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Notes

On the discovery of the ice age: science and myth

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Abstract: The discovery of the ice ages began with the invention of the Great Ice Age by Louis Agassiz, in the first half of the nineteenth century. His ideas were shaped by the interpretation of skeletons and frozen remains of large mammals found in Siberia, at the beginning of the nineteenth century. The concept of the Great Ice Age stands in contrast to earlier notions emphasizing widespread flooding, notions that owed much to the Great Flood described in the Bible, and which gave rise to geological terms such as 'diluvial deposits' and 'glacial drift'. Nordic myth as recorded in Iceland during the Middle Ages likewise contains observations and interpretations concerning the remains of giant animals emerging from frozen ground and makes reference to large-scale flooding. The ancient cosmogony related by Icelandic poets postulates the former existence of a kingdom of ice, represented by a primeval Ice Giant, whose rule is ended by the newly emerged gods. According to the myth, the melting of ice (the blood of the dying Giant) caused widespread flooding that killed the large creatures abundant during ice time.

There was a time, not so long ago (in the 19th century), when the geologically young deposits left behind by vast ice sheets originating in Scandinavia were ascribed to the Great Flood described in the Bible and earlier in the Gilgamesh Epic. These sediments, once labelled 'diluvial' have since been recognized as of glacial origin. The Great Flood, on the other hand, remains an enigmatic phenomenon. Recent explanations range from invoking a regional inundation to calling on cosmic impact. The regional scenario focuses on the drowning of settled lands on the shelf of the Black Sea as a result of the sea-level rise at the end of the last ice age (Ryan & Pitman 1998). The global scenario, put forward a decade ago, envisages worldwide flooding events resulting from huge waves generated by a series of celestial objects hitting the ocean in various places (Tollmann & Tollmann 1995). The Tollmann impact scenario may seem outlandish and entirely beyond belief. However, an analogous celestial bombing run was observed in July 1994, when the numerous fragments of a comet, on colliding with Jupiter, produced a neat row of powerful explosions within that planet's atmosphere (Burnham 1994).

The somewhat trivial lesson from the preoccupation of geologists with the Great Flood for more than two centuries is that we tend to assign meanings to ancient legends and traditions in terms of actual events. If a tradition reports that something bright fell from the sky and caused great damage (including, for example, the killing of whales), we might rightfully suspect that a comet or asteroid hit the ocean (Sagan & Drury 1985; Baillie 1999). Similarly, if a myth reports on rivers marked by unusual stench (as does the cosmogony of the Edda), we ought to give thought to what

that might mean and where we might find such rivers. This open-minded attitude allows us to take on the role of the audience at the fireplace where stories are being told by the bard. The reason why geologists are privileged, among scientists, to slip into such naivety has to do with their training as creators of stories based on rather slim evidence (a fact remarked on by Mark Twain). For example, we can look at some piece of rock in Kansas or northern Germany, and tell a wonderful story about enormous glaciers carrying that rock over hundreds of miles, thousands of years ago.

My point is that those who reconstruct geological history are engaged in a type of myth making, an activity carrying the risk of being assigned to the lunatic fringe by the less adventurous, and yet an activity that is potentially fruitful. In recent times, the most striking example of the process whereby strange and wonderful stories about the past become textbook science is the discovery of impact as the cause of dinosaur extinction (Raup 1986; Alvarez 1997). I hasten to add that geologists are not the only scientists engaged in the sport of creating amazing stories; astrophysicists and climate historians, are also prone to contribute fantastic tales to modern scientific discussion, sometimes enthusiastically (Gribbin & Plagemann 1976; Hoyle & Wickramasinghe 1979; Baillie 1999). Such narratives illustrate how, in our own time, scientifically trained minds attempt to make sense of complex and surprising phenomena, dimly perceived and poorly understood. One striking example of a poorly understood natural phenomenon is the disappearance of large mammals from Eurasia and North America, after the last ice age. On this issue, Darwin in his book

Voyage of HMS Beagle remarked. 'It is impossible to reflect on the state of the American continent without astonishment. Formerly it must have swarmed with great monsters; now we find mere pigmies compared with the antecedent allied races'. (Darwin 1836, p. 170.) The former presence and subsequent disappearance of 'great monsters' has exercised storytellers for uncounted millennia well before scientists started to examine the issue.

