The fall of Phaethon: a Greco-Roman geomyth preserves the memory of a meteorite impact in Bavaria (south-east Germany)

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Arguing from a critical reading of the text, and scientific evidence on the ground, the authors show that the myth of Phaethon – the delinquent celestial charioteer – remembers the impact of a massive meteorite that hit the Chiemgau region in Bavaria between 2000 and 428 BC.

Keywords: Bronze Age, Phaethon, Ovid, meteorite, Celts, myth

Introduction

The term 'geomythology', coined by Dorothy Vitaliano (1968: 5), *'indicates every case in which the origin of myths and legends can be shown to contain references to geological phenomena and aspects, in a broad sense including astronomical ones (comets, eclipses, meteor impacts etc.)'* (Piccardi & Masse 2007: vii). Vitaliano differentiates between two kinds of geological

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folklore: '*. . . that in which some geologic feature . . . has inspired a folklore explanation, and that which is the garbled explanation of some actual geologic event, usually a natural catastrophe*' (Piccardi & Masse 2007: vii). Within the last few years a number of studies have tried to demonstrate that some mythical or legendary traditions are geomyths of the second kind, depicting concrete, geological verifiable natural catastrophes in former times (e.g. Piccardi & Masse 2007).

For a long time the myth of Phaethon (see e.g. Ov. *Met*. I.750-II.408; detailed overview on the Classical texts dealing with Phaethon: Knaack 1965) has fuelled suspicions concerning the possibility that it is the reflection of a real natural event in the sense of a geomyth. Its main features are as follows: Phaethon, the son of Helios, borrows the sun-chariot of his father. But he is not able to keep it on course along the sun's accustomed path and, disoriented, the burning chariot sets parts of heaven and Earth on fire. To prevent an even bigger catastrophe, Zeus strikes Phaethon with his thunderbolt and the youth falls to Earth into the river Eridanos.

Von Engelhardt (1979), among others, advanced the hypothesis that the myth of Phaethon is the reflection of a meteorite impact event (Rappenglück & Rappenglück 2007: 102-3). He suggested that the myth was related to the fall of a large meteorite in the Po Delta (Italy), but failed to provide geological evidence for impact in the relevant region. By contrast, Blomqvist (1994) suggested a connection between the myth of Phaethon and actually existing meteorite craters, in particular the Kaalijärv craters in Estonia. There is considerable controversy concerning the dating of these nine craters, the biggest of which has a diameter of 110m, for which the dates range between 6400 and 400 BC (see Masse 2007: 29). But, when Blomqvist published his theory, these were the only known craters that might fit approximately to the place and time in question (Northern or Western Europe, *c*. 2000-428 BC, see below: Time and place).

This article presents further arguments for interpreting the myth of Phaethon as a geomyth. This will be done by comparing in detail the descriptions in the texts of the myth with an example of a scientifically analysed meteorite impact. Our candidate is the site of Chiemgau in south-east Germany, one of the biggest known Holocene meteorite impacts, where an extraordinary variety of phenomena can be studied by bringing geology, mineralogy, geophysics, archaeology and astronomy to bear (Ernstson *et al.* 2010).

The Chiemgau impact

The Chiemgau field (Ernstson *et al.* 2010) in the Alpine foothills comprises more than 80 mostly rimmed craters spread over a roughly elliptical area *c*. 60 x 30km (*c*. 1800km^2 between 47.8° and 48.4° N, and 12.3° and 13.0° E, at an elevation of 360m to 560m asl). The crater diameters range from a few metres to a few hundred metres (Figure 1). The biggest crater, that of Tüttensee (Figure 2), which is filled by a lake, has a rim wall 8m high, a rim-to-rim diameter of about 600m, a depth of roughly 30m and an extensive ejecta blanket. Geologically, the Chiemgau craters occur in Pleistocene moraine and fluvio-glacial sediments. The impact event itself is chiefly documented by the abundant occurrence of shock metamorphism (e.g. planar deformation features [PDFs]) in quartz, which is generally

