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Geometric analysis and timing of structures on mafic–ultramafic bodies and high grade metamorphic rocks in the Sierras Grandes of San Luis Province, Argentina

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Abstract

The study area comprises a portion of the Sierras Grandes of San Luis Province in west-central Argentina. This sector is composed of high-grade granulite facies metamorphic rocks, mainly gneisses and migmatites, with intercalated igneous mafic–ultramafic bodies. These bodies occur as discontinuous lenses along a narrow central belt concordant with the general NE–SW structural trend. The granulite facies metamorphism reached by this central area has been ascribed to the intrusion of the mafic–ultramafic bodies into an amphibolite facies metamorphic sequence. On both sides of the mafic–ultramafic bodies, a decrease of metamorphic grade to amphibolite facies is apparent. Numerous pegmatitic bodies intruding the metamorphic complex can be found elsewhere and, towards the western limit of the study area, La Escalerilla metagranite constitutes one of the larger granitic exposures of the Sierras. The results of the structural analysis, done along cross-sections transverse to the mafic–ultramafic belt, allow us to establish a structural evolution for this large geological feature. The described deformational events can be correlated with the tectonic framework postulated for the southern Pampean Ranges. © 2001 Elsevier Science Ltd. All rights reserved.

Resumen

El área de estudio comprende el sector central de las Las Sierras Grandes de San Luis, situadas en el centro-oeste de Argentina. El área está compuesta por rocas metamórficas de alto grado de facies granulita, principalmente gneises y migmatitas con intercalaciones de cuerpos ígneos básicos–ultrabásicos. Estos últimos se distribuyen como lentes discontínuos a lo largo de una faja central angosta, concordante con la estructura regional de rumbo noreste-sudoeste. El metamorfismo en facies granulita alcanzado en el sector central, ha sido atribuido a la intrusión de los cuerpos máficos–ultramáficos en una secuencia regionalmente metamorfizada en facies anfibolita. A ambos lados de los cuerpos máficos-ultramáficos es evidente la disminución del grado metamórfico con asociaciones propias de facies anfibolita. Pueden encontrarse numerosos cuerpos pegmatíticos de amplia distribución intruyendo el complejo metamórfico. Hacia el límite oeste del área de estudio, el metagranito La Escalerilla constituye uno de los afloramientos graníticos de mayor envergadura en el ámbito de las sierras. Los estudios estructurales, realizados en secciones transversales a la faja máfica–ultramáfica, permitieron determinar la evolución estructural de este área. Los eventos de deformación indicados pueden correlacionarse con la tectónica general postulada por varios autores para el ambiente de las Sierras Pampeanas Australes. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

The aim of this work is to study the structural characteristics of a sector located in the central part of the Sierras Grandes of San Luis, comprising high-grade metamorphic rocks, mainly gneisses and migmatites with intercalated mafic–ultramafic bodies. These mafic–ultramafic bodies occur as discontinuous lenses along a narrow central belt, 3–5 km wide and 100 km long, that is concordant with the general NE–SW structural trend (Fig. 1).

Several structural profiles were made on the main mafic–ultramafic bodies cropping out between Las Aguilas and El

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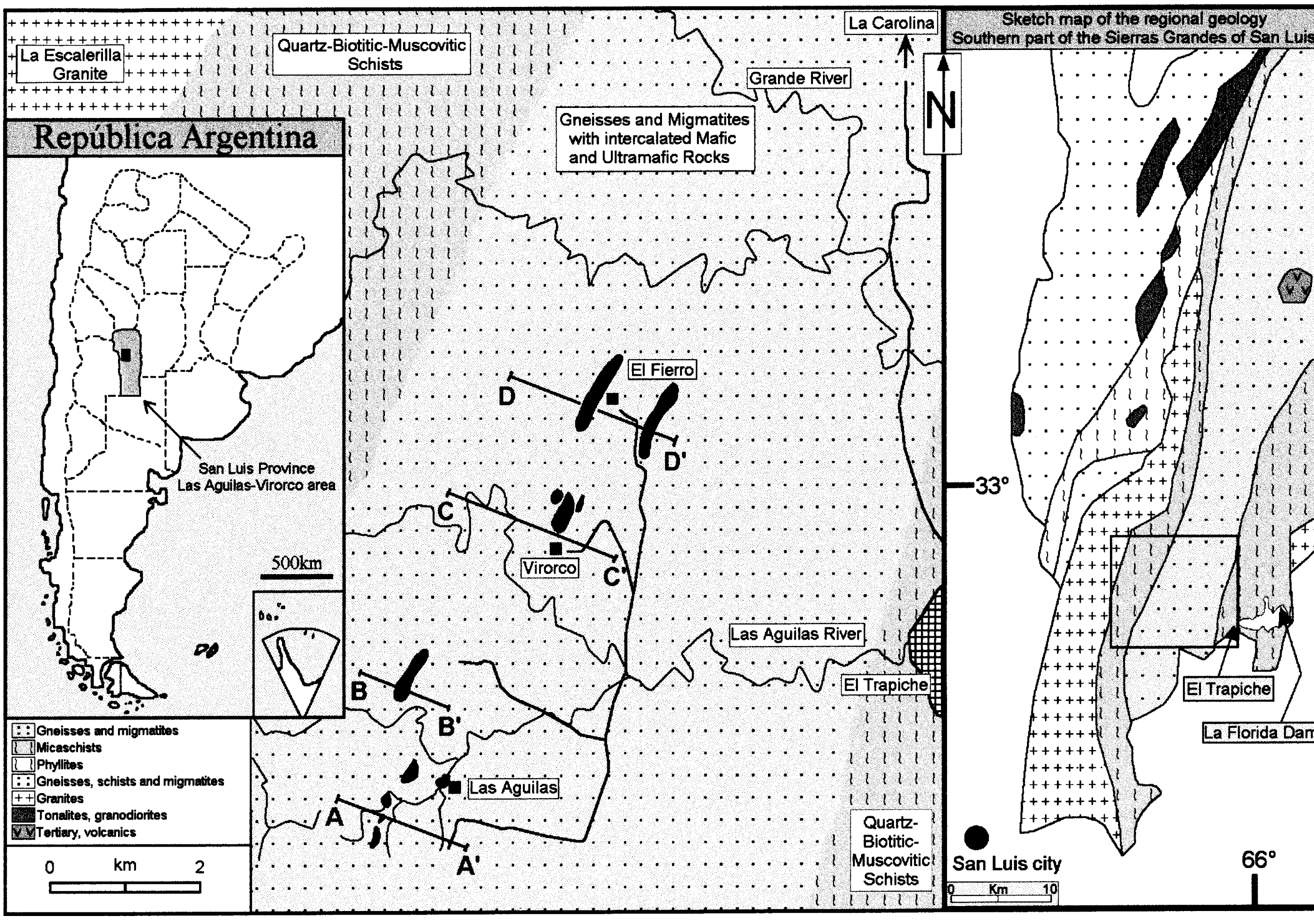

Fig. 1. Location map of the Las Aguilas–Virorco area in San Louis Province, west-central Argentina.

