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A Late Cretaceous $^{40}Ar-^{39}Ar$ Age for the Lappajärvi Impact Crater, Finland

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Abstract. We report on a $^{40}Ar-^{39}Ar$ study of kärnäite from the ~17 km Lappajärvi impact crater, Finland. Four samples from a 3,000 m profile across the crater center give rather well defined age plateaux and indicate complete degassing at the time of the impact event. The mean age is 77 m.y., much younger than geologically derived age estimates.

Key words: Impact cratering – $^{40}Ar-^{39}Ar$ dating – Meteorites – Kärnäite – Rb–Sr dating – Impact melt – Rate of impacts – Chronology – Melt sheet.

Meteorite impact cratering is a fundamental process in surface feature formation of terrestrial planets as has been shown by the lunar, martian, and mercurian missions of the last decade (Neukum and Wise 1976). In a most recent attempt to define a crater production rate for the evolution time of Earth and Moon (Grieve and Robertson 1979) absolute dating of terrestrial impact events has been demonstrated to be essential. In contributing to that tedious but important task we dated the Lappajärvi impact structure, Finland, by the $^{40}Ar-^{39}Ar$ technique and obtained an age of 77 m.y., much younger than the geologically derived upper age limit of 600 m.y. (Grieve and Robertson 1979).

Fredriksson and Wickman (1963) first suggested that the Lappajärvi structure might have been produced by meteorite impact, which was supported later by the identification of shock metamorphism (Svensson 1968; Lehtinen 1976). Recently, the projectile of the Lappajärvi impact has been identified as a chondritic meteorite (Reimold 1979; Göbel et al. 1980).

Lake Lappajärvi (Fig. 1) is located in the Svecofennian gneiss mass of Central Finland (63°09′N/23°42′E) about 300 km northwest of Helsinki. From gravity measurements the original crater diameter of the glacially deeply eroded crater has been suggested to be about 17 km (Elo 1976). The basement rocks of that area consist mainly of mica schists, granite-pegmatite, and smaller bodies of granodiorite and amphibolite. According to Rb–Sr dating the ages of these rocks range from 1,559–1,745 m.y. (Reimold 1979; Maerz et al. 1979).

Autochthonous impact breccias and melt ('kärnäite') are exposed on several islands in the center of the crater area, whereas allochthonous boulders of kärnäite and suevite are found in glacial deposits some kilometres southeast of the lake.

Kärnäite appears as a dense aphanitic rock that contains abundant mineral and lithic clasts of all grades of shock metamorphism

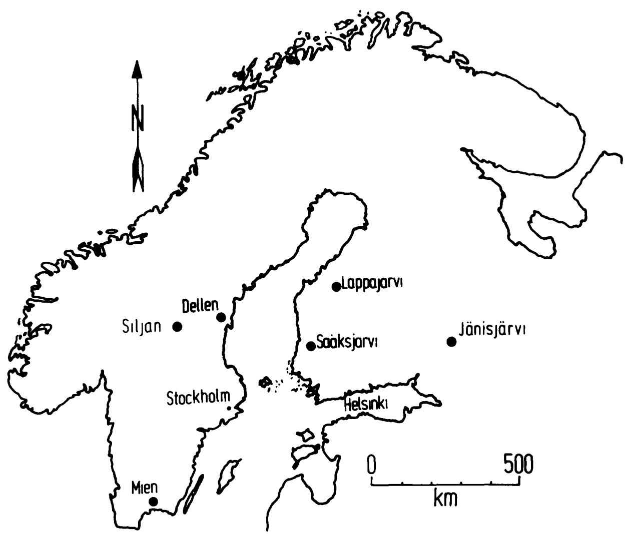

Fig. 1. Locations of the Scandinavian impact structures

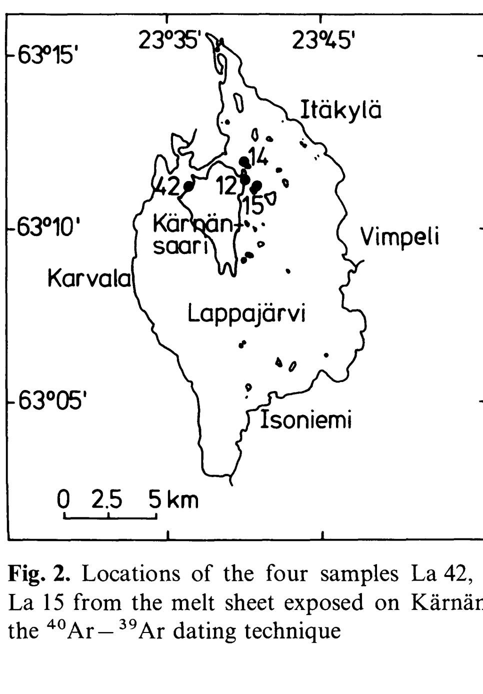

Fig. 2. Locations of the four samples La 42, La 12, La 14, and La 15 from the melt sheet exposed on Kärnänsaari studied with the $^{40}Ar-^{39}Ar$ dating technique

