MISSING IN ACTION? EVALUATING THE PUTATIVE ABSENCE OF IMPACTS BY LARGE ASTEROIDS AND COMETS DURING THE QUATERNARY PERIOD

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ABSTRACT

The Quaternary period represents the interval of oscillating climatic extremes (glacial and interglacial periods) beginning about 2.6 million years ago to the present. Based on modeling by the Near Earth Object (NEO) community of planetary scientists, the known and validated record of Quaternary impact on Earth by comets and asteroids is seemingly depauperate in terms of larger impactors >10,000 Mt (roughly equal to or larger than about 500 m in diameter). Modeling suggests that an average of between 2-3 and perhaps as many as 5 globally catastrophic (ca. ≥1,000,000 Mt) impacts by asteroids and comets could have occurred on Earth during this period of time, each having catastrophic regional environmental effects and moderate to severe continental and global effects. A slightly larger number of substantive but somewhat less than globally catastrophic impacts in the 10,000-100,000 Mt range would also be predicted to have occurred during the Quaternary. However, databases of validated impact structures on Earth, contain only two examples of Quaternary period impacts in the 10,000-100,000 Mt range (Zhamanshin, Bosumtwi), dating to around a million years ago, while no examples of Quaternary period globally catastrophic impact structures have been yet identified. In addition, all of the 27 validated Quaternary period impact structures are terrestrial—no Quaternary period oceanic impacts have been yet validated. Two likely globally catastrophic probable oceanic impacts events, Eltanin (ca. 1,000,000 Mt at around 2.6 mya), and that associated with the Australasian tektite strewn field (> 1,000,000 Mt at around 0.78 mya), are known due to their debris fields for which craters have not yet been identified and validated. These and the 8-km diameter Bolivian Iturralde candidate impact structure (ca. 10,000 Mt at around 20 kya) round out our list of likely large Quaternary impact structures. This suggests that one or more Quaternary period globally catastrophic impacts and several events in the 10,000-100,000 Mt range occurred in oceanic settings and have not yet been identified. At issue here is the default position of the NEO community that no large impacts have occurred during the past 15,000 years and that there is little evidence for human death by impacts during the past 5000 years of recorded history. This bias, deriving largely from reliance on stochastic models and by selectively ignoring physical, anthropological, and archaeological evidence in support of such impacts, is apparent in the messages being given to the media and general public, and in the general lack of grant support and other assistance to scientists and scholars wishing to conduct fieldwork on impacts that may date to the past 15,000 years. Such a position has a chilling effect on what should otherwise be an important arena of inquiry into the risks and effects of cosmic impact on human society. It potentially limits advancement in our understanding of the recent record and flux of cosmic impact, and diverts attention away from significant research questions such as the possible role of impact in Quaternary period climate change and biological and cultural evolution and process.

1. THE IMPACT RECORD *"KAONA"*

We focus on the Quaternary period (the past 2.6 million years) record of cosmic impact upon the Earth in the attempt to elicit meaning from its apparent patterns. Astrophysical modeling suggests that globally catastrophic (≥ ca. 10^6 MT) impacts by asteroids and comets should occur on Earth on average once every million years [1]. The message by the Near-Earth Object (NEO) planetary science community is that while catastrophic impact can happen at any time, there is no record of major regional (ca. 10^4-10^6 MT) or globally catastrophic impact during the past several tens of thousands of years, and that there is no record of humans having been killed by an impact. Table 1,

Table 1. Validated Earth impacts during past 35 million years. Orange/red colors are regional/globally catastrophic impacts, respectively.

