Geological Society of America
Special Paper 247
1990

The Kara/Ust-Kara twin impact structure; A large-scale impact event in the Late Cretaceous

Christian Koeberl
Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058, and Institute of Geochemistry, University of Vienna, Dr.-Karl-Lueger-Ring 1, A-1010 Vienna, Austria
Virgil L. Sharpton
Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058
T. Mark Harrison
Earth and Space Sciences, University of California, Los Angeles, California 90024
David Sandwell
Scripps Institute of Oceanography, University of California at San Diego, La Jolla, California 92093
A. V. Murali and Kevin Burke
Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058

ABSTRACT

The Kara impact structure, on the Kara Sea coast of Russia, consists of two adjacent impact craters, the Kara and the Ust-Kara craters. The Kara crater is located on land and has a pre-erosion diameter of about 65 km, whereas the Ust-Kara crater is mostly submarine and has only limited onshore exposure. The diameter of the Ust-Kara crater was earlier suggested to be about 25 km, but recent morphological studies indicate a diameter >70 km. This is not incompatible with Seasat and Geosat data. It has been suggested that the Kara impact event may be associated with the K/T boundary event. Previously reported K-Ar ages showed wide margins of uncertainty and clustered around 60 Ma, while more recent K-Ar determinations seemed to support an association with the K/T boundary. Our own analyses of several ^{40}Ar-^{39}Ar age spectra, however, indicate an age of >70 Ma for the Kara impact event, perhaps close to the age of the Campanian-Maastrichtian boundary. Even if there is no association with the K/T boundary event, a double impact leading to craters of approximately 65 and 80 km diameter must have been an important geologic event with possible global significance. The record of this large-scale impact event may have been preserved in deep-sea sediment cores.

INTRODUCTION

The Kara impact structure is located on the shore of the Kara Sea in northern Russia. It consists of two adjacent impact craters: the Kara crater, and the Ust-Kara crater (Fig. 1). The Kara crater is located entirely on land close to the estuary of the Kara River; its center has the approximate geographic coordinates 69°05′N and 64°18′E. A segment of the Ust-Kara crater rim is exposed on the shoreline at Cape Polkovnik and other locations in the near vicinity of the Kara River estuary (where it has modest onshore exposures), but otherwise the crater is underwater. The exact location and size of the Ust-Kara crater are not known in detail. The Kara crater is heavily eroded and mostly covered with sediments of postimpact age; thus, it is difficult to constrain its exact diameter. The structure is not easily identified on Landsat imagery (see, e.g., Grieve and others, 1988), which is therefore of limited use in determining the diameter of the crater. Field investigations yield an estimated current maximum diameter of about 60 km (Masaitis and others, 1980; Masaitis and Mashchak, 1982). A preerosion diameter of about 65 km seems

Koeberl, C., Sharpton, V. L., Harrison, T. M., Sandwell, D., Murali, A. V., and Burke, K., 1990, The Kara/Ust-Kara twin impact structure; A large-scale impact event in the Late Cretaceous, *in* Sharpton, V. L., and Ward, P. D., eds., Global catastrophes in Earth history; An interdisciplinary conference on impacts, volcanism, and mass mortality: Geological Society of America Special Paper 247.

