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ISSN: 1103-5897 (Print) 2000-0863 (Online) Journal homepage: https://www.tandfonline.com/loi/sgff20

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To cite this article: Anders Holmqvist, Carl Alwmark, Henning Dypvik & Odd Nilsen (2020): The Lycksele ring structure – still no proof of an impact origin, GFF, DOI: 10.1080/11035897.2019.1701547

To link to this article: https://doi.org/10.1080/11035897.2019.1701547

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ARTICLE

The Lycksele ring structure – still no proof of an impact origin

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ABSTRACT

The origin of the more than 100 km wide Lycksele ring structure in Sweden has puzzled geoscientists for years. In this short note we present results from field analysis, detailed sampling and laboratory analysis executed in search for evidence of an impact, e.g. shatter cones and shock features in minerals. Both approaches gave negative results and consequently an impact origin could neither be confirmed nor rejected. The circular structure of the Lycksele ring and its central uplift are, however, typical features of large, complex impact structures.

ARTICLE HISTORY
Received 29 April 2019
Accepted 21 November 2019

KEYWORDS
Possible impact crater;
possible astrobleme;
Lycksele ring structure;
Swedish Lapland

Introduction

The more than 100 km in diameter Lycksele ring structure (LRS) is a circular structure in the Proterozoic bedrock of Lapland, northern Sweden (Figs. 1 and 2). It was first recognized in 1982, and its discovery was announced in Skellefteå at the annual meeting of the Geological Society of Sweden (Holmqvist et al. 1982). The almost perfect ring structure suggested a possible impact origin, although a diapiric or batholitic origin could not be excluded. Consequently, the origin of the ring structure was questioned whether or not it represents an old, deeply eroded astrobleme. Later Witschard (1984) mentioned the structure, and furthermore proposed the existence of several other large circular structures of possible impact origin in Sweden. The LRS has since then only attracted minor attention among geologists although it has been geophysically investigated in some detail since the mid-1990s. In his PhD thesis Nisca (1995) described the structure after having analyzed it using different geophysical and geographical methods. Large areas of the bedrock inside the LRS consist of coarse-grained Revsund type granite. Therefore, Nisca (1995, p. 167) proposed that the ring structure represents a granite dome (intrusion), since no geological arguments or mineralogical structures in favour of an impact origin had been observed. However, he did not totally exclude an impact origin for the LRS (Nisca 1995, p. 169).

Thunehed et al. (1999) did a detailed gravimetric study of the LRS and its diameter was reported to be ~ 130 km. They estimated its possible age to be between 1.80 and 1.26 Ga due to the fact that its rim cuts older mafic dykes, but is itself cut by younger dolerite dykes. Thunehed et al.'s (1999) interpretation of gravimetric data demonstrated an uplift in the central part and down-faulted more periferal areas of the LRS, issues that already Nisca (1995, pp. 144, 166) pointed out. This geometry is well documented from big impact craters, but cannot be taken as proof of an impact because similar mass movements may arise also in other ways (e.g., through diapirism etc, see below). Thunehed et al. (1999) compared gravimetric profiles across the LRS to gravimetric profiles across some of the world's largest and most well-known impact structures. Due to striking similarities of the profiles, Thunehed et al. (1999) preferred an impact origin for the LRS compared to other alternatives (e.g., basement doming, large granitic pluton or fault-bounded block). However, as no geological or mineralogical scientific evidence to support their view was found, the final proof of an impact origin was still lacking.

In this study we decided to execute a new search for possible geological and mineralogical structures in order to test the hypothesis of an impact origin of the LRS.

Methods

Our field work included sampling, searching for shatter cones at the sampling sites, observing and measuring fractures. The field work in 2012 resulted in 39 samples, and in 2013 additional 14 samples were collected. The studied sites represent both central and more peripheral localities inside the LRS (Fig. 1). The sampling set covers well the entire ring structure and includes an extensive profile along the Umeälven river valley.

From the 53 samples of granite and other quartz-bearing rocks, 29 were selected for microscopy analyses. In order to find shock lamella (planar deformation features – PDFs and planar features – PFs) in quartz grains, polished thin sections were prepared and studied in the polarizing microscope, applying universal stage technique.

Results

No shatter cones were found during the field work, in spite of the fact that most of the visited sites were fairly fresh road cuts, where such features, if present, would have been possible to discover. Shatter cones preferably are best developed in finer grained formations, thus the most fine-grained granite sections were studied accordingly (French 1998).

