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Pseudotachylite Zones in the Leventina Gneiss (Lepontine Alps, Ticino, Switzerland)

by *Alfred Irouschek*[1] and *Martin Huber*[2]

Abstract

At several localities in the top of the Leventina unit pseudotachylite zones have been found and are being investigated. In this preliminary report some of their characteristic features in the field and under the microscope are described.

Zusammenfassung

Im Dach des Leventina-Kristallins wurden an verschiedenen Lokalitäten Pseudotachylitzonen festgestellt. Charakteristische Eigenschaften dieser Gesteine im Feld und im Dünnschliff werden in dieser Mitteilung beschrieben; detaillierte Untersuchungen sind im Gange.

INTRODUCTION

The term *'pseudotachylite'* has first been used by SHAND (1916) to characterize a dark, very fine-grained rock which forms the matrix of a breccia or intrudes as thin veinlets the surrounding granitic gneiss near Parijs (South Africa) and has the isotropic, dense appearance of a volcanic glass (tachylite). A long list of descriptions of similar rocks has accumulated in the literature under different names: *'flinty crush rock'* (CLOUGH, 1888), *'trap-shotten gneiss'* (HOLLAND, 1900), *'purée parfait'* (TERMIER & BOUSSAC, 1911), *'hyalomylonite'* (SCOTT & DREVER, 1953), *'fused mylonite'* (SHAND, 1916), *'Gangmylonit'* (HAMMER, 1914; BEARTH, 1933).

From the different names used for (apparently) the same rock it becomes evident that the various authors had contrasting modes of formation in mind. With the growing number of descriptions of pseudotachylite from different geological environments the controversial origin of this very special rock has attracted

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the attention of many geologists. All authors have come to the conclusion that the origin has somehow to be connected with very fast movements on discrete (fault) planes, but it is a disputed question if the rocks really melted during this brittle deformation. The opinions can be grouped in two main classes: 1) *melting* occurred; the heat being generated either by 1 a) *shock deformation* connected with *meteorite impacts* (e.g. WILSHIRE, 1971) or by 1b) *friction* during *sliding* on a fault plane, probably occurring during earthquakes ("seismic slip", SIBSON, 1975). 2) *Extreme cataclasis* occurred (without melting); the finely pulverized material, that was injected into fractures (and subsequently recrystallized), originated by 2a) *grinding* of rocks against each other ("crush rocks", CLOUGH, 1888) or by 2b) *spallation* of unsupported crack walls (WENK & WEISS, 1982). A further model (3) proposed by REYNOLDS (1954) suggests the existence of hot gases passing through fine-grained solid particles, eroding them and facilitating their chemical reaction. This process of *'fluidization'* combines the existence of cataclastic processes (to form the original "micro-breccia") and melting (to a limited degree).

Much of the earlier work has been summarized by PHILPOTTS (1964), HIGGINS (1971) and FRANCIS (1972). Based on the assumption that a range of the types of pseudotachylite described above exists in the nature, PHILPOTTS (1964) proposed a terminology, namely 1) *pseudotachylites s. str.* (formed by frictional fusion) and 2) *ultracataclasites* (formed by extreme "mylonitization"). Because of the fact that probably a complete gradation between these types exists (ALLEN, 1979) and because it is impossible to use the criteria in the field, we believe that such a genetic terminology is undesirable. We prefer therefore the descriptive term *pseudotachylite* for all these rocks of unknown origin. Terms like hyalo*mylonites*, fused *mylonites*, etc. have the disadvantage that the terminology of mylonitic rock is currently being revised and many definitions will have to be replaced. *Mylonites* are not anymore believed to be the purely brittle product of the grinding of one side of the thrust against the other, as it was originally assumed by LAPWORTH (1885) (see also e.g. HIGGINS, 1971). Today one of the main characteristics of mylonites, the strong foliation, is generally attributed to high *ductile strain* (crystal plasticity) and to synchronous dynamic recrystallization, which gives rise to the small grain size. We would agree with the revised definition as it is proposed by HATCHER (1978, p. 581[1]). If such a definition is adopted one can no longer call a pseudotachylitic rock a "mylonite", but should rather use the term "cataclasite", a fine grained dense rock, which has

[1] "A mylonite is a strongly foliated metamorphic rock that exhibits characteristics of high ductile strain and incomplete recovery, such as megacrysts flattened and extended into the foliation and ribbon quartz (which may now be microscopically recovered). Diminution of grain size is characteristic of this process. Zones of mylonitic deformation may be discrete planar zones or may gradually merge with adjacent nonmylonitic rocks."

formed by brittle processes, but did not loose its cohesion (compare e.g. ZAWADYNSKI, (1952). A precise use of these terms is especially necessary because pseudotachylites are often associated with mylonites and cataclasites. This *association with tectonically formed rocks* and the respective structures like fault zones, has been taken by many authors as distinctive feature of pseudotachylite. This may be correct for most of the occurrences (as in the case of the outcrops described here), but contrasting environments as in the case of the Parijs pseudotachylites (meteorite impact?, WILSHIRE, 1971), or in the case of large landslides (MASCH, 1979) have also to be considered.

