Discussion

Comment on: “K–Ar evidence from illitic clays of a Late Devonian age for the 120 km diameter Woodleigh impact structure, Southern Carnarvon Basin, Western Australia”, by I.T. Uysal, S.D. Golding, A.Y. Glikson, A.J. Mory and M. Glikson


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Abstract

K–Ar isotopic ages presented by Uysal et al. for illitic clay minerals from drill core samples were interpreted to date the Woodleigh impact event at 359 ± 4 Ma, allegedly implicating Woodleigh in the Late Devonian mass extinction. However, only very equivocal evidence is presented by Uysal et al. to support a link between clay mineral paragenesis and impact-related features, and the K–Ar ages reveal a distribution that is essentially a continuum between 308 and 364 Ma. The ‘age’ computed by Uysal et al. is based on an average of the five oldest ages within this group, which has no geological or statistical basis. The stratigraphic age constraints considered by Uysal et al. to be consistent with this age are much weaker than acknowledged, and the impact could have been much older than mid-Devonian. The size of the Woodleigh crater is poorly constrained (and the subject of an ongoing controversy); Uysal et al.’s suggestion of 120 km diameter is probably overestimated by a factor of two, in which case a link to any mass extinction is unlikely. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The first report on the discovery of a large impact structure centered on Woodleigh Station, in the Carnarvon Basin of Western Australia, was published by Mory et al. [1]. Although no precise age constraints were provided, Mory et al. [1] suggested that this impact event could be linked to the Permian/Triassic (P/Tr) boundary and associated mass extinction. Reimold and Koeberl [2] took issue with several aspects of this paper: (1) the discussion and photographs in [1] did not provide evidence for shock metamorphism; (2) the alleged size (120 km) of the Woodleigh structure; (3) quality and interpretation of chemical data; and (4) the validity of a relationship between the large Woodleigh Structure and a mass extinction at the P/Tr boundary. In reply, Mory et al. [7] presented, inter alia, several photographs stated to depict shock deformation in several minerals. Recently presented impact-diagnostic evidence in the form of shock metamorphic deformation, obtained through conventional shock metamorphic analysis — albeit on different samples from the same drill core as that studied by [1,7] — confirms an impact origin of the Woodleigh Structure [3,4].

Recently, Uysal et al. [5] presented K–Ar data for illitic clays from Woodleigh samples and drew the following conclusions: (1) adherence to a 120 km size is retained; (2) K–Ar data for fine-grained illitic clay mineral separates indicate a Late Devonian (359±4 Ma) age for the Woodleigh impact event; (3) the interpreted age, alleged large diameter, and proximity to Late Devonian siderophile element anomalies in the Canning Basin, Western Australia, and in South China suggested that ‘... environmental effects of the Woodleigh impact event are [sic] a likely contributor to a biotic crisis in the Late Devonian (Frasnian/Famennian in age)’. We suggest that available data do not lend any unambiguous support for these conclusions.

2. The size of the Woodleigh impact structure

The topic of Woodleigh’s size has been discussed previously, but Uysal et al. persist in asserting that Woodleigh has a diameter of 120 km, in keeping with their consistent preference for large sizes in discussion of other impact structures (e.g., [8], despite contrasting evidence [9,10]), coupled with the larger size required to trigger biological consequences. The issue of crater size is pertinent to the possible biotic consequences of the impact, and it is crucial to consider all relevant information whether or not it supports the preferred interpretation of K–Ar data. We refer to previous publications [2,3,6] indicating that the true diameter of the Woodleigh impact structure is probably about 60 km. Though various models for size distributions and size–effect relationships have been proposed for bolides, all knowledgeable workers would agree that a 60 km crater-forming event is (1) far more frequent (hence more probable), and (2) far less likely to cause mass extinctions than a 120 km one [11].

3. Constraints on the age of the Woodleigh impact structure

Uysal et al. [5] prepared clay mineral concentrates from samples at 195–587 m depth in various host rocks from two drill cores. No information on the petrography of the drill core rocks, essential to interpreting the K–Ar data, is given. It is unclear, for example, whether the clay mineral separates from Woodleigh 2A samples were derived solely from shocked basement clasts or also from matrix and sandstone pebbles. Uysal et al. state that their figure 2a shows ‘a good example of PDFs [planar deformation features] in a quartz grain...’, when in fact this figure does not show any PDFs at all but rather some ca. 20 μm spaced subplanar fractures. The caption to this figure states that an arrow points at one set of PDF, while the arrow only points to the grain boundary. In the absence of evidence linking the dated clay minerals to a shock event, the reader is being asked to accept such a relationship on faith.

