Tsunami Chronology supporting Late Holocene Impacts

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Introduction

The Holocene Impact Working Group (HIWG) has identified the location of at least eight impacts into the world's oceans in the Late Holocene. Each of these was capable of generating large tsunami that should have left a geological footprint on adjacent shorelines. We have identified from shoreline tsunami deposits five known impact events (Figure 1), two of which are associated with impact craters identified by the HIWG. The other three are associated with legends and historical descriptions. This paper presents the chronology of tsunami events in New South Wales (NSW) and Western Australia (WA)—on opposite coasts of Australia, and in the UK that are linked to impact events.

New South Wales (NSW) and the Mahuika Impact Event

Research along the east coast of Australia since 1989 (Bryant and Nott, 2001; Bryant 2008) indicates that mega-tsunamis have struck and eroded the rocky shores of New South Wales over a distance of 600 km throughout the Late Holocene. Sixty-eight radiocarbon dates have been obtained from marine shell found along the New South Wales Coast in disturbed Aboriginal middens, deposited in tsunami dump deposits and sand layers, and protected beneath

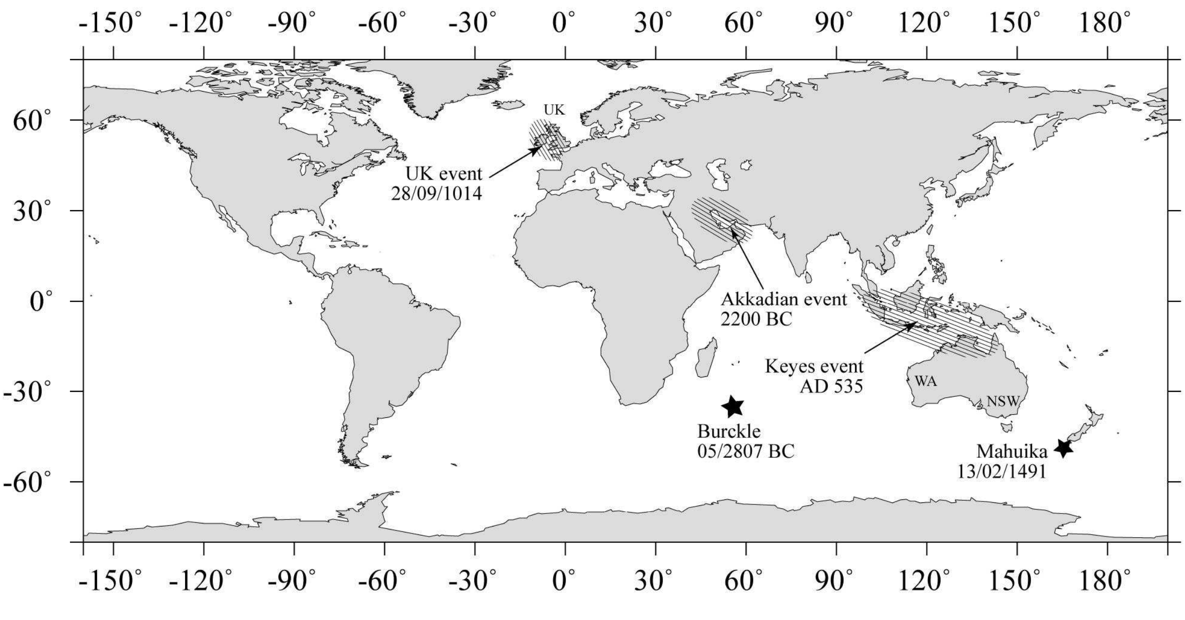

Figure 1 Location of impact events supported by the chronology of tsunami events in New South Wales, Western Australia or the UK

