

GEOCHEMISTRY OF THE DARK VEINLETS IN THE GRANITOIDS FROM THE SÖDERFJÄRDEN IMPACT STRUCTURE, FINLAND: PRELIMINARY RESULTS. T. Öhman¹ and J. Raitala². ¹Department of Geosciences, Division of Geology, P.O. Box 3000, FI-90014 University of Oulu, Finland, <teemu.ohman@oulu.fi>; ²Department of Physical Sciences, Division of Astronomy, P.O. Box 3000, FI-90014 University of Oulu, Finland.

Introduction: The Söderfjärden structure (63.0°N, 21.6°E) just south from Vaasa in western Finland [1,2] is a prime example of a terrestrial polygonal impact crater, formed due the crater-wall collapse along pre-existing fractures during the modification stage [e.g. 1,3,4]. Although it was recognized as a possible impact structure already in the late 1970s [2, see also 5] and has been approved since, a more comprehensive study of Söderfjärden's impact metamorphic rocks and minerals combined with modern geochemical studies has so far been lacking. Our ongoing project aims for a better characterization of the geochemistry and impact metamorphism for this probably Lower Cambrian (~530 Ma) [e.g. 1,2,6], originally ~6.4 km large [1] structure.

Geologic setting: The current lithology in the Söderfjärden area is fairly simple. The bedrock is formed by the so-called Vaasa granite, a migmatitic Paleoproterozoic garnet-bearing granitoid with variable amounts of gneissose enclaves. Rare mica schists and amphibolites are also present [2,7]. At the time of the impact the region was, perhaps, covered by a shallow sea [e.g. 8,9]. Cambrian post-impact siltstones, sandstones and conglomerates effectively protected the structure from erosion, and can now be encountered as boulders in the glacial drift, as well as in three cores drilled into the crater [e.g. 1].

Earlier studies: The first detailed account on the impact-related features in Söderfjärden was given by Laurén et al. [2], continued by Lehtovaara [e.g. 8,9]. From drill cores and boulders they discovered "tuffaceous breccia", which contained e.g. PDFs in quartz [(0001) & {10 $\bar{1}$ 3}, see 8], and an almost isotropic, microcrystalline alteration product of plagioclase, interpreted as possible devitrified maskelynite. Abels [1] gives some more information on the petrography and shock metamorphism, including a more detailed description of the outcrops and the boulder studied here.

The dark veinlets: A glacially polished migmatitic granitoid outcrop in the village of Solf on the eastern rim of the structure displays brownish black microcrystalline veinlets, typically ~0.2–10 mm thick [1]. Up to ~30 cm displacements along the veinlets are present (Fig. 1a). In addition, pinkish prehnite-calcite-quartz (\pm minor sphene) veinlets, verified with XRD, and quartz veinlets occasionally crosscut the dark ones, sometimes running parallel to them. The dark veinlets strike generally NNE (Fig. 1d), but the offsets have no preferred sense of movement. The

veinlets' strike coincides with the foliation (S₂) in the eastern and northern parts of the structure [1,7].

Microscopic examination reveals the heavily brecciated nature of the rock surrounding the veinlets. Green chlorite veinlets are often connected to the dark ones, usually chlorite enclosing the dark inner part (Fig. 1b). In the thickest dark veinlets angular clasts of quartz and albitic plagioclase are surrounded by a blackish matrix. Biotite and chlorite (after biotite) grains often exhibit kink-banding (Fig. 1c), and undulatory extinction is common to quartz. No shock metamorphic features have been observed. A few grains display features somewhat resembling textures of recrystallization from melt, but substantial hydrothermal alteration makes the interpretation very difficult.

