LAPPAJÄRVI IMPACT STRUCTURE, FINLAND – TRIPLE ANNIVERSARY IN 2018 AND PROSPECTS FOR RESEARCH AND OUTREACH. T. Öhman[1,2] [1]Arctic Planetary Science Institute, Lihtaajantie 1 E 27, FI-44150 Äänekoski, Finland, teemu.ohman@planetaryscience.fi. [2]Järviseutu-Seura ry., Lappajärvi, Finland.

Abstract: Year 2018 marks the 160th anniversary of the first description of Lappajärvi impact melt rocks, the 50th anniversary of the identification of PDFs and, hence, Lappajärvi's classification as an impact structure, and the 20th anniversary of the discovery of impact diamonds – the first in the Fennoscandian Shield. A new Craterlake Geotrail, together with renewed interest towards Lappajärvi, offer possibilities for both research and science outreach and education activities.

Geologic outline: Lappajärvi impact structure, ~22 km in present rim-crest diameter (Fig. 1), is hosted by Paleoproterozoic mica gneisses and schists (some graphite-bearing) and granite pegmatites of the Western Finland Subprovince of the Fennoscandian Shield [1–2]. Minor granodiorite intrusions and amphibolites also occur [2]. Impact melt rocks are cropping out particularly on the large central island (Kärnä), while suevites and lithic impact breccias are abundant in the glacial drift S and SE of the crater [1–2]. Both Os-isotope and PGE-studies have shown the Lappajärvi projectile to be an ordinary chondrite, likely an H chondrite [3–4].

At 76.2 ± 0.29 Ma [5], Lappajärvi is the youngest Finnish impact structure and, consequently, its impactites are the youngest rocks in Finland. In addition to the impactites, also the topographic rim is preserved. Currently, the SE rim stands ~100 m above the surface of the lake Lappajärvi, providing magnificent views over the crater and the lake within it.

Four cores were drilled by the Geological Survey of Finland (GTK) in the late 1980s and early 1990s [2], accompanied by geophysical studies [e.g., 6]. These established the presence of ~143 m thick impact melt sheet in the N part of the Kärnä island. In the S part of the island, the still fairly poorly studied drill core [1] indicates that suevite and lithic breccia are ~140 m thick [1–2], and include thin dikes of Cambro–Ordovician siltstones [7]. Such Paleozoic sedimentary rocks are exceedingly rare in Finland. In the E annular trough, a drill hole penetrated Mesoproterozoic (~1200 Ma) sand- and claystones [8], as well as deposits dating from a pre-Weichselian (Saalian?) interstadial [9]. These discoveries underpin the significance of impact craters as unique sedimentary environments, offering glimpses into the otherwise unknown geologic past.

1858 – the first description of the impact melt rock: Henrik Johan Holmberg (1818–1864) was a Finnish polymath, who in 1858 wrote the first description of the Lappajärvi impact melt rock (named kärnäite in the 1920s). Holmberg's lengthy compilation paper [10] about ore showings and interesting rock and mineral discoveries in Finland contained only one sentence about the unusual rock type occurring on the Kärnä island. The rock is described as a porphyry, consisting of reddish brown feldspar crystals embedded in a dark matrix [10]. After this, it took over 50 years for geologists to show interest in Lappajärvi again [11–12].

1968 – the identification of PDFs: Swedish geologist Nils-Bertil Svensson had a major influence in the study of not only Swedish but also Finnish impact structures. In a short paper published in 1968, he identified planar deformation features (PDFs) in quartz grains from kärnäite boulders [13]. Importantly, he defined the PDFs' crystallographic Miller–Bravais indices, which "seem to support strongly" [13] Lappajärvi's impact origin. Svensson's PDF discovery was soon afterwards corroborated by Martti Lehtinen, who also found coesite in the suevites, thus removing any lingering doubts about the impact origin [14–16].

1998 – the discovery of the first impact diamonds in Fennoscandia: Marjatta Koivisto and Juha V. Korhonen from GTK initiated the search for impact diamonds in Lappajärvi in the mid-1990s [17]. Lappajärvi suevites turned out to be diamond-bearing. These diamonds are the result of a solid-state transformation of graphite flakes in the host schists. The discovery of these first impact diamonds in the Fennoscandian Shield was published in an LPSC abstract in 1998 [18], and further elaborated in a paper the following year [19]. The year 1998 also marked the discovery of the rare Cambro-Ordovician siltstones [7].