boulders transported by tsunami. Radiocarbon dates do not simply represent a calendar age. Each can be plotted as a frequency distribution over a span of radiocarbon years. These "radiocarbon" distributions were then converted to calendar ones at ten year intervals using a carefully constructed calibration table based on marine species (Stuiver et al., 1998). The "calendar" frequency distributions were then summed over time to produce a composite time series of tsunami events. Radiocarbon calendar distributions are very noisy and suffer from age reversals. In order to assess whether or not the timing of our dates was random, a simulated time series of calendar distributions was constructed with mid-points at 10 year intervals over the same time span. This "background" time series was then scaled to the total number of samples in our dataset. The simulated times series was subtracted from the NSW one to remove this background "noise". The technique reduced the possibility of a single radiocarbon date being considered a tsunami event. The resultant time series since 6000 BC is plotted in Figure 2. The y-axis has arbitrarily been set in this figure to a maximum value of 1.0. The time series shows the clustering of dates—supported by more than one radiocarbon date—centred on one of ten times: 5000 BC, 4200 BC, 3200 BC, 1400 BC, 700 BC, AD 440, AD 790, AD 1300, AD 1490, and AD 1690. The latter three events may be part of the same event because the biggest age reversals occur over this period. Comet impacts with the ocean are probably responsible for many of these events given the spread and magnitude of deposits along the coast.

The most prominent peak centres on AD 1500±85, which corresponds with the largest number of asteroid observations for the past two millennia and a peak in observable comets (Bryant, 2008). The location of the impact probably responsible for this event has recently been discovered lying in 300 m depth of water on the continental shelf 250 km south of New Zealand at 48.3° S, 166.4° E (Abbott et al., 2003, Bryant et al., 2007). The crater is 20 km in diameter and could have been produced by a comet 1.6 km in size travelling at a speed of 51 km s^{-1} (based on calculations by Marcus et al., 2005). When it struck, it would have generated an earthquake with a surface wave magnitude of 8.3. The lack of sediment that normally settles over time from the ocean suggests that the crater is less than 1000 years old. The comet has been named Mahuika after the Maori God of fire. Tektites found in sediments to the southeast indicate a trajectory for this comet from the northwest, across the east coast of Australia (Matzen et al., 2003). A likely time for this impact was in the late evening on the 13 February 1491. Korean