Fierro on the eastern flank of the Sierras Grandes, San Luis Province (Fig. 1). Detailed cross-sections were made perpendicular to the general trend of these elongated bodies and to the main penetrative structural elements. Schematic profiles are shown in Fig. 2.

Fieldwork comprised recognizing lithological units, measuring the most conspicuous mesostructures, mainly foliations, lineations, folds, faults, and kinematic indicators, and collecting oriented samples. Laboratory work included statistical analysis of field data and meso-microscopic studies of oriented polished thin sections.

Structural analysis distinguished two main and well-documented deformational events (T_2 and T_3). We must make clear that a regional amphibolite facies metamorphism (M_1) that predates the emplacement of mafic–ultramafic bodies could be related to an older event (T_1). This first event (T_1) is structurally poor documented in the study area, and only a compositional layering (L_y) preserved in septa could be assigned to it. The T_2 event generated very tight folding with steeply dipping axes with associated axial plane foliation. A younger mylonitization event (T_3) developed a wide shear zone with pervasive mylonitic foliation.

The interrelationships of the observed tectonic structures were used to establish the timing of the processes involving emplacement of mafic–ultramafic rocks and migmatization. These tectonic events may correlate with nearby areas of a kindred geotectonic framework.

2. Geologic background

The Sierras Grandes of San Luis Province in west-central Argentina belong to the Sierras Pampeanas. The block-like structure of the Sierras Pampeanas was developed during the Tertiary Andean orogeny, whereas the internal structures and metamorphism are very probably of Precambrian to Paleozoic age.

The large pre-Andean crystalline blocks have been studied extensively: Gerth (1913), Gonzalez Bonorino (1961), Gordillo and Lencinas (1979), Rapela and Shaw (1979), Coira et al. (1982), Jordan et al. (1983a,b), Jordan and Allmendinger (1986), Ramos et al. (1986), Dalla Salda (1987), Rapela et al. (1996) and von Gosen and Prozzi (1996). Much attention has been directed at the huge granitic batholites (Rapela et al., 1982, 1995, 1996; Ortiz Suárez et al., 1992) or the abundant mafic and ultramafic bodies (Kilmurray and Villar, 1981; Villar, 1985; Sabalúa, 1986; Brogioni, 1992, 1994; Malvicini and Brogioni, 1992;