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in a fine-grained, mesostasis-rich matrix. Following the petrographic descriptions of Lehtinen (1976) and Maerz (1979) the inclusions consist mainly of quartz that often exhibit 'ballenstructure'. Frequently these fragments are surrounded by rims of orthopyroxene. Feldspar clasts consist of plagioclase and alkali-feldspar. The former often shows 'checkerboard'-texture also known from other impact sites. Lithic clasts are medium to coarse grained granite, and rarely granodiorite or amphibolite. The matrix consists of plagioclase, often exhibiting H-type crystal growth, also zoned and rimmed by sanidine, of orthopyroxene, in part altered into clinopyroxene or biotite, of magnetite, ilmenite, and twinned cordierite (Maerz 1979). The mesostasis is very K-rich and most likely consists of alkali-feldspar and quartz.

We have chosen 4 samples of authochthonous kärnäite for age determinations. These samples are part of a 3,000 m profile across the coherent melt sheet of the crater center (Fig. 2). Rb–Sr dating of kärnäite failed because of the extremely small range of the $^{87}Rb/^{86}Sr$ ratio of kärnäite whole-rock samples (Maerz et al. 1979). Mineral separation of the matrix was not possible because of its small grain size (<35 µm). For the $^{40}Ar-^{39}Ar$ study we selected inclusion-poor kärnäite and analyzed whole-rock samples routinely as has been described previously (Jessberger et al. 1976)[1]. The results are summarized in Table 1 and the age patterns shown in Fig. 3.

All samples exhibit rather similar age patterns with no evidence for major ^{40}Ar diffusion losses after the time of complete degassing. The integrated K–Ar ages (Table 1) are only marginally different from the $^{40}Ar-^{39}Ar$ ages. There are also no elevated ages at higher extraction temperatures indicating the absence of inherited ^{40}Ar such as that encountered in dating lunar impact breccias (Jessberger et al. 1974; 1976). Obviously, the mineral or

[1] Irradiation at the FR2 reactor, Karlsruhe, together with muscovite monitor of known age, Bern 4M (Jäger et al. 1963). Ages are calculated using the ^{40}K decay constants and K isotopic composition recommended by Steiger and Jäger (1977)

Table 1. Summary of $^{40}Ar-^{39}Ar$ results for Lappajärvi impact melt samples. The uncertainty of the K- and Ca-contents are 5%. K–Ar ages are obtained from the integrated ^{40}Ar and ^{39}Ar amounts released in all extraction fractions. $^{40}Ar-^{39}Ar$ ages are calculated from argon released in extraction fractions of the given temperature range. The quoted uncertainty corresponds to the 1σ standard deviation from the weighed average $^{40}Ar/^{39}Ar$ ratio. The quality of the $^{40}Ar-^{39}Ar$ ages as plateau ages may be visualized from Fig. 3

Sample no.	Sample Weight (g)	K (%)	Ca (%)	$^{40}Ar_{atm}$ (%)	K–Ar Age (m.y.)	$^{40}Ar-^{39}Ar$ Age and Range (m.y.)	(° C)
La 12	0.570	3.2	1.8	19.5	78.5	78.6±0.8	660–1,360
La 14	0.553	3.4	1.9	38.2	74.8	76.6±0.3	820–1,550
La 15	0.543	3.3	1.8	23.2	76.8	77.2±0.3	770–1,550
La 42	0.447	3.6	2.0	26.0	76.2	77.5±0.2	700–1,520

