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Aspects of Armageddon: An exploration of the role of volcanic eruptions in human history and civilization

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Abstract

Volcanic eruptions are frequently invoked as the mechanism responsible for changes observed in the archaeological and environmental record. This paper argues that the evidence for this assumption is slight and that while there are examples of this, they are rare. Several case studies are discussed which illustrate the complex nature of the relationship between human cultures and volcanic eruptions and it is suggested that volcanic activity frequently acts as a stimulus rather than a brake to cultural development.

1. Introduction

Despite the popular paradigm, which sees volcanic eruptions as a constant threat and readily associates volcanic eruptions with both past and future human disasters (Velikovsky, 1950; Maddox, 1984; Burgess, 1989; White and Humphreys, 1994; Peiser et al., 1998; Gunn, 2000; Keys, 2000; Rampino, 2002); closer examination of human history often reveals a different story. Evidence suggests that some of our early ancestors lived in proximity to active volcanoes; Pliocene and Pleistocene hominid remains have been found associated with volcanic material in East Africa and hominid footprints have famously been found preserved in ancient African and European tephra fall (Woldegabriel et al., 2000; Mietto et al., 2003). Even in Europe, early humans also appeared to have lived in close proximity to active volcanoes (Raynal et al., 1998; Boef, 2001; Kieffer and Raynal, 2001; Lefevre et al., 2001). As the human species has developed it has endured and survived events which today are classed as "Super Eruptions", which were capable of global environmental forcing (Rampino and Ambrose, 2000; Fedele et al., 2002) but these influences need not necessarily have been entirely negative. While far from proved, the association of the most recent eruption of the Toba super volcano and a broadly coincident human genetic bottleneck, which suggests that the human race was brought to the brink of extinction, has received a large degree of attention (cf. Rampino and Ambrose, 2000), less notice has been paid to the suggestion (Fedele et al., 2002) that the environmental stresses introduced in Europe by the ~37,000 cal yr BP Campanian ignimbrite eruption, actually fostered the expansion of *Homo sapiens* at the expense of the less adaptable *Homoneandertalis*.

It is clear therefore that a broader appreciation of the relationship is called for (cf. Torrence and Grattan, 2002); as this paper reiterates several great centres of civilization, cradles of human cultural development have thrived despite their intimate association with centres of active volcanism. These include the classical civilizations of the Mediterranean basin, the civilizations which occupied the central basin of Mexico and Central America, Japan and South East Asia. To

this day there is little movement of people away from centres of volcanic threat and 455 million people live within 100 km of volcanoes which have been active during the Holocene (Chester et al., 2001; Small and Naumann, 2001) When a broad range of archaeological, palaeoecological and historical data is considered from around the world it is apparent that while there is evidence for the occasional short-term catastrophe, the broader term picture that may be presented is rather more complex.

2. Theoretical issues

There are two fundamental issues which need to be introduced before they are discussed in detail; firstly the volcanic mechanisms by which culture and environment may be modified and factors which may condition human and secondly, environmental sensitivity to the volcanic activity.

2.1. Volcanic mechanisms of environmental change

Volcanic eruptions may influence the environment and hence people on a scale that potentially ranges from the global (Rampino and Self, 1993), to the purely local (Baxter et al., 1999). The mechanisms by which these influences are wielded are very diverse and include climate modification, acid rain/aerosol impact, proximal and distal tephra fall, blast, pyroclastic flow, gas emission and tsunamis; in exceptional cases individual eruptions may generate most or all of these on a significant scale (Machida and Sugiyama, 2002).

Climate change is perhaps the most frequently invoked mechanism by which volcanic eruptions may wield an influence on people, but unambiguous evidence for this is rare. At the extreme end of the scale, super eruptions such as the ~74,000 BP eruption of Toba (Rampino and Self, 1993), or the ~34,000 BP Campanian ignimbrite eruption (Fedele et al., 2002) do coincide with significant global climatic downturns and apparent crises in the genetic and archaeological record (Ambrose, 1998; Rampino and Ambrose, 2000) and eruptions of this magnitude are cited as a threat to contemporary human culture (Rampino, 2002). However, as these eruptions are better understood there is a tendency for the original climatic impact models to be toned down; Oppenheimer's (2002) re-evaluation of the climatic impact of the Toba eruption suggests that it was far more modest than originally proposed and certainly not likely to modify global climate on the scale necessary to intensify an ice-age.

