CARBONATE MELT FRAGMENTS IN RESURGE DEPOSITS FROM THE LOCKNE IMPACT STRUCTURE, SWEDEN.

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Introduction: Melting during hypervelocity impact is common in both crystalline and sedimentary target rocks, but the response of sedimentary and mixed targets to impact melting is poorly understood [1]. The late Ordovician Lockne impact structure in central Sweden (grid reference: 63º00' N, 14º49' E) formed in a mixed target composed of a Precambrian crystalline basement overlain by a sedimentary sequence of ca 30 m black shale and 50 m limestone and, at the time of impact, covered with seawater to a depth of at least 500 m [2,3]. Lockne is a well-preserved crater, owing to a cover of over-thrust nappes that existed in the past protecting the crater from erosion [3]. These nappes formed during the post-impact Caledonian Orogeny. No large bodies of melt have yet been found in the Lockne crater, but the so called *loftarstone* part of the resurge deposits contains microscopic fragments of melt [4]. The aim of this study is to determine the distribution and composition of the melt fragments in the loftarstone.

Loftarstone resurge deposit: Resurge deposits form during early crater modification in marine-target impact craters when the rim is low enough to allow the expelled water to re-enter the crater [5]. They are composed of both coarse and fine clastic materials originating as ejecta that landed in the surrounding sea, erosion of surrounding sea-floor and crater rim, and reworking of impactites within the crater. Loftarstone is the given name for the finer-grained variety of the resurge deposits at Lockne, the coarser being the Lockne breccia [6]. The grain-size of the loftarstone mostly grades from arenitic to silty, but at some localities there may be sporadic occurrences of up to several centimetre large shale-clasts.

Methods: Samples of silty to coarse sandy loftarstone were collected at 7 different localities in and around the Lockne impact structure (Table 1). 16 polished thin sections (sized 4.6 × 2.7 cm) were examined by optical microscopy prior to being coated with 10 nm of carbon and studied via backscatter electron (BSE) imaging and qualitative energy dispersive X-ray (EDX) analyses using a Zeiss Sigma field emission scanning electron microscope (SEM) operated at 20 kV. For identification of mineral phases, Raman spectra were acquired by using a Renishaw inVia Raman microscope with a 514 nm laser.

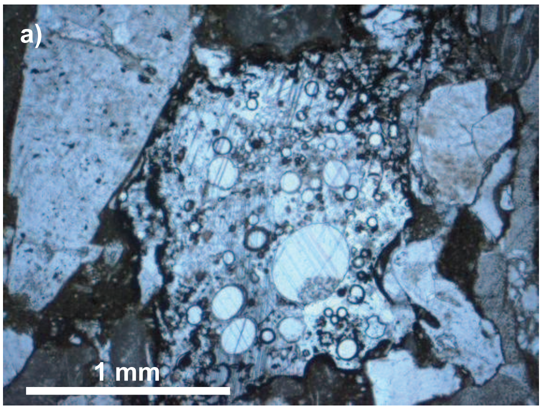
Results: A total of 268 melt fragments were detected in the 16 thin sections. 254 of these melt fragments are largely composed of carbonate melt, and 14 are dominated by silicate melt. The carbonate melt fragments occur in 14 of the thin sections and the silicate melt fragments in 8 of the sections (Table 1). Medium-grained loftarstone from the Hällnäset locality contains the largest number of melt fragments (total of 47), but the very fine-grained bedded loftarstone at Tand, and the fine-grained bedded distal deposit from Hallen, completely lack melt fragments.

Table 1. Distribution of melt fragments in 16 thin sections of the loftarstone resurge deposit. Samples are of various grain sizes and were collected from 7 different localities.

Sample	Locality co-ord. (E-W/N-S)	Grain-size	Nr. of melt-fragments in one thin section	
			carbonate	silicate
L_1	1.Hällnäset (SW*) 1451000/6985000	Coarse	6	-
L_2	-"-	Medium	45	2
L_3	-"-	Fine	30	-
L_4	-"-	Fine	29	-
L_5	2.Blisterloken (SW*) 1447200/6986000	Coarse	3	4
L_6	-"-	Coarse with cm-sized shale fragments	16	-
L_7	-"-	Coarse	12	-
L_8	-"-	Fine	21	-
L_9	-"-	Coarse	22	1
L_10	-"-	Coarse	27	1
L_11	-"-	Medium	2	2
L_12	3.Oxögat (SW*) 1446420/6987380	Medium	32	2
L_13	4.Ånge (N*) 1448205/6991850	Medium	8	1
L_14	5.Torvalla (NE*) 1445060/7004044	Medium	1	1
L_15	6.Tand (W*) 1446340/699025	Very fine, bedded	-	-
L_16	7.Hallen (distal*) 6241040/1416500	Fine, bedded	-	-

*SW, N, NE, W and distal - in relation to the centre of the Lockne impact structure.