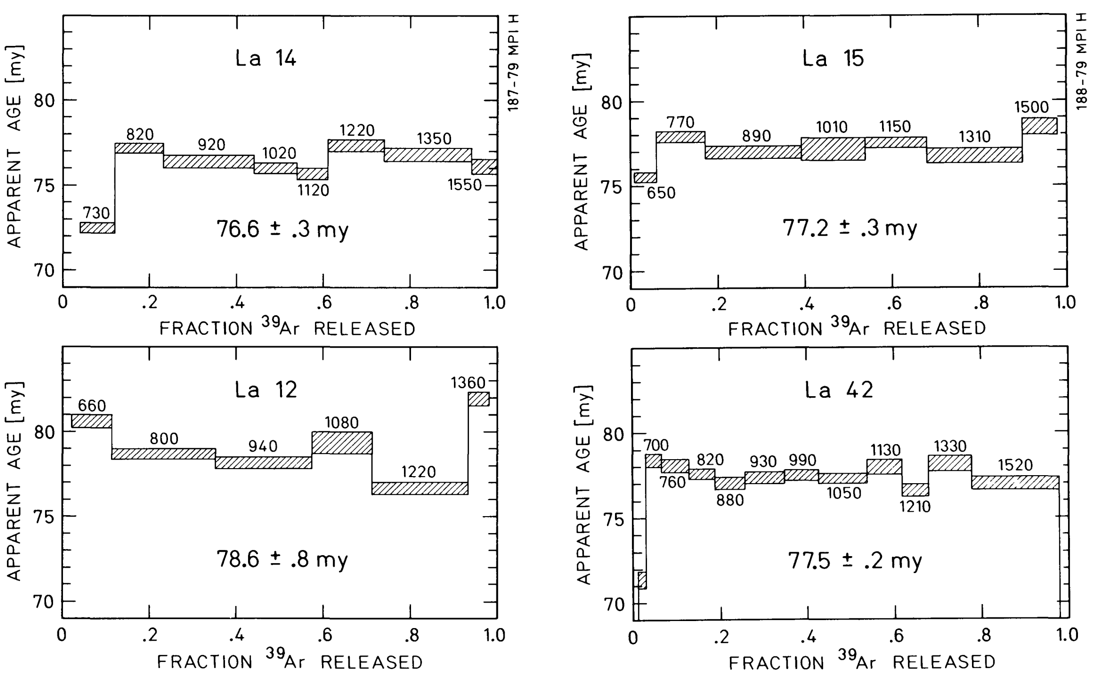

Fig. 3. $^{40}Ar-^{39}Ar$ age patterns for four samples from the Lappajärvi impact structure. Each bar represents the apparent age calculated from the ($^{40}Ar/^{39}Ar$) ratio of argon released within about 45 min at the extraction temperature given in °C. The heating procedure was incremental. The width of the bar is the fractional amount of ^{39}Ar released, the height is the statistical uncertainty of the K-derived ($^{40}Ar/^{39}Ar$) ratio of that fraction

lithic clasts – relicts of the Precambrian target rocks – did not retain ^{40}Ar or they do not contain much K. Many of the inclusions consist of quartz, and Rb–Sr analyses of kärnäite inclusions have also shown that most of the feldspathic inclusions have been equilibrated with the surrounding melt (Reimold and Stöffler 1979).

Sample La 12 shows a slightly different age pattern (Fig. 3) with more scatter of the apparent ages than the other samples. This may be due to the higher portion of clastic material mixed to the melt. This sample appears as a melt agglomorate which is transitional to a suevite breccia rather than a coherent melt as the other samples. There are also differences in the chemical composition especially in the REE patterns (Reimold and Stöffler 1979). The mean age, however, is not affected by the difference, and is well defined to be 77.3 ± 0.4 m.y.

The present study which gives the first lateral age profile across an impact melt body indicates that the whole melt body has been totally degassed in the course of the impact. This extends even to the autochthonous suevitic sample La 12. Other evidence for complete homogenization of the Lappajärvi melt body is presented in (Reimold 1979; Reimold and Stöffler 1979).

On the Scandinavian shield there are six structures classified as 'probable' impact structures (Grieve and Robertson 1979): Mien, Dellen, and Siljan in Sweden, Sääksjärvi and Lappajärvi in Finland, and Jänisjärvi in the USSR (Fig. 1). ^{40}Ar–^{39}Ar ages of Mien and Siljan are 119 m.y. and 362 m.y., respectively (Bottomley et al. 1978). Lappajärvi is 77 m.y. old. An approximate age of 700 m.y. for the Jänisjärvi event is mentioned by Grieve and Robertson. Also for Dellen and Sääksjärvi no accurate ages are available (Bottomley et al. 1978). We therefore propose to date the latter three structures also to further substantiate their impact origin and to obtain the full impact rate for the Scandinavian shield.

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