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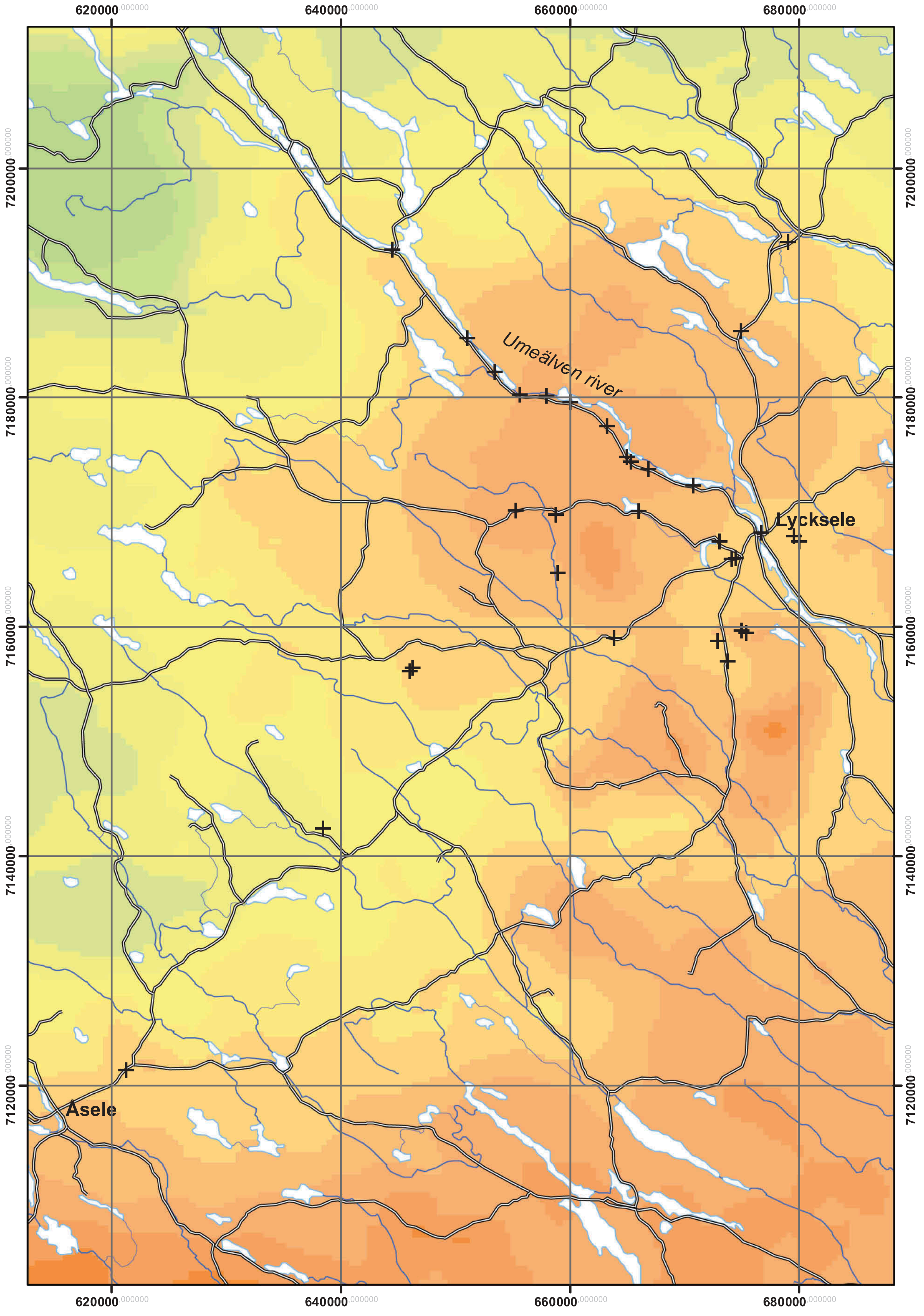

Figure 1. Part of the gravity gradient map of Sweden, produced by the Geological Survey of Sweden, showing higher gravity readings around the town of Lycksele. Sampling sites are marked +. The distance between Lycksele and Åsele is approximately 80 km. The figure does not cover the entire Lycksele ring structure.

