Kara and Ust-Kara impact structures (USSR) and their relevance to the K/T boundary event

Christian Koeberl
Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058
and Institute of Geochemistry, University of Vienna, A-1010 Vienna, Austria

Virgil L. Sharpton, A. V. Murali, Kevin Burke
Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058

ABSTRACT
Ample evidence exists for at least one major meteorite impact event at the time of the Cretaceous/Tertiary (K/T) boundary, and it is therefore important to establish if any recognized terrestrial impact craters are K/T in age. The Kara, USSR, impact structure consists of two adjacent large impact craters (a rare and interesting geologic phenomenon), and it has been suggested that this twin impact structure might be related to the K/T boundary event. However, newly determined \(^{40}\text{Ar}/^{39}\text{Ar}\) and K-Ar ages presented here suggest that these structures are slightly older than 70 Ma, and may thus be too old for a 66 Ma K/T boundary event. Still, these two craters represent a substantial impact event that could have initiated regional, if not global, degradation of the biosphere. Their age suggests a possible relation with the Campanian/Maastrichtian boundary.

INTRODUCTION
The Kara and Ust-Kara twin impact structures are situated at about lat 69°10'N, long 65°00'E at the Kara Sea on the northern shore of the USSR (Arctic Ocean). Twin craters are not common on Earth, and only the Clearwater Lakes are of comparable size (Grieve, 1987). The Kara crater is located completely on land, whereas Ust-Kara is mostly underwater and has modest onshore exposures close to the Kara River estuary (Fig. 1). The structures are barely

![Figure 1. Geologic map of Kara-Ust-Kara crater region and geographic location of twin impact structures. A-B line indicates cross section shown in Figure 2 (for scale bar, see Fig. 2). Modified after Masaitis et al. (1980).](image)
discernible in optical satellite imagery, and their exact sizes are not well constrained. Recent field observations of the Kara crater indicate a maximum diameter of about 60 km (Masaitis and Mashchak, 1982; Masaitis et al., 1980). Because the structure is deeply eroded, an initial diameter of at least 65 km seems reasonable.

The presence of the Ust-Kara crater is inferred from outcrops of suevites, shocked country rocks, impact melts (“tagamites” in Soviet literature), and impact glasses that are distributed in a 16-km-wide band southeast of Cape Polkovnik, just northeast of the Kara crater (Fig. 1). An initial estimated diameter of 25 km (Masaitis and Mashchak, 1982) has been revised on the basis of morphological studies to at least 70 km (Nazarov et al., 1989a). This estimate has recently been supported by satellite altimeter data (Koeberl et al., 1989). Offshore geophysics and drilling in the shallow coastal waters would help to determine the exact size of Ust-Kara.

Since the beginning of the century, suevites (shocked fall-back breccias resembling volcanic tuffs but containing high-pressure polymorphs of quartz, maskelynite, and microdeformation features found only at impact craters) and other impact deposits have been recognized at the structure, but were misidentified as glacial deposits. Later, the structure was interpreted as a volcanic caldera; about 15 years ago the discovery of shock metamorphism in the area led to the conclusion that the structure is an impact crater (Masaitis et al., 1980, and references therein). Shortly afterward, coesite was discovered in rocks from the Kara crater (Vishnevskiy et al., 1977), providing further evidence for the impact origin.

**GEOLOGIC SETTING**

Kara is situated in a marshy tundra plain with numerous swamps, small lakes, and several rivers. A large part of the Kara crater (and the Ust-Kara crater) is set in Permian sandstones and shales. Devonian, Silurian, and Ordovician sedimentary rock (shale and limestone, with minor diabasic dikes) are exposed only in the southern part of the Kara crater. In the center of the structure is a 10-km-wide uplifted core typical of complex impact craters. This central uplift exposes lower to middle Paleozoic sedimentary rocks (similar to those in the southern part of the crater) that are intruded by diabase dikes. The rocks constituting the central uplift are brecciated and show signs of shock, although samples collected at the central uplift are not as heavily shocked as samples from other locations. Shocked rocks are abundant, but because of extremely intense shock metamorphism, they are not easily identified. Some seem to be diabasic or dioritic in composition. The crater is filled with allogenic breccias and with suevites containing impact melt lenses.

Figure 1 shows the distribution of target rocks and impact deposits at the crater. Geophysical observations (Masaitis et al., 1980) are interpreted as showing that the lower part of the crater consists mainly of megabreccias and agglomericated suevites, a total impact deposit thickness of about 0.8 km in the southern part of the crater and about 2 km in the northern part of the crater (Mashchak and Ezeroisky, 1980). Figure 2 is a cross section of the Kara crater as inferred from geophysical measurements.