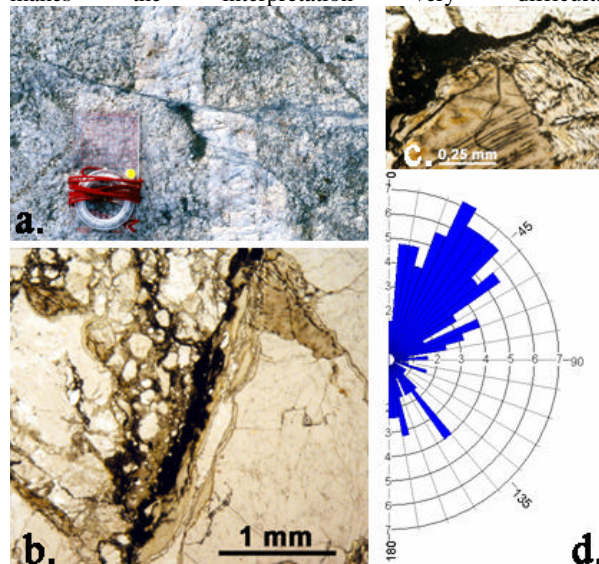


Figure 1. The Solf outcrop. a: A pegmatite dike offset along a dark veinlet. The length of the compass is 12.5 cm. b & c: Microphotographs of the dark veinlets, plane-polarized light. Biotite (brown), often altered to chlorite (greenish, kinked), associated with sphene (black). d: The strikes of the dark veinlets in 5° intervals, plotted as percentages on a rose diagram. The number of measurements is 126.

Microprobe (JEOL 733 & JEOL-JXA-8200, 15 nA, beam Ø 1–20 µm, Dept. of Electron Optics, Univ. of Oulu, Finland) studies indicate the dark veinlets as sphene (CaTi[SiO₄](O,OH,F)), 26 analyses yielding average composition (in w-% \pm 1 σ): SiO₂ 29.9 \pm 0.5, TiO₂ 32.6 \pm 3.8, Al₂O₃ 4.3 \pm 1.7, Cr₂O₃ 0.2 \pm 0.1, V₂O₅ 0.3 \pm 0.1, FeO* 1.4 \pm 1.6, MgO 0.8 \pm 1.1, CaO 26.8 \pm 2.4, K₂O 0.1 \pm 0.1, totals 96.5 \pm 3.3.

A likely source of Ti is biotite with ~3.5 w-% TiO_2 , often altered to chlorite with ~0.3 w-% TiO_2 . Heavily altered (saussuritization & sericization) plagioclase, currently with ~1 w-% of CaO probably provided the Ca for sphene.

A single, ~3–15 mm thick and a few meters long dark grey veinlet with almost no offshoots, striking N–NNE in an outcrop of migmatitic gneissose granitoid on the northern rim near Öjberget [1] is notably different. Especially in the outcrop's northern end this fine-grained veinlet is composed of disseminated graphite and heavily stained plagioclase, with minor chlorite and biotite. No sphene is present and no indications of friction melting or shock metamorphism can be seen. Microscopically the vein has an overall appearance of a mylonite. Near the southern end the veinlet changes in appearance, with mylonitization and content of graphite decreasing, and chlorite veinlets being much more dominant. Pyrite is present as veinlets and “pockets” associated with the chlorite. Small, very fine-grained aggregates of sphene may also be associated with chlorite, similar to but far less distinct than in the Solf outcrop. This interpretation, however, still requires microprobe confirmation.

A granitoid boulder in a gravel pit in Nybackberget on the southern rim displays up to ~4 cm thick dark greenish brown vein with whitish clasts, forcefully intruded into the surrounding granitoid [1]. Macroscopically it resembles an impact melt vein, but microscopically the vein material looks more like having gone through strong cataclasis rather than melting. It is composed mainly of fine-grained biotite with numerous angular quartz, K-feldspar and plagioclase clasts, sometimes with corroded margins. Many clasts are composed of relatively fresh quartz in contact with microcrystalline material having very low birefringence, commonly at one end of the clast but rarely in the centre. The contact between the fresh quartz and the alteration product is sharp, often wavy, and the clasts have retained their original angular shape with no signs of flow (Fig. 2). The first five microprobe analyses from two grains show this clay-like material to be hydrous (totals ~84 w-%) and mainly made of Si and Al (SiO_2 ~46%, Al_2O_3 ~37%) with only traces of Fe, Mg, Ca and K. Grains of K-feldspar display similar, although more diffuse features, and practically identical chemistry of the alteration product (two grains, $n=7$, SiO_2 ~46%, Al_2O_3 ~37%, FeO^* ~1%, MgO ~1%, totals ~86%).

