International expert meeting
Distal impacts of major volcanic eruptions on pre-industrial societies in the Mediterranean

Extended abstracts
Osservatorio Vesuviano, Ercolano (Italy),
5-7 June 2016
<table>
<thead>
<tr>
<th>Participant</th>
<th>Affiliation</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albore Livadie, Claude</td>
<td>French national centre for scientific research &amp; Archeologia-Lettere, Università Suor Orsola Benincasa di Napoli</td>
<td><a href="mailto:alborelivadie@libero.it">alborelivadie@libero.it</a></td>
</tr>
<tr>
<td>Alessandri, Luca</td>
<td>Institute of Archaeology, University of Groningen</td>
<td><a href="mailto:l.alessandri@rug.nl">l.alessandri@rug.nl</a></td>
</tr>
<tr>
<td>Attema, Peter</td>
<td>Institute of Archaeology, University of Groningen</td>
<td><a href="mailto:p.a.j.attema@rug.nl">p.a.j.attema@rug.nl</a></td>
</tr>
<tr>
<td>Arienzo, Ilenia</td>
<td>Istituto Nazionale di Geofisica e Vulcanologia, Sect Osservatorio Vesuviano, Naples</td>
<td><a href="mailto:ilenia.arienzo@ingv.it">ilenia.arienzo@ingv.it</a></td>
</tr>
<tr>
<td>Bakels, Corrie</td>
<td>Faculty of Archaeology, Leiden University</td>
<td><a href="mailto:c.c.bakels@arch.leidenuniv.nl">c.c.bakels@arch.leidenuniv.nl</a></td>
</tr>
<tr>
<td>Blong, Russell</td>
<td>Aon Benfield Group, Sydney, Australia</td>
<td><a href="mailto:Russell.blong@aonbenfield.com">Russell.blong@aonbenfield.com</a></td>
</tr>
<tr>
<td>Bruins, Hendrik</td>
<td>Bona Terra Department of Man in the Desert, Ben-Gurion University of the Negev (Israel)</td>
<td><a href="mailto:hjbruins@bgu.ac.il">hjbruins@bgu.ac.il</a></td>
</tr>
<tr>
<td>Di Rita, Federico</td>
<td>Department of Environmental Biology, Sapienza University of Rome</td>
<td><a href="mailto:Federico.dirita@uniroma1.it">Federico.dirita@uniroma1.it</a></td>
</tr>
<tr>
<td>de Vita, Sandro</td>
<td>Istituto Nazionale di Geofisica e Vulcanologia, Sect Osservatorio Vesuviano, Naples</td>
<td><a href="mailto:sandro.devita@ingv.it">sandro.devita@ingv.it</a></td>
</tr>
<tr>
<td>Di Vito, Mauro</td>
<td>National institute of Geophysics and Volcanology, Rome</td>
<td><a href="mailto:mauro.divito@ingv.it">mauro.divito@ingv.it</a></td>
</tr>
<tr>
<td>Doorenbosch, Marieke</td>
<td>Faculty of Archaeology, Leiden University</td>
<td><a href="mailto:m.doorenbosch@arch.leidenuniv.nl">m.doorenbosch@arch.leidenuniv.nl</a></td>
</tr>
<tr>
<td>Driessen, Jan</td>
<td>Faculté de philosophie, arts et lettres, Université catholique de Louvain</td>
<td><a href="mailto:jan.driessen@uclouvain.be">jan.driessen@uclouvain.be</a></td>
</tr>
<tr>
<td>Field, Michael</td>
<td>Faculty of Archaeology, Leiden University</td>
<td><a href="mailto:m.field@arch.leidenuniv.nl">m.field@arch.leidenuniv.nl</a></td>
</tr>
<tr>
<td>Grattan, John</td>
<td>Institute of Geography and Earth Sciences, University of Wales, Aberystwyth (UK)</td>
<td><a href="mailto:jpg@aber.ac.uk">jpg@aber.ac.uk</a></td>
</tr>
<tr>
<td>Pacciarelli, Marco</td>
<td>University of Naples (Italy)</td>
<td><a href="mailto:marco.pacciarelli@unina.it">marco.pacciarelli@unina.it</a></td>
</tr>
<tr>
<td>Payne, Richard</td>
<td>Environment Department, University of York (UK)</td>
<td><a href="mailto:richard.payne@york.ac.uk">richard.payne@york.ac.uk</a></td>
</tr>
<tr>
<td>Riede, Felix</td>
<td>Aarhus University (Denmark)</td>
<td><a href="mailto:f.riede@cas.au.dk">f.riede@cas.au.dk</a></td>
</tr>
<tr>
<td>Sadori, Laura</td>
<td>Department of Environmental Biology, Sapienza University of Rome</td>
<td><a href="mailto:laura.sadori@uniroma1.it">laura.sadori@uniroma1.it</a></td>
</tr>
<tr>
<td>Sevink, Jan</td>
<td>Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam</td>
<td><a href="mailto:j.sevink@uva.nl">j.sevink@uva.nl</a></td>
</tr>
<tr>
<td>Talamo, Pierfrancesco</td>
<td>Polo Museale della Campania</td>
<td><a href="mailto:pierfrancesco.talamo@beniculturali.it">pierfrancesco.talamo@beniculturali.it</a></td>
</tr>
<tr>
<td>Torrence, Robin</td>
<td>Anthropology Research, Australian Musem, Sydney (Australia)</td>
<td><a href="mailto:robin.torrence@austmus.gov.au">robin.torrence@austmus.gov.au</a></td>
</tr>
<tr>
<td>Van Gorp, Wouter</td>
<td>Institute of Archaeology, University of Groningen</td>
<td><a href="mailto:w.van.gorp@rug.nl">w.van.gorp@rug.nl</a></td>
</tr>
<tr>
<td>Van Leusen, Martijn</td>
<td>Institute of Archaeology, University of Groningen</td>
<td><a href="mailto:p.m.van.leusen@rug.nl">p.m.van.leusen@rug.nl</a></td>
</tr>
<tr>
<td>Vanzetti, Alessandro</td>
<td>Sapienza University of Rome</td>
<td><a href="mailto:alessandro.vanzetti@uniroma1.it">alessandro.vanzetti@uniroma1.it</a></td>
</tr>
<tr>
<td>Zanchetta, Giovanni</td>
<td>Dipartimento di Scienze della Terra, University of Pisa</td>
<td><a href="mailto:zanchetta@dst.unipi.it">zanchetta@dst.unipi.it</a></td>
</tr>
</tbody>
</table>
Contents
Preface - Distal Impacts of Volcanic Eruptions on Preindustrial Societies in the Mediterranean – Attema & Van Leusen .................................................................................................................. 5
State of knowledge of the Campanian Early Bronze Age and its relation with the Pomici di Avellino eruption – Albore Livadie ........................................................................................................................................ 11
The Early Bronze Age in Central Tyrhenian Italy – status quaestionis - Alessandri ................. 17
Explosive volcanic activity in the Central Mediterranean, chronology and climatic events of the Mediterranean basin during the Holocene – Zanchetta et al ................................................................. 25
Geological context of distal Avellino tephra in the Agro Pontino and Fondi basin: preservation and archaeological potential – Van Gorp & Sevink ........................................................................................................ 29
Dynamics and impact of the Vesuvius Pomici di Avellino Plinian eruption and related phenomena on the Bronze Age landscape of Campania region (Southern Italy) – Di Vito et al ............................................................. 35
The Minoan Santorini eruption: Proximal and Distal Impacts - Bruins ........................................ 39
Late-Holocene palaeoenvironmental changes from the Gulf of Gaeta – Di Rita et al ...................... 49
Detecting the impacts of volcanic eruptions by palaeoecology - Payne ......................................... 55
Distal palaeoecological impacts of the great Bronze Age eruption of Mount Vesuvius at Femmina Morta – Doorenbosch & Field ........................................................................................................... 63
The Impacts of Volcanic Eruptions on Human Health - Grattan .................................................. 71
Impact of Volcanic Eruptions on Food Procurement - Torrence .................................................... 79
The impact of the Avellino Pumice eruption on the Early Bronze age Campanian agrarian pattern – Vanzetti et al ........................................................................................................................................... 87
Reported and perceived impacts of distal tephra falls on pre-industrial societies - Blong ............... 87
Vulnerability, Resilience and Adaptation: Social Responses to Volcanic Disasters - Torrence ...... 101
Distal impacts of major volcanic eruptions on pre-industrial societies in the Mediterranean – Riede .................................................................................................................................................. 109
Avellino Event Project Work Program .......................................................................................... 117
Preface - Distal Impacts of Volcanic Eruptions on Preindustrial Societies in the Mediterranean

Peter Attema and Martijn van Leusen Groningen Institute of Archaeology, University of Groningen

The aim of this expert meeting is to present and discuss the state of research into the diverse distal impacts of volcanic eruptions on pre-industrial societies, with a focus on the Mediterranean environment, in order to further the research of the Avellino Event project team. In their introductory presentation the authors will set the agenda for the meeting, placing it in the context of the Avellino Event research program and the long-term Dutch geoarchaeological research in the Pontine Region; they will also present two research problems that must be faced if the program is to be successful.

Dutch researchers have been active in geological and archaeological research in the Pontine Region since the late 1970’s. While physical geographer Prof. Jan Sevink and his students from the University of Amsterdam were mapping the soils of central Tyrrhenian Italy, prehistorians from the same University of Amsterdam, led by Dr. Albert Voorrips, began to record the prehistoric archaeological surface record of the Pontine Region using a then novel “New Archaeology” statistical sampling design. Meanwhile archaeologists from several Dutch universities, under the aegis of the Royal Netherlands Institute in Rome, started to excavate at the protohistoric site of Satricum. Out of this a regional survey project led by the Groningen archaeologist Prof. Peter Attema evolved, primarily aimed at documenting the regional protohistoric and Roman archaeological record. Over 25 years this Pontine Region Project has focused on many different questions, periods and areas within the Pontine Region, all the while accreting an impressive database and numerous publications.

Among the important discoveries that emerged from this interdisciplinary approach to the regional archaeological record of the Pontine plain, the discovery in 2008 by Prof. Jan Sevink of a thin volcanic ash layer in the stratigraphy of archaeological sites that were being investigated in the ‘Hidden Landscapes’ research program led by dr. Martijn van Leusen, was the spark that grew into the Avellino Event research program. The ash appeared to belong to the so-called Avellino eruption of Mount Vesuvius that took place around the transition of the Early to Middle Bronze Age and which was subsequently dated in this distal location by Sevink et al (2011) to shortly after 2000 BC. The ash was not only a welcome chronostratigraphical marker for the geoarchaeological research carried out by the Pontine Region Project, but also gave rise to speculation about the effects of the eruption that gave rise to it, some 140 km to the south. What could have been the demographic and cultural consequences for the Pontine Region if people had fled from the area around Vesuvius into the Pontine plain? If they did, could we find the evidence for it in the environmental and archaeological record? The central question was phrased as follows:

_Around 1995 BC, during the Early Bronze Age, a giant eruption of Mount Vesuvius buried a flourishing landscape of villages and fields in the plains to the north and east of the volcano under more than a meter of ash. Inhabitants of Campanian sites such as Nola (‘the Bronze_
Age Pompeii’) could barely escape with their lives. Italian archaeological research since the 1980s has conclusively shown that the population of the Campanian plain did not fully recover for several centuries after this so-called ‘Avellino Event’. Oddly, no one has yet wondered where the substantial Early Bronze Age population of Campania could have flown to, and what impacts it would have had there.

In June 2015, a 4-year archaeological research program funded by a ‘Free Competition’ grant from the Netherlands Organization for Scientific Research NWO started under the title The Avellino Event: cultural and demographic effects of the great Bronze Age eruption of Mount Vesuvius. The central hypothesis of this research program is that a significant percentage of Campanian refugees must have decided to resettle in the nearest coastal plains to the north - the Pontine Plain and Fondi Basin of South Lazio, and that we should therefore be able to prove this by tracing the ecological, demographic and cultural impacts that this immigrant population must have had. The program consists of three interrelated post-doc projects (see figure below), in the fields of palaeo-ecology, archaeology, and geology/geography, and is now completing its first year. At the Faculty of Archaeology of Leiden University, dr Marieke Doorenbosch is studying the distal palaeoecological impacts of the Avellino Event in South Lazio, and at Groningen University’s Institute of Archaeology drs Luca Alessandri and Wouter van Gorp are, respectively, studying its distal archaeological impacts and reconstructing the buried Early Bronze Age landscape of South Lazio. This core team is supported by the scientific staff and laboratory facilities of the participating universities, including those of the University of Amsterdam.

In its first year, the AEP has focused on conducting the exploratory fieldwork needed to obtain the requisite pollen cores for paleoenvironmental reconstruction, build a more detailed and complete picture of the geology and paleogeography of the study area through coring transects, and obtain samples for consistently identifying the Avellino ash when encountered in corings and test pits. However, it has been an equally important concern of the team to avoid ‘tunnel vision’, and the current expert meeting is its main tool for achieving this. The collected expertise of the participants in the meeting will, we hope and expect, bring the team fully up to date with the status quo of the relevant research in Central Italy; broaden the team’s minds to include outside perspectives on potential volcanic impacts on pre-industrial societies; and possibly lead to adaptations to the project work plan at the end of its 1st year.

The first three sessions of the meeting set the scene. In session 1 we will hear papers on the status quo of Early to Middle Bronze Age archaeological research in Campania and Lazio, with special
attention to issues of chronology, because the correlation of the Avellino tephra with the current archaeological typochronologies requires revision. In session 2 we hear about the distal geological impacts of the Avellino eruption and other relevant eruptions in Italy and the Mediterranean, and in session 3 about their paleo-ecological impacts. In the second set of sessions, we focus on how pre-industrial society responds to volcanic eruptions. Speakers in session 4 will review the status quo of research into the food economy and human health impacts, both in general and in the specific case of Bronze Age Campania; those in session 5 will review the status quo of research into past and present human responses to major volcanic impacts. Both sets of sessions deliberately include ‘outgroup’ speakers and discussants to provide different perspectives on the Avellino Event and help broaden discussions for the project team.

Besides furthering a broad interdisciplinary view of the issues at hand, one important purpose of the meeting is to reflect on the feasibility of the research program. In the closing session we therefore will turn to a critical discussion of the Avellino Event Project work plan and timetable: what are its strengths and weaknesses? What opportunities and threats do we foresee? We intend to present here some crucial issues arising from the team’s discussions:

1. Typochronology vs radiocarbon and tephrochronology of the BA in central Italy: what repercussions should we expect to confront?
2. Direct and indirect proof of immediate post-AV ash immigration into south Lazio: how difficult is this to obtain? What demographic increase do we require to be able to see the impact of such a migration on the landscape in pollen and sediment data?

References
Monday, June 6\textsuperscript{th}, 9-12 am
Session 1

EBA/MBA Archaeology of Campania and Lazio: status quo and implications of an early date for the Avellino eruption

Speakers:

Albore Livadie C. \textit{State of knowledge of the Campanian Early Bronze Age and its relation with the Pomici di Avellino eruption}

Alessandri L. \textit{The Early Bronze Age in the Central Tyrrhenian Italy}

Discussant: Vanzetti A.
State of knowledge of the Campanian Early Bronze Age and its relation with the Pomici di Avellino eruption

Claude Albore Livadie  Aix Marseille Université, CNRS, MCC, Centre Camille Jullian, 13000, Aix-en-Provence, France

The accidental discovery in 1972 of the Palma Campania site, after which the *facies* was named, allowed archaeologists to place this *facies* within the Early Bronze Age of Campania from both chronological and cultural point of view, and in between the earlier Final Eneolithic cultures and the later Middle Bronze Age culture. This was primarily based on the study of archaeological levels underneath the pyroclastic deposits from the Avellino eruption, as was done until then only for the Roman centres buried by the 79 A.D. eruption.

Though followed by many later finds, this first discovery still merits some attention. As known, it occurred at a location called Tirone o Balle, when during construction work for the Autostrada A30 Caserta-Salerno a major concentration of ceramics was uncovered (about 130 pots). Initially, the relevance of this discovery and its enormous archaeological potential were not understood: it was assumed, given the abundance of charcoal and firings marks on the pots, that it represented the waste dump of a bucchero kiln. It was only later (1978), when I was entrusted with its study within the context of my research on Campanian bucchero, that the nature of the site (part of a hut), the circumstances of its burial (a Plinian volcanic event), and its chronological position became clear. The presence of a pumice layer in the ditch along the lay-by of the motorway where the discovery was made, led to the involvement of my colleagues R. Santacroce and M. di Paola (University of Pisa), who subsequently studied the area to reconstruct the eruptive history of the Somma-Vesuvius. From that study resulted their attribution of the burial to the eruption of the ‘Pomici di Avellino’. However, at that time, the age of this event was not clear: G. Imbò (1984), who still followed A. Rittmann (1933), tied it to archaeological finds in the Sarno valley, whereas other volcanologists assumed an early 12th century BC age, taking as terminus ante quem a bowl that formed part of a set of grave goods found in stratigraphical context in a quarry at Pomigliano d’Arco (NA) (Lirer et al. 1973). In the mean time new C14 datings were obtained on samples from paleosols directly underneath the pyroclastics in the Cava dell’Arciprete (AV) (Alessio et al. 1974) and at Pomigliano d’Arco. These dated the event at, respectively, 3510±50 BP (1961-1692 BC cal. 2σ), at 3610±50 BP (2136-1782 BC cal. 2σ), and at 3870±50 BP (2472-2202 BC cal. 2σ).

The first radiocarbon datings of bones that originated from the archaeological level (remains of sheep/goats) were executed by the Gif sur Yvette laboratory. That dating (3760 ±70 BP, 2456-1978 BC cal. 2σ), apart from providing a first chronological indicator for all sites that were affected by the eruption, also affected the relative chronology of the Early Bronze Age of Southern Italy, of which the upper limit was advanced relative to the age indicated by R. Peroni in 1971 (1800-1600 BC).

Chronologically, the *facies* was placed in an advanced period of the Southern Italian Early Bronze Age, not only because of the radiometric dating, but also based on typological comparison with materials that originated from the Campanian site of Camposauro, with the pottery assemblage of
the eolian culture at Capo Graziano, and that of the Maltese culture from the necropolis of Tarxien. On this basis the facies was included in the "Parco dei Monaci-Cotronei" horizon defined by R. Peroni in 1971 as a phase preceding the Protoappennine B period identified in the excavations of Tufariello di Buccino and Vivara (Albore Livadie 1980).

The book "Tremblements de terre, éruptions volcaniques et vie des hommes dans la Campanie antique" (Albore Livadie ed. 1986) undoubtedly represents an important moment in the research, evidencing that among the earth scientists, archaeologists, and historians active in Campania and studying the protohistoric period, a true dialogue and multidisciplinary cooperation had grown. The understanding of the impacts of volcanic catastrophes on societies was further deepened in two European workshops "Volcanologie et Archéologie" (1987, 1989) held at the Centro Universitario Europeo per i Beni Culturali di Ravello (Albore Livadie and Widemann eds. 1990) and in an international seminar (1994) with the title "L'eruzione vesuviana delle Pomici di Avellino e la facies di Palma Campania " (Albore Livadie ed. 1999). At the latter occasion, apart from the presentation of not yet or only partially published materials (Roccarainola, Saviano, Frattaminore, Avella, S. Pietro Torre d'Elia to mention a few), an attempt was made to trace the possible extension of the facies of Palma Campania outside the area directly affected by the eruption (in particular in Basilicata and in Sicilia), a problem which is still far from solved. Use was made of materials from well-defined archaeological facies on the basis of a thoroughly studied ceramic heritage. Further activities included the meeting on "Archeologia e Vulcanologia in Campania" (1996) and the exhibition "Un' eruzione vesuviana 4000 anni fa" following the discovery at S. Paolo Belsito of two skeletons of humans killed by the eruption (various authors, 1999).

In the 1980s and 1990s our knowledge was significantly increased thanks to finds in areas in which hitherto no traces from the protohistorical period had been encountered. Excavations were carried out at Sarno (1983-84) and at Savignano Irpino (1984); research was resumed at La Starza di Ariano Irpino (1988) and at Pratola Serra (1991); investigations were undertaken at Frattaminore (1992-1994), at Pompeii in the “S. Abbondio” location (1993 first campaign), at Palma Campania (1994), and at San Paolo Belsito in the “La Vigna” location (1995). In 1995 the very important excavations at Gricignano started, thanks to the simultaneous construction of the Treno ad Alta Velocità (TAV) and the logistic support by the US Navy; this was followed in 1996 by the second excavation campaign at Pompeii “S. Abbondio” and excavations at Boscoreale and Boscotrecase in connection with the Circumvesuviana railway line (1998).

This was a truly ‘happy’ season for Campanian protohistory, and in 2001 it culminated in the discovery of the village of Nola “Croce del Papa”. As Stefano de Caro wrote, it ‘constitutes one of the most interesting events of the last years in the archaeology of Campania’. The coincidence of several favorable factors, amongst which the distinct phasing of the eruptions that destroyed the village, allowing the inhabitants to flee, and its specific type of burial by tephra, which led to the exceptionally good conservation of the buildings, allowed for the truly reliable reconstruction of a hut from this unique site by the architect E. Castaldo, in the Parco Archeologico della Preistoria at S. Paolo Belsito.

A few years later the Afrogola site came to light where, other than at Nola, the large extension of the excavation allowed for the retrieval of a large number of huts, which however are in a worse state of conservation as a result of the absence of a pumice layer and the heavy burden of the pyroclastic...
flows. More recently several areas have been investigated along the route of the TAV, in particular in the Acerra zone where excavations are still ongoing. At Nola, in the location “Piazza d'Armi”, research in 2008 has brought to light older levels than those found at “Croce del Papa”; important new finds also come from the Salerno zone where several habitations and necropoli were discovered (Oliva Torricella, Piccarielli, Ostaglio and Battipaglia).

The degree of conservation of these archaeological remains is such that they provide a quite deep knowledge and understanding of various aspects of this facies (funerary typology, anthropological data, organization of habitations, environment, vegetation, typology of the ceramics and constructions), and allow for their evaluation, in a wider context, as manifestations of a homogeneous social and economic structure. Looking at the agricultural history of this facies and the early agricultural techniques, several of these sites represent unique situations for which equivalents with the same dynamics of intensive agricultural exploitation are hard to find (Saccoccio et al. 2013).

An important contribution has been delivered by systematic palynological studies of pre- and post-eruption levels at major sites in the Nola area (Vivent et al. 2001). Pedological and palaeobotanical studies have furthered our understanding of early settlement location choice, use of natural resources and subsistence economy. Although it has been established that the eruption did not fundamentally modify the environment and vegetation, nevertheless at a regional scale and over short periods of time (some years or even some decades), the eruption definitely induced systematic changes in the ecosystem structure and substantial variations in the availability of natural resources that are crucial for a subsistence economy (water, soil, fauna, and flora).

All this information together made it possible to outline a comprehensive framework for this facies, from both a cultural and an environmental point of view. When we take into account the results from past and on-going studies, we thus can observe a territorial organization that is based on an intensive exploitation of the land, with settlements that sometimes reach large dimensions, connected by proper beaten earth roads often furrowed by cart tracks, and with large parts of the territory intensively cultivated, generally using a plough, as well as extensive necropoles with pit tombs holding skeletons in more or less flexed position and laid down on one side, and sometimes tumuli.