IMPACT STRUCTURE NAME	LOCATION OF IMPACT STRUCTURE (Terrestrial = T Oceanic = O)	DIAMETER IN KM OF LARGEST CRATER (and Number of Known Associated Craters)	ESTIMATED DATE OF IMPACT Years Before Present (AD 2007)
SIKHOTE ALIN	RUSSIA (T)	0.027 (122)	60
WABAR	SAUDI ARABIA (T)	0.116 (3)	303
SOBOLEV	RUSSIA (T)	0.053 (1)	<1000
HAVILAND	UNITED STATES (T)	0.015 (1)	<1000
KAALIJÄRV	ESTONIA (T)	0.110 (9)	2400 to 2800?
CAMPO DEL CIELO	ARGENTINA (T)	0.050 (20)	4200 to 4700
HENBURY	AUSTRALIA (T)	0.157 (11)	<4700
MACHA	RUSSIA (T)	0.300 (1)	<7000
ILUMETSA	ESTONIA (T)	0.080 (3)	7400 to 7700
TENOUMER	MAURITANIA (T)	1.900 (1)	21,400
BARRINGER	UNITED STATES (T)	1.186 (1)	49,000
ODESSA	UNITED STATES (T)	0.168 (7)	<50,000
LONAR	INDIA (T)	1.830 (1)	52,000
RIO CUARTO	ARGENTINA (T)	*not craters?	<100,000
MORASKO	POLAND (T)	0.100 (8)	<100,000
AMGUID	ALGERIA (T)	0.450 (1)	100,000
TSWAING	SOUTH AFRICA (T)	1.130 (1)	220,000
DALGARANGA	AUSTRALIA (T)	0.024 (1)	270,000
WOLFE CREEK	AUSTRALIA (T)	0.080 (1)	<300,000
BOXHOLE	AUSTRALIA (T)	0.170 (1)	540,000
ZHAMANSHIN	KAZAKHSTAN (T)	14.000 (1)	900,000
VEEVERS	AUSTRALIA (T)	0.080 (1)	<1,000,000
MONTURAQUI	CHILE (T)	0.460 (1)	<1,000,000
BOSUMTWI	GHANA (T)	10.500 (1)	1,070,000
NEW QUEBEC	CANADA (T)	3.440 (1)	1,400,000
KALKKOP	SOUTH AFRICA (T)	0.640 (1)	<1,800,000
AOUELLOUL	MAURITANIA (T)	0.390 (1)	<3,000,000
TELEMZANE	ALGERIA (T)	1.750 (1)	<3,000,000
EL'GYGYTGYN	RUSSIA (T)	18.000 (1)	3,500.000
ROTER KAMM	NAMIBIA (T)	2.500 (1)	3,700,000
BIGACH	KAZACHSTAN (T)	8.000 (1)	3-7,000,000
KARLA	RUSSIA (T)	10.000 (1)	4-6,000,000
KARA-KUL	TAJIKISTAN (T)	52.000 (1)	<5,000,000
STEINHEIM	GERMANY (T)	3.800 (1)	14-16,000,000
RIES	GERMANY (T)	24.000 (1)	15,100,000
CHESAPEAKE BAY	UNITED STATES (T)	90.000 (1)	35,100,000

adapted from the Earth Impact Database maintained at the Planetary and Space Science Center at the University of New Brunswick, reveals a number of patterns for currently validated impact structures during the past 35,000,000 years. For example, due to the presumed stochastic nature of impacts and the fact that impactors are subject to the constraints of a power law distribution, coupled with the active nature of the Earth's lithosphere, smaller diameter terrestrial craters tend to be obscured or lost in the geological record [2].

However, we are equally interested in the data that for various reasons are currently missing from this table. Borrowing from Hawaiian linguistic tradition, these missing data can be considered intimately linked to the *kaona* or "hidden meaning" within the record of validated impact structures.

The first consideration is that virtually all of the validated craters for the past 35 million years were formed on land. Since water covers more than 70% of the surface of Earth, more than two-thirds of all impact structures are in oceans, seas, and lakes.

Second, there are several instances of major gaps in dating between identified impact structures that cannot be due solely to the stochastic nature and flux of impacts. In addition to the difficulty of identifying sea floor craters, other obscuring mechanisms include glacial scouring and placement under thick forests, alluvial soils and desert sands.

