SHOCKED QUARTZ IN THE MÅLINGEN STRUCTURE - EVIDENCE FOR A SMALL TWIN CRATER TO THE LOCKNE IMPACT STRUCTURE C. Alwmark[1], S. Holm[1], J. Ormö[2] & E. Sturkell[3]. [1]Dept. of Geology, Lund University, Sölvegatan 12, 22362 Lund, Sweden (carl.alwmark@geol.lu.se), [2]Centro de Astrobiología (CSIC/INTA), Instituto Nacional de Técnica Aeroespacial, Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Madrid, Spain, [3]University of Gothenburg, Department of Earth Sciences, PO Box 460, SE-405 30 Göteborg, Sweden

Introduction: The Målingen structure, located in the Jämtland province of central Sweden, has for a long time been considered a geological anomaly [1–3]. The occurrence of sedimentary breccias in combination with its circular shape and similar age as the nearby Lockne impact structure evoked the suggestion that it is an impact crater formed in conjunction with Lockne [2–3]. However, in the absence of any subsurface information of the structure the hitherto consensus has been that it is a tectonic feature caused by the Caledonian orogeny that affected the area some millions of years after the Lockne impact, and that the sedimentary breccias are distal deposits originating from the Lockne structure [4].

In this study, thin sections from drill core samples of a polymict breccia from within the Målingen structure have been investigated and searched for microscopic shock metamorphic features, in an attempt to verify whether the structure is indeed impact derived.

This study, of potential shock features within the structure, is part of an ongoing, more extensive project that includes geological mapping, detailed geophysical survey (gravity and magnetics), enhanced biostratigraphic dating, and a core drilling of the Målingen structure [5, 6].

Geological Setting: The Målingen structure is located about 15km SW of the center of the ~7.5 km diameter early Late-Ordovician Lockne impact structure (N 63°00', E 14°49'; Fig. 1a) [7]. It is expressed as a banana-shaped bay within the larger Lake Näckten. The structure itself is situated in Proterozoic crystalline basement, with the central lower parts covered by Paleozoic sediments showing similarities to the resurge- and secular sediments that cover much of the Lockne crater. An apparent elevated rim of fractured and brecciated basement rock surrounds the western and southern sides of the bay, partially even superimposed on sediments of the lower part of the Paleozoic sequence of the area. The diameter of the apparent, circular structure in the crystalline basement is approximately 700m (Fig. 1b).

A 148.80 meter long core (Målingen-1A&B) from the structure was retrieved during a drilling campaign in the summers of 2010 and 2011. The drilling took place about 300 m southeast of the geographic center

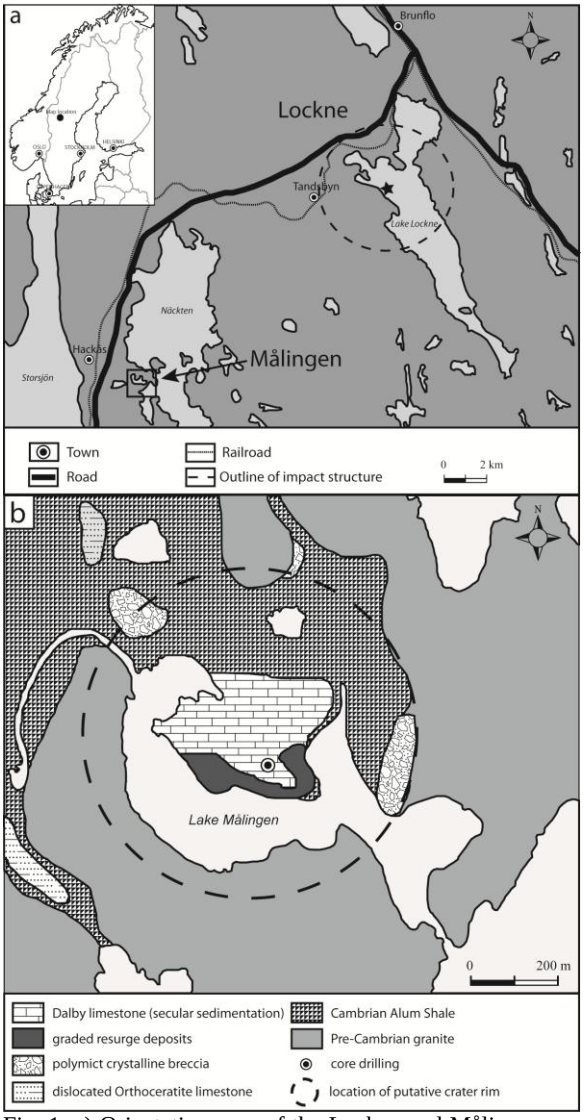

Fig. 1. a) Orientation map of the Lockne and Målingen area. The circle outlines the 7.5 km diameter of the Lockne impact structure. b) Geologic map of the Målingen structure (close-up of the rectangular area in a). Modified from [5].

of the structure. The uppermost part of the core, down to a depth of about 3.2m is made up of Dalby Limestone interpreted as post impact (secular) sediments. It is followed downwards by a normally graded sequence of siltstone, sandstone, and polymict breccia representing the resurge deposits in analogy with the succession

within the Lockne crater [8]. The resurge deposits have a sharp lower boundary (likely erosive contact) to an about 97 m thick unit of dark mudstone interpreted as a slump deposit of the dark, Cambrian target sediments (alum shale), offering a direct analog to the Tramsta Breccia in the Lockne crater [9]. Below this unit there is an about ten meter thick polymict (mainly crystalline) breccia. The breccia is clast supported, with the clasts being dominated by crystalline granitic fragments of the basement rocks, varying in size from millimeter up to a few decimeters. It is followed downward by crystalline basement rocks of varied degree of fracturing and zones of brecciation.

