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The Phyllite and Micaschist Group with associated intrusions in the Sierra de San Luis (Sierras Pampeanas/Argentina) — structural and metamorphic relations

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Abstract — Structural analyses of the Phyllite and Micaschist Group with intercalated intrusions in the Sierra de San Luis (Sierras Pampeanas, western Argentina) reveal a multi-stage magmato-tectonic evolution during Early Paleozoic times. The Tamboreo Tonalite intruded the undeformed clastic sediments of both groups and led to the development of a contact aureole. The Paso del Rey Granite and associated pegmatite dikes are interpreted as pre-kinematic with respect to the first deformation of the micaschists. After a variable, pre- to syn-deformational metamorphism, ~ WNW–ESE compression with a regional greenschist facies metamorphism affected the Phyllite and Micaschist Group as well as the intrusions. The La Florida Granite and associated pegmatite dikes are interpreted to have intruded the micaschists after the first deformational event. The present contacts between the Phyllite and Micaschist Group either are metamorphic transitions or ductile reverse faults. The former suggest that both groups initially were part of one crustal profile. Steeply inclined reverse faults and fold structures do not record a single vergence. A preliminary interpretation suggests that deformations and regional metamorphism took place in the Upper Ordovician-Middle Devonian interval and can be related to the second stage of the Famatinian Cycle after initial emplacement of plutons. The low grade rocks of the Sierra de San Luis, and related micaschists, can be compared with different occurrences in the Sierras Pampeanas basement complex to the north and probably were part of one large "Puncoviscana Basin". © 1998 Elsevier Science Ltd. All rights reserved

Resumen — En la Sierra de San Luis (Sierras Pampeanas, Oeste Argentino), el an lisis estructural indica una evolución magmato-tectónica en etapas multiples durante el Paleozóico inferior. La tonalita Tamboreo se emplazó en las sedimentitas cl sticas no deformadas de ambos grupos acompañado por la evolución de una aureola de contacto. El granito Paso del Rey y dikes pegmatíticos asociados son interpretados como precinemático con respecto a la primera fase de deformación que afectó a los esquistos micáceos. Siguiendo un metamorfismo pre- a sindeformacional de grado variable, las filitas y esquistos micáceos como tambien a las intrusiones fueron afectado por una compresión de dirección ONO — ESE acompañado por un metamorfismo regional de facies de esquistos verdes. El granito La Florida y dikes pegmatíticos asociados son interpretados de haber emplazadose en los esquistos micáceos despues de la primera fase de deformación. Los contactos entre el Grupo de filitas y el Grupo de esquistos micáceos constan de una transición metamórfica o de fallas inversas ductiles. El primer caso sugiere que ambos grupos originalmente pertenecieron a un solo perfil cortical. Fallas inversas de alto angulo y estructuras de pliegues no indican una sola vergencia. Una interpretación preliminar sugiere que esta deformación y el metamorfismo se producieron durante el Ordovícico Superior — Devónico Medio y que podrian ser correlacionado con la segunda fase del Ciclo Famatiniano siguiendo el emplazamiento inicial de los plutones. Las rocas del bajo grado como los esquistos micáceos de la Sierra de San Luis son comparables a las de varias localidades del comlejo de basamento de las Sierras Pampeanas hacia el Norte lo que sugiere la pertenencia de todos estos afloramientos a una sola "Cuenca de Puncoviscana". © 1998 Elsevier Science Ltd. All rights reserved

GEOLOGICAL OVERVIEW

In western Argentina, the basement of the Sierras Pampeanas was affected by different orogenies during Precambrian and Early Paleozoic times (e.g. Aceñolaza *et al.* 1978; Miller, 1984; Ramos, 1988; Rapela *et al.* 1992a; Rapela *et al.* 1992a,b). Previous researchers divided the range into the Western and Eastern Sierras Pampeanas (Caminos, 1973, 1979; Dalla Salda, 1987). Within this context, the basement block of the Sierra de San Luis (Fig. 1) located at the southern tip of the basement ranges, is part of the Eastern Sierras Pampeanas.

The Early Paleozoic tectonic and metamorphic history in the sierra was followed by the deposition of Late Paleozoic clastic sediments (Hünicken *et al.* 1981). Erosion with peneplanation (Jordan *et al.* 1989) and uplift during the Andean (Late Tertiary to Quaternary) crustal shortening led to the present half-horst structure of the mountain chain.

The basement complex of the Sierra de San Luis mostly consists of injected micaschists, migmatites, and gneisses. There, lens-shaped occurrences of mafic to ultramafic rocks with granulites (González Bonorino, 1961; Cucchi, 1964; Sabalúa *et al.* 1981; Malvicini and Brogioni, 1992; Brogioni and Ribot, 1994) are aligned in a NNE–SSW structural trend. In the southwestern part of the Sierra, the Phyllite and Micaschist Group form ~ NNE–SSW trending strips within the higher grade units (Fig. 1, e.g. Ortiz Suárez *et al.* 1992).

The age of the metamorphic sequence is poorly constrained by radiometric data. A Rb-Sr date from granitic gneisses (540 ± 15 Ma: Halpern *et al.* 1970) suggests that parts of the basement complex are of

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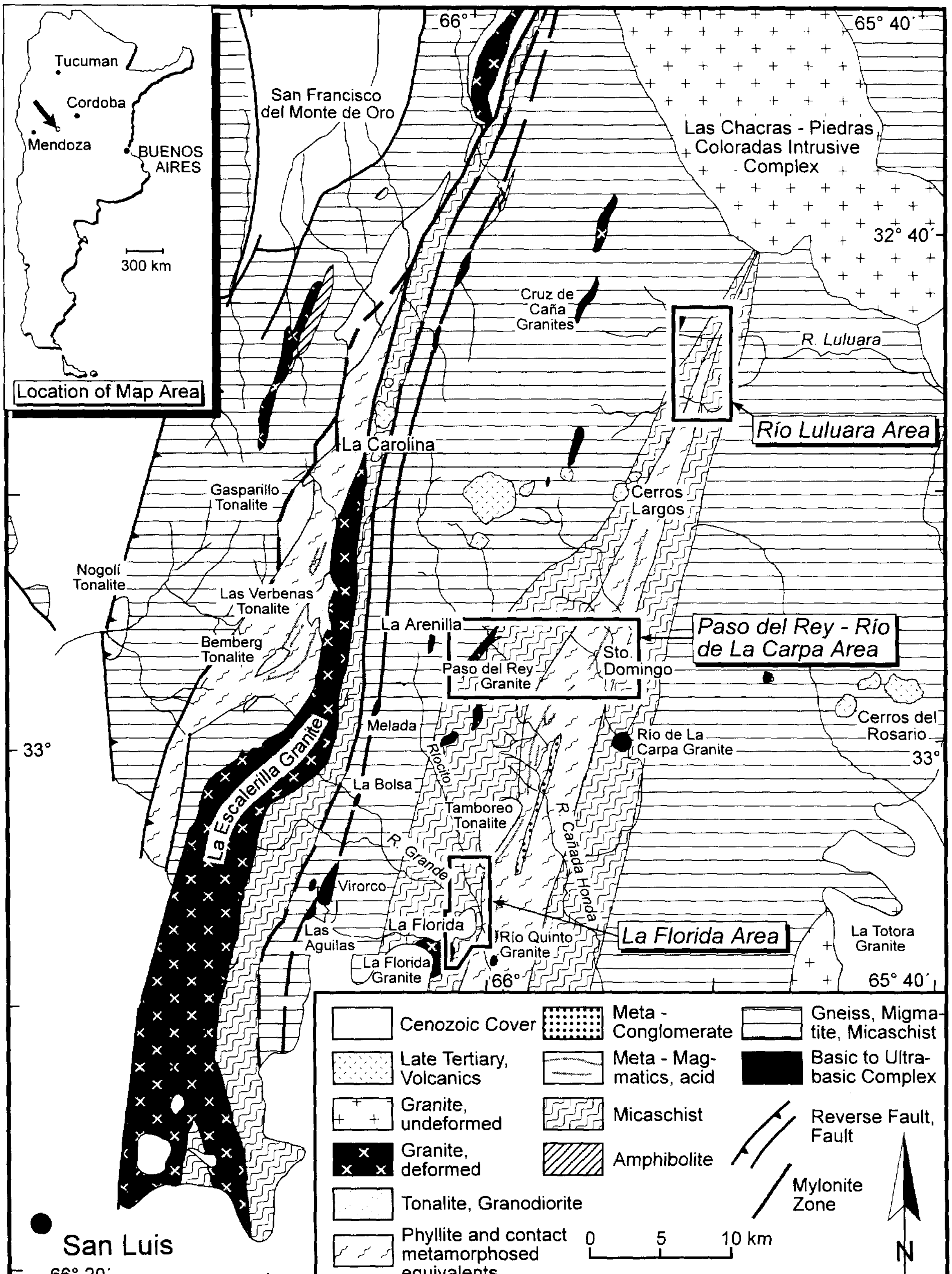

Fig. 1. Geological sketch map of the central and southern part of the Sierra de San Luis; compiled and adapted after Ortiz Suárez and Sosa (1991); Ortiz Suárez *et al.* (1992); Brogioni, Parrini, and Pecchioni (1994); Llambías *et al.* (1996b), and own investigations. Frames depict locations of maps of the three study areas (see Figs. 2, 3, 4, and 11).

Precambrian age. K-Ar data span a long time interval during the Early Paleozoic era (e.g. Linares and Latorre, 1969, 1973; Santa Cruz, 1980; Linares, 1981; Llambías and Malvicini, 1982) and are difficult to relate to distinct metamorphic and structural events. Several tonalite and granite plutons are assigned to the Cambrian, Ordovician-Silurian, and Devonian-Carboniferous intervals of magmatic activity (Kilmurray and Villar, 1981; Rapela *et al.*, 1992a; 1992b). With respect to the main deformation in the mountain range, they are indicated as pre-, syn-, and post-kinematic plutons (Varela *et al.* 1994; Llambías *et al.*, 1991; Llambías *et al.*, 1996a). Since the distinctions between pre- and syn-tectonic intrusions in many parts of the mountain range are not yet substantiated by structural data (cf. Paterson *et al.* 1991; Paterson and Vernon, 1995), only a few plutons can be assigned to one of these groups (Sato, 1993; Sato and Llambías, 1994, v. Gosen and Prozzi, 1996; Llambías *et al.* 1996b; Sánchez *et al.* 1996; Sato *et al.*, 1996, v. Gosen, 1997).

The structural style of deformation within parts of the Sierra was described by Kilmurray and Dalla Salda (1977), Kilmurray (1982), Llambías and Malvicini (1982), Ortiz Suárez (1988), Ortiz Suárez and Ramos (1990), Prozzi (1990), Prozzi *et al.* (1992), v. Gosen and Prozzi (1996), and v. Gosen (1997) while other studies focused on ore deposits (e.g. Hack, 1987; Delakowitz, 1988; Brodtkorb, 1991). The structural histories of the Micaschist and Phyllite Group, with respect to intrusive and metamorphic events, are unclear. This also applies to the relationships between both units (? continuous transitions vs tectonic contacts; Prozzi, 1990; Ortiz Suárez *et al.*, 1992; Prozzi and Ortiz Suárez, 1994).

This paper presents new results from structural analyses within three areas of the southwestern part of the Sierra de San Luis which are at La Florida, Río de la Carpa-Paso del Rey, and around Río Luluara (see Fig. 1 for locations). It focuses on the NNE–SSW trending central strip of phyllites and micaschists along both sides. To the north of Río Luluara, this strip ends at the post-tectonic Las Chacras-Piedras Coloradas Intrusive Complex (Brogioni, 1987, 1992, 1993).

LITHOLOGY OF THE META-CLASTIC UNITS

In the Sierra de San Luis, the *Phyllite Group* ("San Luis Formation" of Prozzi and Ramos, 1988) consists of alternating meta-pelites and meta-sand- to -siltstones, with intercalations of graywackes. Well exposed bedding is indicated by widely distributed alternations of sandstone and siltstone layers. The Phyllite Group is interpreted as a flysch-like sequence (Prozzi, 1990), however, the source area of the clastic sediments is unknown. Within the entire monotonous succession, only two meta-conglomerate horizons were found (e.g. "Conglomerado Cañada Honda": Prozzi, 1990; Ramos *et al.* 1996). However, no reworked coarser material (conglomerates) have been found to indicate the sedimentary base of the Phyllite Group clastics.

In the Paso del Rey-Río de La Carpa area (Figs.1 Fig. 2), the *Micaschist Group* consists of two lithologic units. Sandy biotite-muscovite schists, with intercalations of quartzites and widely distributed pegmatites, contain up to 3 cm-long sericite- (± quartz) aggregates which represent entirely converted porphyroblasts. The latter are not preserved and their alteration products are described as "sericite aggregates" in the text. To the west of Paso del Rey, the micaschists are bounded by a complex consisting of "migmatitic" or "injected" rock types which are referred to here as "migmatites" but are not described in detail below. East of Paso del Rey (Loma Alta area; Fig. 2), a micaschist-quartzite sequence comprises thick grey quartzites with thin intercalations of micaschist layers. Based on the structural relationships with the micaschists, this sequence represents the upper part of the Micaschist Group.

In the area west and north of La Florida, the monotonous Micaschist Group consists of sandy biotite-muscovite to garnet-biotite-muscovite schists with intercalated quartzites, a few amphibolites, and pegmatite layers. In the Río Luluara area, biotite-muscovite schists with sericite aggregates and intercalated quartzite and pegmatite layers occur. They partly grade into a quartzite-dominated succession which can be compared with the micaschist-quartzite sequence of Loma Alta.

The lithologic content of the meta-clastic rocks is comparable to that of the Phyllite Group and a flysch-like sequence can be assumed. Within several parts, bedding is indicated by mm- to m-thick alternations of sandy and pelitic layers.

INTRUSIONS

In the Río de La Carpa area, the sediments of the (later) Micaschist Group to the east of the strip of phyllites were intruded by widely distributed pegmatites with different thickness. The dikes are zoned with a coarse-grained fill of muscovite, k-feldspar, and ± tourmaline in the central parts and finer grained margins. Towards the Río de La Carpa Granite in the east (leuco-granodiorite: Varela *et al.*, 1994), pegmatite injections increase in abundance, thickness, and density. Several m- to tens-of-metres thick sills dominate which are almost exclusively oriented parallel to bedding planes (S_0) of the clastic sequence while cross-cutting dikes could be found only at a few places. They grade into a dense swarm where several metres-thick sills are separated by up to dm-thick layers and lenses of clastic sediments.

At the contact of the *Paso del Rey Granite* (leuco-granodiorite: Varela *et al.*, 1994), no emplacement-related folding could be detected. The granite encloses up to tens-of-metres thick sheets of country rock and its northern margin consists of thick pegmatites. In another exposed occurrence to the south of the study area, up to hundred-metre long apophyses of the granite were injected into the surrounding clastic sequence indicating a high intrusion level. Since no locality was found where the granite cuts across the S_1-foliation, it is interpreted to have intruded the clastic sequence prior to the first deformation (see below; also for descriptions of the other granites). In the country rocks, pegmatite dikes with different thickness are oriented either parallel or at different angles with

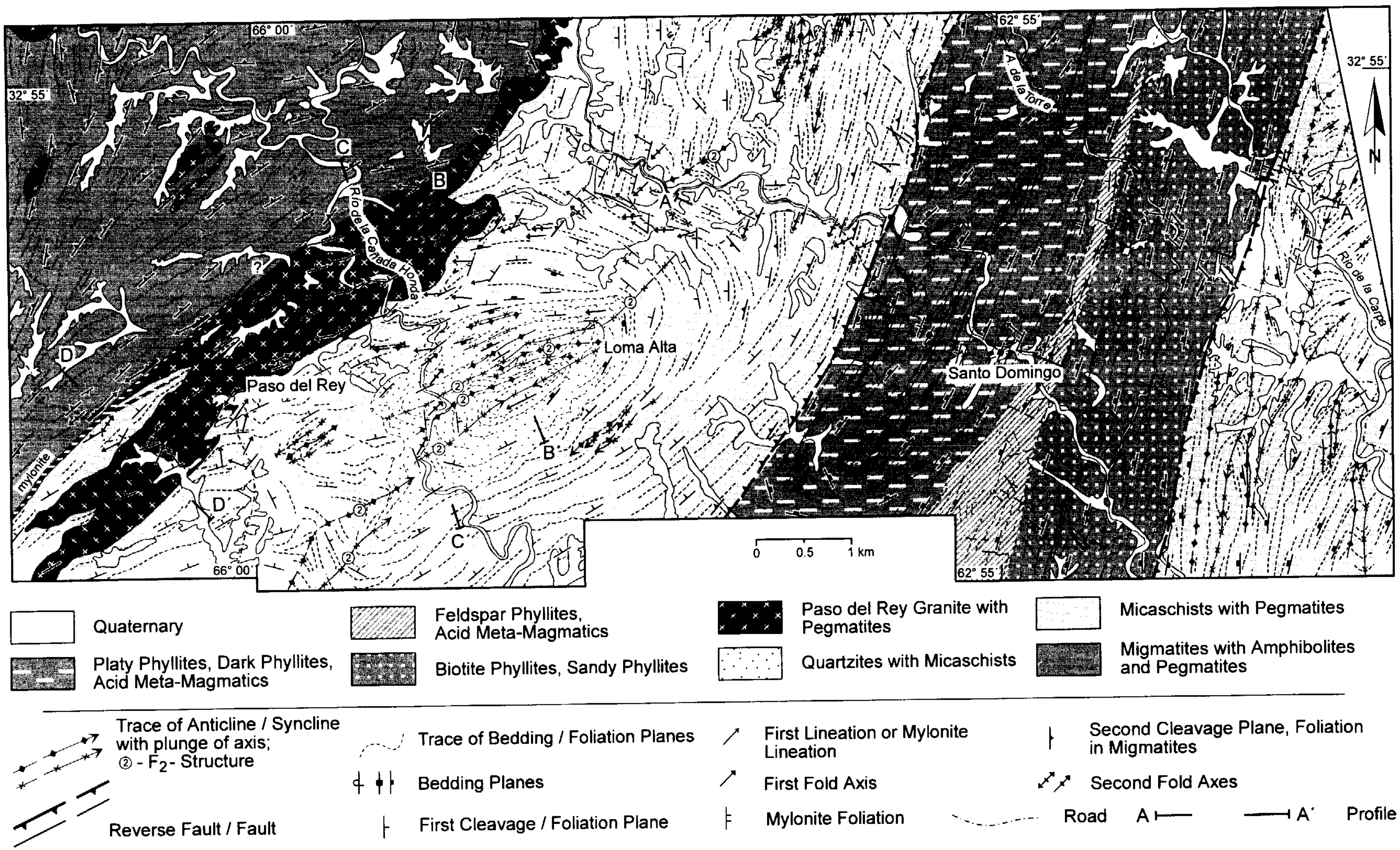

Fig. 2. Simplified structural map of the area between Paso del Rey and Río de la Carpa, based on interpreted aerial photographs and structural mapping (for location see Fig. 1). Along-strike continuations of reverse faults are inferred. A–A' to D–D', locations of profiles.

respect to S_1-foliation planes. They cut through the granite and its contact and are related to the same igneous activity.

Within the country rocks, widely distributed sericite aggregates and muscovite plates increase in abundance and size toward the pegmatites and granite margin where macroscopic sillimanite needles were found in one outcrop. These porphyroblasts can be related to heat transfer from the granite and pegmatites (see below).

The *Tamboreo Tonalite* intruded the undeformed sedimentary sequence of the (later) Phyllite and Micaschist Group in the La Florida area (Fig. 3). The intrusive contact is exposed at several localities (Zardini, 1966; Carotti *et al.* 1984). At the southwestern margin, the tonalite encloses m-scale blocks of the country rocks, and tonalite dikes cut through the clastic sequence. The development of a contact aureole also indicates a high intrusion level (Varela *et al.*, 1994). There, the sediments are converted into hornfelses at the contact, and the effects of the temperature overprint decrease on a distance of several tens-of metres (Carotti *et al.*, 1984). This situation is comparable to the eastern and western margin of the Gasparillo and Las Verbenas Tonalite, respectively, in the area south of La Carolina (Sato, 1993; Sato and Llambías, 1994; v. Gosen and Prozzi, 1996; v. Gosen, 1997).