Third, the impact record of the past 35 million years is missing far more than 70% of both the globally catastrophic impacts as well as the regionally catastrophic impacts. This suggests that we find it difficult to recognize some characteristics and byproducts of large scale impact, including those of most airbursts and oceanic impacts. Our understanding of the recent impact record may be inhibited by the necessarily conservative practice of not validating an impact structure unless it exhibits a full suite of impact hallmarks such as uplifted concentric rings, shocked breccias and quartz, and glass and other impact melts.

2. SATELLITE ALTIMETRY AND OCEANIC IMPACT SIMULATIONS

The search for sea floor impact structures has proven extraordinarily difficult. Techniques such as sea surface satellite radar altimetry (Fig. 1)—the creation of sea floor topographic maps through precise measurement of bulges and depressions on the surface of the sea—has been a boon for understanding dynamic aspects of sea floor spreading and other Earth crust processes. Unfortunately, this technique has limited resolution for our purposes, and

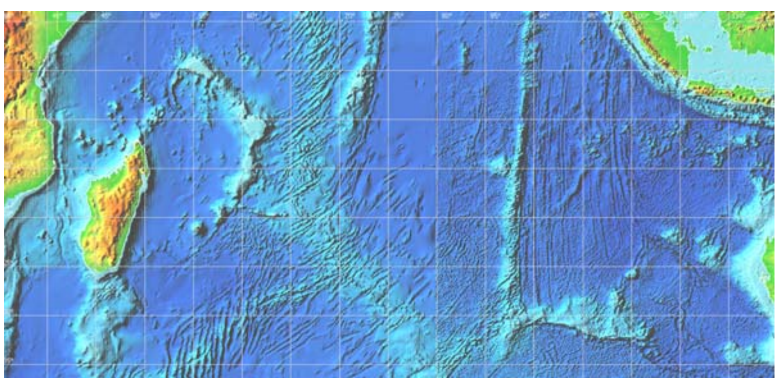

Figure 1. Map of a portion of the Indian Ocean sea floor from on satellite altimetry and transects by oceanic exploration vessels. Longitude 80° east represents the dividing line between higher (east) and lower (west) resolution altimetry [3].

seemingly does poorly with even the larger impact structures. This situation likely reflects the very nature of oceanic impact itself. As illustrated in Fig. 2, oceanic impact results in the creation and collapse of a large water cavity. The subsequent infilling of the cavity actually tends to destroy or reshape aspects of the crater rim and surrounding ejecta sediment blanket due to the surging water column. Two- and dynamic three-dimensional modeling has greatly increased our understanding of the formation and propogation of impact tsunami waves [4], and the potentially massively destructive properties of cosmogenic tsunami are now apparent [5]. However, we still understand relatively little about impact sediment transport [6], and what happens to the sediments and wave forms once they reach the shore. These remain important topics for study by our team.

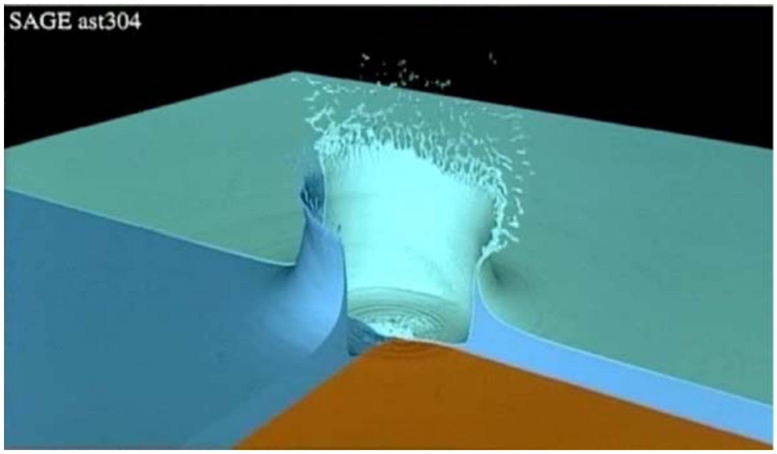

Fig. 2. Three-dimensional model simulation of the splash ring crown of a 1-km diameter oceanic asteroid impact, just prior to the formation of multiple tsunami waves [4].

