

SCANNING ELECTRON MICROSCOPE STUDY OF SHOCK FEATURES IN PUMICE AND GNEISS FROM KOEFELS (TYROL, AUSTRIA)

Rouben Surenian, Vienna

With 1 figure and 3 plates

Summary: Scanning electron microscopy and X-ray microanalysis have been utilized to define the structure of pumice and shocked gneiss from Koefels, Tyrol. The planar features of the quartz in the gneiss from Koefels are compared to gneiss samples obtained from the Ries Crater (Bavaria).

Zusammenfassung: Mittels Rasterelektronenmikroskop und Röntgenanalyse wird versucht, das Gefüge von Bimsstein und geschocktem Gneis aus Köfels, Tirol, zu definieren. Die planaren Deformationsstrukturen des Quarzes im Gneis von Köfels werden mit Gneisproben von Ries-Krater (Bayern) verglichen.

1. Introduction:

Fusion products have long been known to exist in the mass of the largest post-glacial landslide at Koefels, scattered over its surface and cavities, in Oetztal, about 55 km SW from Innsbruck (fig. 1). The Koefels basin is a large semi-circular niche in the eastern slope of the Fundus mountain crest at an altitude of 1400 m, below which the Oetztal and its tributary, the Horlachtal, have been blocked by the giant mass of the landslide deposit (2-3 km³; ABELE, 1974). The initial hypothesis concept on a volcanic origin of these materials (pumicious glass, "Bimsstein") was subsequently shown not to be applicable. SUESS (1936) and STUTZER

(1936) explained the features at Koefels with the meteorite impact theory, which can be supported by the results of modern petrological and structural analysis: MILTON (1964), KURAT & RICHTER (1968, 1972), STORZER et al. (1971), GRATZ & KURAT (1988), SURENIAN (1988). TOLLMANN (1977) attributed the vesicular glass of Koefels and the pseudotachylites of the Silvretta (100 km to the NW) to a double impact event of the same meteorite, but still no lump of the presumed meteorite itself could be unearthed.

According to PREUSS (1971, 1974) as well as HEUBERGER (1975) the fused rocks originated due to

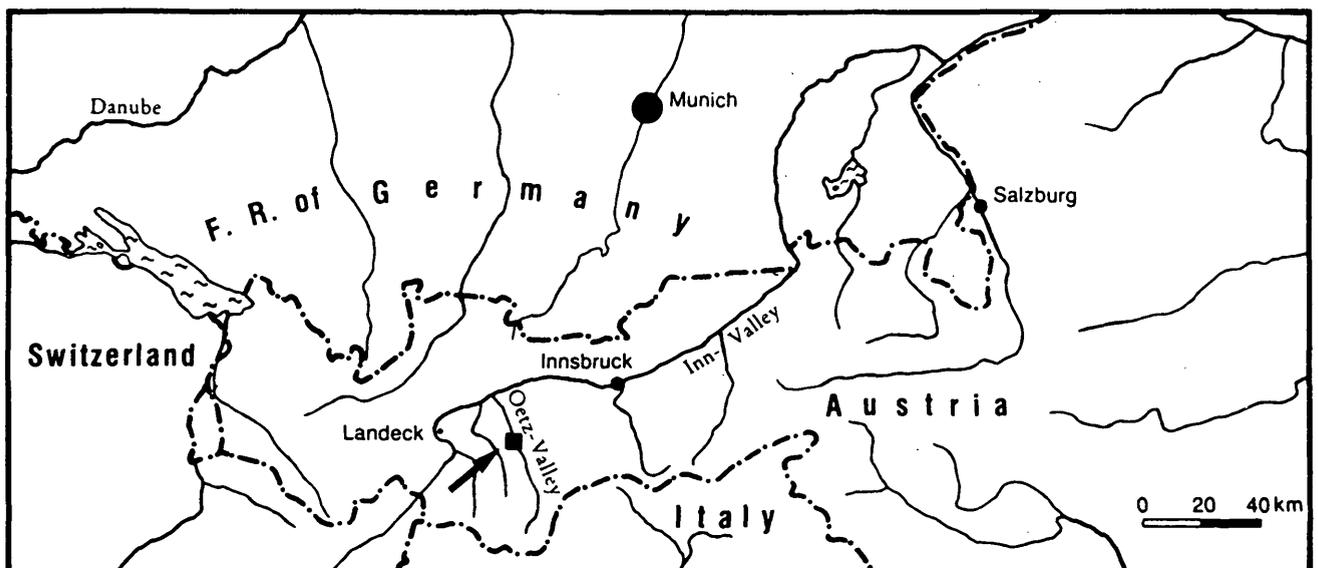


Fig. 1:

Map showing the location of Koefels, Oetz Valley, Tyrol (from HEUBERGER et al., 1984)

heat generated by friction caused during landslide. ERISMANN et al. (1977), introduced "frictionite" as a new term for these glasses, calculated the kinetic energy of the displaced volume and produced synthetic frictionite in the course of experiments (ERISMANN, 1977). HEUBERGER et al. (1984) and MASCH et al. (1985) described the similarities between the fused rocks from the Langtang (Nepal) and the landslide of Koefels; and furthermore, they interpreted the occurrence of non-porous glass (as tubular veins 1 mm to 3 cm thick) in the shattered gneiss of Maurach Gorge as an offshoot from a larger gliding plane which is not exposed. They also use the term "hyalomylonite" (SCOTT & DREVER, 1953) as a synonym to frictionite.

