Geophysical methods in impact crater hunting – Case Summanen

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Abstract

Impact cratering is a ubiquitous process in our solar system affecting all planetary surfaces throughout geologic time. On Earth, there are currently 190 confirmed impact structures, which are distributed unevenly. The Fennoscandian Shield houses 17 % of them. The large amount of impact structures makes Fennoscandia one of the most densely cratered terrains on Earth. A dozen (12) impact structures have been discovered in Finland. The latest discovery, Lake Summanen is located in Central Finland, about 9 km southeast of city Saarijärvi. An impact generated structure was first hinted by airborne geophysical mapping by the Geological Survey of Finland in the early 2000`s (Lerssi et al., 2007) that revealed a circular ~2.6 km wide striking aeroelectromagnetic resistivity anomaly. Recent studies in 2017-2018 confirmed its impact origin based on the findings of shatter cone-bearing rocks and the identification of planar deformation features in quartz.

1. INTRODUCTION

Summanen impact crater (62°39'00''N, 25°22'30''E) is located within the Paleoproterozoic Central Finland Granite Belt and is covered with the Lake Summanen. The lake is somewhat elliptical (8 km x 9 km x 4 km) in shape, whereby the longest axis extends in NW–SE direction due to the erosional influence of the latest (Weichselian) glaciation. The area became deglaciated about 10,700 years ago (Stroeven et al. 2016). At present, the water level of Lake Summanen is at 108.5 m a.s.l. and it is connected to several other surrounding lakes. It also hosts two major islands, Summassaari and Lamposaari.

Lake Summanen was proven to have an impact origin based on diagnostic evidences. Shock-metamorphic features are divided into diagnostic and non-diagnostic features which can be either geological, geochemical, or geophysical. Shock metamorphic features like shatter cones are the only macroscopic evidence of an impact. The most commonly used diagnostic evidence for impact origin are the microscopic planar deformation features (PDFs) in minerals (e.g., quartz and feldspar; French and Koeberl 2010). During the field trip in 2017 a few tens of erratic porphyritic granite boulders, breccias and shatter cone-bearing samples were discovered. Most shatter cone-bearing specimens were found within a distance of 5 km SE from the geophysical anomalies. In two shatter cone-bearing samples PDFs were identified. Measurements of PDF orientations were done at the University of Tartu, with a LOMO FS universal stage mounted on a polarizing microscope using the standard technique (see Langenhorst, 2002) and analyzed using the PDF indexing algorithm ANIE (Huber et al.

2011). These results concluded that Summanen structure represents an old eroded impact structure and were published in Meteoritics & Planetary Science in 2018 (Plado et al. 2018).

2. GEOPHYSICAL CHARACTERISTICS

Geophysical anomaly of Lake Summanen was first identified in the early 2000s by Jouko Vanne, a geologist at the Geological Survey of Finland (Lerssi et al. 2007) who pointed out a regional conductivity anomaly from the geophysical lowaltitude data. In-phase aeroelectromagnetic data (Fig. 1a) over Lake Summanen revealed a strikingly circular c. 2.6 km wide anomaly, which is related to the central part of the lake. The anomaly is distinct as other nearby lakes lack such anomalies. The apparent resistivity map (Fig. 1b) shows an anomaly that is slightly wider and not as circular as the in-phase component anomaly. The anomalies are similar to the apparent resistivity anomaly associated with a nearby (50 km south from Summanen), Lake Karikkoselkä (Pesonen et al. 1999; Lerssi et al. 2007), which impact origin was proven in 1996 (Lehtinen et al. 1996). Noteworthily, lakes in Finland usually do not show such electromagnetic anomalies.

In the winter of 2006 the Lake Summanen was profiled from ice with the electromagnetic multifrequency apparatus (SAMPO) from the Geological Survey of Finland. The transmitter and receiver were located on the profile 500 m apart, and the result was given to the central point of the system. Measurements were performed at every 200 m, but condensed to 50 m in the central parts of two perpendicular SW–NE and NW–SE profiles. For qualitative interpretation, the SAMPO data measured at each frequency were transformed into curves of apparent resistivity as a function of depth using the algorithm of Aittoniemi et al. (1987). The curves were subsequently interpolated into apparent resistivity images (Fig. 2) by Lerssi et al. (2007). Bowl-shaped low resistivity features can be seen on both profiles (Fig. 2). Very low resistivities (<40 Ωm) are associated with Quaternary sediments. The rest of the bowl-shaped depression may be filled with low resistivity (from 40 to about 400 Ωm) sediments, or resistivities are lowered by fracturing of the basement. A report published by GTK (Lerssi et al. 2007) suggested that the possible cause of these features could be old sedimentary rocks or an impact crater structure filled with sedimentary material from the last ice age.