In the meantime, the number of datings for the eruption event has augmented as a result of extensive sampling at the principal sites of the facies, including both already known sites and newly discovered sites, and taking advantage of the availability of the Accelerator Mass Spectrometer at the laboratory of the Università di Napoli Federico II and now CIRCE (CE), directed by F. Terrasi. Preference has been given to ‘short lived’ organic matter contained in syn-eruptive strata, over humic paleosols. Though the numerous dating results from the last thirty years exhibit a range in experimental error that on the whole is quite similar, we still do not have an absolute date of the eruptive event on which both archaeologists and physicists can agree. Personally and on theoretical grounds, I consider the date of 3550±50 BP (Passariello et al. 2009, 1951-1773 BC cal. 2 σ), obtained for a pregnant goat found in the village of Nola-Croce del Papa, to be most reliable.
Some problems, however, remain:

1) The problem of the initial phases of the Palma Campania facies

The start of this facies still remains an unsolved problem, even though the radiocarbon dating (3727±32 BP, 2270-2029 BC cal 2σ) for the Oliva Torricella site (SA) might place the village in a relatively early phase of the Early Bronze Age, long before the eruption of the Vesuvius.

The existence in Campania of archaeology from a time that is even more remote and can be placed in the transition from the advanced Eneolithic (final phase of Laterza, Cetina) to the first phases of the Early Bronze Age, has been documented in recent investigations executed at Acerra “Gaudello”, where some tombs hold significant associations of bronzes (daggers, halberds and pins) and pots of the final Bell beaker horizon, perhaps the facies of Ortucchio, facies of Cetina and an evolved aspect of Laterza.

2) The problem of the end of the facies, or better, the transition to the Middle Bronze Age

A remarkable disequilibrium exists between the mass of data that document the ultimate phase in the life of the settlements that were sealed by the eruption, and the scarceness of archaeological data pertaining to later, post-eruption sites. It has long been thought that the eruptive event must have led to a serious environmental crisis and for that reason signals the end of the Early Bronze Age, creating a break with the successive period (Protoappennine B, Middle Bronze Age 1). However, in spite of the damage inflicted by the eruption on the ecosystem (lasting impacts on river discharge and dense cover of tephra), a reoccupation of some sites that were already frequented in the preceding phase has been observed (Nola - via Cimitile, S. Paolo Belsito). In the southern sector of the Vesuvius, not directly affected by massive deposition of tephra, Boscoreale, Boscotrecase and Pompeii “S. Abbondio” document a much more rapid return of life after the catastrophic event than elsewhere.

Though the radiocarbon date that we have for “La Starza” (Ariano Irpino) points to a rather long interval before resettlement, it seems difficult to imagine a long interval between the eruption and the rebuilding, on the tephra, of a settlement that is characterized by a ceramic assemblage typologically rather akin to that of the facies of Palma Campania. The eruption probably does not mark the end of the facies, which must occur later - but how much?

3) A less important but still interesting problem concerns the possible direction of the flight of migrating population upon the event

One can justifiably hypothesize that the survivors, fleeing from a devastated territory, and prefiguring the current dramatic waves of migration, probably invaded and disturbed the existing population and cultures of the northern and southern Campanian plain (the region of Salerno and the plain of Eboli–Battipaglia), which suddenly became the target for new, perhaps smaller, settlements. Some groups will undoubtedly have tried to reoccupy their birthplaces, but life at those sites will have been rather difficult, either as a result of the low organic matter content of the soils and its ensuing poor fertility, or of the major environmental changes that affected the area.

These issues require multidisciplinary investigations and dedicated field studies. Missing information further includes the possible religious centers (data on cultic practice are rare) and defensive works.
References
Saccoccio F., Marzocchella A., Vanzetti A. 2013, The field system of Gricignano d'Aversa (Southern Italy) and the agrarian impact in the Piana Campana, ca. 3900 cal BP, Quaternary International 303, pp. 82-92.
The Early Bronze Age in Central Tyrrhenian Italy – status quaestionis

Luca Alessandri  
Groningen institute of Archaeology (GIA), Groningen University, Groningen

Pottery chronology

From a relative point of view, the Early Bronze Age (EBA) in Italy develops between the Eneolithic (Copper Age) and the Middle Bronze Age (MBA). The first evidence follows the appearance of the first bell-beaker aspects in the Copper Age ceramic style, for example in "level 9" of the Romita di Asciano or the “S horizon” of Lastruccia. The end has been identified just before the first appearance of the MBA Grotta Nuova facies.

The first organic definition of the EBA phase of Italy, based on ceramic style, has been proposed by R. Peroni (1971). His chronological scheme included four different facies: Asciano, in north-central Italy; Rinaldone 2, in an earlier sub-phase and Montemerano-Scoglietto-Palidoro in the later sub-phase, both distributed from the Arno river to the Volturno river; and Ripatransone, on the Adriatic side. In 1979, A. Guidi suggested the presence of the Asciano facies also in northern Lazio and proposed to subdivide the potsherds from Norchia in three subsequent chronological moments: the ones from the acropolis, the ones from the funerary area and finally the ones from the Piano del Casalone (Guidi 1979). Later on, starting from the researches carried out in the Fiora valley, N. Negroni Catacchio confirmed the Peroni chronological scheme (Negroni Catacchio 1981), with Asciano and Rinaldone 2 at the beginning of the phase, and considered both the Montemerano and the then recently discovered potsherds from Mezzano 1 to belong to the more recent phase (Mezzano-Montemerano-Scoglietto facies, Negroni Catacchio & Miari 1992).

In 1995 a conference about the EBA in Italy was organized, where D. Cocchi Genick presented a general overview of the EBA in central Italy, suggesting the existence of two ceramic EBA sub-phases (Cocchi Genick 1996). In a general paper about the Rinaldone facies the dating of sub-phase Rinaldone 2 to the beginning of EBA was questioned, citing the lack of evidence (Conti et al. 1996). Guidi and P. Pascucci presented an overview of new data from Lazio, reaffirming the dating of the Asciano facies at the very beginning of the BA and the dating of the Mezzano and Piano del Casalone facies to the late EBA (Guidi & Pascucci 1996). F. di Gennaro and M. Pacciarelli proposed the existence of a ‘Luni Tre Erici-Norchia’ style with an earlier Luni Tre Erici aspect and a later Norchia...
aspect, the latter probably dating to the EBA2, corresponding to the Piano del Casalone facies of Guidi and Pascucci (di Gennaro & Pacciarelli 1996; Pacciarelli 2001, 21). Finally, G.L. Carancini proposed the existence of five so called “horizons” (sub-phases) in the EBA Italian metal artefacts and Peroni suggested to place the transition between Cocchi Genick’s BA1 and BA2 inside the second sub-phase (Peroni 1996). In a general synthesis of the EBA chronology presented at the XIII UISPP conference, the already adopted chronological scheme was confirmed, suggesting the existence in Tuscany and in Sabina of a Belverde-Beato Benincasa facies dating to the EBA2 and BM1A, which would include also the Mezzano 1 potsherds (Carancini et al. 1996).

In 1998, Cocchi Genick published a new synthesis, reaffirming most of her previously formulated hypothesis (Cocchi Genick 1998). The author proposed a revised typology of the EBA potsherds, encompassing all Central Tyrrhenian Italy. Afterwards, using only the stratigraphic evidence and the short-lived sites, she went beyond the previously proposed chronological scheme, detecting two subsequent sub-phases and dividing Central Tyrrhenian Italy in ceramic groups (figure 1) defined as sets of archaeological contexts sharing some common types. The key contexts, according to Cocchi Genick 1998, are:

- **The transition period** between the CA (Chalcolithic) and the EBA can be identified in the Querciola settlement (Martini & Sarti 1991; Sarti & Martini 1993; Sarti & Vigliardi 1988; Sarti 1987; Martini et al. 1996).

- **Sub-phase EBA1A** can be identified in the Tanaccia di Brisighella (Farolfi 1976; Mansuelli & Scarani 1961; Massi Pasi & Morico 1996; 1997; Scarani 1962), in the “N horizon” of Lastruccia, in the layers 7-8 of the Romita di Asciano and in the “recent horizon” of Torre Crognola (Guidi 1979; Pennacchioni 1976; 1977; 1979; 1982).

- **Sub-phase EBA1B** can be identified in layer 9 of Riparo dell’Ambra (Cocchi Genick 1986), in the “H horizon” of Lastruccia and in the bottom level of layer 5 at Riparo delle Felci (Cocchi Genick 1998).

- **Sub-phase EBA2** can be identified in Poggio Fornello, in the layer 8 of Riparo dell’Ambra, perhaps in the “E horizon” of Lastruccia, and in the upper level of layer 5 at Riparo delle Felci.

- **The end of EBA2** coincides with the first appearance of the MBA Grotta Nuova facies, as in the Padulettio di Coltano settlement (Bagnoli & Betti 1986; 1992).

Following Cocchi Genick’s synthesis, the CONSIAG settlements near Sesto Fiorentino (Sarti 2000) were published. These settlements span from the end of the Copper Age to the MBA. Three EBA phases were identified on the basis of a pottery typology. For many of them new radiocarbon dates were made available. At the IIPP Conference of 2005, Guidi (2007) presented a new list of the EBA sites of Latium Vetus and proposed a division of the EBA1 in two subphases, on the basis of the pottery from Lucrezia Romana 1 (EBA1A) and Lucrezia Romana 2 (EBA1B, Iaia et al 2005).

**Absolute chronology**

The Italian EBA has been traditionally dated by reference to Central European chronology and has been (partially) linked with the Bronzezeit A, starting around 2300 BC. Recently, archaeological studies of the EBA pile-dwellings around lake Garda (Lombardia, Veneto) enabled the construction of the dendro-sequence GARDA 1, dated by the wiggle-matching technique (Fasani, Martinelli 1996). The sequence covers only the first portion of the EBA and starts at 2171 BC, with the oldest cutting
phase at Ronchi del Garda (2069 BC, Martinelli 2005) and Lavagnone (2068 BC, Griggs et al 2001). Radiocarbon dates from the EBA Muculufa sanctuary on Sicily (Holloway et al 1990) span from 2200 to 1900. Recently some radiocarbon dates from the hut of Case Bastione set the beginning of the Castelluccio facies (EBA) from 2117 to 1782 (Giannitrapani et al 2014). The radiocarbon dates available for the last portion of the Copper Age in the settlements near Rome also suggest a transition around 2200 BC (Pacciarelli 2011).

However, few radiocarbon dates are available for the Central Italy EBA, and none from Latium Vetus (figure 3). The oldest ones (EBA 1) come from Lastruccia 2A layer C2-3 (2451-2204) and Lastruccia 3 Layer 6 (2469-2211). The Italian transition to MBA has been widely discussed by A. Vanzetti (1998; 2013), who hypothesises a start of the Italian MBA 1 during the 17th century BC, in parallel with the final phase of Bronzezeit A (Bz A2c) in central Europe. In Central Tyrrhenian Italy, the most recent date in the EBA2B comes from Poggio Fornello (1877-1665).

The EBA in the Pontine Plain

In the Pontine Plain, the investigations of the Groningen Institute of Archaeology in the plain of Sezze have shown how today’s surficial layers of sediments were deposited at a point in time after the Bronze Age; only in the highest zones materials will then appear at the surface after ploughing. Given the numerous and long systematic survey campaigns to which the Pontine plain has been subjected, the paucity of finds dated to the EBA probably reflects a reality, also considering the low quantity of finds of succeeding phases, and it is reasonable to hypothesize a landscape that was still thinly populated (Alessandri 2013). To date, only few sherds from Proprietà Ricci and Tratturo Caniò (Anastasia 2007), both without secure contexts, have been dated to the EBA. During a recent excavation in the latter (Feiken et al 2012), the Avellino ash layer has been detected. The oldest pottery that has been found above the ash layer dates to the MBA 1. In the coastal area, a single axe has been found in the Sabaudia lake, near La Casarina. In EBA Latium Vetus, the settlement organization was based on non-defensible sites, which would imply the absence or near absence of widespread conflicts.

<table>
<thead>
<tr>
<th>Greece and Aegean</th>
<th>Southern Calabria</th>
<th>Campania and Northern Calabria</th>
<th>Latium</th>
<th>Etruria</th>
<th>Central Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHIII 2400'2200</td>
<td>Laterza (late)?</td>
<td>Epi-Bell Beaker?</td>
<td>Epi-Bell Beaker</td>
<td>Bz A1</td>
<td></td>
</tr>
<tr>
<td>LHI 1580'1500</td>
<td>Cessaniti-Capo Piccolo 1</td>
<td>Palma Campania</td>
<td>Belverde-Mezzano</td>
<td>Bz B1</td>
<td></td>
</tr>
<tr>
<td>LHIi 1490'2000</td>
<td>Rodi-Tindari Calabrian version</td>
<td>Protoexpurrence phase 1</td>
<td>Grotta Nuova and Protoexpurrence phase 2</td>
<td>Grotta Nuova</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Chronological scheme for Central Tyrrhenian Italy, (after Pacciarelli 2001).

On the margins of the Pontine Plain, the Vittorio Vecchi cave was used as a burial place (inhumation), even if some of the practices of manipulation of the bodies, according to the excavators, rather took place in a cultic sphere. Recently a new cave in the Aurunci Mountains has been found to contain a Copper Age burial (Alessandri, Rolfo in press); a femur has been radiocarbon dated to 4000±35
In the same cave other human bones have been found scattered on the surface, together with a huge quantity of MBA 2 potsherds. An excavation has been planned for 2016, also to check if a continuity exists between the two moments.

Figure 3. Radiocarbon dates for EBA in Central Tyrrenian Italy.
References


Monday, June 6\textsuperscript{th}, 1-4 pm
Session 2

Geological Impacts of the Avellino eruption and other major Mediterranean eruptions

Speakers:

Zanchetta G. \textit{Explosive volcanic activity in the Central Mediterranean, chronology and climatic events of the Mediterranean basin during the Holocene}

Van Gorp W. & Sevink J. \textit{Geological context of distal Avellino tephra in the Agro Pontino and Fondi basin: preservation and archaeological potential.}

Di Vito M., de Vita S., Sulpizio R., Talamo P. & Zanchetta G. \textit{Dynamics and impact of the Vesuvius Pomici di Avellino Plinian eruption and related phenomena on the Bronze Age landscape of Campania region (Southern Italy)}

Bruins H. \textit{The Minoan Santorini eruption: Proximal and Distal Impacts}

Discussants: Driessen J. and Riede F.
Explosive volcanic activity in the Central Mediterranean, chronology and climatic events of the Mediterranean basin during the Holocene

Giovanni Zanchetta¹, Mauro Di Vito², Roberto Sulpizio³, Monica Bini¹, Eleonora Regattieri⁴

1) Dipartimento di Scienze della Terra, University of Pisa, Pisa, Italy
2) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli Osservatorio Vesuviano, Naples, Italy.
3) Dipartimento di Scienze della Terra e Geoambientali, University of Bari, Bari, Italy
4) Istituto di Geologia Ambientale e Geingegneria – CNR, Rome, Italy

Introduction
Central Mediterranean, and to lesser extent, eastern Mediterranean, have been characterized by frequent volcanic explosive activity during the last ca. 11 ka (i.e. The Holocene). The products of these eruptions largely dispersed downwind of the volcanic centers and impacted large areas with different intensity (Zanchetta et al., 2011, Sulpizio et al., 2013). Close to the volcanic centers, the disruption was usually severe (e.g. Di Vito et al., 2013), both for the direct impact of the eruption and secondarily for the long-term reworking processes of the volcaniclastic material and slow soil recovery (e.g. Zanchetta et al., 2004) but the impact downwind in very distal settings was less clear (Eastwood et al., 2002). The dispersion of these layers has supplied one of the most powerful means for correlating archives and setting chronologies. In this presentation, we discuss chronology and dispersion of the main explosive eruptions occurred in the Central Mediterranean during the Holocene, including selected records containing the tephra layers. These selected records will give the overview between explosive activity and climate in the region, the basis for evaluating the impact of eruption on environmental conditions.

The records
The most important archives containing multiple tephra layers useful for this overview are represented by Italian and Balkans lakes and to, minor extent, Turkish lakes. In this context, marine records have usually lower resolution (but with some notable exceptions), and supply less information on on-land impact of eruptions. Lake Monticchio (Wulf et al., 2004) and Lake Accesa (Magny et al., 2007) in Italy, Lake Shkadra between Albania and Montenegro (Zanchetta et al., 2012a), Lake Ohrid and Prespa in Macedonia and Albania (e.g. Vogel et al., 2010) probably are the best examples. Other discontinuous local succession can supply further information, like the over the Apennine chain in Italy (Zanchetta et al., 2012b) and in Agro Pontino (Sevink et al., 2013). In Turkish notably are the lakes Inisk (Roeser et al., 2012) and Gönlisar (Eastwood et al., 2007) containing Avellino (but with some doubt) and Thera eruption, respectively.
Results and discussions

The most dispersed tephra layers, which can have had a larger impact on surrounding environment, are discussed in chronological order from the older to the younger. The older is the Somma-Vesuvius eruption of Mercato (ca. 8.4 yr cal BP, Zanchetta et al., 2011, Caron et al., 2012), which in many records just precedes the so called 8.2 event and occurs within the sapropel S1a interval (Caron et al., 2012). The rhyolitic tephra E1 (ca. 8.27±0.05 cal ka BP Caron et al., 2012), correlated with Gabellotto/Fiumebianco activities of Lipari Island, occurs within the interruption of Sapropel S1 (Caron et al., 2012, Marchini et al., 2014); interruption which has been correlated with the 8.2 ka cooling event (Siani et al., 2004; Zanchetta et al., 2011). The E1 tephra is almost unknown in continental archives, even if its presence is reported in Trifoglietti Lake in Calabria (de Beaulieu et al., in progress). The Campi Flegrei Agnano Mt. Spina (ca. 4500 yr cal BP, Passariello et al., 2010) trachytic layer is very widespread, even if in many records its secure identification could be difficult for the presence of a cluster of eruptions, chronologically close to each other having very similar chemical composition (Sulpizio et al., 2010a). The Vesuvian Avellino tephra (ca. 3800 yr cal BP, Passariello et al., 2009; Sevink et al., 2011, Zanchetta et al., 2011) is known to have had a large impact on the surrounding of the volcano (Di Vito et al., 2009, 2013), and to reach Balkans and Turkey (Roese et al., 2012; Çağatay et al., 2015). Both Agnano Monte Spina and Avellino constrains a phase of strong climatic deterioration marking the onset of the “Neoglacial” over the Apennine (Zanchetta et al., 2012a). Within this interval many lakes indicated a strong climatic drying phase (Zanchetta et al., 2012ab, 2016). The Etnean tephra layer FL (ca. 3300 yr cal BP), is found principally in the Balkans records (Zanchetta et al., 2012b; Sulpizio et al., 2010b) and seems to occur close to a new climatic deterioration (Zanchetta et al., 2012b). Although importantly dispersed there are less constrained environmental data in distal settings of two Somma-Vesuvius eruption: Pollena (Somma-Vesuvius, 472 AD), and Pompeii (AD 79) eruptions. In some distal archives there are some ambiguities in the secure identification of Pollena layer for the overlapping composition with 536 AD eruption (Sulpizio et al., 2010b). Pompeii is virtually undescribed in distal terrestrial archives studied for paleoenvironmental reconstructions, and then few inferences can be done on the condition in very distal setting, whereas archaeological and historical data are particularly abundant for the damages around the Vesuvius.

References


Geological context of distal Avellino tephra in the Agro Pontino and Fondi basin: preservation and archaeological potential

Wouter Van Gorp¹ & Jan Sevink²

1) Groningen institute of Archaeology (GIA), Groningen University, Groningen
2) Institute for Biodiversity and Ecosystem Dynamics (IBED), University of Amsterdam, Amsterdam

Introduction

The proximal tephras of the Avellino (AV) eruption are known to have seriously impacted the Early Bronze Age communities of Campania. Its distal tephra has recently been recognized in the Holocene sediments of the Agro Pontino graben and is potentially associated with archaeological sites (Sevink et al. 2011, 2013, Feiken et al. 2012; Bakels et al. 2015). Zanchetta et al. (2011) provided a detailed overview of the major Holocene tephra layers in the Central Mediterranean. The only other major Mid-Holocene tephra layer, apart from the AV-eruption, is that from the Astroni-Agnano MS group (AMS), dating to about 500 years before the AV-eruption and originating from the Campi Flegrei. Eruptions of lesser magnitude are much more common, but it is questionable whether their tephra reached southern Lazio in such quantities that they can be identified as specific layers. The most likely candidates for such Mid Holocene eruptions seem to be the younger (post-AV) AP eruptions of the Vesuvius (see e.g. Santacroce, et al. 2008). Eruptions from the Campi Flegrei, other than and postdating the AMS eruption, were of truly minor magnitude (see e.g. Smith et al. 2011).

The aim of this paper is to assess all Holocene depositional units in the Agro Pontino and Fondi basin for their potential for Holocene tephra preservation, based on earlier work and preliminary results of ongoing coring campaigns. Additionally, we preliminary assess these units for their archaeological potential.

General geological structure of the Agro Pontino and Fondi basin

The Agro Pontino consists of two fundamentally different units: a higher complex of Pleistocene marine terraces in the SW (Fig. 1, A) and a low-lying graben in the NE (Fig. 1, B), with a Holocene sediment fill, largely covering earlier, Late Pleistocene sediments. In the graben, from the Mid Holocene onward and with rising sea level, sediments first filled in earlier formed (Wurmian) fluvial incisions and gradually spread over a slightly dissected former (Eemian) lagoonal plain, filling in its lower parts under very quiet conditions. Exceptions are formed by the coastal lagoonal area near Terracina and southwest of the marine terraces, and by the alluvial fans and lower slopes of the Colli Albani and adjacent limestone hills, where Holocene sedimentation took place under higher energy conditions (e.g. coarse littoral sands and alluvial fan deposits).
The Fondi basin is a triangular tectonic basin, bordered by steep limestone hills, which over time produced little non-calcareous clastic sediment. Late Pleistocene dissection of the inland area resulted in a large lagoon and associated low, marshy plain, which only has been partly filled with lagoonal clays because of the scarce supply of sediment, upon sea level rise in the Holocene. Most of the inland part of this lagoonal plain is now buried under massive colluvial fan deposits, which were formed due to land use-driven soil erosion, starting in the early Roman times. Low energy sedimentary environments occurred during the Holocene in the inland area, but only near the current Lago di Fondi more or less organic clayey sediment is exposed or occurs at shallow depth. Such conditions also existed in the frontal lagoonal area, as already shown by van der Plaats and Vink (1973), Wen (1981), and Sevink et al. (1984).

Criteria for tephra preservation and archaeological indicators
Both the Agro Pontino and the Fondi contain sedimentary sequences that may hold a recognisable and thus identifiable AV-tephra layer in a context where contemporary archaeological remains/features can be encountered (Fig 2). The latter implies that a land surface should have existed, which was dry enough to allow for habitation or other prehistoric activities, and thus have been at or above sea level, lake level or local groundwater level. Furthermore, it should preferentially be buried by later sediment in a low energy environment, to ensure its preservation. Evidently, suitable stratigraphies that occur at greater depth below more recent sediment (e.g. several metres or more), are less suited for the purpose of our study, because they are inaccessible. Using these criteria, units within the Agro Pontino graben and Fondi basin can be assessed for their potential suitability to hold the required record.

We will first describe the context and facies of each depositional unit to identify their suitability for tephra preservation. We will subsequently tentatively describe their archaeological potential.
Holocene depositional units in the Agro Pontino Graben and Fondi basin

Fluviodeltaic plain
The fluviodeltaic plain in the northern part of the Agro Pontino (Fig. 3, unit 1) contains fluvial deposits that originate from the northern Volcanic Alban hills and the adjacent part of the Monte Lepini. Sandy fluvial channel deposits are often confined and represent old river channels. They are flanked by levees and finer, clayey flood basin deposits, which grade into the heavy clays of the lagoonal deposits. Along and near the channels, protohistoric Archaeological indicators have been found, such as at Tratturo Canio (e.g. Feiken, 2014), Ricci (Bakels et al., 2015) and areas in between. The AV-tephra can be identified in the fluvial levee areas, the fluvial basins and lagoons (Fig. 2).