Within the Phyllite and parts of the Micaschist Group, up to several tens-of-metres thick and km-long layers of *acid meta-magmatics* occur (Fig. 3). They are interpreted to be dacitic to rhyodacitic volcanics (Brodtkorb *et al.* 1984; Fernandez *et al.*1991) while dikes occur south of La Carolina (v. Gosen and Prozzi, 1996, v. Gosen, 1997). Geochemical analyses of Hack (1987); Hack *et al.* (1991) point to rhyolitic-rhyodacitic and partly trachyandesitic compositions. The long lateral extent and relatively small thickness of the layers are not indicative of a volcanic or dike/sill origin. In the study areas no clear cross-cutting relationships between the clastic successions and boundaries of the magmatic layers could be detected. Only one layer, a few metres-thick, cuts at a small angle across the southwestern intrusive contact of the Tamboreo Tonalite. It is a dike which was injected after intrusion and cooling of the pluton.

TRANSITIONS BETWEEN THE PHYLLITE AND MICASCHIST GROUPS

On map scale, a thin, NNE–SSW-trending strip of phyllitic rocks between those of the Micaschist Group characterizes the Río Luluara area (Fig. 4). To the east, the Phyllite Group records a gradual transition into biotite-muscovite schists which contain up to cm-long sericite aggregates further eastwards. These transitions were found in the Río Luluara and Ao. de La Cal sections. At Río Luluara, the western contact between phyllites and micaschists is not exposed. Since the lithology changes over a short distance from the westernmost phyllites with quartzites to coarse-grained biotite-muscovite schists with cm-long sericite aggregates and pegmatites, the boundary is interpreted as a faulted contact. To the NNE, a gradual transition between the Phyllite and Micaschist Group within alternating quartzites and schists was found.

In the parallel, southern cross-section along Ao. de La Cal, quartzites with phyllite layers of the Phyllite Group continue westwards and record a gradual increase in grain size of muscovite and biotite. Widely distributed pegmatite dikes occur within clear micaschists. This is confirmed by the "contact" between both units near the Ea. La Valerosa where phyllites gradually pass into western biotite-muscovite schists, and ~ 300 m SW of the Estancia first sericite aggregates occur. Hence, south of Río Luluara no indications for a fault zone between the Phyllite and Micaschist Group to the west and east were found. The different lithologies of the central strip of phyllites continue westwards and eastwards into the micaschists which represent the higher temperature equivalents. On the map in Fig. 4, the NNE- and SSW-continuations of the boundaries between both units, based on the first appearance of larger muscovite and biotite as well as the line of the first appearance of sericite aggregates (converted porphyroblasts), are inferred and more complex trends are possible.

To the south of the Tamboreo Tonalite, a NNE–SSW trending strip of biotite phyllites east of the micaschists (Fig. 3) has an areal extent up to the west of the "El Latino" quarry area (Carotti *et al.*, 1984). There, the occurrence of larger biotite and garnet indicates a westwards increase of the metamorphic overprint. To the south (Ríocito), clear biotite phyllites are restricted to a smaller strip which is bounded by grey phyllites with quartzite layers in the east. The adjacent micaschists to the west of this strip can be compared with the biotite phyllites also in the north and suggest a continuous metamorphic transition. The NNE–SSW along-strike distribution of these phyllites broadly follows the regional structural trend also seen in the micaschists.

STRUCTURE

Deformations of the Micaschist Group

D_1-deformation. Within the Micaschist Group of the Paso del Rey area, the penetrative S_1-foliation planes dip toward NNW to NW and represent the first, planar tectonic fabric found in the field. At a few places (relics of) NNW-dipping bedding planes (S_0) could be detected which are cross-cut by more gently northward dipping S_1-cleavage planes (e.g. at Río Cañada Honda; Figs. 2 and 5: profiles B–B' and C–C'). At Río de La Carpa, the clastic sequence is folded around symmetric and asymmetric, W-vergent F_1-folds with amplitudes and wavelengths on a max. scale of several hundred metres. The open fold structures are combined with an ESE-dipping axial-plane S_1-cleavage. In the La Florida area, S_0/S_1-cross-cutting relationships indicate an $\sim$E-vergent F_1-folding. To the east of the La Florida lake, quartzites with well developed bedding form a large, E-vergent F_1-anticline with a NNE–SSW striking B_1-axis (Fig. 3).

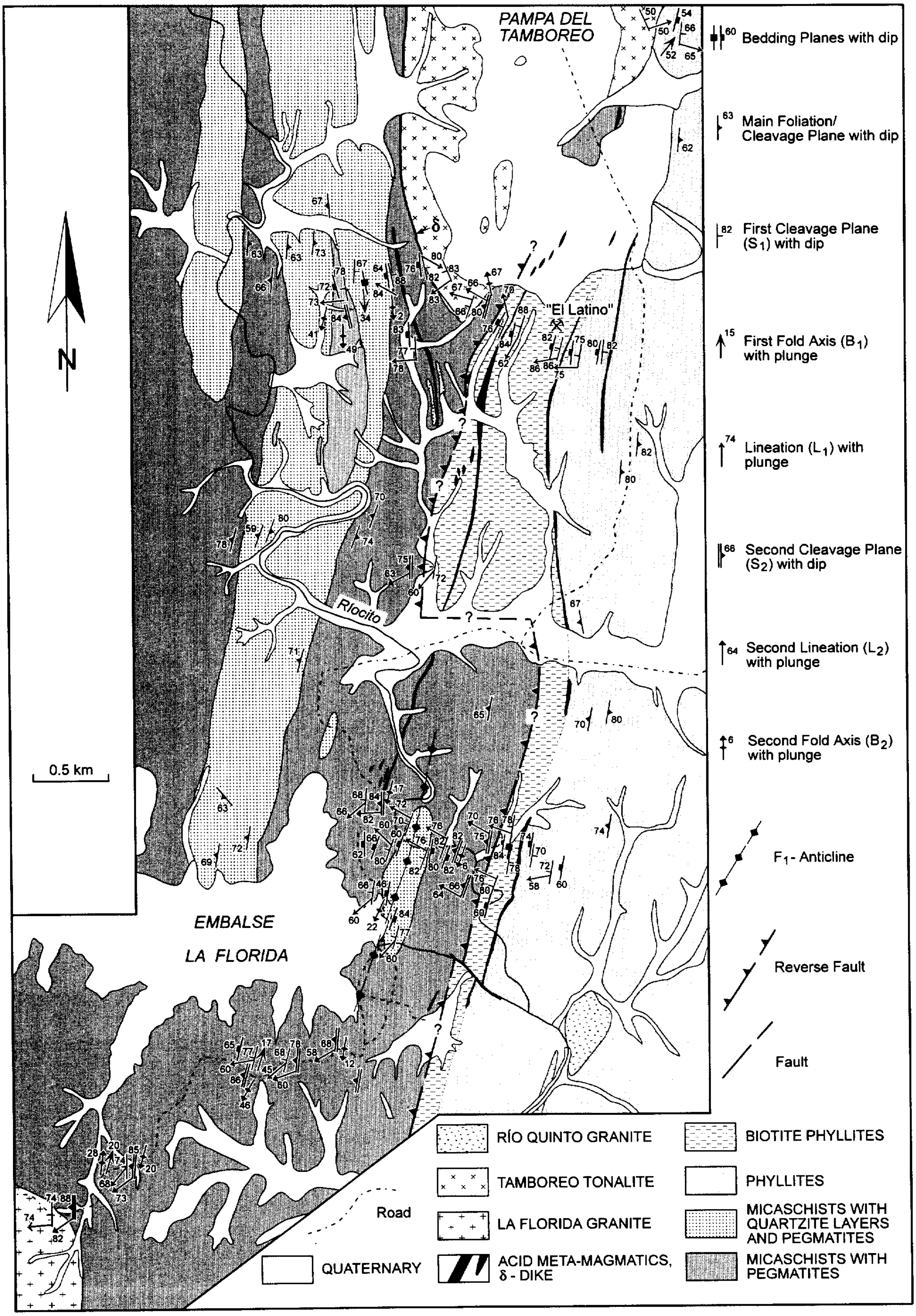

Fig. 3. Geological sketch map of the area between La Florida and Pampa del Tamboreo, compiled and adapted after Hack (1987); Carugno Durán *et al.* (1992), interpreted aerial photographs, and local structural field mapping (for location see Fig. 1). The contact aureole of the Tamboreo Tonalite is omitted and along-strike continuations of reverse faults are inferred.

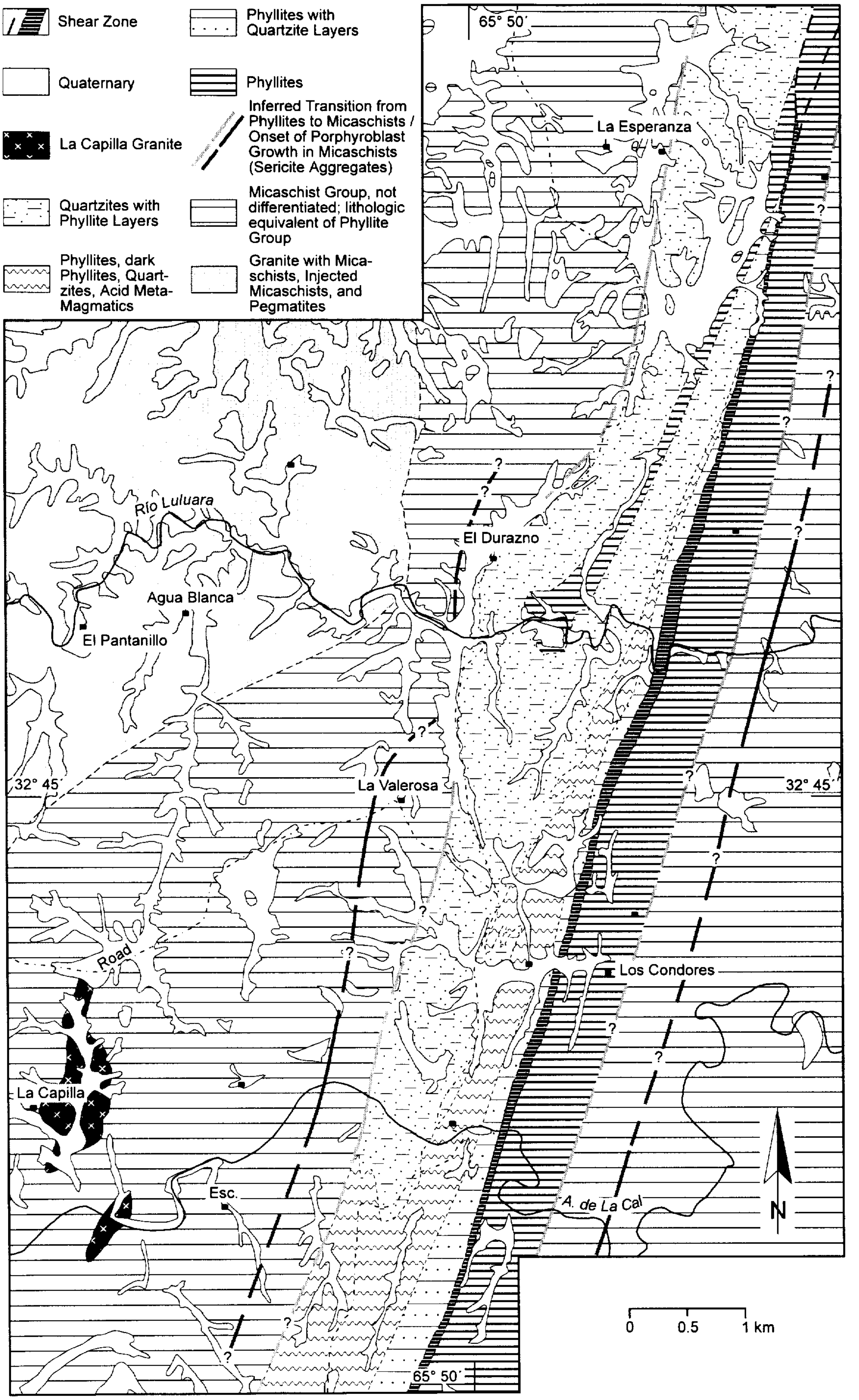

Fig. 4. Geological sketch map of the Río Luluara area, based on interprerted aerial photographs and local fielı mapping; for location see Fig. 1. Note that the Micaschist Group is simplified on the map and represents the lithologic equivalent of the Phyllite Group.

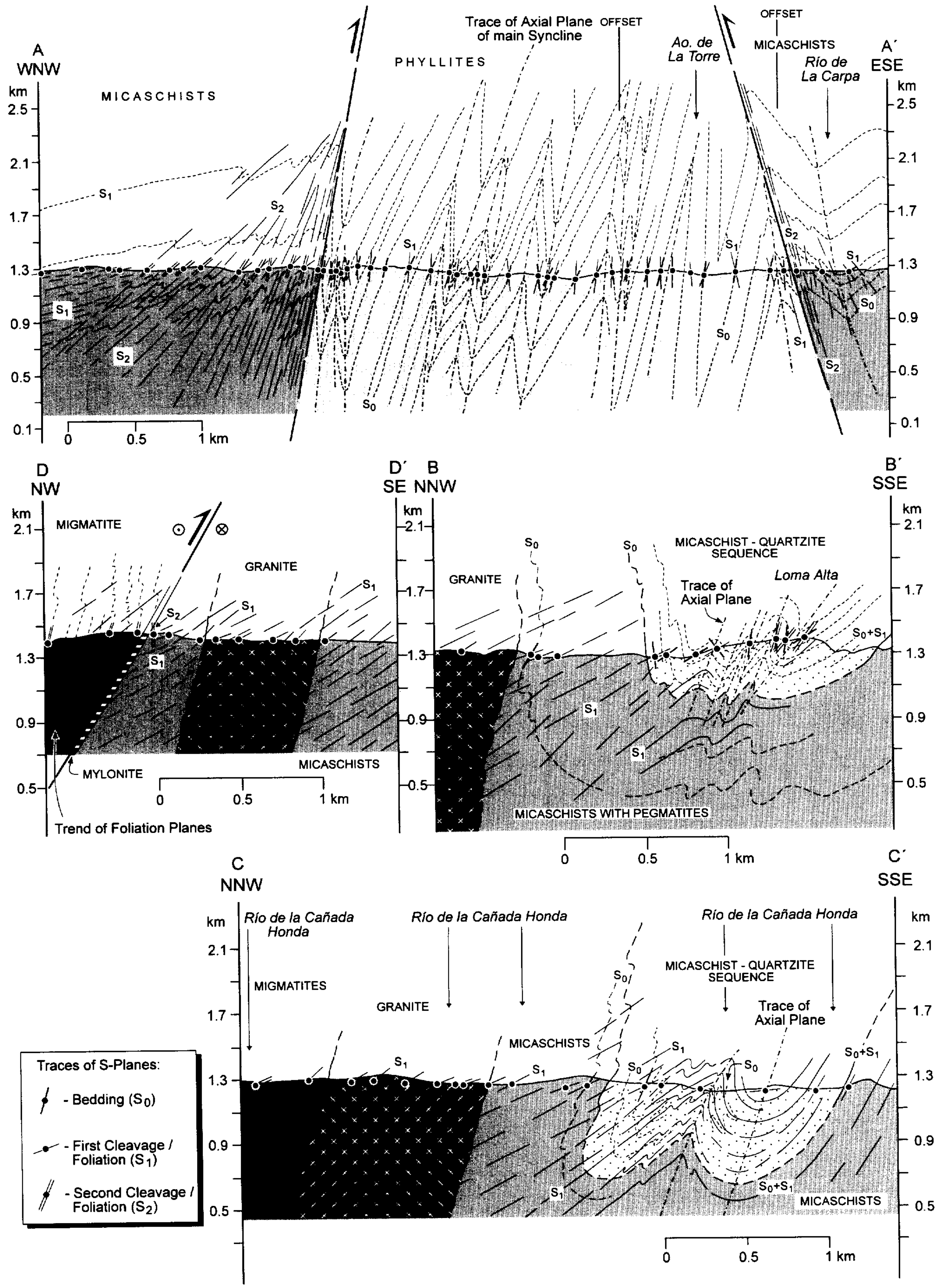

Fig. 5. Simplified profiles across the area between Paso del Rey and Río de la Carpa; for locations see Fig. 2. Traces of penetrative S_1/S_2-cleavage or foliation planes are only given as a trend or are omitted for clarity; subsurface boundaries of the Paso del Rey Granite are inferred.

On S_1-planes, the first stretching lineation (L_1) is indicated by aligned sericite, muscovite, biotite, as well as stretched garnet, and partly tourmaline (pegmatites), large muscovite plates, and flattened and elongated sericite aggregates. Southeast of the Paso del Rey Granite, sericite aggregates are stretched and flattened between S_1-foliation planes which cut across the contact of the intrusion (Fig. 5: profiles B–B' to D–D'). At one locality of the granite contact, sillimanite is aligned on S_1-planes parallel to L_1. The lineation strikes ~ WNW–ESE to WSW–ENE, south of Paso del Rey ~ NNE–SSW (Fig. 6c). At Río de La Carpa it steeply plunges toward ~ E (Fig. 6h) and at La Florida mostly to the west (Fig. 7b, e).

In the Río Luluara area, the entire transitional succession in the east is folded around open and ~ WNW-vergent F_1-folds on a scale of tens-of-metres. The B_1-axes gently plunge toward ~ S (Fig. 8d, h). The micaschists west of the phyllites record a pronounced S_1-foliation, affecting sericite aggregates, and the L_1-lineation is also defined by aligned biotite and muscovite.

D_2-deformation. Southeast of Paso del Rey, along Río de la Cañada Honda and to the east, the S_1-foliation with relics of bedding and tight F_1-folds are folded around SSE-vergent F_2-folds on a dm- to several-metres-scale. Further to the south, tight to isoclinal F_1-folds are bent around an open and SSE-vergent F_2-synform which represents the western continuation of the large-scale, NE–SW trending "Loma Alta Syncline" (Figs. 2, 5: profiles B–B' and C–C', and Fig. 9a). In the Loma Alta area, the entire structure is modified by additional, parallel trending F_2-syn- and anticlines in its northern part which record a SE-vergence, and related S_2-axial-cleavage planes which mostly dip toward ~ NNW (Fig. 6e).

In the La Florida area, F_2-crenulations, -crenulation folds, and -kink folds on a cm- to several m-scale change in intensity over distances of several metres to tens-of-metres. Areas with a slight crenulation are followed by ~ 100 m wide zones with intense folding. The ~ ESE-vergent folds are combined with a WNW-dipping S_2-crenulation cleavage which cuts across more incompetent layers. A few sericite aggregates and larger biotite and muscovite plates are flattened between and stretched along S_2-planes and the L_2-lineation, respectively. The L_2-lineation steeply plunges toward ~ W or E (Fig. 7b, e).

Within the eastern micaschists and transitional rock types of the Río Luluara area, W-vergent flexural-slip and kink folds (F_2) around NNE-plunging axes (Fig. 8d, h) are combined with an axial-plane S_2-cleavage dipping to the east or west. These fabrics are concentrated within m-wide zones, however, to the west they increase in abundance and are partly concentrated within a shear zone (see below). Just to the west of the shear zones, F_2-folds and S_2-cleavage planes overprint D_1-structures in the phyllites only in a few localities.

Deformations of the Phyllite Group

All of the clastics of the Phyllite Group were affected by a first folding event (F_1) creating asymmetric, tight folds with amplitudes and wavelengths on a m- to km-scale. The larger F_1-folds either could be reconstructed by cross-cutting relationships between bedding (S_0) and S_1-cleavage planes or were deduced from aerial photographs. Way-up criteria (cross-beddding, graded bedding, single load casts) suggest that the entire folding event affected an upright sequence. Except in the Río Luluara area, B_1-fold axes plunge towards NNE and SSW (Figs. 6g and 7c, f). At Santo Domingo, the dominant structure is a large, NNE–SSW trending syncline ("Santo Domingo Syncline") which is modified by additional, parallel F_1-anticlines and synclines on both limbs (Fig. 5: profile A–A').

