HUMAN FOOTPRINTS ON VOLCANIC TUFF: A STRATIGRAPHICAL APPROACH

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Cycle: XXII

Abstract

In 2003 several human footprints were found in a Pleistocene volcanic deposit at Roccamonfina (Southern Italy). The work concerns different aspects of the research in order to explain when and why these human footprints were impressed and preserved in these deposits. Stratigraphical studies demonstrated that the sediments are pyroclastic density current deposits, results of multiple collapses of a Sub-Plinian eruptive column of Roccamonfina volcano. Chemical and petrographical analyses were focused on the composition of the volcanic shards in order to understand the evolution of the zeolitization process, reason of the lithification and in this way the conservation of the footprints. $^{40}Ar/^{39}Ar$ dating established that the trampling event occurred around 350 ka and that the trampled surface was covered with another pyroclastic flow, eroded during 19th century for exceptionally precipitation, proved by lichenometric and archives analyses. In this way is possible to delineate the sequence of events from the eruption to the exhumation of the trampled surface.

Introduction and Problems

Several human footprints were discovered few years ago in a volcanic deposit of the Roccamonfina volcanic complex (Southern Italy, Foresta locality, Mietto *et al.*, 2003). The trails were impressed over the surface of one of the numerous pyroclastic flow deposits of this volcano. $^{40}Ar/^{39}Ar$ analyses dated the unit at 345 ± 6 ka (Rouchon *et al.*, 2008; Scaillet *et al.*, 2008). As a consequence, the trails represent the oldest *Homo* tracks ever found in Europe. For the importance of the discovery, hence the necessity of a study that permits to understand: the origin of these deposits, when the footprints were impressed, what kind of mechanisms permitted the impression and the conservation of the footprints. These answers were not supported by bibliography at all because Roccamonfina volcano has always been the subject of several works but only under a general or geochemical-petrographical point of view. So the detailed volcano-sedimentologic characteristics of the deposits were rarely examined. A detailed volcanological study of the deposits is the base for understanding the features of deposition phenomenon. Geochemical, chemical and petrographical analyses instead permit to understand the connection between the post-depositional events and the impression and conservation of the traces.

Geological Setting

The Roccamonfina volcano district is located in Southern Italy and belongs to the Roman Comagmatic Region (Appleton, 1972). The activity of Roccamonfina volcano is linked to the Tyrrhenian rifting. Roccamonfina activity began 630 ka and finished 53 ka (De Rita & Giordano, 1996) and can be divided into three phases. The first one (630-400 ka) consists on the formation of the composite volcano and finished with the partial collapse of this edifice. During the second phase (385-230 ka) about five explosive eruptions took place. The final period lasted until 53 ka, built two lava domes. The footprints are on the first explosive eruption sediments ("Brown Leucitic Tuff" formation, BLT) of the second period (Luhr & Giannetti, 1987).