Thus, myths of ancient giants who once roamed the earth and have long since disappeared have an element of geological truth. A search of the truth content of myths is not necessarily crowned with success. In fact, failure can be spectacular and obvious. Illustrations are not difficult to find in connection with Plato's Atlantic legend. For example, one Atlantis enthusiast took the discovery of freshwater diatoms in the tropical Atlantic off Africa (Kolbe 1955) as evidence that portions of the sea floor were once above sea level in the region. The truth is that the diatoms lived in lakes of the Sahara and were blown to sea after the lakes dried (along with silicified cells of Cyperaceae and Gramineae; Kolbe p. 160). The appearance and disappearance of lakes in the desert, of course, is a story tied to long-term climate fluctuations related to ice age dynamics. The evidence for long-term wet-dry cycles includes lake deposits, as well as pictures on rock walls of wild cattle and other animals hunted in regions now too dry to support such life (Strieder 1984).

There is no doubt that communications of our distant forebears, through myths and pictures, are more than faint echoes of archaic superstitions (Barber & Barber 2004). This is readily appreciated, for example, when contemplating the cave drawings of Altamira and Lascaux, images that show animals no longer extant. They tell us things that we cannot possibly know except from the interpretation of fossil bones. These drawings demonstrate great talent for communicating observations in a setting presumably dedicated to shamanist activities (that is, hunting magic; Kühn 1956, 1971). Beliefs about beings and events in an imaginary world, however abstruse, do not diminish the fact that the mammoths and rhinoceroses sketched on the cave walls represent animals that did once roam the region, before they became extinct (Fig. 1).

We must assume that ancient humans were keen observers of their environment, and gave meaning to their observations by linking them to their needs within the framework of their culture and traditions. How could deep insights into the workings of the world be communicated to following generations? By both creating myths and elaborating on existing myths, re-shaping them to carry the new information gleaned by the most brilliant among

the storytellers. We cannot readily re-trace the emergence of myths generated in ancient cultures long extinct. But we can observe similar processes at work when Charles Lyell (1797–1875), founder of classical geology, called on ice-rafting to bring Scandinavian debris to flooded regions in northern continents, thus giving rise to the notion of 'glacial drift'. In this particular case, the story is fundamentally flawed: the sea level is low during ice ages, because some of the ocean's water is tied up in ice sheets; thus, ice-rafting and flooding of shelves are unlikely companions except during the very time of glacier decay. However, Lyell's basic premise is correct: the material was indeed transported over long distances. A subtle tie-in to the tradition of the Great Flood, modified to carry the new insight, provides the background to Lyell's interpretation (judged 'excellent' by Darwin).

Discovery of the Great Ice Age

The person commonly credited with discovering the ice age is the Swiss naturalist Louis Agassiz (1807–1873), well known as the founder of the Museum of Comparative Zoology at Harvard University (where he resided from 1848). Agassiz envisaged enormous ice sheets expanding from arctic regions deep into Europe and North America. The record of their former presence is seen in the polished rocks of deeply eroded landscapes and in the moraines rimming the formerly glaciated regions. Significantly, many of the large rocks associated with such moraines carry grooves from where they were dragged by the ice across hard ground. The rocks, which are common in northern Germany and Denmark, have long been labelled 'erratic', as they have no obvious source in the vicinity where they occur. They were used in building giant grave structures, between five thousand and four thousand years ago, and as building material all through the last millennium. Ancient legend has it that they were the playthings of giants, a notion that is reflected in common language to the present day. (In southern Sweden, the erratic rocks are 'things thrown by giants'.)