Penetrative axial-plane S_1-cleavage planes represent the dominant planar fabric. Within smaller folds, conjugate sets of S_1-planes intersect at low angles. In the La Florida area, a penetrative S_1-cleavage is related to an ~ E-vergent F_1-folding event which can be compared with that in the micaschists. Small-scale, east-vergent F_1-folds of the bedding, combined with S_0/S_1-relationships and a few way-up criteria, suggest that the phyllites lie on the western limb of an anticline in the east. In the eastern parts of the study area, only this limb of the anticline is recorded, suggesting a great amplitude and wavelength of the F_1-structure. On S_1-planes, the first stretching lineation (L_1) is generally indicated by aligned sericite, biotite, and quartz-filled pressure shadows around pyrite and records a variable but steep plunge toward ~ W or ~ E (Figs. 6g, 7c, f).

Large fold structures in the Phyllite Group of the Río Luluara area could be detected on aerial photographs whereas in the field smaller outcrops only give a limited insight. In contrast to other study areas, the rocks are folded around open, tight, and nearly isoclinal F_1-folds with almost *vertical* B_1-axes (Fig. 8b, f). The large-scale folding is not a limited phenomenon but affects a wide, NNE–SSW trending strip also to the north and south of Río Luluara. The F_1-folds record NNE–SSW trends of the axial planes and are combined with S_1-cleavage planes which represent the dominant and subvertical planar fabric.

In the Río Luluara and Ao. de La Cal sections, the L_1-stretching lineation is not oriented perpendicular to the B_1-axes but mostly plunges steeply toward ~ E (Fig. 8b, f). Thus, it follows the general strike of the lineation in the southern study areas. Since the steepening of the B_1-axes occurs just to the west of a ductile shear zone (see below), their vertical orientation is not related to a later bending of the entire succession but developed during initial compression.

During F_1-folding and S_1-cleavage formation, the Phyllite Group was affected by pressure solution with mass transfer. Deposition sites are quartz veins parallel to

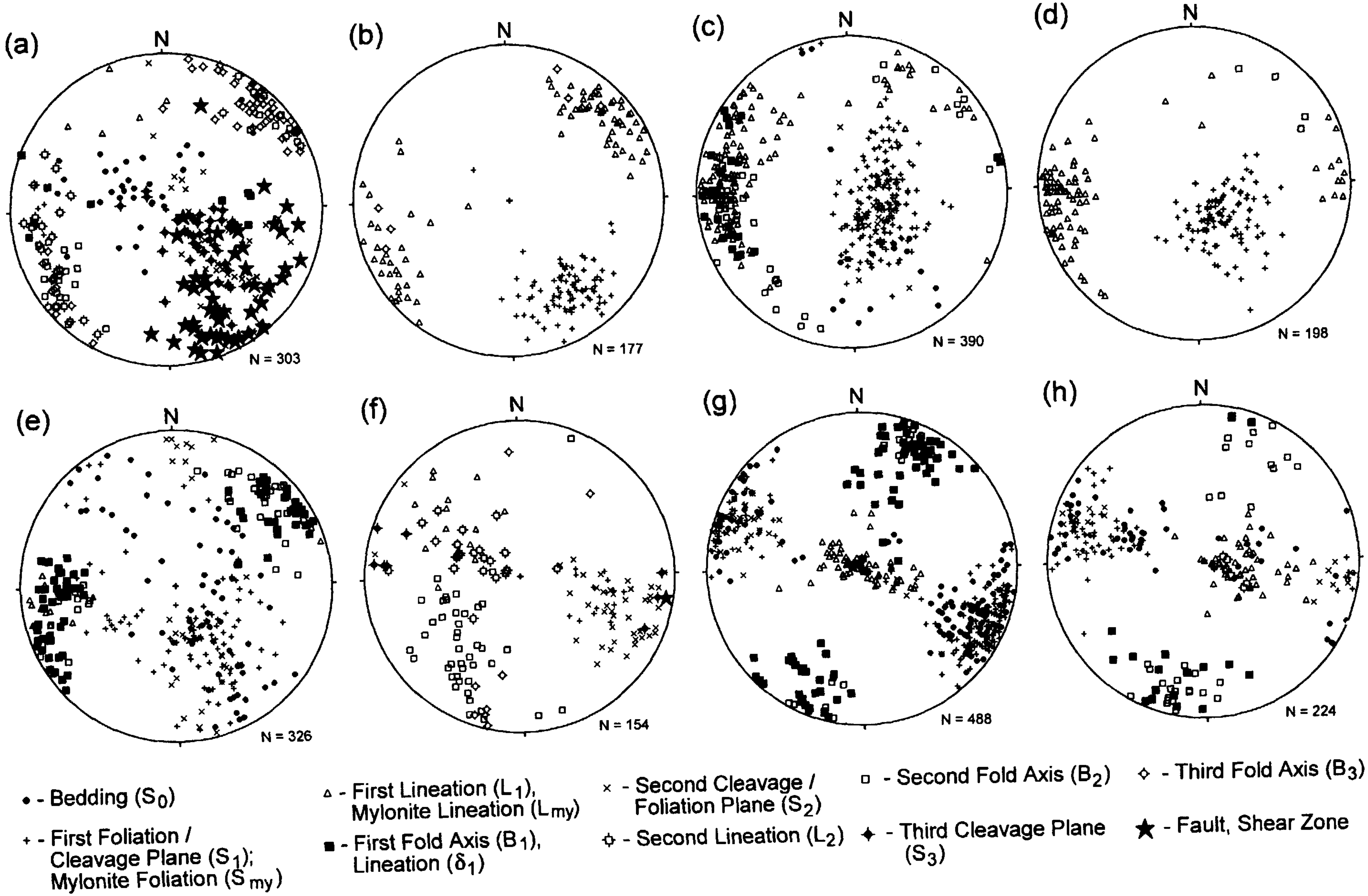

Fig. 6. Diagrams of fabric elements within the metamorphic units in the Río de la Carpa — Paso del Rey area (lower hemisphere projections, equal area). **a)** western complex of Migmatites, **b)** mylonite zone between Migmatites and Micaschist Group, **c)** micaschists SE and NW of Paso del Rey Granite, **d)** Paso del Rey Granite, **e)** Micaschist-Quartzite sequence in the Loma Alta area, **f)** micaschists W of fault zone against Phyllite Group, **g)** Phyllite Group, **h)** micaschists east of Phyllite Group (Río de la Carpa area).

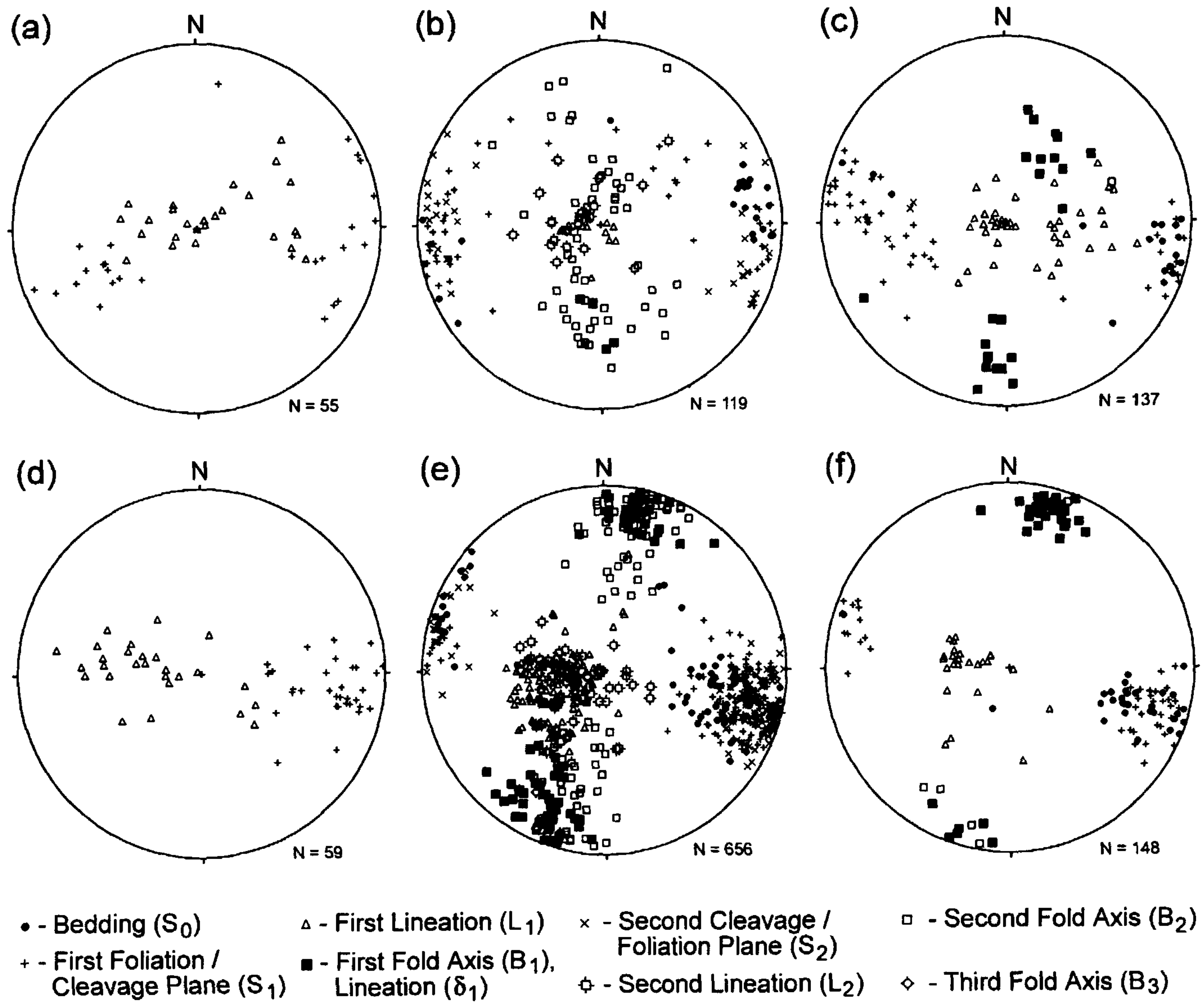

Fig. 7. Diagrams of fabric elements in the different lithologic units of the La Florida area (lower hemisphere, equal area projections); upper row, area south and east of Tamboreo Tonalite; lower row, area between Riocito and La Florida Granite; (**a**) Tamboreo Tonalite; (**b**) e), Micaschist Group; (**c**, **f**) Phyllite Group; (**d**) La Florida Granite.

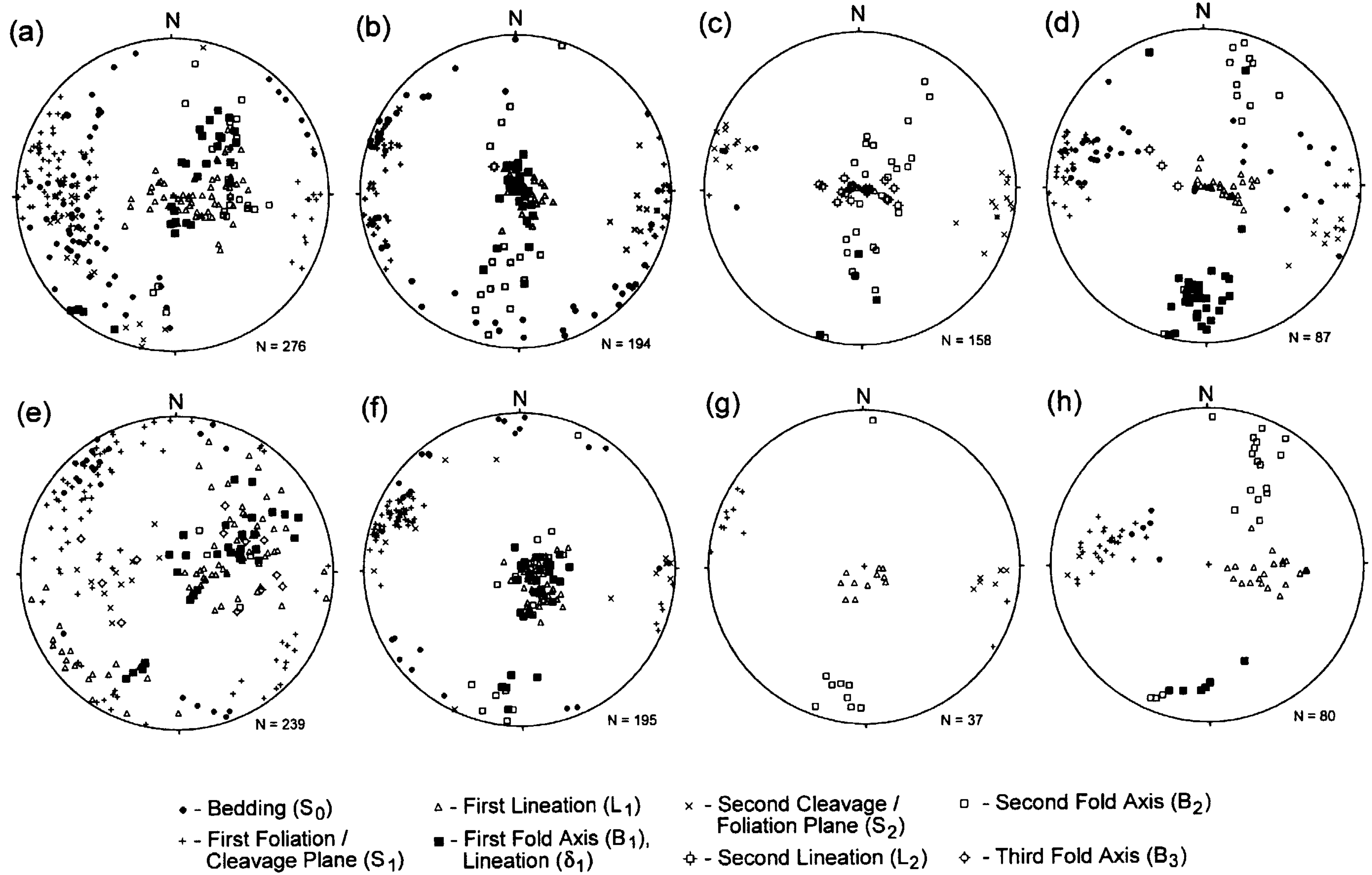

Fig. 8. Lower hemisphere, equal area stereographic projections of fabric elements within the metamorphic units at Río Luluara and to the north (upper row) and along Ao. de la Cal (lower row); (**a**, **e**), western micaschists; (**b**, **f**), phyllites; (**c**, **g**), eastern shear zone within phyllites; (**d**, **h**), phyllites and micaschists to the east of the shear zone.

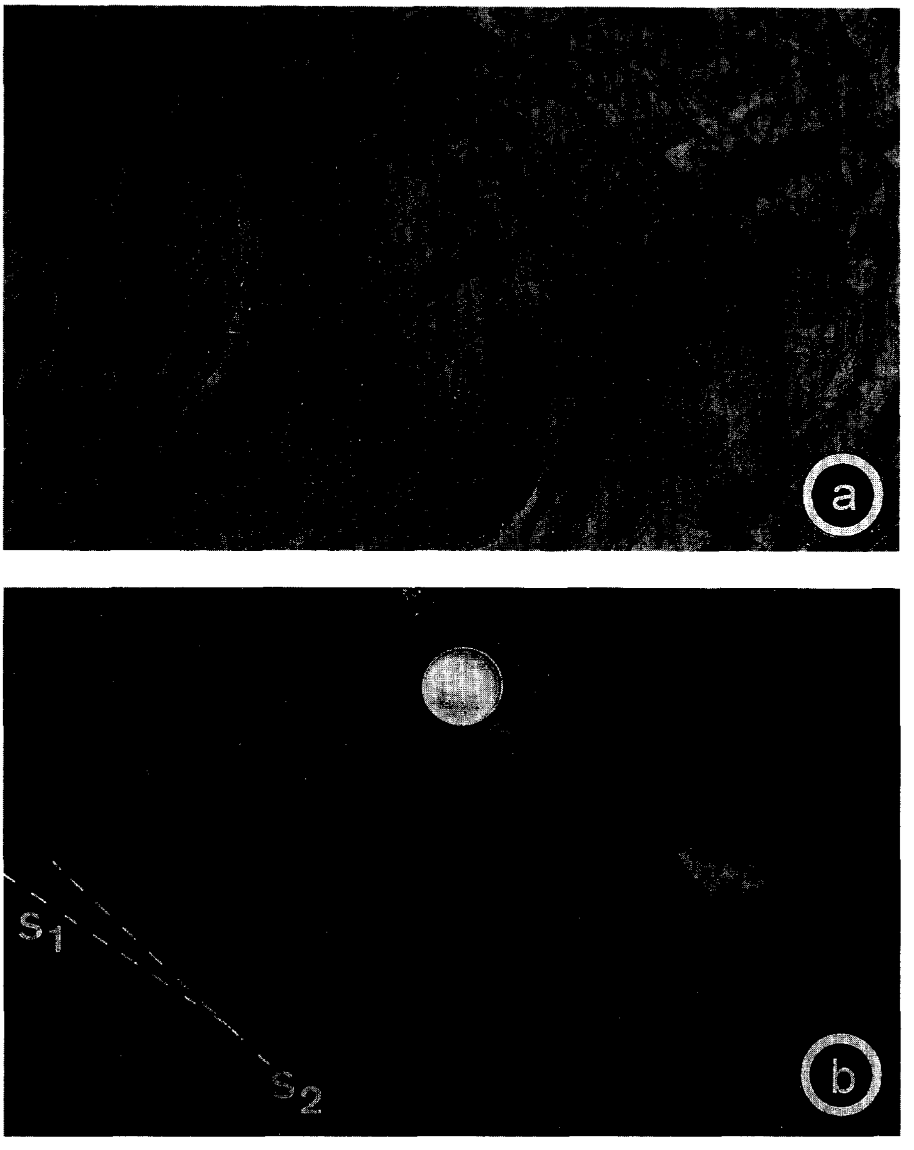

Fig. 9. (**a**), tight F_1-fold structures in quartzites with micaschist layers on the northern limb of the Loma Alta (F_2-) syncline, view toward ~NW; Río de la Cañada Honda, ~2.3 km south of road Paso del Rey-Sto. Domingo. (**b**), ESE-vergent F_2-crenulation folds with S_2-crenulation cleavage in micaschists. Road Paso del Rey-Sto. Domingo, ~400 m to the west of tectonic contact with Phyllite Group.

S_1-cleavage planes and later-formed quartz-filled extension joints. The latter cut across first generation veins at great angles, more or less perpendicular to the L_1-lineation.

In the western phyllites of Santo Domingo and La Florida, W-vergent F_2-crenulation folds on a dm- to max. several ms-scale were found. They are combined with an E-dipping S_2-crenulation cleavage (Fig. 10a). These fabrics indicate a local continuation of the D_1-deformation and are not widely distributed. ~W–E striking and steeply to vertically inclined strike-slip shear planes and faults occur in all parts of the Phyllite Group. They partly represent conjugate sets of intersecting planes, cutting across F_1-folds at great angles to the axes, and can be interpreted as transfer shear planes or faults accommodating the ~WNW–ESE compression during the final stage of compression. In one outcrop, more complex fault arrangements suggest that local along-strike displacements also occurred (Fig. 10b).

Fold interference patterns

On a map view, based on interpreted aerial photographs, different fold generations in the Río Luluara area display complex interference patterns on a hundred metres to kilometre scale (Fig. 11). The structures are concentrated within a NNE–SSW trending strip comprising the western part of the Phyllite Group and the eastern part of the Micaschist Group to the west. In the Ao. de La Cal, tight F_1-structures with vertical axes and an axial-plane S_1-cleavage continue from east to west. They are bent around large, open F_2-folds with subvertical axes and a NNE–SSW trending S_2-cleavage. Further to the west, F_1-structures could be detected as intrafolial folds within the micaschists bent around second generation folds. In the western part of the river section, only F_1-structures were found, and the S_1-foliation represents the dominant planar fabric.