If the various authors disagree on many points of conditions and mechanisms of formation (e.g. depth of formation, role of water, association with seismic processes), one can still find a general agreement about the *main features that characterize the pseudotachylites*. It is commonly found that these rocks show the following characteristics: The dark or black, dense rock of aphanitic appearance occurs either as matrix of breccia (in zones up to 2 m width) or as fine veins (0.2 to 5 cm in width), which show a typical "fault/injection vein" habit (compare SIBSON, 1975). They are either concordant or discordant to the foliation of the host rock (esp. granite, gneiss, amphibolite) and generally have sharp margins. The fact that the pseudotachylites show no trace of the fabric of the host rock makes them distinguishable from rocks with a similar flinty appearance in the field (ultramylonites), which normally have a strong shape fabric. The nearly isotropic, glass-like matrix contains sparse porphyroclasts of quartz and feldspar or (in wider zones) rock fragments. In the matrix microlitic chill textures, spherulites and devitrification structures may develop, but the identification is often very difficult because in many localities a late recrystallization has destroyed the primary features.

GEOLOGICAL SETTING

The lower parts of the steep hillsides which border the Leventina valley between Faido and Biasca (Ticino, Switzerland) are made up by crystalline rocks of the *Leventina* unit which belongs to the deepest parts of the Lepontine Alps. Fig. 1 shows that the dominant rock types are relatively homogeneous granitic gneisses and streaky augen gneisses. The augen gneisses pass often into schistose gneisses. In the upper part of the Leventina unit laminated to finely banded gneisses become more abundant and, at the boundary to the overlying units, a relatively consistent layer of quartzite occurs.

In the frontal part of the Leventina unit the gneisses are strongly folded in the North; but more to the South, in the investigated area, they become gradually less folded and show generally a subhorizontal banding. The foliation dips on both sides of the valley very gently away from the axis of the valley, which here corresponds more or less to the axis of the so-called *'Ticino culmination'*.

The Leventina gneiss is overlain in the East by gneisses of the Simano nappe and in the West by similar gneisses, which by different authors are correlated either with the Simano or with the Campo Tencia nappe. All these tectonic units have been grouped together by MILNES (1974) as the *'Subpenninic complex'*. We will consider here the respective nappes as distinct tectonic units, even if the similar aspect of the gneisses makes a clear distinction difficult.

A schematic cross-section across the Leventina valley near Biasca (Fig. 1) shows that the uppermost part of the Leventina gneiss is often separated from the overlying units by a zone of streaky augen gneiss and schistose gneisses and that the line of separation coincides normally with a quartzite horizon. Below the augen gneiss occur laminated to finely banded gneisses in a zone of some hundreds of metres that can be followed along both sides of the valley. Some of the rocks of this zone show the characteristics of mylonites described from large ductile shear zones.

In the finely banded gneisses pseudotachylites have been found by one of us (A. I.) at several localities. These localities are from N to S (Fig. 1): Valle d'Usèdi (820 m), ridge crest between Val Fouda and Val Cramosino (1020 m), Val Nedra (1040–1100 m), Val d'Ambra (920 m). Other pseudotachylites have been found in boulders in Valle di Ronco (above 950 m). Definite proof that these outcrops form a continuous horizon could not yet be found, as the outcrops are not easily accessible and often covered by hill slide material or forest. Until now the corresponding pseudotachylite outcrops on the eastern side of the Leventina valley have not been located.

To our knowledge similar occurrences of pseudotachylite have not been described before from the Lepontine Alps North of the "root zone". The only description which possibly accords to such rocks is found in CASASOPRA (1939), who investigated the granitic gneisses of the Leventina valley. He described black to greenish rocks with veins, consisting of a very fine-grained, dense micro-breccia which has recrystallized. Pseudotachylites have been found in Val d'Ambra, from where they have been described by CASASOPRA (under the name of "purée parfait" after TERMIER), but the direct correspondence could not be proven.

Other descriptions of possible pseudotachylites in the Lepontine Alps are restricted to the root zone. From Onsernone valley ZAWADYNSKI (1952) has described networks of fine-grained veins, which he called *'Gang-'* or *'Aderkataklasite'* (avoiding the term "mylonite" which he correctly attributes to a foliated rock), and recently such rocks have been reported also from several other outcrops N of the Insubric Line.