3. THE SEARCH FOR QUATERNARY AND HOLOCENE PERIOD IMPACTS

We are part of a collaboration of more than 20 scientists worldwide investigating the possibility that the past 15,000 years—encompassing the end of the Quaternary period and the 11,500 years of our present Holocene period—have been subject to large impacts and the related deaths of many people. Our team's search for recent Earth impact events involves different tools depending on the likely target area (oceanic versus terrestrial), relative size of the impactor, estimated age of the event (Holocene vs. Quaternary period), and whether the impactor is an asteroid or comet. For oceanic impacts we use satellite altimetry along with the search for coastal tsunami sedimentary signatures (Section 4, below) and the presence of impact indicators in deep sea and coastal sediment cores, such as ejecta and layers of high magnetic susceptibility (Section 5, below). For Holocene impacts, we have discovered a treasure trove of information on impactor nature and dating in mythologies and oral traditions (Section 6, below). And recently, we have begun to realize that larger impacts may be signaled by substantive changes in paleoclimate.

The Tsunami Laboratory in Novosibirsk, Russia, has begun to put together an Expert Database on Earth Impact Structures (EDEIS), which is somewhat more liberal than that depicted in Table 1. In addition to including the locations of probable airbursts, it uses a validity index based on numeric values between 1 (the presence of a suspected crater) to 4 (four different confirmed impact criteria). Using this index, we have identified 80 Quaternary structures (V4=40, V3=22, V2=16, V1=2) and 39 Holocene structures (V4=19, V3=10, V2=8, V1=2). Not all, including the V4/3 categories, will eventually be validated, however, this list can help us to begin addressing some of the significant information hidden or missing from Table 1. These include hypothesized impact events likely profoundly affecting human populations, some of which may also have been a trigger for climate change (Figure 3).

Some hypothesized impacts are previously known and have been the subject of much study, such as the large Australasian strewn tektite field event (ca. 780,000 years bp) and Eltanin (ca. 2.615 million years bp), for which craters have not yet been identified [2]. Others, more controversial, include Burckle crater and the presumably associated "Flood Comet" event [2,7] which may represent the "Great Flood" of Biblical and other cultural traditions, and the boundary change from middle to late Holocene around 4800 years bp; the Tabban and Kanmare structures, which may be associated with the AD 535-545 "years without a summer" climatic event [8]; the Rio Cuarto and Campo del Cielo airbursts in Argentina, which may be associated with human population replacement around 4-6,000 years bp [9,10]; the Chiemgau crater field in southern Germany, which may relate to cultural changes in the 1st millennium BC [2]; Mahuika crater just south of New Zealand, which may be related to the beginning of the Little Ice Age at around AD 1450 [11]; and faunal extinctions and major climatic changes during the the Younger Dryas stadial event, which may have been caused by an impact/airburst over the Laurentide ice sheet at around 12,900 years bp [12,13]. The fact that Burckle, Chiemgau, Mahuika, Tabban and Kanmare, and the Younger Dryas Event are all suggested as comet impacts is extremely interesting—and particularly controversial given that comets are thought to make up only 4% of the overall impact risk [1].