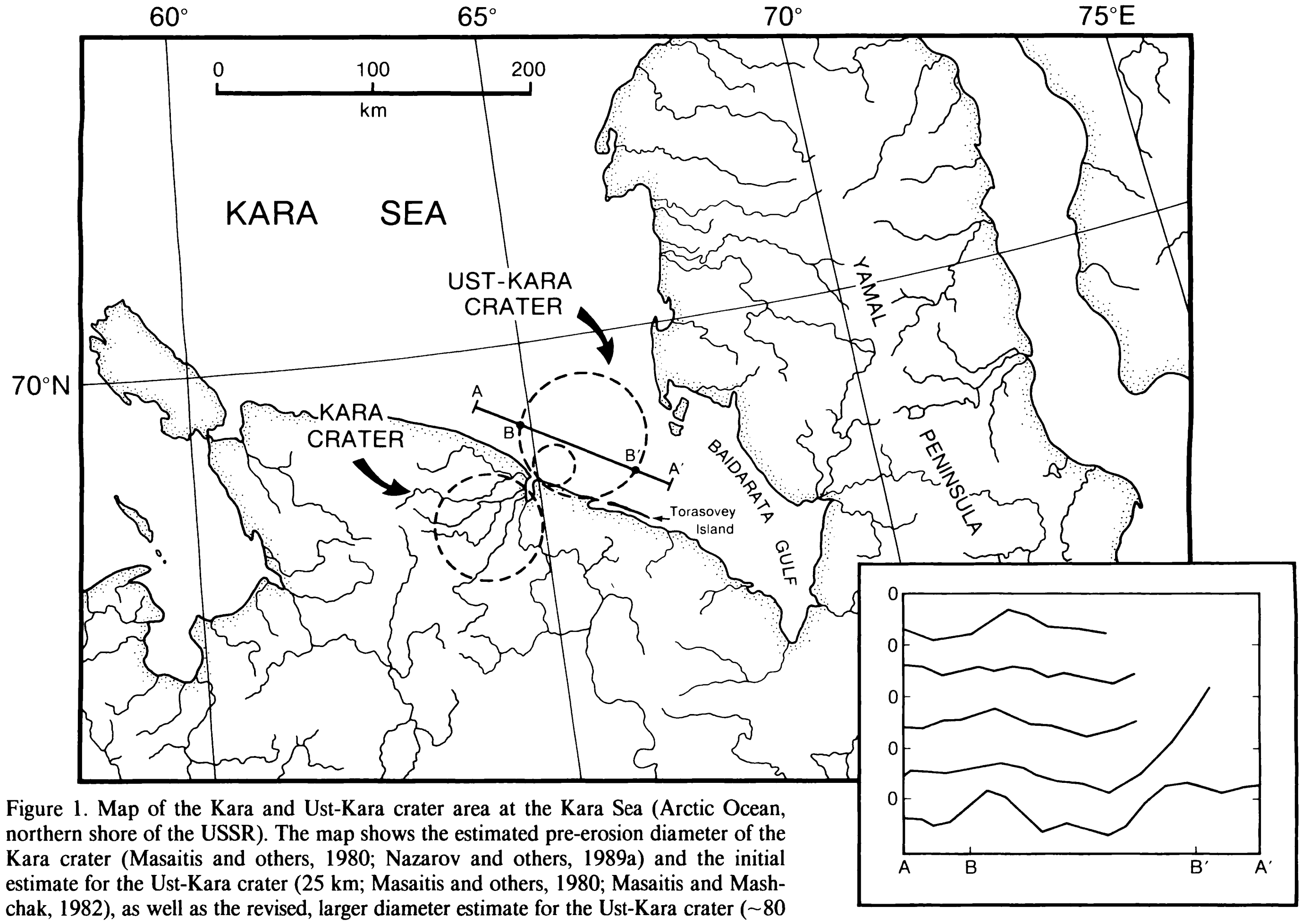


Figure 1. Map of the Kara and Ust-Kara crater area at the Kara Sea (Arctic Ocean, northern shore of the USSR). The map shows the estimated pre-erosion diameter of the Kara crater (Masaitis and others, 1980; Nazarov and others, 1989a) and the initial estimate for the Ust-Kara crater (25 km; Masaitis and others, 1980; Masaitis and Mashchak, 1982), as well as the revised, larger diameter estimate for the Ust-Kara crater (~80 km, see text). The inset shows the horizontal component of the satellite gravity data (five passes) along the line A-A′ as indicated on the map. A-A′ is the ground track of the satellite. B and B′ mark the gravity highs, which occur at the inflection points of the profiles. The profiles represent the sea-surface slopes along the satellite ground track A–A′.

realistic. New field studies support these results (Nazarov and others, 1989a).

The Kara crater has been known since the beginning of the century, but the impact deposits were interpreted previously to be either glacial deposits or tuffs located in a volcanic caldera. The crater was identified as an impact crater in the mid-1970s only after the recognition of shock features (e.g., shatter cones, planar features in quartz, maskelynite, and diaplectic glass) in the local rocks (see, e.g., Maslov, 1977; Masaitis and others, 1980). Additional evidence for an impact origin was provided by the discovery of coesite in quartz samples from the Kara crater, as reported by Vishnevskiy and others (1977). Our own petrographic studies of thin sections of Kara rocks show the presence of multiple sets of planar lamellae in quartz grains, with orientations typical of shock metamorphism during impact (Alexopoulos and others, 1988).