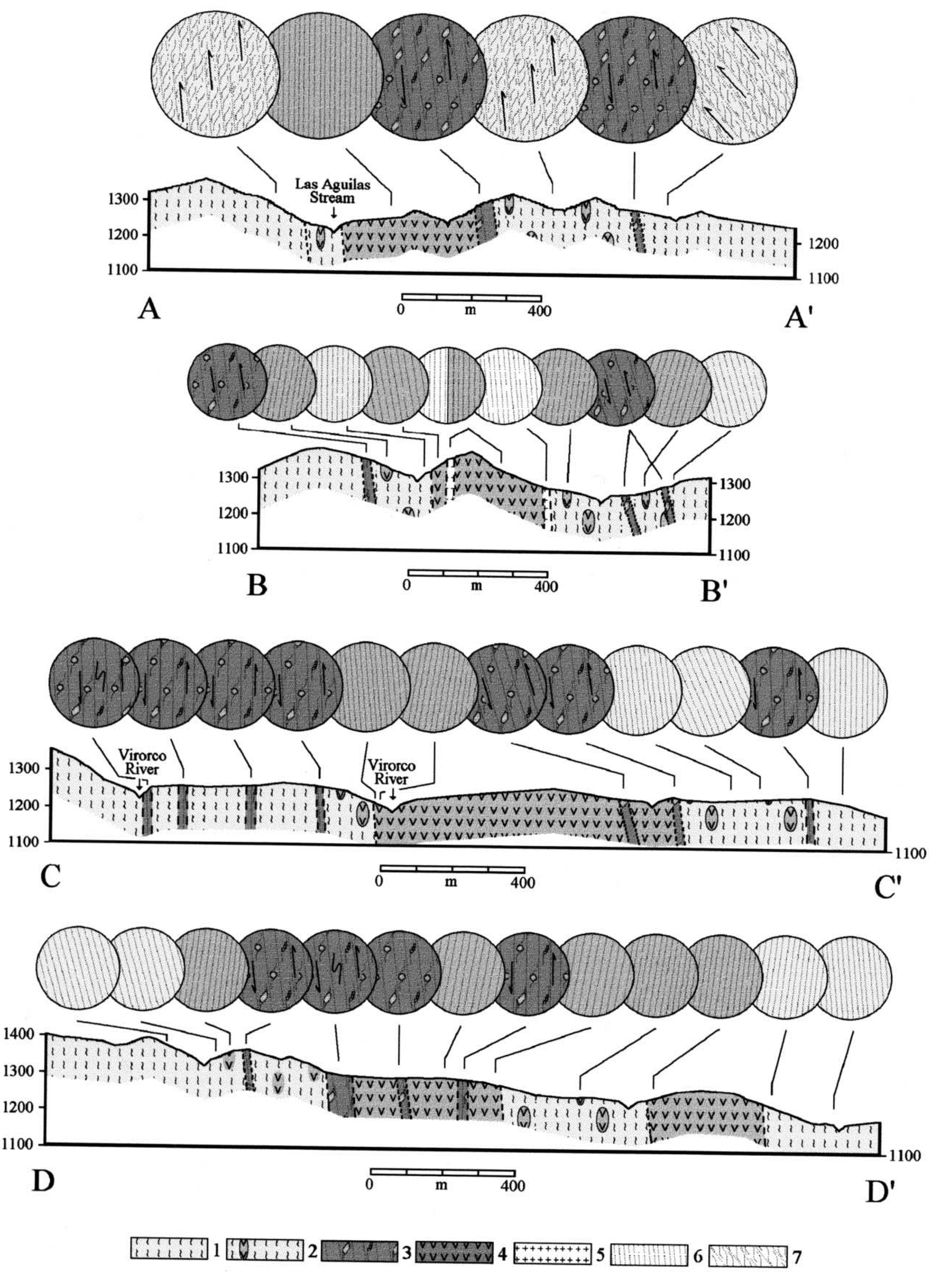

Fig. 2. Schematic geological cross-sections of the central portion of the megashear zone marked on Fig. 1. Only some of the recognized mylonitic–ultramylonitic bands are shown and their thicknesses are out of scale. Legend: 1, gneisses and migmatites; 2, gneisses and migmatites with intercalated mafic rocks; 3, mylonites–ultramylonites; 4, mafic–ultramafic rocks; 5, pegmatites; 6, foliation; 7, foliation with S/C structures.

Gervilla et al., 1993, 1996; Brogioni and Ribot, 1994; Mogessie et al., 1994, 1995, 1996, 1998a,b; Hauzenberger et al., 1996, 1997, 1998; Bjerg et al., 1997). However, little is known about the structural characteristics of the crystalline basement (Cucchi, 1964; Kilmurray and Dalla Salda, 1977; Gordillo and Lencinas, 1979; Criado Roque et al., 1981; Rapela et al., 1996). According to Gordillo and Lencinas (1979), metamorphic grade varies from greenschist to granulite facies, increasing from east to west. Most authors suggest late Precambrian to early Paleozoic ages for the Sierras Pampeanas, but no reliable radiometric ages are available for the metamorphic basement.

The crystalline basement is built up of greenschist facies, amphibolite facies, and granulite facies rocks, numerous mafic–ultramafic bodies, metagranites, and pegmatites. The greenschist facies rocks, phyllites and phyllonites, are mainly found in the eastern part of the Sierras of San Luis Province, but there are also some occurrences within the higher-grade basement (Hauzenberger et al., 1998).

The mafic–ultramafic rocks occur as lenses within granulite facies basement rocks and comprise complexes of norite, hornblende norite, hornblende gabbro, orthopyroxenite, harzburgite, dunite, and associated metabasalts. According to Mogessie et al. (1998b), they are generally composed of orthopyroxene + clinopyroxene + amphibole + plagioclase + base-metal sulphides ± olivine ± phlogopite ± chrome spinel ± PGM and accessories such as apatite. Norites and gabbronorites show the characteristic mineral paragenesis orthopyroxene + plagioclase ± clinopyroxene ± hornblende. The olivine-rich ultramafic rocks are partly altered to serpentine and secondary magnetite.

Phase assemblages together with geothermobarometric calculations indicate that most of the crystalline basement is built up of amphibolite facies rocks with staurolite–garnet–biotite–muscovite–plagioclase–quartz–ilmenite ± fibrolite ± chlorite mineral assemblages. The intrusion of mafic–ultramafic bodies caused locally granulite facies metamorphism with mineral assemblages of garnet–cordierite–sillimanite–biotite–K-feldspar–plagioclase–quartz–rutile–ilmenite ± orthopyroxene. Most samples indicating granulite facies metamorphism were partially retrograded to amphibolite facies. The temperature condition of the first amphibolite facies event is about 540–630°C, the granulite facies is 700–800°C, and the locally overprinting second amphibolite facies event is about 600–650°C. The pressure remained constant at about 4–6.5 kb (Hauzenberger et al., 1997).

According to Sabalúa et al. (1981) and Sabalúa (1986), in the Las Aguilas mafic–ultramafic unit Pt and Pd are related to the sulfide mineralization, with concentrations of Pd 0.75 g/ton and Pt 2 g/ton and concentrations of other metals amounting to 0.70% Ni, 0.76% Cu, and 0.052% Co. Recent studies of the mineralized Las Aguilas ultramafic body in San Luis Province have been made by Malvicini and Brogioni (1992), Gervilla et al. (1993), Mogessie et al. (1994, 1995, 1996), and Hauzenberger et al. (1997).

According to Mogessie et al. (1998a,b, and references therein) and Hauzenberger (1997, and references therein) platinum group minerals (PGM) were identified enclosed in sulfides, at silicate–sulfide interfaces, and in serpentinised layers.

Several regional geological studies with extensive discussion of tectonic models covering the entire Andean and Pampean Ranges are available (Ramos, 1988a,b, and references therein). Gordillo and Lencinas (1979) have documented the geology and petrology of the Sierras Pampeanas in Córdoba and San Luis Provinces.

The first magnetometric studies showed the presence of high amplitude anomalies that are attributed to the presence of the mafic–ultramafic rocks (Sabalúa et al., 1981). Bjerg et al. (1996, 1997) and Kostadinoff et al. (1998) proposed that the relief does not have isostatic compensation and that the mass excess in the eastern portion of the area is caused by the presence of ultramafic rocks. The size of the mafic–ultramafic lens-shaped outcrops is in the order of 200×600 m. Based on gravimetric and magnetometric studies, Kostadinoff et al. (1998) concluded that several major mafic–ultramafic bodies are located at depth whose size exceed previous estimations. They attributed the magnitude of some of the measured anomalies to mafic–ultramafic bodies having a mass of 1.2×10^{12} tons, a volume of 250 km^3, and an ellipsoidal shape of $20 \times 8 \times 5$ km. Recently, Ramé and Introcaso (1997) confirmed the isostatic subcompensation of this mountain range.