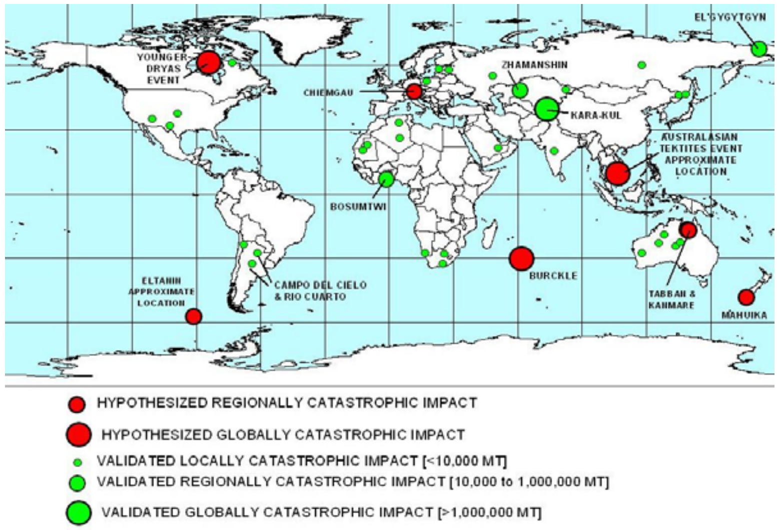

Fig. 3. Validated and selected hypothesized impacts by asteroids and comets during the past five million years.

4. MEGATSUNAMI CHEVRON DEPOSITS

Many coastlines of the world (Fig. 4) exhibit sets of large chevron dunes [14, 15]. These have similar lancet-like forms, showing strong parallelism, often at different angles to the shoreline. Only wind or waves can produce such chevrons. However, many are clearly not wind-blown or storm-wave deposits because they contain fist-sized mud clasts and cobbles [16], extend over 100 m above sea-level on stable coastlines, or are not aligned to the dominant wind direction. Instead, they are the product of megatsunami events. The chevron shape is unlike historic seismic-generated tsunami deposits, and are most likely the product of submarine landslides and oceanic cosmic impact.

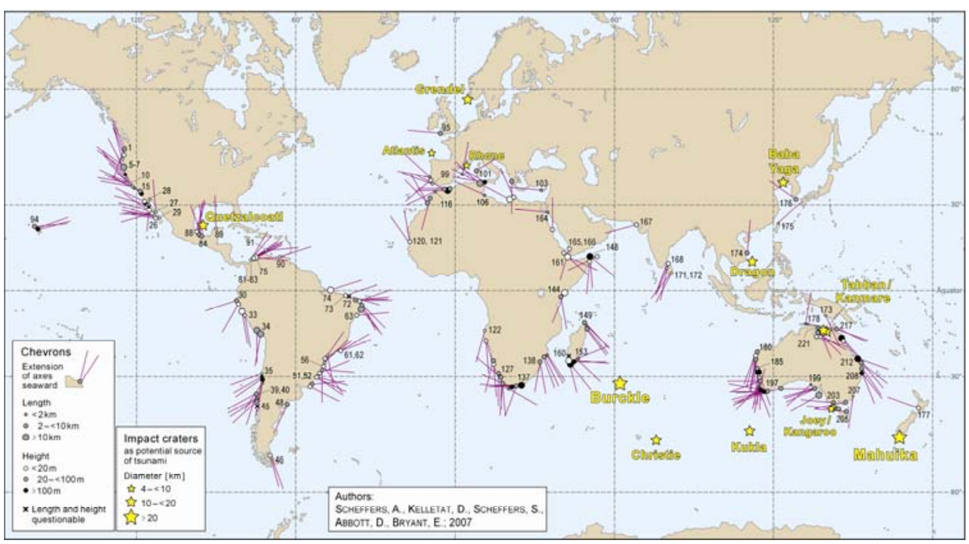

Fig. 4. World map of chevron distribution [15]. The points along the shorelines give only an approximate position due to the scale of the map, and in many cases represent multiple chevrons. The main chevron axes point to possible source areas of tsunami. Hypothesized oceanic craters are depicted by stars (see also Fig. 3). Figure courtesy of Anja Scheffers.

The Ampalaza chevron (Fig. 5) is 30 km in length, 6 km wide, and reaches an elevation of 70 meters above mean sea level (msl). The Fenambosy chevron (Fig. 6) is 45 km long and is more than 200 meters above msl, having overtopped a 150-meter high plateau escarpment. The Groote Eylandt chevrons (Fig. 7) in the Gulf of Carpentaria, are 24 meters above msl, and show the parallel structure typical of chevrons. The Madgascar chevrons contain abundant cosmic impact debris, as do the uppermost sediments of the shallow Gulf of Carpentaria.