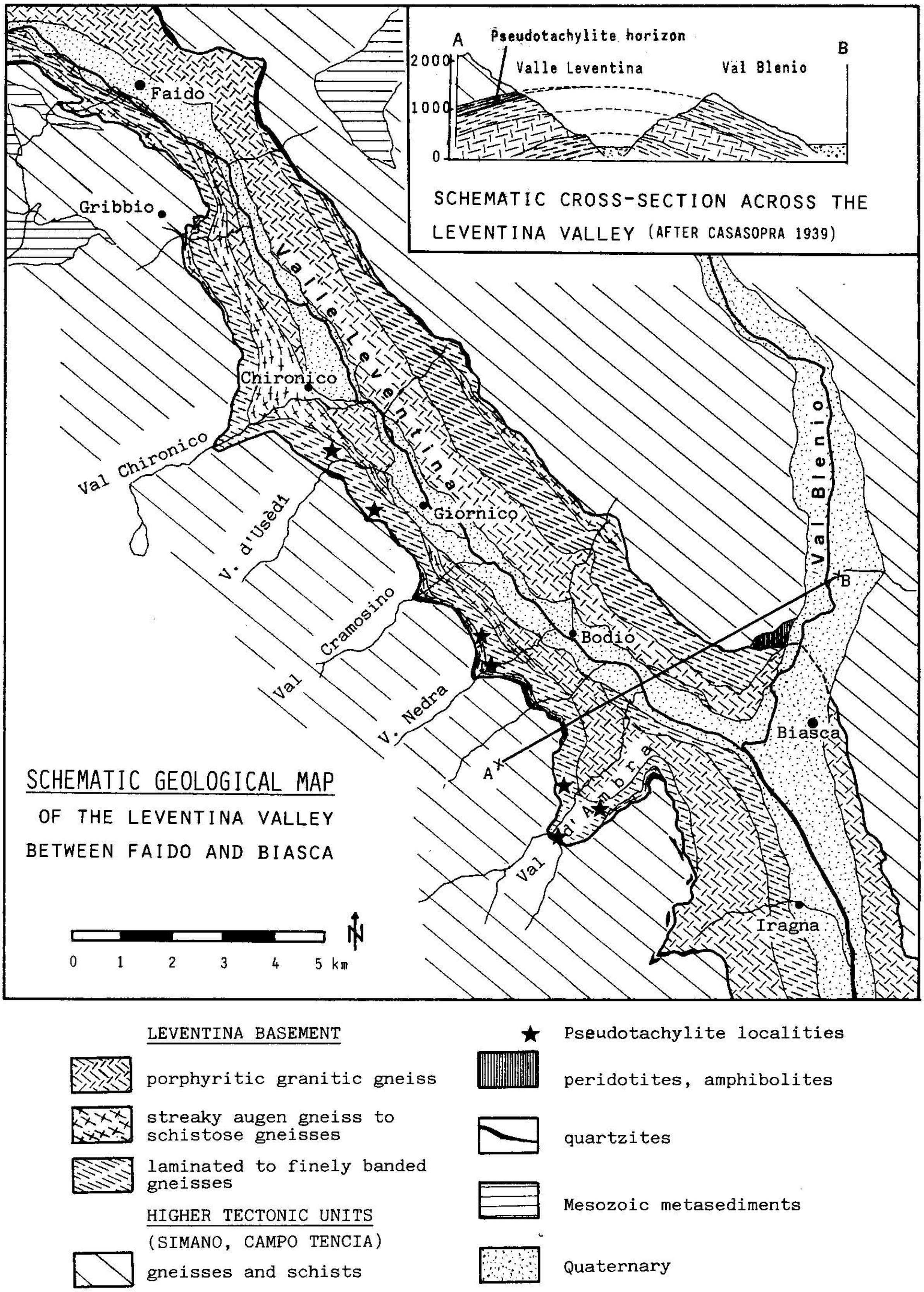


Fig. 1 Geological sketchmap of the Leventina valley between Faido and Biasca; stars indicate locations of pseudotachylite zones. Inset shows a schematic cross-section across the valley North of Biasca (after CASASOPRA, 1939, t. 7).

outcrop face subvertical, SSW striking. : laminated to streaky grey gneisses

0.15 m : fine grained, mica rich dark schist

fracture planes subvertical, E or SE striking. 0.30 m : streaky light grey gneiss

pseudotachylite 0.5 - 1.5 cm (splits into a pair of veins)

foliation 242/11 (dip azimuth / dip angle) 2.20 m : finely laminated light grey gneiss

1.2 m

'paired shears'