Agassiz's insights owed much to the search for causes of the extinction of large mammals, whose bones and teeth were studied by Georges Cuvier (1769–1832), the leading vertebrate zoologist of his time. Cuvier was a mentor to the young Agassiz. Cuvier discovered that the mammoth is not a representative of living elephants. He concluded that the animal must be extinct, therefore. The discovery that extinction is real was a major event in the history of geology with monumental implications for the understanding of the evolution

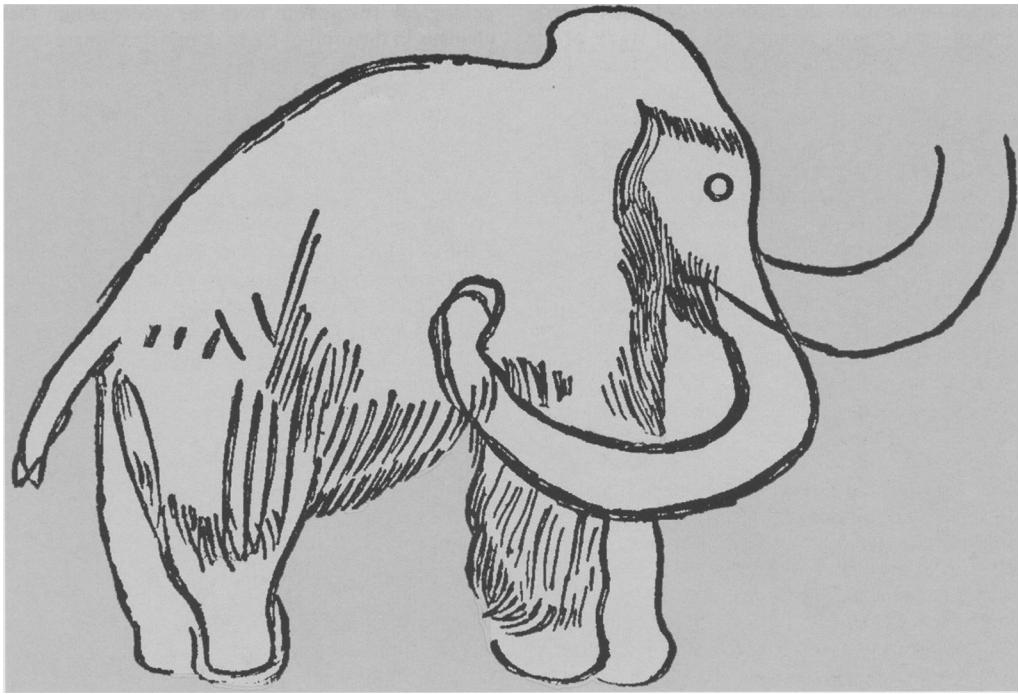


Fig. 1. Cave painting of a mammoth (Les Combarelles, near Les Eyzies, Dordogne). Image adapted from a drawing by Herbert Kühn.

of life (Rudwick 1976). In his search for possible explanations for extinction, Cuvier called on the discovery of frozen mammoth carcasses within Siberian permafrost. He surmised that an abrupt and permanent change of climate, from warm to freezing cold, was responsible for killing the elephants and for preserving them since. Also, he contemplated the inundation of low-lying regions by a rising sea as a cause for extinction. Thus, in contrast to later workers who emphasized over-hunting (Steinmann 1917; Martin & Klein 1984), Cuvier proposed environmental change as the agent of extinction. In addition, the type of change he envisioned is associated with ice age processes.