Lacustrine plain
During the Early Bronze Age, an extensive lake existed in the current low-lying areas in the central part of the graben (Feiken, 2014). This lake was probably closed off from the sea due to beach ridge formation near Terracina and associated fluvial aggradation of the Amaseno River. The lake was fed by streams from the northern hills (Colli Albani and Monti Lepini) and the southwestern Pleistocene beach ridges, and by karstic springs along the edge of the Monte Lepini. These karstic springs fed the lake with waters high in calcium carbonate and sulphur.

Figure 2. AV-tephra in different sedimentary settings: a: Migliara 44.5, b: Campo Inferiore, c: Ricci, d: Borgo Hermada, e: Tratturo Caniò, f: Mezzaluna, g: double tephra layer at Femmina Morta. Arrows indicate location of Tephra layer (Figures a-c,e,f from Sevink et al., 2011, 2013).
Deposits in this palaeolake can roughly be divided into a southwestern and a northeastern part. The southwestern part contains black pyritic clays, which formed under reduced conditions in a quiet lake-marsh setting and where pyrite was formed by supply of sulphur from the karstic springs (Fig. 3, unit 3). These quiet conditions have proven to be excellent for AV-tephra preservation, such as at Migliara 44.5 (Sevink et al., 2011). However, it is hypothesized that the edge of the lake at this side was unsuitable for habitation (Bakels et al., 2015). In the northeastern part (Fig. 3, unit 2), the lacustrine infills either consist of gyttjas deposited in aerobic conditions, which are embedded in peats, such as at Mezzaluna, or of peats, such as near the eastern lake edge near Mazzochio. Here pre-Roman pottery has been found on a Pleistocene marine terrace remnant, which formed the Bronze Age lake edge (Anastasia, unpublished). Both the gyttja and the peat contained the AV-tephra layer around 50-70 cm below the surface. The southeastern lake edge borders the Amaseno floodplain. In the south, the lagoonal clays are shallow and the underlying Borgo Ermada formation is found at less than 1 m depth or even at the surface (Fig. 3, unit 4). This may have been a potential lake edge or stagnant area. Drainage of the central lake towards the Amaseno River probably took place north of this area.

Dissected Graben and southeastern coastal lagoon

During the Würmien, the Amaseno River has dissected the Pleistocene marine terraces, driven by sea level fall of > 100 m (Fig. 3, unit 5). The subsequent infill is largely covered by the younger Roman and modern alluvial and colluvial deposits, obscuring its Holocene development. Only where this cover is relatively thin, underlying strata can be reached. The incision by the Amaseno has led to small tributary incisions west of the main course (Fig. 3, unit 7). These incisions drained the Eemian beach ridge and marine terrace. During sea level rise and especially after the closure of the Amaseno outlet by a beach ridge, the gullies silted up, first by marine lagoonal clays with shell layers and afterwards by calcareous muds, indicating a change from marine to brackish and fresh water conditions. Afterwards, peat developed, indicating increasing terrestrial conditions. However, within one gully system, this sequence occurred diachronous; in the upstream part, the AV-tephra is found enclosed in terrestrial peats, while it is found within gyttja deposits below a thick peat layer in the centre of the gully. About 40 cm above the AV-tephra, a second, thin, unknown tephra layer has been found in the gyttja. The edges of these gully systems have a high potential for both tephra preservation and archaeological indicators (Borgo Hermada site) as these are the margins of a fresh water system. The SW coastal lagoonal area (Fig. 3, unit 6) may contain scarce low energy lagoonal infillings, but these have mostly been reworked by 20th century land reclamations.
Fondi basin
In the Fondi basin, the coastal lagoons are filled with a > 1.5 m thick peat layer, which overlies marine sandy clays (Fig. 3, unit 8). Their current elevation is a few metres below sea level and the peat contains a double tephra layer 20 cm apart, within 1m from its current surface. Mineralogical analysis suggests that the top tephra layer is the AV-tephra layer. The provenance of the bottom tephra layer is not yet clear, but the approximately 500 years older Astroni Agnano eruption from the Campi Flegrei could be a suitable candidate. It is clear that these peats have excellent preservation potential for tephra layers in relation to environmental reconstruction. The transition of the lagoon towards the Pleistocene beach ridge may potentially connect the tephra stratigraphy to archaeological remains, but such a location has not yet been found. The more inland dissected streams generally are filled with peat, organic clays and gyttja (Fig. 3, unit 9). The peats contain the AV tephra in their upper 1m. However no clear indications for contemporary human activity have been found. The northern and southern edges of the current Fondi lake have some potentially suitable areas, but neither the tephra layer nor indications of BA activity have been encountered yet.

Preliminary conclusions
Our most recent studies revealed that both in the Agro Pontino and in the Fondi basin, a double tephra layer may be encountered. This complicates the model in which a distinct tephra layer automatically can be assigned to the AV-tephra, but it also generates the opportunity for future detailed palaeo-environmental reconstructions, using tephra layers as stratigraphic markers.

Apart from these double tephra layers, tephra mineralogy shows a high similarity throughout the basin. However its elevation differs between the central Agro Pontino graben one the one hand and the southeastern gullies and Fondi system on the other hand. In the central Graben, the AV-tephra has been consistently found at a level of 2-3 m asl. Southeast of the near-surface Eemian marine deposits (Borgo Ermada formation), the coastal gullies contain the AV-tephra at depths around 2 – 3 m below sea level, It is hypothesized that the base level of the central lake was controlled by its outlet into the Amaseno River and not by sea level, whereas the southwestern gullies were connected to contemporary sea level.

Analysis of the different depositional environments in the study area leads us to conclude that the fluvial levees in the fluviodeltaic zone, the lake edges near the aerobic lacustrine zone and the margins of the infilled dissected valleys hold the highest potential for both AV-tephra preservation and presence of archaeology. These areas will therefore be further explored. For instance the pre-roman spatial distribution of channels, levees and flood basins in the fluviodeltaic unit is poorly known and needs further detailing and systematic and prospective coring campaigns are anticipated for all of these areas.

References


Dynamics and impact of the Vesuvius Pomici di Avellino Plinian eruption and related phenomena on the Bronze Age landscape of Campania region (Southern Italy)

Di Vito M. A.¹, de Vita S.¹, Sulpizio R.², Talamo P.³, Zanchetta G.⁴

1) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli Osservatorio Vesuviano, via Diocleziano 328, Napoli, Italy (mauro.divito@ingv.it)
2) Dipartimento Geomineralogico, Universita` di Bari, via Orabona 4, Bari 70100, Italy
3) Soprintendenza per i Beni Archeologici di Napoli, Piazza Museo Nazionale, 19, 80135 – Napoli
4) Dipartimento di Scienze della Terra, Via S. Maria, 53 56126 Pisa, Italy

Introduction
The Campania region is distinguished by a marked geological and morphological contrast between its eastern and largely mountainous or hilly part, and its western side, which is dominated by flat, alluvial plains, in which there are the two active volcanoes of Vesuvius and Campi Flegrei.

These volcanoes have produced numerous explosive and effusive eruptions, which variably impacted the local environment, strongly influencing the growth and decline of many human settlements over the millennia. The long history of interaction between man and volcano is recorded in detail in the stratigraphy of areas both near the volcanoes and far from them, up to several tens of kilometres east and north-east of the eruption centres (Di Vito et al. 2011 and references therein). Volcanic eruptions and associated phenomena have often determined interruptions in the occupation of these areas, but have also contributed to the exceptional fertility of the soils, which allowed intense agricultural exploitation. Moreover, the accumulation of significant quantities of loose pyroclastic material on the slopes of the hills surrounding the plain has favoured repeated lahar generation and flooding episodes, causing the development of marshlands and the build-up of thick detrital sequences (Di Vito et al. 1998; Zanchetta et al. 2004).

The Pomici di Avellino Plinian eruption of Vesuvius (PdA; 3.9 ka; Passariello et al., 2009; 2010; Sevink et al., 2011) has been by far one of the most powerful of these events, which had a very strong impact on a large area, striking both the Campanian Plain and the surrounding Apennine Mountains. The volcanological and archaeological studies presented in this paper permitted to reconstruct the dynamics of this eruption, and to estimate its local effects, both in proximal and distal areas.
The Pomici di Avellino eruption

The PdA eruption has been studied by various authors (see Sulpizio et al., 2010a for references). On the basis of the most recent of these studies (Sulpizio et al. 2008; Di Vito et al. 2009; Sulpizio et al. 2010a; 2010b), the sequence of PdA deposits can be divided into five eruption units (EUs) emplaced during three main phases: opening, Plinian and phreatomagmatic.

The opening phase includes a double bedset of white pumice lapilli and fine brown ash (EU1a and EU1b) emplaced by fallout from low, short-lived eruption columns. Fallout blanketed the volcano slopes with centimetre-thick lapilli and ash beds in a NE direction, up to a distance of a few kilometres from the source.

The Plinian phase emplaced pumice fallout deposits (EU2, EU3 and EU4), dispersed towards the NE from 23 to 31 km-high eruption columns, alimented by continuous magmatic explosions. EU2 is composed of white pumice lapilli and rare lithics, whereas EU3 is massive and composed of grey pumice lapilli and abundant lithics with a thin, massive ash layer at the top. EU4 is massive and includes grey pumice lapilli and abundant lithics and loose crystals. A minimum duration of few hours has been calculated for the Plinian phase. EU2 and EU3 are characterized by the rotation of the dispersal axis of 10 degrees, passing from N65E (EU2) to N55E (EU3). These two pumice layers cover a huge area, respectively at least 2,830 and 14,800 km² (1 cm isopach area). EU3, which had the most widespread areal distribution, has been recognised in several stratigraphic sequences from coring conducted in the Adriatic Sea (Sulpizio et al. 2008).

Finally, the phreatomagmatic phase was dominated by pulsating phreatomagmatic explosions, producing a succession (EU5) of both pyroclastic density currents and minor fallout deposits. These currents are the most widely dispersed in the whole eruptive history of Somma-Vesuvius and cover an area of at least 1,100 km² (1 cm isopach area). Fine ash deposits from this phase have been recognised in lake sediments from central Italy, at least 350 km away from the source (Sulpizio et al. 2008). Stratigraphic data suggest the occurrence of at least four main explosive episodes (EU5a–d), separated by eruptive breaks sufficient for the deposition of fine and accretionary lapilli-bearing ash in both proximal and distal areas. Hours- to days-long eruptive pauses are also clearly demonstrated by the recognition of footprints at different heights within the EU5 succession in the plain North of Somma-Vesuvius (Di Vito et al. 2009) up to a distance of about 25 km from the volcano. The emplacement temperature of these currents, estimated by AMS measurements at various sites around the volcano, varied from 250 to 300° C (Di Vito et al. 2009).

The PdA eruption was followed by a long phase of hydrogeological destabilization of the territory with many and repetitive episodes of flash floods and lahars. The analyses of sequences along the Apennine valleys and in the plains north of Vesuvius revealed the presence of thick syn-eruptive volcaniclastic deposits associated with the eruption. These are very frequent from the Cancello Hill to the Sarno Mountains. The progressive accumulation of these “alluvial” deposits lasted at least tens of years after the eruption and determined the further dramatic change of the landscape.

Impact of the eruption and resettlement dynamics

At the time of the eruption the region, especially on the Vesuvius plain and in inner Central Campania, was densely inhabited by communities of farmers and pastoralists belonging to the Early
Bronze Age Palma Campania culture (Albore Livadie 2007 and references therein). The eruption therefore dramatically interrupted a notably well-developed socio-economic and demographic scenario (Talamo 1993a; 1993b; 1999). The evaluation of the impact that the PdA eruption had on the surrounding territory is a useful starting-point for understanding a number of other phenomena. In particular, it made possible a more precise reconstruction of the dynamics of emplacement of the eruption products, and an evaluation of the different ways in which the sites hit directly by the eruption were buried, as well as a more detailed picture of post-eruptive phenomena.

Systematic analysis of the volcanic deposits from each site shaded light on aspects that are essential for comprehension of the processes of destruction and resettlement of the various geographical areas.

Sites were selected according to their distance from Vesuvius and on the basis of differing modalities of burial. Proximal sites studied include: Nola - Croce del Papa (Albore Livadie and Vecchio 2005), Afragola - Badagnano (Laforgia et al. 2009), Pompei - Sant’Abbondio (Mastroroberto 1998; Mastroroberto and Talamo 2001); sites at intermediate distance include Pratola Serra - Pioppi (Talamo 1999); distal sites include Ariano Irpino - La Starza (Albore Livadie 1991-92; 1996).

According to De Lorenzo et al. (2013) the repopulation of the area seems not to have depended on the greater or lesser distance of sites from Vesuvius. An important fact that should be born in mind is that in proximal areas, hit most severely by the eruption, there are clear signs of attempts to reoccupy the sites almost immediately afterwards, for example at Nola, Afragola and San Paolo Belsito. This resettlement did not last long, but the occurrence of pottery identical to the pre-eruption assemblages and the stratigraphic position of these layers, immediately above the PdA deposits, confirm clear continuity with the culture associated with the palaeosurfaces that were buried by the eruption. That these were isolated episodes, though, is confirmed by a survey of known sites referable to the MBA 1–2 and 3 (Proto-Apennine and Apennine). It is clear that during the Proto-Apennine, Campanian territory had a reduced density of population. The various Proto-Apennine sites are grouped around the margins of the areas affected by the deposition of the volcanic products of the two major eruption phases (the Plinian and phreatomagmatic phases), whereas inside these areas it seems to have been an almost complete depopulation that lasted for a long period. Only during the final phases of the MBA, with the development of the Apennine culture, does the previously abandoned territory show evident signs of progressive resettlement. It therefore seems that the time interval between the eruption and the complete resettlement of the territory affected to a reasonable degree by the eruption was at least five centuries. This is a long period, which may not be explained by eruption-provoked environmental crises alone; these surely would have passed more quickly.

References


The Minoan Santorini eruption: Proximal and Distal Impacts

Hendrik J. Bruins  Ben-Gurion University of the Negev, Bona Terra Department of Man in the Desert, Sede Boker Campus, Israel

The Santorini caldera in the Aegean Sea, surrounded by the islands of Thera, Therasia and Aspronisi, forms the centre of volcanic activity that has led to various large explosive eruptions during the past 650,000 years (Keller et al 1990; Druitt et al 1999). Most well-known is the Minoan eruption, classified as “super-colossal” with a Volcanic Explosivity Index (VEI) of 7, and dating from the Late Minoan IA period in the mid-2nd millennium BCE. The last small eruption occurred in 1950.

As an introduction to this “silent” pre-historic eruption, historical observations are presented of two similar volcanic events that occurred in Indonesia during the 19th century: Krakatau (1883) and Tambora (1815). Krakatau between Java and Sumatra is similar to Santorini: a few islands around a volcanic caldera. Precursory eruptions began in May and June 1883. On August 26, the climactic phase of the eruption began, which lasted for two days. Various individual explosions caused tsunamis, apparently related to massive pyroclastic flows, volcanic collapse and caldera development. The official number of people killed was put at 36,417. Volcanic ash fell as far as Singapore, 840 km to the north, Cocos Island, 1155 km to the south-west, and on ships 6000 km WNW from the eruption (Verbeek 1885; Simkin and Fiske 1983). The total volume of the eruption (VEI 6) is estimated by Yokoyama (2015) at 19 km$^3$ dense rock equivalent (DRE).

The Tambora eruption in 1815 is the largest (VEI 7) and deadliest recorded in historical times, with a total eruption volume estimated at approximately 52 km$^3$ DRE. A more recent assessment by Kandlbauer and Sparks (2015) estimated the volume at 41 ± 4 km$^3$ DRE. The volcano is situated on a peninsula protruding into the sea from the island of Sumbawa (Stothers 1984; Oppenheimer 2003). Tambora was dormant for a long period until 1812. The first explosive Plinian eruption occurred on 5 April 1815. The eruption column reached an estimated height of 33 km. The climactic eruption continued on 10 April at 7 pm, beginning with a second huge Plinian phase with an estimated column height of 43 km. But already after about an hour, at 8 pm, collapse of the central eruption column ensued and a sudden transition to pyroclastic flow occurred. At least eight pyroclastic flows and surges were produced. An estimated 11,000 people died from pyroclastic flows and ash falls. Tsunamis were generated as pyroclastic flows struck into the sea. It has been reported that more than 88,000 people died on the islands of Sumbawa and Lombok from direct and indirect impacts (Stothers 1984).

The Minoan Santorini Eruption

The magnitude of this eruption has been upgraded significantly in recent years, as more scientific data have become available. Pyle (1990) arrived at a range of 27-30 km$^3$ dense rock equivalent (DRE). Sigurdsson et al (1990) calculated a higher estimate of 39 km$^3$, based on a volume of ash fallout of 19 km$^3$, consisting of 2 km$^3$ DRE Plinian fall and 17 km$^3$ co-ignimbrite ash (Watkins et al 1978). The latter figure, based on deep-sea cores, would suggest that the volume of submarine pyroclastic flows
should be about 20 km$^3$ DRE (Sparks and Huang, 1980). Sigurdsson et al (2006) produced actual measurements of submarine pyroclastic flow deposits that may be related to the Minoan eruption. The resulting figure of 41 km$^3$ DRE pyroclastic flow deposits is about twice as much. Therefore, the Plinian ash fall (2 km$^3$ DRE) plus the ash fall associated with pyroclastic flows (17 km$^3$ DRE), together with the pyroclastic flow deposits on land on Santorini (1.5 km$^3$ DRE) and the newly mapped marine pyroclastic deposits around the volcano (41 km$^3$ DRE) give a total volume for the Minoan eruption of 61.5 km$^3$ DRE (Sigurdsson et al 2006). In addition, it has recently been advocated by Johnston et al (2014) that an estimated 18–26 km$^3$ DRE pyroclastic materials of the Minoan eruption were trapped within the caldera. This increases the total to about 78–86 km$^3$ DRE, making the Minoan Santorini eruption the largest known Holocene eruption (Johnston et al 2014).

**Dating.** Suggested relations between archaeological strata and Egyptian chronology, particularly at Tell el-Dab‘a (Bietak and Höflmeyer 2007), have been interpreted to support a timing around 1500 BCE (MacGillivray 2009, 2014; Warren 2009). However, radiocarbon dating favours a calibrated age range in the second half of the 17th century BCE (Bronk Ramsey et al 2004; Friedrich et al 2006; Friedrich and Heinemeier 2009; Manning et al 2006, 2014; Bruins et al 2008, 2009; Bruins 2010; Bruins and Van der Plicht 2014).

Sequence $^{14}$C dating of growth rings in an olive branch found on Thera, buried in the Plinian pumice deposit, yielded a date of 1613 ± 22 cal BCE for a variable sequence and 1613 ± 13 cal BCE for a defined sequence (Friedrich and Heinemeier 2009; Heinemeier et al 2009). The difference between conventional archaeo-historical dating and $^{14}$C dating is very significant with respect to the evaluation of distal effects of the Minoan eruption. Correct dating is of course crucial to investigate the impact of the Minoan eruption on society in the Mediterranean region.

**Eruption phases and impacts**

**Phase 0.** The precursory phase deposits have a maximum thickness of 15 to 20 cm, consisting of up to four layers, which indicate four eruptive stages (Heiken and McCoy 1990; Cioni et al 2000; McCoy 2009). The key archaeological site on Thera is the ancient city of Akrotiri, hidden below thick tephra layers until 1967, when Marinatos (1968) began his excavations. Astounding finds were gradually uncovered, including exquisite frescoes that outshine even those found at Knossos in Crete. The precursor deposit within the Akrotiri excavations usually exhibits three layers. Thickness is about 2.2 cm, but sometimes may reach 8 cm (Heiken and McCoy 1990). Such a small amount is insufficient to cause roof collapse (Blong 1984). Rainfall has not disturbed the precursory stratigraphy (Heiken and McCoy 1990), so the duration of its deposition until the commencement of the paroxysmal eruption Phase 1, must have been less than a few months or weeks, depending on the season of the year. It seems that the population fled away during the onset of the precursory volcanic phase (Doumas 1983). Remains of human beings have so far not been found in the excavated part of Akrotiri.

Excavations at Mochlos in northern Crete showed new building activity at the time of the Minoan eruption, indicating population influx. House C.1 at Mochlos, built on top of Minoan tephra, is an example of distinct Theran architecture, including the use of ashlars. A hypothesis has been developed that refugees from Thera, sailing with the prevailing NNW winds from Thera at the onset of the precursory eruptions, arrived and settled at Mochlos (Soles 2009).
Phase 1. The climactic eruption began with a Plinian pumice fall deposit, which is subdivided stratigraphically by Druitt (2014) in four stages. The initial stage (Phase 1a) consists of two pumice layers, each overlain by a thin ash layer, indicating an unsteady Plinian column. The thickest Plinian pumice layer (Phase 1b) is not stratified, signifying a steady Plinian column. An ash-rich pyroclastic surge layer (Phase 1c) indicates that seawater gained access to the vent, though pumice deposition is briefly resumed, as reflected by a thin bed (Phase 1d) that caps the Plinian part of the Minoan eruption.

Hardly any concrete stratigraphic knowledge currently exists in relation to archaeological sites concerning the respective impact of the individual eruption phases on areas beyond the Santorini islands. A possible exception is tephra found in excavations at the archaeological site of Mochlos (Soles 2009).

Phase 2. This volcanic phase (Druitt 2014) is dominated by pyroclastic surge deposits, fine and coarser grained layers, dune-like bedforms, white ash and white rhyodacitic pumice, poorly sorted mixtures of ash and lapilli, impact sags by lithic blocks, usually black glassy lava, up to 5 m in size in the upper unit.

Phase 3. The cool phreatomagmatic pyroclastic flows of this phase produced very thick ignimbrite deposits, having a thickness of 55 m at the caldera wall (Druitt 2014). The stratigraphic contact between the underlying Phase 2 is gradational, indicating neither a break in eruptive activity nor caldera collapse (McCoy 2009). Co-ignimbrite ash clouds were probably very significant during Phase 3, but so far no distinct layers related to Phase 3 have been positively identified as such in distal volcanic ash deposits.

Phase 4. This was a dry eruption phase, without access of water to the vent(s), possibly due to the tuff ring formed in Phase 3. Hot, fluidized pyroclastic flows formed thick ignimbrite deposits on the coastal plains of Thera and Therasia (Druitt 2014). These pyroclastic flows continued into the sea, forming very extensive ignimbrite deposits offshore, possibly 80 m thick, as revealed by a robotic underwater survey by Sigurdsson et al (2006).

Archaeological Sites with Minoan Tsunami Impact
The effect of the 1883 Krakatau eruption inspired the Greek archaeologist Marinatos (1939) to envisage possible distal impacts of the Minoan Santorini eruption on Crete by tsunamis and ash falls in a famous hypothesis. However, the search for tsunami impact in Crete remained elusive for many years until widespread tsunami deposits, including Minoan tephra, were discovered and deciphered at the site of Palaikastro (Bruins et al 2008). Possible tsunami impact was raised as an option in view of damage to certain buildings excavated at Palaikastro (MacGillivray et al 1987:150-151; Driessen and Macdonald 1997:90), but convincing evidence was only established during extensive geoarchaeological fieldwork along the coast (Bruins et al. 2008). Volcanic ash transported by wind from Santorini south-east to Palaikastro preceded the tsunami. Field evidence suggests that tsunami waves were at least 9 m high at impact (Bruins et al 2008, 2009).