2. Structural features of pumice

The non-homogenous matrix of pumice, granitic in composition, has a foamy structure (pl. 1: fig. 1). The cavities of the pumice (mostly ovoidal or stretched) vary in diameter from 5 micrometers to several millimeters and show a distinct gradation in size. The walls between them are of varying thickness (at least 1 micrometer) and may themselves enclose minute cavities. In the more compact portion of the pumice (most of the cavities measure 5 to 50 micrometers) one can observe burst bubbles, often about 5 micrometers in diameter. The vents of the burst bubbles are irregular or star-shaped and are mostly surrounded by radially arranged fissures (pl. 1: fig. 2). In the coarser portion, burst bubbles are larger but not so common and mainly show longitudinal fissures. Embedded in the matrix of pumice are some grains of quartz covered by quartz-glass and cut by fissures (pl. 1: fig. 1).

After etching with hydrofluoric acid, the following phases could be observed (pl. 1, fig. 3): frequently fragmented angular to well rounded grains of quartz and some feldspars (occasionally welded together; pl. 1: fig. 4, 5), hornblende, some fine-grained micas and other minerals (at present under investigation) measuring from 5 to 100 micrometers in diameter. Near these fractured grains derived from a crystalline rock, one can also observe lumps of quartz glass (lechatelierite; pl. 1: fig. 6) and some corroded euhedral crystals of quartz, feldspar and feldspathoids (10-40 micrometers in diameter). There are also some feldspar and feldspathoid crystals which seem to have grown recently (probably an effect of etching with hydrofluoric acid).

3. Deformation features in gneiss

Samples of gneiss from which the pumice originated, were collected from the mass of intensely fractured rocks of the landslide, which formed a natural dam in the Oetzal ("Maurachriegel"). They show ubiquitous effects of strain. In the quartz, sets of crystallographically controlled planar features can be observed. They show cone-shaped patterns ("shatter-cones"), flow structures, partitioning, dislocations and fine-fracturing in lamellae ("fluid inclusion planes" by GOLD, 1968; pl. 1: figs. 7, 8; pl. 2: figs. 1-3). Cleavages, minute cavities, some with very small inclusions, which made microanalysis impossible (only quartz identification was achieved), and undulating features are also observed (pl. 2: figs. 4, 5, 7; pl. 3: fig. 1). Feldspar grains show cone-shaped and deformed lamellae (pl. 3: fig. 3-5), micas show kink bending (pl. 3: fig. 7).

Similar deformation features in quartz, feldspar and mica were also found in samples of autochthonous, shattered gneiss from the "Schartle" about 685 m above the village of Koefels which will be described in a separate report.

Samples of shocked gneiss from the Ries Crater (Oetting) have been investigated for comparison with the gneiss from Koefels. Identical planar features have been observed there and, as expected, the effects of shock waves are intensive, more pronounced and more common. The quartz grains in the gneiss from the Ries Crater show densely-packed and kinked lamellae (pl. 3: fig. 2) also cracks, fracturing and splitting along the planar features and sheared planes, as well as rhombohedral cleavages (pl. 2: figs. 6, 8). Feldspar grains and micas show intensive deformation features (pl. 3: figs. 6, 8).

4. Discussion and concluding remarks

Some mineral phases within the pumice must have been exposed to temperatures greater than 1700°C. This is indicated by lechatelierite and some euhedral crystals of quartz and feldspar observed in the etched pumice. The latter could have been precipitated from a vapour phase. Differences in the shape of vents in the walls of bubbles in pumice seem to indicate a weaker gas emission in the fine portion (smaller pressure difference between inside and outside) and a more vigorous gas emission in the coarser portion of the pumice. The molten material must have cooled rapidly to a temperature below the melting point of quartz and feldspar grains as shown by partially fused quartz and feldspar grains in the pumice. Furthermore, the planar features in quartz grains in gneiss from Koefels, being similar

to those of quartz in shocked gneiss from the Ries Crater (Otting), are apparently generated by pressure ranging from 100 - 300 kilobars (ENGELHARDT & STÖFFLER, 1968). The flow structures in quartz of gneiss could be a result of high residual temperatures formed by shock pressures in the range of about 500 - 650 kilobars (ref. to the above mentioned authors). CARTER (1968) described in detail the origin, the occurrence and the orientation of planar features and deformation lamellae in quartz as the most reliable indicators of intense shock.