Suevites have been produced locally, because they contain clasts of local country rocks and impact melts as well as shocked rocks. Because of the difference in target materials between northern and southern parts of the crater, clasts within suevites vary in petrological characteristics. The impact melts, or tagamites (Masaitis et al., 1980), are gray to dark gray crystalline rocks composed of very fine grained mineral components (quartz, plagioclase, feldspar). These melts are the product of shock melting with later recrystallization. Their morphology is similar to normal basalt flows, although they resemble mixtures of affected country rocks rather than basalt. Impact melts occur as large lenticular bodies (several metres thick) within breccias and suevites. It has not yet been established whether they all were formed within one single melt sheet.

Impact glasses are rare (many have recrystallized and thus no longer exist as glass), inhomogeneous, and small compared to the melt bodies and are of an appearance and structure that is similar to some impact glasses from the Zhamanshi impact crater; e.g., Si-rich zhamanshinites (Koeberl and Fredriksson, 1986). Electron microprobe analyses of Kara impact glasses have been performed to determine their relation to similar glasses from other craters. Complete chemical results from these studies will be reported elsewhere (Murali et al., in prep.; Koeberl et al., in prep.). Kara glass fragments show layered structures with associated chemical variations, inclusions, and vesicles, and have colors ranging from translucent white over brown, blue, and gray to black. Some chemical variations within the blue glasses, such as high CaO content in the blue layers, resemble blue zhamanshinites (Koeberl, 1988). The relation between target rocks and the impact-derived rocks, the degree of impact mixing, and the possible presence of a cosmic component are the subjects of an extensive geochemical study of recently collected crater material. Shatter cones (up to >1 m in length) are abundant in Kara target rocks and in rock clasts within suevites. Impact-derived materials are overlain by postimpact Pliocene-Quaternary sediments. These sediments are as much as 100 m thick. Breccia, suevite, and impact-melt outcrops are exposed only in areas where rivers have cut through the structure.

**K/T BOUNDARY**

Because the K/T boundary is marked by global mass extinctions of both fauna and flora associated with a positive Ir anomaly, Alvarez et al. (1980) postulated a large-scale asteroid impact. This hypothesis has been further strengthened by other arguments, such as the fact that other platinum group metals are also present in roughly cosmic proportions (Smit and Hertogen, 1980; Ganapathy, 1980; Kye et al., 1985), although some of this evidence has been disputed by O'Keefe and Drake (1983) and Hallam (1987). Recently, Bohor et al. (1984, 1987) reported quartz grains containing multiple sets of shock-produced planar lamellae within K/T boundary clays. These features are also observed at known impact sites but are unknown from other geologic environments. Recently, the case for impact has been strengthened by the discovery of stishovite in the boundary layer (McHone et al., 1989).

Because there is ample evidence for at least one impact associated with the K/T boundary event, it is important to identify possible candidates among the known terrestrial impact craters. So far, there is no evidence for a single, large, impact structure of the postulated size and age. Several craters, including Kara, have been considered as possible candidates (Masaitis and
Mashchak, 1982; McHone and Dietz, 1983; Sharpton and Burke, 1987), but because of large uncertainties in age determinations, no convincing correlation has been established. The Manson structure in Iowa has an age indistinguishable from the K/T boundary date (Hartung and Anderson, 1988), but is apparently too small to explain a global distribution of impact products.

AGE DETERMINATIONS OF THE KARA IMPACT STRUCTURE

Several K-Ar ages have been published for the Kara crater (Masaitis and Mashchak, 1982; Badjiakov et al., 1987), and they indicate that the age of the crater is about 60 Ma. These data may indicate an association with the K/T boundary, but because of uncertainties in age estimates, additional and more precise determinations are necessary to make this conclusion. Following the recent expedition to the crater by a group from Moscow, K-Ar age determinations on impact melts (cryptocrystalline rocks) and impact glasses (Kolesnikov et al., 1988; Koeberl et al., 1988; Nazarov et al., 1989b) yielded age estimates that varied between 65.8 and 126.8 Ma, clustering around 71 Ma. Under the assumption of the presence of an excess radiogenic argon component (or contamination by older clasts in the impact products), these data have been interpreted by Kolesnikov et al. (1988) to yield a K-Ar “isochron” of 66.4 Ma.

![Graph showing K-Ar age spectrum analysis and isochron plot of impact melt KA2-305.0. Plot shows very good plateau in stepwise Ar-release diagram and good linear correlation in 36Ar/40Ar vs. 39Ar/40Ar plot; interception at y-axis is identical to atmospheric value, indicating absence of excess Ar.](image)

**Figure 3.** 40Ar/39Ar age spectrum analysis and isochron plot of impact melt KA2-305.0. Plot shows very good plateau in stepwise Ar-release diagram and good linear correlation in 36Ar/40Ar vs. 39Ar/40Ar plot; interception at y-axis is identical to atmospheric value, indicating absence of excess Ar.

