Brittle-ductile Transition Zone in the Northern Bergell Alps

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With 8 figures

Zusammenfassung

Entlang des nördlichen Kontaktes des Bergeller Granits ändert sich der Deformationsstil von plastisch verformten Myloniten (Amphibolitfazies) im Westen (Val Bondasca) zum spröden Bruch (Grünschieferfazies) im Osten (Maloja). Der Übergang wird mit großstrukturellen Beobachtungen, Gefügedaten und Mikrostrukturen belegt die andeuten, daß Versetzungen in der Margneta-Maloja-Casaccia-Region mit der Platznahme des Bergeller Granits zusammenhängen und sich nur bis Isola erstrecken. Sie werden deshalb nicht mit großräumigen Transversalverschiebungen assoziiert („Engadiner Linie").

Abstract

Along the northern contact of Bergell granite the style of deformation changes from ductile mylonites at high metamorphic grade (amphibolite facies) in the west (Val Bondasca) to brittle faulting at low grade (greenschist facies) in the east (Maloja). This transition is documented with large scale structural observations, petrofabric data and microstructure which suggest that faulting in the Margneta-Maloja-Casaccia region is related to emplacement of the Bergell granite, and not extending beyond Isola, rather than to a large-scale strike slip fault ("Engadine Line").

Résumé

Le long du contact septentrional du granite de Bergell, le style de la déformation change, depuis des mylonites ductiles à haut degré métamorphique dans l'Ouest (Val Bondasca) (facies amphibolite) jusqu'à une fracturation à degré de métamorphisme peu élevé (facies schiste vert) dans l'Est (Maloja). La transition est apportée par des observations de structures macroscopiques, de textures et de microstructures, qui suggèrent que les déplacements dans la région sont liés à l'emplacement du granite de Begell et finissent vers Isola. Ils ne sont donc pas associés à un système de failles transversales de grande extension (ligne de l'Engadine).

Краткое содержание

Вдоль северного контакта гранитов Бергелля изменяется стиль деформации от пластически преобразованных милонитов (фаций амфиболитов) на западе – Вадь Бондаска – до хрупких разломов (фаций зеленого сланца) на востоке – Малойа. Переход установлен по макроструктуре, структурам и микроструктуре, наблюдения за которыми показали, что смещение в районе Маргнета – Малойа – Касаччия связано с внедрением гранитов Бергелля и простирается до Изолы. Поэтому это смещение не связывают с крупномасштабными трансверзальными сдвигами (линия Энгадина).

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Introduction

It has been generally recognized that there are considerable unconformities between the northeastern part of Bergell igneous rocks and their immediate metamorphic contact and the low grade Pennine nappes north of it (e.g., STAUB, 1946). More recently these dislocations have been attributed to a large strike-slip fault system which has been called the Engadine Line. The purpose of this note is to contribute some structural petrographic data which bear on possible offsets along a fault system in the Bergell Valley and Upper Engadine, particularly in the vicinity of Maloja Pass.

The present day morphology displays a more or less linear valley system extending from Chiavenna in the SW over 120 km to Prutz in the NE. TRÜMPY studied stratigraphy and tectonics in the Lower Engadine and reinterpreted the offset between the Silvretta crystalline and the S-charl dolomites in the Stragliavita Pass area as due to a more or less left lateral displacement of 20–30 km along a subvertical fault system (TRÜMPY and SCHLUSCHE, 1972) rather than a thrustfault (e.g., STAUB, 1937). While other researchers attributed faulting to local shearing (EUGSTER, 1971) or to vertical rather than lateral displacements related to the uplift of the Lower Engadine window (SCHMID, 1973), TÜMPY generalized his concept to the whole extent of the morphologic zone and introduced the term "Engadine Line". He concluded that the Engadine Line constitutes a left lateral normal fault with an average displacement of 15–20 km (TRÜMPY, 1977 b). According to TRÜMPY, most of the deformation is contained in cataclastic shear zones and only occasionally in folding (Mezzaun-Murtiröl antiform) (e.g., TRÜMPY and SCHLUSCHE, 1972). But he does not exclude that regional plastic deformation of Bergell granite and in fact emplacement of the Bergell granite in early Tertiary are a consequence of faulting along the Engadine Line (TRÜMPY, 1977 b). The Bergell segment of the potential fault is particularly interesting because there are some good exposures and it is structurally relatively well investigated (SCHMUTZ, 1976; WENK, 1973). In most places Quaternary covers the valley floor, which complicates or facilitates interpretation, depending on the viewpoint. Only at Promontogno-Val Bondasca (cross section 4 of WENK, 1973) and at Maloja Pass can a continuous section across the fault be mapped.

