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# Did the Puchezh-Katunki Impact Trigger an Extinction?

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**Abstract.** The 80 km Puchezh-Katunki impact crater is the only one of the six largest known Phanerozoic craters which has not been previously considered as a factor in a biotic extinction event. The age of impact is currently regarded as Bajocian (Middle Jurassic), on the basis of palynostratigraphy of crater lake sediments, but there is no significant extinction in the Bajocian. Earlier K-Ar age determinations of impactites compared with a current Jurassic time scale permit that either the end-Triassic or the Early Jurassic (Pliensbachian-Toarcian) extinction was coeval with the Puchezh-Katunki crater. The stratigraphical and paleontological record contains clues that suggest that an impact may have occurred at these horizons. The age of the Puchezh-Katunki crater needs reevaluation through $^{40}Ar/^{39}Ar$ dating of impact rocks and/or revision of the palynology of the oldest crater fill. A definitive age determination will help constrain the impact-kill curve.

## 1 Introduction

The putative link between extraterrestrial impacts and mass extinction events has been the focus of much interdisciplinary research for over 20 years. The terminal Cretaceous bolide impact that created the Chicxulub crater is now widely regarded as the main cause of the Cretaceous/Tertiary boundary extinction, confirming the original hypothesis of Alvarez (1980). Building on the Cretaceous/Tertiary example, large body impacts have been considered as potential causal agents in other extinction events (Rampino and Haggerty 1996). Such a research agenda was clearly formulated by Raup (1992): "... it is appropriate, even obligatory, to entertain the possibility that impacts could have been responsible for extinctions other than the K-T event." While most known large impact craters have been evaluated in this context, the Puchezh-Katunki crater represents a notable exception.

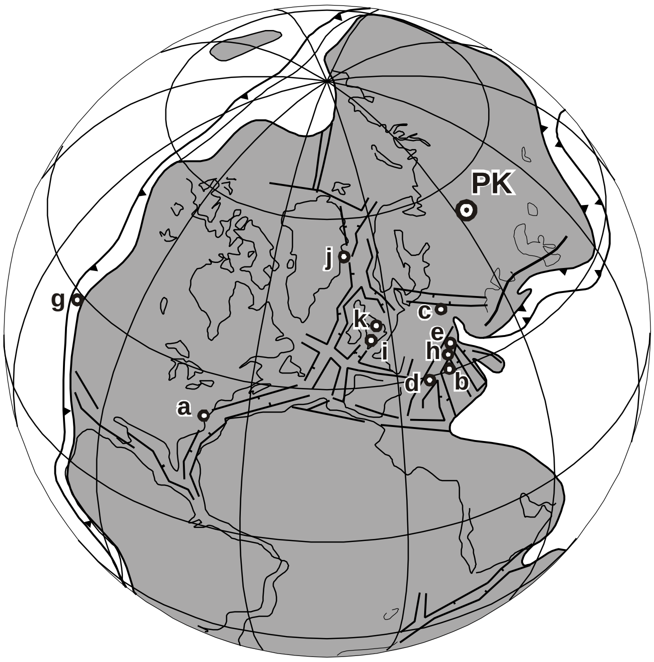


**Fig. 1.** Early Jurassic paleogeographic map showing the Puchezh-Katunki (PK) impact crater (circle, not to scale) and location of reported possible impact indicators (dots) from the Triassic-Jurassic boundary and Early and Middle Jurassic. For key to labels (location and reference), see Table 3. Base map from Ziegler (1990). See text for discussion.

The Puchezh-Katunki structure is a large impact crater at the Volga River, approx. 400 km northeast of Moscow in Russia (Fig. 1). Measuring 80 km in diameter, it is the fifth largest known terrestrial impact crater in the Phanerozoic (Grieve et al. 1995; Grieve 1997) (Table 1). According to Raup‘s (1992) “impact-kill curve”, an impact of that magnitude might have produced a noticeable extinction in the paleontological record. The predicted magnitude of species extinction is approximately 40%; taking into account the uncertainties, a range between 20 to 70% is suggested.