3. Characteristics of the studied units

The mafic–ultramafic bodies (MUB) are located along a narrow belt, 100 km long and 2–3 km wide, with an overall NNE trend parallel to the regional structural trend (Fig. 1). These MUB are somewhat irregular, although their shapes are more or less elliptical in plan view. These bodies are composed of bigger units (up to 2 km long) that are well defined, with some satellite bodies dispersed around them (Fig. 2). The contacts of the MUB and the country rocks are obscured due to deformation, particularly along the structural trend. Close to the contacts, within the gneissic–migmatitic country rocks, the occurrence of small mafic lenses is common. The margins of the MUB are intensely foliated, developing strong mylonitic shear zones, whereas towards their cores deformation decreases its intensity. Notwithstanding this general behavior, thin mylonitic bands are usually found in the central parts of these bodies.

The cores of the largest MUB usually are composed of coarse-grained ultramafic rocks (CUR). Here it is possible to recognize some primary igneous structures, such as different types of mafic dikes cutting, displacing and assimilating each other, suggesting several dike generations. At least two generations of dikes (first dikes, K_1; second dikes, K_2) cutting CUR were observed. These dikes have variable thickness, develop small apophysis, and show variable

distribution with abrupt changes in orientation. Assimilated fragments of CUR are common within dikes. The contacts between K_2 and CUR are sharp whereas those between K_1 and CUR are usually less defined.

Some mafic inclusions of elliptical shape and cm-scale occur at the cores of the MUB, with their long axes sub-parallel to the internal foliation.

4. Structural analysis

4.1. Description of the structures

The MUB together with their country rocks are immersed in a narrow zone 100 km long of pervasive shear deformation. The boundaries of this NNE–SSW megashear zone can be traced at the La Escalerilla granite to the west, and its influence ends at the phyllites outcrops in La Florida dam to the east.

A detailed survey of structural data was performed along sections transverse to the main trend of the megashear zone (Fig. 2). The most conspicuous mesostructures found throughout the cross-sections are penetrative foliations (Fig. 3). We can distinguish two foliations of distinct characteristics.

S_2 foliation is observed in the central area on the mafic–ultramafic rocks (particularly in the cores of the latter). Following Twiss and Moores (1992), it is a poor to moderately developed spaced disjunctive foliation, which is subvertical to steeply dipping towards the west. These surfaces are almost parallel to a gneissic layering mainly identified at the less mylonitized portions of the gneissic and migmatitic country rocks.

S_m mylonitic foliation can be easily recognized in all outcrops of the studied area by its very well developed and regular foliation surfaces showing evidence of strong ductile deformation that is heterogeneously distributed. These foliation surfaces are characteristic of

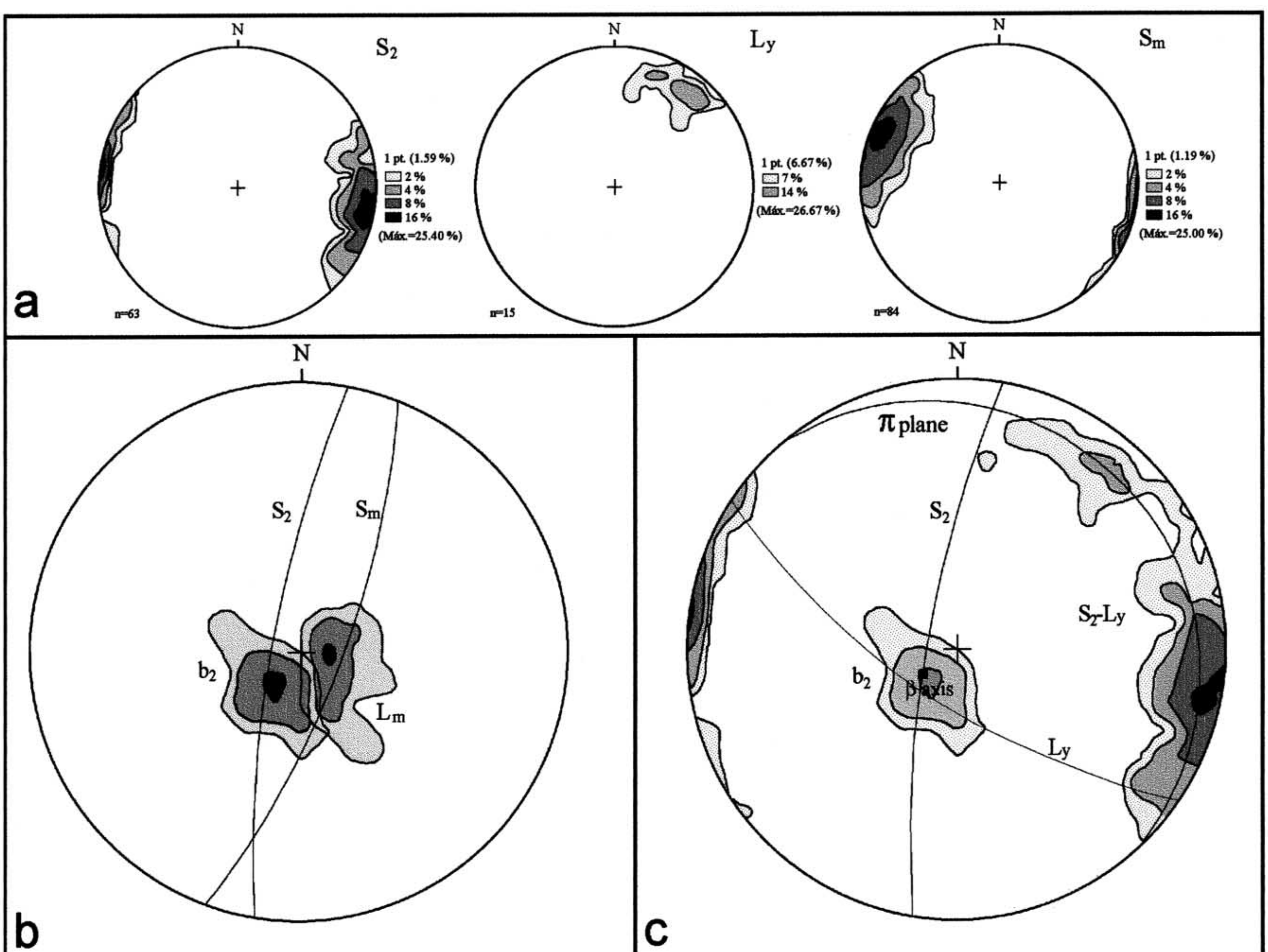

Fig. 3. (a) Density diagram of pole to plane equal area projection of the three main recognized penetrative planar structures: S_2 = foliation (T_2 event), L_y = septa layering (T_1 event), S_m = mylonitic–ultramylonitic foliation (T_3 event). (b) Cyclographic traces of the average planes of S_m and S_2 foliations. Density diagrams of mineral stretching lineations measured on the former (L_m) and steeply dipping axes measured in septa (b_2) are also shown. (c) Density diagram of $S_2 + L_y$ with calculated π-circle girdle. Cyclographic traces of S_2 foliation and density diagram of b_2 are also shown. Observe that the β-axis (square) lies very close to the maximum of the measured axes, and on the average plane of S_2 foliation.

