ZIRCON U–Pb DATING OF THE KARA IMPACT STRUCTURE, RUSSIA, INDICATES NO ROLE IN LATE CRETACEOUS MASS EXTINCTIONS.

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Introduction: Impact events can have major effects on Earth's biosphere and carbon cycle, as demonstrated by the Chicxulub impact and synchronous Cretaceous–Paleogene (K–Pg) boundary mass extinction (ca. 66 Ma). However, it is not known if other large impacts have played a role in global or regional mass extinctions. The Kara impact structure, Russia, with a pre-erosional diameter of at least 65 km, represents one of the ten largest known impacts of the Phanerozoic. Previous age constraints on the impact were primarily based on $^{40}Ar/^{39}Ar$ analyses and indicated that Kara formed in the Late Cretaceous. However, uncertainty on the age has led to contrasting proposals that Kara (i) represents a K–Pg boundary impact (e.g., [1,2,3]), (ii) may have been coincident with an extinction at the earlier Campanian–Maastrichtian boundary (ca. 72 Ma; e.g., [4,5]), or (iii) formed during the Maastrichtian [6,7]. Constraining the age of the Kara impact structure is thus important for placing it into the context of the Chicxulub impact and K–Pg boundary event, as well as proposed, lesser extinctions and the global carbon cycle of the Late Cretaceous. Here we establish a precise age for the impact on the basis of imaging, microstructural analysis, and *in situ* U–Pb dating of recrystallized zircon separated from impact melt.

The Kara impact structure, Russia: The Kara impact structure lies on the shore of the Kara Sea, northern Russia (Fig. 1). Field observations and geophysical data indicate a maximum present diameter of about 60 km, which equates to an initial diameter of at least 65 km given that the structure has been substantially eroded (e.g., [1,8,9]). The impact occurred into Paleozoic carbonate and terrigenous sedimentary rocks with a total thickness of ~5.5 km ([9] and references therein) (Fig. 1). The sedimentary succession is intruded by diabase dykes and sills that mostly date to the Devonian and drilling indicates that the sediments are underlain by a volcanic–sedimentary sequence that dates to the late Proterozoic [9,10]. The crater fill at Kara comprises a ~2 km-thick package of breccias. Lithic breccias grade into overlying suevites with more bombs, fragments of impact melt, and irregular lenses of impact melt that reach 15–20 m in thickness [9]. The breccias of the crater fill contain clasts of Cretaceous sediments that are not otherwise preserved in the vicinity of the structure, indicating that Cretaceous sedimentary rocks were present at the time of impact but have since been eroded away. Paleontological analysis of these sedimentary clasts indicates a Late Cretaceous age [11], placing an approximate maximum age constraint on the impact event. A 30 m-thick lens of Pliocene–Quaternary sediments overlying the structure provides a minimum age constraint for the impact [9].

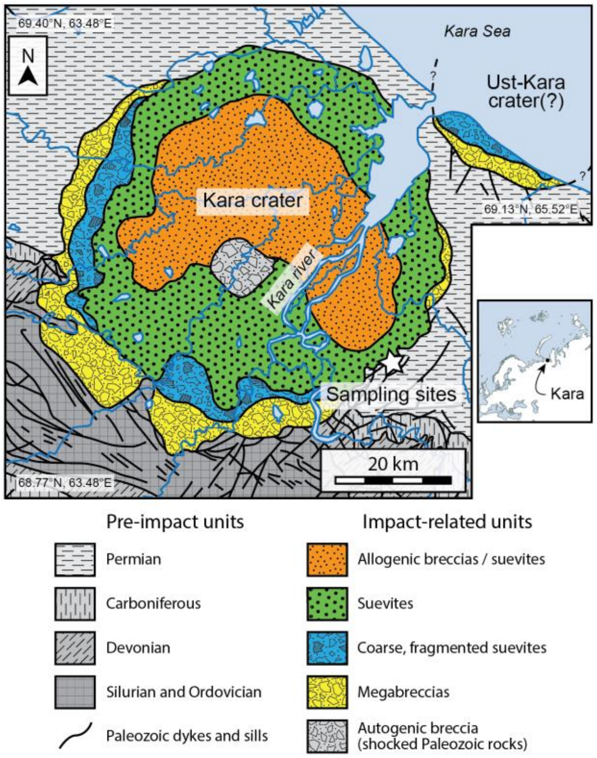

Fig. 1. Geological map of Kara impact structure, Russia. The existence of Ust-Kara crater remains debated. Modified after [4,8,9].