Early age determinations of the Kara impact structure yielded an age of about 57 Ma (Feldman and others, 1979; Mashchak and Ezersky, 1980). Later a revised age of 60 ± 10 Ma was reported by Masaitis and Mashchak (1982), which led to the suggestion that the crater may be related to the Cretaceous/Tertiary (K/T) boundary event (Masaitis and Mashchak, 1982; McHone and Dietz, 1983). Recent K-Ar determinations by Kolesnikov and others (1988) and Nazarov and others (1989b) have been interpreted to yield an age of 66.1 Ma, which would be in agreement with the age of the K/T boundary event. On the other hand, our own ^{40}Ar-^{39}Ar age spectrum analysis (Koeberl and others, 1988, 1990) indicate an age greater than 70 Ma. Even if the Kara impact structure is not associated with the K/T boundary, this giant double impact could represent an event of global importance.

SIZE OF THE UST-KARA CRATER

The Kara impact structure is a twin impact feature, consisting of the Kara and the Ust-Kara impact craters. Double impact craters are rare on Earth and are therefore of special geological and planetological interest. Other examples are the Clearwater Lakes, Canada (diameters 32 and 22 km, respectively), and the Gusev (3 km) and Kamensk (25 km) craters, USSR (Grieve, 1987). The pre-erosion diameter of the Kara crater was inferred to be approximately 65 km, while the diameter of the Ust-Kara crater was estimated to be about 25 km (Masaitis and others, 1980; Masaitis and Mashchak, 1982). Thus, the two Kara craters are larger than any other currently known twin impact structure on Earth.

The original estimate of 25 km for the diameter of the Ust-Kara crater was based on the exposures of suevites (highly shocked fall-back breccia commonly observed in impact craters, containing high-pressure polymorphs of quartz, maskelynite, impact melts, and clasts of country rocks), impact melts, and impact glasses on the shore of the Kara Sea at Cape Polkovnik and other locations near the shore of the Kara River (Masaitis and others, 1980; Masaitis and Mashchak, 1982; Badjukov and others, 1989a). A new geomorphological analysis of the morphology of the crater and the distribution of suevites at the seashore was performed by Nazarov and others (1989a). These studies suggest a diameter between 70 and 155 km for the Ust-Kara crater, which is considerably larger than the original estimate.

In order to better constrain the size of the Ust-Kara crater, we have looked at Seasat and Geosat gravity data, which can be used to determine submarine topography from altimeter measurements (e.g., Tapley and others, 1982; Sandwell and McAdoo, 1988). Our preliminary analysis reveals the underwater expression of a crater. Several ascending profiles (see inset in Fig. 1) that are almost parallel to the shoreline in the Ust-Kara area of the Kara Sea reveal a sharp gravity high of about 10 mGal at approximately 69° 15′N and 66° 20′E, and a small gravity high at about 69° 30′N and 64° 55′E. These features might represent the gravity expression of a crater rim on the sea floor, probably covered by a layer of recent sediments. The two locations are separated by about 70 km, and given the locations of the onshore suevite occurrences, we estimate an approximate diameter of 80 km for the Ust-Kara crater (see Fig. 1). A descending profile shows a small gravity high north of the small gravity high in the ascending profile and is consistent with the estimated crater shape. Because of other gravity highs and lows in the area, however, this interpretation is not unique and should be considered as one of several possibilities to explain the gravity data. Better satellite coverage would certainly be helpful and may become available.

If the new 80-km estimate of the Ust-Kara crater diameter is correct, continuous impact deposits should be found on Torasovey Island. This suggestion seems to be consistent with field observations reported by Maslov (1977) and Nazarov and others (1989a). They reported the possible occurrence of such deposits on Torasovey Island, but so far no confirmation of these observations is available. Impact deposits from the continuous impact ejecta should be present at the shore of the Yamal peninsula, opposite the Kara estuary (see Fig. 1). A search for impact deposits in this area would be helpful to further constrain the exact extension of the Ust-Kara crater.

GEOLOGY OF THE STRUCTURE

The Kara crater is situated within a marshy tundra plain with numerous lakes and rivers. The original basement rocks and impact products are exposed only in areas where rivers cut through the structure. The Kara and Ust-Kara craters are set mainly in Lower Permian sandstones and shales. Devonian, Silurian, and Ordovician sediments are exposed predominantly in the southern part of the Kara crater. Because of the uncertainty in the extent of the Ust-Kara crater, not much can be said about its geologic setting, which in general is similar to that of the Kara crater. The Paleozoic sedimentary complex has a total thickness of about 5.5 km and overlies volcanic-sedimentary rocks of Late Proterozoic age (Masaitis and others, 1980; Nazarov and others, 1989c). Volcanic rocks in the area are rare and limited to Devonian diabases that form dikes which intrude the lower Paleozoic sediments.