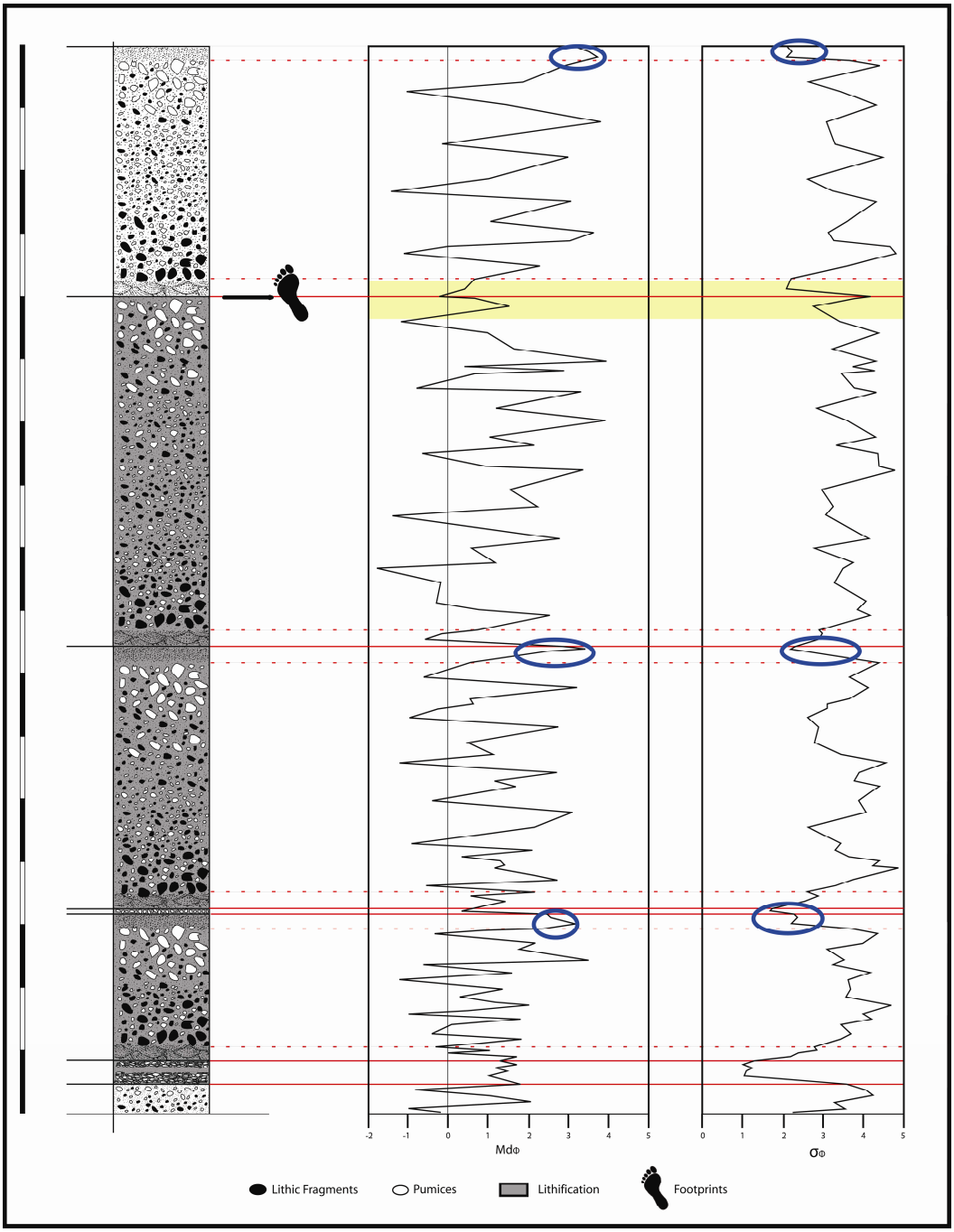
Stratigraphy: The Brown Leucitic Tuff

A detailed mapping of Foresta locality and of the North-East area of the volcanic district, allows recognizing in the BLT fm a succession of different pyroclastic density current deposits. This formation is composed in the whole by seven pyroclastic flow units. Some of them, including the trampled one, are lithified.

The lower portion of the BLT is characterized by the presence of pumices intercalated with fine ash fall, probably caused by the alternation of eruptive self-sustaining column and slight collapses. Above these tephra fall deposits, several pulses of pyroclastic flows have been recognized. Each flow deposit displays a ground-surge layer at the base which is the result of the collapse of the outer part of the eruptive column. The massive portion of the flow units overlay the ground-surge level and is characterized by lithic fragments, pumices, and crystal fragments embedded in predominant fine ash. This portion is the result of the collapse of the inner part of an eruptive column. The human footprints are impressed at the top of the massive part of a flow unit.

Granulometric analyses, followed by a statistical data processing, permitted to characterize the particular eruptive style (*sensu* Walker, 1971) and to subdivide unequivocally the subunits.

The BLT is the result of a Plinian to Sub-Plinian eruption characterized by the deposition of a series of pumice-and ash flow, as supported by granulometric data, flow directions and thickness analyses. The stratigraphy of the BLT reflects the evolution of a pyroclastic density current originated by a fountain collapse. This eruptive event marked the beginning of the explosive phase of the history of Roccamonfina volcano.



Stratigraphy and grain-size analyses of the "Ciampate del Diavolo" site deposits

Geochemical and Petrographical characteristics of the BLT

Roccamonfina volcanic rocks are subdivided into two geochemical series: high K (HK) and low K (LK). Appleton (1972) defined the HK series to encompass ne- and lc-normative leucite-bearing lavas, and the LK series to include Qz-normative olivine basalts, trachybasalts, and biotite augite latites. BLT rocks are halfway these two compositional fields. Analyses were made on both the whole rocks and pumices of the pyroclastic flow units. In each, the ground mass glass has been hydrated and primary leucite has been mostly converted to analcime. So the interpretation of BLT petrogenesis is highly complicated because of the analcimization of leucite and of the abundance of K-chabazite and phillipsite in the samples. Anyway, analyzing the composition of the pumices collected with a stratigraphic order is possible to recognize an evolution toward more basic composition for pumices of the younger flow units. It has been observed that most major pyroclastic eruptions display an evolution toward more basic magma composition and mineralogy (in agreement with Appleton, 1972). This zonation is interpreted to represent a progressive emptying during the BLT eruption of a compositionally stratified magma chamber. So the variations in pumices composition reflect the different level of magma chamber from which the different phases of eruption take origin.