Val Bondasca

The first section proceeds from platy albite-alkalifeldspar gneisses in the quarries at Promontogno through augengneisses (see WENK et al. 1977) with an increase in metamorphic grade. At Marlun, andalusite-cordierite schists are exposed which together with ultramafics and amphibolites, constitute the border series to the Gruf migmatites. SCHMUTZ (1976), who mapped the mafic-ultramafic rocks between Val Bondasca and Chiavenna, visualized the contact between Gruf migmatites and ultramafics as a fault contact produced by young postmetamorphic shear zones with lateral displacements (p. 55) but did not attribute them to the Engadine Line. He emphasized occurrence of mylonitic textures in rocks of the border zone, using "mylonite" to describe cataclastic features. As has been shown (WENK, 1973), mylonites are not confined to the Gruf-Chiavenna complex contact but occur through Tambo augengneisses, Gruf migmatites (most spectacularly at Botta. della Tegiola), and well into the Bergell granite over a section of more than 5 km. In these mylonites there is intense plastic deformation, particularly of quartz which is fully recrystallized and recovered (Liddel et al., 1976), and mylonites must be considered as metamorphic rocks which formed at elevated temperature. This is evident on the microscopic (Fig. 1 a) and submicroscopic scale (Fig. 1 b). Relic rounded feldspars are embedded in a fine quartz matrix while in quartz all dislocations have climbed into low energy configurations. High metamorphic grade is documented by frequent occurrence of sillimanite needles. Also, plastic rather than cataclastic deformation is indicated by extreme preferred orientation in quartzite layers. Textures are of the single crystal type with c axes of quartz lying in the plane of foliation normal to the lineation (Bunge and Wenk, 1977). There is a limited degree of freedom of rotation of a axes, as can be seen by the great circle distribution in 11$\bar{2}$0 pole-figures (Figs. 2 b–d). Interestingly, most of the textures are triclinic with respect to mesoscopic coordinates. Compared with a simple quartzite mylonite texture from Palm Canyon in the Peninsular Ranges of Southern California (Fig. 2 a), in the Bergell mylonites a axes great circles are rotated to variable degrees into the foliation plane, leaving asymmetric tails behind (Figs. 2 c, d). It is attributed to rotations by simple shear which was locally heterogeneous, depending, among other factors, on the thickness of the quartz bands (see also Lister and Williams, 1979). Rotations of up to 60° were observed. The shear direction coincides with the fabric direction a and is perpendicular to the regional direction of fold axes and lineations (l). Lineations and pencil features in the mylonites are parallel to the regional lineations and fold-axes and are therefore assigned to the same general event of deformation which includes emplacement of the mostly crystallized Bergell granite and uplift and folding of the Gruf complex. Clearly these mylonites were not formed by a post-metamorphic cataclastic process and compare well with classical mylonites of the Moine thrust (Christie, 1963) or the Santa Rosa Mountain shear zone (Theodore, 1970). There are some local cataclastic shear zones, particularly at contacts with ultramafic rocks. Lubricating talc layers were active during tectonic deformation and during recent movements providing glide surfaces for landslides (e.g., Ganda Rossa, Piuro). In Val Bondasca there is no indication for major offsets in petrographic units or in metamorphic zones, but since both are more or less parallel to the implied Engadine Line, geometric arguments are not conclusive.

There are some late, north-south running shear zones, such as Val d'Erch, Cant de la Ganda, Vallun de la Trubinasca, and Val Casnaggina, which crosscut geological units but show no significant offset and are also not affected by the Engadine Line (Wenk and Cornelius, 1977).

Rocks in the Bondasca cross section are strongly deformed, but *pentratively*, rather than on a single fault plane. This indicates that the viscosity of the material was low and plastic deformation dominated.