Within the Holocene there are many volcanic eruptions coincident with climatic and/or cultural change, but with most of these associations the precise mechanism by which one could have influenced the other is obscure and a clear tendency exists to simply assume that the eruption and subsequent climate change was large enough to have triggered the coincident environmental or cultural change (cf. Peiser et al., 1998; Gunn, 2000). This approach has recently been challenged (Buckland et al., 1997; Sadler and Grattan, 1999; Hall, 2003). Baillie (1991) has also criticized the apparent tendency to associate events in prehistory which are inevitably imprecisely dated and eloquently listed the range of climatic and archaeological phenomena associated with a relatively modest prehistoric eruption of the Hekla volcano in Iceland. Yet despite this literature there exists in the folklore of British archaeology in particular the belief that the prehistoric eruptions of Hekla are associated with a "time of darkness", volcanic winters which lasted for decades.

To associate volcanic modification of weather with negative consequences is to only see half the story. Put very simply, volcanic eruptions modify climate by introducing sulphur gases into the stratosphere, which then oxidize into an aerosol layer that reduces the quantity of solar radiation reaching the Earth's surface and it must be emphasized that the resultant surface temperature reduction is usually modest. However, the resultant cooling at the earth's surface is non-uniform, which sets up a series of anomalous temperature and pressure gradients which operate between high and low latitudes and between oceanic and continental air masses (see Robock (2000) for

an authoritative review of these mechanisms). The consequence of these processes is that normal weather patterns are disrupted. This may result in the arrival of unseasonable cold and wet weather and subsequent ruined crops, but the same mechanism may deliver unexpectedly mild and dry weather and better than usual yields. These processes can operate on quite an intimate scale; in 1816 following the eruption of Tambora much of France and the Netherlands experienced excess rainfall and agricultural stress (Post, 1977) whilst Denmark experienced dryer and warmer conditions than usual, and in consequence high crop yields and good prices (Neumann, 1990). Both these experiences were the result of the disruption of normal circulation patterns. On a global scale these patterns are repeated many times (cf. Harington, 1992), but archaeologists and geographers have tended not to identify cultures or environments which have benefited from volcanic modification of weather.

The potential impact of volcanic gases and derived acid aerosols and acid rain has recently received considerable attention and is now recognized as a mechanism with a considerable potential to impact upon the human environment (Grattan and Pyatt, 1999). The classic example of this phenomenon was generated by the Icelandic Laki Fissure eruption of 1783 AD. The gases emitted by this eruption formed an acid aerosol (Dry Fog) in the boundary layer of the atmosphere, which damaged crops and vegetation and impacted upon human health and mortality from Iceland to the Mediterranean (Rabartin and Rocher, 1993; Grattan and Charman, 1994; Grattan and Pyatt, 1994; Grattan and Brayshay, 1995; Demare'e et al., 1998; Grattan et al., 1998, 2002, 2003a, b; Durand and Grattan, 1999, 2001; Demare'e and Oglivie, 2001; Grattan and Durand, 2002; Van Swinden, 2002; Thordarson and Self, 2003).

Unless and until the predictions of Day et al. (1999) and McGuire (1996, 1999) are realized we are unlikely to see volcanically generated tsunamis which threaten global change. Volcanic eruptions do generate tsunamis which can be locally devastating, the eruptions of Krakatau in 1883 (Carey et al., 2000) and the Bronze Age eruption of Santorini (McCoy and Heiken, 2000) are good examples of this but these have short-term impacts on cultures which may not be distinguished in the archaeological record.

2.2. Cultural crises and volcanic coincidences

As with physical processes, human cultures should also be conceived as possessing inherent thresholds which, when passed, result in change. These are necessarily diverse and may not always be apparent, but obvious examples of these could include the diversity of subsistence strategies available to or utilized by particular people or culture, the vigour of a culture's political and/or social organization and the sensitivity of the environment utilized by a culture to specific mechanisms of volcanic forcing; these factors may equally operate to mitigate or exacerbate volcanic influences. Of course the immediate and direct impact of an eruption may overwhelm people regardless of the diversity of their subsistence strategies but beyond that point in time survival and re-establishment may occur.