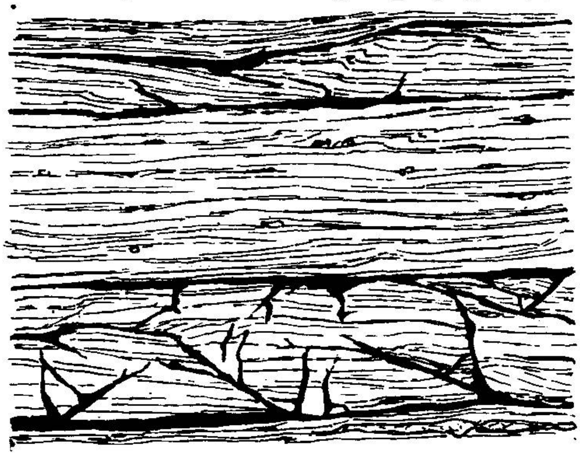
injection veins SW/50-70, NW/30-60

0.8 m

0.4 m

'brecciated zone'

0 m



foliation 230/12 1.35 m : laminated (- streaky) grey gneiss

subparallel to fol.: pseudotachylite 0.2 - 2 cm

0.50 m : laminated grey gneiss (as above)

pseudotachylite 1 cm

1.50 m : relatively homogeneous fine grained gn.

1.00 m : dito, with large quartz lenses

1.20 m : laminated to finely banded gneisses

2.0 m

pseudotachylite

irregular "flow"folds

kink bands axial planes 355/50 1.6 m

foliation SW - WSW/7-15

1.2 m

few inj. veins(250/65) pseudotachylite*)

*) This ps't of 'fault vein' typus changes laterally into a 'brecciated zone' of some cm width.

pseudotachylite (see also Fig.3)

0.4 m

0 m

Fig. 2 Geological relations between grey gneisses of the Leventina and pseudotachylite zones of different aspects (single "fault veins", "paired shears", "brecciated zones"). Val Nedra 1060 m–1075 m.

FIELD RELATIONS

In many localities the pseudotachylites may not be recognized as such in the field; the true nature of these rock is only recognized in thin-section (see e.g. ALLEN, 1979). The macroscopic description in this paper concentrates mainly on the outcrops in Val Nedra between 1040 and 1100 metres, where in the river bed exceptionnaly good outcrops are found. The terminology used to describe the field aspect of these rocks is that proposed by SIBSON (1975, Fig. 2; 1977).

Fig. 2 illustrates a zone of ca. 15 metres of strongly foliated to laminated gneisses at point 1060 m in the river bed. The host rock is a grey gneiss which breaks in layers of cm to dm thickness parallel to the foliation. The foliation, which gives a strong anisotropy to the rock, dips rather constantly with 5 to 15 degrees towards SW. Locally it is deformed by large, conjugate kink bands with steep axial planes and moderately plunging fold axes. Irregular folds occur in distinct zones.

The pseudotachylite horizons run often for several metres subparallel to the foliation before they cut in ramp-like manner discordantly through the gneiss. The existence of ramps and irregular folds makes the relationships between pseudotachylite zone and foliation of the host rock vary from local concordance to local discordance.

We tried in our investigations of the field relations to establish general geometric features of separate types of pseudotachylite zones. We found in our precursory investigatons that it is impossible to classify the pseudotachylite zones in a simple way into distinct classes. The pseudotachylite zones in any outcrop may change their aspect in a vertical sense from vein to vein (Fig. 2) and, more important, they may do so also laterally. A fault vein with very few injection veins (Fig. 3) can gradually show an increasing number of offshoots (Fig. 4) and finally change the character into a breccia-zone where the pseudotachylite fills the space between angular rock fragments (Fig. 5). Often a single fault vein may split into a pair of more or less parallel veins. Our preliminary results do not show a consistent pattern for the geometry of the injection veins and for the related fractures. GROCOTT (1981) described pseudotachylite "generation zones" where the shear fractures have the same geometry as fracture sets developed in shear experiments. Such an agreement either with experimental or theoretical predictions was not found in the examples described here. This lack of agreement is not the result of a subsequent deformation as in other examples (e.g. PASSCHIER, 1982), as we do not find signs of such a superposed plastic deformation. Late brittle fractures have not displaced the pseudotachylites by any substantial amount.

The thickness of the pseudotachylite zones varies between 0.2 cm to 40 cm (for single fault veins or for brecciated zones respectively). Because of the lack of reliable markers the displacement along the fault veins can only be estimat-

Fig. 3 Pseudotachylitic fault vein with two injection veins intruding finely banded gneiss. Val Nedra 1060 m.