mylonitic–ultramylonitic bands that depict internal flow surfaces with thin compositional banding, rotated porphyroclasts, and asymmetric folding. Narrow high sheared zones with S_m foliation are common within the MUB. The average attitude of these mylonitic surfaces is steeply dipping towards the east. Mineral stretching lineations (L_m) measured on S_m surfaces are distributed close to the average dip direction. These lineations are marked mainly by the stretching of quartz-feldspatic porphyroclasts on S_m surfaces of the mylonitic–ultramylonitic shear bands.

The relationship between both foliations can be more readily seen at the very close adjacent parts of the contacts of the MUB and granitic–pegmatitic bodies with the gneissic–migmatitic country rocks. At those places and towards the center of the bodies, it is possible to observe the S_2 foliation preserved with its previous attitude, while precisely at the mylonitized contacts S_2 is completely overprinted by mylonitic–ultramylonitic bands that obscured the relationship of the contacts due to a pervasive S_m development.

The occurrence of small meter-scale horse-like outcrops (hereinafter named 'septa'), totally surrounded by the dominant regional mylonitic foliation (S_m), is notable especially at the center and western sectors of the studied region (Fig. 4). Migmatites and mafic-gneissic intercalations constitute these septa, less frequently quartzose rocks, most of them unaffected by mylonitization and preserving its previous characteristics.

Within some of those septa, the gneissic layering (L_y, probably associated with T_1), well preserved stromatic textures, and the contacts between schistose and quartzose rocks are folded and remain at the hinges with high angle to the surrounding mylonitic foliation (S_m). These folds (F_2) have steeply dipping axes (b_2), are in part cylindrical, and the hinges are moderately thickened in contrast to the limbs. In septa less affected by mylonitization, S_2 surfaces could be measured on the nucleus of the F_2 folds, allowing us to interpret them as an axial plane foliation of those folds.

4.2. Meso- and microscopic kinematic indicators

Some mesoscopic kinematic indicators were identified within the mylonitic–ultramylonitic bands. Rotated porphyroclasts of quartzo-feldspatic composition are the most abundant, producing Sigma and Delta structures that indicate an overall west vergence — that is, anticlockwise shear in a section normal to foliation and parallel to lineation and looking to the north (Fig. 5a). Asymmetric folds (F_3) with subhorizontal axes (b_3) found within the ultramylonitic bands also indicate a west vergence (Fig. 5b). More-

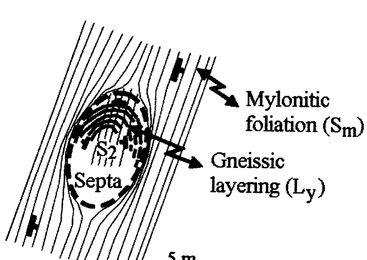

Fig. 4. Cartoon showing a schematic septa and its relationship to the mylonitic foliation.

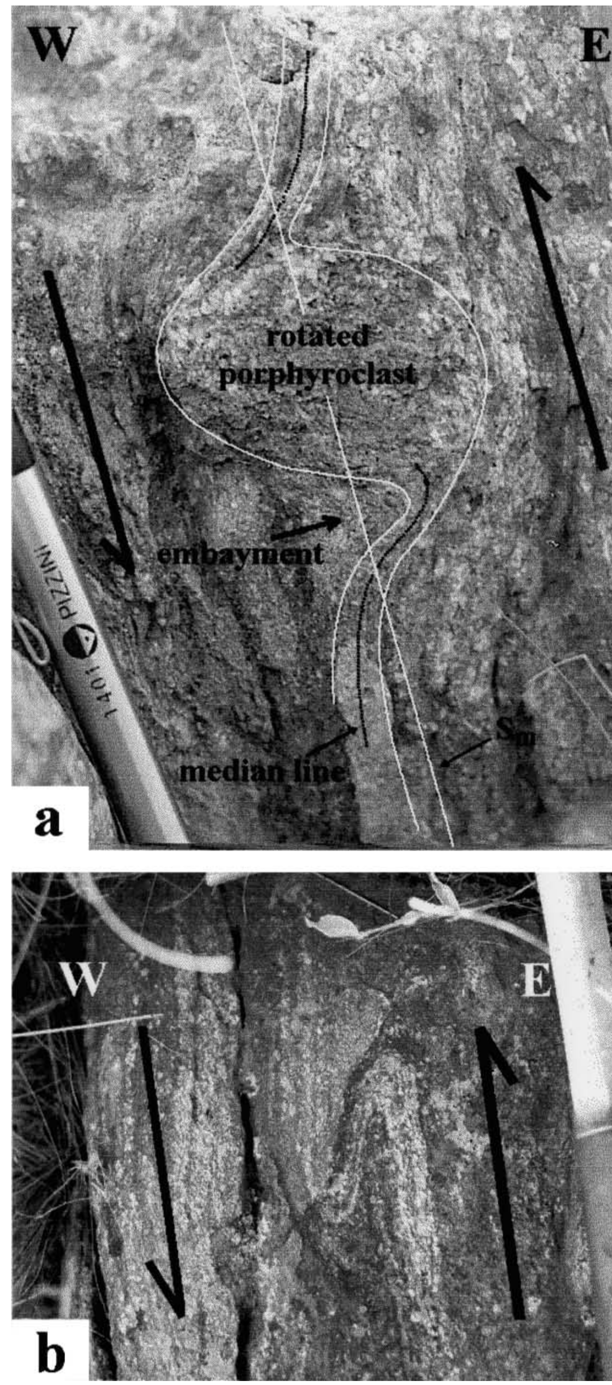

Fig. 5. (a) Photograph of the mesoscopic kinematic indicator (Delta structure) showing sinistral sense of rotation in a vertical section normal to S_m, northeast view. (b) Photograph of asymmetric folding in mylonitic shear bands. The arrows indicate sinistral rotation in a vertical section normal to S_m, northeast view.

over, the presence of abundant S/C structures elsewhere along the megashear zone also supports the same rotational movement.