Maloja Region

A second interesting area lies between Casaccia and Sils. Between Lavinair Crusc and L'Ala, highgrade metamorphic rocks of the granite contact are juxtaposed with low grade schists. Albite is the only plagioclase north of this line

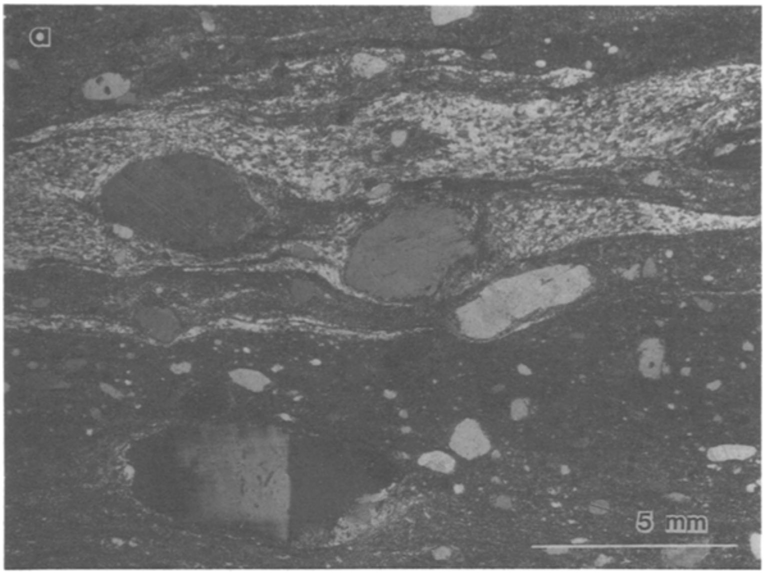

Fig. 1 a. Photomicrograph of mylonite Sci 293 from Botta. Tegiola. Notice fine-grained micaceous matrix with rounded plagioclase and alkalifeldspar clasts. Quartz is in bands or forms tails behind plagioclase. It is extremely fine grained and shows strong preferred orientation indicating plastic deformation. Crossed polars.

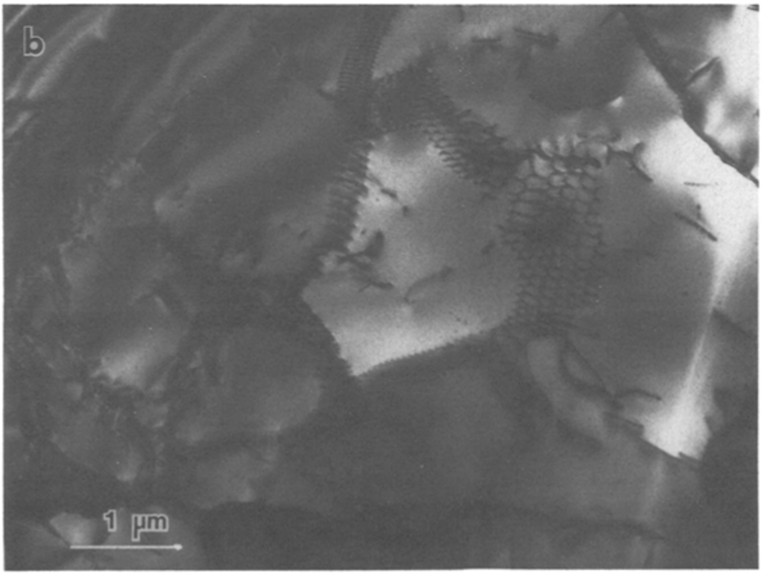

Fig. 1 b. Microstructure of quartz in Sci 293 with polygonization due to dynamic recrystallization. Subgrains are separated by dislocation networks. Dislocation density inside the subgrains is low. Such microstructures are typical of high temperature deformation. TEM brightfield micrograph, 100 KV.