A 10-km-wide uplift in the center of the Kara crater exposes rocks similar to those in the southern part of the crater, incuding some diabase dikes. The presence of a central uplift is typical of complex impact craters (Grieve, 1987). Geophysical studies (including drilling) reported by Masaitis and others (1980) indicate that the lower part of the crater is filled with megabreccias and agglomeratic suevites with a thickness that varies between 2 km in the northern part of the crater and 0.8 km in the southern part. Today the crater area and the impact deposits are overlain by Pliocene-Quaternary sediments of postimpact origin that are up to 100 m thick (Mashchak and Ezersky, 1980).

Impact products at the crater include impact glasses, fine-grained recrystallized impact melts, suevites, and allogenic breccias. The suevite deposits vary from several tens to hundreds of meters thick and contain impact melt (tagamite; Masaitis and others, 1980) lenses up to 10 m thick. The suevites were locally produced and contain glass and clasts of various origins, including some material derived from Cretaceous sediments (sand, sandstones, clays). These sediments were present at the crater site at the time of the impact, but are completely eroded now and can only be found in suevites and related clastic sediments (Nazarov and others, 1989c). The majority of the clasts in the suevites are composed of Permian sediments. Because of the variation in the geology between the northern and the southern part of the crater, the suevites display related variations.

CHEMISTRY OF IMPACT MELTS

Kara impact melts (also called tagamites; Masaitis and others, 1980) are mostly grey to dark grey, fine-grained crystallized rocks with very fine-grained mineral components (e.g., quartz, plagioclase) and are the product of shock-melting with later recrystallization. Usually these impact melts are found associated with glass-rich suevites, which are of higher temperature origin than the glass-poor suevites (Nazarov and others, 1989c). Large bodies of impact melts are rare and form lenticular bodies within the suevite deposits. Most impact melts (and suevites) show signs

TABLE 1. K-Ar AND ^{40}Ar-^{39}Ar AGES FOR SAMPLES FROM THE KARA AND UST-KARA IMPACT CRATERS

Sample	Age type	Age (in Ma)	Reference*
KA2-305,0 impact melt	Ar-Ar	74.9	1
KA2-305,0 impact melt	K-Ar	74.5	2
PL2-147,0 impact melt	Ar-Ar	76.2	1
LV1-051,0 impact melt	Ar-Ar	72.6	1
KA2-095,0 impact melt	Ar-Ar	80.7	1
KA2-306,1 impact glass	Ar-Ar	70.6	1
KA2-306,1 impact glass	K-Ar	66.5	2
KA2-306,2 impact glass	K-Ar	67.6	3
KA2-303,1,1 impact melt	K-Ar	72.9	2
701-e impact glass	K-Ar	73.9	3
K/T boundary		65	4
Campanian/Maastrichtian boundary		73	4

*References: 1 = Koeberl and others, 1989a; 2 = Nazarov and others, 1989b; 3 = M. A. Nazarov, personal communication, 1988; 4 = Harland and others, 1982.

of alteration, probably due to postimpact hydrothermal activity, which has been observed at other impact craters (e.g., Newsom, 1980; Komor and others, 1988; Koeberl and others, 1989). The impact melts analyzed by our group show a uniform chemical composition, which is similar to the Permian target rocks (Murali and others, 1988; Koeberl and others, in preparation).

Impact glasses that are not recrystallized are rather rare and small in size compared to tagamite (impact melt) deposits. Most are inhomogeneous and show signs of alteration similar to impact melts. They display schlieren and flow structures, indicating flow in the melt followed by quenching. Their colors range from colorless or yellowish to light and dark brown or black. Some show a blue color in reflected light, and are similar in appearance and chemistry to blue zhamanshinites (Koeberl, 1988). Other glasses show a layered structure and contain inclusions and vesicles and are similar to normal Si-rich zhamanshinites from the Zhamanshin impact crater. The glasses have a wider range of intra- and intersample chemical variations than the impact melts for both major and trace elements (Badjukov and others, 1989a; Murali and others, 1988). Our complete analytical data on major and trace elements in target rocks and impact products from the Kara and Ust-Kara craters will be reported elsewhere (Koeberl and others, in preparation). The impact glasses do not show the same straightforward relation to the target rocks as the impact melts but seem to have originated by more complex mixing and fractionation processes.