Raman spectroscopy confirms that the carbonate phase in the carbonate melt fragments is calcite, and multiple orientations of calcite twinning are visible via optical microscopy. The carbonate melt fragments are irregular with curved edges and vary in size from ~0.5-2 mm. They contain abundant vesicles which are largely also filled with calcite (Fig. 1a). The less abundant silicate melt fragments are irregular and vary in size between ~0.5mm-1.5 cm. The silicate melt fragments are texturally more homogeneous than the carbonate melt fragments, but some of them also contain vesicles and display flow textures (Fig. 1b). Work is currently in progress to quantitatively determine the chemical composition of the silicate melt fragments.



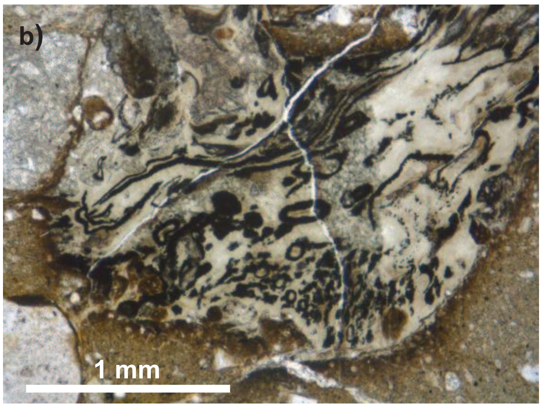


Figure 1. Photomicrographs in plane-polarized light of a) a vesicular carbonate melt fragment, and b) a silicate melt fragment displaying flow textures. Both in loftarstone from Lockne.

Qualitative SEM-EDX analyses and mapping show that many of the carbonate melt fragments are much more complex than initially considered. They are in fact composed of an intricately intermingled texture of both carbonate melt and silicate melt (Fig. 2).

Discussion: Carbonate melt fragments are the most abundant in the Lockne loftarstone resurge deposits. They have a vesicular texture, which indicates the release of a gas, possibly CO_2, during melting. The carbonate melt fragments are recrystallized, and the carbonate phase is calcite. The calcite twinning is probably a result of deformation during the post-impact Caledonian Orogeny. The complex intermingling textures in the carbonate melt fragments are most likely a result of liquid immiscibility between a carbonate melt and a silicate melt. Carbonate-silicate immiscibility has also been inferred from other impact structures with mixed targets, e.g. the Ries impact structure in Germany [7] and the Haughton impact structure in Canada [8]. No melt fragments were detected in the very fine-grained and bedded loftarstone deposit, which may simply be a result of that the melt fragments are harder to identify in these finer fractions.

The composition and origin of the silicate melt fragments in the loftarstone is currently work in progress, but this study shows that some of the target carbonates at Lockne were melted during the impact, and are included as melt fragments in the loftarstone resurge deposit.

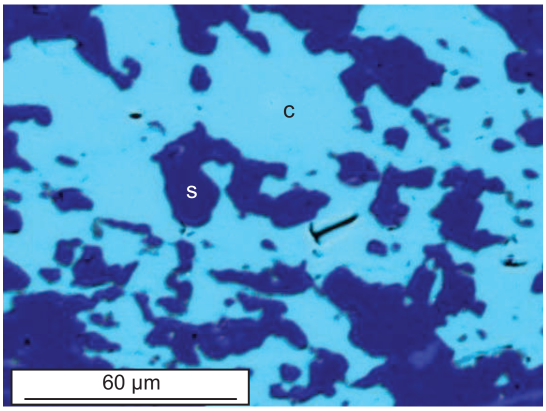


Figure 2. False coloured ED X-ray map of the interior of a carbonate melt fragment in loftarstone from Lockne showing the distribution of the two elements Si (dark blue) and Ca (light blue), representing the two melt phases; silicate melt (s) and carbonate melt (c).

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