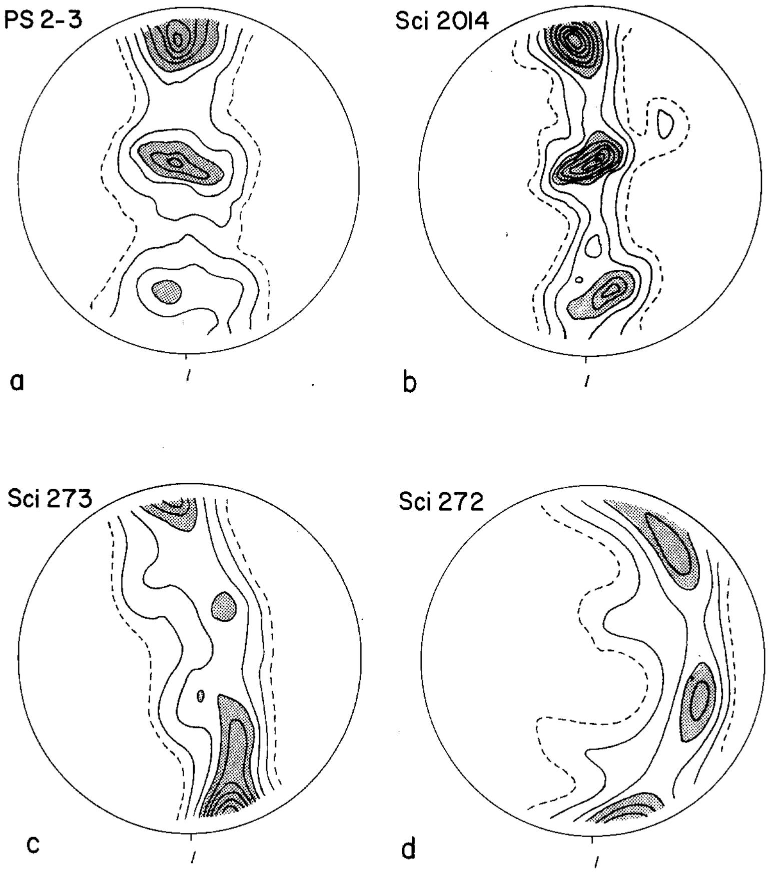

Fig. 2. Textures of mylonitic quartzites. $11\bar{2}0$ X-ray pole-figures measured in reflection scans. (a) For comparison symmetric texture from the Santa Rosa Mountain shear zone, Palm Canyon, Southern California. (b–d) Quartzite bands from Botta. Tegiola with various amounts of simple shear which distorts the highly symmetric pattern and introduces a rotation of the a axes great circle into the schistosity plane. Equal area projection on the well developed schistosity plane. Lineation direction (l) is indicated. Contours in multiples of random distribution. 0.5 (dashed)-1-2-3-4-5-6-7-8. Concentrations > 3 m.r.d. are shaded.

Fig. 3. View from P. Salacina towards the Engadine. La Margneta is to the right with folded layers visible. A fault extends in the valley to the right of L'Ala and is indicated with a dashed line (center). Notice the white dolomite beds extending from Blaunca (left) to Crap da Chüern (cliffs at Lake), cliffs at the corner of the delta and towards Isola.

(GAUTSCHI, 1980; WENK, 1979). GYR (1967) and NIEVERGELT (1981) have attributed this jump in grade to displacements along the Engadine Line.

A fault in this section can hardly be denied. It can be documented by field mapping the rock series on either side of Lej da Segl. Dolomite beds provide good markers. An extensive bed from Muotta Radonda-Blaunca-Sasc da Corn on the north side of the lake has a striking counterpart on the south side, east of Isola, and from there into Val Fedoz (Figs. 3 and 4). A small cliff at the tip of the delta northwest of Isola fits right into this zone. The view from Blaunca confirms that there cannot be any sizeable offset if this is the same bed. Dolomites on either side of the lake have the same composition and are deformed. They show distinct but weak preferred orientation with c-aces lying normal to the bedding plane and a axes displaying a concentration in the lineation direction (Fig. 5)