At Pseira, an offshore island along the northern coast of Crete, about 5 km west of Mochlos, possible tsunami impact has been suggested by Betancourt (2009). Other archaeological sites along the north
coast of Crete, where building destruction may relate to tsunami impact, as suggested by the excavators, are Amnisos (Marinatos 1939) and Papadiokambos (Brogan and Sofianou 2009).

The Minoan tsunami appears to have been of regional significance in the eastern Mediterranean region, as a tsunami layer dated to the period of the Minoan Santorini eruption was discovered on the continental shelf near the ancient harbour of Caesarea along the Israeli coast (Goodman-Tchernov et al 2009).

**Archaeological Sites containing Distal Minoan Volcanic Ash Deposits**

Volcanic ash from the Minoan Santorini eruption was found in three places by Keller (1980) on the island of Kos, about 180 km ENE from Thera. Archaeological excavations by Marketou (1990) on Kos at the site of Seraglio also revealed tephra in LM 1A context, but details about its thickness are not provided.

On Rhodes, a 10 cm thick tephra layer was found during excavations at Trianda (Doumas and Papazoglou 1980), 248 km due east from the Santorini volcano. Subsequent excavations by Marketou (1990) uncovered a distinct tephra layer with a maximum thickness of 70 cm. Doumas (1990) mentioned that tephra up to 100 cm thick was found at Rhodes near Trianda. Although the internal stratigraphy and genesis of these tephra deposits have not been studied, the amounts are impressive. Marketou (1990:112) concludes: “It is beyond any doubt that the tephra which fell on Rhodes had serious effects and influence on the settlement of Trianda. It seems that the people were obliged to leave a part of their town and limited themselves to the northern part nearest to the sea”.

On Crete, volcanic ash from the Minoan Santorini eruption was initially found only dispersed in soil samples, but not as discrete layers. The first finding (Cadogan et al 1972) was from a LM destruction level in a house at Pyrgos along the south coast of Crete. The westernmost area in which volcanic ash was identified by Vitaliano and Vitaliano (1974) came from the outskirts of Heraklion along the road to Knossos. The amount of tephra particles increased significantly in eastern Crete. Volcanic ash particles were also found in LM destruction layers at the archaeological sites of Gournia, Vathypetro, Malia and Kato Zakros (Vitaliano and Vitaliano 1974). On Pseira, tephra particles were found in the upper 20 cm of soil in a terraced agricultural field (Betancourt et al 1990).

Extrapolation of Minoan tephra thickness (isopachs) in deep-sea cores (Watkins et al 1978) over Crete suggests a thickness of compacted tephra of about 0.5 cm near Knossos to 2 cm in easternmost Crete. Discrete tephra layers were more recently uncovered in eastern Crete during archaeological excavations at many sites, going from west to east: Mochlos (Soles and Davaras 1990), Papadiokambos (Brogan and Sofianou 2009), and Palaikastro (MacGillivray et al 1998).

Tephra air-fall from the Minoan Santorini eruption in the eastern Mediterranean region shows both a south-easterly dispersal, fitting prevailing winds in the lower atmosphere, and an easterly to north-easterly dispersal, fitting wind directions at higher altitudes in the stratosphere. Large tephra deposits over Rhodes and Kos may have resulted from huge co-ignimbrite ash clouds. For example, the 1815 Tambora eruption showed an increase in tephra thickness farther away from the volcano.

In the conference lecture, new research results will be presented of a pristine tephra layer from Crete with clear internal micro-stratigraphy, showing for the first time distal eruption phases. A more
significant ash deposit must have impacted eastern Crete than previously understood from adjacent deep-sea tephra layers.

References


Monday, June 6th, 4-7 pm
Session 3

Paleo-ecological Impacts of the Avellino Eruption

Speakers:

Payne R. Detecting the impacts of volcanic eruptions by palaeoecology

Doorenbosch M. & Field M.H. Distal palaeoecological impacts of the great bronze age eruption of mount Vesuvius at Femmina Morta

Discussants: Sadori L. & Bakels C.
Late-Holocene palaeoenvironmental changes from the Gulf of Gaeta


1) Dipartimento di Biologia Ambientale, Sapienza - Università di Roma, Roma, Italy
2) Dipartimento di Fisica e Geologia – Università di Perugia, Perugia, Italy
3) Istituto per l’Ambiente Marino Costiero (IAMC) – CNR, Napoli, Italy
4) Istituto di Scienze Marine (ISMAR), CNR, Bologna, Italy
5) DiSTAR – Dip. Scienze della Terra, dell’Ambiente e delle Risorse – Univ. di Napoli Federico II, Napoli, Italy
6) GRC Geociències Marines, Dept. Estratigrafia, Paleontologia i Geociències Marines. Universitat de Barcelona, Barcelona, Spain
7) Istituto Nazionale di Geofisica e Vulcanologia, Pisa, Italy
8) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy
9) Dip. Scienze e Tecnologie Ambientali Biologiche e Farmaceutiche (DiSTABiF), Seconda Università di Napoli, Caserta, Italy

Introduction

A new high resolution pollen, planktonic foraminiferal and oxygen isotopes record from a shallow water marine sedimentary core from the central Tyrrhenian Sea (Gulf of Gaeta) provides information on vegetation and climate changes occurred in the central Mediterranean region during the last 5000 cal. years BP (Margaritelli et al., 2016). Nine time intervals characterized by clear vegetation and climate changes and associated with archaeological-cultural periods have been described: Eneolithic (ca. 3080–ca. 2410 BC), Early Bronze Age (ca. 2410 BC–ca. 1900 BC), Middle Bronze Age-Iron Age (ca. 1900 BC–ca. 500 BC), Roman Period (ca. 500 BC–ca. 550 AD), Dark Age (ca. 550 AD–ca. 860 AD), Medieval Climate Anomaly (ca. 860 AD–ca. 1250 AD), Little Ice Age (ca. 1250 AD–ca. 1850 AD), Industrial Period (ca. 1850 AD–ca. 1950 AD), Modern Warm Period (ca. 1950 AD–present day). In this paper we aim to characterize the major vegetation changes influenced by climate and human impact.

Environmental settings

The Gulf of Gaeta is located on the west coast of Italy and is part of the Tyrrhenian Sea, which is the deepest major basin in the western Mediterranean Sea. The Gulf is bounded by Cape Circeo in the North, Ischia and the Gulf of Naples in the South, and the Pontine Islands in the West. The Gulf of Gaeta is strongly influenced by the presence of the Volturno River, which represents the longest river in southern Italy (175 km). The continental shelf of the Gulf of Gaeta is the seaward extension of the Garigliano and Volturno coastal alluvial plains filled by Plio-Quaternary clastic and volcanic deposits. The distribution of the modern vegetation of the Gulf of Gaeta borderlands appears to be strongly related to both the inland orographic complexity and the vicinity of the sea, being influenced by insolation, altitude, moisture availability and soil. Sclerophyllous shrublands and Quercus ilex woodlands generally dominate the coastal promontories and the south-facing slopes at low altitudes.
(ca. 0-600 m), while mixed evergreen/deciduous and deciduous forest formations are more frequent at higher altitudes, favoured by orographic humidity (Di Pietro, 2011). In the volcanic district of Roccamonfina, chestnut cultivations represent the main element of the land cover. Conifer forests have a restricted patchy distribution and mostly include coastal and inland Pinus plantations. The agricultural areas, with arable lands and permanent orchards and olive groves, extensively cover plains and foothill zones.

**Materials and Methods**

The study was undertaken on a composite marine sequence based on the two parallel cores SW104_C5 (40°58′24.993″N, 13°47′03.040″E), and C5 (40°58′24.953″N, 13°47′02.514″E), drilled in Gulf of Gaeta, at 93 m water depths during the oceanographic cruise AMICA2013. The correlation between the two cores SW104_C5 and C5 was allowed by the identification of a Vesuvius tephra in the magnetic susceptibility of the two records. The studied interval, namely the first 480 cm of the composite record, is characterized by light grey hemipelagic sediments interlayered by five tephra layers.

Pollen analysis was carried out on 86 samples, collected in the upper 480 cm of the SW104-C5-C5 composite core. The main percentage sum is based on terrestrial pollen excluding pollen of aquatics and non-pollen palynomorphs (fungal and algal spores, as well as microscopic fragments of various organisms found in the pollen slides). Planktonic foraminiferal analysis was based on 346 samples collected every ca. 1.3 cm. Quantitative planktonic foraminiferal analysis was carried out on the fraction >90 µm to avoid the juvenile specimens. In order to characterize environmental changes, the distribution pattern of the herbivorous-opportunistic planktonic foraminiferal species (*Turborotalita quinqueloba*, *Globigerinita glutinata*, *Globigerina bulloides*) and carnivorous ones (*Globigerinoides ruber*, *Globigerinoides quadrilobatus*, *Orbulina spp.*, *Globigerinella siphonifera*) has been investigated. Oxygen and Carbon isotope analyses were carried out on about ten specimens of the planktonic foraminiferal species *G. ruber* alba variety.

The age-depth model of the composite core was mostly based on 210Pb and 137Cs radionuclides evidence for the last ca. 150 years and tephrostratigraphy represented by five tephra layers recorded at the depths of 53, 319, 403, 414 and 437 cm, namely Vesuvius (1906 AD), Vateliero-Ischia (2.4-2.6 ka BP), Capo Miseno (3.7-3.9 ka BP), Astroni3 (4.1-4.3 ka BP), Aagnano M. Spina (4.42 ka BP) tephras respectively. The age-depth model takes also into account reliable time-constrained biostratigraphic events, such as the abundance peak of *Globorotalia truncatulinoides* left coiled (1718 ±10 yr AD, Lirer et al. 2013; 2014) and the acme interval of *G. quadrilobatus*, (base 3.7 ± 0.048 ky BP top 2.7 ± 0.048 ky BP, Lirer et al., 2013). In addition, the good visual comparison between the δ<sup>18</sup>O<sub>G.ruber</sub> signal from the study site (with data from south Tyrrhenian Sea (Lirer et al., 2013, 2014), Gulf of Taranto (Grauel et al., 2013), Adriatic Sea (Piva et al., 2008) and eastern Mediterranean (Schilman et al., 2001) supports the robustness of the proposed age model.

**Results and discussion**

The results of pollen analysis show significant changes in the forest cover, vegetation structure and floristic composition. These variability is related to both the effects of the human pressures on the
vegetation development and oscillations in the forest canopy influenced by climate that are clearly pointed also in planktonic foraminifers and oxygen isotope records.

Eneolithic (ca. 3080-2410 BC; 5030-4360 BP)
During this interval, the pollen record documents a slight and slow opening of the forest vegetation especially in the broadleaved evergreen taxa, suggesting a progressive establishment of an arid climate in the third millennium BC. Planktonic foraminiferal and oxygen stable isotope records generally indicate warm-water conditions, associated with increase in temperatures at ca. 2600 BC, and reduced river runoff. Impact of human activities in the landscape can be considered negligible, mostly due to the absence of clear pollen evidence of cultivations.

Early Bronze Age (ca. 2410-2000 BC; ca. 4360-3950 BP)
During the Early Bronze Age, a clear process of deforestation is documented in the pollen record. This trend of landscape opening, starting at ca. 2700 BC and reaching a maximum at around 2200 BC, mostly affected the evergreen vegetation and coincides with the 4.2 ka BP event. The data from Gaeta are consistent with other pollen records in the Central Mediterranean (south of 43° N), showing a deforestation pattern (ca. 2500-1900 BC) that had a great impact on the evergreen forests cover (Di Rita and Magri, 2009 and refs therein). The high abundance of G. ruber, G. siphonifera and Globigerinoides elongatus in the lower part of this interval reflects warm summer conditions until ca. 2400 BC. At the same time, the occurrence of G. truncatulinoioides and G. glutinata suggests the prevalence of cold, well-mixed, nutrient-rich waters in winter. From ca. 2300 BC to ca. 2050 BC, a strong increase in T. quinqueloba abundance, associated with the δ¹⁸O₀₉₀ruber signal enrichment reflects cold climate conditions consistent with the 4.2 kyr event. Anthropogenic pollen indicators suggest a negligible human impact on the natural environment in the Gulf of Gaeta borderland. Very sporadic records of Olea and Vitis were probably from natural populations.

Middle Bronze Age-Iron Age (ca. 2000-500 BC; 3950-2450 BP)
Between ca 2000 and 900 BC, a newly forested landscape, featured by good amounts of deciduous trees and a rapid recovery of evergreen trees, suggests the setting of warm and humid climate conditions with marked seasonality. A similar pattern of evergreen vegetation recovery is also observed in many coastal and inland pollen sites of the central Mediterranean region (Di Rita and Magri, 2009, 2012 and references therein). This vegetation process finds a good correspondence with the acme interval of the planktonic foraminifer G. quadrilobatus (from ca. 1752 BC to ca. 750 BC), indicative of warm and oligotrophic surface water in summer. High frequencies of the herbivorous-opportunistic species T. quinqueloba and G. glutinata concur in indicating high productivity surface water, strong seasonality and the presence of continental runoff.

Between ca 900 BC and 500 BC a new drop in forest vegetation is recorded, coupled with an increase in Artemisia and other xerophytes. This process may be the effect of new dry climate phase probably induced by the 2.8 ka BP event. This climate change does not find clear evidence in the foraminiferal record, however positive values in the oxygen isotope record may account for a cold shift. As to the human impact, the increase in frequency of Olea and Vitis may be related to the management and exploitation of natural populations. Around 3.6 ka BP, the pollen record reports the first evidence of cereal cultivation.
Roman Period (ca. 500 BC - 550 AD; 2450-1400 BP)
The pollen data in the first 500 years of the Roman period shows relatively open condition, as suggested by appreciable values of herbaceous taxa. Significant amounts of xerophytes, including *Artemisia*, suggest the permanence of quite dry climate conditions.

During the second half of the Roman Period ca. 0-550 AD, the pollen record indicates a significant expansion of the forest cover (AP>90%, peaking at around 350 AD), suggesting that tree populations may have developed under increased warm and humid climate conditions. This feature is also supported by an increase in abundance of herbivorous-opportunist planktonic foraminifera. In addition, the δ^{18}O_{G.ruber} record allows to identify three cold intervals, previously documented by Lirer et al. (2014), which can be correlated with the solar activity (Roman I, Roman II and Roman III).

The impact of human activity increased significantly since the second century BC, mostly related to the increase in *Olea* frequencies suggesting regional exploitation, and reached a maximum at the end of the Roman period in correspondence with the beginning of *Castanea* and *Juglans* cultivation.

Dark Age (ca. 550-860 AD; 1400–1090 BP)
Between the end of the Roman Period and the beginning of the Dark Age, ca 400-700 AD, a decline in the values of trees suggests a reduction of forest cover. This pattern was favoured by a rapid decrease in both evergreen and deciduous broadleaved taxa, as well in conifers, although a marked expansion of *Castanea*, among anthropogenic indicators, contributed to keep high the tree percentage values. According with the δ^{18}O G. ruber values, the early Dark Age (from 550 to 750 AD) was characterized by warm climatic conditions reflected by the increase in warm foraminiferal species, such as *G. ruber*, *G. siphonifera* and *Orbulina* spp. Between ca. 700 and 860 AD, a new natural forest recovery, related to deciduous and conifers tree population expansion, is clearly recorded.

Medieval Climate Anomaly (860-1250 AD; 1090-700 BP)
A decrease in deciduous trees and a considerable parallel increase in herbaceous taxa document a rapid and significant opening of the vegetation landscape favoured by an oscillation towards a more arid and cool climate. Consistently, a reduction in abundance of *G. ruber alba* associated with a slightly increase in *G. ruber* pink, suggest less temperate and humid conditions from ca. 1000 to ca. 1100 AD. From 1100 to 1250 AD pollen data show a new forest recovery, mostly related to an increase in both deciduous and evergreen arboreal taxa, suggesting a climate change toward more warm and humid condition that favoured the growth of broadleaved populations. A marked shift in δ^{18}O_{G.ruber} signal towards negative values, associated with a strong increase in *G. ruber* abundance, marked the warmest interval of the Medieval Warm Period. Evidence of human activities mostly suggests chestnut, walnut and olive cultivations.

Little Ice Age Period (LIA) (ca. 1250-1850 AD; 700-100 BP)
During LIA the cool climate change, reported in the δ^{18}O_{G.ruber} and planktonic foraminifers’ record, determined a significant decrease in forest cover. The deforestation process seems to have particularly affected the broadleaved taxa. Conversely, conifers show a moderate increase under the coolest interval. Also human activities, related to olive, chestnut and cereal cultivations, appears limited.
Industrial Period (1850–1950 AD; 100-0 BP)
The occurrence of warm and humid climate is highlighted by the dominance of herbivorous-opportunistic planktonic foraminiferal species and the $\delta^{18}O_{G.ruber}$ signature and the contemporary increase in G. ruber pink and G. elongatus and the absence of cold planktonic foraminiferal taxa. A clear trend toward humid conditions is reflected by the pollen record, highlighting a general forest recovery. Widespread agricultural practice is revealed by cultivations of Olea, Vitis, cereals and hemp.

Modern Warm Period: 1950 AD to the present day
In recent time, the contemporary abrupt decrease in G. ruber alba variety and the most prominent negative shift of $\delta^{18}O_{G.ruber}$ signal of the last two millennia, suggests a significant human-induced climate warming. A recovery of the arboreal vegetation, dominated by Pinus, may reflect extensive plantation of pine forests in the coastal areas of the Gulf of Gaeta. The human impact on natural ecosystems is also visible in the record of the pollen anthropogenic indicators pointing to a territory increasingly occupied by cultivations and intensive land exploitation for agriculture.

Acknowledgements
We acknowledge financial support from the Italian Project of Strategic Interest NEXTDATA (http://www.nextdataproject.it) “A national system for recovery, storage, accessibility and dissemination of environmental and climatic data from mountain and marine areas”

References
Grauel, A.L., Goudeau, M.L.S., de Lange, G.J., Bernasconi, S.M., 2013a. Climate of the past 2500 years in the Gulf of Taranto, central Mediterranean Sea: a high-resolution climate reconstruction based on $\delta^{18}$O and $\delta^{13}$C of Globigerinoides ruber (white). The Holocene 23, 1440-1446.
Detecting the impacts of volcanic eruptions by palaeoecology

Richard Payne Environment, University of York, United Kingdom

Volcanic eruptions have stochastic, but sometimes severe impacts on ecosystems and human societies. Palaeoecological and archaeological studies are necessary to allow us to understand the past and plan for the future. This talk will address the use of palaeoecological records to identify and reconstruct the impacts of volcanic eruptions. I will first consider how volcanic eruptions affect ecosystems, and therefore the changes which we might expect to see in palaeoecological records. I will then consider some contrasting examples where previous studies have used palaeoecology to address volcanic impacts. Finally I will consider some of the challenges which need to be addressed if the palaeoecological approach is to become more established.

What can we expect to see?

It is useful to begin by considering the ways by which volcanic eruptions may affect ecosystems to allow us then to consider how these may be represented in palaeoecological records. High quality ecological studies of the impacts of volcanic eruptions have only been conducted in the last few decades so the range in size and eruption style is limited, but these can nevertheless provide a guide to the processes which may have operated in the deeper past. The available research suggests four general mechanisms by which volcanoes may affect ecosystems.

1. **Physical effects**. Volcanic eruptions may have physical effects on biota through several pathways. In proximal sites the modes of impact are obvious: crushing or burial by lahars, pyroclastic flows or tephra; incineration by lava or pyroclastic material; direct destruction by explosive volcanic activity (Gorshkov and Dubik; Griggs, 1915; Eggler, 1948). For most eruptions, however, such impacts only affect a relatively localised area in the immediate vicinity of the volcano. In the distal zone the physical impacts of volcanic eruptions are primarily mediated by the properties of tephra. Tephra may abrade external surfaces, irritate mucus membranes, block pores (including plant stomata), coat surfaces impeding plant photosynthesis and gas exchange and bury, weigh-down and crush organisms (Griggs, 1915; Wilcox and Coats, 1959). Tephra in the landscape may inhibit gas exchange between soil and atmosphere (Hinckley et al., 1984) and modify hydrology (Vucetich and Pullar, 1963). These impacts may lead to the death of individuals and shifts in the competitive balance between species.

2. **Chemical effects**. Volcanoes modify the chemical environment of ecosystems around them through production of gases and tephra. The gases volcanoes emit can vary greatly but frequently include considerable quantities of \( \text{CO}_2 \), \( \text{SO}_2 \), \( \text{H}_2\text{O} \) and sometimes \( \text{HCl} \) and \( \text{HF} \). Ecosystems can be exposed to these gases as both dry deposition (gaseous and particulate) and wet deposition (precipitation, aerosols) following contact with water. Impacts may include oxidation and acidification. Impacts on vegetation frequently resemble those of acid air pollution with defoliation and necrosis (Parnell and Burke, 1990; Delmelle et al., 2002).
Further chemical inputs may come from the tephra itself. Studies of leachates from Mt St Helens 1980 tephra showed a host of heavy metals (Zn, Cu, Cd, F, Pb, and Ba) in sufficient concentrations to have biological impacts (Smith et al., 1983). A corollary of these negative impacts is the possibility for enhanced growth as volcanic products may provide a supply of limiting nutrients such as P and K (Jones and Gislason, 2008).

3. Climate effects. Volcanic eruptions have the potential to modify climate by the production of stratospheric aerosol following large explosive events. Following historically-documented eruptions the scale of the cooling is in the order of >~1°C for several years, but with considerable variability between eruptions and monitoring sites (Angell and Korshover, 1985; Mass and Portman, 1989; Douglass and Knox, 2005). There is considerable debate about the potential climatic impacts of larger eruptions which have not occurred during the era of instrumental climate records (Scuderi, 1990; Jones et al., 1995; Zielinski, 2000) but most estimates suggest that even following the largest Holocene eruptions cooling is unlikely to greatly exceed 2°C and unlikely to last more than a decade. In the very short term, volcanic impacts on weather may include heavy rainfall and lightning.

4. Biological feedbacks. Finally, it must be remembered that impacts on one component of an ecosystem are highly likely to have impacts on other components of that ecosystem even if those components are not directly affected. Thus, even if a plant species is entirely resilient to tephra deposition or acidic precipitation following an eruption, it nevertheless might still be affected by impacts on its predators, pathogens or competitor species.

The biological consequences of these impacts are, of course, variable. At the most extreme, volcanic processes can cause extensive mortality, even entirely eliminating life (at least, multicellular life) from a landscape and setting the stage for a classic primary succession (Fridriksson, 2013). Even beyond the immediate proximal zone, mortality due to volcanic effects seems apparent in most types of organism, ranging from microbes (Urrutia et al., 2007) to insects (Marske et al., 2007) to fish (Hidayati et al., 2014) to birds (Dalsgaard et al., 2007). Other species may increase in abundance to fill vacated niches or take advantage of new opportunities, for instance the decomposition of dead organisms (Staley et al., 1982) or supply of nutrients (Urrutia et al., 2007). Where there is no direct mortality there may still be reduction in growth rates. For instance, tree ring records graphically attest to reduced tree growth following volcanic disturbance (Stoffel and Bollschweiler, 2008; Bollschweiler et al., 2009). Volcanic impacts may lead to physiological changes and adaptations in organisms, for instance production of extended rhizomes (Antos and Zobel, 1985) or changes in xylem density in trees (Eggler, 1967). Volcanic modifications of the landscape may also lead to changes in the relationship between species, for instance changes in plant-pollinator relationships (Martínez et al., 2012) and changes in how raptors use the landscape (Cabezas-Cartes et al., 2014). All of these processes may lead to restructuring of ecosystem composition. The temporal duration of impacts is highly variable. Some may be extremely transitory, others may have a duration of decades, centuries or even millennia (Kilian et al., 2006). There are parallels with the impacts of air pollution where experimental studies have shown that there is considerable hysteresis in post-exposure recovery and some changes may be essentially irreversible (Isbell et al., 2013).
Detecting volcanic impacts using palaeoecology

Understanding volcanic impacts provides a good example of the need for palaeoecology as the number of contemporary events which have been studied is very limited. Consequently, there is a long history of attempts to link palaeoecological evidence to volcanic activity. Volcanic events have been implied in most Holocene palaeoenvironmental records, including ice cores (Hammer et al., 1980), speleothems (Baker et al., 1995), corals (D’Arrigo et al., 2009) and tree rings (LaMarche and Hirschboeck, 1984). The focus of this review, however, is sedimentary records of preserved remains of organisms in environments such as peat bogs and lakes. In the rest of this paper we will consider some of the potential of this approach, some examples, and some of the challenge to application. We focus particularly on *tephropalaeoecological* studies: those which have attempted to investigate volcano-induced environmental change by palaeoecological analysis across tephra layers (Payne and Blackford, 2008).

