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NEW EVIDENCE FOR AN IMPACT ORIGIN OF LAKE LAPPAJÄRVI, WESTERN FINLAND

A PRELIMINARY REPORT

by

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ABSTRACT

Field and labaratory investigations have produced new petrological, mineralogical and chemical evidence in favor of a meteorite impact origin of Lake Lappajärvi. Petrological evidence includes the occurrence of a shock-metamorphosed rock series with two types of impact lavas (locally called »kärnäite»), fallout breccias and impact breccias. These rocks contain coesite, maskelynite, diaplectic (thetomorphic) quartz and microline glasses, planar elements in quartz and feldspar as well as kink bands in biotite, graphite and plagioclase.

The shock-metamorphosed rocks are rhyodacitic in composition. Compared with the rocks of the bedrock surrounding the supposed astrobleme, the nickel content of the kärnäite and of the fallout breccia is 10—20 times higher whereas the cobalt content remains unchanged.

The area covered by the supposed astrobleme exhibits a small and uniform variation of the magnetic intensity map when compared with the anomalies for the surroundings.

Calcite, chalcedony and zeolites occur as secondary minerals. The most common zeolite is heulandite, but mordenite, chabazite, erionite and stilbite are also found.

Introduction

The island of Kärnänsaari on Lake Lappajärvi, Western Finland, has long been recognized as exhibiting a dark, fine-grained, compact rock called »kärnäite». This rock has been interpreted as of volcanic origin, younger than the surrounding Precambrian bedrock. Although the volcanic origin of this kärnäite »lava» has recently been questioned by several scientists in private discussions, nothing was published on the subject until Svensson (1968) paid attention to the Lake Lappajärvi basin as a possible meteorite impact structure (astrobleme). Svensson based his conclusion on the fact that the quartz fragments found in kärnäite contain multiple sets of closely spaced planar features. McCall (1968), however, doubts the validity of these planar features in quartz as a proof of a meteorite impact origin of the Lake Lappajärvi basin.

During the summers 1967—69 the author carried out some field studies in the Lake Lappajärvi area. These studies connected with subsequent laboratory investigations have produced new data which strongly suggest that the Lake Lappajärvi basin does represent an astrobleme.

This paper gives a brief preliminary report of the results obtained. A more detailed account will be published on a later occasion.

The lake basin

The topography of the basin of the present Lake Lappajärvi exhibits a shallow depression. The roughly elliptical lake is elongated in a north-south direction and covers an area of ca. 12×24 km². In the central and northern part of the lake, the island of Kärnänsaari and a few small islands indicate that the center of the crater-like depression is more resistant against erosion. The outcrops on the islands reveal kärnäite only. The bedrock of the area surrounding the lake consists of granodiorite, biotite plagioclase gneiss and granite. The shortest distance between the outcrops of this bedrock and those of the kärnäite is ca. 6 km. The contact between the kärnäite and the surrounding bedrock is not exposed. No sign of shock metamorphism has been found in the bedrock either in the field or in the laboratory.

The field investigations disclosed a series of shock-metamorphosed rocks including two types of kärnäite, fallout breccia and breccia containing angular fragments of bedrock and quartz, feldspar and biotite. The typical features and stages och shock metamorphism (Chao, 1968; v. Engelhardt and Stöffler, 1968) are represented in this rock series. The breccias have been found only as boulders on the islands and on the south-eastern shore of the lake. The breccia boulders are also common in the moraine and in the esker material south-east of the lake. This fact is consistent with the direction of movement of the continental ice cover as deduced from the striations on the kärnäite outcrops.

Kärnäite

Common kärnäite (here called type II) is a peculiar lava-like hard rock, bluish black in color, which splits subconchoidally into sharp edged pieces. Its texture is not porphyritic as was previously stated by Holmberg (1858) and by Eskola (1951) but the rock contains numerous mineral and bedrock fragments in a crystalline fine-grained groundmass (Saksela, 1949). The fragments display various stages of alteration and fusion up to ghost-like remnants. In a weathered surface the rock may sometimes have the appearance of a breccia or agglomerate. The quartzite or sandstone fragments mentioned by Berghell (1921), Ramsay (1921) and Saksela (1949) are actually broken pieces of quartz.

Another less common type of kärnäite (called type I) contains a glassy groundmass with microlites of sanidine, plagioclase, orthopyroxene and cordierite. The mineral fragments of this kärnäite type consist mainly of quartz which represents the only unfused fragment mineral (v. Engelhardt, 1967, p. 1686). The biotite and the feldspar fragments are almost entirely decomposed.

The kärnäite of type I grades continuously over into that of type II and a sharp distinction between the two types is not always possible.

Breccias

The fallout breccia is grey-green or brownish in color with a reddish tint due to secondary alteration. The rock consists of fluidal glass fragments of varying size in a fine-grained material (»rock flour»). Generally, the fallout breccia is brittle and breaks readily when struck. A greater proportion of glassy material makes the rock harder. Such hard breccia pieces occur as coherent fragments in the more soft cementing material. The glass is often altered to zeolites, iron oxide and clayey substance.

The fluidal glass is very heterogeneous. It contains abundant fragments of diaplectic quartz and quartz glass and a few fragments of diaplectic and fusion feldspar glass. True lechatelierite has not been found, but some quartz fragments show softened ends. Coesite has not been detected in thin section, but it seems to occur in the fallout breccia in connection with the diaplectic quartz glass fragments.