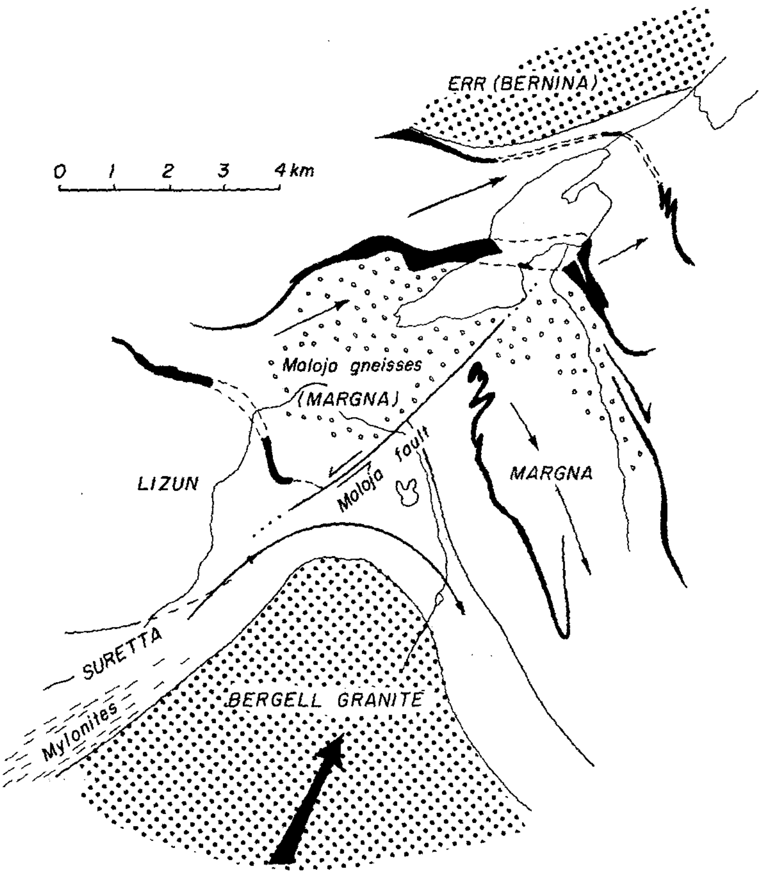

Fig. 4. Geological-structural sketch map of the Maloja area. Carbonate beds are indicated in black. Main systems of fold axes and lineations are shown by arrows and some tectonic units are indicated. Heavy arrow gives probable emplacement direction of Bergell granite. North ist towards top, use Sils Lake for geographic reference.

probably resulting from activation of the (0001) ⟨ 11$\bar{2}$0 ⟩ slip system. But there are other dolomites, as indicated on the geological sketch map (Fig. 4). The correlation across the lake has to be maintained by the stratigraphy, which is supportive. On both sides we find underneath the dolomite a large sequence of characteristic Maloja gneisses (Staub, 1946) with alternating chlorite schists and albite-sericite-microcline conglomerate gneisses. Above the dolomites are ophiolites, graphitic schists, and more carbonate beds. The stratigraphy is very different across other carbonate beds such as that at La Margneta-Plan Fond (south of the Line) or that of Piz Blanch-Alpe Scela-Casaccia-Plan dal Mot. Both of these latter beds end at the Line and have no continuation. They may correlate, which

