SHOCK METAMORPHISM OF QUARTZ IN SAARIJÄRVI AND SÖDERFJÄRDEN IMPACT STRUCTURES, FINLAND. T. Öhman1,2 and U. Preeden3, 1Center for Lunar Science and Exploration, Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd., Houston, TX 77058, USA (ohman@lpi.usra.edu), 2NASA Lunar Science Institute. 3Department of Geology, University of Tartu, Ravila 14A, EE-50411, Tartu, Estonia.

Introduction: Saarijärvi [1–3] and Söderfjärden [4–6] impact structures in north central (65°17.4′N 28°23.3′E) and western (63°00.6′N 21°35.5′E) Finland, respectively, are generally considered to be proven impact structures [e.g., 7 and references therein]. Unfortunately, documentation of shock metamorphism has been relatively scarce. This has been largely due to the lack of true impactite outcrops in both structures and, thus, rarity of material available for study. Both of them have, however, been drilled for exploration purposes. The current study takes a new look at the drill cores in order to further establish the origin of these structures.

Geologic background: The Saarijärvi structure is located in the Archean Kuhmo basement complex of the Karelian domain. The host rocks are mainly gneissose granitic and tonalitic rocks of the trondhjemitetonalite-granodiorite-series. These are cut by three generations of Paleoproterozoic metadolerite dikes [1, 2, and references therein]. Approximately 10 m of water and Quaternary sediments cover the structure which is filled by a ~156 m thick section of Ediacaran (Vendian [8]) and Early Cambrian sedimentary rocks [2, 9]. These were originally regarded as post-impact sediments [e.g., 1]. We, however, prefer the interpretation [3] that these sand-, silt-, and claystones are actually part of the pre-impact target lithology, thus making Saarijärvi Early Cambrian or younger (see below). The present apparent diameter is ~1.5–2 km [1–3, 9], while the original diameter may have been closer to 4 km. In addition to extensive erosion, Saarijärvi is notably modified by post-impact tectonism [2, 3].

Söderfjärden structure in the Svecofennian domain is mainly hosted by a Paleoproterozoic migmatic gneiss-bearing granitoid with gneissose enclaves, known as Vaasa granite [4, 10]. The impact probably occurred on-shore on the sub-Cambrian peneplain, but sedimentation under marine conditions prevailed soon after the impact [6, cf. 5]. At present, the structure is covered by Quaternary sediments (~74 m) and Cambrian sedimentary rocks (~318 m) [4, 6]. The age of the impact is probably Early Cambrian (~530 Ma), and the original diameter was ~6.4 km [6]. Unlike Saarijärvi, Söderfjärden is a complex structure with a central uplift seen in seismic, gravity, and aeromagnetic data [4, 6].

The evidence for impact origin in Saarijärvi is provided by scarce indexed planar deformation features (PDFs) [1], multiple orientations of planar fractures (PFs), feather feature lamellae (FFL; see [11] and references therein), mosaicism (all in quartz) [1–3], and rather poorly developed shatter cones in granitoids and metadolerites [2, 9]. In Söderfjärden the impact evidence comes from brief references to indexed PDFs and multiple orientations of PFs in quartz, possible PDFs in plagioclase and microcline, and rare mosaicism of feldspars [4–6]. However, in both structures detailed documentation of shock metamorphism has so far been lacking.

Samples and methods: The Saarijärvi samples are mainly from the vertical core D3533-02 drilled in the center of the structure (Finnish national grid coordinates X=7244.900 Y=3564.945) penetrating the entire sedimentary sequence [1, 2]. The uppermost sample is of poorly-sorted grey sandstone (depth: 25.81 m) which represents Early Cambrian sediments. Three moderately well-sorted light-colored sandstone samples were taken from the Ediacaran part of the sequence (~156 m). The fifth sample (170.4 m) is of the sandstone dike injected into basement granitoids. The sixth sample is of light-colored sandstone from the upper (30.65 m) portion of drill core R311 (X=7245.360 Y=3565.000, inclined 45° towards ESE) in the northern section of the structure.

Five Söderfjärden samples come from the vertical drill core SF2-1975 (DH2) in the western part of the central uplift (X=6989.492 Y=1529.168). Samples taken from the interval ~50–66 m are of polymict breccia dike injected into the basement granitoids. The breccia sometimes includes small melt particles, and it lies directly below the Quaternary sediments (i.e., no Cambrian sediments are present [4, 6]).

Altogether eleven polished thin sections of the samples were studied with universal stage in order to determine the crystallographic orientations of planar microstructures in quartz. A new version of the stereographic projection template was used for indexing the planes [12].

Results: Multiple orientations of FFL, PFs, and PDFs in quartz are present both in Saarijärvi and Söderfjärden samples (Figs. 1 and 2). The PDFs are non- to moderately-decorated, with a spacing of 3–8 μm. Up to three sets per grain are observed, but only one set is typically present, particularly in Saarijärvi, where “toasting” (i.e., brownish coloration, see references in [12]) of grains with PDFs is fairly common [2]. In Saarijärvi, both PDFs and FFL are rare, whereas in Söderfjärden PDFs are notably more common than FFL (Fig. 1). In both histograms (Fig. 1) the
PDF orientation is prominent, but in Söderfjärden the basal Brazil twin orientation (0001) is the most ubiquitous. PF orientations in both structures are mostly (0001), but other orientations (e.g., {1011}) are present as well. All five FFL orientations in Fig. 1 are typically observed in other impact structures [11]. It is notable that in Saarijärvi the PFs and FFL, as well as the rare PDFs, occur in the quartz-rich parts of both the Cambrian and Ediacaran sedimentary rocks [see also 2, 3].

Fig. 1. Angles between quartz c-axis and poles to PDFs and FFL from Saarijärvi and Söderfjärden impact structures. All measured sets included. Note the low number of measurements, particularly in Saarijärvi. Tabular and uniquely indexed plane data [see, e.g., 12, 13] omitted for brevity.

Conclusions: The presence of multiple sets of PFs, PDFs, and feather features (PF+FFL, Fig. 2; See [11] for discussion.) in quartz, with orientations typical for shock metamorphism (Fig. 1, see [11, 13]) clearly establishes that Saarijärvi and Söderfjärden structures were created by impacts. Multiple sets of PFs and PDFs indicate weak to moderate shock pressures up to ~15 GPa [e.g., 13]. A similar shock pressure regime is implied by the FFL [11]. In addition, these shear-induced FFL record high differential stresses typical for weak shock waves [11]. These results confirm the earlier tentative shock metamorphic studies [e.g., 1–3, 5, 6, 9].

As discussed before [2, 3], the origin and evolution of the Saarijärvi impact structure are not yet fully understood. However, unequivocal evidence of shock metamorphism from both the Cambrian and the Ediacaran parts of the sedimentary sequence in Saarijärvi, including a sandstone dike injected into the crater-floor granitoids, very strongly imply that these sediments are indeed pre-impact in origin. Thus, we concur with our earlier study [3] that the age of Saarijärvi is likely Early Cambrian or younger.

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Fig. 2. PFs (0001) with FFL {1011} and {1122} in quartz from sandstone at the bottom (156.25 m) of the sedimentary sequence in Saarijärvi. Cross-polarized light.