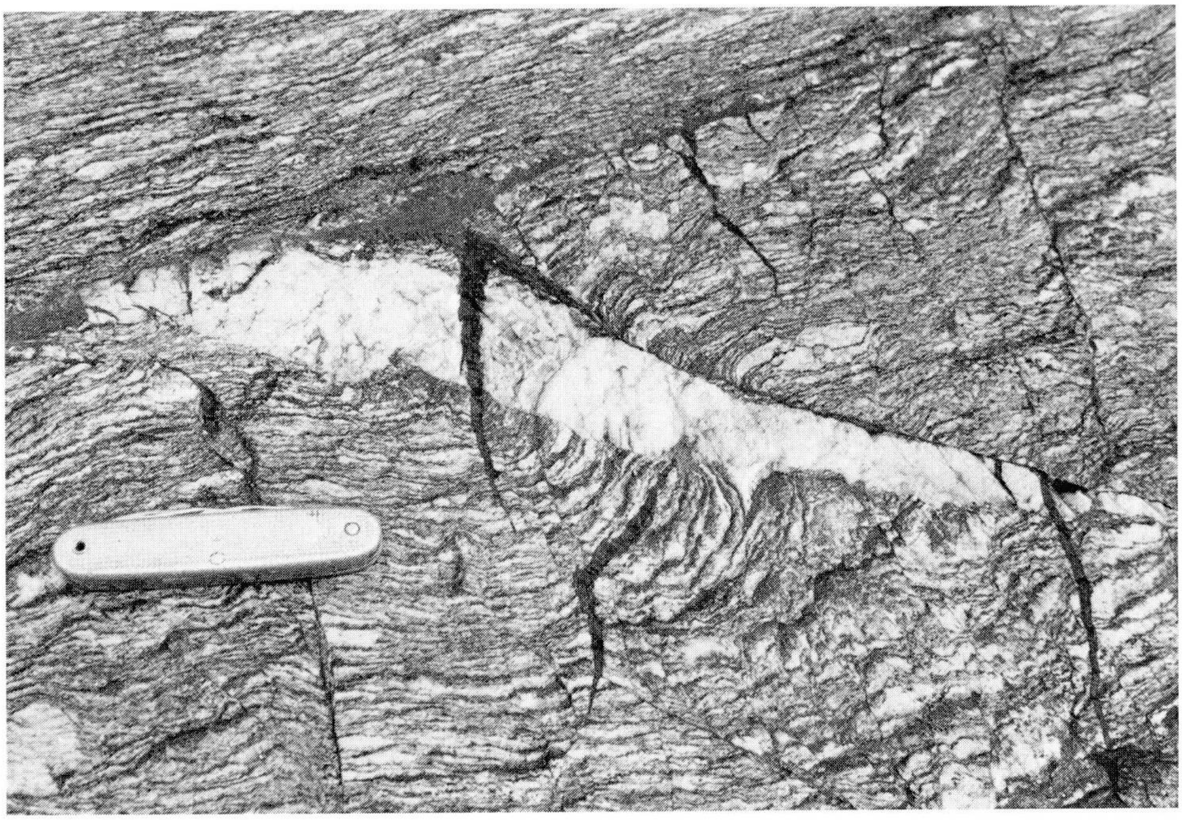


Fig. 4 Injection veins branching off a fault vein subparallel to the gneiss foliation and cutting through a disrupted quartz vein. Val Nedra 1080 m.