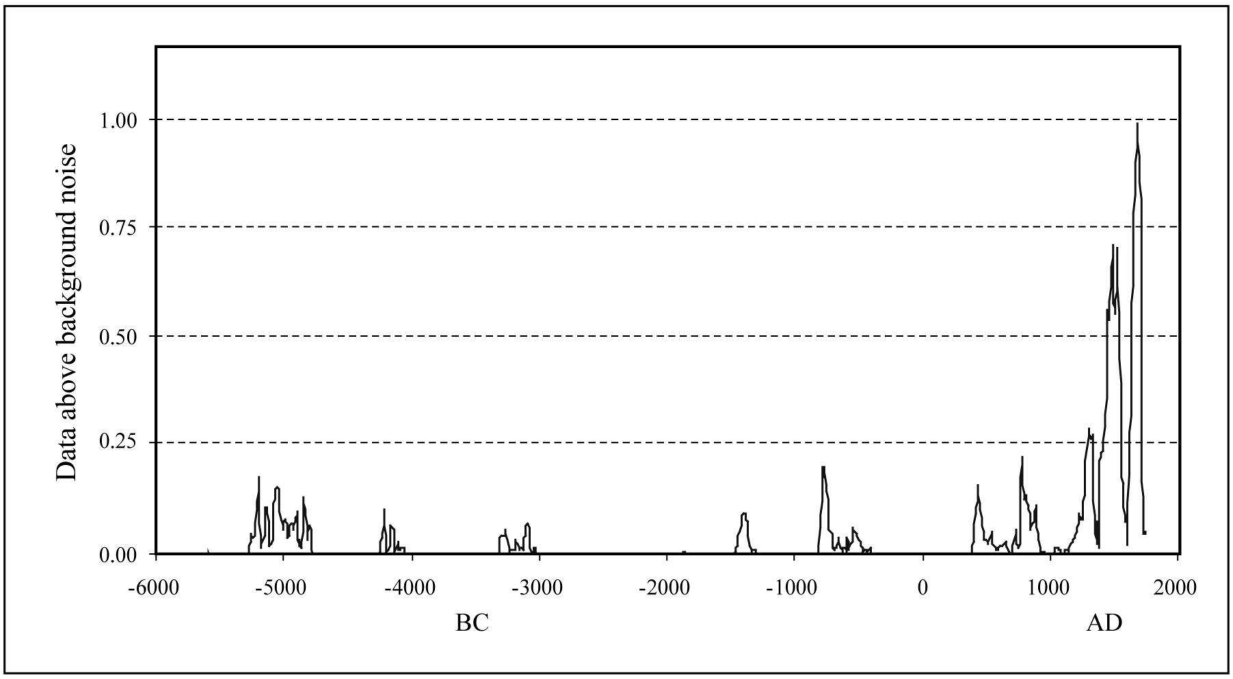

Figure 2 Time series of probable tsunami events affecting the New South Wales coast of eastern Australia

astronomers were observing the small and not very active comet X/1491 B1 (formerly 1491 II) in the evening sky of 20 January 1491. This comet appears to have been a Jupiter family object with a period of less than 20 years. The Koreans followed the comet's movement in the constellation Cetus and last sighted it brightly on 12 February. It disappeared by the 14th. According to calculations by Hasegawa (1979), X/1491 B1 was making a close approach to the Earth. Sekanina and Yeomans (1984) calculate that a collision with the Earth was possible on 13 February. From the perspective of the east coast of Australia, this comet approached the Earth around midnight from the northwest, most likely at a 45° angle to the horizon. The direction, season, and time of day agree with Aboriginal legends. Baillie (2006) also recognized the potential of this comet for an impact with the Earth. He points out that its timing matches the largest ammonium spike in a millennium in Antarctic ice cores that can be interpreted as the signature of a comet impact.

Western Australia (WA)

The presence of tsunami deposits along the coast of Western Australia has been described in a number of studies (Nott 2000, 2003, 2004, Bryant and Nott, 2001, Nott and Bryant, 2003, Bryant et al., 2007, Bryant, 2008, Scheffers et al., 2008). Fifty-four radiocarbon dates have been obtained from marine shell found along this coast. A similar analysis was applied to these dates as for those described above. The results are plotted in Fig. 3. There again are ten significant tsunami events. This time centred on 4200 BC, 2870 BC, 2150 BC, 100 BC, AD 540, AD 790, AD 1040, AD 1300, AD 1440, and AD 1680. Again the latter three events may be part of the same event. A more recent event in the last 250 years cannot be ruled out, but is impossible to date using radiocarbon because the ages come out as modern. By far the most extensive event is the one that has occurred within the last 800 years. Its signature is preserved at more than six locations along the coast, from Kalbarri in the south to Cape Leveque in the north—a distance of 1800 km.

Three of the events are noteworthy because they occur at times of other calamities in the region. The 1440 event overlaps with the AD 1491 mega-tsunami event documented along the New South Wales coast of Australia. Any tsunami generated by this impact would not have