The potential of the approach

The power of the tephropalaeoecological approach is perhaps best illustrated by some specific examples.

Blackford et al. (2014) investigated the mid-Holocene eruption of Aniakchak in southwestern Alaska at a tundra site in northwestern Alaska. The authors conducted high-resolution analyses of pollen and oribatid mites across a 3-4mm thick visible tephra layer, and extracted a number of samples for AMS radiocarbon dating. The pollen data showed a switch from cyperaceae to poaceae-dominated vegetation across the tephra layer. The oribatid mites showed changes in community which began immediately below the tephra, but might nevertheless be due to the volcanic event (due to subsurface dwelling mites). The most dramatic evidence for volcanic impact, however, was in the dating with suggestions of a ~100 year accumulation hiatus following the eruption. Taken overall this data suggests a rather dramatic impact of the eruption in this site at over 1000km distance from the volcano. If this hiatus in peat accumulation (whether due to a true halt in accumulation or erosion/oxidation of peat) is present more widely it might indicate a neglected climate feedback.

Barker et al. (2000) investigated the response of diatom communities to tephra deposition in Lake Massoko in northern Tanzania. Following a large volcanic event at c.1190BP the authors identified an abrupt shift in diatom assemblages. The planktonic species *Synedra acus* replaced *Aulacoseira* spp. and persisted as the dominant species for c.110 years. The authors hypothesize that the change was due to tephra forming a ‘cap’ over basal sediments. This cap would have limited P diffusion and increased the Si:P ratio. The study nicely illustrates how palaeoecological studies can help untangle the mechanisms by which volcanic eruptions have affected ecosystems in the past, and may do in the future.

Finally, a number of studies have investigated the impact of the Icelandic Hekla 4 tephra deposition in Britain and Ireland. In peatland sites in northern Scotland Blackford et al. (1992) showed coincidence between tephra deposition and a decline in *Pinus* pollen. This was an interesting finding due to the widespread occurrence of a mid-Holocene *Pinus* decline in this region. The authors proposed the impact of volcanic acids or a volcanic-induced climate change as conceivable mechanisms. However, soon after this study further work, this time in northern Ireland, failed to identify any such synchronicity (Hall et al., 1994). Many further studies followed with some
suggested to provide evidence for impacts on vegetation, and others not (Charman et al., 1995; Dwyer and Mitchell, 1997; Caseldine et al., 1998). In all of these studies the identification of volcanic forcing was qualitative but more recently these datasets have been statistically analysed (Payne et al., 2013). This re-analysis highlighted that only in the original Altnabreac site studied by Blackford et al. (1992) was evidence for a link between volcanism and vegetation change very convincing. While this does not disprove the idea that Hekla 4 had impacts on vegetation in Britain, it does show that the evidence for this theory is currently weak. This example nicely illustrates some of the complexity involved in using palaeoecological data to assess volcanic impacts on the environment.

Collectively these three examples illustrate the ways in which palaeoecological studies can contribute to knowledge of volcanic impacts, but also some of the difficulties involved.

**Three key challenges**

Three practical issues in studies using palaeoecology to understand volcanic impacts on the environment include:

1. **Availability and quality of archives.** A prosaic, but important, challenge to the wider application of this approach is simply the availability of suitable archives. Palaeoecology is generally easiest in regions with abundant lakes or peatlands, high rates of sediment accumulation and limited anthropogenic disturbance. Consequently, it is unsurprising that the majority of studies applying the tephropalaeoecological approach have been in the temperate and boreal zone. The first challenge in tephropalaeological studies in more arid regions, such as the Mediterranean basin, is simply finding good sites with intact, and ideally high resolution, stratigraphy. A secondary challenge will often be the adequate preservation of microfossils in those sites, particularly if they have been subject to considerable human disturbance.

2. **Taphonomy.** A frequent assumption of the tephropalaeoecological approach is that both tephra and the microfossils being analysed are stable in the stratigraphic column, but it is clear that this is not always the case. In lake and marine sediments there is considerable evidence for secondary deposition and differential taphonomy (McCoy, 1981; Anderson et al., 1984; Boygle, 1999). In peat bogs, movement of tephra appears to be less pronounced but still considerable (Payne et al., 2005; Payne and Gehrels, 2010), particularly when disturbed by human activity (Swindles et al., 2013). Concentration profiles of cryptotephra frequently show considerable dispersion and often secondary peaks, requiring difficult judgements about which horizon exactly should be considered to mark the eruption. There is similar evidence for post-depositional movement of many of the microfossils which are the focus of palaeoecological study (Clymo and Mackay, 1987) so linking tephra profiles and palaeoecological records requires a judgement to be made about the taphonomy of both sets of particles.

3. **Distinguishing cause/effect from coincidence.** Perhaps the greatest challenge to the use of palaeoecological records to understand the impacts of volcanic activity is in making links between records of volcanism and those of palaeoecological change. It is fundamentally impossible to prove cause-effect relationships with palaeoecological data so a degree of judgement will always be required. The limited range of modern ecological study is a particular handicap. It will be clear from the preceding discussion that the number of
potential mechanisms at work is large, and plausible responses varied and complex. For instance, if we consider the example of tree-rings: both anomalously narrow and anomalously wide rings have been attributed to volcanic activity e.g. (Baillie and Munro, 1988; Pearson et al., 2009). It is therefore often difficult to determine whether a palaeoecologically-observed change is due to a volcanic event purely on the basis of the nature of the response so chronology becomes critical. Particularly problematic are studies which attempt to infer links between palaeoecological change and volcanic activity based on chronological alone, without direct evidence from the stratigraphic profile in the form of tephra layers. Such studies are particularly prone to what Baillie (1991) has called ‘suck in’ and ‘smear’: the tendency of researchers to attribute links between events which may be unrelated on the basis of (often limited) chronologies. Or, to quote Renfrew and Grayson (1979) ‘an eruption here, a destruction there, a plague somewhere else -- all are too easily linked in hasty surmise’ (Sadler and Grattan, 1999).

However, even when we do have direct evidence to place a volcanic event in context with biostratigraphic data, linking change in biota to volcanism remains complicated and subjective. The case will be strongest where evidence is replicated between cores and sites and consistent with what might be expected from ecological studies. There is also a strong case for the use of appropriate statistical tools to address these questions (Birks, 1994; Payne et al., 2013). While statistics can never prove cause-effect, they can help us address questions such as: is this change part of pre-existing trend? Is it consistent with what we might expect to see following a volcanic eruption? How does the magnitude of (inferred) impact vary between sites?

Palaeoecological studies have proved themselves to be of considerable value to help understanding the impacts of volcanic eruptions. Future studies need to focus on replicating results, maximising resolution and exploiting the potential of the approach for a greater variety of sites, regions and eruptions.

References


Distal palaeoecological impacts of the great Bronze Age eruption of Mount Vesuvius at Femmina Morta

Marieke Doorenbosch & Michael H. Field  
*Faculty of Archaeology, University of Leiden*

**Introduction**

The major Early Bronze Age eruption of the Monte Somma Vesuvius (1995+-10 BC) must have had an enormous impact on the landscape and inhabitants of the Campania region. The population fled the area and a significant percentage of the refugees might have resettled in the Pontine Plain and the Fondi Basin of South Lazio, north from Campania. Environmental impacts brought about by the influx of the postulated substantial body of immigrants from Campania should be detected when reconstructing the vegetation in the coastal wetlands of South Lazio before and after the Avellino eruption. The distal ash from the Avellino has been found in the sediments of the Pontine plain and the Fondi basin (Sevink et al. 2011) and this lithological horizon acts as a stratigraphic marker.

**Femmina Morta 197**

In this paper the preliminary results from pollen and macrobotanical analyses from samples taken at section 197 at the site Femmina Morta (see figure 1) will be discussed. The botanical research of sediments from this site is ongoing. Femmina Morta is located in the lagoonal area between the Pleistocene and Holocene beach ridges in the Fondi basin. At this site a peat sequence was present in which two sandy layers, which were identified as tephra layers, were present (see figure 2). The upper tephra most likely is the Avellino tephra, but the discovery of multiple ash layers in this area is new and definite identification has yet to take place (van Gorp and Sevink in prep.). In October 2015 cores were taken for pollen analysis. In February 2016 a trench was dug with the aim of taking samples for macrobotanical research.
Plant macrofossil investigation

Initial effort has concentrated on examining the sediment samples collected from either side of the upper tephra layer exposed in the section, which was 2 cm thick. The cohesive nature of the peats below and above the upper tephra layer allowed accurate 2 cm interval sampling. Plant macrofossil analysis of these two samples (sample 5 – 54-56 cm depth and sample 6 – 50-52 cm depth) would give an insight into the vegetation and environment immediately before and after the tephra was deposited. In addition, the aim was also to extract plant macrofossils from terrestrial plants – if they occurred. These would be used to obtain accurate radiocarbon dates allowing the construction of a precise chronology for the profile.

Sediment subsamples of 100 cm³ were wet sieved through a nest of sieves and plant macrofossils were picked from the resulting residues. The method used is described in Field and Peglar (2010).

Of note when comparing the assemblages from samples 6 and 5 is the difference in taxa diversity and plant macrofossil concentrations. Sample 5’s assemblage, taken from below the tephra, has 15 taxa represented and contains 107 plant macrofossils, whereas sample 6’s assemblage has 5 taxa represented and only yielded 26 plant macrofossils. If taxa diversity and plant macrofossil concentration are assumed to give an indication of the nature of the vegetation that existed at the time of sediment deposition, then these figures would suggest that the tephra fallout did have an impact on the local vegetation.

Just prior to the deposition of the tephra the sample 5 assemblage shows that a reed swamp existed at the site which was composed of taller plants such as Cladium mariscus and Typha sp. In amongst these taxa were growing other waterside and damp ground plants such as Lythrum salicaria and Epilobium cf. hirsutum. On the margin of the water-body where more open areas occurred there would have been less competition for light. Here shorter plants, such as Eleocharis sp., Juncus subnodulosus (figure 1), Mentha cf. aquatica, Ranunculus flammula and Samolus valerandi, would have grown. Only four obligate aquatic plant taxa are represented. The bottom of the water column was inhabited by the large aquatic alga Chara sp. The presence of Groenlandia densa suggests that the water column contained little suspended sediment and was probably basic. Nymphaea alba, together with the other aquatic taxa recorded, points to slow moving or still water which was mesotrophic.

Figure 2. The Femmina Morta 197 section that was exposed during February 2016. The lighter upper tephra and the lower grey tephra are clearly visible.
After the tephra had covered the area *Cladium mariscus* survives, but most of the plant taxa growing at the margin of the water-body disappear. *Polygonum minus* is the only species found in sample 6 that was not recorded in sample 5. In the water-body *Chara* sp. and *Nymphaea alba* remain. If the tephra fallout was a short-term event, it may be expected that the taller plants were relatively unaffected. However, the shorter plants may have been completely covered by the ash and as a result be killed off in the short term before re-generation took place.

Unfortunately, as yet no terrestrial plant macrofossils have been found to be radiocarbon dated.

Figure 3. The testa of a seed of *Juncus subnodulosus* from sample 5 (Femmina Morta section 197). Note the characteristic rectangular epidermal cells and the forked projections.

**Palynological research**

The aim of the palynological research of the core taken at Femmina Morta 197 was to reconstruct the regional vegetation development in the area. Changes in the vegetation might be the result of an increase in local population density.

34 subsamples at a 1 cm interval were taken from the core, from 48 cm to 84 cm depth. Samples were treated with 10% KOH, 37% HCl, Bromoform/Ethanol (s.g. 2.0) and acetolysis. To every sample tablets containing *Lycopodium* spores were added for the determination of pollen concentration. Pollen and spores were identified according to the keys of Beug (2004). At the moment of writing the paper 13 subsamples have been analysed of which 4 samples were derived from directly above the upper tephra layer and 9 samples from directly below. The results are shown in a reduced pollen diagram (see figure 4. Taxa that were present in low quantities were left out, a complete pollen diagram will be published later), drawn with TILIA and TILIA Graph (Grimm 2011). Percentages are based on an upland pollen sum. Taxa that were probably present locally were left out of the sum.

The diagram consists of 2 zones, zone 1 below the tephra and zone 2 above the tephra. In zone 1 pollen from *Fagus* and *Pinus*...
represent vegetation that was growing not in the immediate surroundings of the sample area. *Fagus* was probably present in the mountains, whilst *Pinus* might have grown in the coastal area. The forest vegetation in the surroundings of the bog was dominated by deciduous (*Quercus robur*-type and *Quercus cerris*-type) and evergreen (*Quercus ilex*-type) oak species. Other trees present in the surroundings were mainly *Corylus*, *Ostrya*, *Fraxinus excelsior* (and some *F. ornus*) and *Carpinus*. Ericaceae, *Phillyrea* and *Olea* were dominating taxa in the scrubland. The presence of Cerealia, *Rumex acetosa*-type, *Artemisia* and *Plantago lanceolata* indicate open places in the vegetation that were influenced by human activities. This suggests that the area was already inhabited prior to the Avellino eruption.

The pollen and spore assemblage representing the local vegetation is consistent with the macro fossil assemblage and mainly consists of Cyperaceae (possibly *Cladium mariscus* and *Eleocharis*, which were found in the macro remains), *Sparganium*-type (represented in the macro botanical assemblage as *Typha* sp.), Poaceae and monolete psilate fern spores. Taxa representing vegetation from open water are *Myriophyllum* sp. (*verticillatum*-type and *alterniflorum*-type) and *Nymphaea*, of which macro fossils have been found. *Alnus* pollen is present in low percentages, suggesting the tree was scattered throughout the bog area.

Zone 2 represents the vegetation development after the tephra deposition in the area. The similarity in the pollen data between zone 1 and 2 suggests that the ash covering the area had not notably affected the regional vegetation. As has been suggested in the macro fossil analysis section the tephra deposition might have been a short-term event, leaving the dominating forest vegetation relatively unharmed. Cyperaceae in the local pollen assemblage seems to have decreased, as was also shown in the macro analysis. Other taxa show no changes immediate after the tephra fallout. Percentages of *Alnus* and Poaceae pollen increase markedly in the following period, this is however not likely to be a direct result of the Avellino eruption.

Figure 5. Pollen diagram from 13 samples taken above and below the upper tephra layer from Femmina Morta 197. Exaggeration of curves 5x in grey.
**Preliminary conclusions**

The tephra fallout seems to have had an effect on the local vegetation, as is represented by the macro fossil analysis. The regional vegetation seems not to have been notably affected. People were most likely already present in the area before the Avellino eruption and had affected the natural vegetation, which was also shown in a previous study in the nearby Pontine Plain by Bakels et al. (2015). After the Avellino eruption an increase of the population might have taken place due to refugees from the Avellino region. Effects of such a possible increase in inhabitants and their activities are not visible in the botanical research of *Femmina Morta*. However, this research is still ongoing and the results presented in this paper are preliminary.

**References**

Tuesday, June 7th, 9-12 am
Session 4

Impacts of the Avellino Eruption on Health, Food Economy and Infrastructure

Speakers:

Grattan J. *The impacts of volcanic eruptions on human health*

Torrence R. *Impact of Volcanic Eruptions on Food Procurement.*

Vanzetti A. Marzocchella A. & Saccoccio F. *The impact of the Avellino Pumice eruption on the Early Bronze age Campanian agrarian pattern.*

Discussant: Grattan J
The Impacts of Volcanic Eruptions on Human Health

John Grattan  Aberystwyth University

Overview of major health impacts of volcanic processes
Volcanic and geothermal activity area amongst the most dramatic of all natural phenomena, and they pose numerous risks to human health. Volcanic vents and fissures provide a conduit by which magma – the molten rock, gases and water within the earth – may interact with human biological systems. The majority of fatalities from volcanic activity in the past few centuries have resulted from as pyroclastic flows, lahars, and suffocation or building collapse from ash or debris; from tsunamis, which may spread for hundreds of miles from the active site; and from indirect consequences of eruptions, such as famine or infectious disease outbreaks. Apart from the thermal and physical injuries resulting from an eruption, ejecta may also contain toxic elements and compounds, including silica, fluoride and heavy metals, which may lead to risks of acute or chronic toxicity. These compounds may be carried within eruptive columns, plumes or runoff and thus have health impacts at a significant distance away from the active site.

Although morbidity following volcanic eruptions is often comparable to those seen in other natural disasters - such as earthquakes - a number of disease processes are more specific to the characteristics of volcanic and geothermal processes. The nature of the eruption (or other volcanic event) influences the duration of emissions, the chemical composition of the toxic compounds expelled, and the range of dispersal. Volcanic products vary in terms of particle size, concentration, pH, and water solubility. All these factors can influence the bioavailability of toxins, and thereby processes by which adverse health effects may result. The duration of exposure plays one of the most crucial roles in determining health outcomes. For example, some insults may be short-lived and reversible, as with conjunctival irritation from ash particles, or may be chronic, as with inhalation of silica particles resulting in the life-long respiratory problems of silicosis. Apart from the obvious thermal and physical injuries resulting from an eruption, volcanic materials may also contain toxic elements and compounds which disrupt biological systems. These compounds may be released in the form of gases, or carried with volcanic matter falling from eruptive columns or ash plumes. Some toxic compounds, such as radon, may persist in volcanic products (and continue to cause injury) long after the eruptive event ceases.

Near-vent eruptive processes
Explosion
Initial explosive events herald the start of many eruptions and can generate a number of hazards. The behaviour of eruptions relate to the rate at which gases are released from magma or surrounding material. Where magmatic or other gases cannot freely escape and become concentrated, dramatic explosions are more likely. Some eruptions are “phreatic”, in which vaporized groundwater acts to eject pre-existing rock and soil. These are often followed by a
“magmatic” eruption, in which upwelling molten rock is released. The emission of large fragments of debris, such as “blocks” and “bombs”, may cause severe physical injury, such as lacerations and fractures. Heavy fallouts (especially of pumice) can lead to burial and asphyxiation, either directly or through, for example, roof collapse.

Lava flows
One of the more visually dramatic outcomes of volcanism is the ejection of fluid or semi-fluid material, such as basaltic lava. In some locations (for example, Hawaii), eruptions may be associated with fountaining of molten material, in which globules of plastic lava are sprayed over a kilometre high. These may feed into lava lakes and lava flows, which course away from the volcano. The direct threats to health posed by lava flows are primarily thermal injuries. One of the more visually dramatic outcomes of volcanism is the ejection of fluid or semi-fluid material, such as basaltic lava. In some locations (for example, Hawaii), eruptions may be associated with fountaining of molten material, in which globules of plastic lava are sprayed over a kilometre high. These may feed into lava lakes and lava flows, which course away from the volcano. The direct threats to health posed by lava flows are primarily thermal injuries. Often fatalities occur because of unexpectedly rapid flows, because escape routes have been cut off, or from steam explosions created when the lava strikes a water source. Lava flows may result in illness less directly by exposing humans to toxic chemicals. For example, the basaltic lava flows in Hawaii are often associated with the release of sulphur dioxide and aerosolized droplets of sulphuric acid Lava may also act to taint subterranean wells by the process of leaching.

Pyroclastic flows
Pyroclastic flows are intensely hot flows of gas and dispersed fragments of debris, which may travel at speeds up to 200km/h. The exact composition and temperature varies greatly, but may reach 1000°C. The gas content will usually include H2O (which may be superheated), CO2, SO2 and H2S. With their considerable kinetic energy, these deadly “volcanic hurricanes” simultaneously sear and blast objects in their path. The fatality rate of those caught in such flows is usually extremely high: common causes of death include asphyxiation (often from burial), trauma, and severe burns (especially for the respiratory system). For example, during the 1902 eruption of Mount Pelée on the island of Martinique, such a superheated gas cloud rapidly enveloped the city of St. Pierre, resulting in over 30 000 fatalities.

Pyroclastic flows result in varying degrees of thermal injury to the skin ranging from superficial erythema, to deep penetration into the subcutaneous tissues, to the extreme of complete incineration. Victims are commonly described as appearing dried and “mummified,” rather than charred (the outcome usually observed with fire injuries). Respiratory effects appear to occur as a result of intense heat, oxygen deficiency, ash inhalation, and toxicity of the gas. Asphyxia from plugs of ash in the upper airways was described as the cause of death in those caught in the flow of the Mt St Helens eruption. Survivors may suffer from pharyngeal burns, including throat pain, shortness of breath and inability to swallow. Health effects subsequent to the acute injury include pneumonia and tracheobronchitis from irritation and secondary infection of injured respiratory tissues.
Tephra dispersal
Tephra dispersal is a major cause of morbidity following eruptions. Tephra thrown into the atmosphere may cause disease through the fallout of particles from eruption columns or plumes on human populations, or through the movement of individuals into eruptive clouds (such as occurs with aircraft passengers and crew). Smaller particles of pumice, scoria and ash may be distributed over a wide area around the eruptive site, and in some cases plumes may affect settlements situated hundreds of kilometres away.

Volcanic ash (solid ejecta <2mm in diameter) has the potential to physically irritate or injure mucous membranes, eyes and skin, and particles <10 µm in diameter - especially those in the fine and ultrafine category - can penetrate to the bronchioli and alveoli to produce mucous hypersecretion and bronchoconstriction. The eyes are particularly vulnerable to the emission of fine tephra particles. Common ocular injuries include abrasions of the cornea and conjunctivitis from accumulation of ash in the conjunctival sac. Superficial tissues such as the skin, lips, mouth and other mucous membranes may also be exposed. Nasal and throat irritation are commonly reported by those exposed to ashfall.

The ‘respirable’ portion of tephra refers to particles less than 10 µm in diameter, and those under 2.5 µm may penetrate furthest into the lungs: the terminal bronchiolar and alveoli. The proportion of respirable ash varies greatly across eruptions. Higher levels of total suspended particles (TSP) caused by ash-fall may precipitate some pre-existing respiratory complaints, including asthma and bronchitis. The probable mechanism by which ash produces such respiratory symptoms is by provoking hypersecretion of mucus and bronchoconstriction (narrowing of the air passages). Dispersal of tephra may also produce health effects over a longer duration, and in these terms, one of the most troublesome compounds produced by volcanic activity is silica. Inhalation of fine particles of crystalline silica, including quartz, is a well-established cause of both acute and chronic inflammatory reactions in lung tissue. Certain forms of silica, such as cristobalite and tridymite, occur in lava and may be formed when amorphous silica or quartz is heated to high temperatures.