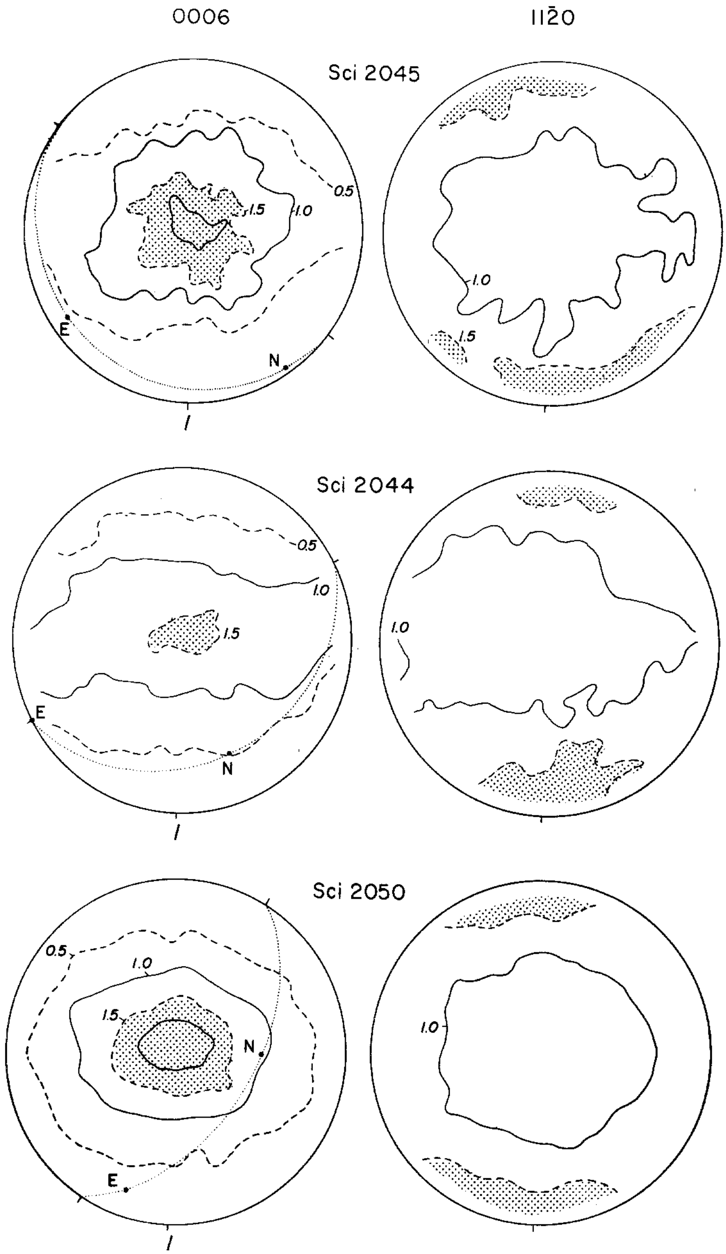

Fig. 5. Textures of dolomite on both sides of Lej da Segl. 0006 and 11$\bar{2}$0 X-ray pole-figures measured in reflection scans. Sci 2045 500 m NE of Isola. Sci 2044 Pt. 1806.8, 600 m NW of Isola. Sci 2050 Crap da Chüern. Equal area projection of upper hemisphere on the schistosity plane. Lineation (l), and the horizontal plane (dotted circle) with N and E are indicated. Contours in multiples of a random distribution 0.5 (dashed)-1.0-1.5(dashed)-2.0. Concentrations > 1.5 are shaded.

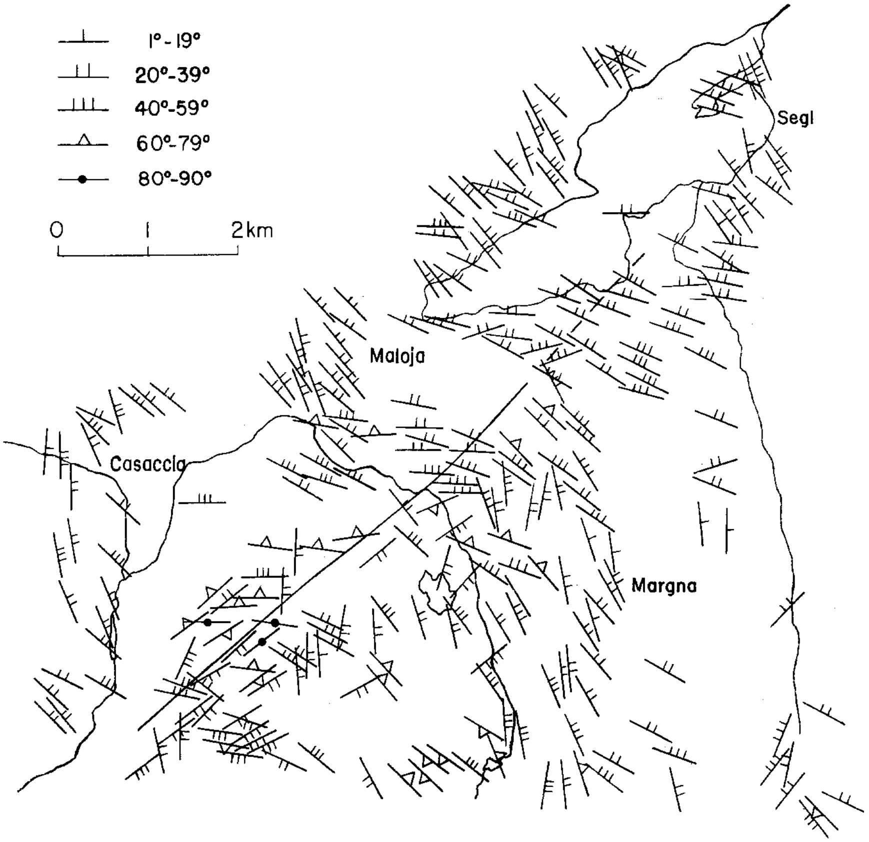

Fig. 6. Map of planar structures. The trace of the Maloja fault is indicated.

would signify an offset of 4 km for this segment between Casaccia and Maloja but more or less zero offset at Isola. Structures support such a concept (Figs. 6–7).