Figure 1. The 6m-diameter Hohenwarth and 11m-diameter #004 craters.

accepted as evidence of a meteorite impact (Stöffler & Langenhorst 1994: 165) (Figure 3). Further indication of a meteorite impact is given by the occurrence of impact melt rocks, various rock glasses (Figure 4), heavy deformations of the Quaternary cobbles and boulders, accretionary lapilli, the ejecta blanket around the Tüttensee crater, and strange matter in the form of iron silicides such as gupeiite and xifengite, and various carbides, e.g. moissanite SiC. There are carbonaceous spherules containing fullerene-like structures and nanodiamonds that point to an impact-related origin (Yang *et al.* 2008). Examples of the spherules (Figure 5) were found embedded in the fusion crust of cobbles from a crater as well as in soils found widespread across Europe (Rösler *et al.* 2006: 68, 70; Yang *et al.* 2008: 937), suggesting major fallout. Furthermore, a remarkable variety of secondary effects can be observed, e.g. abundant strong corrosion of rocks down to skeletal formation (Figure 6) is not only attributed to melting/decarbonisation but probably also to dissolution by nitric acid precipitation from the impact explosion cloud.

A gravity survey of the Tüttensee crater and its environs revealed an anomaly of positive gravity, that can be explained by soil liquefaction and densification generated by the high-energy shock pressure of the impact. The impact seems to have also affected the most prominent lake of the region, the glacially formed Lake Chiemsee, often called the Bavarian Sea, with a surface area of about $80km^2$ and a depth in parts of more than 70m. Cobbles and sand embedded in peat bogs close to Lake Chiemsee, and flood sediments at several sites near the shore of the lake, point to tsunami waves several metres high, caused by one or several impacts into Lake Chiemsee. Recent sonar soundings in Lake Chiemsee revealed the structure of a double-crater.

From preliminary calculations, we have deduced the meteorite itself to have been a very low-density object ($<1.3g/cm^3$) of a size roughly 1100m across that entered the atmosphere at a velocity of about 12km/s on a low-oblique trajectory. The first fragmentation, which occurred at an altitude of 70km, provides an explanation for the widespread fallout mentioned above. The modelled scenario applies for a meteorite that was intact on entering the denser layers of the atmosphere. These considerations and calculations are preliminary in nature due to the present limited knowledge of the impact field pattern.

Figure 2. The Tüttensee crater and the 8m-high rim wall exhibiting an artificial gap.

Parallels between the myth of Phaethon and impact phenomena

In a previous article, Rappenglück and Rappenglück (2007: 103-4) proposed arguments for interpreting the story of Phaethon as the reflection of an actual natural phenomenon. The authors showed that the descriptions of Phaethon's course along the sky and the details of his fall, as a staggering fall head first, or the combination of Phaethon's reddish-burning hair with his pitch-dark veil, perfectly depict the approach of a celestial object and the phenomena which occur during its passage through the atmosphere. In the more detailed analysis that follows we will compare passages from the myth of Phaethon (italics), with evidence found in the Chiemgau crater field and observations from very recent impact events. For details on the Chiemgau crater field in general see also Ernstson *et al.* (2010) in addition to cited references.

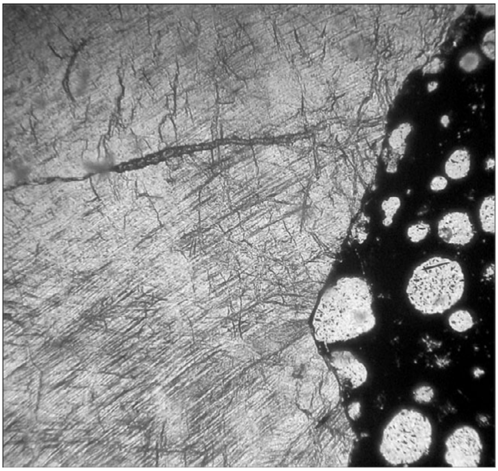

Figure 3. Quartz with planar deformation features (PDFs) and sets of irregular discontinuous subparallel fractures in contact with dark vesicular glass. The slightly bent PDFs reflect a slightly deformed crystal lattice. Photomicrograph, plane parallel light, field width 480μm. Partially melted gneiss from crater #004.