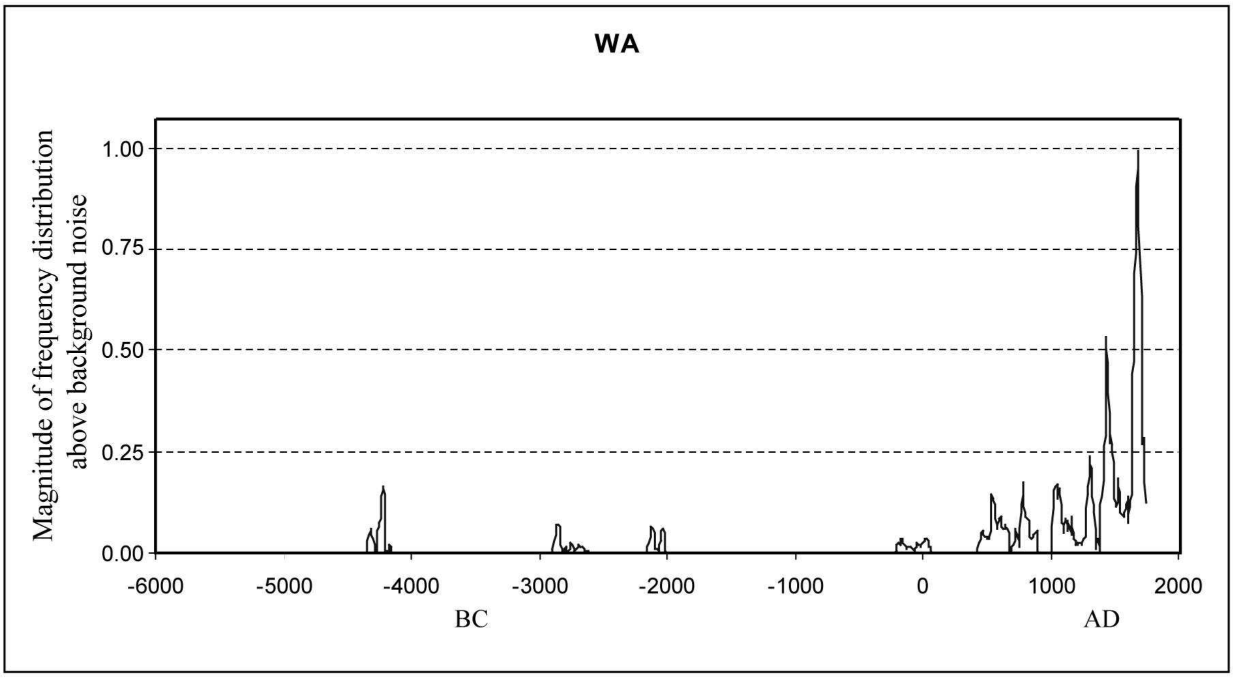

Figure 3 Time series of probable tsunami events affecting the West Australian coast of Australia.

affected the west coast of Australia to the degree documented in this paper. This point will be discussed later. The second event dated at AD 540 coincides with a catastrophic event triggered in AD 535 by an unknown explosion or eruption in the Indonesian-Northern Australian region (Keyes, 2000). Abbott et al. (2007) believe that the explosion has its source in a comet that fragmented into two and struck the Gulf of Carpentaria in northeast Australia. However, any tsunami generated in the Gulf would not have entered the Indian Ocean. The event around 2870 BC corresponds to a global catastrophe caused by a comet impact in 2807 BC documented by Masse (2007) and linked to the Burckle Impact crater shown in Figure 1.. Finally, an event centred on 2150 BC may also have a cosmic origin although the evidence is less conclusive. Its timing corresponds with the fall of the Akkadian empire in the Middle East at around 2200 BC, which has been linked to an impact (Masse, 2007).

United Kingdom (UK)

On 28th September 1014 widespread coastal flooding occurred in Britain (Haslett and Bryant, 2008). William of Malmesbury in The History of the English Kings (vol. 1) states that “a tidal wave, of the sort which the Greeks call euripus and we ledo, grew to an astonishing size such as the memory of man cannot parallel, so as to submerge villages many miles inland and overwhelm and drown their inhabitants” (Mynors, Thomson & Winterbottom, 1998, p. 311). For the same year, the Anglo-Saxon Chronicle states that “on the eve of St. Michael’s Day [28th September], came the great sea-flood, which spread wide over this land, and ran so far up as it never did before, overwhelming many towns, and an innumerable multitude of people” (Ingram, 1823). Some accounts suggest that this flood affected Kent, Sussex, Hampshire (Green, 1877), and even as far west as Mount’s Bay in Cornwall, where the Bay was “inundated by a ‘mickle seaflood’ when many towns and people were drowned” (Saundry, 1936). Healy (1995) describes organic deposits in Marazion Marsh, that lie behind a coastal barrier in Mount’s Bay, that is dated to no later than AD 980 and overlain by a sand layer, which could be a signature of the flood event. In North Wales, it has been suggested that recently described field evidence for tsunami impact may be related to this Celtic event (Haslett and Bryant, 2007). The flood is also mentioned in the Chronicle of Quedlinburg Abbey (Saxony), where it states many people died as a result of the flood in The Netherlands, and it is remembered in a North American account by Johnson (1889).