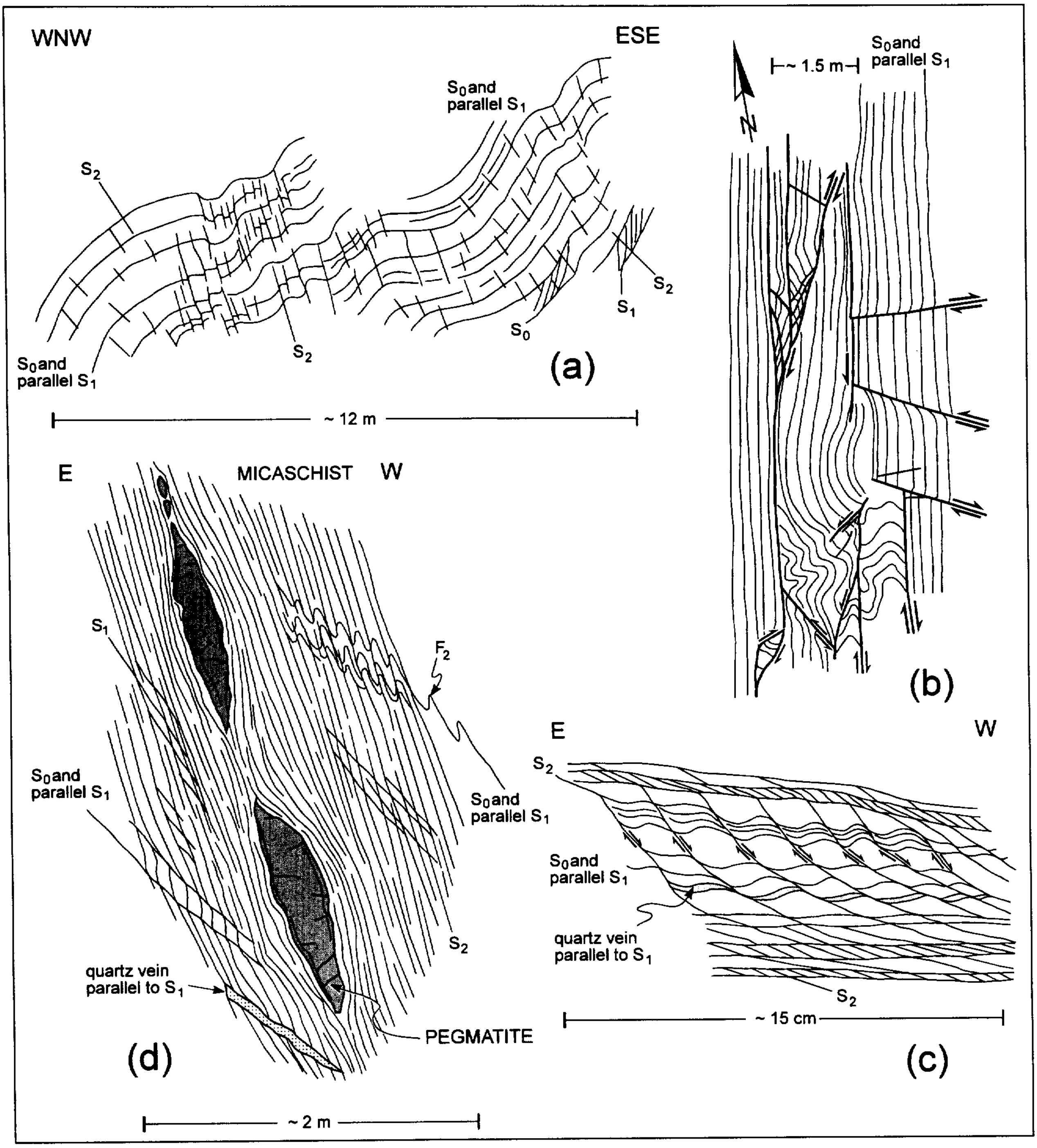

Fig. 10. (**a**), W-vergent F_2-crenulation folds with incipient S_2-crenulation cleavage in grey phyllites; ~150 m W of St. Domingo, road to Paso del Rey; (**b**), brittle transfer faults in dark phyllites, combined with fault displacements parallel or under small angles to S_1-cleavage and folding around nearly vertical axes; road St. Domingo-Paso del Rey, just E of tectonic contact with Micaschist Group; (**c**), S_2-cleavage planes in sandy micaschists with antithetic displacements related to E-directed rotational D_2-deformation; road Sto. Domingo-Paso del Rey, ~80 m W of contact between Phyllite and Micaschist Group; (**d**), penetrative S_2-foliation in sandy micaschists combined with F_2-crenulation folds, foliation flows around boudinaged pegmatite layer; ~200 m W of contact with Phyllite Group, road to Paso del Rey.

In addition to F_1- and F_2-structures, some large F_3-folds with a NNE–SSW trend could be interpreted on aerial photographs (Fig. 11). The interpretation suggests that F_2-structures dominate in the western part of the Phyllite Group while F_1-folds have a limited distribution. However, this partly contradicts the field evidence. In many areas, it was difficult to distinguish between F_1- and F_2-structures which is exemplified by the "contact" between the Phyllite and Micaschist Group SE of La Valerosa. There, large open F_2-structures are exposed in phyllitic micaschists with quartzite layers and are combined with a penetrative S_2-cleavage (Fig. 12). It cuts across smaller F_1-folds which are bent around F_2-structures. Both have steeply inclined to vertical axes.

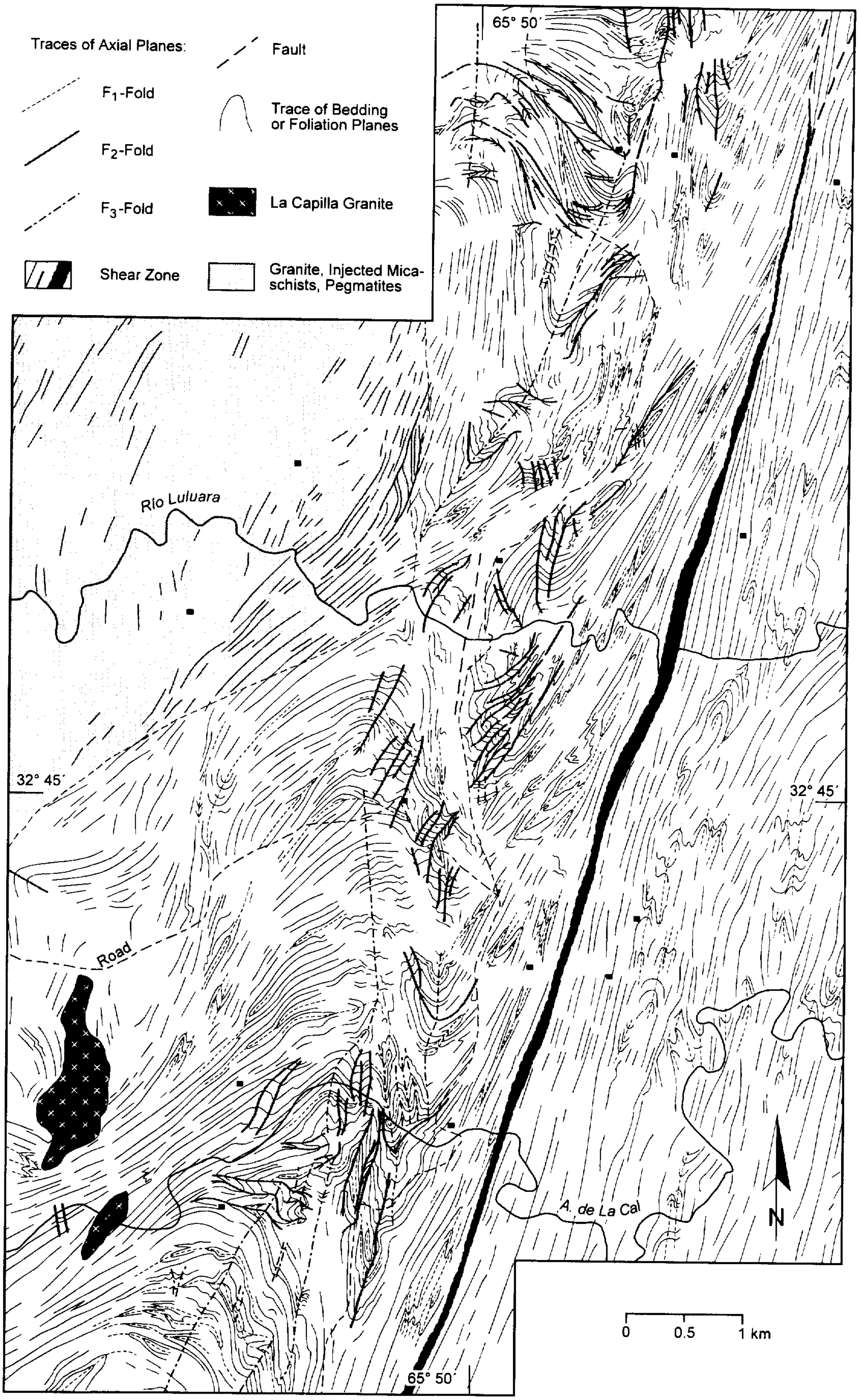

Fig. 11. Simplified structural map of the Río Luluara area based on interpreted aerial photographs and local structural field mapping (for location compare Fig. 1). Interference patterns of F_1-, F_2-, and partly F_3-fold structures are concentrated in a narrow, NNE–SSW trending strip covering the western part of the phyllites and parts of the western micaschists (for distribution of both units, see Fig. 4).

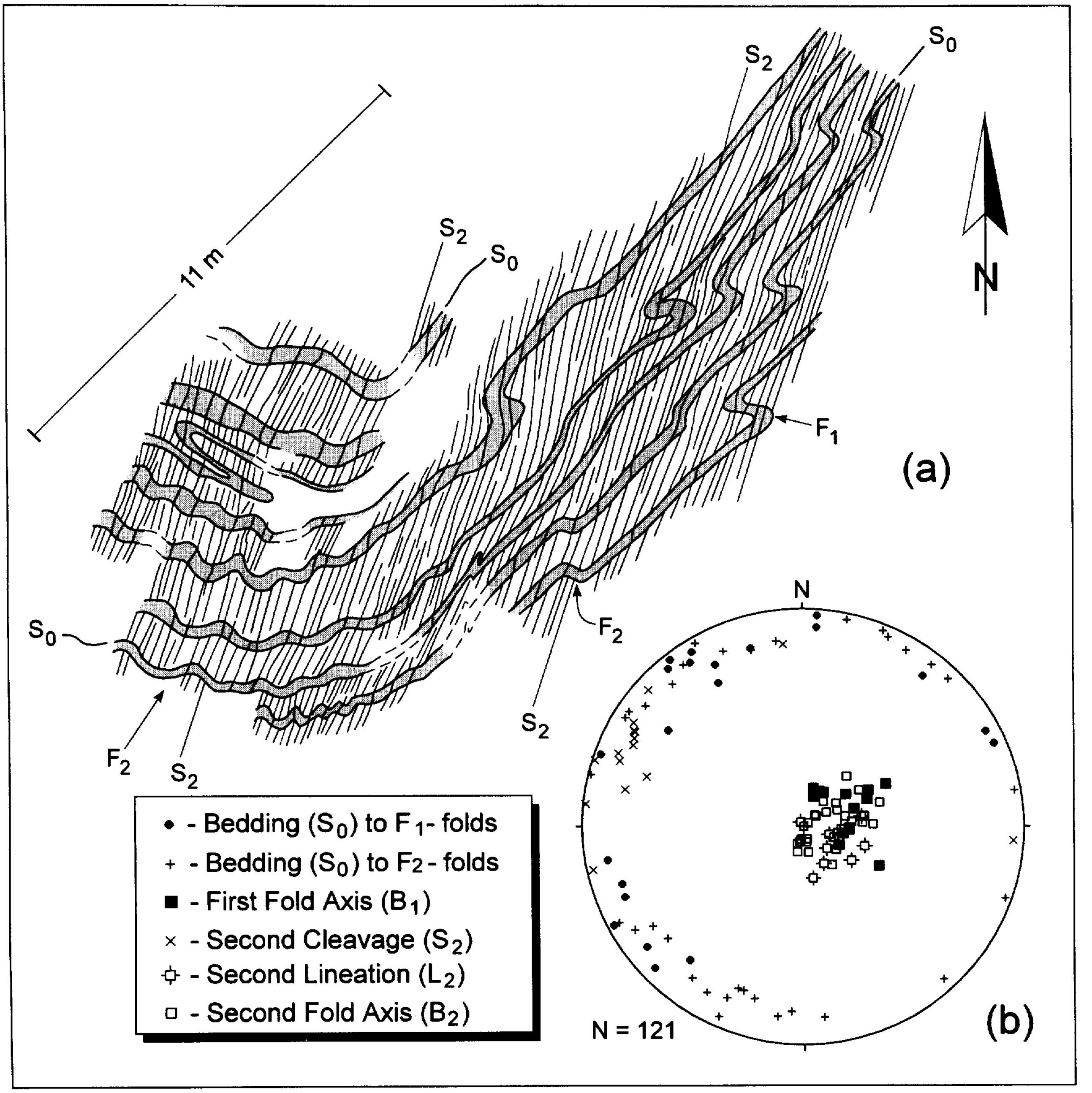

Fig. 12. Interference of F_1- and F_2-fold structures in phyllitic micaschists with quartzite layers southeast of Ea. La Valerosa, south of road. S_2-cleavage planes are related to F_2-folds and cut across F_1-folds without an S_1-cleavage fabric. Both, B_1- and B_2-axes are almost vertical and parallel to the L_2-stretching lineation (stereoplot of fabric elements is a lower hemisphere, equal area projection).

However, the F_1-folds do not record an S_1-cleavage or relics of it. An overprint of F_1-folds by F_2-structures with or without weak evidence of S_1-cleavage formation was found in several outcrops. This made it difficult to separate generations of fold structures. In the analysis of microfabrics below, the different indications found in the field are used.

Since larger folds around gently inclined axes have not been found, it is probable that some have sheath fold geometries. This implies a great amount of stretching parallel to the steeply inclined to vertical lineations. A possible interpretation is suggested by the small width of the phyllites compared to that in the southern study areas. Intense compression may account for the condensed multiple folding and may have supported the development of sheath fold geometries. In addition, it can be assumed that the generation of interference patterns was influenced by massive subsurface granitoid bodies within the meta-psammopelitic sequence. By this process, phyllites and micaschists were ductilely deformed and folded between more competent bodies. Observations in the (?) synkinematic granite just north of Río Luluara (Fig. 11) suggest that its internal deformation was slight.

Within the western micaschists, large interference patterns continue southwards outside the study area. South of Cerros Largos, they consist of at least three fold generations with steeply inclined to vertical axes. In addition, fold interference patterns are described by Dalla Salda (1987) and are not a unique phenomenon in the Sierra de San Luis.

Deformation of the intrusions

The Paso del Rey Granite is inhomogeneously and in parts penetratively affected by S_1-planes of the country rocks which are also concentrated in the marginal parts of the pluton or its apophyses. Comparable features could be detected at the Tamboreo Tonalite and La Capilla Granite (Río Luluara area). In all cases, the S_1-foliation/cleavage of the country rocks could be traced in the intrusions. In the interior parts of the Tamboreo Tonalite, Río Quinto Granite (Carugno Durán *et al.*, 1992), Paso del Rey Granite (south of the study area), and northern occurrence of the La Capilla Granite (type locality), S_1-planes are replaced by single shear planes and shear zones. The orientations of the L_1-lineations, indicated by aligned biotite and elongated quartz, are comparable to those of the country rocks (Figs. 6c, d; 7a–c). This makes it reasonable to suggest that the plutons intruded the undeformed sedimentary pile.

At Paso del Rey, pegmatite dikes are sheared and flattened (layers parallel to S_1) or folded with cross-cutting S_1-cleavage or C_1-shear planes (layers oblique and/or under great angles to S_1). At Río de La Carpa, pegmatite sills are folded around F_1-structures. In hinge zones, S_1-cleavage planes cut across bedding of the clastic sediments and are replaced by steeply inclined C_1-planes within the pegmatite sheets. There, L_1 is indicated by aligned sericite and elongated quartz. On the limbs, the margins of the layers are foliated whereas the central parts or thick pegmatite sills only record single C_1-shear planes and zones.

In the acid magmatic layers, a penetrative, planar S_1-foliation and L_1-lineation, the latter recorded by aligned sericite and partly elongated quartz, can be directly compared with equivalent fabrics in the country rocks. Evidence of older deformation was not found within the country rocks or the undeformed magmatics. This also applies to the dike at the southwestern margin of the Tamboreo Tonalite, which was deformed with the pluton.

In the western part of Río Luluara, a granite intrusion (Figs. 4 and 11) encloses large blocks of micaschists with sericite aggregates and up to several cm-long muscovite plates, as well as injected schists. In one outcrop of the granite contact north of the Río section, limited dextral and sinistral shear zones within the micaschists, which gradually pass into magmatic textures or are invaded by granite melt, make it possible to assume an intrusion during the D_2-deformation. From aerial photographs of this poorly exposed area, a NNE–SSW trending dextral shear zone could be inferred.

At the eastern contact of the La Florida Granite, no indications for a fault or fabrics of a syn-tectonic emplacement could be detected. Within the micaschists to the east, sericite aggregates, larger biotite, and muscovite plates increase in abundance and size towards the granite and can be related to heat transfer from the intrusion. These micaschists were injected by widely distributed pegmatite dikes which increase in abundance, density, and thickness towards the granite. They also occur within the pluton and can be related to the final stage of intrusive activity. The dikes are either oriented parallel to S_0 and/or S_1 or cut across. They are bent around F_2-folds and are cross-cut by S_2-cleavage and/or C_2-shear planes which partly fan around fold hinges (D_1-fabrics of the pegmatites; Fig. 13). These planes also affect dikes which are parallel or slightly oblique to the S_1-fabric of the micaschists. There, shearing is concentrated along pegmatite margins and was partly combined with boundinage.

At its eastern intrusive margin, the La Florida Granite is cross-cut by an S_1-foliation which could be compared with the S_2-foliation of the micaschists. In the western, more central parts of the pluton, a few randomly oriented xenoliths of the country rocks record an older penetrative foliation which could not be related to single, minor C_1-shear planes in the granite. Wide areas of the granite are macroscopically undeformed and this also shows that the pluton was more intensely sheared only along its margin. This difference in deformation intensity can be related to the contrast between the stiffer granite and the weaker micaschists. Based on the above observations, the granite pluton and subsequent pegmatites are interpreted as intrusions in the Micaschist Group after the D_1- and prior to the D_2-deformation. A few post-D_1 pegmatites were also found in the Paso del Rey area.

Tectonic contacts between Phyllites and Micaschists

To the west of Sto. Domingo, S_1-foliation planes of the Micaschist Group are overprinted by small-scale, ESE-vergent F_2-crenulation folds (Fig. 9b) with axes plunging ~SSW to SW. They are combined with syn- and/or antithetic S_2-crenulation cleavage planes (Fig. 10c) which increase in abundance and density eastwards (Fig. 5: profile A–A'). S_1-planes and parallel quartz veins are folded around ESE-vergent to isoclinal F_2-folds on a dm-scale, and pegmatite layers are boudinaged in the S_2-foliation (Fig. 10d). The entire zone of incipient (west) to penetrative S_2-shearing (east) can be related to the formation of the F_2-structures in the Loma Alta area which, on map scale, continue northeastwards (Fig. 2). At one exposed contact (Fig. 14a), the micaschists are reverse-faulted eastwards over the Phyllite Group parallel to S_2-planes and the L_2-lineation which plunges steeply toward ~WNW (Fig. 6 f). Just east of the mylonitic schists, the phyllites are cross-cut by penetrative S_1-cleavage planes steeply dipping toward the west.