Fig. 5. Ampalaza chevron, Madagascar.

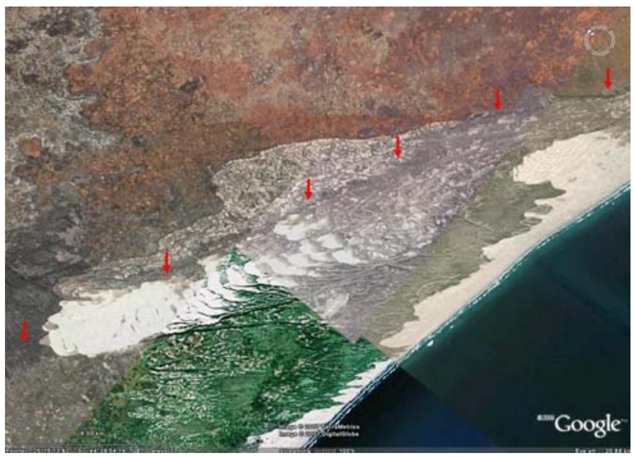

Fig. 6. Fenambosy chevron, Madagascar. Red arrows depict the front edge of the 150-meter high plateau escarpment that was overtopped by the megatsunami wave.

Fig. 7. Grooyte Eylandt chevrons.

5. EJECTA IN CHEVRON DEPOSITS AND SEDIMENT CORES

Sea floor sediment cores around hypothesized recent impact structures—Burckle, Tabban, and Kanmare—contain layers of high magnetic susceptibility at the tops of the column, and also contain frequent impact related materials detectable by scanning electron microscopy (SEM). These include impact spherules near Burckle (Fig. 8).

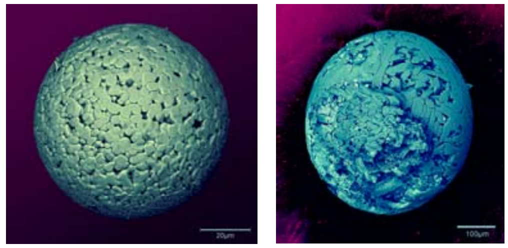

Fig. 8. Impact spherules from upper levels of deep sea cores near Burkle candidate impact structure.

Of particular interest is that the Madagascar chevrons contain abundant ejecta. This includes glasses, to which were adhered occasional particles of iron, chromium, and nickel (Fe-Cr-Ni) splash (Fig. 9).

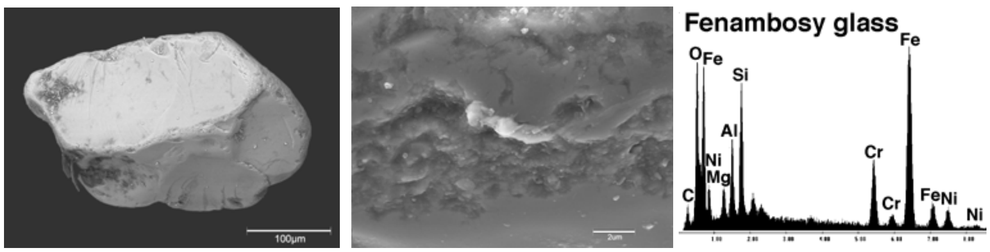

Fig. 9. Fenambosy glass sample (left) with Fe-Cr-Ni splash (middle), and associated spectrum analysis (right).

Although the Gulf of Carpentaria chevrons have not yet been field sampled, the uppermost layers of sediment cores near Tabban and Kanmare candidate impact structures contain melted carbonaceous microfossils and whitlockite, magnetite spherules (Fig. 10) and translucent graphite (Fig. 11).

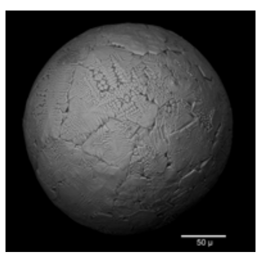

Fig. 10. Magnetite spherule.

