts. Sediments are dominantly derived from granite-gneisses and siliceous volcanics of the uplifted basement. Sedimentation in the Andean type setting

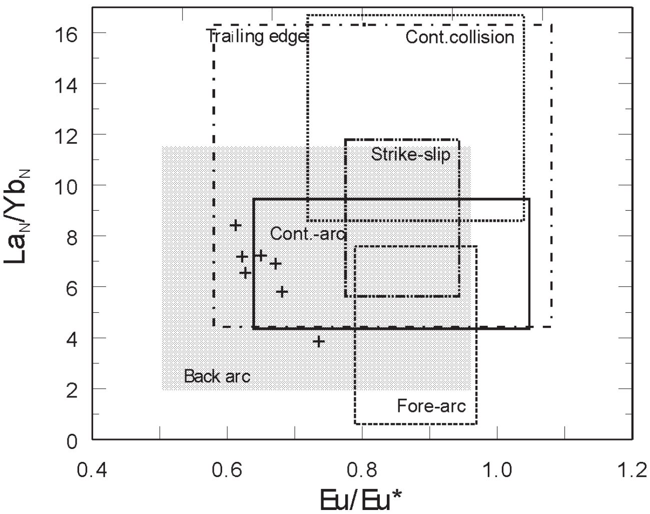

Figure 10: La_N/Yb_N *vs*. Eu/Eu* diagram after McLennan *et al*. (1990) for selected samples of metagreywackes of the Conlara Complex. Boxes correspond to the compositions reported for Mc Lennan *et al.* (1990) for sedimentary basins of known tectonic setting. Symbols as in figure 2.

takes place in marginal and retro-arc basins.

If Th/Sc *vs*. Cr together with $(La/Sm)_N$ *vs*. Eu anomaly are analyzed for the Conlara Metamorphic Complex the original basin seems to correspond to back arc or trailing edge basins and another group to the continental arc basins in the sense of McLennan *et al*. (1990) (Fig. 7b, 10). Negative Eu anomalies (Fig. 10) also demonstrate intracrustal differentiation of the magmatic precursors by processes involving separation of plagioclase, such as partial melting or fractional crystallization. On the other hand data from the rest of the metamorphic units indicate a continental arc basin (Fig. 9).

Plotting of the samples in areas of overlap of the fields for trailing edges, back arc and continental arc (Fig. 7b, 10) may indicate that the progressive development of a back-arc basin that evolves as continental arc basin might be the evolving setting in which mixed source detritus are deposited. Uplifted old basement and arc-related detritus must be the end members of the mixtures. In any case Pringles Metamorphic Complex and San Luis Formation show consistent upper crustal signatures with variable degree of recycling that in all the cases is low to moderate. On the other hand, Conlara Metamorphic Complex samples different source for the metagreywackes but similar upper crustal sources for the metashales.

Sedimentation age of around 529 Ma is assigned to the San Luis Formation (Söllner *et al*. 2000). Emplacement of the mafic rocks that controlled the granulite facies metamorphism overprint in the previous amphibolite facies in the Pringles Metamorphic Complex took place around 480 Ma (Sims *et al.* 1997). Cooling of the entire basement at temperatures around muscovite closure is constrained at around 430-440 Ma (López de Luchi *et al.* 2002). Therefore basin development took place in the interval 530-pre 480 Ma.

If the mafic rocks represent the heat source for the peak metamorphic conditions and the chemical signature is indicative of a back-arc setting (Brogioni 2001), the sedimentary basin should be closed by the time of the mafic emplacement. Then the chemical signature of the metaclastic rocks agrees with the inferred arc stage of the Ordovician evolution of the western margin of Gondwana. At c. 460 Ma, the Precordillera terrane should have accreted with Gondwana and produced syn-collisional deformation and subsequent metamorphism on the eastern side of the Precordillera terrane (see Thomas and Astini 2003 for a comprehensive review). In the San Rafael block, the Pavón Formation that was deposited in a foreland basin generated after the accretion of the Precordillera with Gondwana yielded Caradoc graptolites (Cingolani *et al.* 2003 and references therein).

In this context the sources for the sediments may have derived from the Pampean Orogen to the east combined with probably some old crust exposures. Detrital zircon grains of the Pringles metamorphic Complex are of mixed origin but mainly include a Neoproterozoic to Early Cambrian peak with very subordinate older peaks (Sims *et al.* 1998) which may support the Pampean related sources. To the west the source might have been controlled by the active continental margin. Moreover Cingolani *et al.* (2003) mentioned that in the Pavón Formation there are indications of an active continental margin or acontinental island arc source.

Conclusions

The composition and provenance of central and eastern belt of the metamorphic units of the Sierra de San Luis have been assessed using geochemical studies. Geochemical criteria applied to the metamorphic rocks of the Sierra de San Luis suggest that provenance may have been somewhat varied. However, the tectonic setting for all the units is arc related. Chemical composition indicates that greywackes and shales made up the Pringles and Conlara Metamorphic Complexes whereas the San Luis Formation is mainly composed of shales.

Data indicate a source with an average upper crustal composition for the Pringles Metamorphic Complex, the San Luis Formation and the shales of the Conlara Metamorphic Complex.

A component with less evolved signature is inferred for the metagreywackes of the Conlara Metamorphic Complex.

Although Zr/Sc reflects crustal recycling and samples with the highest values may imply the input of more reworked sources, the separation of samples with equivalent Zr/Sc and distinctive Th/Sc (>0.8 for the

Pringles Metamorphic Complex and <0.8 for the metagreywackes of the Conlara Metamorphic Complex) is not well understood because the rest of the parameter for the Conlara Metamorphic Complex do not yield reliable indications of mafic input.

Independently of the rock type the tectonic setting is related with continental island arc or active continental margins.

Further isotopic and geochronological studies on the metamorphic sequences are needed to define the age and isotopic signature of the sources. These data will allow a comparison with the chemistry of the inferred sources and to test the different paleotectonic models proposed for the evolution of the western margin of Gondwana.

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