The fine-grained breccia resembles the fallout breccia without fluidal glass fragments. Sometimes, however, it contains large bedrock fragments. In such fragments the various diaplectic minerals and mineral glasses are well preserved. The breccia varieties which do not contain any fluidal glass fragments and in which the minerals display a marked shock metamorphism are called impact breccia in this paper.

Constituents

The following data are briefly reported for the constituens of the shock-metamorphosed rocks of the Lake Lappajärvi area:

The presence or absence of coesite was tested by eluting ca. 50 g of finely powdered rock sample in water. The most fine-grained part of the material was decomposed in a mixture of hydrofluoric and nitric acids (concentration 5 %). Coesite was strongly enriched in the residue from which it was identified by X-ray powder pattern and by infrared absorption spectrum. Coesite was positively found in six specimens of the fallout breccia and in one granite fragment of an impact breccia specimen. In all these specimens the amount of coesite is less than 0.25 %. A sample of pure coesite from Meteor Crater, Arizona, was used as a standard.

Diaplectic quartz is commonly found in all the shock-metamorphosed rocks of the area. In addition to the planes reported by Svensson (1968), the author also found planar elements parallel to $(10\bar{1}0)$, (0001) and $(51\bar{6}1)$. The elements parallel to $(10\bar{1}3)$ are most common in the Lappajärvi rocks. The refractive indices of the diaplectic quartz vary: $\omega = 1.492$—1.541 and $\varepsilon = 1.496$—1.551. Diaplectic quartz glass is found under the microscope in the fallout breccia and in the fine-grained granite fragments of the impact breccia.

In the coarse-grained bedrock fragments of the impact breccia the plagioclase is more readily transformed into diaplectic glass than is microcline or even quartz. The latter mineral appears most reluctant to become disordered by the shock wave. In the fine-grained bedrock fragments, on the other hand, quartz becomes isotropic before plagioclase, microcline being most resistant.

Maskelynite (diaplectic plagioclase glass) is common in the granodiorite and granite fragments of the impact breccia. In addition to the wholly isotropic grains of the mineral, multiply twinned plagioclase grains are found in which one set of lamellae is transformed into maskelynite. In more weakly shocked plagioclase grains planar elements are common and the grains are often bent, sometimes showing kink bands.

In rocks in which the plagioclase has been transformed into maskelynite the microcline is crystalline although strongly deformed and with an abnormally low birefringence. The planar elements are generally short and bent in microcline. Open planar fractures are more common in microcline than in quartz or in plagioclase. The higher resistance of microcline against the shock wave is possibly due to the crosshatching which prevented plastic deformation of the structure.

In some granite fragments of the breccias the perthitic structure and the crosshatching of the microcline have disappeared. In such grains the optic axial angle is very small and the X-ray powder pattern reveals monoclinic symmetry (sanidine).

The biotite fragments in the kärnäite and in the fallout breccia are almost invariably decom posed into an oxidized brown mass. The impact breccia, however, contains abundant fragments of fresh biotite displaying well developed kink bands. The fallout breccia and the impact breccia generally contain fine-grained graphite full of kink bands.

In addition to coesite, the presence of spinel with $a_0 = 8.063 \pm 0.005$ Å (fallout breccia, specimen No. 236) and with $a_0 = 8.055 \pm 0.007$ Å (kärnäite type I, specimen No. 38) has been detected by X-ray powder pattern. Such an extremely fine-grained (microlitic) spinel was apparently produced by the shock metamorphism.

Six of the specimens subjected to the coesite test showed small amounts of extremely fine-grained pentlandite with a remarkably small unit cell of $a_0 = 9.95$—10.02 Å. It is not clear whether or not the mineral was produced by the shock metamorphism.

The following zeolites have been identified: heulandite, cottony mordenite, chabazite, erionite and stilbite. These zeolites occur in vesicles and fissures of the fallout breccia and of the impact breccia.

Chemistry

Two new chemical rock analyses of the kärnäite (type II) and two of the fallout breccia have been made. The results of these analyses will be presented on a later occasion. The rhyodacitic compositions of the rocks analyzed agree with that summarized by Eskola (1921).

Cobalt and nickel were determined for a few specimens. In the rocks of the surrounding bedrock the average Co content is 6 ppm and that of Ni 15 ppm, with Co/Ni = 0.4. In the shock-metamorphosed Lappajärvi rocks the Co content averages 4 ppm and that of Ni 370 ppm, with Co/Ni = 0.01. The strong relative increase of the Ni content in the shock-metamorphosed rocks probably indicates that the nickel partly originates from the meteorite.

Geophysical data

In the area around the Lake Lappajärvi basin the aeromagnetic map (Geological Survey of Finland, sheets 2313 and 2314) exhibits strong magnetic anomalies with steep gradients, elongated parallel to the general strike of the rocks (N 50°—60° E). Some strong anomalies elongated parallel to N 30° W also occur. Within the Lake Lappajärvi basin itself the magnetic intensity is weak and fairly uniform.

A detailed gravimetric study of the Lappajärvi area has not been made. In the general gravity map of Finland (Bouguer anomalies), however, the Lake Lappajärvi basin occupies a negative anomaly area of 5—10 milligals.

Retrospect

The petrological, mineralogical, chemical and geophysical data briefly summarized above suggest that the Lake Lappajärvi basin represents an astrobleme. The occurrence of coesite and the various diaplectic (thetomorphic) minerals and mineral glasses as well as fusion glasses are particularly informative. The only natural mechanism known to produce such a deformation of the rock constituents is meteorite impact.

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