Phaethon starts with the sun chariot in the morning (Ov. *Met.* II.111-160; Nonn. *Dion.* 38.307-9): it seems that Classical authors thus described a celestial object that came from the direction of the rising sun, initially being outshone by it, then growing rapidly bigger and increasing quickly in luminosity. Such an observation has been reported by eyewitnesses of the Tunguska event in 1908 which gave the impression of a *'second sun'* (Gallant 2002: 1), set free by the first true sun. Graeco-Roman writers put this into a metaphor: Phaethon had lost the control of the sun's chariot and fallen out of the vehicle.

Phaethon is struck by the lightning blast of Zeus' thunderbolt (Plat. *Tim.* 22C; Ov. *Met.* II.311-13, II.325; Apoll. Rhod. 4.597-8; Plin. *Nat.* 37.XI.31; Lucr. V.399-401; Nonn. *Dion.* 38.410; and others) and *the sun chariot becomes fragmented* (Manil. 1.746; Val. Fl. V.431; Ov. *Met.* II.316-18). This description reflects very well the explosion and cascading fragmentation of a large meteoroid in the atmosphere. Exactly such an event explains the Chiemgau impact crater-strewn field with its remarkable number of craters and the large ellipse of their distribution.

Other authors (Lucr. V.404; Diod. V.23.3; Nonn. *Dion.* 38.412-15) observed that *the chariot of the Sun continued its course*. This is easy to understand: the explosion and fragmentation of the meteoroid would have happened close to the sun. Hence, the impression would have been that the chariot of the Sun itself had been disrupted. But after

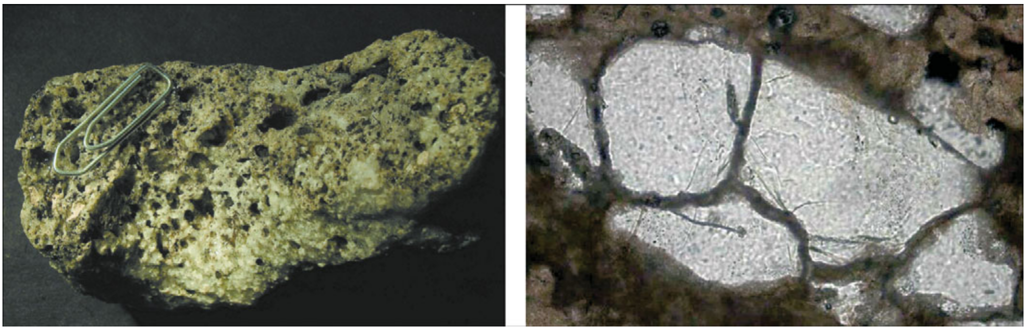

Figure 4. Glass from crater #004: cobble practically completely transformed to a foamy glass (left); glass filling fissures in quartz grain (right). Photomicrograph, crossed polarizers; field width 0.8mm.

the huge airburst dissipated, an airburst accompanied and followed by certain atmospheric phenomena, the sun was seen moving along its usual orbit. Thus the celestial vehicle somehow must have remained intact.

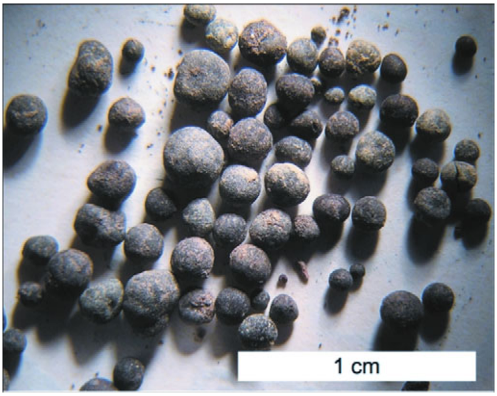

Figure 5. Carbonaceous spherules.