At the eastern margin of the Phyllite Group in the Río de la Carpa section (Figs. 5: profile A–A', and 14b), the micaschists, being overprinted by open, ~W-vergent F_1-syn- and anticlines around NNE–SSW trending axes, are cross-cut by steeply eastward inclined

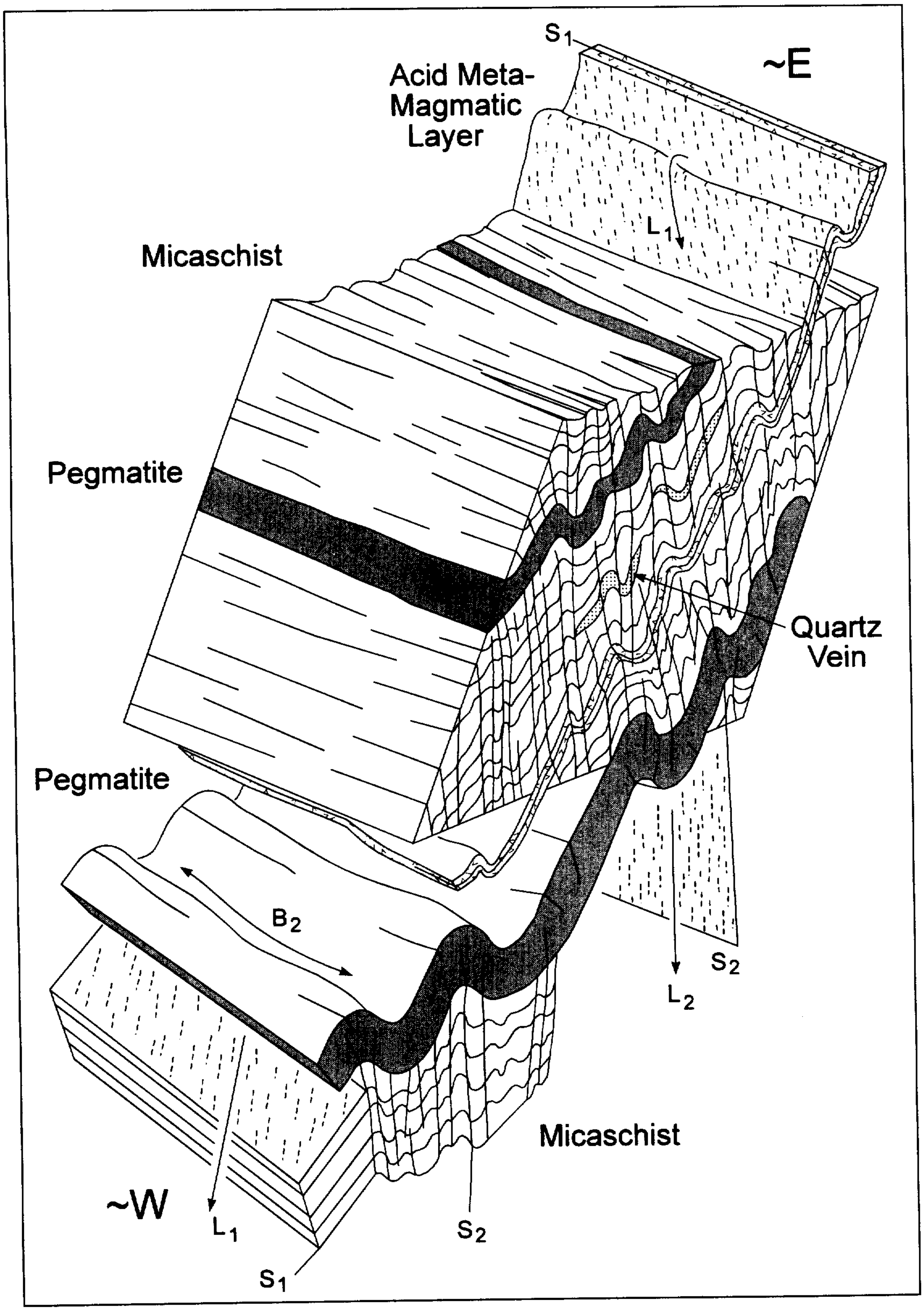

Fig. 13. Simplified and schematic block diagram to illustrate the deformation within the Micaschist Group plus intercalated magmatics in the La Florida area. F_2-folds with S_2-crenulation cleavage are the first fabrics affecting the pegmatite dikes while the acid meta-magmatic layer records a planar S_1-foliation with an L_1-lineation (see text for further explanations).

C_2-shear planes which increase in abundance and density toward the western contact with the phyllites. The zone of parallel to dense S_2-planes is several tens-of-metres wide, and the micaschists are interpreted to have been reverse faulted over the phyllites. In the latter, S_1-planes steeply dip toward ESE and are parallel to S_2-planes within the lifted micaschists. Within both units, the stretching lineations steeply plunge east-southeastwards. As at the western margin of the Phyllite Group, the fault line could be traced only on aerial photographs and its continuation to the north and south is unclear.

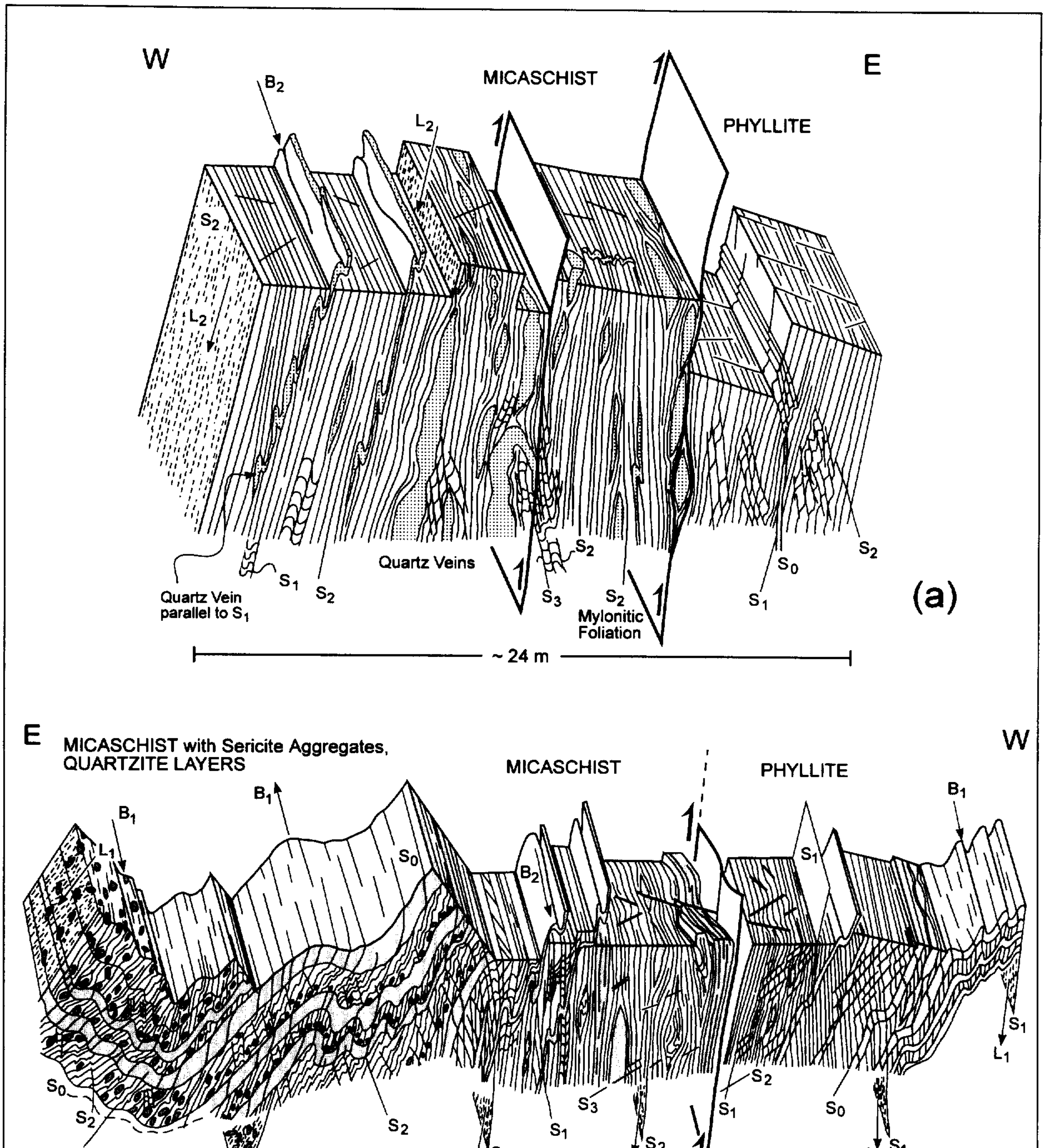

Fig. 14. Simplified and schematic block sketches of the tectonic contacts between Phyllite and Micaschist Group; (**a**), west of Sto. Domingo (valley just south of the road to Paso del Rey); (**b**), Río de la Carpa river section. See text for explanations.

East of La Florida (Riocito), the inhomogeneous D_2-deformation within the micaschists is recorded by intensely sheared strips aside of other parts with only a few crenulations. Within a several-metres wide zone at the contact with the Phyllite Group, penetrative S_2-foliation planes develop whilst S_1-planes are bent around tight, E-vergent F_2-folds (Fig. 15). The tectonic contact is also indicated by slices of a graphitic phyllite and a micaschist which are affected by fabrics of a D_2-deformation and are separated by high-angle reverse faults. S/C-fabrics suggest that the micaschists were lifted eastwards over the phyllites. S_0/S_1-intersections and small-scale E-vergent F_1-folds indicate that the adjacent biotite phyllites lie on the western limb of an F_1-anticline.

To the north of the La Florida Lake (SE of the Tamboreo Tonalite), sandy micaschists with a planar S_2-crenulation cleavage lie on the penetrative S_1-foliation of the garnet-bearing biotite phyllites and are interpreted to have been reverse faulted eastwards over the latter. The probable SSW continuation of the reverse fault could only be inferred. At one locality and within a ~10 m

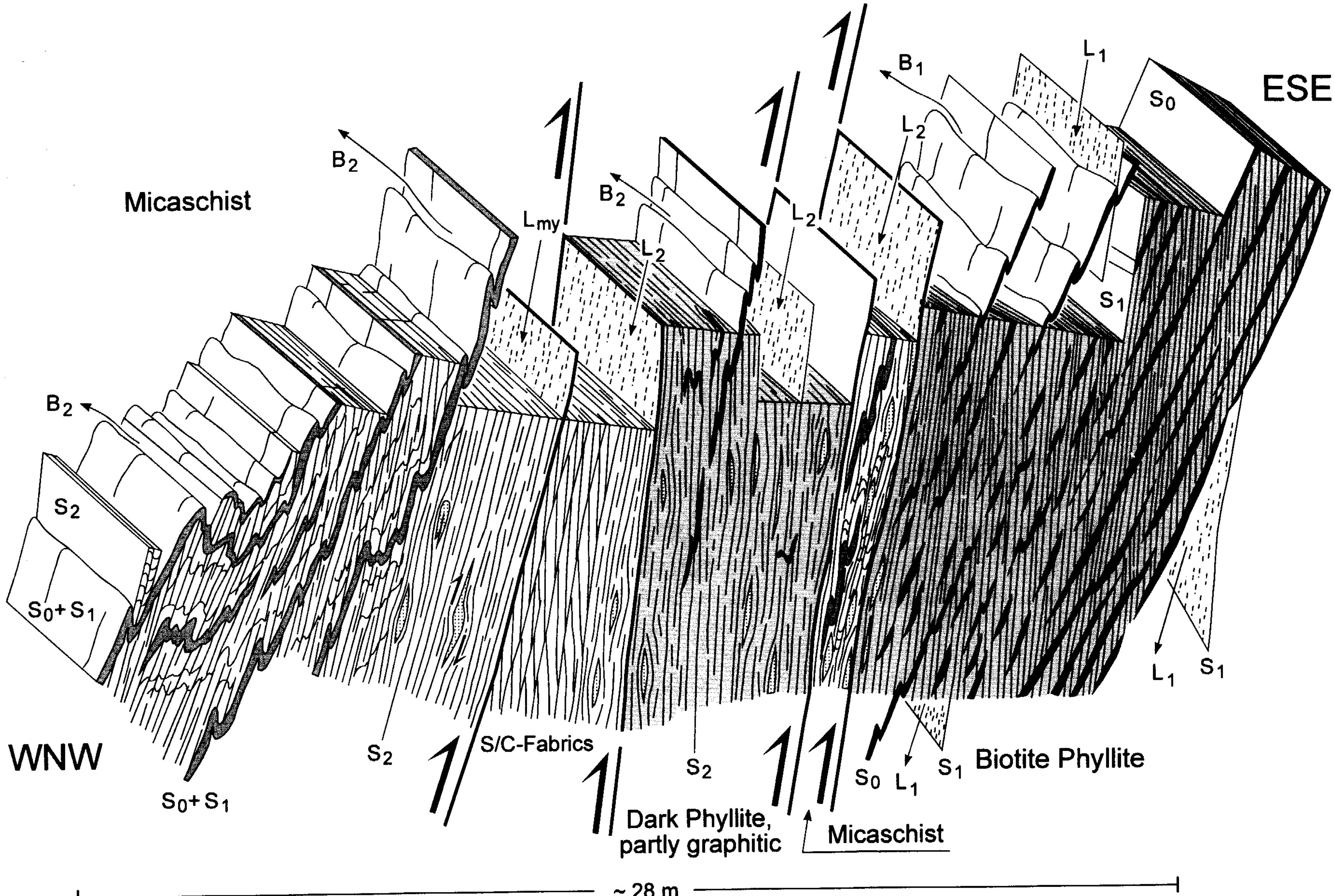

Fig. 15. Simplified and schematic block sketch of the tectonic contact between the Phyllite Group (east) and Micaschist Group (west) at Riocito, east of the La Florida lake. Isolated slices of micaschists and dark phyllite indicate a repetition within the east-directed high-angle reverse fault zone (max. height of outcrops is ~4 m; for further explanations see text).

wide zone, intensely foliated (S_2) micaschists with S/C- and shear band fabrics are reverse faulted eastwards over the phyllites. As at Ríocito, however, the continuation of the reverse fault zones had to be inferred due to the outcrop situation and do not join along strike (Fig. 3). It can be assumed that they either are connected by a tear or transfer fault in the W–E valley north of the La Florida Lake or continue as separate lines across the valley.

In the eastern phyllites of the Río Luluara section, ductile C_2-shear planes, related to symmetric and isoclinal F_2-folds on a dm-scale, grade into the dominant S_2-foliation fabric of a maximum 100 m wide, NNE–SSW trending, ductile shear zone (Fig. 4). There, bedding and S_1-cleavage planes are sheared off, and isolated fragments occur within a subvertical and mylonitic S_2-foliation. Inhomogeneous deformation is recorded by intensely sheared strips which alternate with more quartzitic layers where relics of bedding and S_1-foliation planes are preserved. A few S/C-fabrics record a reverse uplift of the eastern block parallel to the pronounced stretching lineation (L_2) which steeply plunges toward ~E or ~W (Fig. 8c).

On a distance of several kms, the northern and southern continuations of the shear zone could be inferred on aerial photographs and follow the general NNE–SSW trend of the structures. In the Ao. de La Cal section, however, the exposed shear zone is characterized by an intense S_1-foliation whilst fabrics of the second event are restricted to only a few outcrops. This suggests that displacements started during D_1 and in some parts continued during the D_2-event. Single shear bands and asymmetric δ-clasts again indicate an uplift of the eastern block parallel to the steeply inclined L_1-lineation (Fig. 8g).

Boundary between Migmatites and Micaschists

To the west of Paso del Rey, the boundary between the Micaschist Group and migmatites is indicated by a ~NE–SW trending, ~10–20 m wide mylonite zone which dips with ~60° toward ~NW (Figs. 2 and 5: profile D–D'). The northeastern continuation of the mylonite zone could be traced along the northern margin of the Paso del Rey Granite which consists of widely distributed and thick pegmatites. Further northeastwards, the mylonite zone cuts into the migmatites and could not be followed.

In the mylonite zone, micaschists, migmatites, and pegmatites are converted to protomylonites and mylonites. The pronounced mylonite lineation gently plunges toward ~NE or W to SW (Fig. 6b) and suggests a strike-slip displacement. Within the platy mylonites no clear macroscopic shear sense indicators were found. Microscopic evidence indicates a sinistral displacement which is based, however, on only a few asymmetric (σ-) clasts and shear bands.

The latest stage of displacement is indicated by steeply northwestward inclined to vertical, ductile shear planes, shear zones, and thin reverse fault zones within the migmatites (Fig. 6a). They led to the development of lens-shaped fabrics and are related to open and SE-vergent F_3-folds which overprint the planar S_2-foliation of the migmatites as well as parts of the mylonite fabric. The deformation records the continuing compression and uplift of the migmatites after cessation of strike-slip displacement along the mylonite foliation.

MICROFABRICS AND METAMORPHISM

Pre- to syn-D_1-fabrics

In the *Micaschist Group*, the S_1-foliation is indicated by aligned muscovite and biotite. In the Paso del Rey-Río de La Carpa area, it flows around up to cm-long muscovite plates and lens-shaped quartz-muscovite aggregates. The latter consist of muscovite plates or aggregates in the center. It is surrounded by a rim which mostly consists of quartz and is interpreted as a diffusion halo related to the growth of a central porphyroblast (compare e.g. Woodland, 1963; Atherton, 1976; Kerrick *et al.* 1991). These ellipsoidal aggregates with long axes parallel to L_1 are mostly concentrated within distinct layers of the micaschists. As poikiloblastic muscovite plates they contain fibrolitic sillimanite which could not be detected in the matrix. Muscovite porphyroblasts also enclose tourmaline, garnet, as well as quartz grains and aggregates.

Up to several cms-long sericite (± chlorite ± biotite ± quartz) aggregates also occur in the Río Luluara area. At Paso del Rey-Río de La Carpa, they can enclose fibrolite and were also found in quartz-muscovite aggregates. There are no relics of the original (pre-D_1) porphyroblasts preserved, however, the sericite fill makes it possible to assume andalusites. In the western micaschists of the Río Luluara area, the aggregates mostly consist of chlorite aside of sericite. Some sericite aggregates exhibit a poorly defined planar internal fabric (S_i; opaque grains), oriented at different angles to the external planar S_1-planes. No clear indications for sigmoidal inclusion trails were found. Enclosed also are biotite porphyroblasts with a planar S_i, muscovite plates, and garnet, partly with a planar S_i in the core and a rim without inclusions.

