SHATTER CONES AT THE KEURUSSELKÄ IMPACT STRUCTURE AND THEIR RELATION TO LOCAL JOINTING.

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Introduction: Shatter cones are the only recognized macro- to mesoscopic recognition criterion for impact structures [1]. Their genesis is still not resolved but there is wide agreement that it involves interaction between a target rock heterogeneity and a shock wave of a magnitude only occurring during meteorite impacts or upon man-made explosions [2]. It is, however, not understood what these interactions are exactly, what heterogeneities are required, or what the variations in size and orientation of shatter cones depend on.

We have carried out a geological field study at the Keurusselkä impact structure, Finland, which had been discovered by [3] through detection of multiple occurrences of abundant and well developed shatter cones. Schmieder et al. [4] reported an Ar-Ar age of 1150 Ma for a pseudotachylitic breccia from Keurusselkä. Prominent macroscopic joints and shatter cones were examined in the field and samples of the main basement lithologies are being studied. Petrographic analysis was carried out in order to make a contribution to the resolution of the shatter cone genesis conundrum. Furthermore, our field work was aimed at better constraining the area extent of impact related deformation.

The Keurusselkä Structure is situated in south-central Finland within the Central Finland Granitoid Complex (CFGC) that formed during the Fennoscandian orogenesis ca 1880 Ma ago [5]. Country rock at Keurusselkä includes medium to coarse-grained, even feldspar porphyritic, granites and granodiorites, locally carrying dioritic or gabbroic enclaves, and granitic and amphibolitic gneisses. Due to extensive erosion the crater topography is not preserved. Hietala & Moilanen [3] determined the extent of the crater structure on the basis of the alleged distribution of their shatter cone observations to 30 km diameter. Raiskila et al. [6] and Pesonen et al. [7] described a circular magnetic anomaly allegedly coinciding with the extent of the area of shatter cone findings. However, the anomaly may well be caused by gabbro intrusions present in the area. The country rocks are significantly altered (sericitization of feldspar and chloritization of mafic minerals). Invariably all rocks display a foliation also at the thin section scale. All our samples display amphibolite grade metamorphic overprint that, according to [5], was attained during the pre-impact Svecofennian orogenesis.

Joints: Macroscopically prominent joints are observed pervasively within and outside the Keurusselkä impact structure. Their average spacings at given sites were recorded in centimeter, centimeter to decimeter, decimeter to meter, and meter categories.

Joint orientations favor four general trends of 0°, 30° to 50°, 90° and 110° to 130° strikes. All these trends were determined inside and outside the alleged area of the impact structure. Consequently, we propose that the main joint orientations are related to the regional geology, specifically deformation during the Fennoscandian orogeny. Nironen et al. [5] observed three regional lineaments in the CFGC at 0°, 20° to 40° and 120° to 135° orientations, coincident with three of our four joint trends. The fourth trend may follow a local Svecofennian lineament that was not previously recognized and is oriented perpendicular to the northerly lineament trend. Dips on joint surfaces are highly variable ranging from subhorizontal to almost vertical.

Prominent joints are more closely spaced over the innermost part of the structure (to 10 km from the alleged center as defined by [3]), where the spacings are mostly in the centimeter to decimeter range. Spacings at decimeter to meter range occur to a distance from the center of 26 km. Outside that, most prominent joints have spacings at the meter range.

Shatter cones: The Keurusselkä impact structure features well exposed and, despite the extensive geological overprint of the structure, well preserved shatter cones, especially at many sea-shore localities in the central part of the structure (Fig. 1). At such locations, sections of joint surfaces are commonly striated (although considerably more open forms rather than conical structures occur). Joint sets of different orientations combine to form semiconical or even fully conical features (Fig. 2). Similar observations were made at Vredefort by [8]. Shatter cone striations were measured, particularly at Jylhänniemi and Sammakkoniemi within the centralmost area, where a total of seven areals, each of ca 1 m^2 extent, were closely examined. These areals were chosen for their unusually high numbers of joints and shatter cones showing orientations judged typical for the Keurusselkä impact structure. Results include the observation that shatter cone orientations often follow the joint orientation trends, or are formed as combinations of segments of several striated, differently striking joint planes.

Regarding the areal extent of shatter cone occurrences, we have identified a small number of striated joint surfaces and partial cones as far as 13.5 km from the center of the structure.

Fig. 1: View of a 1 m wide intensely shatter coned granite gneiss at Jylhänniemi (24.65° E /62.15° N) in the central area of the Keurusselkä impact structure.

Fig. 2: One of the investigated areas at Jylhänniemi with highlighted joints (black) and shatter cones (yellow) indicating that shatter cones are forms combining segments of striated joint surfaces.

Microdeformations: Petrographic analysis of a large number of samples of shatter cones and country rock is in progress in order to ascertain the shock deformation degree within the impact structure and, specifically, and to investigate whether shock deformation possibly occurs only just below shatter cone surfaces. Shock deformation is so far limited to one of 24 investigated samples covering the entire extend of the structure. This shocked shatter cone sample was taken at Jylhänniemi 5km from the presumed center of the structure. It contains a high number of quartz grains with planar fractures (PF) and planar deformation features (PDF). PDFs are mostly present in one or two sets per host grain only. It is currently investigated whether only the material close to the shatter cone surface has been shock deformed or deformation is pervasive throughout the 30 cm sized shatter cone sample. Also crystallographic orientation measurements on PFs and PDFs are in progress. Clearly, the rarity of shock deformation observed so far already indicates that the wider impact structure has been deeply eroded below the 8-10 GPa threshold recognizable by rare PDF occurrence.

The thin sections show fractures running through the sample from the shatter cone surface. Most fractures follow the host rock's foliation and extend along grain boundaries, although some are oriented almost perpendicular to the foliation. Several curved fractures severing slivers of rock from the surface are observed, too. Displacements of up to 100 µm are observed where fractures cut through some mineral grains. The shatter cone shows surface melt, which also fills many of the fractures extending into the rock interior (up to 3.5 mm). Melt compositions involve two silica-rich phases with high percentages of iron oxide. The iron oxide might be related to secondary alteration on shatter cone surface and along joint surfaces. The two phases differ in their Ca abundances. Microprobe analysis will be carried out to obtain quantitative results.

Conclusions: Our new findings of shatter cone occurrences would favor a somewhat smaller extent of the impact structure, at 27 km diameter, slightly less than the value by [3]. Joint orientations seem to mirror, to a large degree, the regional deformation incurred prior to the impact. However, the reduced spacing between joints inside the structure can be related to impact deformation; preexisting joints, faults and shear zones have obviously been reactivated by the impact.

Shatter cone formation is closely linked to the occurrence of preexisting joints. The observation that shatter cones occur on sections of joint surfaces or are formed by combination of segments of different joint trends hints at a close correlation between their genesis and the reactivation of preexisting lineaments.

The presence of both PFs and PDFs in the shatter cone sample, in comparison to their general absence in country rock samples so far studied petrographically, may suggest that shatter cone formation may be related to local shock pressure excursions along pre-existing joints/fractures in keeping with the widely held idea that scattering, reflection and refraction of shock waves on heterogeneities in the target rock may lead to shatter cone formation.

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