Siderophile element enrichments in impact glasses and impact melts may be used for determining the composition of the impact projectile (Koeberl, 1986). Masaitis and others (1988) interpreted the abundances of Ni, Co, and Cr in Kara impactites as suggestive of a chondritic projectile. Nazarov and others (1989c) report Ir concentrations in impact melts and suevites ranging from 0.3 to 1.0 ppb. However, they also report Ir concentrations of 0.2 to 0.6 ppb in the Permian sediments. They attribute the Ir in the country rocks and in the impact melts to mixing with diabases that contain up to 2.3 ppb Ir and have also higher Cr and Ni contents. Ratios of these elements are not consistent with chondritic proportions. In our samples of impact melts and target rocks (including magmatic rocks) we have rarely seen Ir concentrations more than about 0.2 to 0.4 ppb, in agreement with other analyses (C. Orth, personal communication, 1988). One impact glass contains 0.43 (± 0.5) ppb Ir, but as in other samples, the Ir/Au, Ir/Ni, or Ir/Co ratios are not chondritic. Despite some analytical differences, we agree with Nazarov and others (1989c) that so far a cosmic component has not been established unambiguously, and intend to analyze other platinum group elements for a better characterization.

AGE AND IMPORTANCE OF THE KARA IMPACT EVENT

A key question is the age of the Kara and Ust-Kara impact craters. Earlier K-Ar age determinations clustered around 60 Ma, but were afflicted by large uncertainties (Feldman and others, 1979; Masaitis and Mashchak, 1982; Badjukov and others, 1987). Based on these ages, it was suggested that the Kara impact may be related to the K/T boundary event (e.g., Masaitis and Mashchak, 1982; McHone and Dietz, 1983; Sharpton and Burke, 1987; Badjukov and others, 1987), but due to the uncertainties in age these conclusions were not compelling. There is sufficient evidence for at least one large impact at the K/T boundary (see Hartung and Anderson, 1988, and contributions in this volume), and thus it is important to establish if there are any known large impact craters of that age.

New K-Ar age determinations on impact melts and glasses by the Moscow group (Kolesnikov and others, 1988; Nazarov and others, 1989b) yielded apparent ages between 65.8 and 126.8 Ma (M. A. Nazarov, personal communication, 1988), which (using certain assumptions) were interpreted to yield a K-Ar "isochron" of 66.4 Ma. We performed a set of analyses of ^{40}Ar-^{39}Ar age spectra, which yielded ages >70 Ma (Koeberl and others, 1990). ^{40}Ar-^{39}Ar age determinations for impact craters have been shown to be more reliable than K-Ar age determinations (e.g., Bottomley and others, 1990). The samples showing the best plateaus in the Ar release spectra have ages between about 73 and 76 Ma, but the ^{40}Ar-^{39}Ar ages in all samples range from about 71 to 81 Ma (see Table 1).

Nazarov and others (1989b) suggest that their K-Ar data show the presence of excess radiogenic Ar in their samples; however, the Ar age spectra analyses of our samples do not support that interpretation. Any mixing with, for example, Permian target rocks as suggested by Nazarov and others (1989b), would not lead to the flat ^{40}Ar-^{39}Ar age spectra (Fig. 2) and the linear correlations in the ^{36}Ar-^{40}Ar versus ^{39}Ar-^{40}Ar plots (Fig. 2) that we have observed in our samples (Koeberl and others, 1988, 1990). Nazarov and others (1989b) reported a K-Ar age of 74.5 Ma for the impact melt sample KA2-305,0, which is in agreement with our data. Our Ar age spectrum and the three-isotope plot (Fig. 2) do not show evidence for mixing with older material, which differs from the findings by Nazarov and others (1989b) that the higher age is due to contamination with older material. Recent paleomagnetism data of Kara impactites (Badjukov and others, 1989b) do not seem to be in agreement with a K/T age.