According to the deformation of the sericite fill of the aggregates, the conversion of former porphyroblasts generally took place pre- to post-D_1. In the Paso del Rey area, lens-shaped sericite aggregates are sheared and flattened in the S_1-foliation fabric (Fig. 16a) suggesting a pre-D_1 origin of the former porphyroblasts. In most places, no clear indications for a synkinematic growth of the initial porphyroblasts were found. Single sericite aggregates at a steep angle to S_1, without a clear S_i or with a continuation of S_1 in a slightly curved S_i within marginal parts of the aggregate, however, could have derived from syn-D_1 porphyroblasts since S_1-planes flow around the aggregates (Río de La Carpa and Río Luluara; Fig. 16b, c). In the Río Luluara area, several cms-long sericite/muscovite aggregates were found in the field which are flattened in S_1-planes. New porphyroblasts grew which are entirely

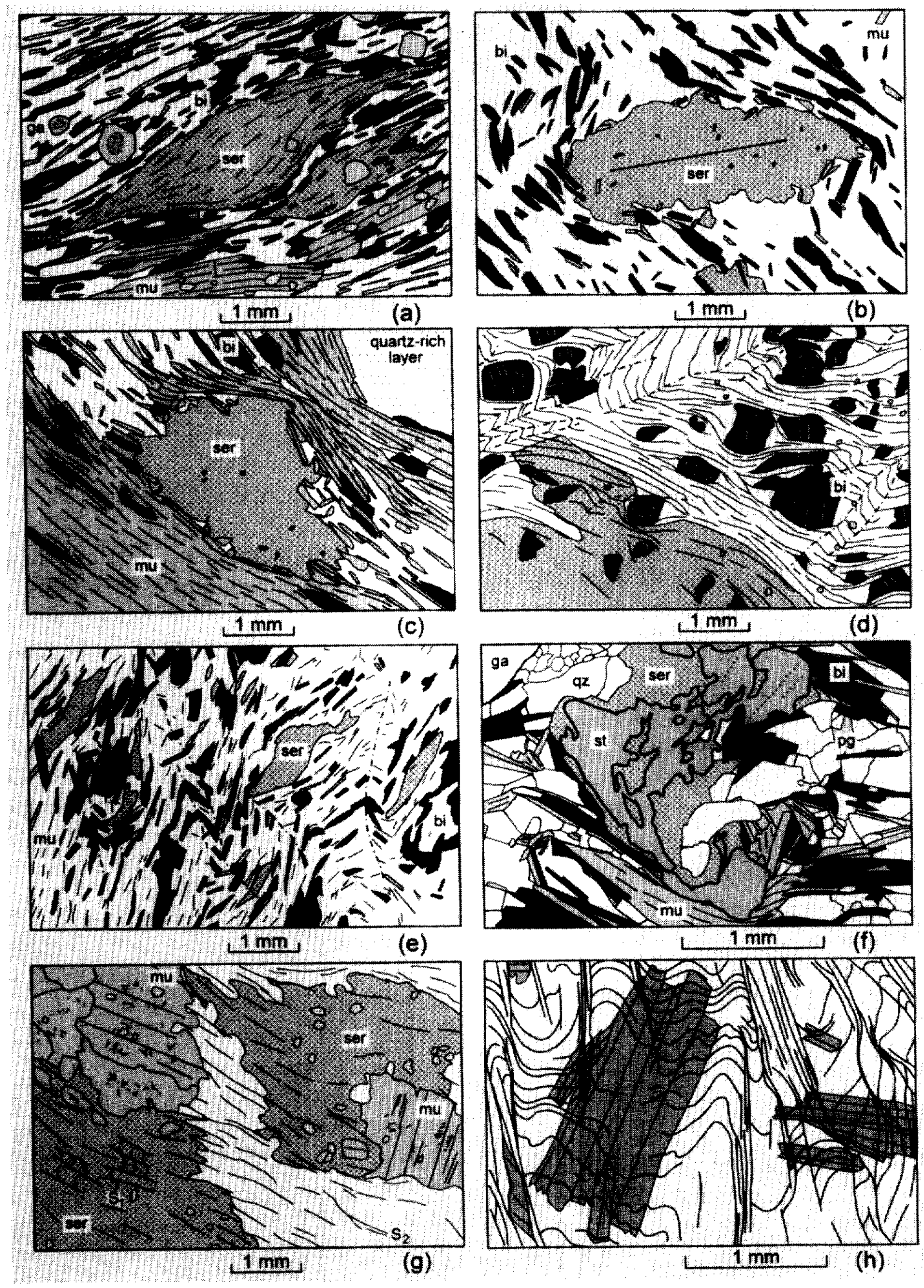

Fig. 16. Simplified sketches from thin sections of the Micaschist Group, drawn from photographs. **(a)** Sheared and flattened sericite aggregate (centre) and quartz-sericite aggregate within the S_1-foliation at Paso del Rey. They partly contain small garnets which can have an older core (left). Poikiloblastic muscovite plates enclose quartz grains and are partly bent. **(b)** Sericite aggregate within the S_1-foliation fabric displayed by biotite and muscovite. The S_1-foliation is deflected around the aggregate where a poorly defined internal fabric is schematically indicated by a thick line (Río Lulara area, eastern micaschists). **(c)** S_1-foliation fabric recorded by muscovite-rich layers and single biotite deflected around sericite aggregate. Biotite partly contains a planar internal fabric (schematically depicted by white lines, left); Río Luluara area, eastern micaschists). **(d)** Contact between chlorite-sericite aggregate (bottom, left) and mica matrix. The phyllosilicate fill of the aggregate, enclosed biotite, and biotite in the matrix are affected by the S_1-foliation which is bent around F_2-crenulations. Biotite porphyroblasts enclose a planar internal fabric (schematically depicted white lines; Río Luluara area, SSW of Estancia La Valerosa). **(e)** F_2-crenulations of S_1-foliation fabric affecting already sheared and flattened sericite aggregates. Biotite and muscovite are polygonally recrystallized (Paso del Rey area). **(f)** Relic of a staurolite porphyroblast. S_2-cleavage planes are indicated by the ~ W–E orientation of muscovite and biotite and flow around the porphyroblast (bottom) which is partly replaced by sericite. Staurolite contains relics of a poorly preserved internal fabric (stippled lines, top) which represents the older S_1-foliation (road El Trapiche-La Florida). **(g)** Sericite aggregates and muscovite plates within the S_2-cleavage fabric of the Loma Alta area. The aggregates have diffuse boundaries and are internally sheared. There, aligned sericite displays the S_1-foliation which is crenulated between S_2-planes (left). Muscovite plates contain fibrolite. **(h)** Statically grown biotite porphyroblasts enclose undisturbed S_1-foliation planes which are crenulated between S_2-planes. Older biotite is affected by S_2-planes (bottom left; La Florida area, south of Tamboreo Tonalite). (bi — biotite, ga — garnet, mu — muscovite, pg — plagioclase, qz — quartz, ser — sericite aggregate, st — staurolite, dash-dot lines — traces of axial planes of F_2-crenulations).

replaced by sericite. Their preserved outer shape suggest that they were andalusites. Since they are also affected by the S_1-foliation, which flows around the edges, they are interpreted as syn-D_1 porphyroblasts.

In the matrix, single plagioclase, garnet cores, and up to mm-long and widely distributed biotite porphyroblasts can enclose a planar S_i. In the latter, it consists of fine-grained, aligned quartz and opaque grains and is oriented under different but mostly great angles with respect to S_1 (Fig. 16c, d). In several thin sections, these S_i trails in matrix biotites have comparable orientations. They could be traced into those of sericite aggregates and enclosed biotite suggesting that pressure solution dominated during foliation development (Vernon, 1988). S_1-planes also curve around these porphyroblasts. Muscovite plates and biotite porphyroblasts are recrystallized in the S_1-foliation or -cleavage while new grains grew parallel to S_1.

Within the *Phyllite Group* of the La Florida area, biotite porphyroblasts (~0.5 to 1 mm long) enclose a fine-grained, planar S_i (quartz and opaque grains) which is oriented at different angles with respect to S_1-planes but can be traced across several porphyroblasts (Fig. 17a, b). Curved or sigmoidal trails were not found. The biotites partly overgrew and enclosed bedding as straight S_i and afterwards were affected by S_1-cleavage planes, displayed by aligned sericite, muscovite, micro-biotite, and chlorite (Fig. 17a). These flow around the porphyroblasts and led to their slight rotation relative to S_0-planes. In the planar S_1-cleavage, biotites are partly stretched and/or disrupted, record pressure shadows (Fig. 17b), are recrystallized, and partly have later grown rims. Since it is probable that solution processes at grain contacts operated during S_1-cleavage formation (see also Bell *et al.* 1986), a syn-kinematic growth of the larger biotites is not reasonable. Such biotites also occur in the other areas and can be compared with those in the micaschists. A planar S_i within (cores of) single garnet idioblasts

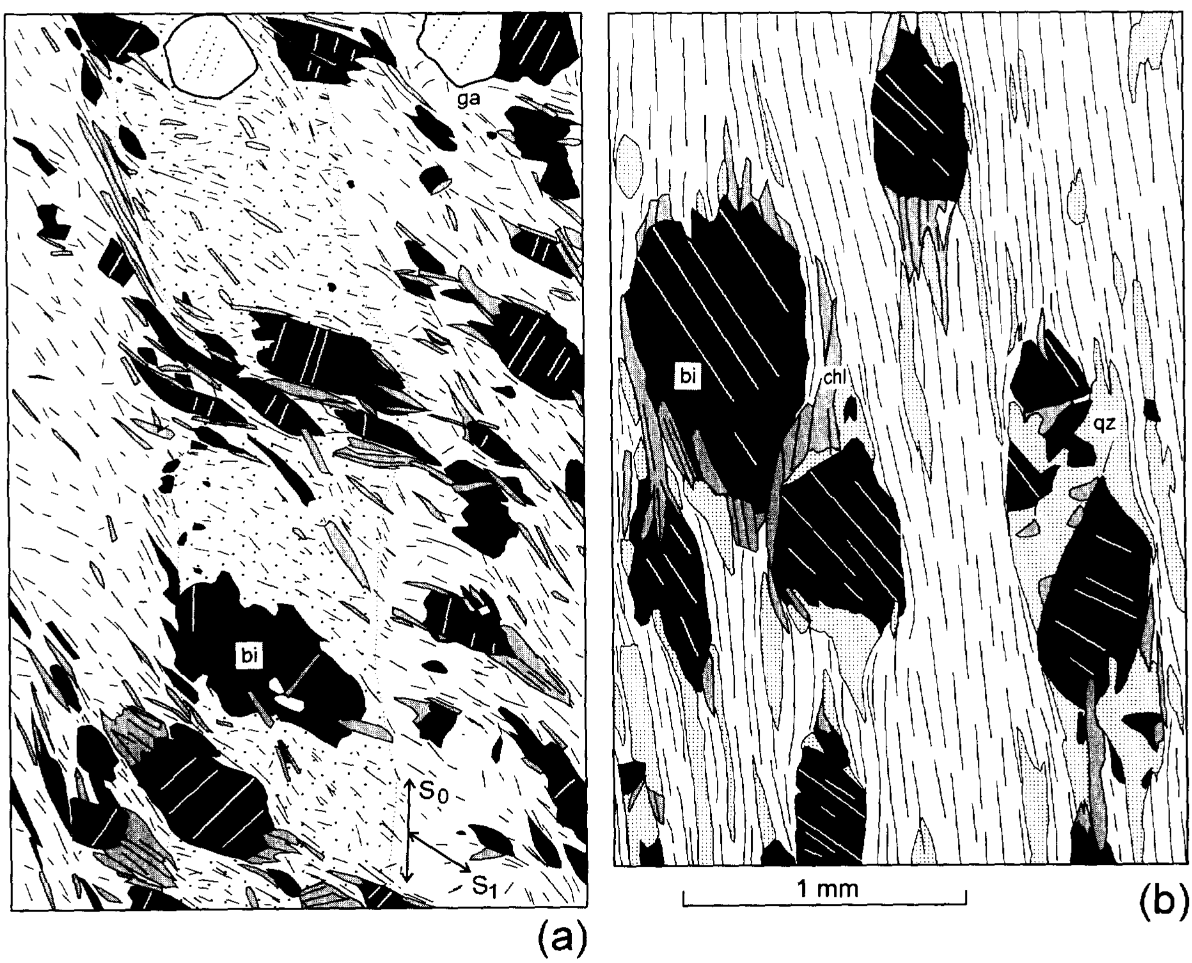

Fig. 17. Simplified sketches from thin sections of the Phyllite Group, drawn from photographs. **(a)** Biotite porphyroblasts with planar internal fabrics (simplified by white lines) are affected by S_1-cleavage which cuts across bedding (S_0). The internal fabrics are interpreted as relics of overgrown bedding planes and were slightly rotated relative to the latter during cleavage formation. Single garnet porphyroblasts contain comparable internal fabrics (dotted lines). S_1 is recorded by muscovite, chlorite, and micro-biotite (light grey and thin lines; scale as in (b); La Florida area, Riocito). **(b)** Biotite porphyroblasts with fine-grained, planar internal fabrics (simplified as white lines) are affected by a penetrative S_1-cleavage. Strain shadows and gaps between pieces of disrupted biotite are filled with quartz and chlorite. The internal fabrics are oblique to the penetrative cleavage and have comparable orientations across the porphyroblasts (La Florida area, El Latino quarries). (bi — biotite, ga — garnet, chl — chlorite, qz — quartz).

displays orientations similar to those of the biotites (Fig. 17a) and suggests a comparable growth pre-D_1.

In the Paso del Rey-Río de La Carpa area, small lens-shaped quartz-chlorite ± sericite aggregates probably were garnet porphyroblasts and are flattened in S_1. In one thin section of the La Florida area, up to 1 mm long and deformed sericite-chlorite ± biotite aggregates contain a planar S_i oblique to S_1 and could represent former andalusites. At the contact with the Tamboreo Tonalite, larger muscovite and biotite flakes randomly grew and later are deformed between S_1-foliation planes. Together with chlorite, sericite, and micro-biotite, they display the S_1-planes. In addition, some small garnets record a planar S_i under different angles to S_1.

In the Phyllite and Micaschist Group, coarser quartz was ductilely deformed between S_1-planes and partly to entirely replaced by mostly undeformed recrystallization grains. In sandy parts of the phyllites, clastic quartz with sericite-chlorite beards in S_1-planes contain only single and small recrystallization grains at the margins.

In thin sections from both units, a planar S_i at different angles to S_1-planes is interpreted as an enclosed relic of bedding, indicating porphyroblast growth prior to (and partly during) the D_1-deformation, which also led to an increase in grain size of quartz. This is supported by the fact that S_1-planes represent the first planar fabric detected in the field and affected the clastic rocks as well as the intrusions. In the micaschists of Paso del Rey-Río de La Carpa, the entire overprint of an older planar fabric by these S_1-planes cannot be excluded. A sequential development of crenulations and porphyroblast growth (Bell and Rubenach, 1983), deformation partitioning (*sensu* Bell, 1985; Bell *et al.*, 1986), and reactivation of S_1-planes, however, could not be found. The detected crenulations are younger and overprint the S_1-planes (Fig. 16d, e).

Early metamorphism

The type and grade of the early metamorphism could not be determined precisely. Since no indications for staurolite were found, most of the sericite aggregates can be interpreted as former andalusites which are described by Ortiz Suárez (1988) from an area in the northeastern part of the Sierra. This is also supported by the finding of pre- to synkinematic andalusite in the La Florida area (Hack, 1987). It is possible that the formation of enclosed fibrolite took place via a "sericite" phase (Glen, 1979) or simultaneously with the present sericite aggregates (Woodland, 1963). The diffusion haloes in quartz-muscovite aggregates are indicative of thermally metamorphosed rocks where deformation was absent or very limited (Losert, 1968; Atherton, 1976). Since muscovite plates and aggregates plus enclosed fibrolite were deformed during D_1, their formation and the generation of diffusion haloes must have taken place before. There was no clear indication found that muscovite and fibrolite originated from former porphyroblasts (? andalusite and/or? cordierite) which could have led to an initial formation of diffusion haloes. This is supported by single sericite aggregates (? andalusite) which can occur in muscovite-quartz aggregates. Thus, the present interpretation suggests that an increase in temperature and (diffusional) mass transfer (Carmichael, 1969; Eugster, 1970; Kerrick, 1990) were responsible for the formation of (?) andalusite, fibrolite, muscovite, and the diffusion haloes. Some syn-kinematic porphyroblasts suggest a continuation of the heating during D_1 (Río de La Carpa, Río Luluara).

Given the growth of andalusite and later fibrolite, and assuming a position of the Al_2SiO_5 triple point midway between those of Holdaway (1971) and Richardson *et al.* (1969); compare also Kerrick (1990), then a $P<\sim 4.6$ kb and a $T>\sim 560°C$ for the maximum metamorphic overprint can be roughly estimated. In Río Luluara micaschists without fibrolite growth, the maximum metamorphic P-T was lower than at Paso del Rey and Río de La Carpa but higher than in the La Florida area (no fibrolite and a few sericite aggregates). This indicates a variable grade of early metamorphism within the micaschists.

The overprint in the Phyllite Group indicates a minimum temperature for the biotite zone. Based on the above evidence, the short distance, and the gradual transitions into the Micaschist Group in the Río Lulurara area, and comparable but variable temperature effects in the La Florida area, the present picture suggests a low-pressure and temperature-dominated metamorphism which can be related to heat transfer from intrusions in the subsurface. Lux *et al.* (1986) have shown that heat transfer from intrusions at intermediate crustal levels can be the cause for low-P/high-T metamorphism.

D_1-fabrics of the intrusions

In the Paso del Rey, La Capilla, Río Quinto Granite (Carugno Durán *et al.*, 1992), and Tamboreo Tonalite, S_1-planes are indicated by aligned and deformed magmatic muscovite and/or biotite which are recrystallized. Magmatic quartz is ductilely deformed in S_1-planes and partly to entirely replaced by single and mostly undeformed recrystallization grains. Single recrystallization grains in deformed plagioclase could be detected in the Paso del Rey and La Capilla Granite. In C_1-shear zones of the Tamboreo Tonalite, epidote and clinozoisite aside of sericite are concentrated in deformed and stretched plagioclase and are clustered in the matrix. There, static grain growth of quartz is widely distributed. Single sericite and muscovite randomly grew across aligned biotite while chlorite grew at the expense of biotite. The microfabrics in the ductile S_1-foliation planes/C_1-shear zones are directly comparable to those in the country rocks and pegmatites and point to an emplacement of the intrusions prior to the common D_1-deformation.

In the acid meta-magmatic layers, the S_1-foliation is recorded by aligned metamorphic sericite. Aside of a few hypidiomorphic quartz phenocrysts, and small alkali feldspar and plagioclase grains in the matrix, porphyroclasts of alkali feldspar are stretched and partly disrupted in the S_1-foliation. Single muscovite clasts are re-oriented, stretched, and recrystallized in S_1. In the matrix, quartz is dynamically recrystallized and can also display static equilibrium fabrics. Along the margins of ductilely deformed quartz clasts, recrystallization grains occur as well while smaller clasts are progressively to entirely replaced.

Post-D_1-fabrics and fault zones

Staurolite porphyroblasts, up to 3 mm long, were found in the *Micaschist Group* at one locality south of the Florida Lake (Fig. 16f). They enclose S_1-parallel layers as an S_i (quartz grains, opaque grains and needles). Static staurolite growth after D_1 partly followed S_1-foliation planes. The planar S_i of garnets is parallel to S_1 which is in accordance with that of staurolite. In other parts, however, garnet grew pre-D_1. Hence, some porphyroblasts (or parts of them) are stretched while idioblastic rims of others or entire grains are not affected by D_1. During the D_2-deformation, S_1-planes with staurolite porphyroblasts are crenulated between mica-rich S_2-planes which flow around staurolite edges. Afterwards, staurolite was partly replaced by sericite (± chlorite) aggregates (Fig. 16f). In some garnet porphyroblasts, an idioblastic rim overgrew S_2-planes.

In the deformed parts of the *La Florida Granite*, an alignment of biotite parallel to S_1 and ductile deformation of quartz are the most obvious indications of the D_1-event ($=D_2$ in the country rocks). In magmatic quartz and in some plagioclase and alkali feldspar grains, a few recrystallization grains could be detected.

In the micaschists, older muscovite and biotite are re-oriented in S_2-crenulation cleavage planes and are polygonally recrystallized in the hinge zones of F_2-crenulations folds. Sheared and flattened sericite aggregates are bent around F_2-crenulations (Fig. 16e) and, as quartz-muscovite aggregates, are affected by S_2 (Fig. 16g). Muscovite plates are slightly bent and partly replaced by sericite. S_2-planes are also recorded by aligned and recrystallized muscovite and biotite plates as well as new sericite, muscovite, biotite, and chlorite.

Within the western micaschists near and at the fault zone against the Phyllite Group east of Paso del Rey, garnet porphyroblasts with s-shaped S_i or idioblastic margins grew during or after the S_2-foliation development, respectively. At the tectonic contact in the La Florida area, garnet is rotated and affected by stretching while a slightly curved S_i in some porphyroblasts suggests that at least the rim grew during shearing. F_2-folds also overprint older garnets where rims grew syn- to post-D_2.