The results of multidisciplinary scientific investigations of the Puchezh-Katunki crater, including studies of the 5374 m deep Vorotilovskaya borehole drilled at the crater’s center, were recently summarized in a book in Russian (Masaitis and Pevzner 1999). The age of the impact is regarded as Bajocian. It is stratigraphically bracketed by the youngest target rocks, Early Triassic in age, and the overlying lake sediments, thought to be Bajocian (Middle Jurassic) in age. Here I present arguments that the age cannot be regarded as definitively determined. I consider the uncertainties of the crater age and give a literature review of possible impact indicators from the latest Triassic to Middle Jurassic, in order to investigate if the Puchezh-Katunki impact is recorded in the global sedimentary

**Table 1.** The largest known Phanerozoic impact craters (after Grieve 2001)

| Crater name | Diameter | Age | Location |
|---|---|---|---|
| Chicxulub | 170 | 65.0±0.1 Ma (K-T boundary) | Yucatán, Mexico |
| Manicouagan | 100 | 214±1 Ma (Late Triassic) | Quebec, Canada |
| Popigai | 100 | 35.7±0.2 (Late Eocene) | Siberia, Russia |
| Chesapeake Bay | 85 | 35.5±0.6 (Late Eocene) | Virginia, USA |
| ***Puchezh-Katunki*** | ***80*** | ***see discussion*** | ***Russia*** |
| Morokweng | 70 | 146±2 (latest Jurassic) | South Africa |

record and to explore the possibility that it may be related to either of the two extinction events in this interval, the end-Triassic or the Pliensbachian-Toarcian (Early Jurassic). Notably, there is no significantly elevated extinction rate registered in the Bajocian fossil record (Sepkoski 1996). A definitive dating of the Puchezh-Katunki crater will help constrain the validity and shape of the impact-kill curve.

## 2 The Puchezh-Katunki Impact Structure

The 80-km-wide Puchezh-Katunki impact structure is nearly completely buried under Neogene and Quarternary sediments. The only natural exposures of impactites are found along the banks of Volga River. Geophysical surveys revealed the crater morphology that features a central dome, ring depression and ring terrace (Masaitis et al. 1996).

The target stratigraphy consists of Archean crystalline basement rocks and overlying uppermost Proterozoic to lowermost Mesozoic sedimentary rocks. In the area adjacent to the crater, the crystalline basement occurs at a depth of ~2 km. The sedimentary sequence typically consists of 500 m Vendian clastics, 800 m Devonian limestone and shale, 450 m Carboniferous carbonates and marl, 250 m Lower Permian carbonates, evaporites and clay, 160 m Upper Permian clastics, and 80 m Lower Triassic clay and siltstone (Masaitis et al. 1996; Masaitis and Pevzner 1999).

Impact rocks and crater lake sediments were penetrated by nearly 180 drill holes, including the super-deep Vorotilovskaya borehole at the centre of the crater (Masaitis and Pevzner 1999). The lithologic column of the uppermost part of the crystalline basement, the sequence of impact rocks and the overlying crater lake deposits is shown on Fig. 2.

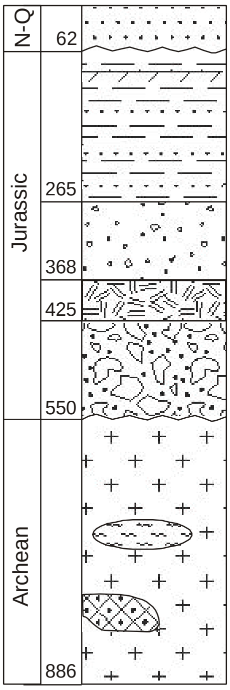


**Fig. 2.** Stratigraphic column penetrated by the uppermost part of the Vorotilovskaya borehole drilled through the center of the crater (after Vorontsov in Masaitis and Pevzner 1999).
Legend: 0-62 m – Neogene and Quarternary sand and clay; 62-265 m – Crater lake sediments: clay, siltstone and sandstone, subordinate carbonate (Kovernino Formation); 265-368 m – Koptomict gravel; 368-425 m – Suevite; 425-550 m – Allogenic polymict breccia; 550-886 m – Crystalline basement rocks: gneiss, amphibolite, peridotite.