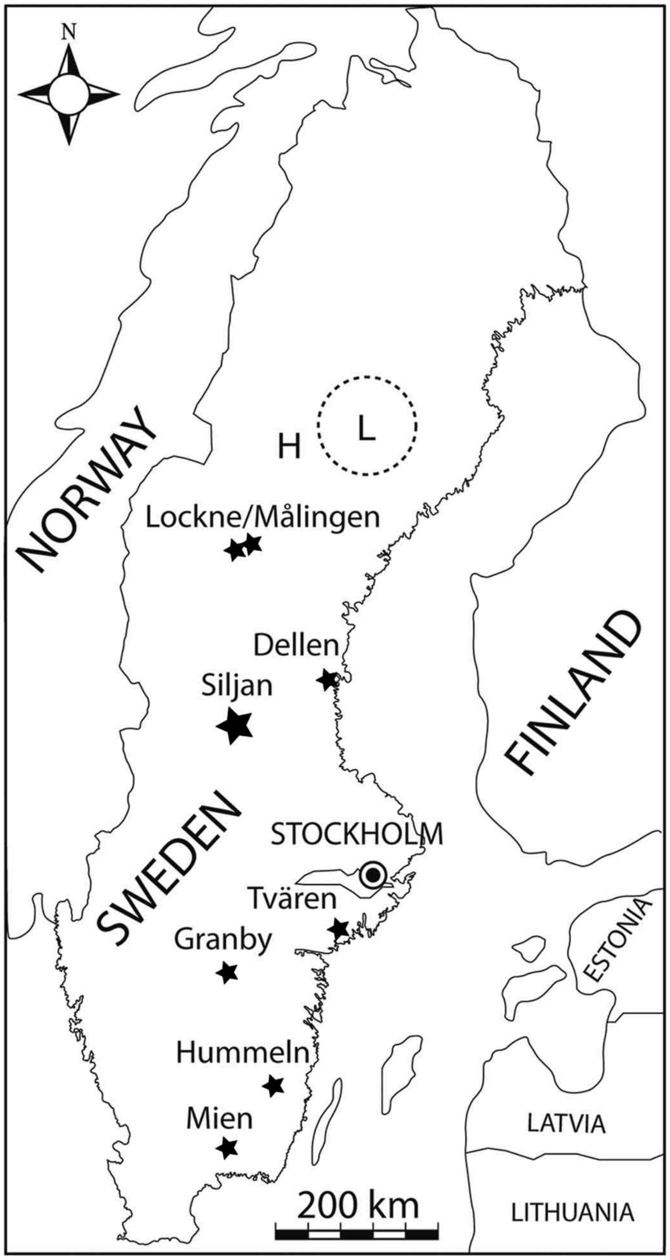

Figure 2. Map of Sweden showing all confirmed impact craters (stars) and the location and size of the Lycksele ring structure is marked by L. The Hoting area, H, is southwest of the LRS.

The thin section analyses in the optical microscope also gave a negative result. The studied quartz grains did not show any clear-cut PDFs or PFs. Consequently, our study did not discover any new convincing evidence of the Lycksele ring structure being an impact-created structure.

Discussion

The presence of shatter cones and/or shock quartz would have been the definite proof of an impact origin (Melosh 1989; French 1998). Since these were not found, a diapiric origin for the LRS may instead be considered. However, the absence of shocked quartz and shatter cones of course do not prove a diapiric origin. The most reasonable conclusion is that so far we can neither prove nor exclude the impact hypothesis with certainty.

If the LRS has a Proterozoic impact origin, why do we not find the critical features to prove this origin? An explanation may well be that the rocks at the present level of erosion represent very deep sites from the supposed time of impact, too deep for shock metamorphic features to be produced. During the Svecofennian, the Fennoscandian shield, where the LRS is situated, most likely hosted high mountain chains. Extensive and long lasting erosion and later uplift resulted in the present bedrock surface, representing rocks from many kilometres of burial at the time of impact. Elming et al. (2009) estimated that the present day surface in the Hoting area (situated about 100 km SW of the center of the LRS, Fig. 2) represents an about 10.4 km deep level at ca. 1.6 Ga. Furthermore, we have to consider that a vast impact crater would have had an uplift in its central part, which is also seen in the geophysical models. Thus, the central part of the LRS may come from a depth of a few additional kms to the mentioned 10.4 km uplift. If we suppose an impact early in the time span of 1.80–1.26 Ga (Thunehed et al. 1999) it is hard to know if the rock material deep down, inside the LRS was in a totally crystalline state, or if the Revsund granite exposed today had been affected at all by the impact shock, as it was deeply buried at the time.

Even more challenging and relevant also for other impact sites, is the question at what distance from the centre of an impact shock structures will appear. The distribution of shock waves along horizontal distances has been studied at several impact sites around the world, but in fewer cases when it comes to vertical distances. One may argue that the LRS is much larger than the majority of known impact structures, and consequently, PDFs would be expected to occur deeper down. On the other hand, the bedrock in the LRS case is probably eroded to a significant depth (see above), certainly deeper than most of the world's well known impact craters.

In later years some workers have studied the distribution of shock quartz in drill cores, taken up from different depths beneath impact craters: e.g., Puchezh-Katunki (Fel`dman et al. 1996), Bosumtwi (Ferrière et al. 2008), West Clearwater Lake (Rae et al. 2017), Siljan (Holm-Alwmark et al. 2017), and others. When taking part of their results one might ask if a shock wave usually fades out faster in vertical than in horizontal direction, something that would be of interest in the case of LRS. Before drawing the right conclusions about how or if shock waves affect rocks and minerals at greater depths, more research has to be done on samples from deep sites inside impact craters around the world. We also have to bear in mind that other factors than depth alone (size and velocity of the meteorite, angle of impact, lithology of the target, rheology etc.) play a role here.

By presenting this study of the Lycksele ring structure we hope to generate some new interest and discussion of the structure. In spite of the negative results, we are not yet ready to completely reject the hypothesis of an impact origin for the LRS. This still remains an open question. This letter is published not only to convey the recent results, but also to make other scientists aware of what has been done.

Acknowledgments

Our good friend and colleague, Odd Nilsen, was a key scientist in this project and sadly passed away on March 12. 2014. The authors want to thank Sten-Åke Elming, Div. of Exploration Geophysics, Luleå University of Technology for encouragement and for proposals to improve the manuscript, as well as for financial support (AH) and Magnus Ripa for a thorough and constructive review that improved the quality of the manuscript. Financial support from University of Oslo is also acknowledged (HD and ON). We also want to thank Birger Schmitz, Lund University, for taking part in the microscope work.

Disclosure statement

No potential conflict of interest was reported by the authors.

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