The alteration product in both cases is apparently kaolinite ($\text{Al}_4[\text{Si}_4\text{O}_{10}](\text{OH})_8$), a typical outcome of feldspars altered in low-temperature hydrothermal systems. Thus it seems that the quartz clasts, which by first glance appear quite similar to quartz partly converted to diaplectic glass and then devitrified, are in fact quartz–K-feldspar intergrowths, with the K-feldspar being later kaolinitized. This is in agreement with the fact that no shock metamorphic effects have been observed, at least some of which would be

expected in a rock having experienced shock pressures of over ~35 GPa required to produce diaplectic glass.

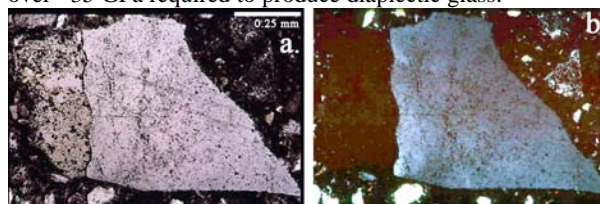


Figure 2. Microphotographs (a: plane-polarized; b: cross-polarized light) of a quartz–K-feldspar intergrowth (totally kaolinitized K-feldspar on the left, almost isotropic in b) from a dark vein in a granitoid boulder from Nybackberget.

Conclusions and further work: So far there is no unequivocal evidence of friction melting or shock metamorphism in the Solf or Öjberget outcrops, or in the large boulder from Nybackberget. Thus, the only thing relating the veinlets in the outcrops to the impact is their location on the crater rim, and the fact that no other similar veinlets have been observed in other outcrops farther from the rim. We will continue our work by carrying out more geochemical and petrographic studies on samples from the outcrops, as well as from cataclastic and mylonitic boulders, in order to decipher if there's a causal connection between the Söderfjärden impact and the dark veinlets. In addition, PDF orientations from quartz clasts in drill core samples will be measured with U-stage for shock barometry.

References: [1] Abels A. (2003) *Investigation of impact structures in Finland (Söderfjärden, Lumparn, Lappajärvi) by digital integration of multidisciplinary geodata*. Ph.D. thesis, Westphalian-Wilhelms University Münster, Germany, 292 pp. [2] Laurén L. et al. (1978) *Geol. Surv. Finland Bull.* 297, 81 pp. [3] Eppler D. T. et al. (1983) *GSA Bull.*, 94, 274–291. [4] Öhman T. et al. (2005) In: Henkel H. & Koeberl C. (eds.) *Impact tectonism*, Springer (in press). [5] Talvitie J. et al. (1975) *Dept. of Geophysics Contr.* 59, Univ. Oulu, Finland, 15 pp. [6] Tynni R. (1982) *Bull. Geol. Soc. Finland*, 54, 57–68. [7] Raitala J. (1985) *EMP*, 33, 133–155. [8] Lehtovaara J. J. (1985) *GFF*, 107, 1–6. [9] Lehtovaara J. J. (1992) *Tectonophysics*, 216, 157–161.

Acknowledgements: This work was made possible by funding from the Finnish Graduate School in Geology, the Väisälä Foundation and the Magnus Ehrnrooth Foundation. Special thanks to Dr. A. Abels for very valuable comments and to Ph.D. T. O. Törmänen for assistance with ore microscopy.