On a microscopic scale, a great diversity of kinematic indicators can be found in oriented thin sections of mylonitic rocks: Sigma and Delta porphyroclasts, asymmetric drag folds, 'fish-like' sillimanite grains, S/C structures, and grain shape preferred orientations. All are in agreement with the sense of shear and the direction of vergence indicated by the mesoscopic kinematic indicators described above. Some examples of these microscopic indicators are shown in Fig. 6.

4.3. Orientation data analysis

The spatial orientations of the measured structural elements and their relationships were analyzed with or on stereographic projections (Schmidt net, lower hemisphere). The orientation of the S_2 and S_m foliations are shown on density diagrams (Fig. 3a, poles to planes) as two maxima with very close attitudes, representing two average surfaces at 280/81 and 110/78, respectively — indicated as dip direction and dip of the surfaces. The projections alone do not allow differentiation between these planes. However, they were differentiated by field criteria, as indicated above, and are shown schematically in Figs. 2 and 7.

While the S_2 foliation is mainly steeply dipping to the west with some scattered data, the mylonitic foliation (S_m) has an average orientation of surfaces dipping at high angle to the ESE with strong consistency. It is notable that, close to the mylonitic–ultramylonitic bands, the S_2 foliation tends to acquire the orientation of S_m, making it difficult to differentiate them on a statistical basis.

The layering (L_y) measured mainly in septa shows a high angular relation to the mylonitic foliation (Fig. 3a). This is so because only hinges of large folds (F_2) with steeply dipping axes (b_2) are well preserved in septa, whereas the limbs tend to parallelize with S_m and disappear away from the hinges. When the average planes of S_2 and S_m are plotted against the fold axes (b_2), the latter plot fairly well on the S_2 plane, supporting the already stated field observation that S_2 could be an axial plane foliation of F_2 folds (Fig. 3b).

The L_m lineation measured on S_m surfaces (Fig. 3b) represents a 'down-dip' stretching lineation. No lineations were recognized on S_2 surfaces.

Furthermore, if the S_2 and L_y data are added and the corresponding π-plane calculated, the result is that the pole of the π-plane, i.e. the β-axis is coincident with the b_2 maximum, and also with the intersection of the S_2 and L_y average planes (Fig. 3c). This pattern again supports that S_2 is an axial plane foliation of the hinges found in septa where the layering (L_y) is folded around b_2 axes.

5. Discussion

The results of the structural analysis, done along cross-sections transversal to the MUB belt of the Sierras Grandes of San Luis, led us to establish a structural evolution for this large geological feature. According to Hauzenberger et al. (1998), the amphibolite facies country rocks were locally metamorphosed to granulite facies as a result of the intrusion of MUB. At least two main superimposed tectonic events are well documented in the study area. A three-dimensional sketch showing the relationships between these two events (T_2 and T_3), and their main structural features, is presented in Fig. 7.

A deformational event (T_2), best documented in septa and MUB, is characterized by very tight folding (F_2) with steeply dipping axes (b_2) and an associated axial plane foliation (S_2). T_2 was developed on rocks of granulite to amphibolite facies after the MUB emplacement, developing a spaced foliation on the MUB. This S_2 foliation is best preserved at the cores of the larger MUB and granitic–pegmatitic bodies and, even if less well defined, also in the gneissic–migmatitic country rocks and as an axial plane foliation of F_2 folds preserved in septa. Von Gosen and Prozzi (1996) also reported similar foliation characteristics for the interior of La Escalerilla granite.

Hinges of mesoscale folds (F_2) are common in septa affecting gneissic layering (L_y) and migmatitic textures, reinforcing the interpretation that the emplacement of the MUB, the migmatization process, and probably the emplacement of much of the granitic–pegmatitic bodies, were processes developed previously to the deformational event T_2.

A younger deformational event (T_3) promoted the generation of a wide shear zone with intense, inhomogeneous, mylonitization and the development of a new foliation (S_m). This event was developed under amphibolite facies conditions (M_3) and partially retrogrades the granulite facies rocks according to Hauzenberger et al. (1997, 1998). The overall shear sense points to a WNW vergence, indicating an inverse movement on a plane steeply dipping to the ESE. Mineral stretching lineations (L_m) on mylonitic surfaces (S_m) and shear sense kinematic indicators such as S/C structures, asymmetric folding (F_3) with subhorizontal axes (b_3) parallel to the trend of mylonitic–ultramylonitic bands, and rotated porphyroclasts of Sigma and Delta type support a sinistral shear rotation looking to the north.

Fig. 8 depicts a schematic structural evolution of the studied area. In a general geotectonic view, the described deformational events can be correlated with the tectonic framework initially postulated by Dalla Salda (1984, 1987) for the Southern Pampean Ranges and later reinterpreted by Ramos (1988a), Rapela et al. (1990), Dalla Salda et al. (1992a,b; 1993), Ramos et al. (1993), and Kraemer et al. (1995), among others. The MUB emplacement and the deformation process T_2 can be ascribed to the final phases of the Pampeano Orogenic Cycle, although some new data point to late Cambrian-early Ordovician emplacement ages (Sims et al., 1998). Nevertheless, the widespread mylonitization affecting the MUB along a broad megashear zone