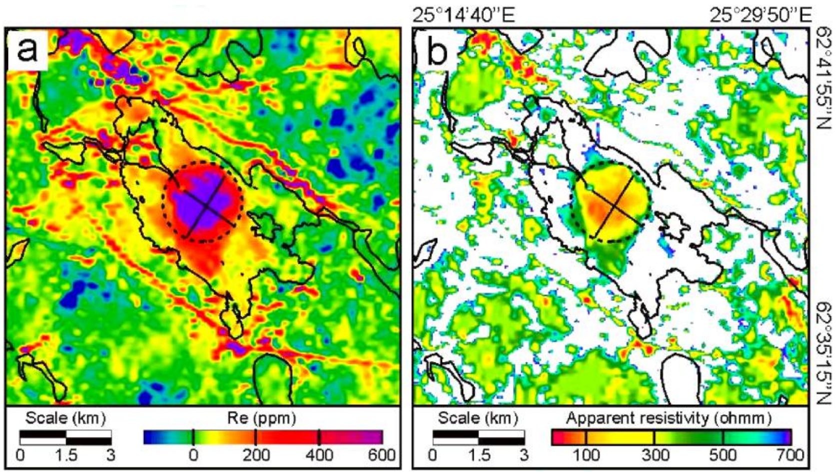

Figure 1: Aeroelectromagnetic (a) in-phase component and (b) apparent resistivity anomaly maps of the Lake Summanen area. Dashed ring with diameter of ~2.6 km indicate interpretational outlines of the anomalies within Lake Summanen. Black lines within the outlines show locations of SAMPO measurements (Fig. 2).

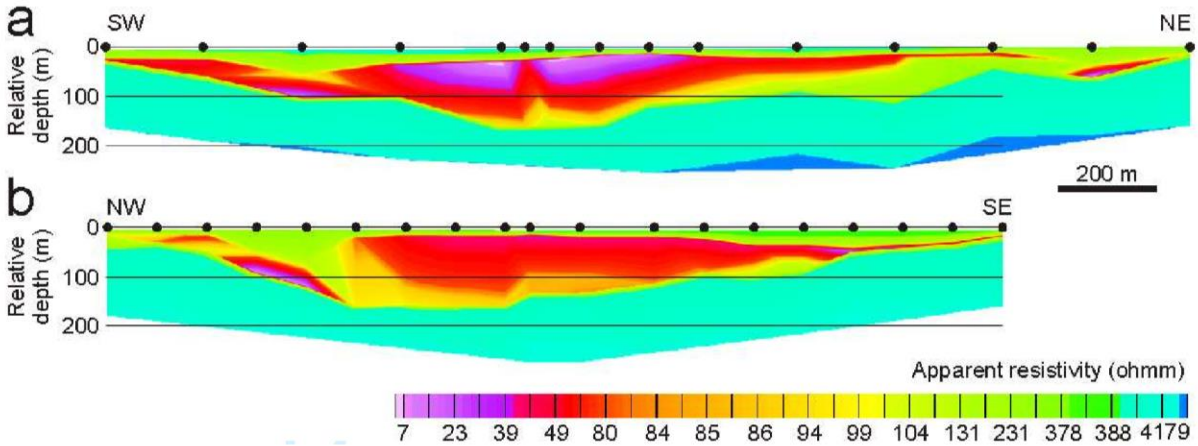

Figure 2: Apparent resistivity models based on the wideband SAMPO electromagnetic measurements from the ice of Lake Summanen (Lerssi et al. 2007). Black dots indicate locations of the original measurements (mid-points of the SAMPO system).

Lake Summanen is also surrounded by strong (up to 1000 nT) regional magnetic anomalies with a general trend from the SW to the NE. The lake area is characterized by weak magnetic relief: lack of prominent anomalies. Such a pattern is not a diagnostic feature for an impact origin, however, it is typical for many impact structures in Fennoscandia that miss highly magnetic impact melt rocks, such as, Jänisjärvi (Elo et al. 2000), Karikkoselkä (Pesonen et al. 1999), Suvasvesi South (Donadini et al. 2006), and Tvären (Ormö & Blomqvist 1996).

3. FUTURE STUDIES

The impact age of Summanen is undefined but must be younger than the age of the target rock 1.88 Ga. Radiometric and paleomagnetic dating techniques will be applied to date the Summanen event. Additionally, there is a need for gravity profiling and modelling. Seismic reflection and wide-band EM surveys may also provide additional information of the structure including the estimate of its erosion level. Drilling is essential to understand geological history of the structure.

4. CONCLUSION

Research of impact structures is constantly developing and receiving increasing international attention. The role of geophysical methods is important how these, mostly ancient, structures can be reliably identified. For example, the electromagnetic anomalies can be the last remaining sign in old, deeply eroded, structures. New developing methods should be used in the study, such as muongraphy. Muons can be used to derive an areal density of bedrock in great depths. In addition, unmanned Aerial Vehicles (UAV) used in magnetic surveys provides more detailed data than traditional airborne electromagnetic measurement. New technologies offer cost-effective, fast, and indestructible research capability. Several meteorite impact structures host economically valuable resources (ores, hydrocarbons, water). Impact sites have also become popular tourist attractions and they will increase tourism in the region and as such strengthen the local economy. Geoscientist must be informed about the potential of impact structures. The Summanen structure is an ideal target for drilling and providing data for multidisciplinary (geology, geophysics, geochemistry and environmental) research.

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