## 3 Dating the Puchezh-Katunki Crater

Raup (1992) succintly pointed out that “the dating problem will have to be investigated before we have definitive answers to the impact-extinction question.” The prevailing view on the age of the Puchezh-Katunki impact regards it as Bajocian (Middle Jurassic), on the basis of palynostratigraphy from the oldest crater lake sediments (Masaitis et al. 1996; Masaitis and Pevzner 1999). The lacustrine Kovernino Formation, thought to have deposited in the lake that filled the crater, contains palynomorphs that are said to range from the Bajocian to the Bathonian. However, several problems call the validity of this age determination into question.

It is difficult to demonstrate that crater lake sedimentation immediately followed the impact. This argument, however, is weakened if one accepts that pollens suggesting the same age were also recovered from the matrix of impact breccias.

The palynological data is presented as a taxonomic list and abundances (Masaitis and Pevzner 1999), using a taxonomic terminology and methodology preferred by Russian workers which is different from practices followed by western palynologists. Therefore comparison and independent evaluation of data are difficult. I am not aware of published illustration of the pollens and spores recovered from the Kovernino Formation. The latest comprehensive work (Masaitis and Pevzner 1999) quotes the list of pollen taxa by referring only to the explanatory notes of the geological map of the area. A modern revision of the palynostratigraphy is warranted.

Independent K-Ar radiometric dating of impactites yielded scattered, ambiguous results, ranging from 200±3 Ma to 183±5 Ma (Masaitis and Pevzner 1999) (Fig. 3). Due to these discrepancies, radiometric ages were deeemed unreliable and not considered further in the estimation of crater age. Various compilations of the cratering record cite different numeric ages for the Puchezh-Katunki structure, according to the time scale used to convert the Bajocian biostratigraphic age (Grieve et al. 1995; Grieve 2001).

In general, K-Ar dating of impact rocks is often fraught with problems. Older apparent ages can result from the lack of complete resetting (i.e. retention of older $Ar^{40*}$ from the target lithology), whereas younger apparent ages may reflect $Ar^{40*}$ loss through devitrification or post-impact hydrothermal processes (Deutsch and Schärer 1994). However, as the youngest unit in the target rocks is Early Triassic in age, the stratigraphic brackets permit that any one of the radiometric age determinations could in fact be accurate. A comparison with the recently revised Jurassic numeric time scale (Pálfy et al. 2000) (Fig. 3) reveals that either the end-Triassic (~200 Ma) or the Early Jurassic (Pliensbachian-Toarcian, ~183 Ma) extinctions could hypothetically be coeval with the Puchezh-Katunki impact. Therefore a definitive age determination of the Puchezh-Katunki crater is desirable.

To this end, new radiometric dating employing the more accurate and precise $^{40}Ar/^{39}Ar$ method is planned. This dating technique has been successfully employed in the age determination of other large impact craters, such as Chicxulub (Swisher et al. 1992) and Popigai (Bottomley et al. 1997). The lack of a coherent impact melt sheet and widespread hydrothermal alteration makes the radiometric dating challenging. Alternatively, the age of the impact may be verified if its distal ejecta were discovered in well-dated stratigraphic successions.

## 4
## Reported Possible Impact Signatures in the Lower and Middle Jurassic and near the Triassic-Jurassic Boundary

In order to evaluate the feasibility of different ages for the Puchezh-Katunki crater, here I briefly review the literature records of possible geological evidence for a large impact near the Triassic-Jurassic boundary or in the Early to Middle Jurassic (Fig. 3, Table 2). The location of the reported possible impact signatures are shown on an Early Jurassic paleogeographic map (Fig. 1). Anomalously high Ir concentration and the presence of shocked quartz and/or microspherules are considered possible direct impact indicators. Sharp negative carbon anomalies and a paleontological record of catastrophic changes in ecosystems may be regarded tentatively as indirect impact indicators.