The present age data argue against a link between the Kara impact event and the K/T boundary event, but rather point to an age that is greater than that of the K/T boundary. The most realistic ages seem to be in the 73 to 76 Ma range, which led to the suggestion (Koeberl and others, 1990) of a possible relation with the Campanian/Maastrichtian boundary, which falls into that age range (Harland and others, 1982). Even if the Kara impact event is not linked with the K/T boundary event, it must have had severe effects on the geo- and biosphere. An impact event that produced two craters of about 65 and 80 km diameter, respectively, must have released kinetic energy on the order of several times 10^{22} J, which is sufficient to launch dust into the atmosphere and distribute impact products over large distances. Depending on the size distribution, the mass, and the residence time of the dust in the atmosphere, climatic variations might be expected that could affect the biosphere and cause extinctions.

CONCLUSIONS

The Kara and Ust-Kara craters are twin impact structures on the Kara Sea shore of Russia. Double impact craters are very rare on Earth, and the two craters are among the largest preserved on Earth. The preerosion diameter of the Kara crater (which is located on land) has been estimated to be about 65 km (Masaitis and others, 1980; Nazarov and others, 1989a), while the diameter of the Ust-Kara crater (which is mostly underwater) has recently been suggested to be as large as 70 to 155 km (Nazarov and others, 1989a). This is supported by our preliminary analysis of Seasat and Geosat gravity data, which suggests to us a diameter of about 80 km for the Ust-Kara crater.

Although the Kara impact event has been suggested to be associated with the K/T boundary event, our ^{40}Ar-^{39}Ar age determinations indicate an age >70 Ma and a possible association with the Campanian/Maastrichtian boundary (Koeberl and others, 1990). We suggest that the double impact may have released enough energy to inject dust and impact products into the atmosphere, which could have caused climatic changes that affected the biosphere. It seems likely that impact products from the Kara event have been distributed over large areas at least in the Northern Hemisphere and are preserved in sea sediments. A search for signatures of the Kara impact event in deep-sea drill cores is planned.

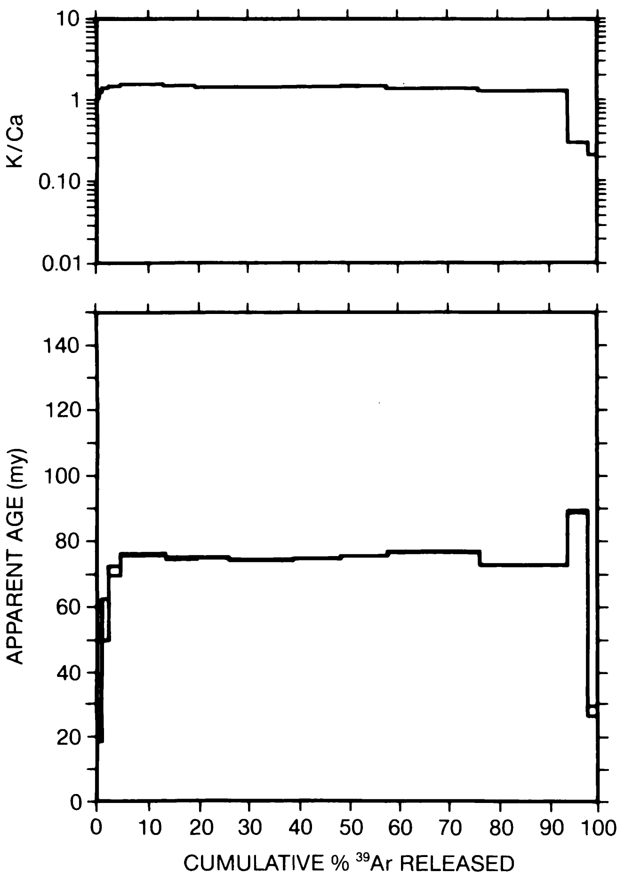
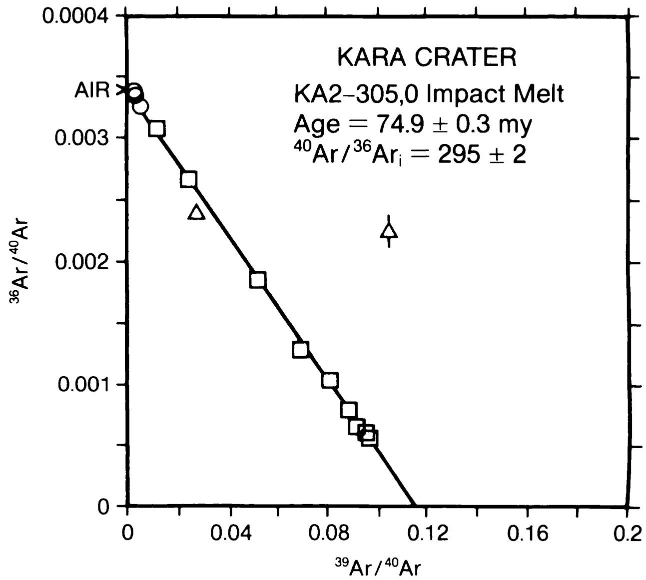