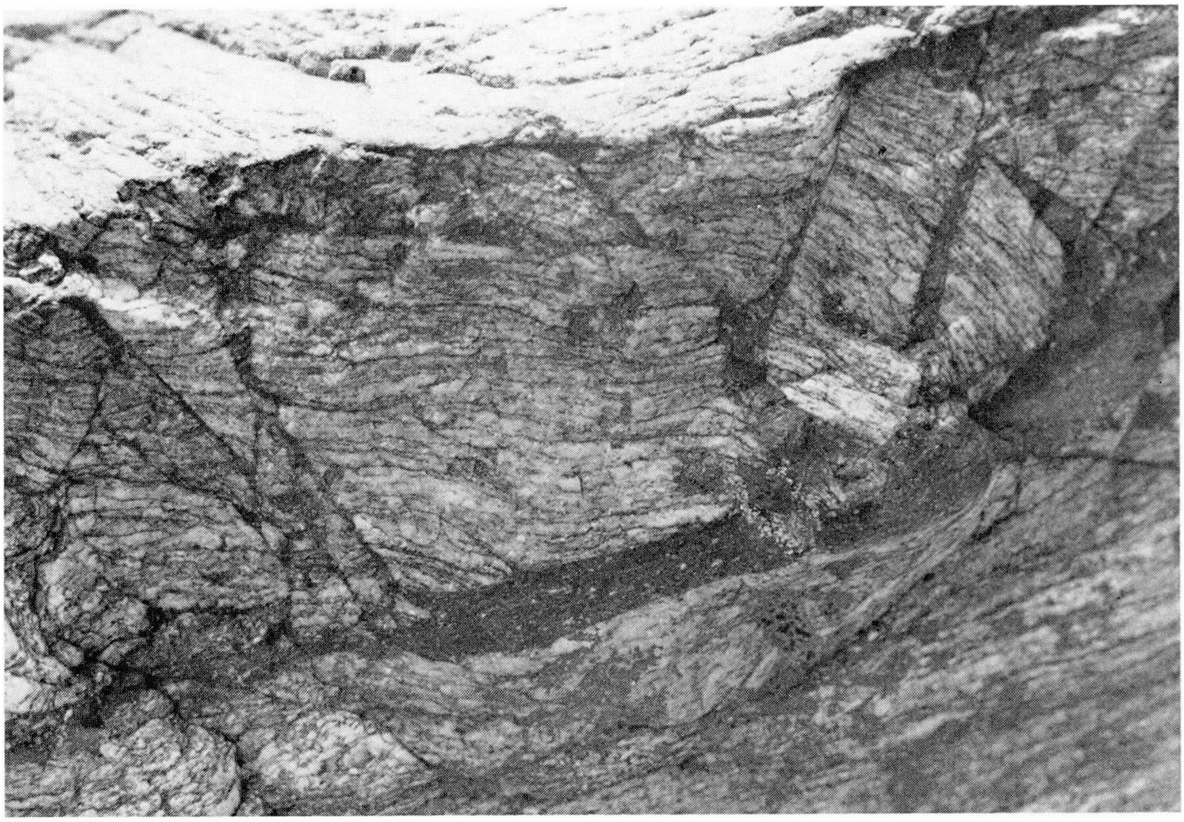


Fig. 5 Brecciated zone with slightly rotated fragments of host rock. Val Nedra 1070 m.

ed, but in one case the offset along the fault vein appears to be more than two metres.

MICROSCOPIC DESCRIPTION

The contact of the dark pseudotachylite veins with the surrounding rock is in most cases absolutely sharp. In other cases, however, an asymmetrical profile across the veins can be observed: one side of the vein is made up of minute brecciated xenoclasts of quartz and feldspar floating in a dark groundmass, whereas the opposite margin consists of many small, nearly isotropic microlites. A banding of dark and light zones inside the veins is often suggestive of flow structures (Fig. 6).

The extremly fine grained, aphanitic *matrix* of the pseudotachylite veins contains many inclusions of quartz and feldspar of different size without apparent orientation. Broken fragments of the surrounding rock occur less frequently in the matrix. Fresh mica is sometimes arranged in a regular network with two preferred orientations which are not related to the foliation of the host rock (Fig. 7). These small mica scales are part of an outermost rim around quartz grains which are separated from it by a collar of brown colour. Between crossed nicols this mantle around the seemingly homogeneous quartz grains is