Gas emissions
Steam, from both magmatic and superficial sources (such as overlying lakes or ground water) is the most common volcanic gas. Other, often very toxic, gases are also emitted during eruptive events and there are numerous accounts of volcanic gases causing death. In terms of adverse impacts on human health, volcanic gases may be classified as follows: gases which act as ‘inert’ asphyxiants; those with irritant effects on the respiratory system; and those which combine both properties and act as noxious asphyxiants. Of the ‘inert’ asphyxiants, carbon dioxide, CO2, is among the most notorious gases because it is heavier than air, and may pool at ground level and result in asphyxia. It illustrates the effect of an inert asphyxiant gas: it replaces oxygen, but does not have a directly toxic effect on biological tissue. Concentrations of CO2 are particularly high near emission vents, and the degassing of volcanic soil may result in the collection of carbon dioxide in cellars, huts and in low-lying areas. Low concentrations (eg under 5%) produce accelerated breathing, and often feelings of discomfort, by direct activation of the respiratory centres in the brain. Headache and vertigo are early symptoms. If sufficient concentrations are reached (for example, concentrations of 7-10% for a few minutes), fainting occurs. Elevated levels of CO2 in the bloodstream (hypercapnia) eventually result in circulatory failure and death from acidosis.
Volcanic gases which have primarily irritative (that is, directly injurious) effects include the hydrogen halides, hydrofluoric acid, HF, and hydrochloric acid, HCl, and the oxides of sulphur and nitrogen. Sulphur dioxide, SO$_2$, is a well-established as a cause of acute and chronic disease. Both the gas, and the sulphuric acid aerosols into which it forms, are highly irritant, particularly to the eyes, nasal passages, throat, and respiratory tract.

The pungent gas hydrogen sulphide, H$_2$S, acts as both an asphyxiant and a powerful irritant. Its metabolic effect is to inhibit cytochrome oxidase, one of the enzymatic drivers of cellular metabolism. At low concentrations, H$_2$S may cause irritation of the conjunctivae and mucous membranes. Early signs of poisoning include headaches, ocular and respiratory irritation, and loss of smell (anosmia). Apart from these effects, inhalation of the gas also directly damages the respiratory tract, and precipitates pulmonary oedema in the lungs. At 1 000 ppm, fainting occurs. Ultimately, H$_2$S causes cessation of breathing by direct action on the respiratory centres of the brain and high concentrations may be fatal.

**Health risks from other processes associated with volcanism**

**Crater lakes**

A number of active volcanoes contain crater lakes, some of which act to condense volcanic gases and hydrothermal fluids, thereby yielding extremely acidic, sulphur-saturated contents. These lakes can also be a source of fluoride and other elements, including Cu, Pb, Zn, Ni, As, Sb, Hg, Mg and Cd. These contaminants may be released into waterways or soils through a gradual seepage or overflow, or more dramatically through the action of lahars (volcanic mudflows), which are discussed below. Outflows from volcanic lakes may also result in destruction of food sources or heavy metal contamination.

**Lahars**

A fast-moving, and potentially lethal, consequence of volcanic eruptions is the lahar. These torrential flows of mud, water and debris wash down the sides of the volcano, and area associated with crater lakes, the melting of snow and ice during or after eruptive events, or the superimposed effect of rainfall. Lahars from some volcanic lakes may be hot and acidic.

**Tsunami**

Amongst the most destructive impacts of volcanic eruptions are tsunami. Amongst the most famous of historical tsunami linked specifically to volcanic events are the Minoan (or Thera) eruption in the Santorini archipelago of the Aegean, which occurred 3600 years ago and triggered a massive tsunami which hit Crete 100 kilometres to the south.

**Indirect effects of volcanic events**

Natural disasters, regardless of their cause, must be evaluated in terms of a number of common threats to human health. Disasters often result in a state where there is a marked reduction in the ability for people to sustain their normal living conditions, thus risking their life, health or livelihoods. As with many disasters, the population displacement secondary to volcanic emergencies creates its own health risks from poor sanitation, overcrowding and contamination of food or water sources.
A number of factors increase the vulnerability of communities to disasters, including: (i) poverty, and its consequences such as malnutrition, homelessness, and isolation; (ii) urbanisation. It has been noted that urban areas “concentrate” risk because of dense concentrations of people, services and infrastructure that are easily disrupted (including pipelines and roads). The risk of communicable disease is usually proportional to the population density and displacement. Disasters put pressure on water and food supplies, and increase the risk of contamination by disruption of pre-existing sanitation services such as piped water and sewage. Disaster victims are often at risk of climatic exposure (hypothermia or hyperthermia). Anxiety and depression are common immediately following disasters – and post-traumatic stress disorder (PTSD) can affect people over many months or years after such an event.

Death and disease with volcanic activity have resulted either from the direct physical injury caused by ejecta (the products of eruption, including gas, lava, tephra, and lahars), or from indirect effects of eruptive events (such as building collapse, population displacement, and fire). Volcanic activity also results in health effects indirectly through their damaging effects on food and water sources. Eruptive products may travel along many routes, and in a variety of chemical forms, before finally appearing in human biological systems. Carriage in the atmosphere and hydrosphere are the most common modes of dispersal, but poisoning may also occur as a result of volcanic products entering the soil and food chain.

Food security issues through burning, defoliation or burial of crops and reduced photosynthesis from ash clouds. This geophysical activity may continue for many years, sometimes requiring complete relocation away from non-viable land. One classic example is the impact on Icelandic society following the eruption of Laki in 1783. During this eruption, during which over 140 cones formed along a 27 kilometre fissure, it is estimated that 150 megatons of sulphur dioxide and eight megatons of fluoride compounds were discharged. This vast quantity of gas, and the aerosolised sulphuric acid if formed, had destructive consequences for vast tracts of surrounding pasture-lands. With the extensive crop damage, stock starved from loss of feed. The deposition of high concentrations of fluorine on pastures and waterways also proved fatal for numerous animals.

Volcanic emissions may also be deposited onto bodies of water, including irrigation or filtration plants, thus rendering the water highly turbid and unusable. Water runoff from volcanic or low-level geothermal sites also contains heavy metals, including arsenic, which can be deposited in soil or water (including seepage into subterranean wells) following activity. Some of these elements and compounds have safety levels established in drinking water and could potentially cause harm if ingested in quantities exceeding these concentrations.
<table>
<thead>
<tr>
<th>ERUPTIVE EVENT</th>
<th>EXPOSURE PATHWAY</th>
<th>DIRECT HEALTH IMPACT</th>
<th>INDIRECT / DELAYED HEALTH IMPACTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosion</td>
<td>Blast, rock fragments, shock waves</td>
<td>Trauma, skin burns, Lacerations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lightning</td>
<td>Electrocution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forest and bush fires; combustion of buildings and vehicles</td>
<td>Burns; smoke inhalation</td>
<td></td>
</tr>
</tbody>
</table>

| Lava           | Lava flow       | Engulfing and burns   |                     |
|                | Forest/bush fires | Burns               |                     |

| Pyroclastic flows and other thermal emissions | Pyroclastic flows; Ash flows and falls | Skin and lung burns | Asphyxiation          |

| Ashfall | Dispersion of fine ash/dust less than 10μm in diameter | Exacerbation of pre-existing respiratory disease (such as asthma/COPD*) | Chronic silicosis if free silica content high and exposure prolonged |
|         | Dispersion of siliceous dust | Acute silicosis |                     |
|         | Contamination of water supplies with fluoride, possibly also heavy metals | Gastrointestinal upset and electrolyte disturbance / toxicity |                     |
|         | Contamination of food/ Destruction of crops and livestock | Gastrointestinal upset and electrolyte disturbance / toxicity | Malnutrition from food scarcity, Toxicity e.g. from fluoride or metal contamination |

| Gas Emissions H₂O, SO₂, CO, CO₂, H₂S, HF | Pooling in low-lying areas | Asphyxiation/ suffocation | Toxicity e.g. from fluoride or metal contamination |
|                                          | Dispersion of irritant gases | Exacerbation of pre-existing respiratory disease (such as asthma/COPD*) |                     |
|                                          | Acid rain | Exacerbation of pre-existing respiratory disease (such as asthma/COPD*) |                     |
|                                          | Radon emissions | Dispersion of radon gas | Lung cancer |
|                                          | Drainage of crater lakes; Lahars | Mudflows, floods | Engulfing, drowning |

Toxicity e.g. from fluoride or metal contamination |

| Table 1. Summary of major health impacts of volcanic/geothermal events [adapted from Baxter et al, 1986] |
REFERENCES
Impact of Volcanic Eruptions on Food Procurement

Robin Torrence Australian Museum

All disasters are created by a complex, entangled mix of environmental and socio-cultural factors (Oliver-Smith 1996; Oliver-Smith and Hoffman 2002; Shimoyama 2002). Although the concrete, physical components of the environmental forcing mechanism set limits on potential human responses, social scientists have demonstrated that an equally important variable is the ‘vulnerability’ of the population, defined as the capacity of a social group ‘to anticipate, cope with, resist and recover’ from an incident (Blakie et al. 1994: 9 cf. Tobin and Montz 1996; Turner et al. 2003). This concept has been useful in demonstrating that all volcanic disasters are fundamentally social in nature, but vulnerability is usually assessed after the event and in the context of a specific event. In contrast, the growing number of archaeological and social science studies that describe the social consequences of volcanic disasters provide a wealth of data that could be better analysed and recast into a broad predictive framework (cf. Sheets 2012; Riede 2014). As a first step in this direction, Table 1 pulls together key environmental and socio-cultural variables (including food procurement) that shape the character of a disaster and the subsequent recovery (cf. Zeidler 2016: Fig. 10; Reide 2015: 238-9; Jones 2015; Sheets and Cooper 2012: 12-16; Redman 2012: 240; Torrence and Grattan 2002: 11-15). This abstract reviews the key elements listed in Table 1, but emphasises productive areas for future research on volcanic disasters.

Environmental Forcing Agent

The wide range of potential volcanic hazards and their catastrophic effects, e.g., lavas, tephras, pyroclastic flows, lahars, gas emissions, and subsequent mobility of volcanic products are described in many text books. Blong’s (1984: 311-343; 360-364) handbook provides an excellent summary of types of damage to subsistence strategies resulting from volcanic events of varying magnitude. Level of primary productivity and timing of the event within the annual cycle or in relation to broader climatic change are critical factors. Increases in the depth, texture and adhesiveness of the tephra reduce the viability of plants, whereas destruction of insect fauna can be detrimental or beneficial depending on their role in the agricultural ecosystem. Negative consequences for animals include gases (particularly fluorine), fouling of water sources, dusty air, gritty texture of tephra adhering to forage, and damage to forage through smothering and defoliation. Impacts have differential effects on pregnant or lactating animals so herd composition and timing during the year can be crucial.

Most discussions of volcanic events emphasise the negative impacts on food procurement, but the benefits should also be considered. The emplacement of tephras (especially dustings or thin layers) can improve soil structure and increase fertility through inputs of key elements that stimulate higher productivity (e.g., Blong 1984: 348-350). Following the 1994 eruptions in Rabual, Papua New Guinea, farmers observed higher crop yields ‘due to the input of nitrogen from the decaying plant matter buried beneath the ash, lower incidence of disease and a dramatic drop in the insect population,’ although simultaneous defoliation of the trees led to a marked rise in understory and weeds that
demanded additional labour (Lentfer and Boyd 2001: 50). Elston et al. (2007) discovered that a layer of cinders erupted from Sunset Crater in Arizona created a layer of mulch over areas previously unoccupied due to soil aridity. The effect was to decrease evaporation and increase soil moisture which also made nutrients more available to crops and extended the growing season. Consequently, a large area was made available for groups forced to abandon gardens destroyed by thicker deposits of tephra from the same eruption.

Evidence that volcanic tephra has improved productivity of both animal and plant biota, especially in lakes and near shore ecosystems is summarised by Pendea et al. (2016: 62; cf. Fitzhugh 2012) who monitored a change from terrestrial to marine resources and a related shift in settlement locations from inland to aquatic settings following volcanic activity. Evaluating the costs and benefits for each case is not straightforward, however, as illustrated by Cronin et al.’s (1998) detailed study of two minor tephra falls in New Zealand which shows how trace elements can have both positive and deleterious effects depending on quantities, solubility, soil composition, and rainfall.

Measuring vulnerability

Clearly, human populations already in a weak condition due to poor health, illness, a run of poor harvests, lack of rainfall, cold summer, crop diseases, etc. or situated in settings degraded due to longer term climatic alterations or over exploitation have a decreased potential for responding to hazards. Different food procurement systems are associated with varying kinds and levels of potential risks depending on factors such as mobility of resources (e.g., hunter-gatherers vs fishers vs pastoralists vs agriculturalists), seasonality, specialisation (ie availability of alternative resources), systems of land tenure (e.g., size and spatial location of fields and pastures; size of hunter-gatherer territories), etc. (Table 1). Societies vary in the ways and degrees to which they have incorporated mechanisms to dampen risks. The scale of storage facilities and the amount of diversification in the resources exploited can dampen the effects of disasters (e.g., Zeidler 2016: 89-90). In societies where some groups (e.g., elite social class, high caste) are better resourced than others, impacts will have differential effects. In these cases, the existence and nature of systems for sharing and redistributing essential foodstuffs can create differential levels of vulnerability across the impacted population.

Spatial scales

In addition to the variables in Table 1, studies need to consider the relevant spatial and temporal scales of the analysis. These are not trivial matters since impacts such as acid fogs and temporary climate change can extend across the globe (e.g., Fei and Zhou 2016; Sigl et al. 2015; Grattan et al. 2007). More locally, the spatial scale over which affected groups directly obtain their subsistence resources needs to be considered. Obviously, this will vary according to food production system and land tenure. Access to alternative resources should also be considered since groups might shift subsistence strategies to cope with loss of resources. In addition, it is critical to consider the scale and spatial patterning of kinship and other social networks since these can provide emergency supplies and are essential for successful refuging and recovery outside the afflicted zone. Survival for groups lacking long distance ties will depend on other means of access to resources in non-affected areas.
Given these factors, studies would benefit from sampling a large enough region to include a wide range of potential responses (e.g. Reide 2016a; Zeidler 2016; Sheets 2007; 2012; Sheets et al. 1991; Oetelaar and Beaudoin 2016; Blong 1982). Sheets (2016: 153) makes the helpful suggestion that cultural responses within impacted regions should be compared with those among neighbouring groups that did not experience the environmental effects. Taking a comparative approach might also assist with the difficult problem of disentangling correlation from causation within a single cultural trajectory (cf. Grattan and Torrence 2007; Grattan 2006).

**Temporal scales**

Although frequently overlooked, the temporal scale over which human responses are observed is critical. An assessment of the degree and character of impacts measured immediately after an eruption -- along the scale of months or a year -- could be very different from one made several decades or centuries later. Some environmental forcing agents have a short time span, but others may be prolonged or even delayed until years after the onset of the disaster. For example, thin dustings of tephra can be emplaced over many years. The timing of these events puts limits on how people may respond. Groups might be able to re-occupy a region, but be unable to remain due to health hazards from dusty tephras or to sustain subsistence because of periodic damage to biota. Alternately, with an additional investment of labour, e.g., washing tephra off plants or introducing irrigation, if may be possible to persist despite continued volcanic activity (cf. Rabaul case in Torrence 2012: 153).

Since the products of a volcanic event are not necessarily stable once they are emplaced, the type and level of impacts may vary through time. Clearly, the properties of fresh airfall tephra up to several years after a volcanic event differ greatly from the soils that may form on that base. A whole host of factors come into play in the weathering of volcanic products even in the rather short term: e.g., movement and erosion by wind, rain, or snow; geochemical change; or timing and character of revegetation, which in turn depends on local climate and proximity of seed banks, etc. Furthermore, some impacts may be delayed. Many tephras are remobilised, as in the case of landslides, redeposited lahars (e.g., Blong 1984: 285-291; Crittenden and Rodolfo 2002) or dams of water courses that later burst with catastrophic consequences over very large areas, even at significant distances from the volcanic centre (e.g., Reide 2014: 2015; 2016a; Torrence et al. 2009; Gaillard et al. 2007).

Temporal scales are critical for archaeological research (especially prehistory) since the tools used to measure duration are relatively coarse. Rarely is one able to monitor changes reliably on scales less than 3 or 4 generations. On a positive note, recent research has noted that archaeological time scales are often more appropriate for disaster research because the social consequences often take years or decades to unfold (e.g., Riede 2015: 230; Hoffman 1999; Oliver-Smith and Hoffman 2002; Driessen 2007; Holmberg 2007). For this reason, it is very important to focus on the kinds of responses that fit the accuracy and precision of the instruments used to measure duration. In many cases, archaeology may only be able to monitor abandonment and re-occupation as responses to a volcanic event. Linking the timing of these to cultural changes can be a difficult case of separating causation and correlation especially if the length of abandonment is significant (e.g., Torrence and Doleman 2007; Zeidler 2016). Jones (2015; cf Riede 2016a; 2016b: 1) illustrates how archaeological studies that monitor cultural behaviour both before and after the volcanic event are more likely to identify
causation. Another advantage of archaeology is the potential to compare and contrast the effects of multiple events with different levels of severity within the same geographic setting (e.g., Pendea et al. 2016; Torrence 2016; Vogel et al. 2016; Sheets 2007; 2012; Sheets et al. 1991; Zeidler 2016; Torrence and Doelman 2007; Gaillard et al. 2007; Torrence et al. 2004; Shimoyama 2002; Mastrolorenzo et al. 2002; 2006).

Recovery

Given the coarse temporal scales of most archaeological research, monitoring the patterns of recovery following a disaster is likely to be a more realistic goal than trying to observe immediate social responses. A major asset of archaeological research is the ability to track resilience and innovation over generations as populations find ways to cope with and exploit environmental change. Following a volcanic event, the first problem to be solved is whether to stay in place or to seek refuge elsewhere. In considering food procurement, both environmental and socio-cultural factors are important. Some groups may have been unable to move to a safer place because they were socially and economically marginalised or they maintained very strong social and cultural ties to place. In such scenarios long term survival following severe impacts is unlikely. At the other end of the spectrum, people may find it easy to abandon the region because they can obtain resources elsewhere, either through use-rights or access via kin or social ties to landowners in less affected areas. Somewhere in the middle of the spectrum where the spatial extent of the disaster is greater than the size of the social ties, survival will depend on population density and cultural practices in the surrounding area. People might be offered assistance as ‘refugees,’ tolerated if restricted to marginal areas, able to obtain resources through success in warfare, or perish.

Those who seek refuge will later make decisions concerning when and how to re-occupy the affected landscape of their homelands. Important in this process are the nature of the impacts, alternative sources of subsistence, population density in the refuge area, and ties to homeland. One might expect to find changes in the food economy during different stages of re-colonisation as tephras stabilise and the biota recovers. For example, previous economies based on multi-cropping might change to incorporate high rates of foraging or adopt different animal/crop mixes. In tropical regions the tephra falls might facilitate a shift from shifting to permanent forms of cultivation (e.g. Torrence 2012).

The period of abandonment of heavily impacted regions can last many generations at which time it can become a difficult archaeological problem to identify the relationship between the impacted population and the re-colonisers (cf. Sheets 2016: 154; Riede 2008; 2015; 2016a; Oetelaar 2015; Oetelaar and Beaufoin 2016; Torrence 2016; Zeidler 2016; Vanderhoek and Nelson 2007). Cultural attachments to place are important in the recovery stage because they can encourage people to visit (e.g. Sheets 2016: 153), monitor recovery, and take action to maintain their ownership, (e.g., such as re-planting orchards, establishing gardens, etc. prior to re-settlement) or even to take risks by returning quickly (e.g., Torrence 2012: 154). It is possible that failed attempts at re-colonisation might be detectable in the archaeological record.

Long term studies of environmental recovery tend to focus on near volcano settings and rarely include humanly modified ecosystems (e.g., Turner et al. 1997; Dale et al. 2005; Lentfer and Boyd 2001; Thornton 1996; 2000). Unfortunately, archaeological studies of the recovery of food
procurement systems following a volcanic event are rare. Exceptions include empirical studies of plant fossils (phytoliths, starch) by Pearsall (1996; 2004), Lentfer and Torrence (2007), Lentfer et al (2010) and Parr et al. (2009). Theoretical scenarios by Pearsall (2007) and Torrence (2012) have generated useful hypotheses about tropical ecosystems; similar modelling would be productive for other environmental settings.

**Summary**

Key variables for studying volcanic disasters are listed in Table 1. Social factors underlie all aspects of human behaviour and are fundamental for the successful management of risks created by environmental perturbations. Ideally, the temporal scale of a study should begin prior to the volcanic event and continue for a substantial period afterward. Comparisons with previous and subsequent events would also be desirable. It is useful to match the spatial scale with the social networks that existed prior to the event. Insights can be gained by comparing how groups coped across a range of environmental impacts and to contrast cultural change in the impacted area with adjacent regions that did not experience the event. From a perspective of understanding changes in food procurement, it would be ideal to obtain a long palaeoenvironmental record to monitor ecosystem recovery with a range of different human management and subsistence strategies.

**References**


Oetelaar, G., Beaudoin, A. 2016. Evidence of cultural responses to the impact of the Mazama ash fall from deeply stratified archaeological sites in southern Alberta, Canada. Quaternary International 393: 17-36.


From a stratigraphic sequence to a landscape evolution model: Late Pleistocene and Holocene volcanism, soil formation and land use in the shade of Mount Vesuvius (Italy). Quaternary International 394: 155-179.
The impact of the Avellino Pumice eruption on the Early Bronze age Campanian agrarian pattern

Vanzetti A.¹, Marzocchella A.² & Saccoccio F.¹
1) Università di Roma “La Sapienza”
2) Polo Museale della Campania, Ministero MiBACT

Only in the 1980s, with the excavation of the site of Palma Campania, the Piana Campana - Southern Italy - started to reveal the wealth of information about its prehistoric Late Holocene landscape preserved below the present surface. The preservation of such detailed data is due to the rather close occurrence of volcanic events, producing repeated and progressive growth in thickness of sedimentary cover over wide areas, with a significant or even devastating impact, stemming from many different volcanic centers, from the Phlegraean Fields caldera and the Somma-Vesuvius volcano. Settlements, burials, and other infrastructures show anyway an almost continuous human presence in the analyzed area since Late Neolithic times (ca. 6.2 ky cal BP). Aim of this contribution is the description of the agrarian field system preceding the Avellino Pumice eruption and the impact of such an eruption (ca. 3.9 ky cal BP), when compared to lower magnitude events. Some hints can be derived as for the consequences on the economic and social structure of the Early Bronze Age communities that inhabited the Piana Campana.

Several Early Bronze age sites, sealed by the Avellino Pumice eruption, have been recovered in the Piana Campana, that are related to infrastructures such as wells, tracks, and agrarian features, including both simple cuts produced by the ploughshare and comprehensive field systems.

The analysis of such evidence coupled with the related coeval settlements and burials seems to define an intense occupation of the area during the phase, as shown through a simple site-catchment approach (Saccoccio, Marzocchella, Vanzetti 2013). The occurrence of several volcanic minor events during the time-span between the two major volcanic events of Agnano M. Spina (ca. 4.7-4.5 ky cal BP) and Avellino Pumice (ca. 3.9 ky cal BP) has been recognized, for example in the stratigraphic sequence exposed at the site of Gricignano d'Aversa (at least four pumice layers from different eruptions). These events don’t disrupt the sequence of exploitation of the extraordinary agrarian vocation of the Piana Campana, as proved by repeated settlements, infrastructures and plough marks.