Cuvier's notion of a great inundation as a cause for extinction was soon readily adapted into the biblical flood tradition. His other concept, that of severe and sudden cooling, helped generate the idea of the Great Ice Age, which was subsequently so vigorously and successfully promoted by Louis Agassiz. Agassiz assumed that the extinct elephants, rhinoceroses, sabertooth cats and hyenas whose bones are widespread in Eurasia were tropical animals, just like their closest living relatives. Following Cuvier's suggestion, he had these large animals wiped out by the sudden arrival of a Big Freeze, which initiated the Great Ice Age. In a

powerful vision, he combined Cuvier's findings with local Alpine lore about the previous large extent of mountain glaciers, to summon the destructive forces of global catastrophe (Agassiz 1866, p. 208):

The gigantic quadrupeds, the Mastodons, Elephants, Tigers, Lions, Hyenas, Bears, whose remains are found in Europe from its southern promontories to the northernmost limits of Siberia and Scandinavia ... may indeed be said to have possessed the Earth in those days. But their reign was over. A sudden intense winter, that was also to last for ages, fell upon our globe: it spread over the very countries where these tropical animals had their homes, and so suddenly did it come upon them that they were embalmed beneath masses of snow and ice, without time even for the decay which follows death.

Thus, the same frozen carcasses in Siberia that had so intrigued Cuvier (and that had given rise to ancient legends about enormous subterranean life forms in Siberia itself) became a cornerstone of Agassiz's new theory of global glaciation. In Switzerland, where Agassiz held a professorship in Neuchâtel, he could readily verify the effects of greatly extended ice tongues, led by local observers (such as Jean-Pierre Perraudin, a Swiss mountaineer; Ignace Venetz, a highway engineer from Wallis; and Jean de Charpentier, director of the salt mines at Bex; see Imbrie & Imbrie 1979). On

a much larger scale, the evidence for former glaciation of vast regions around and well south of the Baltic Sea, mentioned above, was readily available (see Fig. 2). Clearly, the erratic blocks had their origin in Norway and Sweden, and obviously some powerful agent other than rivers had to transport the largest of these. After moving to Harvard, Agassiz was able to inspect even more evidence of former glaciation, and with an even larger extent of ice than that postulated for Scandinavia. Thus, Agassiz became thoroughly convinced of the reality of the Great Ice Age, and his ideas prevailed in spite of early opposition.

The discovery of former widespread glaciation and the associated invention of the Great Ice Age was an important advance in the understanding of the origin of existing landscapes and indeed of the history of the planet. The concept of the Great Ice Age was much superior to then-prevailing ideas on landscape evolution, which relied heavily on the Great Flood. Agassiz's vision of enormous ice sheets burying much of North America and all of Scandinavia including the Baltic Sea and the North Sea was well supported by later findings. The ice sheets, as we know from geophysical evidence involving loading of the continents and their rise after removal of the load, attained a thickness of several kilometres in places. In addition, much of the northern North Atlantic was covered with ice, whether sea ice or icebergs derived from surrounding glaciers. The ground was frozen over much of middle Europe and deep into the Russian plains. The Alps were covered with thick ice, with glacier tongues extending well into Bavaria, France and Italy. It still seems reasonable today to assume, as did Agassiz, that such an environment was unable to support a rich megafauna of elephants, rhinos and bison and their predators.

Nevertheless, the Great Ice Age as promulgated by Agassiz is not really history, but a mixture of science and fantasy. The catastrophe he envisaged did not happen that way: there was no sudden change from a tropical climate to a frozen world. In addition, the onset of the ice ages some three million years ago had nothing to do with the extinction of mammoth, mastodon and woolly rhinoceros. On the contrary: the giant mammals were creatures of the ice ages, not its victims. They died out at the end of the last ice age. (The animals that ended up frozen are of widely different age. They had the misfortune to fall into cracks or ponds in the icy ground while foraging; see Vereshchagin 1974; Guthrie 1990.)

The one great idea that has stood the test of time was Agassiz's insistence that there had been a lot of ice around, not too long ago. With this, he set the stage for climate reconstruction in Earth history. Such reconstruction, eventually, gave rise to a

geological revolution from the recognition that changes in the orbit of Earth dominate climate evolution on scales of tens of thousands of years (Milankovitch 1930; Imbrie & Imbrie 1979; A. Berger *et al.* 1984).