Dating the surface

Two are the aspects concerning the dating. These aspects aim to understand when the footprints were impressed and why it is possible to observe the footprints now.

The first one is the dating of the eruptive events. Several samples collected along the stratigraphic log were analyzed in the Berkley Geochronology Center, with the collaboration of prof. Paul Renne. The results show that the age of the trampled pyroclastic flow unit is comparable with the overlaying unit (trampled deposit 349 ± 3 ka, overlaying deposits 350 ± 3 ka). The trampling event and the lithification process occurred during about 6000 years.

The second aspect concerns the timing of the exposure of the surface. The determination of the timing of the surface exposure was permitted by historical archives research (Dott. Marco De Angelis) and lichenometric data (Dott. Adolfo Panarello). Historical researches are based on the study of the origin of the “Ciampate del Diavolo” (Devil's trails) place name. The evidences concern abundant precipitation around 1807-1816 and numerous geological instability in Foresta area, with landslides. These landslides involved the not lithified parts over the trampled surface, permitting the exposure of the surface.

Lichenometric analyses use the growing rate of a particular lichen to understand the time exposure of the ichnological site. The lichens are the first vegetal formed over a volcanic surface so their dimensions are proportional to the time exposure of the surface. With this calculation it was possible to deduce when the trampled surface was exposed. The result is that the exposure was the early 19^{th} century. In fact during 19^{th} century abundant meteoric precipitation occurred causing numerous avalanches in the Foresta area, determining the exposure of the trampled surface.

In this way both the methodologies confirm that before the beginning of the 19^{th} century the surface was covered by other deposits not lithified.

Post-depositional processes: the lithification

The lithification process took place very shortly after the emplacement of the pyroclastic flow unit (under a geological point of view). In this kind of deposits the zeolitization is the lithifying process. But when and how does this process occur?

SEM and EMPA analyses were made on zeolite crystals and volcanic shards in order to compare their composition. The $^{40}Ar/^{39}Ar$ dating of the trampled and of the overlaying units suggest that the timing range between the two explosive events is less than 6 ka. So the zeolitization process has lasted at most 6000 years, because only the trampled deposits and the two below it are lithified, not the overlaying ones. During this time interval meteoric water permeated the incoherent volcanic deposits. Precipitations are a

common phenomenon occurring after explosive eruptions (Mount St. Helens, 1980; Pinatubo, 1991) .The large amount of water permeated the deposits and permitted the passage of the hominids over a plastic and cold surface. Then zeolitization occurred. This is a chemical process of alteration of volcanic instable glass by means of fluids. These fluids dissolved the unstable parts and precipitated zeolite minerals, which are generally stable at low temperature (about 60-40 °C). The zeolites cemented the ground mass creating a rigid framework among the components of the rock (minerals, lithic fragments, scoriae …). The deposit was lithified permitting the conservation of the human footprints, also after next pyroclastic events.

Summarizing, an initial series of pyroclastic flow units were deposited. During the repose period between an eruptive event and the following one of the same volcanic series, meteoric precipitations occurred, saturating the surface. Then numerous hominids walked over the plastic and relatively cold surface, leaving the traces of their passage. Because of the fluids, the zeolitization process developed, permitting the lithification and so the conservation of the footprints. Therefore the eruptive activity started again with the same characteristics, but the lithification process did not occur again. During 19th century anomalous documented precipitations eroded the overlaying not lithified units, permitting the exposure of the trampled surface.