Phaethon is half-burnt (Apoll. Rhod. 4.598; Nonn. *Dion*. 38.93)*; he is a black globe* (Val. Fl. V.431); *he is enwrapped by fiery ash and pitch-black darkness that prevents him from seeing* (Ov. *Met*. II.231-4); *he breathes hot air, as from an oven* (Ov. *Met*. II.229-30); *he smolders* (Ov. *Met*. II.324-6.); *the world is covered by Phaethon's ash* (Ov. *Met*. II.286; Stat. *Theb*. 1.221); *wildfires burn up the country* (Plat. *Tim*. 22C; Diod. V.23.2; Ov. *Met*. II.210-28; Nonn. *Dion*. 38.418-20): on its supersonic passage through the atmosphere, a meteoroid is subjected to a process of ablation that may result in a big dark dust trail (Norton 2002: 35), an impression well documented in P.I. Medvedev's painting of the Sikhote Alin fireball 1947 (Norton 2002: 39). Upon impact, extreme temperatures from shock release must spontaneously have ignited the ground vegetation and resulted in charred forests and ash layers. Hence, both the giant dark dust trail of the object and the spontaneous heating and igniting of the ground would have made their mark on the target, exactly what is observed in the Chiemgau impact area. Carbonaceous material has been found abundantly, in some cases showing peculiar character. The most common occurrence is charcoal more or less regularly intermixed e.g. in the Tüttensee ejecta blanket. For the already mentioned carbonaceous spherules (Figure 5) an impact-related origin has been debated (Yang *et al*. 2008: 943). Both the possibility of their formation in the impact process and their being constituents of the meteorite must be considered. Carbon spherules with similar characteristics have been found also in soils widespread over Europe (Rösler *et al*. 2006: 70; Yang *et al.* 2008: 937), thus pointing to an extended fallout phenomenon.

Moreover, at the Chiemgau impact site a crater was examined in which rocks throughout the whole of the rim wall (11m in diameter) experienced temperatures close to 2000°C (Rösler *et al.* 2006: 68). Chemical analyses of the glass which coats many cobbles serve to establish the presence of considerable enrichment in calcium and potassium, which is practically absent in the original cobbles. Therefore, an intermixing from burned-up or vaporised vegetation must be considered. This is substantiated by the fact that, in the same crater, the transformation from charcoal to glassy carbon can be seen, whereas the charcoal in question still reveals the structure of wood. Hence, extreme temperatures, abundant carbonaceous matter and widespread fallout phenomena are basic elements of the Chiemgau impact, and show that the descriptions of Phaethon's veil of ash, the world being covered by ash, and other heat-, fire- and ash-related phenomena fit with the properties of an impact event.

Figure 6. Deeply corroded clasts from the Chiemgau crater strewn field.

Eclipse-like darkness for one day (Ov. *Met*. II.329-31, 381-5): the aforementioned carbonaceous spherules and other fine particles, which filled the atmosphere after the impact, would have filtered the sunlight for an unknown period of time.

Poisonous vapours exhaling from the lake Phaethon had fallen in affected the health of animals and human beings (Apoll. Rhod. 4.597-600); *birds drop from the sky* (Apoll. Rhod. 4.601-603; Aristot. *Mir*. 81): as mentioned above, cobbles from the Chiemgau impact crater-strewn field show extreme corrosion (Figure 6), which we explain by the action of strong acid dissolution, among other causes. Also, the health consequences on humans affected by 'sulphurous' vapours have been reported from the small meteorite impact near Carancas, Peru, in 2007 (Macedo & Macharé 2007: 2, 4-5). Such phenomena may be reflected in the narrative's reference to poisonous vapours.