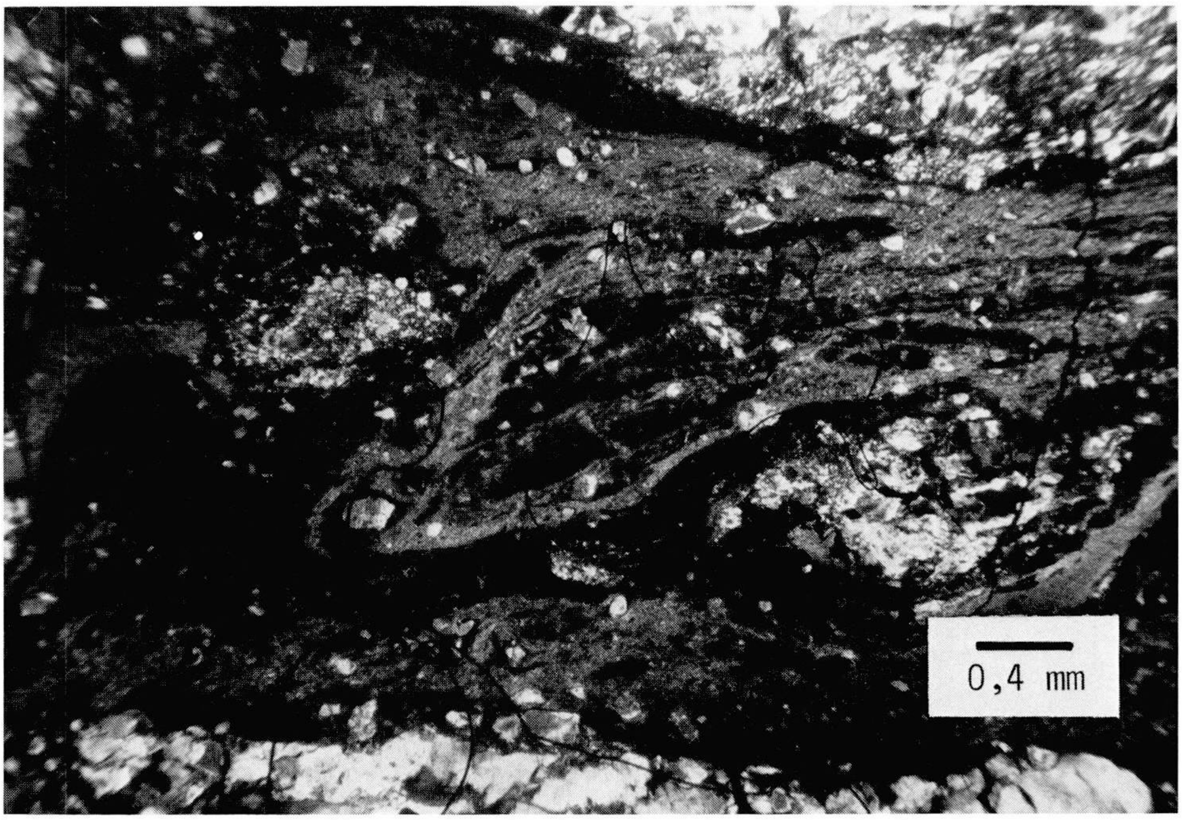


Fig. 6 Microscopic banding in the pseudotachylite matrix suggestive of flow-structures. Crossed nicols.

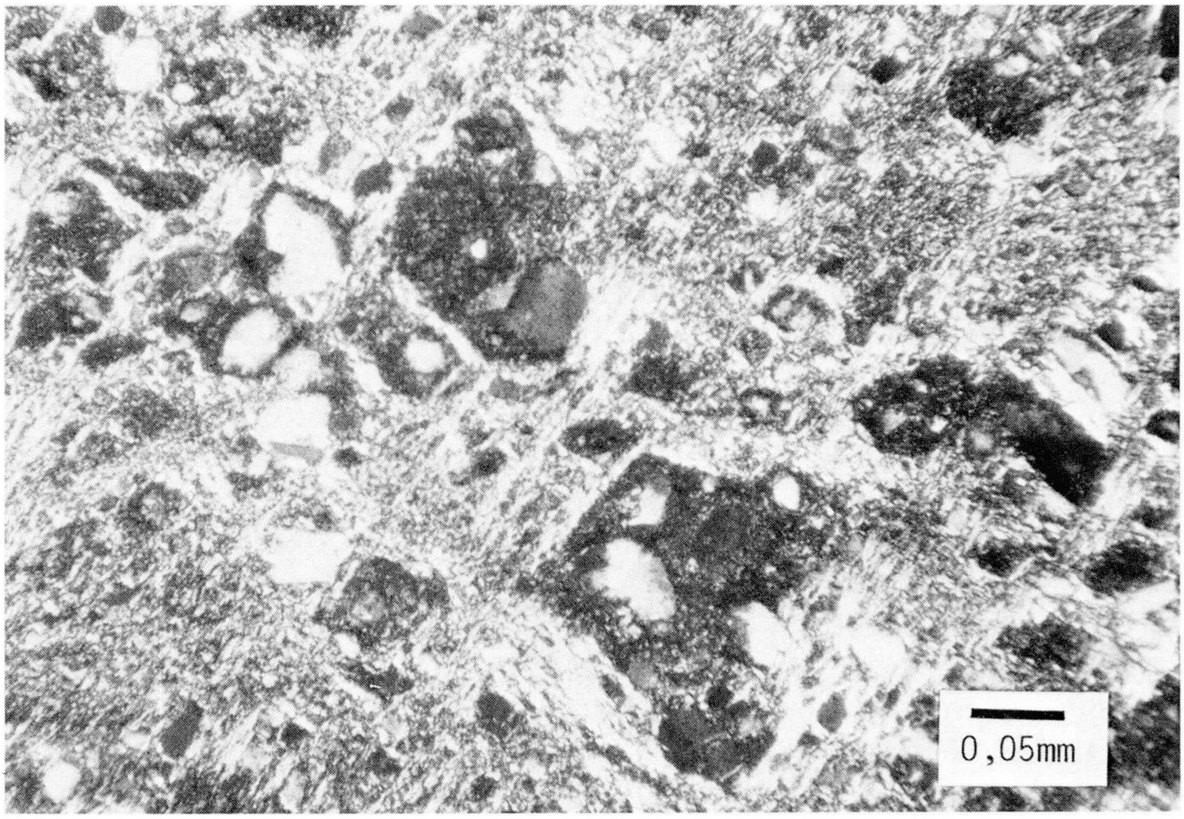


Fig. 7 Network of fresh mica around rimmed quartz grains (for explanation see text). Crossed nicols.