It is necessary to recognize that in the past cultures were frequently in crisis irrespective of volcanic activity. Dodgshon et al. (2000), noted 49 years in which famine occurred in the highlands of Scotland between 1550 and 1800 AD. Living in an environment which was to a large extent marginal for the production of cereals, the people of the highlands at that time were vulnerable to slight modifications in climate and growing season, but none of these events coincided with a culprit eruption, and all were generated by a combination of "natural" climatic fluctuation and socio-economic stress.

A starker illustration of this point can be made by considering the natural catastrophes recorded in Europe in the 9th century AD (Palmer and Palmer, 2002). Twenty-four such catastrophes, featuring extreme weather, plague and famine can be identified in the Frankish annals (Table 1). The listed natural phenomena are familiar to any student of volcanic modification of the environment; extreme rainfall and flooding, extreme cold temperatures, extended cold winters, extremely hot summers, illness and pestilence. But none of these events coincide with a known

or suspected volcanic eruption of any magnitude and it can only be concluded that such extremes were a normal part of weather at this time.

3. Volcanic events and cultural catastrophes

In order to explore the influence volcanic eruptions may bring to cultural continuity, it is useful to present two events where volcanic activity did play a significant role, in Papua New Guinea and Japan.

In Papua New Guinea, cultural discontinuities have been observed following several volcanic eruptions. Between 5900 and 1000 cal BP, five eruptions of Dakatau and Witori volcanoes prompted cultural responses in West New Britain. The environmental impact of these events was severe and the forest across large areas of West New Britain was completely destroyed. The scale of the territorial abandonment which followed ranged between 0 and 1600 years. The reasons for this disparity were investigated by studying developments in lithic technology, Table 1 In the period 800–874, annals in western Europe list 24 years that contained reports of unusual and harsh weather, failure of crops, pestilence in cattle and widespread famine and plague in the human population

Date AD	Phenomena recorded in the chronicles
809	Pestilence and widespread loss of animals
810–11	Great loss cattle and other beasts. Extremely cold winter
820	Extreme rainfall in the summer led to the failure of the harvest and death of cattle
823	A great pestilence throughout Francia
824	Hail flattened the crops and pestilence followed
834	Flooding widespread
838–39	A great flood killed 2347 people in Frisia. Winter very hard
841	The summer was very cold which delayed the harvest
842–43	Winter very long and cold—damage to agriculture, livestock and bees
843	People ate earth mixed with flour. Famine in western Gaul, many thousands have died
845	Plague
849–50	Winter floods. Ferocious electrical storms
850	Summer scorchingly hot
852	Excessive heat and general famine
855–56	Winter excessively cold and dry. Pestilence has killed many
856–57	Plague: swollen abscesses, rotting flesh and loss of limbs
859–60	Very severe winter. Blood red snow. Merchants with horse and cart could cross the sea into Venice
868	Winter: severe winds and flooding—many dead
868	Summer: severe famine in Burgundy and Gaul, many deaths. People eating human corpses and dogs
870	Deaths caused by severe heat, cattle pestilence
872	Harvest ruined by unseasonable weather
873	Blood rained from the sky: Famine and plague
873–4	Unusually long and hard winter
874	Famine and plague in Gaul and Germany have killed nearly a third of the population

There are no eruptions of note in the 9th century (data extracted from [Palmer and Palmer, 2002](#)).

supported by a detailed programme of radiocarbon dating. It was seen that the key factors governing length of territorial abandonment following each volcanic event were the degree of social organization and subsistence practices and not solely the magnitude of the event. As communities developed more complex agrarian technologies they were able to adapt to their environment in a way that was beyond earlier communities which relied on the forest ecosystem

for subsistence (Torrence et al., 2000; Torrence, 2002).