The area under investigation can be conveniently divided into four sectors (Fig. 8). Structures north of the Engadine Line are very uniform over a large area from Casaccia to Sils (Fig. 8 a). Foliations dip gently (30–40°) to the northeast. There are two types of lineations, A_1 an A_2, one plunging east and the other northeast, outlined by dashed circles. Generally only one lineation is apparent at a given outcrop, but occasionally both can be distinguished, though their age relation is rather ambiguous and has not been studied in detail. An almost identical pattern is observed in the region south of the Engadine Line in the eastern sector Valacia-Ca d'Starnam-Isola-Fex (Fig. 8 b), indicating that at least not

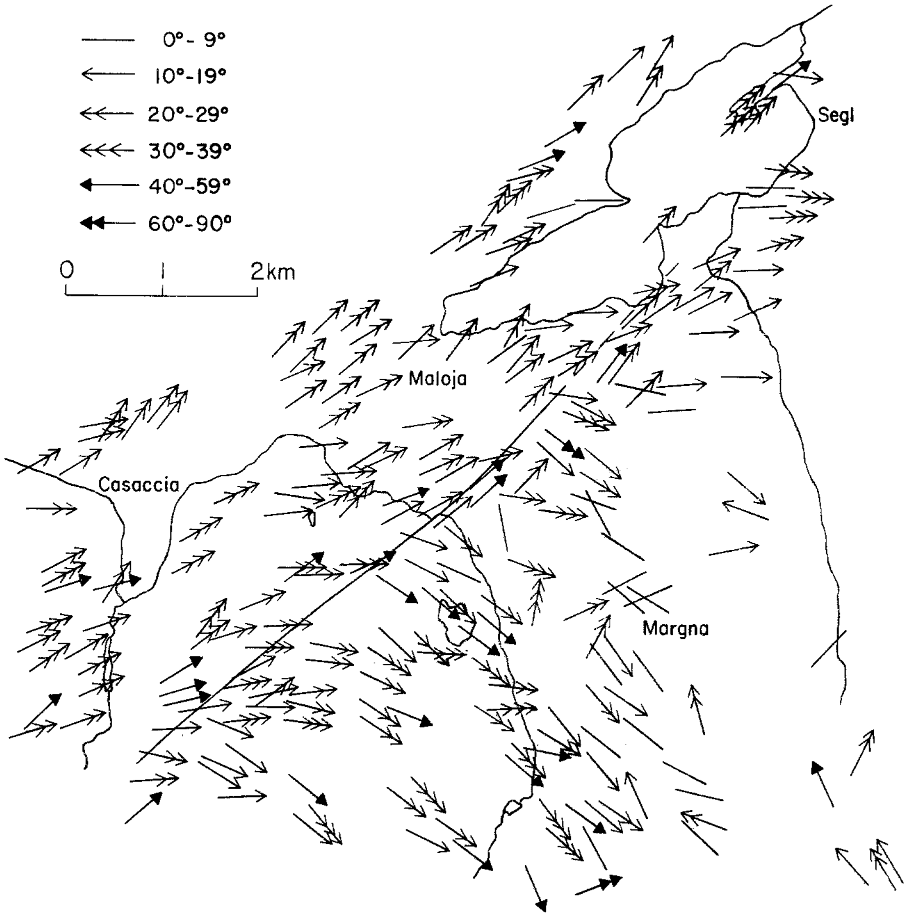

Fig. 7. Map of linear structure. The trace of the Maloja fault is indicated.

much "wrench faulting" has occurred between the two sides. Progressing farther west on the southern side (Margneta-Margna-Fedoz, east of Orlegna), the pattern changes, by adding to the previous distribution southeast trending lineations and fold axes (Fig. 8 c). Rocks here have been southwest-northeast compressed and are penetratively folded (illustrated best in the structures of carbonate beds below La Margneta, Fig. 3). The same system dominates west of the Orlegna (Cavloccio-Salacina), with more open folds, as expressed in the larger scatter of foliation poles (Fig. 8 d). Ever farther west lineations gradually bend into the east-northeast plunging system (Fig. 7), which is the major structure in most of the Western Bergell Alps as far as Chiavenna (WENK, 1973).

