U-Pb DATING OF THE SUVASVESI IMPACT STRUCTURES – DOUBLE IMPACT OR NOT.

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Introduction: The Suvasvesi impact structures (both ~4 km diameter) covered by lakes are closely spaced (~ 5 km) and located in the southeastern part of Finland (see Fig. 1). The northern (N) structure formed in Archean biotite-schists of the Karelian craton (~ 2.7 Ga) separated by the Suvasvesi fault zone from the ~ 1.8 - 1.9 Ga Paleoproterozoic granites, granite pegmatites, and mica schists of the Svecofennian terrane (see Fig. 1). The northern impact structure was dated with the Ar-Ar step heating method at an age of 85.6 ± 1.9 Ma (2σ); the Ar-Ar step heating data of the southern (S) structure were interpreted as a minimum age of ~710 Ma [1].

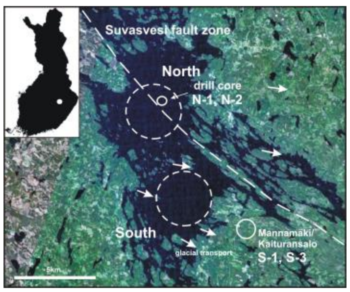

Figure 1: Landsat image of Suvasvesi impact structures and geographic position in Finland. Samples are from a drill core (North) and from glacial float at Mannamäki – Kaituransalo (South).

Sample description: Impact melt rock samples (SuvN1, SuvN2) from a borehole into the N structure show a fluidal texture with clast-rich and clast-poor domains containing only small zircon grains ≤30 µm.

The impact melt rock samples SuvS1 and SuvS3 from the Suvasvesi S were samples as glacial surface float near Mannamäki/Kaituransalo (for more petrological and geochemical description for N1, N2 and S1 see [1], S3 has a fluidal texture within a glassy ground mass with strongly altered, shocked mineral clasts). The zircon grain size for these samples is mostly <30 µm except for one granular grain ~150 µm in length.

The morphology for all zircon grains for the four samples range from nearly unaffected to grains with cracks, as well as grains with porous or granular texture.

Analytical method: 23 zircon grains with 25 spots in samples N1 and N2; 22 grains with 30 spots in sample S1; and 42 grains with 53 spots for sample S3 were analysed *in situ* with an IMS1280-HR ion probe (HIP Heidelberg). The primary ion beam has a size of ~10 µm. The O^- primary beam intensity was about 15 nA. The specific intensities for U and Pb isotopes were analysed using single collection mode. The common Pb corrections were done using the evolution model of [2] and ages calculated using the constants of [3].

Results: Figure 2 shows the U-Pb dating results plotted in concordia diagrams. The 25 spots analysed for drill core samples N1 and N2 yielded a lower intercept age for a discordia line of 70.4 ± 9.6 Ma (2σ), which is nearly in agreement with the Ar-Ar age of [1]. The youngest 3 analysis points plot on concordia between 72 ± 10 and 94 ± 12 Ma (2σ). The upper intercept is 1868 ± 35 Ma (2σ), within the age range of the Svecofennian terrane adjacent to the Suvasvesi fault zone (Fig. 1).

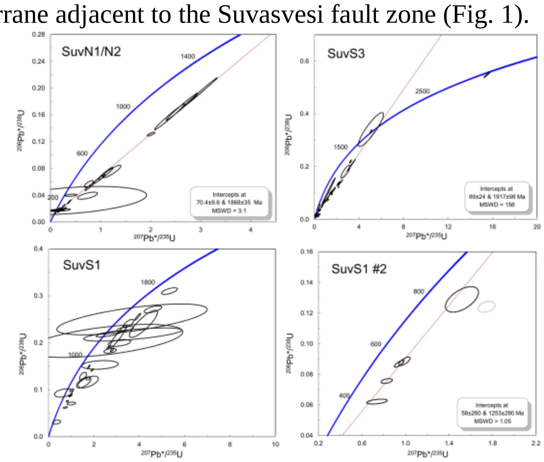

Figure 2: Concordia plot for samples SuvN1/N2, SuvS1, SuvS1#2 (6 analysis on one single grain, see Fig. 3) and SuvS3 of the impact metamorphic zircon grains. Error ellipses are 1σ.

For sample S3 collected southeast of the S structure, the correlation of a potential discordant line is not as straightforward as for the North drill core samples. The line points toward the same U-Pb age as for the N samples, i.e., a lower intercept age of ~ 70 Ma and an upper intercept at ~ 1.9 Ga, with two concordant $^{206}Pb/^{238}U$ ages of 1853 ± 40 and 1889 ± 408 Ma (2σ). One 'outlier' data point with a concordant $^{206}Pb/^{238}U$ age of 2815 ± 58 Ma (2σ) was excluded from intercept age calculations as it likely relates to the Archean Karelian basement. The youngest concordant $^{206}Pb/^{238}U$ ages of this samples are between 70 and 90 Ma, similar to the Ar-Ar age of [1] for the N drill core samples.

There is a larger scatter of the U-Pb data for sample S1 in the concordia diagram, but there seems to be a general trend from a Paleoproterozoic age to a young age around the lower intercept, which is the same as for N1, N2 and S3. The youngest $^{206}Pb/^{238}U$ age of 196 ± 35 Ma (2σ) nearly falls on the concordia curve.