In Japan clear evidence can be found for a volcanic eruption which generated a cultural discontinuity, which may be interpreted as a catastrophe (Machida, 1999; Machida and Sugiyama, 2002) and this event may be used as an example of a volcanic eruption wielding a severe influence upon a culture. The Kikai–Akhoya eruption is estimated to have occurred at ca. 7300 cal BP, and has been assigned a VEI of 7. The eruption was centred on the Kikai caldera, which is located 100 km to the south of the Japanese mainland. The eruption is noteworthy for the extensive tephra fall, the 30 cm tephra fall isopach lies up to 700 km from the caldera and the Takeshima-Koya pyroclastic flow which travelled 100 km across the sea and reached the Japanese mainland. The environmental impact of this event was considerable and evidence has been assembled which points to significant vegetation changes, swarms of landslides, and flooding, indeed so much material was eroded from the landscape that delta construction appears to have taken place (see Machida and Sugiyama, 2002). The scale of the vegetation change is indicated by the work of Sugiyama (1999) who suggests that the broad leaved evergreen forest, typified by *Lucidophylus* phytoliths was destroyed and that the regional ecology did not return to pre-eruption conditions for 8–900 years. Associated with this devastation was the Japanese Neolithic Jomon ceramic culture, which disappears from the archaeological record and is eventually succeeded by other ceramic styles, from distant regions, which is indicative of cultural discontinuity and change. Archaeological research to date suggests that reoccupation of the region did not occur until the ecology had recovered, up to 900 years after the Kikai eruption.

From these two case studies we may draw some broad conclusions. Cultures may be vulnerable to the direct impact of volcanic eruptions, but in these cases the principal mechanism for long-term cultural change appears to be the modification of the ecology upon which the culture relied. Scale of volcanic event is not necessarily the sole factor in determining cultural impact. We can see in West New Britain that the subsistence strategies adopted conditioned post-eruptive vulnerability and recovery. In Japan, the scale of the Kikai–Akhoya event and the environmental change which followed overwhelmed the Jomon pottery culture. These lessons are important when we consider other, better known case studies, where the volcanic impacts and cultural impacts are equivocal.

4. Volcanic eruptions, adaptation and continuity

In many areas the proximity of active volcanoes has not been an obvious brake on cultural development, and it is possible to suggest that adaptation is the norm rather than the exception. Even where several volcanic catastrophes are apparent in the archaeological record, it is difficult to discern anything other than broad continuity in the long-term archaeological record.

4.1. Vesuvius and the Palma Campania

A clear example of this may be found in the settlement of the Palma Campania which surrounds Vesuvius. The impact of the Avellino pumice eruption upon the Early Bronze Age settlement of the Palma Campania has been explored in detail (Albore-Livadie et al., 1998; Albore-Livadie, 1999). People were killed by the eruption while they worked in fields 13 km to the north east of Vesuvius, and were buried by the tephra fall where they fell and pyroclastic flows travelled at least 20 km to the north west.

An Early Bronze Age settlement found beneath the modern town of Frattinore, contained material which had been ignited by the pyroclastic flow. Within the 20 cm tephra fall isopach, which extends for over 60 km to the north east, resettlement on the alluvial plain did not occur for ca. 230 years, but appears to have been immediate on the high ground which rings the basin. This does not indicate a wider cultural catastrophe but perhaps an understandable reluctance to construct permanent settlement on the plain in the short term and its longer term unsuitability for agricultural exploitation. The wider area of Italy, beyond the immediate reach of the eruption

exhibits no signs of stress or discontinuity, a situation which was repeated following the AD 79 event (Sigurdsson et al., 1982). Allison (2002) demonstrated that in economic terms the impact of the eruption on the region was minimal, its productivity was maintained and there is no evidence of a failure of the region to continue to contribute to Roman commerce; this is a picture rather at odds with the determinist model which could be constructed following a reading of Pliny, or the recent examinations of the eruption victims excavated in Herculaneum (Mastrolorenzo et al., 2000, 2001). Resettlement following the AD 79 eruption was rapid, taking only a few decades. In part this rapid recovery could be seen as a reflection of the overall economic, social and political vigour of the Roman state whose response to the catastrophe may be interpreted as being robust. Thus an immediate catastrophe for its direct victims appears to have had no impact on the world beyond the immediate physical reach of the volcano.

