

Deformation and fusion of two faultrocks in relation to their depth of formation: the Hyalomylonite of Langtang (Himalaya) and the pseudotachylites of the Silvretta nappe (Eastern Alps).

by Ludwig Masch.

### 1. The hyalomylonite of Langtang (Himalaya)

In the discussion on the problem of frictional fusion on fault planes the hyalomylonite of Langtang had played an important role. It was the first unambiguous occurrence of a glassy rock on a fault and demonstrated very convincingly that frictional fusion on fault planes could occur (Scott & Drever, 1953). By means of its vesicular structure and the associated rocks-breccias - the hyalomylonite differs from the typical pseudotachylites (Higgins, 1971). Milton (1964) was the first, who pointed at the resemblance to the "fused rock from Köfels" or "pumice of Köfels" that occurs in the deposits of a large landslide in the gneissic Ötztal-nappe (Austria). Erismann, Heuberger, Preuss (1977) showed that "best agreement of morphological, mineralogical, calculated and experimental evidence of the generation of the fused rock of Köfels is offered by the "frictionite" hypothesis (Preuss, 1971) based on heat generation by friction between stationary and moved material during the landslide".

#### 1.1 Field occurrence.

Scott & Drever (1953) presented a detailed petrographic description of the hyalomylonite and reported its formation on a thrust fault. The field data were however scanty. Detailed field work was therefore carried out on the hyalomylonite and the associated brecciated rocks by Masch & Preuss (1977) and on the morphology and geology of the area by Masch, Heuberger, Schröcker in 1978. (in prep.)

This new field work established, that the hyalomylonite of Langtang was formed on the gliding surface of a large landslide. The landslide occurred prior to the last stage of glaciation, is in part eroded and now covers an area of approximately 30 km<sup>2</sup>. The volume of the displaced masses was about 3 km<sup>3</sup>.

In contrast to pseudotachylites, that were produced endogenically by shearing movements due to stresses in the crust, the hyalomylonite of Langtang is generated during the exogenic displacement of a rock mass by gravitational forces.

For the landslide of Köfels, that is of comparable size, Erismann et al. (1977) calculated a velocity of 50 m/sec and a kinetic coefficient of friction of 0.15. The total displacement in the case of the Langtang landslide is of an order of 2000 m, the depth of formation is in between 400 and 1000 m.

The hyalomylonite of Langtang is by means of these evidences a fault rock that formed at unusual high slip rates, low confining pressure and low wall-rock temperature. It differs in these respects from the pseudotachylites, for which Sibson (1975) derived seismic slip rates in the order of cm/sec and a depth of formation of 4-5 km and wall rock temperatures of 150°C.

## 1.2 The Langtang landslide.

The landslide occurs in sillimanite-bearing biotite-gneisses and a sequence of biotite-gneisses and granitic layers of the Langtang-Migmatite-Zone. The gliding surface is composed out of several larger portions exhibiting slightly different orientations with a SSW dip of  $18^{\circ}$  -  $25^{\circ}$ . The gliding surface is rough in cm dimension by protruding fractured grains of quartz and feldspar. In some places it is almost polished, evidently this is due to mylonite bands in the footwall-rocks.

During the last stage of glaciation the higher portions of the displaced masses were totally eroded. The lower parts were preserved up to a maximum thickness of 400 - 500 m. In this portion two magnificent exposures exhibit the deformation and fusion along the gliding surface in an extension over 300 m (fig. 2 in Masch & Preuss, 1977). The most important observations regarding these phenomena are:

- a. The hyalomylonite covered the gliding surface as a continuous sheet of an almost uniform thickness of 0.5 to 3 cm. Vesicular glass protrudes as pockets from this sheet into the hanging wall and occasionally fills tensional fractures in the footwall.
- b. Deformation of the wallrocks of the footwall is distinctly different from that of the hanging wall. The footwall rocks - sillimanite-bearing gneisses - are unaffected with the exception of a marginal zone of a maximum thickness of 15 m that is shattered without destruction of the gneissic structure. The biotite-gneisses with granitic layers of the hanging wall are intensely brecciated at the base with complete loss of the gneissic structure. The higher portions are intensely shattered. Even the highest preserved portions exhibit fracturing.
- c. Dikes filled with microbreccia rise from the gliding surface and cut the brecciated hanging wall.