This collection of records implies a significant event in 1014 affecting a number of locations around the British Isles (southeast England, Cornwall, possibly Cumbria). Storm surge can be ruled out because a single storm could not generate a surge over so wide an area in different bodies of water. The event has characteristics of a tsunami given the geography and apparent severity of the flood (Haslett and Bryant, 2008). Indeed, Baillie (2007) considers the 1014 flood to have been a tsunami caused by a comet impact. He cites GRIP ice core data indicating a high ammonium spike in 1014. Investigations of Comet Hale-Bopp and others indicate that ammonium is a major component (1-2%) of a comet’s composition. His theory is supported by another high ammonium anomaly recorded in the GISP2 ice core data coincident with the 1908 Tunguska bolide over Siberia. Haslett and Bryant (2008) have shown that a single impact in the ocean west of Ireland could generate a tsunami that would strike all the coastlines of northwest Europe associated with this event. This UK event clearly requires further investigation.

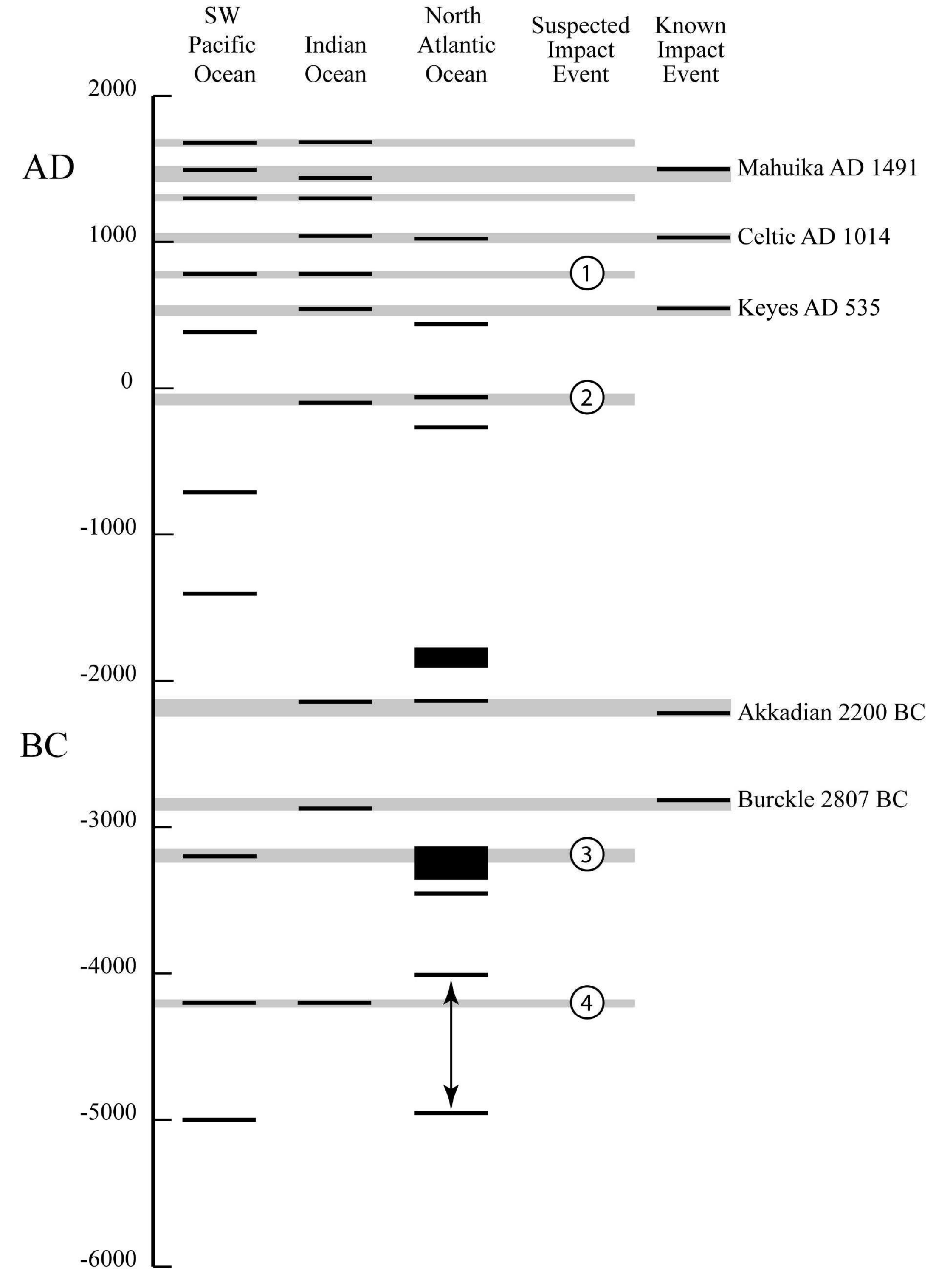

Figure 4 Summary of tsunami events and corresponding impacts

Discussion and Conclusions

Figure 4 summarises the chronology presented in this paper. In essence, our data for New South Wales, Western Australia, and Western Europe are evidence of impacts in three oceans: the southwest Pacific, the Indian and the North Atlantic. The North Atlantic region has additional evidence for at least seven major tsunami documented on the Iberian Peninsula. These events occurred in 60 BC, 218-216 BC, 1763 BC, 1862 BC, 2153 BC, 3309 BC and 4000-5000

BC (Luque et al., 2002, Scheffers & Kelletat 2005; Ruiz et al., 2005). In addition, three pre-historic tsunami are known from the northern British Isles. These events occurred at AD 500, 3250-3150 BC and 3300 BC (Bondevik et al., 2005; Caseldine et al., 2005). The source of all of these events remains unknown, but Baillie (2007) points out that the size and association of some events with climatic anomalies begs for an impact explanation. These events are also listed in Figure 4.