The case of the Gricignano fieldscape

During the rescue excavation of the site of Gricignano US Navy Support Site (USNSS), located about 20 km North of the city of Naples, and immediately South of the East-West flowing Clanis river, a 90ha wide area has been sampled by preventive soundings. The soundings were located mainly inside building foundation trenches, crossing the Avellino Pumice pyroclastic surge and reaching at the bottom the thick pyroclastic surge of the Phlegraean eruption of Agnano Monte Spina (hereafter
referred to as the “major eruptive bracket”). In the major eruptive bracket, the discontinuous pumice volcanic deposits of at least 4 minor volcanic events - locally labelled as “Phlegraean” Tephra - were crossed, most probably to be referred to the Astroni volcanic centre. An essential factor in the development of the typical landscape stratigraphy registered in the whole building area is the impact of the cultivations, which generally employed the plough for breaking the ground. At USNSS the landscape is systematically cultivated. A continuous human presence is also testified by remarkable evidences like huts, tracks, graves that were found in the paleosols located between the volcanic deposits. Cultivation is anyway so pervasive that the abandoned villages are rapidly damaged by the renewed tracing of fields, and in this process the living floors get almost always disturbed and destroyed. A reason of such an intense and continuous prehistoric human presence in the Piana Campana is probably to be found in the fertility of the volcanic soils. Other excavations carried out in the immediate vicinity (Gricignano Industrial area, Teverola, High-Speed train line, among others) have shown traces of similar patterns of agrarian exploitation.

As already stated, almost all the paleosols found in the major eruptive bracket at Gricignano US Navy revealed agrarian plough marks, both as dark soil-filled cuts on pumice layers and as pumice fall-filled marks on top of soils.

But it is the paleosol (PS1) directly sealed by the Vesuvian Avellino Pumice surge deposits that allowed a full definition of the field pattern. This catastrophic event granted an extraordinary preservation of an unexpected agrarian landscape, notably recognized by one of us (A. Marzocchella, then in charge as officer of the Soprintendenza per i Beni Archeologici della Campania) as an extraordinary testimony of ancient economic behaviour.

PS1 has been investigated, between 1995 and 2005, with 549 trenches of various size, covering a surface of about 6.5ha, corresponding to the 7.5% of the total area of USNSS, ca. 90ha. Some of them were also opened outside the limits of the site, both South and West. All of them brought to light pieces of the agrarian landscape sealed by the Avellino Pumice eruption, so that it is certain that the limits of USNSS did not correspond to the limits of the agrarian landscape.

Using GIS, all the elevations related to PS1, collected during the exploration (totalling 1419 points), were interpolated in order to reconstruct the agrarian paleosurface. The maximum height recorded is 21.86m asl, located in the middle of USNSS, while the minimum value, located in the NE corner, is 17.97m asl. It is useful to remember that over the western border of the support site it is possible to identify a SW-NE lowland area, possibly connected to a tributary of the Clanis river and once a marshy zone, while a slightly higher ridge (possibly the remains of an Agnano-Monte Spina surge flow accumulation?) is recognizable inside USNSS, running from the NW corner to the southern border, with a NW-SE orientation. Another lowland area is located to the East of the site, clearly marked in historical times by the drainage system. Some minor elevation shifts have been locally observed.

The extraordinarily preserved field system recognized as sealed by the Avellino Pumice eruption, shows a considerable local impact on the landscape, as an uninterrupted sequence of fields stretches over the considered area. Some recurrent and specific features were identified:

- elongated parallel furrows resulting from ploughing with crest interdistances of about 0.35m;
- shallow gullies bordering the parallel lines of furrows (at prevailing interdistances between 2 and 8m), creating a consistent water management infrastructure;
- low banks, between 0,75 and 1,30m wide, made of hardened soil and rising up to 0,20m above the surface;
- one cart track bearing multiple wheel ruts due to repeated cart transit, with a wheel gauge of about of 1,30m;
- a probable fence marked by a double line of small (post?)holes with a length of about 20m and NNW-SSE orientation, not exactly parallel to the field system.

It is clear that all the features are part of a single agrarian and infrastructural system, destroyed by the eruption: a real fossil campagna (farmland).

Let’s go in more detail about the field system. The cart track is flanked by several banks. It is possible to define agrarian lots, by considering the space delimited by a couple of banks or by a bank and the cart track; each of these lots includes several gullies. The area so delimited defines a roughly regular partitioning of elongated fields: it corresponds to the definition of coaxial system, used in NW Europe, but with only shallow infrastructures (not major lynchets). The maximum length recorded is of about 700m, but its interruption is only due to the end of the investigated area. Lots show various widths: they span from a minimum of 27m to a maximum of 87m. The presence of such wide lots is probably due to a lack of documentation, as not all the area of USNSS was excavated or sampled; anyway, the measures seem to be approximate multiples of the minimum width recorded for a lot: a value between 27m and 30m.

After publication in Saccoccio, Marzocchella, Vanzetti 2013, a more detailed analysis has been conducted on the orientation of the banks: slight changes of orientation of the banks seem to occur in coincidence with changes in elevation, and particularly at the transition between higher and lowland areas. It is possible that this pattern reflects a precise choice of the prehistoric farmers to avoid steeper slope flow of water, thus searching to reduce steeper slopes of gullies, in order to avoid excessive water speed, possibly causing erosion and local landslide. On the contrary, the whole system seems to be instead designed in order to distribute any excess of water, and to facilitate local absorption. Thus modifying the orientation of the agrarian features, the flow of the water is reduced, erosion is limited and moisture diffused. The change in the orientation could also be useful in order to manage the connection with the steep slope connected to the river’s lowland, located just outside the western limit of the considered area, but this has not been reached by excavations.

After the definition of these general features, we have to remark the presence of some features (banks and gullies) placed orthogonal to the main alignments. These orthogonal banks seem to define small sub-lots of about 0,5 ha. Anyway, this is not a constant feature, and the function of these partitions is far from clear. We hypothesize that, due to the silty-sandy nature of the soil, permeable, rather loose and at risk of erosion, it is possible that these features could be used, as well, in order to create a sort of barrier for the excessive flow of rainfall water, limiting again the consequent phenomenon of erosion and landslide. In fact almost all of these banks occur in correspondence of elevation drops, where the control of the quantity of water flowing through the natural slope was more important. Anyway, in the SW area of the site there is, on the contrary, an orthogonal bank just over an elevation top. Therefore, given the fact that the pattern is the result of sampling, there remains the doubt between a mainly functional or allotting interpretation.
Other field evidences in the Piana Campana
Traces of ploughed fields and infrastructures are often encountered in excavations cutting through the Avellino Pumice deposits, inside the Piana Campana. They are rarely well published and generally barely quoted in preliminary reports, without much detail. This hinders the acquisition of a comprehensive view of the human agrarian impact in the Plain. In three cases, the field system is discernible.

At Palma Campania/Tirone or Valle, less than 0.5 ha of the field system was excavated in a low-lying area, about 200 m southwest of ascertained contemporary village remains (as they are destroyed by the eruption). The fields have a SW-NE main axis, marked by elongated, parallel gullies, defining agrarian strips, and a transverse gully probably occurred. Fields extended on both sides of a W-E channelled stream that flowed in the most depressed area. The stream was flanked on both sides by cart tracks, acting as headland paths. Another ephemeral track ran NW-SE, possibly defining a triangular plot with a different cultivation pattern. The main orientation of the fields is here not parallel to the main tracks, as was the case at USNSS.

At Acerra/Spiniello, the settlement area is unknown. Fields have been found in a rather flat area, north of the Holocene Clanis valley. The excavation area is less than 0.5 ha. A system of elongated field strips was defined by parallel N-NW/S-SE gullies. An obliquely transverse cart track cuts through the fields, running almost S-N (there remains the doubt whether this is a stable track or an ephemeral crossing, that took place close to the eruptive event). At S. Paolo Belsito/Montesano, a cart track was flanked on one side by two parallel gullies, defining a field strip. De Caro (2000a, 2000b) reports that fields, with orthogonal orientation were also found at Casalnuovo di Napoli in two adjacent trenches.

The general outline of the field systems appears to be similar: in all cases they are characterized by elongated fields, internally subdivided in strips by gullies. Only at GR/Nss have major lots been recognized, each limited by shallow banks. The cart tracks occur both along the main axis of the field system (USNSS, S.Paolo Belsito/Montesano), and diverging from it, transversely cutting the fields (Palma Campania/Tirone and possibly Acerra/Spiniello). The field strip interdistances are anyway different from site to site, that is, given a general pattern of elongated fields, organized by strips, with locally recurrent widths, each community adapted the system to the specific situation.

Inside the elongated fields, at both Palma Campania and Acerra, plots with different agrarian practices could be identified, reflecting a variation in cultivation or in crops; at Acerra the change in agrarian practice occurs without a physical interruption of the field strip; at USNSS, such traces still require some detailed analysis.

Mobile extensive economy and a shifting settlement pattern
In order to evaluate the impact of the Avellino Pumice eruption on the agrarian practices, it is useful to consider the progressive relocation of the settlement pattern and its relation with the volcanic events. Many settlements of the Early Bronze Age Palma Campania archaeological facies have been recorded in the Piana Campana, but not all were directly destroyed by the Avellino Pumice eruption. This suggests that human communities maintained a certain degree of mobility, following a typical occupation pattern since at least the Copper Age. Data from Gricignano support this mobility model:
between Agnano Monte Spina and Avellino Pumice eruptions, settlement traces show a frequent shift in location and both plough marks and cart tracks change orientation through time, reflecting shifts in the overall pattern.

Excavated settlements are formed by a number of huts and complementary buildings, generally with similar NW-SE orientation. Huts are organized in clusters, partitioned by internal fences, apparently without external defensive structures. The interdistances between contemporary and contiguous sites support an estimate of the average extension of their probable exploitation area: a 2.1km average radius results from the four interdistances between sites. This value seems to reflect an intense, albeit dispersed, occupation pattern, less than the 5km standard maximum radius reported for traditional peasant communities (Higgs 1975).

The exploitation areas are internally organized, as seen at USNSS. At Palma Campania and Ottaviano/Raggi, about 2km apart, the field orientation is the same, and a same, or shared, agrarian system can be hypothesized. The site at Afragola T.A.V. V/1, sealed by the Avellino Pumice eruption, shows a more complex organization of the exploitation area. The site is located 1km SSE of the settlement at Afragola T.A.V. V/17 and it presents some production structures, ovens and firing platforms, not surely associated with habitations. It could be a specialized processing off-site, connected to the nearby settlement.

As recorded at San Paolo Belsito and Nola (Passariello et al. 2009), the occupation starts within a century after the Avellino Pumice eruption, and the material culture can still be referred to the Palma Campania archaeological facies. Anyway, we see only a limited use of the Campanian flatlands for settlement, and mainly at the end of the Early or the start of the Middle Bronze Age. Moreover, the wider time spacing of eruptions didn’t allow a good preservation of the record and of field systems, continuously reworked through the years.

Pollen analysis, albeit scarce in the area, can help us in documenting the human impact on the landscape over centuries. In fact, pollen research dates back to the studies by Dominique Vivent, in cooperation with Claude Albore Livadie (2001). Samples, extracted from paleosols, span the whole sequence from below Agnano Monte Spina to over Avellino Pumice. The Arboreal Pollen/Non Arboreal Pollen (AP/NAP) ratio constantly displays a strong dominance of NAP, probably induced by volcanic events but sustained by human intervention. Despite the lack of other pollen analysis for the Piana Campana these data are confirmed by other prehistoric sites coeval to Gricignano. The pollen diagrams show a generally low AP value that slightly increases from around 10% before the Avellino Pumice eruption to around 20%, after the event. This can be related to a reduction in the human presence/exploitation of the landscape. Vivent and Livadie (2001) anyway remarked that the Avellino Pumice eruption shouldn’t have prevented man to return soon in the landscape, with a restored similar vegetation cover, and a significant human impact. Since the extraordinarily preserved field systems under the Avellino Pumice eruption seem to be among the last testimonies of a long tradition of mobile settlements and extensive agriculture in the Piana Campana and in Southern Italy, enhanced by the use of the plough since 6th millennium BP, it is possible that social and political factors acted in neglecting former extensive and mobile economy. At this stage it is interesting to recall that Mauro Cremaschi and colleagues (Cremaschi, Pizzi, Valsecchi 2006) have displayed a similarly high, but anyway less striking pattern of deforestation for the later Terramare area, around the middle of the second millennium BCE.
During the Late Eneolithic and Early Bronze Age, we are facing a typical case of a structured, but still mobile economy, like often proposed by anthropologists and archaeologists for ranked societies without private property. Anyway the impressive field systems suggests that the detailed knowledge possessed by later more stable agrarian societies, like the Terramara one, had a strong background in Early Bronze age and Late Copper Age practices.

References
Saccoccio F., Marzocchella A., Vanzetti A., 2013. The field system of Gricignano d’Aversa (Southern Italy) and the agrarian impact in the Piana Campana, ca. 3900 cal BP. Quaternary International 303, pp. 82-92.
Tuesday, June 7th, 1-4 pm
Session 5

Human Responses to Major Volcanic Eruptions

Speakers:

Blong R. Reported and perceived impacts of distal tephra falls on pre-industrial societies

Torrence R. Vulnerability, Resilience and Adaptation: Social Responses to Volcanic Disasters

Riede F. Distal impacts of major volcanic eruptions on pre-industrial societies in the Mediterranean

Discussant: Grattan J
Reported and perceived impacts of distal tephra falls on pre-industrial societies

Russell Blong  *Risk Frontiers, Macquarie University, Australia*

**Introduction**

Except in the very largest eruptions (VEI 7) the impacts of an eruption at distances greater than 100 km from the vent result primarily from tephra fall. Here we report some observations of the impacts of distal tephra falls taken from a not very extensive literature which includes mostly anecdotal evidence and rather limited analysis. Subsequently, we summarise perceptions of the consequences of a distal tephra fall as reported in oral histories on pre-industrial societies scattered across mainland Papua New Guinea from the Long Island eruption dated to the 1660s. The Bronze Age Avellino event was VEI 5, the 1660s Long Island VEI 6.

Oral histories relating to the fall of ash (‘taim tudak’ – time of darkness) across the PNG highlands were collected and published in the late 1970s. It is worth remembering that the first European contact with many of the highland societies first occurred post-1933. Some of the stories were collected in the local language. Some were collected in Neo-Melanesian pidgin; some were collected by me in extremely poor pidgin. Some were collected from numerous people in a group; some were collected from individuals. Most of the stories were collected by observers – anthropologists, missionaries, patrol officers, oral historians – with years, even decades, of exposure to specific local languages/cultures.

Most of the oral histories of a time of darkness appear to relate to a fall of volcanic ash, but some probably refer to hail falls, or solar eclipses. Some events are indeterminate. A total of 99 stories were collected, but only 45 accounts are considered here – those inside the area of more than 50,000 km² where Tibito Tephra (as the most recent large Long Island ash fall is known) has been stratigraphically (and geochemically) determined to be the uppermost tephra, and where the legend fairly clearly relates to a fall of volcanic ash. In all, 25 separate languages/cultures are represented in this sample, at distances from Long Island of 150 to 500 km with tephra fall thicknesses from 0.5 to 7.5 cm.

Numerous caveats should be kept in mind: both interviewees and interviewers may have had unknown agendas; often three languages were often involved in producing each of the accounts; in some cases syncretism may have occurred with other events bound into the one story; some groups say they have migrated since the taim tudak occurred – though probably no more than 10-20 km; stylisation of some accounts has occurred as they include instructions on what to do in the event of another ash fall.

Despite these caveats, when the content of the oral histories is judged against the consequences reported by European and other observers reported in the literature from across the globe for similar thicknesses of ash fall, the histories can be regarded as essentially accurate accounts of the potential effects of ash falls of similar thickness except: (i) Durations of the time that darkness lasted are
exaggerated in almost all the accounts; and (ii) there is severe underestimation of how long ago the taim tudak occurred even when allowing 30 years between generations. Neither of these two aspects of the oral histories are considered here.

Deaths
In theory, deaths in pre-industrial societies from distal tephra falls can occur from five main causes: (i) Roof collapse; (ii) Respiratory difficulties; (iii) Silicosis; (iv) Post-ash fall starvation; and (v) Internecine warfare/competition for resources.

In practice, few if any deaths from respiratory difficulties are known to have occurred in modern times though severe cases of asthma have been reported. Where pneumonosilicosis has been investigated (e.g. Montserrat, 1990s and later) it has been less severe than anticipated. Starvation as a result of crop failure following ash fall has been reported not infrequently; perhaps 80% of the 60,000 deaths in Indonesia resulting from the 1815 (VEI 7) eruption of Tambora followed crop destruction/failure, starvation and disease. Deaths probably also occurred beyond the area of tephra fall in the ensuing ‘year without a summer’. Post-ash fall competition for food or other resources may also lead to migration and/or conflict but I am unaware of published information that records human deaths as a result.

Figure 1 shows the available information about the deaths reported in oral histories collected in Papua New Guinea as a result of the fall of Tibito Tephra. Only a few accounts mention deaths, but it is surprising that deaths have been reported from areas where field investigations show the ash fall thickness to be as little as 1 to 4 cm.

Figure 1. Information about human deaths in oral histories relating to the fall of Tibito Tephra from the 1660s eruption of Long Island, Papua New Guinea. Score: 0 = Not Mentioned; 1 = No deaths; 2 = Some people died; 3 = Many people died.
Buildings
Volcanic ash at distal locations may arrive wet or dry. Freshly-fallen tephra generally compacts quickly (within a few days) to about half its original thickness. Bulk densities of recently fallen but compacted tephra generally lies in the range 0.5 – 2.0 kg m\(^{-3}\). Figure 2 indicates the probability of damage to (modern-day) unreinforced masonry and post-and-beam construction, perhaps the building typologies that are closest to European Bronze Age structures, using the relationship \( y \) (kPa) = 0.0162 x (tephra thickness in mm) to convert tephra fall thickness to tephra loads. The hexagons near the left margin of the graph show some of the house experiences reported in oral histories from Papua New Guinea, with buildings failing at low loads. These reports are in accord with anecdotal evidence from eruption consequences reported around the globe by European and other observers in the last few hundred years.

![Figure 2. The probability of selected degrees of damage to unreinforced masonry and post-and-beam construction based on modern experience. Solid lines refer to unreinforced masonry, dashed lines to post-and-beam structures. The hexagons illustrate consequences reported in the PNG oral histories.](image)

Crops
Figure 3 summarises the most important relationship between tephra fall thickness and the effects on plants (Arnalds, 2013). However, plant/agriculture – tephra fall relationships are not this simple; Figure 4 illustrates some of the complexities, emphasising that tephra has properties other than mere thickness, that the environment including climate, weather, season, and biological activity and that plant development stage, the type of crop (tuber, stem, fruit) and numerous other attributes may all be important. Furthermore, crops are part of complex ecosystems – for example, the consequence of a tephra fall for a specific crop may depend more on whether insect predators or insect pollinators are more affected by the tephra. Figure 4 also illustrates some of the potential influences of tephra fall on animals (both food sources and ecosystem participants).
Given the range of possible outcomes for a pre-industrial society in terms of deaths, shelter, and food sources as suggested in the figures above together with other potential influences which might include death/injury to influential leaders, migration, inter- and intra-group tensions (even those extant before the ash fall), conflict, and the season in which the eruption occurs, it is not surprising that there may be both winners and losers, or at least perceptions (once some time has passed) that the ash fall was a good thing or a bad thing. Figure 5 shows the perception recorded in oral histories collected around 300 years after the Long Island eruption.

Figure 5 suggests that highlanders more than 300 km distant from Long Island more often regarded the fall of Tibito Tephra as Beneficial rather than Harmful, or at least were Ambivalent about its
consequences; some sufficiently so that instructions were developed to encourage specific behaviours in the case of a repeat fall. Whether these associations are causal or incidental and whether perceptions arise from the emergence of more visionary leaders, or (possibly) the coeval arrival of the sweet potato vine and improved diets across much of the highlands around the same time as the ashfall are moot points. Perceptions may be as important as realities in interpreting the aftermath of ash fall on pre-industrial societies in both highland Papua New Guinea and post-Avellino Europe.

Figure 5. Was the ‘taim tudak’ occasioned by the VEI 6 eruption of Long Island generally viewed as harmful or beneficial? Score: 0 = Not Mentioned; 1 = Harmful; 2 = Ambivalent – good and bad; 3 = Beneficial.

References

Arnalds O, 2013, The influence of Volcanic Tephra (ash) on Ecosystems, Advances in Agronomy, 121, 331-380


Newhall C and Self S, 1982, The Volcanic Explosivity Index (VEI) - An estimate of explosive magnitude for historical volcanism, J Geophys Res Oceans Atmos, 87(C2), 1231 - 1238.


Vulnerability, Resilience and Adaptation: Social Responses to Volcanic Disasters

Robin Torrence Australian Museum

Key concepts

A preliminary list of variables relevant for understanding how humans have experienced and reacted to volcanic disasters is presented in Table 1 for discussion at the workshop. In this review I propose a general conceptual framework for understanding social responses. On the whole, archaeology is not well equipped to monitor short term events (in the order of less than 50 years), but this limitation is far out-weighed by the depth of understanding about social processes that can be achieved by considering volcanic disasters over longer time scales. Adopting a very broad temporal framework can also help detect whether changes that occurred post volcanic disaster were a direct consequence of the environmental hazard itself or derived from ongoing social changes that had been initiated prior to the event. In other words, selecting an appropriately long time frame should help disentangle causation from correlation (Torrence and Grattan 2002a: 7-11). In addition, some impacts, particularly large events, might have had long lasting effects on a cultural group’s world view or acted as catalysts for social change not apparent until many years afterwards (e.g., Chester and Duncan 2007; Plunket and Uruñuela 2006; Driessen 2002; Hoffman 1999; Driessen and Macdonald 1997).

Oliver-Smith and Hoffman (2002: 12) note that ‘disasters have pasts, presents, and futures’ and they ‘unfold over time, often considerable amounts of time.’ In the following I use the social scientists’ concept of ‘vulnerability’ to represent a disaster’s ‘present.’ This is envisaged as the immediate impacts that occur in the range of days to a few years following the onset of the environmental forcing event. ‘Future’ is conceived as the period of ‘recovery’ of a society, the specific nature of which (e.g., persistence, change or collapse) is determined by its ‘resilience.’ Futures can also be considered in terms of the innovations resulting from the experiences of the disaster. Over a long time period changes made in coping with a disaster might contribute to ‘adaptation,’ which is the process of becoming resilient. In turn, the degree to which a social group is adapted prior to a disaster, its ‘past’ in terms of Oliver-Smith and Hoffman’s quote, is critical for understanding how each social group will respond to a new volcanic event. So the three aspects of a disaster -- vulnerability, resilience and adaptation -- are interconnected along a time line, such that the nature of adaptation will affect the degree of resilience which, in turn, conditions the vulnerability at the time of the event. I now consider the value of each of these concepts for archaeological research on social responses to volcanic events.
Vulnerability

Normally conceptualised on the shortest time scale and including the period directly following an event (often in the range of weeks or several months), social scientists have developed the term ‘vulnerability’ of social groups, because it focuses attention on the human societies that have been affected, rather than the material damage that had previously been the major subject of disaster assessments (e.g., Riede 2014; 2015a; Blaikie et al. 1994; Wisner et al. 2004; Oliver-Smith and Hoffman 2002; Hoffman and Oliver-Smith 1999; Oliver-Smith 1996). Defined as ‘susceptibility to harm’ (Gallopin 2006: 295; cf. Torry 1979), studies that focus on vulnerability have tended to measure and describe the immediate consequences of the event, when damage to resources, housing, etc., and other negative consequences are the most prominent outcomes, rather than record the persistence of populations and cultural behaviour, which needs to be assessed on longer time scales. In Table 1 variables normally considered when measuring vulnerability are 2-4, 6-7 and the first variable in 13. The basic premise that societies vary in the degree to which they are harmed by a volcanic event is especially useful for modern day disaster managers and can help archaeologists interpret the consequences of immediate impacts, but, in general, vulnerability is limited in its applicability for archaeological case studies whose main concern are understanding general cultural processes.