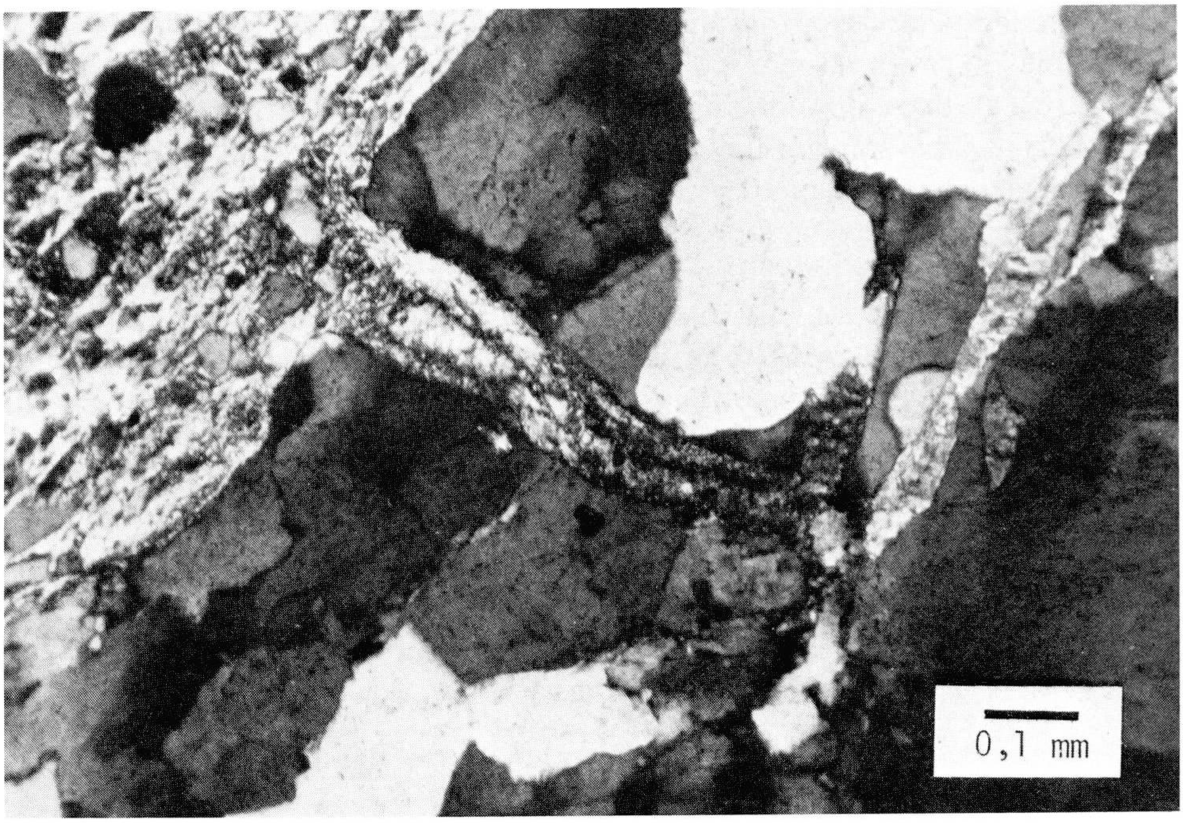


Fig. 8 Micrograph of an injection vein cutting through quartz grains of the host rock. Crossed nicols.

seen to be composed of very small microlites. This marginal zone of microlites appears with crossed nicols nearly isotropic. It has been suggested that this may be the result of interference between minute microlites or grain fragments (PASSCHIER, 1982). The quartz grains may contain submicroscopic inclusions and small fractures filled with opaque minerals. The injection veins branching off the fault veins show the same general features. Fig. 8 shows such an injection vein cutting through a quartz grain.

The grains in the marginal zone at the contact of the host rock with the pseudotachylite veins are fractured and twins in plagioclase grains are kinked. Micas are strongly buckled and wedged. In a short distance (about 20 cm from the contact) these deformation phenomena in the grains have disappeared. Locally a small displacement across the vein can be observed.

DISCUSSION

Much disagreement exists between the various authors about mechanisms and conditions of formation of pseudotachylites. The principal *'pseudotachylite problem'* is if these rocks have been through a liquid phase or not (i.e. if they are the product of fusion or fracture). Diverging opinions exist in the questions of depth and temperature of formation, of the role of water during formation and of possible links with seismic processes.

Future investigations of the pseudotachylites in the Leventina gneiss will add more facts to solve some of these problems. They will concentrate on two main aspects: The *mineralogy* (giving more evidence about the possible existence of a melted phase) and the *structures* (helping to decipher the deformation history of the rocks of the Leventina gneiss). We anticipate that with the further work in the Lepontine Alps we intend to carry out, more occurrences of pseudotachylitic rocks will become known. The pseudotachylite zones may be found associated with tectonically active zones. Because this part of the Alps is rather well known their investigation may ultimately help in deciding if they formed as a result of extension accumulated during tectonic uplift or if they are the result of reactivation of a major ductile shear zone, exhumed and brought up into a brittle regime. We have to consider not only theoretical considerations from experiments or model calculations, but will also have to fit the evolving tectonic picture into the thermal and structural history of the Lepontine Alps as it has become evident from previous investigations.

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