Previous absolute age constraints on the Kara impact event: Previous efforts to assign an absolute age to the Kara impact event have come from fission track dating, K–Ar analysis, and $^{40}Ar/^{39}Ar$ analysis. The first $^{40}Ar/^{39}Ar$ data for Kara indicated that the impact likely occurred between 71 and 81 Ma [4]. Further $^{40}Ar/^{39}Ar$ work on two of the samples previously analyzed by [4], as well as data for two additional samples, suggested an age at the younger end of this range [6]. A weighted mean age of 70.3 ± 2.2 Ma (2σ) was calculated from the three youngest of the four plateau ages and this has generally been considered the best estimate age for the Kara impact event. The $^{40}Ar/^{39}Ar$ age reported by [6] was recently recalculated, using updated decay constants and their uncertainties, to 70.7 ± 2.2 Ma [12].

Methods: Zircon was separated from eight samples of massive impact melt that were collected from outcrops on the Anaroga river during the Vernadsky Institute expeditions in the 1980s and the Finnish–Russian Nordenskiöld–Kara expedition in 2001. The grains were mounted in epoxy, polished in order to expose their interiors, and imaged in cathodoluminescence (CL), backscattered electron (BSE), and secondary electron (SE) modes on an FEI Quanta FEG 650 scanning electron microscope (SEM) at the Swedish Museum of Natural History, Stockholm, Sweden. A selection of grains underwent microstructural characterization by electron backscatter diffraction (EBSD) analysis on the same SEM. Uranium–lead dating was carried out on the Cameca IMS1280 ion microprobe at the NordSIMS Laboratory, Swedish Museum of Natural History. Building on the recent application of analytical pits as small as 5 µm to impact-recrystallized zircon [13], a Hyperion H201 RF plasma high-brightness oxygen source was used to produce analytical pits of 5 µm and 15 µm diameter in two analytical sessions.

Results: *Imaging.* Zircon grains of interest for U–Pb dating fell into two categories: (i) those that retain pre-impact features, such as concentric growth zoning and core–rim relationships, and do not display impact-related features, which were dated with the aim to shed light on the age of the target rocks, and (ii) those that recrystallized during the impact, which were dated with the aim to constrain the timing of the event.

Microstructural characterization. Electron backscatter diffraction analysis of five zircon grains revealed pervasive recrystallization textures. Three of the grains display equant, sub-micrometer- to micrometer-scale granules that have systematic crystallographic relationships; such features have been interpreted to represent reversion from a high-pressure $ZrSiO_4$ polymorph, reidite, when observed at other impact structures [14]. The two other grains that were analyzed are composed of distinct domains that are up to 30 µm wide and comprise vermicular zircon radiating from a central point, and these do not record the systematic crystallographic relationships mentioned above.

Uranium-lead analysis. Twenty-seven analyses performed on 23 undeformed zircon grains highlight age populations at ~300 Ma, ~350 Ma, and ~535 Ma, with further dates represented by single analyses: ~675 Ma, ~750 Ma, ~1500 Ma, ~1750 Ma, and ~2165 Ma.

Sixty-eight analyses were performed on 41 recrystallized zircon grains from the eight samples. Approximately 50 analyses define a plateau in ^{207}Pb-corrected ages at ~75 Ma. The youngest 48 analyses (on 31 grains from eight samples) are statistically indistinguishable and therefore considered to be unaffected by inherited radiogenic Pb or post-impact Pb loss. This large population gives a weighted mean ^{207}Pb-corrected age of 75.34 ± 0.66 Ma (2σ, full external uncertainty, MSWD = 1.4; probability of fit = 0.05), which we consider to be the best estimate age for the Kara impact event.

Discussion: The first attempt to date the Kara impact structure with U–Pb analysis of impact-recrystallized zircon gives a consistent ~75 Ma age that is distinguishably older than the previous best estimate age, which was based on ^{40}Ar/^{39}Ar data.

The new zircon U–Pb age for Kara indicates that the impact occurred in the Campanian and was not related to the K–Pg boundary, the Campanian–Maastrichtian boundary, or a supposed marine extinction event at ca. 80 Ma [15].

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