![Graph showing K-Ar age spectrum analysis and isochron plot of Ust-Kara crater.](image)

**Figure 4.** 40Ar/39Ar age spectrum analysis and isochron plot of Ust-Kara impact melt PL2-147.0. Release spectrum is more complicated than that in Figure 3. Decrease in apparent age at higher temperatures may be related to 39Ar recoil.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age± (Ma)</th>
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<tbody>
<tr>
<td>KA2-305.0 impact melt</td>
<td>74.9 ± 0.3</td>
</tr>
<tr>
<td>PL2-147.0 impact melt</td>
<td>76.2 ± 0.3</td>
</tr>
<tr>
<td>LV1-051.0 (1) impact melt</td>
<td>72.4 ± 3.7</td>
</tr>
<tr>
<td>LV1-051.0 (2) impact melt</td>
<td>72.6 ± 1.4</td>
</tr>
<tr>
<td>KA2-095.0 impact melt</td>
<td>80.7 ± 0.7</td>
</tr>
<tr>
<td>KA2-305.1 impact glass</td>
<td>70.8 ± 0.1</td>
</tr>
</tbody>
</table>

**TABLE 1.** 40Ar/39Ar AGES, KARA AND UST-KARA CRATERS

Note: Sample PL2-147.0 is from Cape Polkovnik, Ust-Kara crater.

* Plus or minus indicates analytical precision of measurements. Age of sample KA2-306 may have been lowered by partial loss of radiogenic Ar from glass phase.
To further investigate impact melt ages and assess whether excess radiogenic Ar was present, we performed a series of 40Ar/39Ar age spectrum analyses. Our results are given in Table 1. 40Ar/39Ar age spectra and 36Ar/40Ar vs. 39Ar/ 40Ar plots are shown in Figures 3 and 4. Results shown in Figure 3 are the least complex; they yield relatively flat age spectra and considerable linear spread on isochron plots. The age spectra in Figure 4 are somewhat more complex and thus more ambiguous with respect to interpretation. The decrease in apparent age for high-temperature increments may be related to 39Ar recoil (Hunee and Smith, 1974) during irradiation.

The isochron approach to data representation allows for measurement of both the age and the trapped argon component (i.e., argon not produced by in situ decay of 40K; see Heizler and Harrison, 1988, for details). All samples, except I.VI-051.0, have significant gas fractions with essentially atmospheric 40Ar/39Ar ratios. This, combined with the good linear correlation of the data, strongly indicates that the samples are not contaminated with excess 40Ar or argon from incompletely outgassed parent material. Our interpretations do not support the assumption of excess argon components in the K-Ar ages (Nazarov et al., 1989b).

The relatively poor reproducibility of the ages from sample to sample (i.e., total age range from 71 to 81 Ma) does not allow us to date precisely the time of formation for the Kara–Ust-Kara structure. None of our samples have apparent ages younger than 70 Ma, and thus a conclusion that the Kara–Ust-Kara impact has been responsible for the K/T boundary event is unwarranted on the basis of available data. On the basis of our current data, we conclude that the impact more likely occurred between 71 and 75 Ma and thus may be related to another important extinction horizon at the Campanian/Maastrichtian (74 Ma) boundary.

**SUMMARY AND CONCLUSIONS**

We have studied samples from the Kara–Ust-Kara twin impact structure to investigate its possible connection with K/T boundary extinctions. The Kara impact structure consists of two very large craters (each about 70 km in diameter), which is a rare geologic phenomenon on Earth. The results from our age determinations do not seem consistent with a K/T boundary age for the Kara–Ust-Kara impact structures. Our independent regression of the K-Ar data (Nazarov et al., 1989b; Nazarov, 1988, personal communication), without assuming excess Ar, also leads to ages greater than 70 Ma. Our most realistic age estimate for the Kara impact structures is greater than 70 Ma, and is probably about 73 to 74 Ma.

The size of the impact craters (65 and >70 km) indicates a large-scale, high-energy impact event, which must have had severe regional, if not global, effects and could possibly have caused degradation of the biosphere. The age obtained in the course of this work suggests a possible rotation with the Campanian/Maastrichtian boundary, which occurred around 74 Ma, and is known to be an important extinction horizon. We suggest that further dating may be helpful in resolving the differences between K- Ar and Ar-Ar dates and could further illuminate a possible connection between the Kara structures and the Campanian/Maastrichtian boundary. A search for geochemical and mineralogical anomalies in sediments at that boundary may also be helpful.

**REFERENCES CITED**


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