Recognizing that ice sheets were once widespread is one thing; realizing that ice ages came and went in a long succession is another. That successive ice ages came in regular cycles tied to Earth's orbit has only been accepted in the last few decades. The cycles in question are dominated by a 100 000-year period whose origin is still under discussion, and by regular changes in the tilt of the Earth's axis (41 000-year period), as well as by the precession of the seasons (*c.* 21 000-year period) (A. Berger *et al.* 1984). The basic idea underlying modern understanding of the ice age cycles is due to Milankovitch; he postulated that changes in seasonal contrast in the northern hemisphere represent the crucial factor responsible. The Serbian engineer Milankovitch, building on earlier work by the Scotsman James Croll (1821–1890) and advised and greatly encouraged by the German climate scientist Wladimir Köppen (1846–1940), proposed that the amount of sunlight received during northern summer at 60°N determines whether ice shields can wax or must wane. He calculated the changing intensity of insolation for the last 600 000 years, from astronomical principles governing Earth orbital eccentricity, axis tilt and precession of seasons. Matching his calculations to the observed sequences of glacial deposits, he was satisfied that his hypothesis was supported and that he had found a way to date the deposits.

An important ingredient in Milankovitch's mechanism is the precession of the equinox; that is, the fact that seasonal markers (spring and fall equinox, longest day, shortest day) migrate along an elliptical orbit. Whenever the longest day and the closest approach to the sun coincide, summer insolation is especially strong, and glaciers recede. The precession effect (about 20 minutes per year, and thus measurable in a person's life time even with simple instruments) was known to ancient astronomers and became involved in myth building about the world beyond (Barber & Barber 2004). The concept of great world cycles involving an endless alternation of catastrophic destruction and fruitful creation is familiar from Hindu cosmogony, but the time-scales do not match those of modern ice-age science. Presumably, the Hindu myth illustrates eternity in imaginative but accessible fashion, and the time-scale is chosen to be beyond human experience and comprehension.

Although Hindu myth does not anticipate Milankovitch theory in any meaningful sense, it does anticipate the scientific introduction of a realistic time-scale for geological processes by several

thousand years. The originator of infinite time in geology was James Hutton (1726–1797), author of the *Theory of the Earth* (Edinburgh 1775). His rock cycle with its endless manifestations through Earth history ('no vestige of a beginning, no prospect of an end') is based on a grand vision of mythological appeal and power, rather than on observation. An alternative vision is that of the Saxon mining engineer Abraham Werner (1750–1817). In Werner's mind, Earth history moved from primordial conditions (represented by metamorphic and igneous rocks) to conditions ever closer to present ones (represented by sedimentary rocks), in well-defined steps. Werner saw Earth as an evolving system, from one era to another, a view that is in principle superior to that of Hutton's endless cycles. (Nevertheless, textbooks tend to give the nod to the scholarly Hutton over the enthusiastic Werner.)

There is a lesson for ice-age science from this ancient controversy of cycles versus history. It is that the discovery of cycles must not obscure the fact that ice ages evolve (Berger & Jansen 1994). The cycles do not really repeat even though it might seem that way (Berger 1999).

Ice age concepts in the Edda

The references to ice-age processes in Nordic myth, created by people who lived with and next to ice, are of a comparatively simple nature. They imply that ice was once widespread in Scandinavia; that freezing cold prevented settlement of the region; that 'in the beginning' the ice melted and the climate improved; that sea level rose in consequence of the melting, and that large mammals drowned in the ensuing inundation of lowlands.

In these major points, the myths anticipate many of the striking insights of the first part of the nineteenth century. In fact, the myths are closer to the truth in some aspects of ice-age lore, as when they link a sea-level rise to the melting of ice, and in placing the extinction of large mammals (referred to as ancient 'giants') into the proper time period, at the end of the ice age.