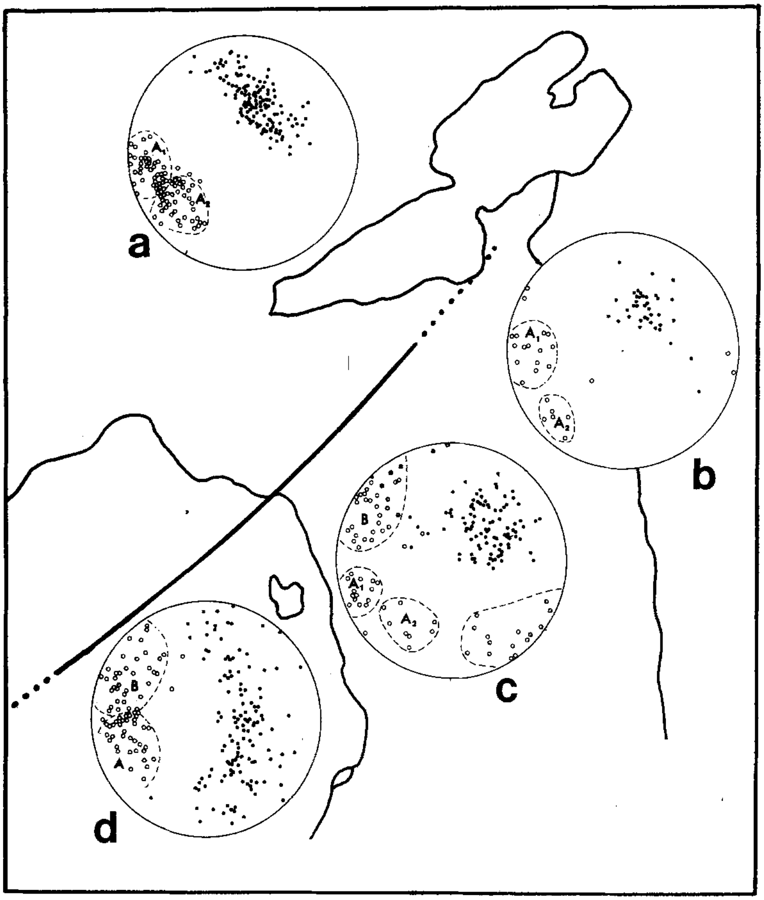

Fig. 8. Diagrams of planar (dots) and linear (open circles) structures in various sectors of the Maloja region. Patterns a and b are very similar, while patterns c and d show a second system of NW–SE trending fold axes (B).

Discussion

Large normal faults which extend over hundreds of kilometers and are thought to represent major tectonic dislocations in the crust usually display a similar strike slip offset over their whole extent, i.e., the offset does not change from 20 km to nothing over a short distance. Also they generally do not pass straight through brittle low grade rocks and ductile high grade rocks. In the latter, strain would most likely be accommodated in a different way. The Insubric Line separating the Southern Alps from the Pennine Alps or the San Andreas fault in California are such examples. On the other hand, local faults related to thrust movements of nappes or emplacements of plutons distribute strain more heterogeneously by folding. It is this latter type which, in my view, applies to the Maloja offset. In fact, rocks of la Margneta are strongly folded, as seen both on the geological map (Fig. 5) and the structural maps (Figs. 6 and 7) and in structure diagrams (Figs. 8 c, d), quite in contrast to rocks north of the Line. If we correlate the above mentioned marbles, this would mean that between Casaccia and Isola a sequence of 8 km (measured horizontally) has been shortened to 4 km, a great deal of it by folding but some by thrusting and a general steepening of the beds in the Margna series. To my knowledge there is no geologic evidence to support a large left-lateral displacement in this region. By reversing strain alpine cordierite, kyanite, andalusite and sillimanite in Val Bondasca would have originated in the Engadine and andesitic dikes at Lizun (NIEVERGELT and DIETRICH, 1977) and Maloja (WENK, 1980) could hardly be related to Bergell granite. Also, because of the easterly plunge, it would juxtapose lower Pennine nappes with Austroalpine units.

It is thought that the final emplacement of Bergell granite is responsible both for the ductile deformation and for brittle faulting in the region between Promontogno and Maloja. Shearing along the northern contact produced mylonites in the highly metamorphic western part and faulting in the eastern part. The traverse represents an excellent example of a brittle/ductile transition zone over 10 km at similar pressure (5 kb in the west and 2–3 kb in the east) as implied from metamorphic grade (WENK et al., 1976) but with a large change in temperature.

The northeastern contact zone was subject to compressive strain with folding in the Margna and Muretto area. The change of style in the accommodation of strain is mainly due to the matamorphic grade. Bergell granite and surrounding rocks were relatively strong in the northeast corner and caused dominantly brittle deformation during emplacement. Fault formation and petrographic characteristics of the fault contact can best be studied between L'Ala and Orden (just south of the bridge) and in Lavinair Crusc.

These conclusions should be considered as a result of a preliminary reconnaissance and are therefore hypothetical. They need to be substantiated further by detailed structural analysis of the region Orden-Ala-Margneta-Margna. The purpose of this note is to add data and some new thoughts for consideration in the wrench fault discussion. Based on this analysis, it is proposed that the dislocation in the Maloja region be called "Maloja fault" rather than "Engadine Line".

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