The goddess of the earth, Tellus, rose her face . . . and sunk with a big quake, shaking all, and now sat somewhat deeper than before (Ov. *Met*. II.275-8): a gravity survey of the Tüttensee crater and its environs suggests a liquefaction and densification of the highly porous target rocks, which was caused by the high shock pressure of the impact. Soil liquefaction and ground subsidence are well known in the context of strong earthquakes (Seed & Idriss 1982). The description of Tellus sitting down with a big tremor and being seated lower than before seems to provide a perfect description of such a process.

Three times Neptune rose his head and arms from the water, but three times he could not stand the fiery air (Ov. *Met*. II.270-71); *flood just after Phaethon's fall* (Hyginus, *Fabulae* CLII.A2): several locations at the shore of Lake Chiemsee show indications of a tsunami event. Since other natural causes for a big wave (landslide, subaqueous mass movement, volcanic activity etc.) can be excluded, the only plausible conclusion is that it was caused by a meteorite impact into the lake. Sonar measurements of the bottom of Lake Chiemsee have revealed the structure of a double crater, substantiating the evidence. Nearby, at the archaeological excavation site of Chieming-Stöttham, which is situated at the eastern shore of Lake Chiemsee, the impact-related layer exhibits not only impact characteristics but also components pointing to an impact-induced flood wave coming from the lake. Neptune rising from the water and retreating might be a narrative rendition of such a tsunami wave.

Water is extremely hot; it steams and boils (Ov. *Met*. II.242; II.250; II.253): in conjunction with the Tunguska event of 1908, Tunguse people reported the formation of a lake in which the water continued boiling for two days (Kokoulin 1908). In the case of the Carancas impact in 2007, the water in the crater was also described as boiling (Macedo & Macharé 2007: 2).

The mourning sisters of Phaethon, the Heliades, are changed to trees, and their tears become amber (Apoll. Rhod. IV.603-606; Ov. *Met*. II.346-65; Plin. *Nat*. 37.XI.31): in the area of the Chiemgau impact, evidence of different effects of the event on trees can be observed. Besides the already mentioned burning and carbonisation of wood, fragments of trees can be found, e.g. in the ejecta layer of the Tüttensee crater, fragments which have been extremely twisted. In regions where trees survived the impact but were heavily damaged, the wood of the trees would have reacted with an intense production of resin. At Tunguska, not only vast areas were covered by cut trees, but also '[t]*raumatic resin ducts were observed in the transition zone between early- and latewood of the annual ring formed in 1908'* (Yonenobu & Takenaka 1998: 367). An intensely resinating tree may very well be described as 'crying', and its 'tears' may be compared to amber.

Time and place

Such close parallels with phenomena known from impacts in general, and from the Chiemgau impact in particular, renew the question raised by Blomqvist, whether the myth of Phaethon may preserve some memory of an actual meteorite impact, in this case the Chiemgau impact. Does the myth give clues to the place and time of the supposed event, and do they match those of the Chiemgau impact?

Blomqvist (1994: 9) concluded that 2000 BC might provide the *terminus post quem* for the tradition of Phaethon's disastrous ride. His conclusion is based on the date attributed to the tradition of the motive of the sun chariot and from archaeological evidence of light chariots drawn by horses in general. The *terminus ante quem* is given by the *Hippolytos* of Euripides, a drama which was performed in 428 BC and for the first time definitively tells the story of Phaethon performing his disastrous journey in the sun chariot. Very probably the myth is already mentioned in the *Heliades* of Aeschylus, written between 468 and 456 BC. An earlier occurrence, e.g. in the works of Hesiod, is more controversial (see Knaack 1965; Diggle 1970: 4-5, 10-15, 23-4; Blomqvist 1994: 6-7; Csaki 1995: 8-20).

Some indications are provided by Classical authors for the event being situated in Northern or Western Europe (Blomqvist 1994: 9-14) for example, the mention of the river Eridanos and the amber tears of the Heliades. As is well known, geographical descriptions of an oral nature struggle with many problems, including vagueness and misinterpretation. These difficulties are reflected in the uncertainty of ancient authors in situating the Eridanos.