For a larger zircon grain (SuvS1 #2, Fig. 3), 6 analyses were possible (Fig. 2). The $^{206}Pb/^{238}U$ ages of these analyses are 547 ± 22, 470 ± 12, 754 ± 26, 537 ± 18, 289 ± 12, and 782 ± 62 Ma (2σ), all with $^{207}Pb/^{206}Pb$ ages around ~ 1.2 Ga. Excluding one of the data points, the 5 other spot ages define a discordia line with intercept ages of 58 ± 260 and 1253 ± 280 Ma (2σ). Considering its large error, the lower intercept age is in agreement with the new zircon age of the N structure, its Ar-Ar age [1], and the results for sample S3.

Discussion/Conclusion: The lower intercept and the youngest (concordant) ages of all four samples agree reasonably well with the published Ar-Ar age of Suvaevesi N of 85.6 ± 1.9 Ma (2σ) [1]. This could lead to the conclusion that both impact structures may have formed at the same time as an impact doublet or as two individual impacts within a rather short time interval, although the latter scenario seems somewhat unlikely.

Some of the U-Pb results for samples S1 and S3 do not fully agree with the theory of a double impact. Taking together all results, there is good confidence from the present and previous studies that the age of north impact is ~ 85 Ma. However, both boulder samples found close to the South structure were interpreted in [1] as having been glacially transported (see Fig. 1), assuming the south structure was their source of provenance. The Ar-Ar result of sample S1 suggest a minimum age for the southern structure of ~ 700 Ma [1], but in contrast U-Pb dating ages are comparable to the north structure of ~ 85 Ma, as well as the the U-Pb data for sample S3.

EBSD maps of the large zircon grain SuvS1 #2, indicate this grain represents a former reidite in granular neoblastic (FRIGN) [5] zircon grain that formed during impact. This shock transformation commonly causes the (nearly) complete loss of pre-impact radiogenic Pb* (e.g., [6]), in turn leading to an age at or around the impact event. As the U-Pb spot ages are, beyond the lower intercept age of ~85 Ma, complex and mainly discordant, this zircon grain may have formed during another, older impact event, resulting in the FRIGN zircon grain texture, the age of which is poorly constrained. The upper intercept age of grain SuvS1 #2 agrees within uncertainty limits with the $^{207}Pb/^{206}Pb$ ages; this could mean the zircon may have suffered the (partial) loss of pre-impact radiogenic Pb* during both an older S and a younger N impact. This effect could also explain the scatter for all U-Pb data, as observed in the concordia diagrams for S1 and S3. In this scenario, all four samples would have been affected, more or less, by the N impact at ~ 85 Ma, but sample S1 and maybe S3 could have been affected by an additional S impact event much earlier, perhaps around or before ~1.2 Ga, as indicated by the upper intercept for SuvS1 #2 and its $^{207}Pb/^{206}Pb$ ages (Fig. 2).

Finally, the two lakes that conceal the impact structures are of very different depth, which could indicate different ages of the two underlying impact craters. The S structure (~30 m deep) is much shallower than the N structure (~90 m [7]). As both craters are about the same size at time of their formation within the crystalline-metamorphic bedrock, one would expect they should degrade in a similar way over time. However, the S structure seems to show a much higher level of erosion and, thus, appears to be older than the N structure. One possible conclusion is that the two closely spaced impacts may be separated by more than 1 Ga in time (i.e., ≥ 1.2 Ga for S *vs.* ~ 85 Ma for N). Only drilling of the S structure and the dating of fresh impact melt samples may solve this problem.

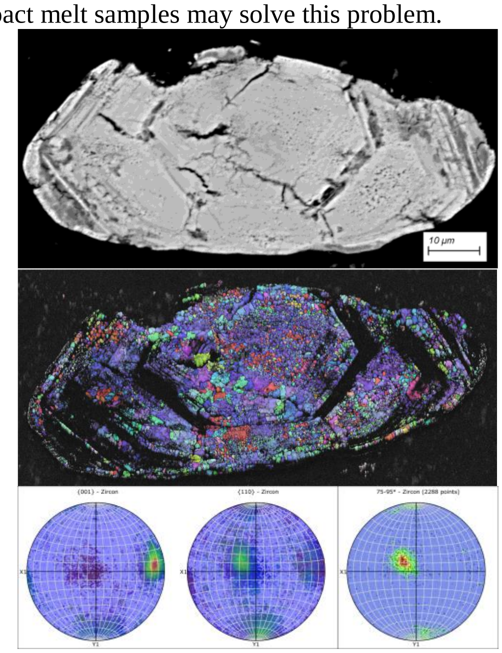

Figure 3: BSE, EBSD and pole figure image of the granular zircon grain SuvS1 #2 from the gneissic impact melt sample. EBSD (pole figure) image is showing the typical pattern for recrystallised impact metamorphic (FRIGN) zircon grains (see e.g. [4], [5]).

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References: [1] Schmieder M. et al. (2016) *Meteoritics & Planet. Sci., 51,* 966-980. [2] Stacey J. S. and Kramers J. D. (1975) *Earth Planet. Sci., 26,* 207-221. [3] Steiger R. H. and Jäger E. (1977) *Earth Planet. Sci., 36,* 359-362. [4] Timms N. E. et al. (2017) *Earth Science Reviews, 165,* 185-202. [5] Cavosie A. J. et al. (2018) *Geology 46,* 891–894. [6] Hauser N. et al. (2019) *Meteoritics & Planet. Sci., 54,* 2286-2311. [7] Werner S. C. et al (2002) *Physics and Chemistry of the Earth Parts A/B/C 27,* 1237-1245.