From their set of 25 K–Ar ages, Uysal et al. [5] selected five to pool for a mean age which they interpreted to date a hydrothermal event – hypothesized to originate from impact heating – at
359 ± 4 Ma. Several problems with this interpretation undermine the validity of the conclusion. First, Uysal et al. [5] present no evidence to relate the paragenesis of the analyzed clay minerals to a discrete hydrothermal event. Even if the analyzed clay minerals were demonstrated to post-date a shock event, no evidence (i.e., impact melt rocks) is presented for heating, and there is no reason a priori to expect that a shock event would degas radiogenic argon from pre-existing clay minerals. Thus, K–Ar ages on clay mineral separates cannot provide minimum ages unless every < 4 µm sized crystal from the countless analyzed for each sample (weights are not given, so that it is impossible to accurately estimate the number) can be shown to post-date a shock event.

A second problem is that despite a distribution of apparent ages for 12 samples that is essentially a continuum between 308 and 364 Ma (Fig. 1), Uysal et al. [5] elected to pool the five oldest ages within this group. There is no valid statistical, geological or geochronological justification for this selection. The statement that ‘consistent K–Ar ages within analytical uncertainty of better than 3% ... can be regarded as geologically meaningful’ is arbitrary when applied to a subset of a continuum having large errors relative to the data range. The most straightforward interpretation of this distribution – provided that each clay sample is paragenetically homogeneous – is that clay mineral growth occurred more or less continuously between 364 and 308 Ma, in which case any impact event upon whose products the clays formed would be simply constrained to have occurred prior to 364 Ma.

Even if the selection of five K–Ar dates from the continuum were justified, the uncertainty arising from a simple weighted mean calculation is unreasonably optimistic because each of the ages has a significant systematic error due to uncertainty in spike calibration as well as decay constants. The proper way to determine the error of such a mean value would be to calculate the weighted mean 40Ar*/40K considering only analytical errors, then mathematically propagate in the systematic errors. The resultant error of the weighted mean would be at least 2–3 times as large as the ±4 Ma reported, although we reiterate that such an arbitrary selection from the data is unjustified to begin with.

The stratigraphic constraints invoked by Uysal et al. [5] are based on regional stratigraphy deduced by Mory et al. [1] and Iasky et al. [6] from the Yaringa 1 core. However, it is only as a consequence of their interpretation of the crater’s structure that the pre-upper Devonian strata are considered to be of pre-impact age. The ages of the Kopke Sandstone and Sweeney Mia (characterized as pre-impact by Uysal et al. [5]) are largely inferred on the basis of conformable relationships with underlying strata and some conodont work to be early Devonian; they were previously thought to be Upper Silurian–Lower Devonian [12].

The only unequivocal stratigraphic age constraint at Woodleigh is that the basement in the central uplist is shocked. Nowhere has the crater floor been identified in Woodleigh 2A or in Yaringa 1. If Yaringa 1 intersects the pre-impact sequence, then why do these cores apparently betray no evidence of shock or brecciation? Woodleigh 2A may not go deep enough to answer any of these questions. Features of the structure itself and the seismic data summarized by Iasky et al. [6] indicate that it is entirely conceivable that the structure is heavily eroded, that all these sediments are in fact younger infill, and, therefore, the more logical conclusion that impact is pre-Devo-
nian. The Early Jurassic estimate used as the upper bound is conservative, but is reasonably constrained by the cover over the central uplift. The youngest age may be better constrained to early Permian rather than Jurassic, as the post-impact sediment (paraconglomerate) from Woodleigh 2A has clasts containing Permian palynomorphs [1], although if the impact structure is taken to be 60–70 km in diameter, then these cores (Yaringa) are outside the structure.