Open questions: Despite the fact that a number of key questions have been answered during the 160 years of study, several unresolved issues remain. These include, e.g., mineralogical, petrological, geochemical, and structural details of the poorly studied suevite core [1–2], the true nature of the Kärnä island (an erosional remnant, a true central uplift or, as seems likely, a combination of both [e.g., 1, 6]), the extents of the melt sheet and the annular trough, and structural details of the rim and how the pre-existing structures affected the crater rim collapse [6]. In addition, the secondary phases in kärnäite and suevites [e.g., 5, 16] contain quite unusual and as yet unidentified minerals (Fig. 2).

Geophysically, a highly interesting yet almost completely unknown fact is that because of the crater, the Lappajärvi area is still seismically active (Fig. 1). Finland's largest seismographically recorded earthquake occurred on the SE rim of Lappajärvi in February 1979

[1, 20; M. Uski, pers. comm. 2017]. In addition, minor quakes in the region are clearly concentrated on crater rim area (Fig. 1). Further analysis of the seismic data could shed more light on, e.g., the rim structure and the origin of these small earthquakes.

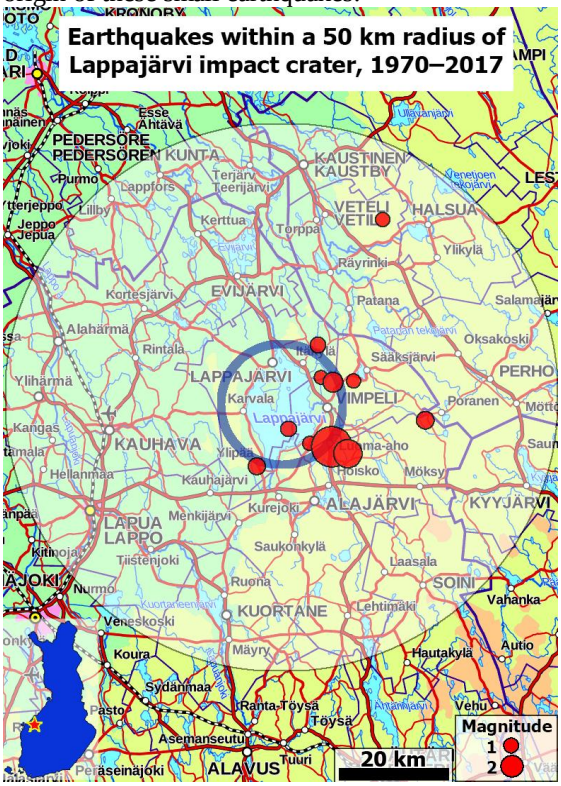

Fig. 1. The dots mark the epicenters of earthquakes within a 50 km radius of Lappajärvi crater. The blue circle approximates the 22 km rim-to-rim diameter. The two largest dots denote the Feb. 17 1979 quakes, although their true locations should probably be further NW, closer to the lake shore [20; M. Uski, pers. comm. 2017]. Earthquake data: Inst. of Seismology, Univ. of Helsinki. Base map: National Land Survey of Finland.

Fig. 2. Kärnäite includes an unknown mineral that changes its color from green to grey within minutes of being exposed.

Outreach activities: In 2016–2017, the Craterlake Geotrail, encompassing the crater and covering various aspects of the bedrock, the impact cratering process, and Quaternary geology was developed in collaboration with GTK. A guidebook with site descriptions in both Finnish and English and accompanying map services (Google Maps and the National Land Survey of Finland's geodata portal) are available online [21]. Because most of the sites are easily accessible, the guidebook and the online map services enable self-served geotourists to explore the Geotrail although physical signs and trail markings are yet to be built. The Geotrail marks the first step in developing the area to fulfill the requirements of a national geopark in the near future. Recently renewed geological exhibition in Kivitippu hotel, plus the acquisition of thousands of unique images from the former NASA's Nordic Regional Planetary Image Facility by Järviseutu-Seura in 2016 provide further support for reaching that goal.

Conclusions: In 2018, the Lappajärvi crater celebrates its 50th anniversary of being a proven impact crater [13], as well as 160 years of scientific research of its impactites [10]. A lot remains to be studied, however. Furthermore, several projects to enhance the geotourism and science outreach and education potential of this unique area have been undertaken [21].

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