Figure 2. ^{40}Ar-^{39}Ar age spectrum and three-isotope plot for the impact melt sample KA2-305,0 (from Koeberl and others, 1989a). The flat release pattern and the good linear correlation in the three-isotope plot do not show evidence for mixing with older material.



ACKNOWLEDGMENTS

We are grateful to M. A. Nazarov and his colleagues at the Vernadsky Institute of Geochemistry, USSR Academy of Sciences, Moscow, USSR, for valuable samples, useful discussions, preprints, and data. We thank H. Newsom and B. Schuraytz for very helpful comments on the manuscript. The Lunar and Planetary Institute is operated by the Universities in Space Research Association under contract NASW-4066 with the National Aeronautics and Space Administration. This is Lunar and Planetary Institute Contribution No. 728.

REFERENCES CITED

Alexopoulos, J. S., Grieve, R.A.F., and Robertson, P. B., 1988, Microscopic lamellar deformation features in quartz; Discriminative characteristics of shock-generated varieties: Geology, v. 16, p. 796–799.

Badjukov, D. D., Nazarov, M. A., and Alexeev, A. S., 1987, The K/T event; Amount of the crater ejecta and the possible impact site, *in* Lunar and Planetary Science XVIII: Houston, Texas, Lunar and Planetary Institute, p. 40–41.

Badjukov, D. D., Nazarov, M. A., and Suponeva, I. V., 1989a, Impact glasses from the Kara and Ust-Kara structures, *in* Lunar and Planetary Science XX: Houston, Texas, Lunar and Planetary Institute, p. 36–37.

Badjukov, D. D., Bazhenov, M. L., and Nazarov, M. A., 1989b, Paleomagnetism of impactites of the Kara impact crater; Preliminary results, *in* Lunar and Planetary Science XX: Houston, Texas, Lunar and Planetary Institute, p. 34–35.

Bottomley, R. J., York, D., and Grieve, R.A.F., 1990, ^{40}Argon-^{39}Argon dating of impact glasses: Proceedings 20th Lunar and Planetary Science Conference: Houston, Texas, Lunar and Planetary Institute, p. 421–431.

Feldman, V. I., and 5 others, 1979, Some pecularities of geochemistry of impactites of Janisjarvi, southwest Karelia, and Kara, Polar Ural, astroblems, *in* Lunar and Planetary Science X: Houston, Texas, Lunar and Planetary Institute, p. 382–384.

Grieve, R.A.F., 1987, Terrestrial impact structures: Annual Review of Earth and Planetary Science, v. 15, p. 245–270.

Grieve, R.A.F., Wood, C. A., Garvin, J. B., McLaughlin, G., and McHone, J. F., 1988, Astronaut's guide to terrestrial impact craters: Houston, Texas, Lunar and Planetary Institute Technical Report 88–03, 89 p.

Harland, W. B., and 5 others, 1982, A geologic time scale: Cambridge University Press, 131 p.

Hartung, J. B., and Anderson, R. R., 1988, A compilation of information and data on the Manson impact structure: Houston, Texas, Lunar and Planetary Institute Technical Report 88–08, 32 p.

Koeberl, C., 1986, Geochemistry of tektites and impact glasses: Annual Review of Earth and Planetary Science, v. 14, p. 323–350.

——, 1988, Blue glass; A new impactite variety from Zhamanshin crater, U.S.S.R.: Geochimica et Cosmochimica Acta, v. 52, p. 779–784.

Koeberl, C., and 5 others, 1988, The Kara and Ust-Kara impact structures (USSR) and their relevance to the K/T boundary event [abs.], *in* Global catastrophes in Earth history; An interdisciplinary conference on impacts, volcanism, and mass mortality: Houston, Texas, Lunar and Planetary Institute Contribution 673, p. 95–96.