Fig. 11. Translucent graphite.

Virtually all of the sediment cores also contained frequent micro-grains of shocked quartz (Fig. 12) with multiple planar deformation features (PDFs), as can be seen in the Fig. 12 SEM photograph of one of the grains.

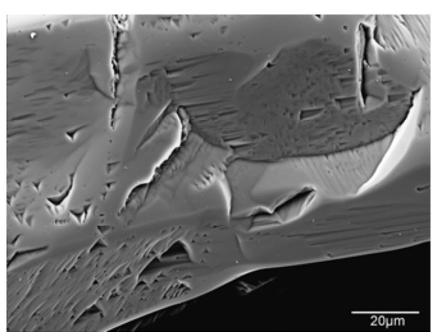

Fig. 12. Micro-grain of shocked quartz exhibiting multiple PDFs.

At all sample locations are numerous melted and unmelted benthonic forams, some with manganese oxide micro-nodules (Fig. 13) or metal splash (Fig. 14).

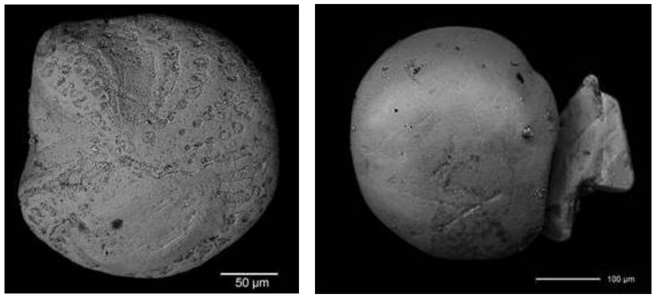

Fig. 13. Melted benthonic foraminifera containing manganese oxide micro-nodules.

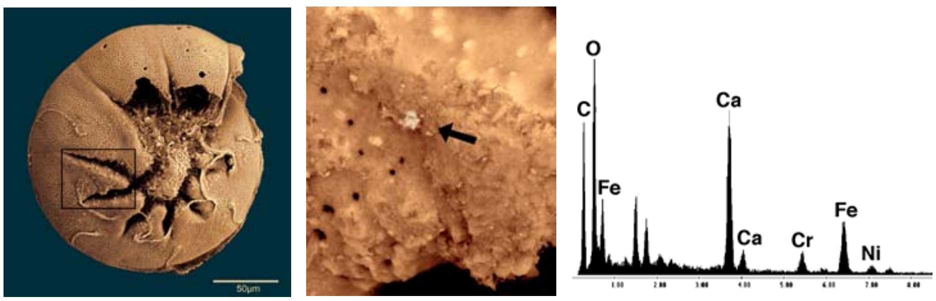

Fig. 14. Unmelted benthonic foram (left) with Fe-Cr-Ni splash (middle), and associated spectrum analysis (right).

A cross-section through individual melted forams (Fig. 15) reveal calcite constituents similar in nature to those present at validated impact stuctures situated in carbonaceous bedrock, such as at Haughton crater in Canada.

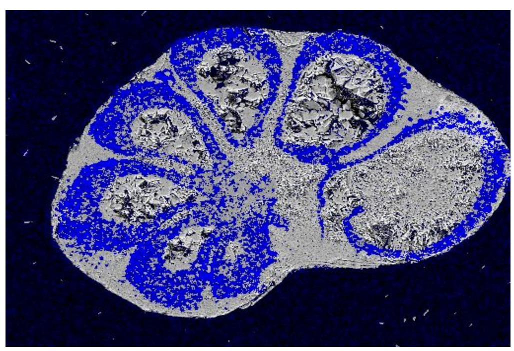

Fig.15. Section of melted foram with calcite-filled chambers.