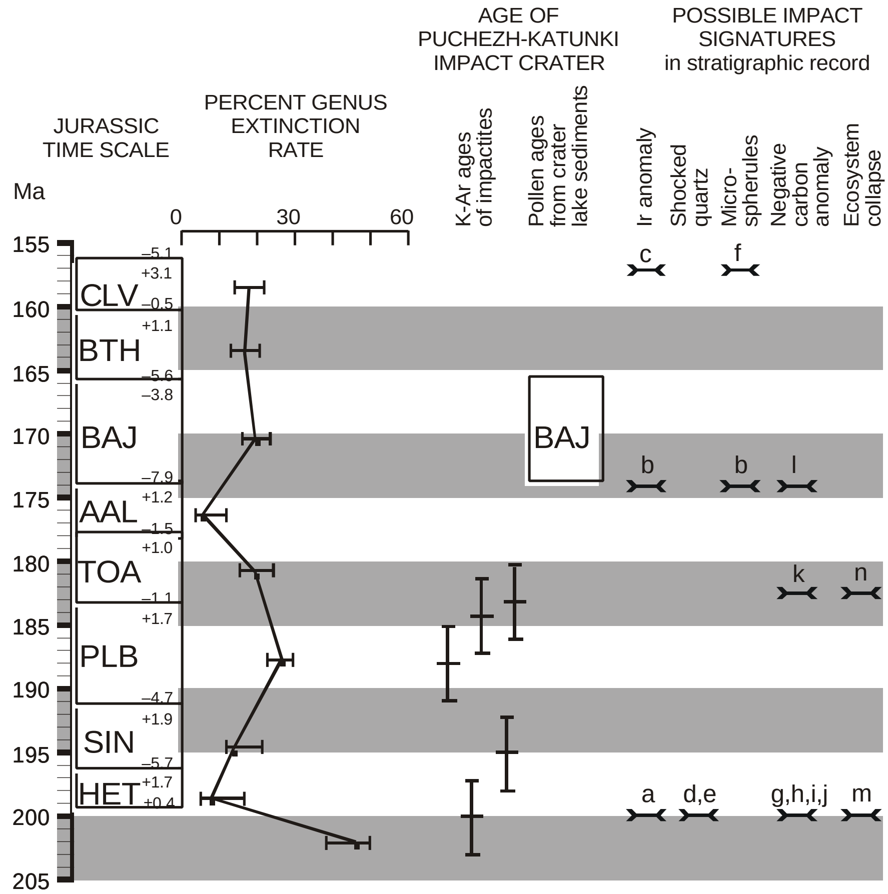


**Fig. 3.** Summary of age determinations of the Puchezh-Katunki crater (Masaitis and Pevzner 1999), possible impact signatures in the terminal Triassic and Early to Middle Jurassic stratigraphic record, and extinctions rates (Sepkoski 1996). Numeric time scale from Pálfy et al. (2000). For key to labels (location and reference), see Table 3. Stage abbreviations: HET – Hettangian; SIN – Sinemurian; PLB – Pliensbachian; TOA – Toarcian; AAL – Aalenian; BAJ – Bajocian; BTH – Bathonian; CLV – Callovian.

None of the three direct indicators is fool-proof, but their combined presence may make the strongest case for impact. The interpretation of the stable isotope stratigraphic record is more contentious. A negative carbon anomaly may reflect different kinds of disruption in the carbon cycle, including that through an impact-induced shutdown of marine primary productivity. However, this postulation requires additional support from other lines of evidence. Similarly, ecologic collapse in itself cannot be uniquely associated with impact.