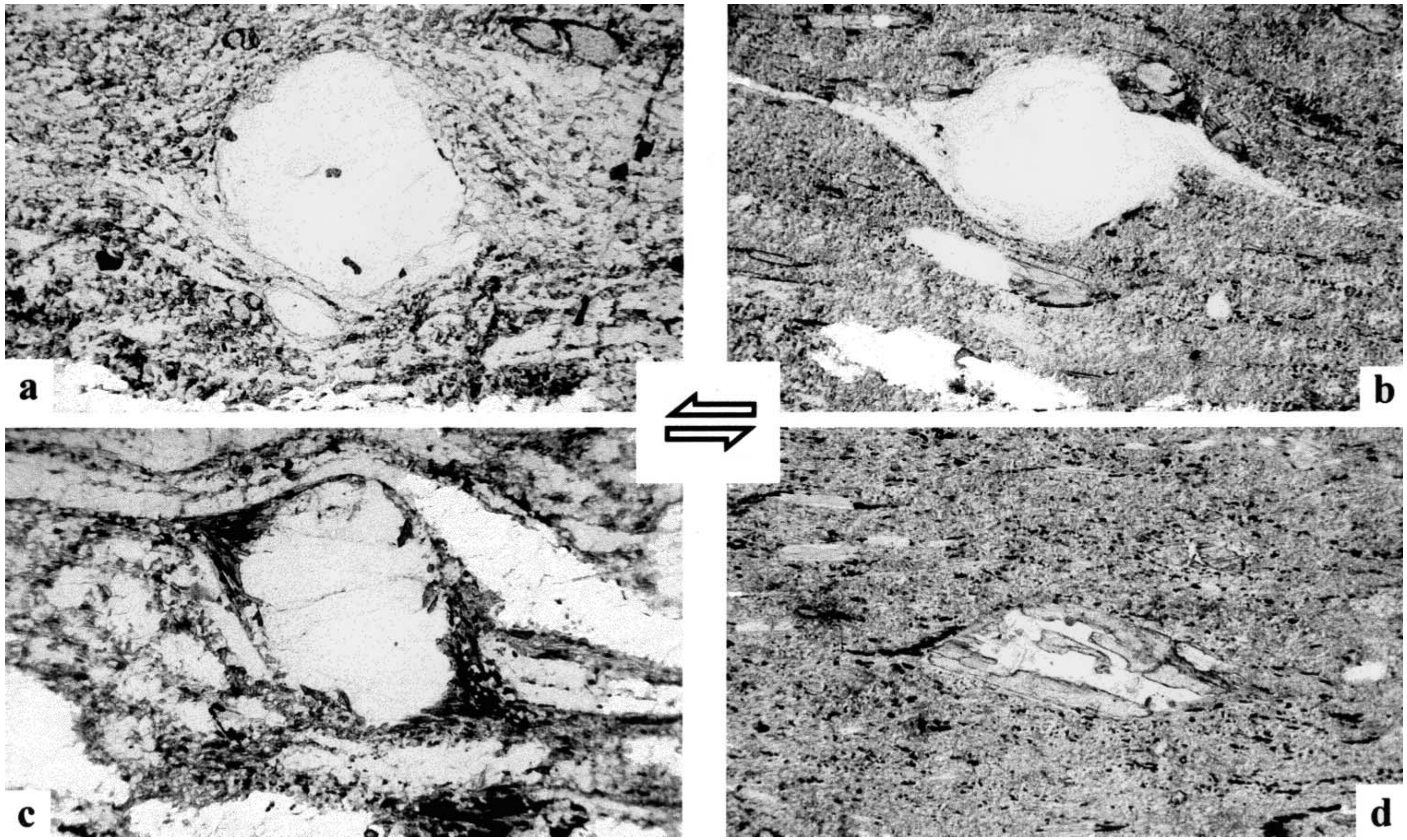

Fig. 6. Microscopic kinematic indicators in mylonites. Thin sections were oriented parallel to lineation and normal to S_m foliation and viewed to the northeast. For simplicity, S_m foliation, actually subvertical, was placed subhorizontally in this figure. The indicators show a sinistral sense of shear, with the vergence of the hanging wall to the WNW: (a) Delta-type porphyroclast. Plagioclase porphyroclast with thin tails of recrystallized grains that start to leave the grain at their upper right edge and sweep down to lower right, and at lower left edge and sweep up to upper left. Note that the tails do not cross an imaginary median line drawn through the centre of the porphyroclast and parallel to foliation. This is an example of delta-type grain without 'stair-stepping'(Paschier et al., 1993). (b) Delta grain developed in a plagioclase porphyroclast. Note that tails leave the feldspar at top right and lower left and sweep down to lower right and up to upper left, respectively, crossing the imaginary median line described above. This is an example of delta grain with stair-stepping. (c) $Sigma_b$ porphyroclast. Plagioclase porphyroclast of the $Sigma_b$ type in an S/C mylonite. Note tails of fine grained recrystallized plagioclase and newly crystallized biotite that extend parallel to foliation and 'step up' to the left. (d) Fish-like Sigma grain. Original prismatic sillimanite porphyroclasts reoriented at low angle to mylonitic foliation and tilted up in the direction of shear. Note pseudomorphic replacement of sillimanite porphyroclast mainly by quartz and biotite and the development of thin tails of biotite and opaques.