## 1.3 Fault rocks.

Applying the nomenclatures of Higgins (1971) and Sibson (1977) the fault rocks exhibited on the normal fault (gliding surface) of the landslide are:

fault breccia (fig. 1)

fault gouge

pseudotachylite (hyalomylonite)

It is considered that bands of breccia being envelopped by the hyalomylonite, exhibit the mode of deformation during gliding undisturbed. The breccias were generated by brittle failure out of the wallrocks. Porphyroclasts consist of feldspar and quartz with angular shapes. The dikes filled with breccia and gouge prove that the fault rocks were without primary coherence. Secondary coherence achieved by chlorite, sericite and kaolin. Porphyroclasts of feldspar and quartz in the hyalomylonite may be rounded and show rims of clear glass. Microprobe analyses are intended to clarify, whether this is due to reaction with the melt or to melting of the mineral. The rounded shapes of the porphyroclasts in the dikes are attributed to abrasion. The filling of the dikes is in part attributed to the implosive effect of an opening tensional fracture and in part to the explosive effect of released gases from the melt. Instead of impinging on the gneisses of the footwall

the hyalomylonite is in one place generated on a layer of gouge and microbreccia of an thickness of 10-30 cm. Since incoherent material is expected to diffuse frictional heat by turbulence (Erismann et al. 1977) this indicates a certain degree of coherence was regained even during the gliding process.

According to the applied scheme of classification the hyalomylonite is a pseudotachylite. By means of its generation on the gliding surface of a landlide it deserves a name by its own. In spite of the fact that mylonite is inconvenient for a rock exhibiting brittle instead of quasi-plastic deformation (Sibson, 1977) the hyalomylonite should therefore not be renamed.

#### 1.4 Mylonites and pseudotachylites.

The footwall rocks of the whole site of the landslide show plastic deformation of quartz, turmaline, biotite and bands of mylonites and ultramylonites (fig. 2 and 3).

Field relations and petrographic examination indicate that this deformation is not related to the displacement of the landslide. There is no transition from mylonites to the breccias and the hyalomylonite. The hyalomylonite intersects, the breccias disrupt the mylonites. Nevertheless, by their low angle S-SW dip the mylonites might have induced the formation of the gliding surface. The hyalomylonite and the breccias have inherited plenty of rock and mineral fragments of the mylonites and the deformed host rocks.

Pseudotachylites were identified only microscopically. Evidently they are more rare than the mylonites. Their field relations are not precisely known. By their lack of vesicles and their cryptocrystalline matrix they differ distinctly from the glassy, vesicular hyalomylonite. Evidently they were formed in greater depth.

#### 2. The pseudotachylites of the Silvretta-nappe (Eastern Alps).

The eastern margin of the Silvretta-nappe bordering the Lower Engadine Window is cut by numerous dikes of pseudotachylites (Hammer, 1930, Bearth, 1933, Masch, 1974). The host rocks are amphibolites and high grade gneisses of different composition. The age of metamorphism is variscan. The thrust movements occurred in the lower tertiary. The generation of the pseudotachylites is not related to the thrusting, but is due to the upfolding of the whole pile of penninic and austrian metasediments to a large SW-NE trending anticline (Bearth, 1933, Masch, 1974). The stresses in the overlying Silvretta nappe were released in series of shear failures (Masch, 1974 fig. 11 and 13), on which the pseudotachylites were generated by frictional fusion. The observable displacements are in the range of 1 mm to 1 m. The pseudotachylites are 1 mm to several cm thick. In dikes up to 2m, the pseudotachylite is only the matrix of large often rounded fragments of the wallrocks. There are transitions from pseudotachylites on systems of shear and tensional fractures to those "quasiconglomerate" (Sibson, 1975) structures.

## 2.1 Depth of formation.

The today maximum overburden is 12 km and renders a minimum value for the depth of formation. The alpidic greenschist metamorphism of the margins of the Silvretta-nappe and the metasediments of the Lower Engadine Window provide a maximum value of about 10 km. The pseudotachylites of the Silvretta-nappe were formed in greater depth than the hyalomylonites of the Langtang.

## 2.2 Deformation.

The host rocks of the pseudotachylites show in varying degrees mylonitisation and blastomylonitisation that is related to the thrusting movements. The pseudotachylites occur on brittle shear and tensional fractures that generally exhibit only minor drag effects. The most pronounced drag effects are observed in amphibolites.

The brittle nature of failure is also confirmed by microscopic investigation. There is only in places a marginal ductile deformation of quartz, biotite and hornblende (fig. 14 in Masch, 1974). In rare cases a pseudotachylite runs out in a mylonite band (fig. 4).

Yet these rather marginal features may not be subordinate, as two other observations indicate. Generally, quartz relicts in pseudotachylites show angular shape and occasionally cleavage (fig. 15 Masch, 1974). Most evidences of intracrystalline plastic deformation exhibited by relicts—undulose extinction, deformation lamellae, deformation bands, recrystallisation—may be inherited from the deformed host rock.