**Table 2.** Possible impact signatures in the terminal Triassic and Early to Middle Jurassic stratigraphic record

| Label | Type | Locality | Age | Reference | Remarks |
|---|---|---|---|---|---|
| a | Ir anomaly | Newark Basin | Tr/J boundary | (Olsen et al. 2002a, b) | Preliminary results, moderately elevated Ir values (Also note that no shocked quartz has been found in the Newark Supergroup, despite repeated search (Mossman et al. 1998; Olsen et al. 2002b) |
| b | Ir, microspherules | Southern Alps | Bajocian | (Jéhanno et al. 1988) | From ferruginous hardground; two spherule populations, one consists of micrometeorites, the other may have derived from ablation of a larger meteorite with an estimated minimum D of 50 m |
| c | Ir | Poland | Callovian | (Brochwicz-Lewinski et al. 1986) | Occurs in a condensed stromatolitic layer, where organic fixation may account for geochemical peculiarities |
| d | shocked quartz | Northern Appenines | Tr/J boundary | (Bice et al. 1992) | Grains occur at three levels, planar deformation is not convincing for impact origin, biostratigraphic constraints are loose |
| e | shocked quartz | Northern Alps | Tr/J boundary | (Badjukov et al. 1987) | Impact origin of grains has been seriously doubted |
| f | microspherules | Poland | Callovian | (Brochwicz-Lewinski et al. 1984) | Same locality as in (c) |
| g | C spike | Queen Charlotte Is. | Tr/J boundary | (Ward et al. 2001) | Short-lived negative anomaly recorded in marine organic matter; authors consider productivity collapse as most likely explanation |
| h | C spike | Hungary | Tr/J boundary | (Pálfy et al. 2001) | Negative anomaly recorded in marine carbonate and organic matter; authors consider productivity collapse or $CH_4$ release as potential causes |
| i | C spike | England | Tr/J bound. | (Hesselbo et al. 2002) | Negative anomaly recorded in organic matter |
| j | C spike | East Greenland | Tr/J boundary | (Hesselbo et al. 2002) | Negative anomaly recorded in terrestrial plant material |
| k | C spike | England | Toarcian | (Hesselbo et al. 2000) | Methane release is implied beacuse parallel change in terrestrial and marine organic matter observed |
| l | C spike | England | Bajocian | (Hesselbo et al. 2001) | From terrestrial organic material |
| m | fern spike | Newark Basin | Tr/J boundary | (Fowell and Olsen 1993; Fowell et al. 1994) | Invokes similarity to K-T fern spike, implies large-scale terrestrial ecosystem disruption |
| n | extinction | NW Europe | Toarcian | (Little 1996) | Benthic species extinction linked to Oceanic Anoxic Event |

A perusal of the compilation presented in Fig. 3 and Table 2 permit the following observations. The Triassic-Jurassic boundary, marked by one of the „big five" mass extinctions, have been repeatedly linked to an impact event. Existing direct evidence for shocked quartz is disputed but a moderate Ir anomaly was recently reported (Olsen et al. 2002a, b). The fossil record of the extinction event is compatible with forcing by short-term, drastic environmental change, as is the disruption of the global carbon cycle. Scenarios that implicate intense and brief flood basalt volcanism of the Central Atlantic magmatic province appear better substantiated (Pálfy et al. 2002, Pálfy in press), but the role of an impact cannot be excluded.

Direct evidence for impact that would correlate with the Toarcian or Pliensbachian-Toarcian extinction is lacking. The paleontological record and the geochemical anomalies provide only hypothetical and circumstantial clues. Impact causation for this extinction has never been proposed, and the well-documented oceanic anoxic event and coeval volcanism of the Karoo-Ferrar province provide more plausible alternative forcing mechanisms (Pálfy et al. 2002).

From the Bajocian an iridium anomaly, microspherules and a carbon isotope excursion were reported, although none have been observed in more then one section. This stage is not noted as a time of elevated extinction rates but it represents the presently accepted age of the Puchezh-Katunki crater.