It was generally identified with rivers in Europe: the Po, the Rhone, the Rhine, or with the 'okeanos' at the end of the world. Such speculations range from it being situated in the far north or in the far west of Europe. Even in Hellenistic times, when there was a prevailing agreement that the Eridanos should be identified with the Po, ambiguities were not eliminated (for references to Classical texts see Milchhöfer 1965). Hence the Eridanos gives a clue to a Northern or Western European location but not much more. Finally, two authors (Apoll. Rhod. IV.599; Aristot. *Mir*. 81) state that Phaethon fell into a lake. In view of the Chiemgau impact area and its large Lake Chiemsee this information might be seen from a new perspective.

An important additional clue is given by some writers who explicitly state that the land of the Celts had been the scene of action, and/or that the story of Phaethon was told by the Celts (e.g. Paus. I.4.1). Nonnos stressed that *'. . . Phaethon . . . was swallowed up in the Celtic river ...'* (Nonn. *Dion*. 38.93), and that the story of Phaethon was well known by *'the Celts of the west'* (Nonn. *Dion*. 38.97-102). Ioannis Malalae on his part reported (*Chronographia*, Logos protos 3 in FHG [Fragmenta Historicum Graecorum]; Joannis Antiocheni, *Istoria cronike*, 2.9-10) that God sent a fireball down from heaven on the Gigants living in the Celtic country which burnt them and the country. The ball got stuck in the river Eridanos/Iordanos and was extinguished. According to Ioannis Malalae the Greeks reflected this event in the myth of Phaethon, but he considers Plutarch's report of a fiery sphere that had hit the Celtic country more credible.

In summary, the myth provides us with a number of clues that allow us to conclude that the fall of Phaethon, i.e. the meteorite impact that appears to be reflected in this myth, took place in Northern or Western Europe at some time between *c*. 2000 and 428 BC, while the detailed description (see above) suggests that this spectacular event was kept well in mind, possibly over many centuries up to the creation of the first written versions of the myth.

Radiometric and archaeological methods were applied to date the Chiemgau impact, whence earlier estimations of its dating (Rappenglück & Rappenglück 2007; Rappenglück *et al.* 2009; Ernstson *et al.* 2010) had to be modified slightly. OSL dating of the layers at the Chieming-Stöttham excavation site verified that there was a complete luminescence bleaching, leaving no residuals. It is anticipated that sunlight erases luminescence, zeroing electron traps of quartz minerals within a few minutes at most, an effect which could occur during tsunami ejecta. The filling of traps with electrons produced from environmental radiation is proportional to the age of sediment deposition which, in turn, determines the date of the event of last exposure to light. So far, ages around 2000 BC have been obtained (Zacharias *et al.* 2009).

Another approach to dating the Chiemgau impact was provided by archaeological assemblages. The excavator of the Chieming-Stöttham site (Möslein 2009) suggested, on the basis of archaeological finds, an age for the impact-related layer somewhere between the Early Neolithic and the Urnfield culture, i.e. *c*. 4400-800 BC. The discovery of a Hallstatt potsherd and an iron lump in this layer may be accidental. Potsherds found in the ejecta layer of the Tüttensee crater limit the *terminus post quem* to 2200 BC (the beginning of the Bronze Age), if not to 1300 BC (the beginning of the Late Bronze Age). On the basis of these different dating methods the *terminus ante quem* of the Chiemgau impact probably should be adjusted to 800 BC, while the *terminus post quem* is narrowed to 2200, if not 1300 BC.