The (inferred) geological references are hidden here and there, like fossils in a dingy quarry, within the chaos of fantastic stories and strange beings that make up the world of ancient Nordic myth, as recorded in the skaldic poetry of the 'older' and 'younger' Edda, preserved in Iceland. The songs and stories of the 'older Edda' were written down between around 800 and 1250 AD, by various authors, many of whom are unknown. The 'younger Edda' was written by the poet Snorri Sturluson (1178–1241). He recorded the ancient myths to make them available for a

younger generation of bards and poets, but he did so from the perspective of a Christian. There are indications that he may have re-interpreted some of the ancient myths to make them more compatible with a Christian framework (Simek 2003). However, it seems unlikely that a biblical influence could have introduced elements indicative of arctic knowledge. Thus, any ice-related lore may be confidently assigned to ancient Nordic roots.

The language of the Edda (Old Norse or Old Icelandic) is not readily accessible without intensive study. I did not attempt to read the documents in their original versions, but relied heavily on German translations. An important source for Edda poetry in German is the nineteenth-century translation by Karl Simrock, that went through many editions. The latest one of these is a modernized version edited by Manfred Stange (2004; based on Simrock 1882). Additional sources in English, German and Norwegian are listed in an earlier article on geological aspects of the Edda (Berger 1991).

A central figure in the cosmogony of the Edda is the giant *Ymir*, from whose body the world is made, upon his demise. (The concept of a cosmological human body in Indo-European creation myth is explored by Lincoln 1986.) In the *Vafthrúdnismál* the origin of the world from Ymir is described thus: 'From Ymir's body was the world made, from his bones the mountains, from the skull of the frosty giant the sky, from his blood the sea.'

The appearance of *Aurgelmir*, ancestor of ice giants, involves the melting of earthy ice and rime (presumably permafrost), by warm winds from the south and by rain (in appropriate animist guise). A reference to stinking rivers (rivers of putrefaction) is reminiscent of the observation of early explorers about the stench created by the decay of giant ice-age animals exhumed in Siberian rivers. (The odour of decay is likewise remarked upon by modern explorers; Pfitzenmayer 1926; Stone 2001, p. 70.) The Edda text is quite explicit about the odious circumstances of the emergence of *Aurgelmir*: 'From icy ancient streams oozed puss that grew into the [ancestral] ice giant'. (*Vafthrúdnismál*, answer to Odin's sixth question.)

The exhumation of seemingly newly dead bodies from the frozen ground, apparently living within the Earth and killed when seeing the Sun or the Moon, must have stimulated myth making over many millennia (Lister & Bahn 1994). Indeed, ice-earth is the site of the origin of the earliest creatures in Edda cosmogony: like *Aurgelmir*, the ancestors of gods and people (*Buri*, *Burr*) emerge from melting permafrost. In addition, a host of giants emerge from the body of *Ymir-Aurgelmir*. Presumably, the evidence for an ancient time of creation involving an abundance of giants was not difficult to find. After

all, people used fossil mammoth bones as building material and for fuel (Haynes 1991).

The modern world begins with the killing of the Ice Giant Ymir-Aurgelmir by Odin and his brothers Vilje and Ve. That is, in the cosmogony of the Edda the ice has to retreat before the world is suited for people and their gods. Ymir's blood (which is explicitly related to water in the sea in the myth; Simek 2003, p. 174) pours out from the wounds and drowns the ancient giants, the children of Ymir. Both sea-level rise and the evidence for enormous floods at the rims of retreating ice sheets may have been involved in creating the myth. Observations available to all would have shown giant bones within ancient flood deposits, as well as teeth and bones along the shores of the North Sea, washed up by the waves, from areas once hosting giant animals but now under water.