## 5 Prospects of Search for Puchezh-Katunki Ejecta in the Sedimentary Record

The paleogeography of the Russian Platform, as inferred from the distribution of marine strata, did not favor the preservation of a proximal ejecta blanket. No Lower or lower Middle Jurassic marine sediments are known in the vicinity of the Puchezh-Katunki crater, i.e. within $5R_{crater}$=200 km.

In most parts of the Russian Platform, marine sedimentation did not start until the later part of the Middle Jurassic, with the exception of the Donets folded area (Krymholts et al. 1988). In this area, marine strata were deposited from the Early Toarcian onward (Krymholts 1972). This depocenter, however, is some 800 km to the southwest from the Puchezh-Katunki crater. Therefore only a relatively thin distal ejecta layer may be expected, but so far no thorough search has been carried out.

## 6 Discussion

Whether or not the Puchezh-Katunki crater, the fifth largest in the Phanerozoic, is related to any extinction event, bears directly on the proposed relationship

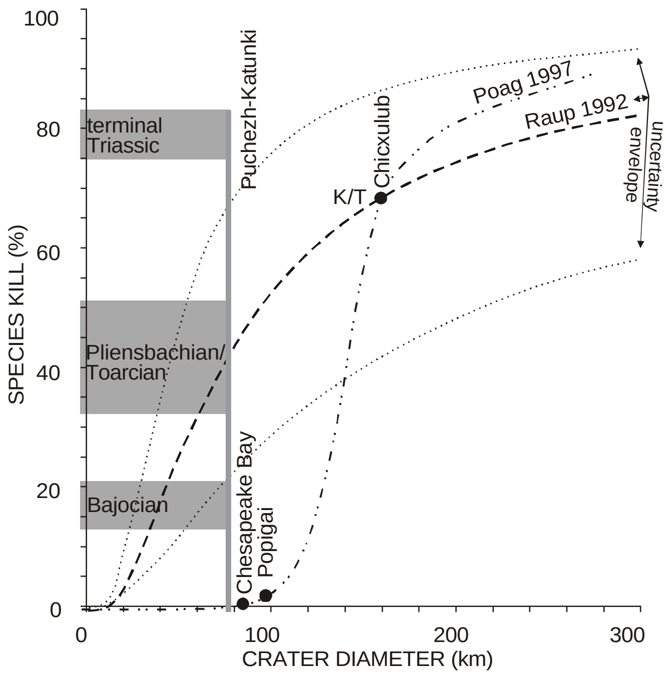


**Fig. 4.** Potential constraints of the impact-kill curve from the Puchezh-Katunki crater. Predicted extinction levels corresponding to the size of of the crater shown for the original impact-kill curve of Raup (1992) and the modified version of Poag (1997). Percent species extinction estimates for possible ages of the Puchezh-Katunki are shown based on Sepkoski (1996). Note that the percent estimates are for entire stages.

between large impacts and extinction. The impact-kill curve concept of Raup (1992) attempts to correlate the size of the impact (expressed by the crater diameter) and its biotic effect (measured by percent species kill) (Fig. 4).

Raup's (1992) original, sigmoidal kill curve was based solely on the extinction time series data and estimates of the impact flux. Remarkably, the discovery of Chicxulub revealed a crater size that matched the prediction of the curve for the K/T event. However, modifications were suggested subsequently on the basis of other craters. Jansa (1993) used the early Eocene Montagnais crater, which is 45 km in diameter, to place a lower threshold on the killing effect of an impact and argued for a hyperbolic, rather than sygmoidal kill curve.

The kill curve was recently revisited by Poag (1997), using data from two large, nearly coeval Late Eocene impact craters (Popigai, D=100 km and Chesapeake Bay, D=85 km). The lack of a significant extinction event directly related to these impacts contradicts the predictions of the original Raup curve, requiring at least its modification (Poag 1997) (Fig. 4).