But the vortex structure (fig. 7, Masch, 1974) exhibited by the quartz relicts in pseudotachylites from one locality must derive from plastic deformation during the generation of the pseudotachylites. It is absent from the host rocks and could not be produced by the flowing melt.

Relicts of andesine in pseudotachylites in hornblende-gneisses and amphibolites show secondary twin lamellae obeying the symmetry of pericline law. By means of their orientation they indicate ordering of the andesine during secondary twinning, whereas the primary pericline lamellae indicate low structural state at the time of their formation (fig. 16 Masch, 1974, labelled as deformation lamellae). The development of twin lamellae in an ordered plagioclase must be stress-induced (Laves, 1952). There is no crucial observation, whether this secondary twinning was achieved during the generation of the pseudotachylites. It is observable even some cm apart from a pseudotachylite in the host rocks. In a general way it would fit as an unusual feature to the unusual fault rock pseudotachylite. Comparable secondary twinning is known from impact structures (Robertson et al. 1968, fig. 19). It is indicative of a high-stress environment.

New field and petrographic work is necessary to clarify the precise relation of pseudotachylite generation and probably associated plastic deformation. This may lead to the recognition of different, probably depth-related, types of pseudotachylites, as proposed by Sibson (1977). A second point of interest is the relation of pseudotachylites to the mylonites and blastomylonites at the base of the Silvretta nappe. And it is desirable to search for nonfused equivalents of the pseudotachylites. In the basal portions of the Silvretta nappe there are no zones of brecciation equivalent to the hyalomylonite of Langtang.

- Fig. 1 Fault breccia embedded in hyalomylonite. Crossed pol. Diameter of clasts: 0.02 - 0.2 mm. Langtang (Nepal).
- Fig. 2 Biotite-gneiss of footwall, hyalomylonite occurrence, Langtang (Nepal). Quartz exhibiting deformation and recrystallisation. Crossed pol. Magnification as fig. 1.
- Fig. 3 Mylonite with fluxion structure. Host rock of hyalomylonite occurrence, Langtang (Nepal). Crossed pol. Magn. as fig. 1.
- Fig. 4 Pseudotachylite in granodioritic augengneiss running cut in a mylonite band with fluxion structure (centre). Crossed pol. 1. Silvretta-nappe, Alps.