Between local S_2-crenulation cleavage planes in the *Phyllite Group*, biotite, muscovite, and sericite are bent or kinked. They are partly re-oriented parallel to S_2-planes where aligned chlorite also occurs. Just east of the fault against the western micaschists (Paso del Rey), sericite is aligned in S_1 and records polygonal F_1-hinges. In the eastern fault zone proper (Río de La Carpa), an S_2-crenulation cleavage within one thin section is depicted by aligned sericite/muscovite, biotite, and chlorite. There, recrystallization of biotite statically outlasts D_2. In the slice of dark phyllites at Riocito, a few small-scale F_2-crenulations display comparable textures. In the phyllites to the east, inclusion-free rims of garnet overgrew S_1-planes indicating that final growth outlasted D_1 under static conditions, comparable to the micaschists in the west. At Río Luluara, S_2-foliation planes in the shear zone of the phyllites are penetrative and partly record relics of crenulated S_1-planes. At Ao. de La Cal, however, the intense S_1-foliation is indicated by aligned sericite, biotite, and also chlorite as well as intensely flattened quartz layers.

In F_2-crenulation folds of the Phyllite and Micaschist Group, quartz records static equilibrium fabrics. Along the margins of large, ductilely deformed quartz statically grown recrystallization grains occur. Continuous heating led to the formation of fine-grained, granoblastic quartz mosaics with straight grain boundaries meeting at triple junctions. In the fault zones, the growth of recrystallization grains mostly outlasts shearing under static conditions. S_1-, S_2-planes, and F_2-crenulations, also in the fault zones, are overgrown by randomly oriented and undeformed biotite (Fig. 16h), chlorite, and muscovite/sericite.

Regional metamorphism

In the *Micaschist Group*, the regional metamorphic overprint during the *D_1-deformation* is indicated by the growth of garnet, muscovite, sericite, and biotite as well as recrystallization of quartz, biotite, and muscovite. Local recrystallization of feldspar suggests at least middle greenschist facies conditions. Staurolite growth in the interval between the D_1- and D_2-deformations south of the Florida Lake (east of the La Florida Granite) indicates local amphibolite facies conditions which could not be confirmed in the other study areas. Also a post-D_1 nucleation of some garnet porphyroblasts to the south and growth of garnet rims to the east of the Florida Lake make it possible to assume an increase in temperature from east to west which possibly was related to the intrusion of the La Florida Granite also in the subsurface. The microfabrics in the other intrusions and pegmatite dikes suggest that they were also affected by greenschist facies temperature conditions.

During the *D_2-deformation*, middle greenschist facies metamorphism continued and affected the *micaschists* as well as the La Florida Granite plus pegmatites. It is recorded by continuing recrystallization of quartz, ± feldspar, biotite, and muscovite. For the La Florida area, Hack (1987) reports a temperature of 440–450°C at a pressure of 2.07 kb based on biotite-garnet geothermometry. During the D_1- and D_2-deformation in the *Phyllite Group*, recrystallization of biotite, muscovite,

± feldspar (D_1), (continuing) growth of these phyllosilicates and ± garnet (D_1), as well as ductile deformation plus recrystallization of quartz, suggest comparable conditions of the middle greenschist facies (see also Carotti *et al.*, 1984).

Straightened boundaries between undeformed quartz recrystallization grains, growth of biotite and garnet rims, as well as biotite, muscovite, and chlorite porphyroblasts, suggest that within wide areas of the Micaschist and Phyllite Group, regional greenschist facies metamorphism statically outlasted the D_1-deformation, and in many parts, also the D_2-event. This shows that both units, together with the different magmatic rocks, were affected by regional metamorphism during and after the compressive deformations. It followed the initial metamorphic overprint and possibly was also of the low pressure type. The growth of chlorite continued through the final static branch of metamorphism after D_2 when it also partly to entirely replaced biotite and garnet. This indicates a decrease in temperature during and after the second deformation. In some parts of the phyllites and micaschists, as well as in parts of the fault and shear zones, however, deformation locally continued through the final branch of metamorphism and there synkinematic quartz fabrics occur.

INTERPRETATION OF THE PHYLLITE-MICASCHIST RELATIONS

In the La Florida area, the Tamboreo Tonalite intruded both undeformed clastic successions and led to the development of a contact aureole. Both groups contain layers of acid magmatics. One layer cuts across the contact with the tonalite and represents a dike. This shows that a deposition of the clastic sediments of the Phyllite Group *after* the first deformation plus metamorphism of the micaschists, and subsequent intrusion of the La Florida Granite with pegmatite dikes, is impossible.

This is supported by the gradual and short-distance transitions between phyllites and micaschists in the Río Luluara area which cannot be explained by a regional metamorphism. Since minerals of a higher grade of metamorphism are deformed (present sericite aggregates), the thermal overprint took place prior to and during the compressive deformation. As the Phyllite Group represents a continuous, NNE–SSW trending strip in the southwestern part of the Sierra de San Luis (Fig. 1), a comparable and initial, metamorphic transition to the Micaschist Group can be assumed also for the Paso del Rey-Río de La Carpa area. Hence, most of the phyllites and micaschists were part of one continuous crustal succession.

According to this interpretation, at least thin pegmatite dikes are expected to occur within the Phyllite Group. However, they are not reported from the Phyllite Group in the study areas and do not occur in the Tamboreo Tonalite and acid meta-magmatic layers. Hence, it can be assumed that the granites intruded only the deeper seated parts (micaschists) and did not reach the phyllites.

In the Paso del Rey-Río de La Carpa area, faulting of the micaschists took place during D_2 while equivalent fabrics in the Phyllite Group are F_1-syn- and anticlines with S_1-cleavage planes at Santo Domingo. Single S_2- and S_3-planes in the phyllites and micaschists, respectively, cut across the planar fabrics (Fig. 14) and can be related to final movements. At the eastern fault (Río de La Carpa), a second crenulation cleavage could be detected in the phyllites only in one thin section from the contact. Hence, an onset of displacements of both units during the D_1-event cannot be excluded. This is supported by the evidence from the La Florida area where ~ E-vergent F_1-folds in the micaschists and phyllites, single F_2-crenulations and S_2-planes in the phyllites, and comparable microfabric developments at the contacts do not rule out a common D_1-deformation of both units which continued during the D_2-event in the fault zones. Furthermore, continuous transitions between the Phyllite and Micaschist Group, fold interference patterns, and the shear zone in the Río Luluara area show that both units were affected by common deformations plus metamorphism. Thus, the D_1-event within the micaschists of the Paso del Rey-Río de La Carpa area probably took place in a deeper crustal level. As in La Florida, it is possible that it was separated from the D_2-deformation by a time interval.

The compressive deformations were combined with maximum temperature conditions of the middle greenschist facies, which persisted after active deformation ceased. A local amphibolite facies can be related to the post-D_1 intrusion of the La Florida Granite plus widely distributed pegmatites which possibly led to variable orientations of the metamorphic isogrades in the micaschists. Field studies suggest that reverse faulting was concentrated within distinct zones and is not everywhere related to the contact between the Phyllite and Micaschist Group. This shows that faults do not follow the boundaries between both units along their entire length through the Sierra.

TIMING OF EVENTS

With respect to age constraints on the magmatic activities within the Sierra de San Luis, several opinions exist which are mostly based on a few radiometric data. Hence, the interpretations below are preliminary. In the southwestern part of the Sierra de San Luis, the Bemberg Tonalite, having intruded the undeformed Phyllite Group (Sánchez *et al.*, 1996, v. Gosen, 1997), gave an Upper Cambrian-Lower Ordovician age (~513 Ma; Rb-Sr, whole rock errochron; Sato *et al.*, 1996). If one accepts a comparable time span for the intrusion of the Tamboreo Tonalite, then deposition of the turbiditic sediments of the Phyllite and parts of the Micaschist Group can be broadly compared with the age of the Puncoviscana Fm. s.l. of northwest Argentina (Prozzi, 1990) which covers the Late Precambrian — Early Cambrian time interval (Aceñolaza *et al.*, 1978; Toselli and Aceñolaza, 1978; Jezek *et al.*, 1985; Willner *et al.* 1987; Aceñolaza *et al.*

1988). This suggests that the initial metamorphism and following deformations plus regional metamorphism are of Ordovician and/or younger age.

Llambías *et al.* (1991) reported a Rb-Sr whole rock-isochron from the Paso del Rey Granite. They interpret the 454 ± 21 Ma as the age of emplacement during the Middle to Upper Ordovician. If this turns out to be true then first deformation and regional metamorphism of the micaschists and pegmatites, and also some granites, were younger and took place during Upper Ordovician and/or later times. On the other hand, the date could also reflect the first deformation plus metamorphism.

From the Río de La Carpa and Paso del Rey Granites, Varela *et al.* (1994) describe K-Ar biotite data (372 ± 20, 381 ± 13, and 391 ± 9 Ma). They can be related to the closure of the K-Ar system within the Lower to Middle Devonian interval. Given these data as indicators for the lower age limit of regional metamorphism, they can be interpreted to reflect the *end* of the thermal overprint after cessation of compressive deformation in the Micaschist and Phyllite Group with intercalated intrusives. This could suggest that the main deformations and accompanying regional metamorphism took place before one event within the Phyllite Group. Given the above data as preliminary indicators for the timing of deformation and metamorphism then a broad interval between the Upper Ordovician and Middle Devonian can be inferred.

It should be mentioned that Knüver and Miller (1981); Willner (1983) deduce a deformation and slight metamorphism during the Silurian in the Sierra de Ancasti. López *et al.* (1996) and Toselli *et al.* (1996) report Devonian mylonite formations in the basement to the east of the Famatina System. These observations suggest that important compressive movements in the Eastern Sierras Pampeanas continued through the Devonian.

REGIONAL IMPLICATIONS

In the Sierra de San Luis, the maximum thickness of the Phyllite Group can be estimated to reach 2.5 to 3 kms in the cross-section at Sto. Domingo. For the western strip of phyllites in the Sierra, an initial thickness of 3.5 kms was estimated south of La Carolina (v. Gosen and Prozzi, 1996). These preliminary data suggest that the turbiditic sequence was part of a large basin which covered higher grade basement rocks of the Eastern Sierras Pampeanas. Outside the Sierra de San Luis, phyllites occur at the western margin of the Sierras de Córdoba in the Sierra de Pocho (Hünicken and Pensa, 1980; Prozzi, 1990; Baldo *et al.* 1993). Their lithologies are directly comparable to those in the San Luis area. This also accounts for several intercalated acid meta-magmatic layers.

Additional occurrences of phyllitic rocks with conglomerates and acid magmatics in the Eastern Sierras Pampeanas to the north and northeast are summarized by Lucero Michaut (1979), Prozzi and Ortiz Suárez (1994, with further references); and Ramos *et al.* (1996). Although detailed comparisons of the different occurrences are lacking, these scattered localities suggest a large depositional area which can be connected with the Puncoviscana basin of northwest Argentina (Prozzi, 1990; Kraemer *et al.* 1995). This is supported by the fact that marbles have not been described in either the Phyllite or Micaschist Group of the Sierra de San Luis. However, they do occur in the Sierra de El Gigante to the west (Gardini, 1993) and in the Sierra del Morro-Oeste southeast of the Sierra de San Luis (Delakowitz *et al.* 1991).

Furthermore, the scattered occurrence of low grade rocks is possibly connected with higher grade units representing their lateral and/or vertical equivalents. This is shown by studies in northwest Argentina, where the (very) low grade successions of the Puncoviscana Fm. s.l. continuously pass southwards into higher grade metamorphic equivalents (Aceñolaza and Toselli, 1981; Willner *et al.*, 1987; Miller *et al.* 1994) with an increase in age from north to south (Adams *et al.* 1989). Short-distance metamorphic transitions also occur within single Sierras (e.g. Toselli and Oyarzabal, 1984), and the metamorphism in formerly deeper levels to the south is related to extensive magma intrusions (Miller *et al.*, 1994).

As shown above, the Phyllite Group of the Sierra de San Luis continuously passes into lithologic equivalents with an initially higher metamorphic overprint (Micaschist Group s.l.). Such short-distance transitions between different metamorphic complexes can be related to the initial intrusive activity of the Famatinian Cycle. The separation of these younger "cover sediments" from basement units, depicting a pre-Famatinian history, remains a problem. Complicated fold interference patterns, exposed in the Río Luluara and Cerros Largos areas, are not the result of an older "Pampean Orogeny", which was followed by deformation(s) during the "Famatinian Cycle", but belong to one continuous Famatinian compressive history with regional metamorphism. A general distinction between two orogenies in the Sierra de San Luis is difficult since no transgressive contact between the basement and the cover sediments is known yet. However, Llambías *et al.* (1996b) have shown that the Gasparillo Tonalite contains deformed xenoliths and they postulate a pre-Famatinian basement in the western part of the Sierra.

Although the timing of deposition of the Puncoviscana Fm. s.l. in northwest Argentina is broadly comparable to that of the Phyllite Group (plus parts of the Micaschist Group) in the Sierra de San Luis, their histories seem to have been different. The Pampean Orogeny during Middle Cambrian times (Aceñolaza *et al.*, 1978; Miller, 1984) led to compressive deformation of the Puncoviscana Fm. with a very-low to low grade metamorphism (Willner *et al.*, 1987). It is related to the collision of the Pampean Terrane with the Arequipa-Antofalla craton (see Ramos, 1988). Since the present evidence suggests that the Phyllite Group in the Sierra de San Luis was not affected by compressive deformation and regional metamorphism during the Pampean Orogeny, its position to the east of an evolving magmatic arc at the western terrane margin is possible (Vujovich, 1993; Vujovich *et al.* 1994).

The Famatinian Cycle (sensu Aceñolaza and Toselli, 1976) was characterized by an initial intrusive activity in the western part of the Sierra de San Luis which can be related to the formation of a wider magmatic arc (Ramos, 1991; Sato *et al.*, 1996) due to east-directed subduction beneath the western margin of the Pampean Terrane (Ramos, 1988, 1991; Vujovich *et al.*, 1994). Compressive deformation(s) and regional metamorphism, partly accompanied by intrusive activity, led to an irregularly distributed and complicated pattern of structures and metamorphic grades. They were the effects of the second (compressive) stage of the Famatinian Cycle which presumably falls in the Upper Ordovician to Middle Devonian time interval.

CONCLUSIONS

The structural and metamorphic evolution of the Phyllite and Micaschist Group in the central strip of the southwestern Sierra de San Luis can be summarized as follows:

1) The Tamboreo Tonalite intruded the undeformed sequences of the Phyllite and Micaschist Groups and led to the development of a contact aureole. The Paso del Rey Granite and associated pegmatite dikes are interpreted as pre-kinematic with respect to the D_1-event of the micaschists. The thermal climax of a first metamorphic overprint is indicated by the growth of large porphyroblasts (? andalusite) and fibrolitic sillimanite within the country rocks. A pre- to partly syn-deformational and variable metamorphism was found in all study areas and probably was caused by heat transfer from intrusions.
2) ~WNW–ESE compression with a regional greenschist facies metamorphism affected the Phyllite and Micaschist Group in all study areas. The older intrusions were deformed along with the country rocks. The La Florida Granite and associated pegmatite dikes, however, are interpreted to have intruded the micaschists after their first deformational event. Local staurolite growth in the La Florida area can be related to this intrusion. In many parts of the study areas, regional greenschist facies metamorphism outlasted the compressive deformations.
3) Contacts between both the Phyllite and Micaschist Group are either tectonic (Paso del Rey-Río de La Carpa, La Florida) or transitional (Río Luluara). Field relations in the Rio Luluara and La Florida areas, suggest that both groups were initially part of one continuous succession within the crustal profile.
4) Ductile reverse faults between both groups in the Paso del Rey-Río de La Carpa and La Florida areas suggest that parts of the Micaschist Group were originally in a deeper crustal position. The shear zone in the Río Luluara area shows that faults are not always localized at the boundaries between units. In the Paso del Rey-Rio de La Carpa area, the Micaschist Group was deformed once prior to the D_1-deformation with greenschist facies metamorphism in the Phyllite Group.
5) Steeply inclined reverse faults and fold structures do not record a single vergence. This is exemplified by complex fold interference patterns in the Río Luluara area. No gently inclined thrusts were found in the study areas. The regional significance of two single strike-slip faults in the Paso del Rey and Río Luluara areas has to be constrained by further studies.

A preliminary interpretation of some radiometric data suggests that deformation and greenschist facies metamorphism of the Phyllite and Micaschist Groups with intercalated magmatics occurred in the Upper Ordovician-Middle Devonian interval and can be related to the second stage of the Famatinian Cycle. After initial emplacement of plutons, these events led to the present configuration of the metamorphic complex.

The low grade rocks of the Sierra de San Luis can be compared with different occurrences in the Sierras Pampeanas basement complex to the north. They all probably were part of one large "Puncoviscana Basin" where deposition took place in the Late Precambrian-Early Cambrian interval. Due to short-distance transitions into higher grade metamorphic units, however, not only the low grade sequences were part of such a depositional realm. The complex and multi-stage tectonic, magmatic, and metamorphic evolution of the different units makes it difficult to reconstruct this basin and depict the clear contact with the pre-Famatinian basement complex. In contrast to the Puncoviscana trough in northwest Argentina, which was affected by the Pampean Orogeny, the Phyllite Group and related higher grade metamorphics of the Sierra de San Luis were only involved in Famatinian compression and metamorphism.

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REFERENCES

Aceñolaza, F.G., Miller, H. and Toselli, A. (1978). Das Altpaläozoikum der Anden Nordwest-Argentiniens und benachbarter Gebiete. *Münstersche Forschungen zur Geologie und Paläontologie, 44/45*, 189–204.

Aceñolaza, F.G., Miller, H. and Toselli, A.J. (1988). The Puncoviscana Formation (Late Precambrian — Early Cambrian). Sedimentology, tectonometamorphic history and age of the oldest rocks of NW Argentina. In H. Bahlburg, C. Breitkreuz and P. Giese (Eds.), *The Southern Central Andes*. Lecture Notes in Earth Sciences *17*, 25–37.

Aceñolaza, F.G. and Toselli, A.J. (1976). Consideraciones estratigráficas y tectónicas sobre el Paleozoico inferior del Noroeste Argentino. *Memoria II. Congreso Latinoamericano de Geología, Actas, 2* (1973), 755–764.

Aceñolaza, F.G. and Toselli, A.J. (1981). Geología del noroeste argentino. *Publicaciones Facultad de Ciencias Naturales, Universidad Nacional de Tucum, 1287*, 1–212.

Adams, C., Miller, H. and Toselli, A. (1989). New K-Ar Ages on the Metamorphic History of the Puncoviscana Formation and Equivalents, NW Argentina. *Zentralblatt f*, ür Geologie und Paläontologie, Teil I, *1989*(5/6), 987–997.

Atherton, M.P. (1976). Crystal growth models in metamorphic tectonites. *Philosophical Transactions of the Royal Society of London, A283*, 255–270.

Baldo, E.G.A., Schmidt, C., Bertolini, S. and Martinez, M. (1993). Características estructurales y petrográficas de las filitas del borde occidental de la Sierra de Pocho, Córdoba. *IX. Reunión Microtectónica (Mendoza, 13 de Octobre de 1993), Resumenes*, 2 pp.

Bell, T.H. (1985). Deformation partitioning and porphyroblast rotation in metamorphic rocks: a radical reinterpretation. *Journal of Metamorphic Geology, 3*, 109–118.

Bell, T.H. and Rubenach, M.J. (1983). Sequential porphyroblast growth and crenulation cleavage development during progressive deformation. *Tectonophysics, 92*, 171–194.

Bell, T.H., Rubenach, M.J. and Fleming, P.D. (1986). Porphyroblast nucleation, growth and dissolution in regional metamorphic rocks as a function of deformation partitioning during foliation development. *Journal of Metamorphic Geology, 4*, 37–67.

Brodtkorb, M.K. de. (ed.) (1991). Geología de yacimientos de wolframio de las Provincias de San Luis y Córdoba Argentina. *Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata, 1*, 196.

Brodtkorb, M.K. de, Pezzutti, N.E. and Dalla Salda, L.H. (1984). Presencia de vulcanismo ácido en el Precámbrico de la Provincia de San Luis. *IX. Congreso Geológico Argentino, Actas, II*, 181–190.

Brogioni, N. (1987). El batolito de Las Chacras — Piedras Coloradas, Provincia de San Luis, geología y edad. *X. Congreso Geológico Argentino*, Actas, *4*, 115–118.

Brogioni, N. (1992). Geología del batolito de Las Chacras — Piedras Coloradas Provincia de San Luis. *Revista del Museo de La Plata (Nueva Serie), Sección Geología, 11*, 1–16.