6. MYTH, ORAL TRADITION AND IMPACTS

Science views mythology and oral history with suspicion and contempt. This was fueled by the mid-20th century polemics of Immanuel Velikovsky and others who unsystematically used myths torn from their historical contexts in order to “prove” specious theories regarding social and natural history and the laws of physics. Fortunately, the nascent disciplines of geomythology [17, 18] and traditional astronomy [19, 20] have begun to provide a different and more scientific perspective on mythology and oral history. For example, it can be demonstrated that ancient Hawaiians were skilled observers and recorders of transient celestial phenomena including comets, supernovae, variable stars, meteor storms, eclipses, and even auroral substorms [19, 20]. Due to the need to perpetuate the lineage, power, and sanctity of royal chiefs and priests, these celestial observations were woven into the supernatural details of myths associated with chronologically-ordered Hawaiian chiefly genealogies. The end result is that we can demonstrate the accuracy of these observational records through more than 1500 years of oral history by matching the myth storylines with the records of transient celestial events historically recorded in Asia, the Middle East, and Europe, as well as with reconstructible classes of events such as eclipses and planetary conjunctions. Equally remarkable is traditional iconography. In the early 1820s the Hawaiian war god, Ku, was described to the first missionaries as having the appearance of a tailed comet. The few surviving images of Ku (Fig. 16) closely resemble the nucleus of a near-Earth comet, such as the hand-drawn telescopic image of Comet Donati 1861 (Fig. 17).

Fig. 16. Hawaiian war god Ku

Fig. 17. Nucleus of Comet Donati 1861

Even more intriguing is the fact the two hair/headdress styles of the 100 or so surviving Ku images (Fig. 18, 19) likely reflect the Hawaiian observation of pre- and post-perihelion comet tails (Fig. 20).

Fig. 18. Ku hairstyle 1 (pre-perihelion).

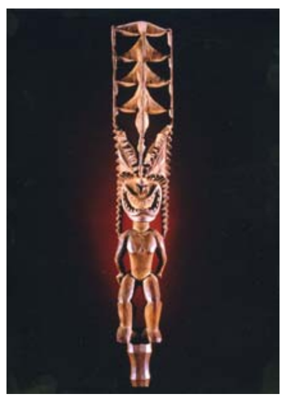

Fig. 19. Ku hairstyle 2 (post-perihelion).

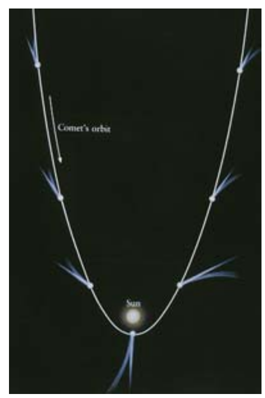

Fig. 20. Orientation of pre- and post-perihelion comet tails.

It turns out that the rest of the world likewise has a rich mythology, and that cosmic impacts are among the natural phenomena encoded in myth [2, 8, 9, 11]. However, it is important to emphasize that while myth is useful for model building and providing details not captured in historic records, it cannot itself take the place of hard physical data.

7. CONCLUSIONS: IMPACTS, CLIMATE CHANGE AND EVOLUTION

Our research suggests that impacts on the Earth by large comets and asteroids have taken place more recently and with greater frequency than presently argued by most NEO planetary scientists. This does not mean that current models of impact rates and risks are necessarily wrong. For example, the late Quaternary and Holocene record of impact may have been unduly influenced by the sequential fragmenting of one or more giant comets over the course of tens of thousands of years as has been described by the proponents of so-called coherent catastrophism [21].

As noted in Section 3, a most intriguing correlation emerging from our work is the possibility that several of the hypothesized larger oceanic impact events may be correlated with periods of rapid climate change. Because of the recent nature of these events, if validated, they may provide the exquisite opportunity to better understand the mechanisms of ocean-atmospheric climate coupling. They should also provide an important window into the role that impacts may have in biological and cultural evolution. And they should help to refine current models of cosmic impact risks and effects, including the potential threat from megatsunami events.

8. ACKNOWLEDGEMENTS

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