According to one version of the myth, Odin and his brothers, after finishing off the primeval Ice Giant, used his body to make the earth we know, with mountains and forests and lakes and rivers and grassy fields: a place for people. To protect

the people's land from unwelcome invasions of a new race of ice giants (the latter-day masters of frost), the gods built a wall around Midgard from the eyebrows of Ymir. A wall that fits the description is still clearly visible as the 'Ra' across Sweden and the 'Salpausselkæ' in Finland. It is made of the moraines left by retreating ice. The arc-like forested moraines indeed look like giant eyebrows when viewed from a high vantage point. The existence of the wall identifies the geography of Midgard, the abode of people, as well as that of Utgard. Thus, 'Midgard' and 'Utgard' may not have originated as vague references to nowhere in particular (a usage suggested by Simek 2003), although poetic custom may have moved them in that direction through time.

There may be more than one way to divide the land of the ice giants from that of the gods (that is, the people). Besides the 'Wall' there is the river *Ifing*, that never freezes over. The only waterway fitting that description is the Norwegian Sea. On the other side is Greenland. There is no question that Greenland belongs to the ice giants whereas



Fig. 2. Characteristically shaped erratic blocks, used in building grave mounds in prehistoric times (c. 5000 years ago). The local legend postulates a magic origin for the rows of boulders, which line up as if in a procession. Image W.H.B., near Visbeck, N. Germany.

coastal Norway belongs to the gods (that is, the people) after deglaciation. Thus, although the boundary between Midgard and Utgard is not uniquely defined, it has its origin in reality. Likewise, the location of the rivers of putrefaction can be readily (but somewhat vaguely) assigned to permafrost country. Presumably, this land was to the east of southern Scandinavia, suggesting a memory of an eastern origin for the people settling in Scandinavia in the middle Holocene (or in any case a strong influence of eastern cosmogony).

How old are the myths of the Edda? The answer surely depends on which parts of the collection of myths one is talking about. Like a cathedral in northern lands, the beginnings date much further back than the completion. I have argued elsewhere that at least some of the core elements (that is, cosmogony) are older than 3500 years, based on a naturalistic interpretation of the story of Ragnarok, the prophecy about the end of the world (Berger 1991). Unless evidence for a much older age than 6000 years is found, we must assume that the insights about the demise of the great primeval Ice Giant and the drowning of the giant mammals of the last ice age were derived in the same way as in the nineteenth century: by observation and speculation. By 6000 years ago, the demise of the Ice Giant had run its course and sea level had stabilized (except for isostatic adjustments and local tectonics). Modern science is still debating why the Ice Giant bled twice, with a pause of more than a thousand years separating the melting periods. One widely discussed idea is that the large-scale inflow of melt water during the first phase of melting changed the circulation of the ocean in such a way as to decrease the heat import into the northern North Atlantic, from the tropics (Broecker & Denton 1989). Even now, it seems, the concept of flooding has its uses in the attempt to explain the end of the last ice age.

Conclusions

The bones and frozen carcasses in Siberian permafrost have stimulated thinking and myth making for thousands of years. Pre-scientific thinkers generated ideas on the origin of the world from these observations. Scientists, beginning with Georges Cuvier early in the nineteenth century, were drawn to the concept of large-scale climate change, with Louis Agassiz specifically inventing the 'Great Ice Age', itself a construct of mythical appeal, to explain the observations. The link between myth and science is given by certain features within Nordic legend: the fact that the demise of an enormous ice giant delivers the means for building a new world, the fact that giant creatures emerge from frozen ground, and the reference to stinking rivers

(icy rivers oozing puss) which has not been explained properly in the literature. It is the smell of decaying of carcasses emerging in riverbanks in arctic regions of Asia.

In addition, Edda cosmogony anticipates the concept that flooding was important in explaining the demise of an ancient race of giants during the termination of the rule of the Ice Giant Ymir. The core insight here is that the end of the ice age resulted in the extinction of an ancient race of ice giants, quite the opposite of the hypothesis of Louis Agassiz, but fully supported by modern dating methods. In modern science, the grand debate continues, regarding the relative importance of climate change and over-hunting at the end of the last ice age, in causing the extinction of the giant Pleistocene mammals. Presumably both factors were important. In any case, the myths have no reference to hunting; when they first emerged the great ancient giants were already extinct.

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