Equal in size to Popigai and thus the second or third largest in the Phanerozoic (Table 1), the Manicouagan crater (D=100 km) was suggested to be linked to the end-Triassic extinction (Olsen et al. 1987). However, its U-Pb age of 214 Ma (Hodych and Dunning 1992) corresponds to the early Norian, a time of no significant extinction well before the Triassic-Jurassic boundary at 200 Ma (Pálfy et al. 2000). It postdates by several million years the end-Carnian, a time of a disputed vertebrate extinction event (Benton 1991). The sixth largest Phanerozoic crater, Morokweng (D=70 km) is 146±2 Ma in age (Koeberl et al. 1997), thus the impact is coeval within error with the Jurassic-Cretaceous boundary age (Pálfy et al. 2000). The end-Jurassic extinction, apparently a second-order peak in Sepkoski's data (1996), was disputed as a biotic event of major significance (Hallam 1996).

Reliable dating of the Puchezh-Katunki structure is important in this context, as it may provide critical evidence for possible biological effects of impacts that produce craters in the 80-100 km diameter range. As long as the link between the Chicxulub crater and the K/T event remains the only firmly established impact-extinction link, it is difficult to confirm or further constrain the impact-kill curve. Dating uncertainties of the Puchezh-Katunki crater permit discussion of the following possibilities.

(1) If the Puchezh-Katunki impact is Bajocian as currently suggested by the palynostratigraphic data (Masaitis et al. 1996; Masaitis and Pevzner 1999), its biotic effects may be negligible. This is in agreement with the suggestion of Poag (1997) that the minimum extinction threshold on the kill curve is well above 100 km crater diameter.

(2) If the Puchezh-Katunki impact is of Triassic-Jurassic boundary age, it would require a major revision of the previously accepted crater age. Furthermore, its biotic effect would exceed the predictions of the original kill curve of Raup (1992).

(3) If the Puchezh-Katunki impact is of early Toarcian age, a significant revision of the previously accepted crater age would still be required. The relationship between extinction magnitude and crater size would be consistent with the original kill curve, falling within the uncertainty band of Raup (1992), and would be comparable with that of the Morokweng crater and the Jurassic-Cretaceous bioevent.

Should the Puchezh-Katunki impact be related to an extinction but the somewhat larger Popigai and Chasepeake Bay impacts are not, it lends support to complex extinction models, e.g. the multiplicative multifractal model of Plotnick and Sepkoski (2001). This model suggests that the extinction magnitude is not exclusively controlled by the external perturbation, i.e. the impact size alone, but it also depends on the state of the biota at the time of perturbation. Furthermore, that size alone does not determine the biotic effect of an impact, is proposed for Chicxulub and the K/T event, where the carbonate- and evaporite-rich target stratigraphy may have played an important role in unleashing the environmental catastrophe.

## 7 Conclusions

The age of the Puchezh-Katunki impact structure is not known with certainty. The cited Bajocian palynostratigraphic age needs better documentation before it can be accepted. Existing K-Ar radiometric ages are scattered between the Triassic-Jurassic boundary and Early Jurassic (Pliensbachian-Toarcian).

The possibility cannot be ruled out that the Puchezh-Katunki impact is coeval with either the end-Triassic or the Early Jurassic (Pliensbachian-Toarcian) extinction.

Much of the Russian Platform was emerged during the Early and early Middle Jurassic. Some Puchezh-Katunki ejecta may be preserved in the Donets folded structure, some 800 km southwest of the crater, where marine sedimentation prevailed from the early Toarcian onward.

Possible distal ejecta and direct or indirect geochemical impact signatures are known from several localities and stratigraphic horizons within the suggested possible age range of the Puchezh-Katunki crater.

A more conclusive crater age determination is expected from $^{40}Ar/^{39}Ar$ dating of impact melts and/or glass – such a project is planned.

Better radiometric and stratigraphic dating will help either prove or disprove the presently highly hypothetical impact-extinction link. The results should provide important constraints on the impact-kill curve (Raup 1992), as the biological effects of an impact that produced a crater 80 km in diameter can be assessed.

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