Both the time and location deduced for the mythic 'Fall of Phaethon' coincide fairly well with the time and location of the Chiemgau impact event. We have a location in Western Europe. There is mention of a big river – the Danube River is very close to the affected region. There is reference to a lake – Lake Chiemsee was directly affected. There is also the indication linking the myth with 'Celtic' lands. According to ancient Greek convention, the term 'Celtic' was used to refer generally to peoples living in the west of Europe, as perceived from the perspective of an inhabitant of Greece (Dobesch 1995: 29, 32). In this respect it is noteworthy, that the region of the Chiemgau impact is situated in the core region of the former Celtic culture.

In addition, using data related to the myth of Phaethon, we deduced that the hypothesised impact should have happened between *c*. 2000 and 428 BC. Within this time frame, only two meteorite impacts are known from Europe: the already mentioned Kaalijärv event (if it did not happen earlier) of relatively small size, and the much bigger Chiemgau impact with a number of well-matching details, dated between *c*. 2200-800 BC. It is thus possible that the myth of Phaethon preserves some memory of this last impact event.

Transmission of information and reasons to create a myth

The details encoded in the myth require the presence of eyewitnesses close to the area of the impact. From the Tunguska event a number of detailed reports exist, provided by persons concerned, who experienced the event at a distance of 10-60km from the epicentre. The topography of the Chiemgau area with its hilly landscape and numerous lakes and rivers may have contributed to the localisation of the effects of the impact and could have provided insular shelter, e.g. in the lee of a hill. The near peaks of the Alps, rising up to 1500-1700m and about 10km away from the biggest crater, provided a perfect vantage point enabling any observer who managed to find shelter to have observed the scene in detail.

But what might have prompted Mediterranean people to construct the Phaethon myth, based upon an event that took place in a remote area? Formerly, people worldwide, among them the ancient Greeks, reacted intensely to the very appearance of a comet, and also to the fall of comparably small meteorites, events that might result in cultic memory for many centuries (Rappenglück 2005: 324-5). Logically we might assume that a meteorite impact of the size of that of Chiemgau would at least have left traces in the memory of populations nearby. But it is important to realise the large dimensions of the Chiemgau impact event. The reconstructed trajectory must have made people of at least all northern Eurasia eye-witnesses of the fiery entrance of the celestial object. The explosion of the body in the atmosphere, supposed to have taken place at an altitude of *c*. 70km, could have been visible within a circumference of at least a 500-600km radius. From comparisons with the audible effects of the Tunguska event it can be estimated that the sound of the explosions could have been heard from a distance of 1000km or more. The extension and intensity of earthquakes caused by the impact and of the shock waves are hard to estimate. Again the Tunguska event, during which the shock waves circled the Earth twice and the ground shook several hundred kilometres away, gives an idea of the extension and intensity of such an event.

Fragments of the exploding body may have caused the phenomenon of 'stone rain' even in parts of Southern Europe while the fallout of carbon micro-spherules would have affected vast areas of Europe. Within the Mediterranean world, different phenomena must have been noticeable in Northern Italy and some of the effects evident probably even in more distant parts of Southern Europe. In addition, news of this apocalyptic event would have spread rapidly and reached the Mediterranean world by established trade routes and other contacts (Schnekenburger 2002). The retelling of these experiences and associated information must have called for an explanation: it was an event that was clearly in sharp contrast to the regular order of the cosmos. The invention of the myth of Phaethon would have provided an appropriate answer, a narration that ended up describing the anomalous event, not as a physical reality, but rather as a mythical rendition of what was a shocking experience in the context of the traditional view of the cosmos. When later on the transmitted information had lost its actual relevance, the dramatic details still afforded a wonderful source for either moral instruction or pure entertainment, and in few instances the narrative details still associated with the myth allow traces of its former grounding in a physical event to come into view.

Conclusions

The myth of Phaethon's fall and the Chiemgau impact are not only similar in terms of place and time, they also share other structural elements. In short, the details provided by the geological evidence correspond very closely with those found in the mythical descriptions. Hence, it can be suggested with good probability that the myth of Phaethon is a geomyth and instantiates some cultural memory of a specific natural catastrophe, namely a meteoritic impact in the Chiemgau region.

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