Less well known are the impacts of the AD 472 Pollena eruption of Vesuvius (Rosi and Santacroce, 1983). This eruption, generated a substantial eruption column, VEI 3 (Simkin and Siebert, 1994), pyroclastic surges and scoria flows and the local highlands were blanketed with extensive, 430 cm depth, tephra fall. The major environmental impacts of the event appear to be associated with secondary flows and the mobilization of unconsolidated pyroclasts by heavy rainfall. These processes buried buildings and destroyed essential agricultural infrastructure. In contrast to the AD 79 event, this eruption occurred at a time of political, economic and social stagnation and the fragmentation of the Roman state. Interpretation of the available archaeological evidence indicates that a profound regional decline set in following this event (Mastrolorenzo et al., 2002). The eruption was not the sole cause of this decline; as Mastrolorenzo et al. (2002) point out, the archaeological evidence suggests that the region was already undergoing an economic downturn and the eruption appears to have intensified and perhaps extended this process.

In this case study, we see that it is difficult to view the response of cultures to volcanic forcing purely from the standpoint of the physical scale of the volcanic event. The smallest of the three volcanic events, the AD 472 eruption had the most severe impact, but this event impacted upon a culture severely weakened by political, social and economic instability and thus potentially more vulnerable to forcing by a natural disaster.

4.2. Catastrophe or opportunity—the Minoan eruption of Santorini

With the exception of Vesuvius perhaps no volcano has coloured the popular paradigm of the role of volcanic eruptions in human history as Santorini and the role it may have played in the downfall of Minoan culture and their dominance of trade in the eastern Mediterranean and Aegean seas. Yet this is an association which serves to illustrate the pitfalls which await the unwary researcher rather than a paradigm which we can use to illuminate similar research problems.

The impact of the Late Bronze Age (LBA) eruption of Thera (Santorini) has been the focus of considerable research, yet despite the magnitude of the event (VEI 6.9, Simkin and Siebert, 1994) and the geographical location of the volcano, at the heart of the sea going Cycladic civilization, debate ranges as to the extent to which, if at all, the eruption significantly disrupted the environment and influenced the cultural trajectory of the peoples of the Aegean and Eastern Mediterranean (Marinatos, 1939; Driessen and MacDonald, 2000; Driessen, 2002; Bottema and Sarpaki, 2003). Claims for the impact of the eruption have been considerable including widespread famine (White and Humphreys, 1994) and global climate change (Baillie and Munro, 1988; Kuniholm, 1990; Kuniholm et al., 1996), but the case remains unproven (cf. Eastwood et al., 2002; Manning, 1999; Manning and Sewell, 2002) and even the precise dating of the eruptions remains the subject of vigorous dispute.

Within the limitations of current dating, what can be seen is that the Minoan culture which has been excavated on Crete entered a long period of decline which coincides with the appearance of a vigorous sea going culture which had its power base in mainland Greece. Such a change in the balance of regional power could be seen as the result of the weakening of Cretan culture by the

eruption, but it need not be. Human history is a continuous record of florescence followed by decline of economic and military power. In this case the regional centre of gravity can be seen to move, but it is difficult to identify a significant shift in the cultural trajectory of the region. To resolve these questions it will be necessary to provide the clear evidence of both the environmental impacts of the eruption and evidence of inherent vulnerability to these mechanisms in the Minoan culture, which are currently lacking.

4.3. Multiple volcanic events—Japan

Similar examples of regional catastrophes, tolerance and recovery may be noted in Japan (Shimoyama, 2002a, b), where with the exception of unequivocal disasters such as the Kikai–Ahoia event discussed above, most excavations point to adaptation and recovery rather than catastrophe.

Typical of these studies is the excavation of the Hashimerugawa archaeological site which was directly affected by six tephra falls between 5500 and 1000 cal BP. The eruptions of Kaimondake, between the 6th and 9th century AD initially deposited a 5 cm thick scoria deposit (the Ak-1 tephra) on the settlement, but life appears to have continued unaffected. A subsequent eruption of Kaimondake deposited a 20 cm thick tephra layer (AK-2 tephra). This event did affect all factors of village life, with damage to both the village and its essential resources, such as the river. Despite the severity of the event the villagers adapted to the stress, cleaning out houses and repairing damage, “the preexisting community continued in being” (Shimoyama, 2002a, p. 336). The settlement was finally abandoned in the face of a 30 cm thick tephra fall, the MK tephra. However, even in this case it does not appear that abandonment was a decision made in panic. Excavation suggests that the act of abandonment was a deliberate strategy adopted in the face of severe environmental pressure from the volcano. It is interesting to note that the excavators concluded that the most significant cultural change noted in the settlements affected by eruptions of Kaimondake occurred as the result of the introduction of a new form of government, not as a result of change induced by volcanic activity! Throughout the life of the settlement it is clear that strategies were adopted which allowed the communities affected to adjust to the impacts of the eruptions and maintain their way of life.