Koeberl, C., Fredriksson, K., Götzinger, M., and Reimold, W. U., 1989, Anomalous quartz from the Roter Kamm impact crater, Namibia: Evidence for post-impact hydrothermal activity?: Geochimica et Cosmochimica Acta, v. 53, p. 2113–2118.

Koeberl, C., Sharpton, V. L., Murali, A. V., and Burke, K., 1990, The Kara and Ust-Kara impact structures (USSR) and their relevance to the K/T boundary: Geology, v. 18, p. 50–53.

Kolesnikov, E. M., Nazarov, M. A., Badjukov, D. D., and Shukolyukov, Yu. A., 1988, The Karskiy craters are probable records of catastrophe at the Cretaceous-Tertiary boundary [abs.], *in* Global catastrophes in Earth history; An interdisciplinary conference on impacts, volcanism, and mass mortality: Houston, Texas, Lunar and Planetary Institute Contribution 673, p. 99–100.

Komor, S. C., Valley, J. W., and Brown, P. E., 1988, Fluid inclusion evidence for impact heating at the Siljan Ring, Sweden: Geology, v. 16, p. 711–715.

Masaitis, V. L., and Maschak, M. S., 1982, The shower of cosmic bodies falls 65 m.y. ago?, *in* Lunar and Planetary Science XIII: Houston, Texas, Lunar and Planetary Institute, p. 469–470.

Masaitis, V. L., and 5 others, 1980, The geology of astroblemes: Lenigrad, Nedra Press, 231 p. (in Russian).

Masaitis, V. L., Mashchak, M. S., and Ivanov, B. A., 1988, Kara and Ust-Kara craters formed at the K-T boundary by low-density projectile, *in* Abstracts of papers, 8th Soviet-American Microsymposium: Moscow, Vernadsky Institute of Geochemistry, p. 61–62.

Mashchak, M. S., and Ezersky, V. A., 1980, Clastic dikes of the Kara crater (Pai-Khoi), *in* Lunar and Planetary Science XI: Houston, Texas, Lunar and Planetary Institute, p. 680–682.

Maslov, M. A., 1977, On the origin of the Kara depression: Meteoritika, v. 36, p. 123–130 (in Russian).

McHone, J F., and Dietz, R. S., 1983, Possible impact craters near the K/T boundary: Geological Society of America Abstracts with Programs, v. 15, p. 640.

Murali, A. V., Koeberl, C., Nazarov, M. A., Sharpton, V. L., and Burke, K., 1988, Kara and Ust-Kara impact structures, USSR: Geochemical relationship of the target rocks and ejecta: Meteoritics, v. 23, p. 291–292.

Nazarov, M. A., Badjukov, D. D., and Alexeev, A. S., 1989a, Morphology of the Kara and Ust-Kara impact craters, *in* Lunar and Planetary Science XX: Houston, Texas, Lunar and Planetary Institute, p. 762–763.

Nazarov, M. A., Kokesnikov, E. M., Badjukov, D. D., and Masaitis, V. L., 1989b, Potassium-argon age of the Kara impact event, *in* Lunar and Planetary Science XX: Houston, Texas, Lunar and Planetary Institute, p. 766–767.

Nazarov, M. A., and 5 others, 1989c, Geology and chemistry of the Kara and Ust-Kara impact craters, *in* Lunar and Planetary Science XX: Houston, Texas, Lunar and Planetary Institute, p. 764–765.

Newsom, H. E., 1980, Hydrothermal alteration of impact melt sheets with implications for Mars: Icarus, v. 44, p. 207–216.

Sandwell, D. T., and McAdoo, D. C., 1988, Marine gravity of the southern ocean and Antarctic margin from Geosat: Journal of Geophysical Research, v. 93, p. 10389–10396.

Sharpton, V. L., and Burke, K., 1987, Cretaceous-Tertiary impacts: Meteoritics, v. 22, p. 499–500.

Tapley, B. D., Born, G. H., and Parke, M. E., 1982, The Seasat altimeter data and its accuracy assessment: Journal of Geophysical Research, v. 87, p. 3179–3188.

Vishnevskiy, S. A., Maslov, M. A., Pal'chik, N. A., and Ponomarev, G. Ya., 1977, Coesite in rocks of the Kara structure: Doklady Akademii Nauk SSSR, v. 232, p. 446–448.

Manuscript Accepted by the Society October 24, 1989