Except for the Burckle event of 2807 BC, all of the impact events we have identified in this paper are linked to tsunami deposits in more than one ocean. By far the most prominent event is Mahuika, which most likely occurring in AD 1491. However, the event is associated with age reversals in radiocarbon, which may have resulted from overturning of carbon-rich ocean waters or injection of vaporised carbonates into the atmosphere. It is difficult to separate any tsunami deposit dated between AD 1300 and AD 1700 into more than one event because of this issue. AD 1491 has been chosen as the likely date of the impact because it is associated with the disappearance of an observed comet close to the Earth and one of the largest ammonium spikes in Antarctic ice cores.

There are possibly four synchronous events occurring in more than one ocean that have not been linked yet to an identifiable impact. These occurred around AD 790, 60 BC, 3200 BC and 4200 BC (Figure 4). Baillie (2007) has already identified the 3200 BC event as being a prime candidate for an impact event that affected more than one ocean. If the results presented in this paper are correct, then they indicate that impactors generating tsunami are more likely to be clustered in time or to occur as a swarm that has a widespread impact path across the Earth’s surface. Swarming has already been identified at two sites on land, at Campo del Cielo and Rio Cuarto, both in Argentina (Masse, 2007). Campo del Cielo consists of 26 small craters and an associated meteorite field covering an area of 238 sq km dating around 2500 BC. Rio Cuarto consists of an impact area covering 48,000 sq km dating between 4000 BC and AD 1000. It released over 1000 Mt of energy (Masse, per comm.). Had it occurred over the ocean, the resulting mega-tsunami would have been more than sufficient to produce many of the deposits mentioned in this paper. The threat from comets may not be as a single object occurring at rare intervals. Instead, the idea of phases of coherent catastrophism from comet impacts, formulated by Asher et al. (1994) is more likely. More difficult to detect are impacts occurring as a swarm over the ocean. Unless such a swarm contains pieces approaching 500 to 1000 metres in size, it will leave no crater as evidence of its impact. Its only signature, besides the myths and legends of people who saw it, would be the type of mega-tsunami evidence that forms the bases of the chronology presented in this paper.

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