Material and Methods: Three intervals of the 148.80 meter long Målingen-1 A&B drill core were sampled for this study; 108 meters, 114 meters and 115 meters. The sampled intervals are all within the polymict breccia. Two thin sections were prepared from each sample. The thin sections were searched for shock metamorphic features in quartz grains under optical microscope. Quartz grains displaying planar deformation features (PDFs) were further studied using a Leitz 5-axes universal stage [10] mounted on an optical microscope, and the crystallographic orientations of identified PDFs were determined according to techniques described in [11, 12].

Results: Shock metamorphic features in the form of PDFs where found in four grains, all from the 114 meter interval. No PDFs could be identified in the 108 and 115 meter intervals. The quartz grains with PDFs are between 100-400 µm in size, angular and commonly display undulose extinction (Fig. 2).

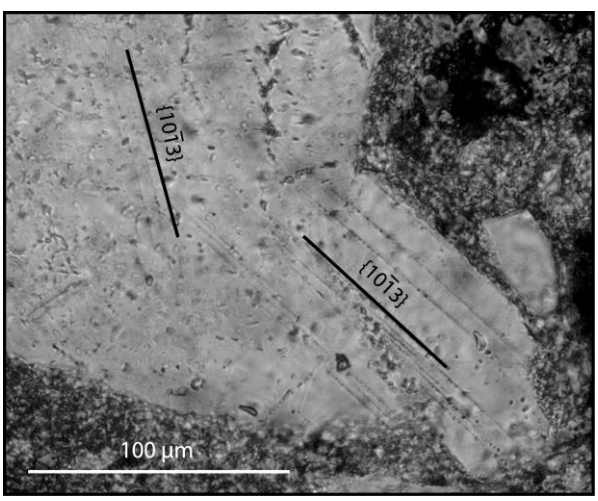

Figure 2. Thin section photomicrograph of part of shocked quartz grain displaying two decorated PDF sets with {10$\bar{1}$3} equivalent orientations (uncrossed polars).

Of the four shocked grains, two display a single set of PDFs, both oriented parallel to the basal plane *c* (0001). The two other grains contain two and three sets, respectively. The two-set grain displays one set oriented along (0001) and one parallel to crystallographic plane ω {10$\bar{1}$3}. The three-set grain displays one set oriented along (0001) and two parallel to crystallographic plane ω {10$\bar{1}$3}. The PDFs themselves appear in straight parallel sets with a spacing between individual planes of 1-5 µm, usually penetrating the better part of the host grain and they are decorated.

Discussion and Conclusion: PDFs oriented along crystallographic planes typical for shock metamorphosed quartz are present in the Målingen structure. The fact that the shocked quartz are found in the lower parts of structure below the sediment fill, i.e., in the allochtonous breccia, allows us to exlclude that the shocked material is transported from Lockne, proving that the Målingen structure is indeed impact derived.

The sedimentological aspects, such as the ages of the deposits that fill the depression at Målingen, are identical to features at the Lockne impact structure, and therefore, a coeval age is likely. Thus, Målingen is most likely a small twin crater to Lockne. Whether the bolide responsible for the formation of the Målingen structure was a separate object or part of a clustered object that became separated in space, possibly when entering the Earth´s gravitational field, is at this stage not known. Further studies, e.g., chemical analyses in order to determine the type of impactor for Målingen, could perhaps shed some light on this, as the impactor for Lockne has previously been determined as L-chondritic [13].

References: [1] Thorslund P. (1940) *SGU C436*, 1–191. [2] Sturkell E. et al. (1994) Excursion Guide to the Lockne Impact Crater. ISBN 9187786087. [3] Grahn Y. (1997) *MAPS 32*, 745–751. [4] Lindström M. et al. (1996) *GFF 118*, 193–206. [5] Ormö J. et al. (2011) *LPSC XLII*. [6] Melero Asensio I. et al. (2011) *LPSC XLII*. [7] Grahn Y. et al. (1996) *J. Micropaleontol. 15*, 21–35. [8] Ormö J. et al. (2007) *MAPS 42*, 1929–1943. [9] Sturkell E. et al. *MAPS (in press)*. [10] Emmons R.C. (1943) *Geol. Soc. Am. Mem. 8*, 205 pp. [11] Engelhardt W. von and Bertsch W. (1969) *Contrib. Min. Petr. 20*, 203–234. [12] Ferrière L. et al. (2009) *MAPS 44*, 925–940. [13] Alwmark C. and Schmitz B. (2007) *EPSL* 253, 291–303.