Recovery and Resilience

An important insight that archaeology brings to disaster studies is the simple observation that the effect of a volcanic event continues over the entire period during which societies recover -- when they might remain stable, continue but change, and/or collapse-- as well as the continuing influences that the experiences may have on descendant communities (e.g., Torrence 2016; Riede 2015a: 230; Sheets 2012; McAnany and Yoffee 2010; Cashman and Cronin 2008; Chester and Duncan 2007; Cronin and Cashman 2007; Dillian 2007; Holmberg 2007; Torrence and Doelman 2007; Hoffman and Oliver-Smith 1999). Due to a number of recent excellent, detailed archaeological studies of volcanic events, there has been a shift in the social science literature away from seeing volcanic events in the light of Armageddon (i.e. catastrophic events) to a focus on the actual processes of recovery (e.g., Riede 2015b; 2016; Cooper and Sheets 2012; Grattan and Torrence 2007b; Grattan 2006; Torrence and Grattan 2002b; Sheets et al. 1991) and even on how the experiences of a specific volcanic event might shape how groups cope with a subsequent disaster (e.g., Torrence 2016; Hutchison et al. 2016). These studies report that many and, perhaps the majority of societies, who have experienced a major volcanic event pick themselves up, dust themselves off and continue more or less in the same trajectory, although the return to the state prior to the event can take some years and changes already taking place at the time of the event will also shape the future.

A key concept in understanding the nature of recovery is ‘resilience,’ which is defined as the ability to maintain continuity by avoiding or withstanding failure (Lorenz 2013). In Table 1 the key variables that influence the speed and direction of recovery relate to the robustness of the population and available resources as well as the nature of available options: e.g. 2, 3, 5-13. The potential for direct access to alternative resources through storage and/or mobility will generally need to be supplemented by exchange, redistribution and refuging. The size and strength of social links is an especially critical aspect of resilience in the case of large volcanic disasters where the impact is experienced over a large region. One aspect of resilience that has recently been emphasized is
attachment to place (Torrence 2016; 2008; Torrence and Doelman 2007: 53). Whether the strength of ties to land is part of an ideology or a consequence of population pressure, the nature of the connection to homeland and the practice of continual monitoring of abandoned places (e.g., Sheets 2016; Lentfer and Boyd 2001) will affect the speed and nature of re-colonisation.

**Innovation and Change**

Until recently, many discussions of how volcanic events have impacted on societies tended toward sensationalism and emphasized vulnerability and ultimately collapse (Grattan 2006; Grattan and Torrence 2007a). Scholars commonly view cultural changes after the volcanic impact as representing a failure of the previous social system to persist. An alternative scenario is presented in Plunket and Uruñuela’s (2006) study of the effects of the VEI 6 eruption of Popocatepetl in Mexico. This event forced the movement of vast numbers of refugees who expanded the population of the two urban centres of Cholula and Teotihuacan. In turn, the abundant and cheap source of labour contributed to monument building that reinforced ongoing social change (cf. Sheets 2012:52-3). As noted by Hoffman (1999: 311), ‘disasters motivate social actions, and social action motivates change providing contexts for new agendas, new power relations, and the emergence of new leaders as part of the recovery process.’ This same form of argument was used in Torrence’s (2016) hypothetical reconstruction of processes that occurred in New Britain. She proposed that the loss of control by elites over resources due to devastation by the WK-2 eruption opened up avenues for social change that promoted a rapid return to homelands as well as other significant changes such as the adoption of pottery making.

Probably due to the short temporal focus of most studies, surprisingly few have identified innovations that have promoted recovery and persistence. A notable exception is Oetelaar and Beaudoin’s (2016; Oetelaar 2015) archaeological studies of culture change among northwest Plains Indian groups in North America. In this case new techniques for food processing were invented that enabled a return to the homelands abandoned due to the combined effects of climate change and tephra from the Mount Mazama eruption. Viewed in the relatively short term, Plains culture failed to survive this event (ie collapsed) and the region was abandoned. In contrast, re-colonisation 500 years later illustrates how innovations made to cope with the need to feed the larger population sizes in the refuge areas enabled a return to their tribal lands. Furthermore, the new methods for processing and storing food provided an excellent risk back-up that would enable the groups to persist through future periods of resource stress. This study is a good example of how cultural changes made following a volcanic disaster may in turn contribute to resilience over the very long term.

A large number of studies have highlighted the way that experiences of volcanic eruptions are incorporated into ideology. An interesting case is reported by Dillian (2007) in which obsidian from a small volcano, whose eruption was witnessed by neighbouring groups, became integral to ritual life. Plunket and Uruñuela (1998; 2006; 2008), Chester and Duncan (2007), and Holmberg (2007) also describe instances in which volcanic events have impacted on belief systems and ritual practices.
Adaptation

Clearly, not all cultural changes stimulated by volcanic disasters make direct contributions to resilience, but some adaptations may provide significant benefits to societies who experience relatively frequent major perturbations. By adaptation, I mean changes in society that occur after an event and that increase resilience by actively dampening or effectively mitigating the effects of subsequent volcanic disasters. The Oetelarr and Beaudoin’s (2016; Oetelaar 2015) study mentioned above is an excellent example. Oliver-Smith and Hoffman (2002: 9) note that ‘cultural adaptations include innovation and persistence in memory, cultural history, worldview, symbolism, social structural flexibility, religion, and the cautionary nature of folklore and folk tales,’ but these are only a sample. The importance of social memory in structuring how populations react to disasters and, particularly, the practical information maintained through oral history and mythology or lost during modernisation has been demonstrated in historical and anthropological studies (Hutchison et al. 2016; Cashmin and Cronin 2008; Cronin and Cashmin 2007; Davies 2002). In another case, Torrence (2016; 2008; Torrence and Doelman 2007) has argued that the practice of exchanging obsidian (a raw material used for stone tools) among groups within and beyond the Willaumez Peninsula, Papua New Guinea was preserved over 30,000 years because it created social ties that played an essential role in facilitating effective refuging outside the afflicted area, in a region that was impacted by relatively frequent volcanic events.

Societal complexity

One of the pioneers of disaster studies, Gilbert White (1974) first proposed that societal organisation was a fundamental element in the way that groups responded to disasters (cf. Riede 2014: 337). White argued that pre-industrial societies were less resilient than industrial groups because losses could not be mitigated so effectively. Sheets (1999; 2007; 2008; 2012; Sheets et al. 1991; cf. Shimoyama 2002) has examined the relationships between societal complexity and resilience through a review of an impressive number of 36 case studies that record how ancient groups have coped with volcanic events in Mexico and Central America. He concludes that societies with a highly centralised mode of decision making and dependent on redistribution of food resources are more vulnerable than small-scale groups where choices are made at the household level and families are responsible for their own subsistence. However, Sheets also notes that population density (ie potential access to alternative resources) and the presence of inter-group conflict have also been important factors.

A limitation of Sheets’ comparative analyses is that the magnitude of the volcanic hazard is only acknowledged when societies of the same scale are compared, as in the case of the massive Ilopango event versus a smaller eruption in El Salvador (Sheets 2012: 56-57). Another problem is that the societies in his sample have varied histories in terms of their previous experience of volcanic disasters. Some regions were impacted by volcanic eruptions relatively frequently, whereas in others these have been rare events. It is significant that the history of the most resilient case, the Arenal area of Costa Rica, was characterised by the largest number of volcanic events. The question then arises whether over time these societies had adapted to their hazardous environment by developing a subsistence pattern with relatively high mobility and the practice of flexible decision-making within the community. In other words, vulnerability to a single volcanic event may be dependent on prior long-term history that has led to adaptation. Additional studies of multiple events in a single region
<table>
<thead>
<tr>
<th>Key variables for assessing potential impacts, vulnerability, and resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Environmental forcing agent</strong></td>
</tr>
<tr>
<td>• Speed of onset</td>
</tr>
<tr>
<td>• Magnitude (e.g., VEI)</td>
</tr>
<tr>
<td>• Spatial scale</td>
</tr>
<tr>
<td>• Duration/history</td>
</tr>
<tr>
<td>• Timing of occurrence within natural and cultural annual cycles</td>
</tr>
<tr>
<td><strong>2 Primary productivity robustness</strong></td>
</tr>
<tr>
<td>• Average primary productivity</td>
</tr>
<tr>
<td>• Inter-annual variability in primary productivity</td>
</tr>
<tr>
<td><em>Inter-annual variability in rainfall</em></td>
</tr>
<tr>
<td><em>Inter-annual variability in temperature</em></td>
</tr>
<tr>
<td>• Annual variability in primary productivity</td>
</tr>
<tr>
<td><em>Annual variability in rainfall</em></td>
</tr>
<tr>
<td><em>Annual variability in temperature</em></td>
</tr>
<tr>
<td>• Disease/pest load</td>
</tr>
<tr>
<td><strong>3 Human demographic robustness</strong></td>
</tr>
<tr>
<td>• Population structure (% dependents)</td>
</tr>
<tr>
<td>• Population physical fitness</td>
</tr>
<tr>
<td>• Disease load</td>
</tr>
<tr>
<td><strong>4 Architectural robustness</strong></td>
</tr>
<tr>
<td><strong>5 Familiarity with hazards</strong></td>
</tr>
<tr>
<td>• Length of time since previous disaster</td>
</tr>
<tr>
<td>• Direct experience by population</td>
</tr>
<tr>
<td>• Effectiveness of social memory (oral history, myth, etc.)</td>
</tr>
<tr>
<td><strong>6 Decision-making mechanisms</strong></td>
</tr>
<tr>
<td><strong>7 Effectiveness of communication</strong></td>
</tr>
<tr>
<td><strong>8 Access to resources</strong></td>
</tr>
<tr>
<td>• Population pressure in relation to available resources</td>
</tr>
<tr>
<td>• Spatial scale of territory (use-rights, shared, exclusive ownership)</td>
</tr>
<tr>
<td>• Spatial dispersion of resources</td>
</tr>
<tr>
<td>• Social distribution of resources (nature, extent of exclusion)</td>
</tr>
<tr>
<td>• Flexibility in use-rights, ownership and inheritance</td>
</tr>
<tr>
<td>• Redistribution mechanisms</td>
</tr>
<tr>
<td><strong>9 Societal conflict</strong></td>
</tr>
<tr>
<td>• Within group</td>
</tr>
<tr>
<td>• Between neighbouring groups</td>
</tr>
<tr>
<td><strong>10 Mobility options</strong></td>
</tr>
<tr>
<td>• Hunter-gatherer</td>
</tr>
</tbody>
</table>
Papua New Guinea (Torrence 2002; 2008; 2012; 2016; Torrence and Doelman 2007) are not conclusive, but also suggest that resilience may be a consequence of experience built up over a very long period of time.

In conclusion the concepts of resilience and adaptation, and to a lesser extent vulnerability, are useful for structuring discussions about social responses to volcanic disasters because they highlight the importance of an appropriately scaled analysis that incorporates a thorough understanding of prior history (adaptation and resilience) as well as the social processes that operated both during and after the event. Archaeological research would also benefit from moving away from a focus on single event vulnerability to exploring whether and in what ways societies have changed to increase resilience following a major disaster and if these behaviours were preserved. Finally, a comparison of cultural adaptations across environments where there were different incidences of hazard would also help sort out the complex relationships between event magnitude, resilience and long-term adaptation.

References


Distal impacts of major volcanic eruptions on pre-industrial societies in the Mediterranean

Felix Riede Aarhus University

Though relatively rare in human time, volcanic eruptions are common over historical and evolutionary time – and they have occurred in regions that have not been witness to volcanic activity in recent times. I here aim to provide a perspective, comments and prospects on investigating the medial-to-distal impacts of volcanic eruptions on traditional societies in the past. The pertinent issues I focus on are hypothesis-driven research design, the power of tephrochronology for both improving chronological precision, and ways of testing potential impact mechanism. Finally, I will argue that the most significant cultural changes related to a given volcanic eruption happen outside of the areas directly affected.

Generating hypotheses
Many excellent studies of the varied ecological and societal impacts of volcanic eruptions exist. These include major sourcebooks and review articles (e.g. Blong, 1984; Chester, 2005; Grattan and Torrence, 2007; Oppenheimer, 2011; Sheets and Grayson, 1979; Torrence and Grattan, 2002). Thorarinsson’s paper (1979) and Blong’s (1984) systematic review of this disparate field and its many sources still, in my view, stand as the key resources: The former usefully divides impacts into proximal, medial, distal and ultra-distal zones; the latter presents not only narrative accounts of a wide variety of events, but also collates quantitative information. Anecdotes are transformed into data and these can, in turn, be used to put into place a framework for generating hypotheses about human impacts and linking mechanisms (Fig. 1). The spatial and temporal dimensions are critical when applying this framework to a given archaeological case study: Distance from eruptive centre will suggest certain primary impact mechanism; the unfolding of syn- and post-eruptive hazards over time has implications for how temporally discrete impacts may have been, i.e. how event-like a given eruption really was. In the distal impact zone, direct, spectacular and apocalyptic impacts are rare.

Testing hypotheses
Drawing on an explicit a priori framework for hypothesis generation, the material artefactual and geological record can in principle be used to test suggested patterns in relation to:

1. chronological sequences (the temporality of risk),
2. geographically varying impacts (spatiality of risk), and
3. in relation to impact mechanism assessment (middle-range links).
Important to note here are the many ways in which the effects of tephra fall can be temporally

Tephrochronology in particular can aid with resolving chronological relations. Explosive eruptions create often widespread ash isochrons that provide time-identical and transferrable marker horizons; these can be found in different geological but also archaeological stratigraphies and make, in principle, for excellent terminus post/ante quem markers (Riede and Thastrup, 2013). The expansion and refinement of, in particular, cryptotephra methods for detecting minute traces of tephra over the last 15 years has been remarkable making it now possible to trace the total affected area of many eruptions over much extended geographic scales (see, for instance, Davies, 2015; Lane et al., 2014; Ponomareva et al., 2015 for recent reviews). Note, however, that also other proxies for the presence of volcanic ash exist (e.g. heavy minerals) and that relevant observations – sometimes even of fairly massive macro-tephra layers – are often logged in the literature of very different academic fields (i.e. palynology, soil science, geology/geography, archaeology). The effort to collate databases of existing observations is well worth, however, it as it can reveal evident gaps and drive future research efforts (Bronk Ramsey et al., 2015; Riede et al., 2011). Being able to more precisely capture the spatial extent of a given ash fallout facilitates evaluations of the spatiality of risk and impact. The detection of dated tephras additionally facilitates the refinement of chronologies based on absolute dates. Such refined chronologies can then aid significantly in evaluating the temporality of risk and impacts. Important to note here are the many ways in which the effects of tephra fall can be temporally.

Figure 1. A schematic model for the temporality and ‘spatiality of risk’ (November, 2008) vis-à-vis volcanic eruptions

<table>
<thead>
<tr>
<th>PROXIMAL</th>
<th>MEDIAL</th>
<th>DISTAL</th>
<th>ULTRA-DISTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50km</td>
<td>&lt;500km</td>
<td>&lt;1000km</td>
<td>&gt;1000km</td>
</tr>
</tbody>
</table>

- earthquakes*
- tephra fall*
- pyroclastic density currents*  
- debris avalanches  
- lahars*  
- tsunamis*  
- acid rain*  
- ash remobilization*  
- sediment remobilization*  
- dust veil/sunsets*  
- regional cooling/warming*  

Spatiality of risk
extended in different environments and in interaction with different forms of human land-use. These secondary hazards can sometimes last for decades; also more subtle societal effects (e.g. taboos) can lead to, for instance, long-term abandonment despite the fact that ecological proxies would suggest suitable conditions for habitation. Vice versa, a return to devastated areas can be for social (i.e. religious) reasons alone rather than for renewed settlement and economic exploitation (e.g. Sheets, 2011).

Finally, the finding of tephra itself can assist in evaluating impact mechanism. Tephra can be hazardous fine-grained (Riede and Bazely, 2009), it can be highly abrasive (Riede and Wheeler, 2009) and it can be loaded with a variety of non-salubrious chemicals (Riede and Kierdorf, in prep.) – and all of these effects are testable even in case studies concerned with Pleistocene eruptions.

Long-range impacts

It is well-documented in historical eruptions that the number of displaced greatly outnumbers the number of people killed or directly injured (Table 1). Detailed investigations of how such disaster refugees bring their troubles elsewhere (e.g. Nolan, 1979; Oliver-Smith, 2009) are suggestive of how communities well outside the area of direct impact may be affected. Indeed, my own work suggests that at times it is those areas that show a stronger signal of cultural change as they both receive migrants and are subject to the reconfigurations of post-eruption socio-political networks (Riede, 2014a, 2014b, 2015a; Risch and Meller, 2015). Indeed, social networks consistently appear vital in sociological studies of disaster coping, and they probably had decisive effects on this in the past, too.

Broadly speaking, there will be a negative correlation between proximity to the eruptive centre and any obvious impact signals. Yet, the study of long-range and indirect impacts can in fact be most rewarding; it would lead us to avoid overly sensationalist stories and at the same time lead us to think hard and explicit about the complex relationships between primary and secondary hazards, migration and societal responses. In addition, we should also not shy away from thinking thoroughly about how volcanic eruptions are experienced at long range when the source of a given effect – noise, pressure wave, etc. – is not evident. Might such unusual phenomena (whose range we often can estimate using, for instance Blong’s data) have been even more or at least additionally challenging to traditional societies? Here, the human and historical sciences also stand the most to contribute.

<table>
<thead>
<tr>
<th>Impact</th>
<th>N_{events recorded}</th>
<th>N_{persons affected}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Killed</td>
<td>~250</td>
<td>~90000</td>
</tr>
<tr>
<td>Injured</td>
<td>~150</td>
<td>~16000</td>
</tr>
<tr>
<td>Homeless</td>
<td>~100</td>
<td>~300000</td>
</tr>
<tr>
<td>Migrated</td>
<td>~250</td>
<td>~500000</td>
</tr>
</tbody>
</table>

Table 1. The human impacts of recent (20th-century) eruptions. Most eruptions entail several forms of response. From Witham (2005).
Concluding thoughts

Disaster scientists have long argued that catastrophes are never ‘natural’, but always the result of the complex interactions between one or several geological agents and communities at risk (O’Keefe et al., 1976). Yet, and despite their otherwise excellent nature, many textbooks on volcanology present the societal dimension – for instance as ‘humanistic volcanology’ (Lockwood and Hazlett, 2010) – as a mere afterthought and often devoid of the same rigour that is applied to the physical volcanological systems. Catastrophes have “winners and losers” (Scanlon, 1988) and even deep-time eruptions and their impacts should, in my view, fundamentally be treated from a political ecological perspective. Yet, few if any major treatments on the topic of human impacts of volcanic eruptions offer an even-handed approach that combines physical, social and ‘palaeosocial’ volcanology. Such is an approach is, I believe, as much a desideratum as it is possible to forge. Standing on the should of giants, first steps have perhaps been taken (Riede, 2015b) – but that is really for others to evaluate. What is clear to me is that we are currently in an excellent position to combine the powerful new tools of tephrochronology, geological and archaeological methods and to evaluate the results against a systematic comparative record of human impacts in order to develop strong worked-through case studies. In turn, these case studies can become part of the corpus available for further comparison.

References


Riede, F., Kierdorf, U., in prep. Did the eruption of the Laacher See-volcano (12,920 years BP) cause fluoride poisoning amongst contemporaneous fauna and foragers? Medical Hypotheses.


Tuesday, June 7th, 4-6 pm
Session 6

Closing panel discussion – SWOT analysis of the Avellino Event Project

Chair: Driessen J
We all know that no research plan survives contact with reality. The original work program, summarized in the diagram below, consists of seven phases indicated by Roman numerals. The startup phase I was to be used for job advertising & interviews, obtaining permissions and arranging logistics for the first joint field campaign, building the team’s GIS environment and website, and desktop studies. Fieldwork, encompassing the geoarchaeological coring campaign, archaeological revisits, and pollen cores & macroremains sampling, was to be conducted in phase II (months 7 – 9). About half of the analysis phase III (months 10 – 15) is used to complete preliminary internal reporting on the fieldwork, the other half in preparations for the second joint field campaign. At the start of this phase, the petrography and Strontium isotopic work should have been tendered. Invasive fieldwork at selected sites was to take place in phase IV (months 16 – 18), again followed by a lengthy analysis and publication phase in which preliminary internal reports are prepared on the primary field and lab results (phase V, months 19 – 27); optionally, a brief third field campaign may be necessary during this phase for ‘mopping up’ remaining uncertainties in the field data. Technical publications based on these internal reports are prepared by the postdocs in phase VI (months 28 – 36), and synthetic publications by the postdocs and the applicants in phase VII (months 37 – 48). In the final three months of the program, postdoc 3 will focus on archiving and the submission of specific datasets to digital repositories.

One year into the program, we note that the following adjustments may/will be necessary:

- Phase I: formal start of work on documentary (deliverable b) deferred to end of year one; participation of media students from Hanze technical school
- Phase 2: we have split the first fieldwork phase into several minor coring campaigns; this creates an iterative approach which allows for the incorporation of new insights in the strategy for the second phase. Because at least one more and perhaps two additional ash
layers have been encountered during the first field campaign, tephrochronology, AV-ash identification and characterisation, vegetation reconstruction before and after all ash layers and dating by terrestrial macroremains become more important, and a paper on this subject is envisaged. The main focus for geo-archaeological reconstruction now is on the Central and Southeastern Agro Pontino, because the first field campaign showed better potential preservation of ash in combination with archaeological sites in the Agro Pontino than in the Fondi basin. We have furthermore introduced investigations at the La Sassa cave, in an attempt to recover human bones for the isotope analyses.

- Phase III: deferral of tender for the isotope and petrography flanking studies
- Phase IV: we will defer the second fieldwork period to spring/summer 2017

Deliverables and milestones

Postdocs 1 and 2 begin Phase I with a desktop study describing the status quo of paleoecological and archaeological research in South Lazio (internal deliverables a1-2); meanwhile postdoc 3 focuses on the building of the team’s GIS environment. All three then conduct two joint field campaigns each followed by an analysis phase (phases II – V), producing preliminary reports on the work within 3 months of the end of the fieldwork (internal deliverables n1-3, o1-3). The research assistant for macrofossils analysis produces a technical report after the second fieldwork period (internal deliverable p).

In the first fieldwork period (phase II) postdoc 1 will focus on the collection of the requisite pollen cores from the Pontino and Fondi basins, whilst postdocs 2 en 3 will conduct an extensive systematic geoarchaeological coring campaign to map the distribution of geological and archaeological strata. Phase III is used for the analysis of the coring and survey results and the selection of targets for the phase IV fieldwork (test pits and paleoecological, geological and archaeological sampling); the final decision on this selection is made by the team together with the advisory committee, and constitutes milestone d.

In phase V the data and samples collected in the phase IV fieldwork are analyzed. For the most part this is done by the postdocs but samples for petrographic and Strontium isotopic analysis will be analyzed by external laboratories under the supervision of postdoc 2 (deliverables q, r). In phase VI and VII the postdocs prepare the publication of technical reports and synthetic articles (deliverables e1-3 and l1-3)

The applicants supervise the development, by an external company, of the teaching videos and TV documentary (deliverables b, f, and g) as well as the work of the student assistant responsible for publicity (deliverable m); this work is completed with the publication of the open courseware video shorts on the RUG servers (milestone h). They will organize an international expert meeting on the impacts of volcanic eruptions marking the end of year 1 (milestone c) and arrange the publication of edited proceedings to mark the end of phase V (milestone l). In the final phase they produce the synthetic publications (deliverable j) and supervise the preparation, by postdoc 3, of the digital archives for submission to international repositories (milestone k).