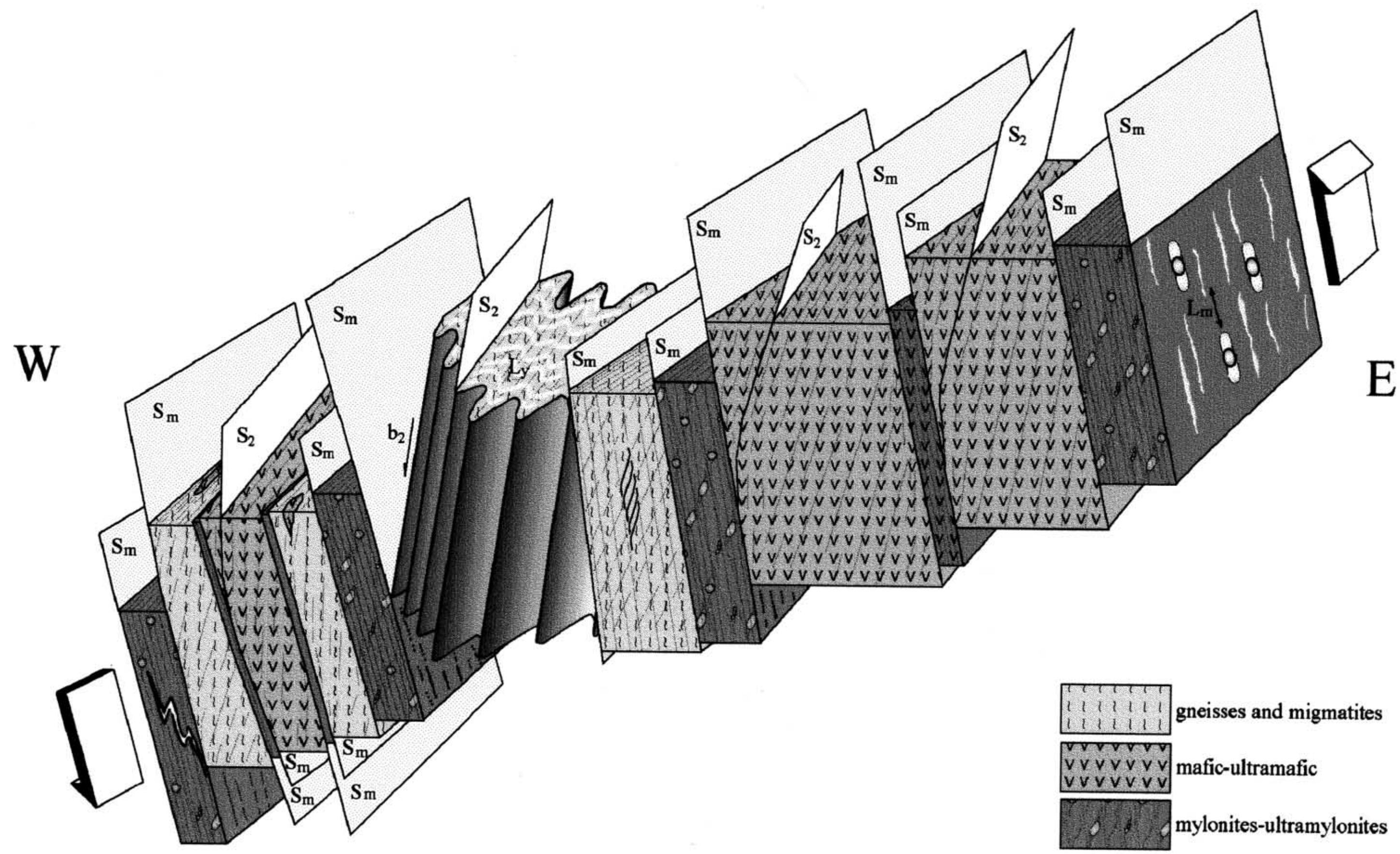

Fig. 7. Schematic three-dimensional sketch showing the relationships between the described superimposed tectonometamorphic events and their main structural features.

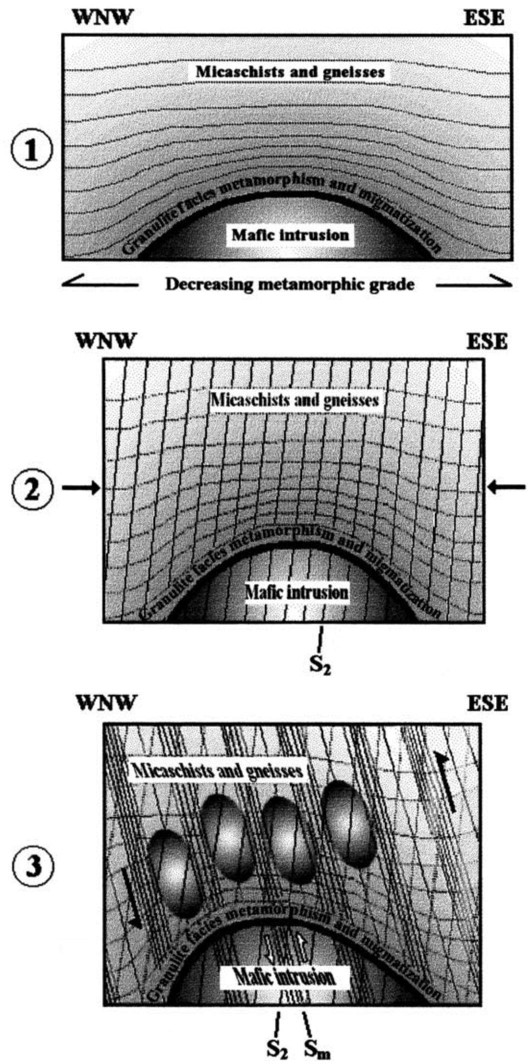

Fig. 8. Cartoon showing a schematic structural evolution involving the mafic–ultramafic rocks. Sections are oriented subnormal to the general trend of main structures. Stage 1: Development of a compositional layering (T_1 event?) on amphibolite facies country rocks (M_1), before mafic intrusion. Mafic intrusion generates local granulite facies metamorphism (M_g) and migmatization. Intrusion promotes a metamorphic gradient from granulite facies metamorphism near mafic bodies to amphibolite facies away from the bodies. Stage 2: A compressive event (T_2) develops on previously metamorphosed rocks (M_g to M_1), promoting folding (F_2) and foliation (S_2). Stage 3: A shearing event with pervasive mylonitization develops (T_3), generating retrograde metamorphism (M_3) on M_g rocks. Kinematic indicators (ellipses represent small mafic–ultramafic bodies discussed in the text) show inverse movement with WNW vergence of structures. The shearing event was responsible for the transport to upper levels of small blocks (present exposures) of mafic–ultramafic rocks and adjacent country rocks. These mafic–ultramafic outcrops are fragments of the major bodies located at depth, as demonstrated by gravimetric and magnetometric anomalies.

obscured the structural relations as well as the original spatial orientations. The retrograde metamorphism M_3 and the T_3 mylonitization of this belt have been ascribed to the Famatinian Orogenic Cycle by Ortiz Suárez and Ramos (1990), Ortiz Suárez et al. (1992), von Gosen and Prozzi (1996), among others. However, Sims et al. (1998) suggest a Devonian age for widespread mylonitization in the Southern Sierras Pampeanas. Finally both processes, M_3 and T_3, can also be correlated with the Famatinian mylonitization that took place at the Pampean Ranges of Córdoba, as described by Baldo et al. (1996).

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