Brogioni, N. (1993). El batolito de Las Chacras-Piedras Coloradas, Provincia de San Luis geocronología Rb-Sr y ambiente tectonico. *XII. Congreso Geológico Argentino y II.* Congreso de Exploración de Hidrocarburos, Actas, *4*, 54–60.

Brogioni, N. and Ribot, A. (1994). Petrología de los cuerpos La Melada y La Gruta, faja máfica-ultramáfica del borde oriental de la Sierra de San Luis. *Revista de la Asociación Geológica Argentina, 49*(3-4), 269–283.

Brogioni, N., Parrini, P. and Pecchioni, E. (1994). Magmatismo pre y syn-colisional en el cordon de El Realito, Sierra de San Luis, Argentina. *7. Congreso Geológico Chileno*, Actas, *II*, 962–966.

Caminos, R. (1973). Some granites, gneisses and metamorphites of Argentina. *Special Publication of the Geological Society of South Africa, 3*, 333–338.

Caminos, R. (1979). Sierras Pampeanas Noroccidentales Salta, Tucuman, Catamarca, La Rioja y San Juan. *Segundo Simposio de Geolog*, ía Regional Argentina (Academia Nacional de Ciencias, Córdoba), *I*, 225–291.

Carmichael, D.M. (1969). On the mechanism of prograde metamorphic reactions in quartz-bearing pelitic rocks. *Contributions to Mineralogy and Petrology, 20*, 244–267.

Carotti, M., Conde Serra, A.R., Mallaviabarrena, M. and Rinaldi, C.A. (1984). Características de los yacimientos de Scheelita de la Pampa del Tamboreo, Provincia de San Luis. *IX. Congreso Geológico Argentino*, Actas, *VII*, 220–230.

Carugno Durán, A., Ortiz Suárez, A. and Prozzi, C. (1992). Deformación en granitoides del Río Quinto, Provincia de San Luis. *VIII. Reunión Microtectónica (Bariloche), Actas*, 83–86.

Cucchi, R.J. (1964). Análisis estructural de cuarcitas y granulitas bandeadas miloníticas de la Sierra de San Luis. *Revista de la Asociación, Geológica Argentina, 19*(3), 135–150.

Dalla Salda, L. (1987). Basement tectonics of the southern Pampean Ranges, Argentina. *Tectonics, 6*(3), 249–260.

Delakowitz, B. (1988). Geologisch-geochemische-lagerstättenkundliche Untersuchungen zur Genese von Wolframlagerstätten in der Sierra del Morro-Oeste, Provinz San Luis, Argentinien. *Münchner Geowissenschaftliche Abhandlungen*, Reihe, *B4*, 1–108.

Delakowitz, B., Höll, R., Hack, M., Brodtkorb, M.K. de and Stärk, H. (1991). Geological and geochemical studies of the Sierra del Morro-Oeste (San Luis Province, Argentina): Meta-sediments and meta-volcanics from a probable back-arc setting. *Journal of South American Earth Sciences, 4*(3), 189–200.

Eugster, H.P. (1970). Thermal and ionic equilibria among muscovite, k-feldspar and alumosilicate assemblages. *Fortschritte der Mineralogie, 47*(1), 106–123.

Fernandez, R., Pezzutti, N. and Brodtkorb, M.K. de (1991). Geología, petrografía y yacimientos entre Pampa de Tamboreo-Paso del Rey-Santo Domingo, Provincia de San Luis. In: M.K. de Brodtkorb (Ed.), *Geología de yacimientos de Wolframio de las Provincias de San Luis y Córdoba, Argentina*. Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata 1, 153–170.

Gardini, C.E. (1993). La estructura íntima del basamento de la Sierra de el Gigante, San Luis. *XII. Congreso Geológico Argentino y II.* Congreso de Exploración de Hidrocarburos, Actas, *III*, 1–10.

Glen, R.A. (1979). Evidence for cyclic reactions between andalusite, "sericite" and sillimanite, Mount Franks area, Willyama Complex, N.S.W.. *Tectonophysics, 58*, 97–112.

González Bonorino, F. (1961). Petrología de algunos cuerpos básicos de San Luis y las granulitas asociadas. *Revista de la Asociación Geológica Argentina, 16*(1-2), 61–106.

Gosen, W. von (1997). Transpressive deformation in the southwestern part of the Sierra de San Luis (Sierras Pampeanas, Argentina). *Journal of South American Earth Sciences* [submitted].

Gosen, W. von and Prozzi, C. (1996). Geology, Structure, and Metamorphism in the area south of La Carolina (Sierra de San Luis, Argentina). *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos Actas, *II*, 301–314.

Hack, M. (1987). Geologisch-geochemisch-lagerstättenkundliche Untersuchungen zur Genese von Wolframlagerstätten in der Pampa del Tamboreo, Provinz San Luis, Argentinien. *Münchner Geowissenschaftliche Abhandlungen*, Reihe, *B1*, 1–108.

Hack, M., Brodtkorb, M.K. de, Höll, R. and Brodtkorb, A. (1991). Geología y consideraciones genéticas de los yacimientos scheelíticos entre el Dique La Florida y Pampa del Tamboreo, Provincia de San Luis. In: M.K. de Brodtkorb (Ed.), *Geología de yacimientos de Wolframio de las Provincias de San Luis y Córdoba, Argentina*. Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata 1, 113–152.

Halpern, M., Linares, E. and Latorre, C.O. (1970). Estudio preliminar por el método estroncio-rubidio de rocas metamórficas y graníticas de la Provincia de San Luis, República Argentina. *Revista de la Asociación Geológica Argentina*, *25*(3), 293–302.

Holdaway, M.J. (1971). Stability of andalusite and the Aluminum silicate phase diagram. *American Journal of Science*, *271*, 97–131.

Hünicken, M.A., Azcuy, C.L. and Pensa, M.V. (1981). Sedimentitas Paleozoicas. In: M. Yrigoyen (Ed.), *Geología y recursos naturales de la Provincia de San Luis*. VIII. Congreso Geológico Argentino, Relatorio, 55–77.

Hünicken, M.A. and Pensa, M.V. (1980). Estratigrafía y tectónica de las sedimentitas neopaleozoicas (Formación Chancaní) y de las filitas (Formación La Mermela) del borde occidental de las Sierras de Pocho y Guasapampa (Provincia de Córdoba Republica Argentina). *Boletín de la Academia Nacional de Ciencias*, Córdoba, *53*(3-4), 255–279.

Ježek, P., Willner, A.O., Aaceñolaza, F.G. and Miller, H. (1985). The Puncoviscana trough — a large basin of Late Precambrian to Early Cambrian age on the Pacific edge of the Brazilian shield. *Geologische Rundschau*, *74*(3), 573–584.

Jordan, T.E., Zeitler, P., Ramos, V. and Gleadow, A.J.W. (1989). Thermochronometric data on the development of the basement peneplain in the Sierras Pampeanas, Argentina. *Journal of South American Earth Sciences*, *2*(3), 207–222.

Kerrick, D.M. (1990). The Al_2SiO_5 Polymorphs. *Reviews in Mineralogy*, *22*, 406

Kerrick, D.M., Lasaga, A.C. and Raeburn, S.P. (1991). Kinetics of heterogeneous reactions. In D.M. Kerrick (Ed.), *Contact metamorphism*. Reviews in Mineralogy, *26*, 583–671

Kilmurray, J.O. (1982). Estructura y petrología de la region de Trapiche, Dique La Florida, Provincia de San Luis, Argentina. *V. Congreso Latinoamericano de Geología, Argentina*, Actas, *II*, 239–249.

Kilmurray, J.O. and Dalla Salda, L. (1977). Caracteres estructurales y petrológicos de la region central y sur de la Sierra de San Luis. *Obra del Centenario del Museo de La Plata*, *IV*, 167–178.

Kilmurray, J.O. and Villar, L.M. (1981). El basamento de la Sierra de San Luis y su petrologia. In M. Yrigoyen (Ed.), *Geología y recursos naturales de la Provincia de San Luis*. VIII. Congreso Geológico Argentino, Relatorio, 33–54.

Knüver, M. and Miller, H. (1981). Ages of metamorphic and deformational events in the Sierra de Ancasti (Pampean Ranges; Argentina). *Geologische Rundschau*, *70*(3), 1020–1029.

Kraemer, P.E., Escayola, M.P. and Martino, R.D. (1995). Hipótesis sobre la evolución tectónica neoproterozoica de las Sierras Pampeanas de Córdoba (30°40'–32°40'), Argentina. *Revista de la Asociación Geológica Argentina*, *50*(1-4), 47–59.

Linares, E. (1981). Catálogo de edades radimétricas determinadas para la República Argentina, IV-Años 1979–1980. Catálogo de edades radimétricas de Argentina realizadas por INGEIS y sin publicar, III-Años 1977–1978. *Publicaciones especiales de la Asociación Geológica Argentina*, Serie B (Didáctica y Complementaria), *10*, 1–63.

Linares, E. and Latorre, C.O. (1969). Edades potasio-argón y plomo-alfa de rocas graníticas de las Provincias de Córdoba y de San Luis. *IV. Jornadas Geológicas Argentinas*, Actas, *II*, 195–204.

Linares, E. and Latorre, C.O. (1973). Nuevas edades radimétricas por el método potasio-argón, de rocas graníticas de Córdoba y San Luis. *V. Congreso Geológico Argentino*, Actas, *1*, 405–410.

Llambías, E., Cingolani, C., Varela, R., Prozzi, C., Ortiz, A., Caminos, R., Toselli, A. and Saavedra, J. 1991. Leucogranodioritas sincinemáticas ordovícicas en la Sierra de San Luis, República Argentina. *6. Congreso Geológico Chileno, Resúmenes Ampliados*, pp, 187–191.

Llambías, E.J. and Malvicini, L. (1982). Geología y génesis de los yacimientos de Tungsteno de las Sierras del Morro, los Morillos y Yulto, Provincia de San Luis. *Revista de la Asociación Geológica Argentina*, *37*(1), 100–143.

Llambías, E.J., Quenardelle, S., Ortiz Suárez, A. and Prozzi, C. (1996). Granitoides sin-cinematicos de la Sierra Central de San Luis. *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos, Actas, *III*, 487–496.

Llambías, E.J., Sato, A.M., Prozzi, C. and Sánchez, V. (1996). Los pendants de gneises en el plutón Gasparillo: evidencia de un metamorfismo pre-famatiniano en las Sierras de San Luis. *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos, Actas, *V*, 369–376.

López, J.P., Durand, F.R. and Toselli, A.J. (1996). Zonas de cizalla en el flanco noroccidental de la Sierra de Velasco, La Rioja, Argentina. *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos, Actas, *II*, 179–185.

Losert, J. (1968). On the genesis of nodular sillimanitic rocks. *XIII. International Geological Congress*, *4*, 109–122.

Lucero Michaut, H.N. (1979). Sierras Pampeanas del norte de Córdoba, sur de Santiago del Estero, borde oriental de Catamarca y ángulo sudeste de Tucuman. *Segundo Simposio de Geología Regional Argentina (Academia Nacional de Ciencias, Córdoba)*, *I*, 293–347.

Lux, D.R., DeYoreo, J.J., Guldotti, C.V. and Decker, E.R. (1986). Role of plutonism in low-pressure metamorphic belt formation. *Nature*, *323*, 794–797.

Malvicini, L. and Brogioni, N. (1992). El yacimiento hidrotermal de níquel, cobre y metales del "Grupo del Platino", Las Aguilas Este, Prov. de San Luis, Argentina. *IV. Congreso Nacional de Geología Económica, I. Congreso Latinoamericano de Geología Económica, Actas*, pp, 93–102.

Miller, H. (1984). Orogenic development of the Argentinian/Chilean Andes during the Palaeozoic. *Journal of the Geological Society London*, *141*, 885–892.

Miller, H., Toselli, A.J., Rossi de Toselli, M.J. and Aceñolaza, F.G. (1994). Regional and geochronological development of the metamorphic basement in Northwest Argentina. *Zentralblatt für Geologie und Paläontologie*, Teil I, *1993*(1/2), 263–273.

Ortiz Suárez, A.E. (1988). El basamento de Las Aguadas, Provincia de San Luis. *Revista de la Asociación Argentina de Mineralogía, Petrología y Sedimentología*, *19*(1/4), 13–24.

Ortiz Suárez, A., Prozzi, C. and Llambías, E.J. (1992). Geología de la parte sur de la Sierra de San Luis y granitoides asociados, Argentina. *Estudios Geologicos*, *48*(5-6), 269–277.

Ortiz Suárez, A. and Ramos, G. (1990). Estructura del perfil Santo Domingo — La Arenilla, Provincia de San Luis, República Argentina. *XI. Congreso Geológico Argentino*, Actas, *II*, 387–390.

Ortiz Suárez, A.E. and Sosa, G.M. (1991). Relaciones geneticas entre las pegmatitas portadoras de estaño y metamorfitas asociadas en la zona de La Carolina/San Francisco del Monte de Oro. Provincia de San Luis. *Revista de la Asociación Geológica Argentina*, *44*(3-4), 339–343.

Paterson, S.R. and Vernon, R.H. (1995). Bursting the bubble of ballooning plutons: A return to nested diapirs emplaced by multiple processes. *Geological Society of America Bulletin*, *107*(11), 1356–1380.

Paterson, S.R., Vernon, R.H. and Fowler, T.K., Jr. (1991). Aureole tectonics. In D.M. Kerrick (Ed.), *Contact Metamorphism*. Reviews in Mineralogy *26*, 673–722.

Prozzi, C.R. (1990). Consideraciones acerca del basamento de San Luis, Argentina. *XI Congreso Geológico Argentino Actas*, *I*, 452–455.

Prozzi, C. and Ortiz Suárez, A. (1994). Rocas metamórficas de bajo grado en las Sierras Pampeanas (Argentina). *7. Congreso Geológico Chileno*, Actas, *II*, 1167–1171.

Prozzi, C., Ortiz Suárez, A., Ulacco, H., Ramos, G., Lacreu, H., Carugno, A., Aguilera, D. and Caviedes, J. (1992). Características geológicas y técnicas de las lajas (filitas) de la provincia de San Luis. *IV. Congreso Nacional de Geologia Económica, I. Congreso Latino americano de Geología Económica, Actas*, pp. 467–476.

Prozzi, C.R. and Ramos, G. (1988). La Formación San Luis. *Primeras Jornadas de Trabajo de Sierras Pampeanas*. (San Luis, 24 al 26 de Agosto de 1988), Abstract, p. 1.

Ramos, G., Prozzi, C. and Ortiz Suárez, A. (1996). Conglomerados del basamento de Sierras Pampeanas. *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos, Actas, *I*, 607–617.

Ramos, V.A. (1988). Late Proterozoic-Early Paleozoic of South America — a collisional history. *Episodes*, *11*(3), 168–174.

Ramos, V.A. (1991). Los ambientes tectonicos de los distritos wolframiferos de las Sierras Pampeanas. In M.K. de Brodtkorb (Ed.) *Geologia de yacimientos de Wolframio de las Provincias de San Luis y Córdoba, Argentina*. Publicación del Instituto de Recursos Minerales, Universidad Nacional de La Plata *1*, 185–196.

Rapela, C.W., Coira, B., Toselli, A. and Saavedra, J. (1992a). El magmatismo del Paleozoico Inferior en el Sudoeste de Gondwana. In J.G. Gutiérrez Marco, J. Saavedra and I. Rabano (Eds.), *Paleozoico Inferior de Ibero-America*. Universidad de Extremadura (Mérida), 21–68.

Rapela, C.W., Coira, B., Toselli, A. and Saavedra, J. (1992b). The Lower Paleozoic magmatism of southwestern Gondwana and the evolution of the Famatinian Orogen. *International Geology Review*, *34*(11), 1081–1142.

Richardson, S.W., Gilbert, M.C. and Bell, P.M. (1969). Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria; the aluminum silicate triple point. *American Journal of Science*, *267*, 259–272.

Sabalúa, J., Chabert, M. and Santamaria, G. (1981). Mineralización de sulfuros de hierro, cobre y níquel, en el cuerpo básico de las Aguilas, Provincia de San Luis. *VIII. Congreso Geológico Argentino*, Actas, *IV*, 497–507.

Sánchez, V., Ortiz Suárez, A. and Prozzi, C. (1996). Geología y petrografia de la Tonalita Bemberg, Provincia de San Luis. *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos, Actas, *IV*, 669–677.

Santa Cruz, J.N. (1980). Edades K-Ar de rocas del area de las cuencas de los Ríos Quinto y Conlara, Provincia de San Luis. *Revista de la Asociación Geológica Argentina*, *35*(3), 434–435.

Sato, A.M. (1993). Deformación de la tonalita pre-cinematica de Las Verbenas, Sierra de San Luis, Argentina. *I. Simposio Internacional del Neoproterozoico-Cambrico de la Cuenca del Plata (La Paloma / Uruguay)*, *1*(25), 1–5.

Sato, A. and Llambias, E. (1994). Granitoides pre-cinematicos del sur de la Sierra de San Luis, Argentina. *7. Congreso Geológico Chileno*, Actas, *II*, 1200–1204.

Sato, A.M., Ortiz Suárez, A., Llambías, E.J., Cavarozzi, C.E., Sánchez, V., Varela, R. and Prozzi, C. (1996). Los plutones pre-ocloyicos del sur de la Sierra de San Luis: Arco magmático al inicio del Ciclo Famatiniano. *XIII. Congreso Geológico Argentino y III.* Congreso de Exploración de Hidrocarburos, Actas, *V*, 259–272.

Toselli, A.J. and Aceñolaza, F.G. (1978). Geocronología de las Formaciones Puncoviscana y Suncho, Provincias de Salta y Catamarca. *Revista de la Asociación Geológica Argentina*, *33*(1), 76–80.

Toselli, A.J., Durand, F.R., Rossi de Toselli, J.N. and Saavedra, J. (1996). Esquema de evolución geotectónica y magmática eopaleozoica del Sistema de Famatina y sectores de Sierras Pampeanas. *XIII. Congreso Geológico Argentina y III.* Congreso de Exploración de Hidrocarburos, Actas, *V*, 443–462.

Toselli, A.J. and Oyarzabal, F. (1984). Relacion de la Formación Puncoviscana con el basamento metamórfico de la Sierra de Quilmes. *Revista de la Asociación Geológica Argentina*, *34*(1-2), 156–157.

Varela, R., Llambías, E., Cingolani, C. and Sato, A. (1994). Datación de algunos granitoides de la Sierra de San Luis (Argentina) e interpretación evolutiva. *7. Congreso Geológico Chileno*, Actas, *II*, 1249–1253.

Vernon, R.H. (1988). Microstructural evidence of rotation and non-rotation of mica-porphyroblasts. *Journal of Metamorphic Geology*, *6*, 595–601.

Vujovich, G.I. (1993). Arcos magmáticos islándicos en el sector occidental del terreno Pampia. *XII. Congreso Geológico Argentina y II.* Congreso de Exploración de Hidrocarburos, Actas, *IV*, 16–22.

Vujovich, G., Miller, H. and Ramos, V.A. (1994). Proterozoic metavolcanics from western Sierras Pampeanas terrane, Argentina. *Journal of South American Earth Sciences*, *7*(3/4), 309–323.

Willner, A.P. (1983). Geología de la Sierra de Ancasti. — 11. Evolución metamórfica. *Münstersche Forschungen zur Geologie und Paläontologie*, *59*, 189–200.

Willner, A.P., Lottner, U.S. and Miller, H. (1987) Early Paleozoic structural development in the NW Argentine basement of the Andes and its implication for geodynamic reconstructions. In G.D. McKenzie (Ed.) *Gondwana Six: Structure, Tectonics, and Geophysics*. Geophysical Monograph *40*, 229–239.

Woodland, B.G. (1963). A petrographic study of thermally metamorphosed pelitic rocks in the Burke area, northeastern Vermont. *American Journal of Science*, *261*, 354–375.

Zardini, R.A. (1966). Composición, estructura y origen del plutón de la Pampa del Tamboreo (Provincia de San Luis). *Acta Geológica Lilloana*, *VIII*, 49–73.