Dating attempts cited in Mory et al. [23] yielded a wide variety of results: a paleomagnetic study ‘implies that the age of impact was between 318 and 265 Ma’ (p. 145 in [23]), K–Ar dating of smectic minerals is quoted as ‘geologically meaningless’ (p. 101 in [23]), UV laser probe 40Ar–39Ar analysis of biotites yielded no ages younger than 664 Ma (p. 99 in [23]), and apatite fission-track ages were found to be Late Jurassic–Early Cretaceous (p. 94 in [23]). In the absence of sufficiently precise stratigraphic constraints, dating of impact events has been accomplished in many cases by analyzing materials (e.g., impact melt rock, pseudotachylite) clearly related to impact processes, and using methods whose isotope systematics are unambiguously controlled by the impact event (e.g. [13,14]). These requirements are lacking in the report of Uysal et al. [5], and we conclude that their data and arguments provide few if any objective constraints on the age of a Woodleigh impact event.

4. Relationship of Woodleigh to Late Devonian extinction events

Mory et al. [1] claimed that the formation of Woodleigh could have coincided with the P/Tr mass extinction. This suggestion was criticized by [2] and is obviously superseded by the scenario of Uysal et al. [5], as they now find that their K–Ar data favor coincidence of the Woodleigh event with yet another mass extinction, namely the Late Devonian Frasnian/Famennian (F/F) boundary. As noted in the foregoing, there is nothing intrinsic to the K–Ar data of Uysal et al. [5] that supports this conclusion as an objective deduction.

While the Late Devonian is associated with one of the five largest mass extinctions in the geological record, the situation is far from clear-cut. Glassy spherules, probably similar to microtektites, have been discovered in several Late Devonian sections: above the F/F boundary in South China (e.g., [15]) and slightly above this boundary in Belgium (e.g., [16]). The Chinese spherules could be coeval with a minor Ir anomaly reported in the Canning Basin in Australia, but no Ir anomaly has been found in the Belgian sections [17]. Conodont stratigraphy, if the biozones are isochronous, clearly shows that the spherule layers in China and Belgium do not belong to the same event. The matter is further complicated by the fact that the spherule layers are difficult to correlate with isotope shifts reported at various stratigraphic levels across the F/F boundary.

Whether one favors impact events (e.g., [18]) or terrestrial causes (e.g., [19]) for the Frasnian–Famennian extinctions, there is consensus that there was not one Late Devonian extinction event, but several. The evidence indicates a complex sequence of extinctions and radiations, with evidence for at least five different layers containing microtektites and/or enhanced iridium contents, spanning seven conodont zones estimated to cover about 3 Myr (according to [18], 365.5–368.5 Ma – notably not including the 359±4 Ma age of Woodleigh claimed by Uysal et al. [5]). The enhanced Ir abundances in the Chinese sections may, or may not, be of extraterrestrial origin, as already noted by Wang et al. [20]. The Ir anomaly in the Australian layer, at 0.3 ppb (not really a ‘strong iridium anomaly’, as quoted by [5]) may result from biological activity [19,21]. The microtektite layers do not coincide with periods of extinction, rather of radiation [19]. Any relationship between these possible impact-related layers and the Woodleigh structure remains to be demonstrated.

5. Summary

The K–Ar data presented by Uysal et al. [5] for clay minerals in rocks from the Woodleigh impact structure are widely dispersed and do not convincingly indicate a discrete event. The data do not
objectively constrain the age of the impact event, nor do they establish an association with Late Devonian, or any other, mass extinctions. The selection of data to pool for a mean ‘age’ is highly model-dependent, and the model (impact-induced hydrothermal control of post-shock clay minerals’ K–Ar ages) is not well established. Whether or not Woodleigh is large enough for the impact to have caused major biotic effects such as mass extinctions is another question. Uysal et al.’s interpretation of the K–Ar data is implicitly linked to an affirmative reply to this question, despite previous indications [2] that the 120 km adopted size is exaggerated. In summary, we do not contest the basic tenet of Uysal et al. [5] (that large impact events are plausible causes of mass extinctions), but proof of specific correlations must be based on far more convincing evidence than was presented for Woodleigh. At a minimum, documentation of dated materials’ paragenesis in relation to an impact event is required, and should this be possible, it would be productive to analyze smaller samples with better-controlled context, as might be afforded by the vacuum-encapsulated 40Ar/39Ar technique [22].

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