The observed features in pumice and gneiss from Koefels can serve as strong indicators for a meteorite impact. This meteorite fall transmitted sufficient energy to produce the shock effects in the crystalline rocks and can also be considered to be the original cause which triggered the largest post-glacial landslide in the crystalline Alps at Koefels. The geomorphology of the Koefels basin with the semi-circular niche in the Fundus mountain and the Mau-rach dam are evidently indicators of a rare event with astonishing geological and mineralogical consequences.

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Author's address:

Dr. Rouben Surenian, Geologische Bundesanstalt, Rasmofskygasse 23, A-1031 Wien

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Explanation of plates

Plate 1

- Fig. 1: Foamy structure of pumice from Koefels: partially fused quartz (melting effects) surrounded by the glassy matrix; some clay (melting effects) surrounded by the glassy matrix; some clay (melting effects) surrounded by the glassy matrix; some clay incrustation on the quartz surface.
- Fig. 2: Burst bubbles in a cavity of the fine portion of pumice with radially-arranged fissures (Koefels).
- Fig. 3: HF-etched pumice containing mainly grains of quartz with some feldspars and other minerals from Koefels.
- Fig. 4: Fractured quartz grain from the etched pumice, showing sharp cracks in various directions (Koefels).
- Fig. 5: Feldspar fragment in the HF-etched pumice showing (shocked and/or twinned) lamellae and some partial fusion at the bottom (Koefels).
- Fig. 6: Quartz-glass (lechatelierite) found in the HF-etched pumice from Koefels.
- Fig. 7: Quartz grain in an etched gneiss sample, showing cone-shaped lamellae ("shatter cones"). Crystals on the surface of the grain are etching artefacts (Maurach/Koefels).
- Fig. 8: Flow structure in quartz of an unetched gneiss showing differential movement of fine lamellae under conditions of high residual temperatures. Many solution pits are mostly arranged along the lamellae. At the bottom of the picture: quartz overgrowth patterns (Maurach/Koefels).

Plate 2

- Fig. 1: Cone-shaped and deformed quartz grain split up into sheets, with planar features on the surface. The effects of tearing are seen at the cracks where some of the planar features are discontinuous (in etched gneiss from Maurach/Koefels).
- Fig. 2: Closely-spaced channels (dislocations and solution patterns), most of them in the sense of curvature of the cone-shaped lamellae in quartz. Some of these curved channels intersect each other and the lamellae in opposite direction (etched gneiss from Maurach/Koefels).
- Fig. 3: Cone-shaped, fine-fractured and crumbled lamellae, fitting into the overall picture of deformation patterns often seen in the quartz grains of gneiss from Maurach/Koefels.
- Fig. 4: A set of sharp planar features (some intersecting each other) on an etched quartz grain surface in gneiss with very small inclusion, traces of linearly arranged etch pits and a crack (Maurach/Koefels).
- Fig. 5: Two sets of well developed planar elements, partially curved (top left), partially intersecting, and some of which diverge from common points, which is remarkable. Linearly arranged etch pits and a crack are also seen on this quartz from etched gneiss of Maurach/Koefels.
- Fig. 6: The quartz in the etched gneiss sample from Ries Crater/Otting shows effects similar to those seen in the Koefels sample (fig. 5) but are more intensive: cracks and cleavages are along the planar features.
- Fig. 7: Irregularly arranged planes showing planar elements, cavities, inclusions, and cracks in quartz of gneiss from Maurach/Koefels.
- Fig. 8: The quartz of the gneiss from Ries Crater shows sheared and broken planes with narrowly spaced and splitted lamellae, cracks and rhombohedral cleavages. These features result from shock waves caused by higher pressure than seen in fig. 7.

Plate 3

Fig. 1: Undulating features in a quartz grain in the gneiss from Maurach/Koefels.

Fig. 2: Densely-packed and kinked lamellae in quartz indicate intensive shock waves in the etched gneiss from Ries Crater/Otting.

Fig. 3: Cone shaped lamellae in feldspar ("shatter cones") (unetched gneiss sample from Maurach/Koefels).

Fig. 4: Wavy features in a plagioclase grain with some intersecting lamellae (unetched Marauch sample).

Fig. 5: Fractured grain of feldspar in the etched gneiss from Maurach/Koefels.

Fig. 6: Intensive effects of fracturing in an etched feldspar grain from Ries Crater (Otting).

Fig. 7: Kink bending in a mica from gneiss (Maurach/Koefels).

Fig. 8: Mica, showing totally shattered features. Kink bending is still recognized, etched gneiss from the Ries Crater (Otting).