4.4. Multiple volcanic events and small island communities

Comparatively isolated island cultures dependent on a relatively stable subsistence resource may be conceived to be vulnerable to even small-scale disruption of their environment by volcanic activity, but recent research does not support this hypothesis.

A study of the pre-European settlers of the Fijian island of Taveuni, which contains over 150 scoria cones (Cronin and Neall, 2000) suggests that the inhabitants were exposed to 28 moderate (VEI p_2) volcanic eruptions. A series of eruptions that occurred between 300 and 500 AD, did cover much of the southern part of the island in lavas and thick blankets of tephra, resulting in the apparent abandonment of the affected areas for several hundred years, but elsewhere on the island settlement was continuous with no sign in the available records for stress-induced change. Following most eruptions resettlement of marginally affected areas was seen to be rapid, and while several settlements have been buried by volcanic products in the island’s history there is no evidence that these events led to wider disturbances of the population.

5. Volcanic proximity: cultural brake or spur?

El Chichón, which is typical of many volcanoes in southern Mexico and Guatemala, has erupted frequently throughout 2500 years of continuous proximal human occupation. Human artefacts may be found embedded in pyroclastic flow deposits, evidence of rapid reoccupation between volcanic events (Tilling et al., 1984). The classic Mayan civilization, which developed and thrived in this area was exposed to several substantial eruptions including two classified as

VEI 4, dated to 553–614 AD and 676–788 AD (Espíndola et al., 2000), and volcanic tephra was used to give Mayan ceramics their classic temper (Ford and Rose, 1995). The first of these events appears to have had little discernible impact upon the Mayan civilization. It has been proposed the second of these events coincides with the collapse of this culture in the western Maya lowlands, which has been dated to 760–810 AD (Adams and Jones, 1981) and it has been suggested that the eruption may have been a factor in a 200 year drought which made the period 800–1000 AD the driest in the Holocene (Hodell et al., 1996). However, current understanding challenges the assumption that volcanic activity was responsible for this long period of environmental stress and drought. Detailed palaeoecological analysis (Goman and Byrne, 1998) identifies a long process of anthropogenic forest clearance which was followed by drought; further our current understanding of volcanic modification of climate would not support the possibility that a relatively modest VEI 4 eruption could trigger a 200 year drought in central America (Robock, 2000). Finally the window of opportunity afforded by the degrees of error in dating both the eruption and the cultural collapse do not prompt confidence in ascribing a dependent relationship between the two events.

Other volcanoes in Central America are intimately associated with cultural development. The eruption of Xitle volcano, the products of which have unequivocally destroyed the Pre-classic Cuicuilco pyramid 2000 years ago, may have stimulated the development of the great ceremonial centre of Teotihuacan (Gonzalez et al., 2000). Nor was Xitle the only volcano which affected pre-classic cultures in the basin of Mexico. Plunket and Urundela (1999, 2000), describe the impact of a Plinian eruption in the second half of the 1st century AD upon pre-classic settlement on the north eastern slopes of the volcano. It is clear from their archaeological research that although the settlements were buried by considerable ash-fall, the settlements had been evacuated before the event. Knowledge and perhaps apprehension of the volcano is apparent in volcano shrines which were excavated in different houses. As in other case studies described here contemporary settlements beyond the tephra fall do not appear to have been abandoned and it is thought that affected villagers were subsumed into these communities, demonstrating the value of wider social networks and kin groups in times of upheaval, which has been noted as an effective survival strategy in the context of small island groups by Galipaud (2002).