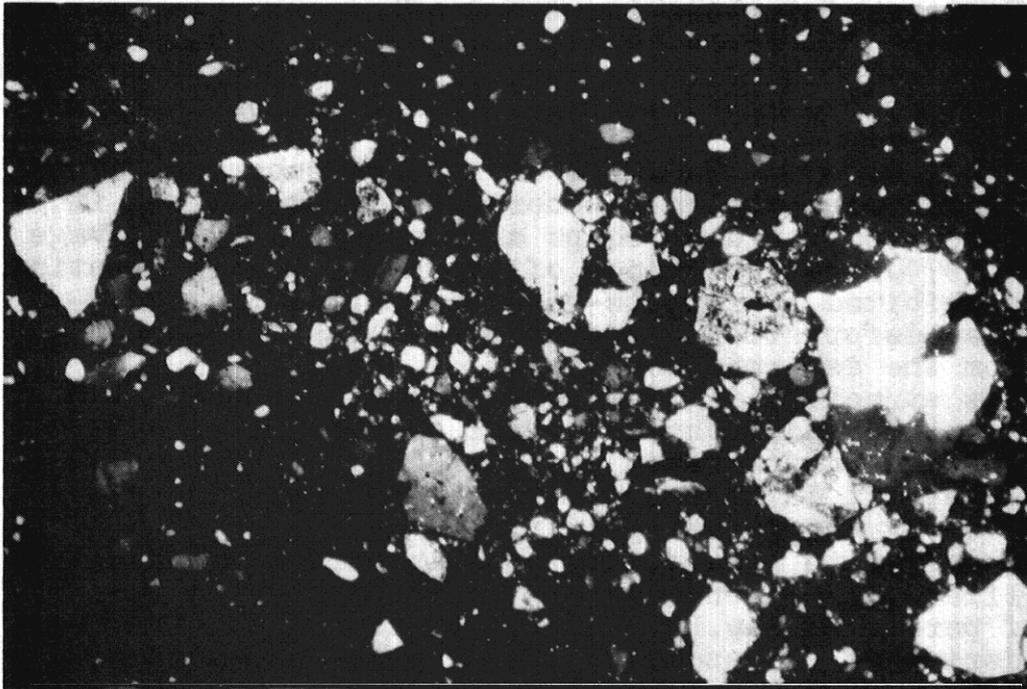


Figure 1



Figure 2



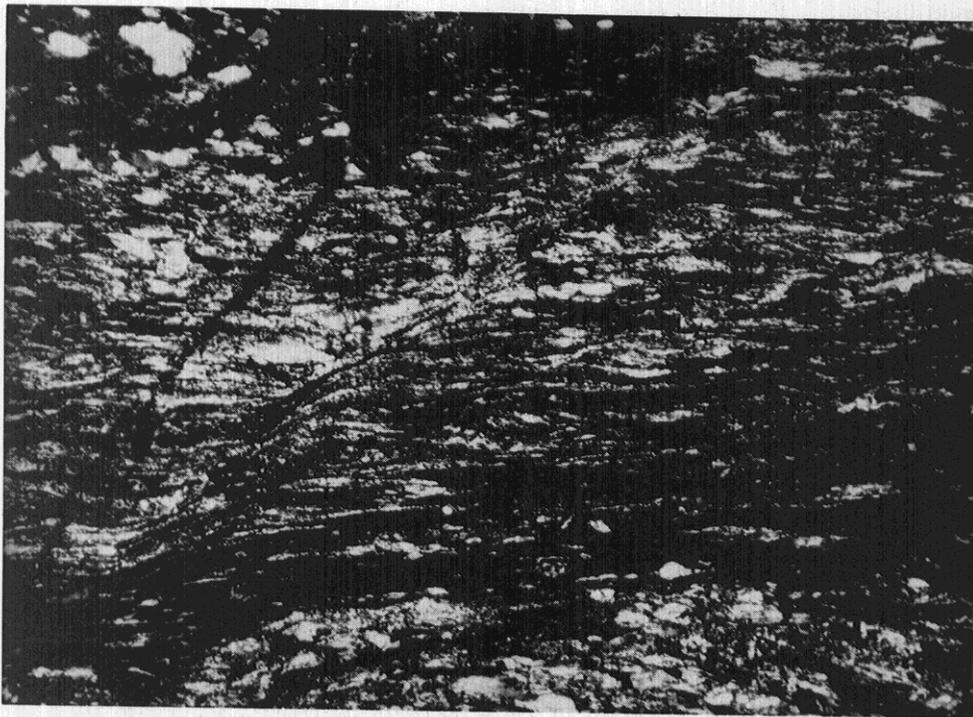


Figure 3

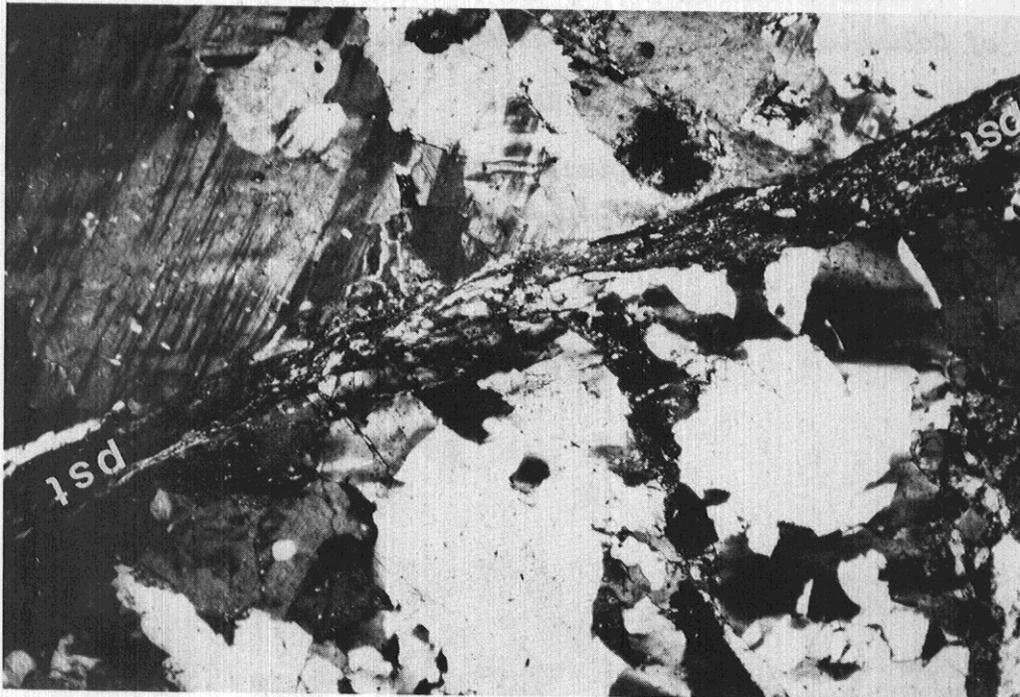


Figure 4

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