Overall, while individual eruptions did undoubtedly impact on specific settlements or regions and may consequently have disrupted regional balances of power, it is not difficult to see the proximity of active volcanoes to Central and South American cultures in the long term as being a spur rather than a brake. The persistence of settlement in the southern basin of Mexico and the great cultures which grew and flourished there in the face of considerable volcanic activity (Del Pozzo et al., 1997), bear witness to the resilience with which cultures may respond to persistent hazard.

Another example of this relationship may be found in the history of Iceland. The Icelandic people have weathered frequent severe volcanic eruptions and endured several of the severest eruption in recorded history including the Eldgjá fissure of 934 AD and the notorious eruption of the Laki fissure in 1783. Taken together the impacts of the Laki Fissure eruption were severe generating poor climate and crop damaging acid rain and fog which were felt across Iceland (Thordarson and Self, 2003), Europe (Grattan et al., 2005) and beyond (Demaree et al., 1998). Together these mechanisms brought about the death of up to a quarter of Iceland's people and three-quarters of its livestock (Steingrimsson, 1998). To any culture, particularly one so isolated and marginal as Iceland in the 18th century, this would be a severe blow. Abandonment of the island was considered, but the Icelanders and their vigorous culture survived and subsequently flourished. Today the volcanic threat is also one of the country's economic strengths—its geothermal energy resources.

6. Cultural adaptation and risk assessment

In pre-literate communities important knowledge may be communicated via oral histories, as was the case of the inhabitants of the Papua New Guinea highlands who had a strong oral

tradition about the Long Island eruption ca. 1660 (Blong, 1982), but it is clear that cultures can adapt to volcanic risk by incorporating the necessary risk avoidance strategy into their cultural organization. This phenomenon is well illustrated by the Maori people of New Zealand (Lowe et al., 2002). Exposed to frequent volcanic activity in North Island, Maori culture appears to have adapted to the hazard by establishing tapu (taboo) over areas which were clearly at risk. Maori legend tells of catastrophes which befell those who broke these tapu and these areas only appear to have been entered when the perceived benefit was particularly high, or the threat from competing clans was severe, necessitating the need to balance one risk against another.

Galipaud (2002) suggests that in Melanesian societies, frequent experience of volcanic activity has led to volcanic eruptions being perceived as part of the normal order of life and knowledge of the hazards has led to cultural adaptation. Low population density and a network of alliances and obligations allow threatened groups to relocate and avoid destruction, returning later when the event had passed and the island ecology was re-established.

Adaptation is not only seen in relatively isolated communities. Following the eruption of Mt. Pinatubo, the response of the inhabitants of Bacalor township in the Philippines to recurrent dangerous lahars was novel and entirely unanticipated. Threatened by repeated lahars a large proportion of the population of this town preferred to stay and adapt to the threat rather than relocate to other areas. In some cases the response to the threat was an architectural one; houses were raised on concrete stilts, perhaps several times (Rodolfo, 2000; Crittenden and Rodolfo, 2002).

7. Discussion

This paper does not pretend to be an authoritative review of the relationship of volcanoes and people. What it has sought to do is illustrate the complex nature of the relationship and suggest that researchers need to approach this problem with a more mature paradigm than has been common in the past 20 years. That volcanoes have erupted and generated occasionally devastating impacts is not in doubt, but following the disaster is the recovery and this paper serves to illustrate that current knowledge points to recovery and adaptation as being the norm. The influences volcanic eruptions bring to bear on peoples and cultures must be seen operating within a system which may contain pre-existing vulnerabilities, which can be social and economic as well as climatic. For the future with current focus on extreme events such as meteor impacts and super eruptions we should perhaps consider the robustness of modern political and economic structures to such a strain, rather than focus simply on the physical magnitude of the event itself. A super eruption would apply stress to all aspects of modern life. Air travel would be practically impossible, climate change would be severe and affect cereal and rice production worldwide, telecommunications would be severely restricted, electricity supplies would fail as power lines collapsed or short circuited under the weight of volcanic ash and huge areas would be affected by tephra fall and toxic gases. It is inevitable that our culture will have to endure a super volcanic eruption; whether it is a catastrophe or stimulus depends on the planning and organization which takes place now (Sparks et al., 2005).

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