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SUMMARY DOCTORATE ACTIVITY

Courses:

2007

DR. NEREO PRETO: Cyclostratigraphy course using Matlab
PROF. HUGH JENKYNS: Chemostratigraphy course
DR. LUCA PERUZZO: Brief course on the use of Scanning Electron Microscope

2008

DR. MARIO FLORIS: Introduction to GIS techniques
DR. FABRIZIO NESTOLA: Analytic Methodology Course
PROF. PESARIN; PROF. SALMASO: Introduction to Statistical Methods
SIG. RA GABRIEL WALTON: Corso di inglese scientifico
DR. FIORETTI; DR. DI TORO; PROF. ARTIOLI: Corso di comunicazione scientifica
AA.VV.: Seminars of the Associazione Italiana di Vulcanologia (AIV)
English Course at the Centro di Diffusione Lingue, Padova
PROF. H. U. SCHMINCKE: Short course: *Igneous systems as reflected in volcaniclastic rocks* (Bozen)
AA.VV.: Short Course: *Recent Developments on explosive volcanism* (Reykjavík, IAVCEI Congress)

2009

International Summer School of Volcanology on *"Field volcanological laboratory: the Nisyros and the adjoining volcanoes, Greece - A window on the pre-eruptive magma processes"*, Nisyros, Dodecanese, Greece, 25-30 September 2009

Communications:

2008

Santello L. (15 April 2008) - Human Footprints on volcanic tuff: the Roccamonfina Volcano case - Volcanological group of IFM-GEOMAR, Kiel, Germany

Santello L. – Il Roccamonfina: un volcano fossile – Marzano Appio, 5 Dicembre 2008

2009

Santello L. - Human footprints on volcanic tuffs - Seminar, Department of Earth Sciences, Bristol, 13 February 2009

Santello L., Mietto P., Belvedere M., Panarello A. & Avanzini M. (2009) - Following Pleistocene human tracks: genesis and interpretation of the trampled Brown Leucitic Tuff (Roccamonfina Volcano, Southern Italy) – 10.1474/ Epitome.03.0852. Geoitalia2009, Rimini 9-11 September 2009

Santello L., Mietto P., Belvedere M., Panarello A. & Avanzini M. (2009) - Preservation of human footprints on volcanic tuffs: the Roccamonfina case (Caserta, Southern Italy) - 10.1474/ Epitome.03.1077. Geoitalia2009, Rimini 9-11 September 2009

Santello L. (2009) - Evoluzione del complesso vulcanico del Roccamonfina, Conoscere il Roccamonfina: 1. il Geosito - Atti del convegno, Roccamonfina, 11 Luglio 2009, ISBN 978-88-89021-15-6

Santello L. (2009) - Stratigrafie e cronologie del Roccamonfina in relazione alla presenza di orme fossili preistoriche, Ciampate del Diavolo: "Mezzo Passo nella leggenda… un Passo nella Storia" - Tora e Piccilli, 17 Ottobre 2009

Posters:

2007

Santello L., Avanzini M., De Angelis M., Mietto P., Panarello A. & Rolandi G. (2007) – Stratigraphic features of Roccamonfina volcano (Caserta, Southern Italy) related to the presence of Pleistocenic human footprints - 10.1474/ Epitome.02.1097. Geoitalia2007, Rimini 12-14 September 2007

2008

Santello L., Avanzini M., De Angelis M., Mietto P., Panarello A. & Rolandi G. (2008) - Stratigraphic features of Roccamonfina Volcano (Caserta, Southern Italy) related to the presence of Pleistocene human footprints – Abstract in *IAVCEI 2008, General Assembly*, Reykjavík, Iceland.

Santello L., Avanzini M., De Angelis M., Mietto P., Panarello A. & Rolandi G. (2008) - Stratigraphic features of Brown Leucitic Tuff (Roccamonfina Volcano, Southern Italy) related to the presence of Pleistocene human footprints – *Rend. Online Soc. Geol. It.*, **3**, 704-705.

2009

Santello L., Mietto P., & Panarello A. (2009) - Pleistocene human footprints: interpretation of the trampled Brown Leucitic Tuff (Roccamonfina Volcano, Southern Italy) – AIV, School of volcanology, Nisyros, 25-30 September 2009

Santello L., Belvedere M. & Mietto P**.** (2009) **-** Following Pleistocene human tracks: genesis and interpretation of the trampled Brown Leucitic Tuff (Roccamonfina Volcano, Southern Italy) - INGV, Conferenza A. Rittmann: "La vulcanologia italiana: stato dell'arte e prospettive future", Nicolosi (Catania), 11-13 June 2009, ISBN 987-88-89972-11-3

Awards:

2008

IAS Grant: "*Sedimentologic characterization of the pyroclastic flows of the Roccamonfina volcano (Caserta, Southern Italy)*" - 1000€

Travel Grant: IAVCEI 2008, General Assembly, Reykjavík, Iceland.

2009

Aldo Gini grant : "Ricerche stratigrafiche su tufi del vulcano di Roccamonfina (Caserta) in relazione alla presenza di impronte umane Pleistoceniche - 3900€

***Teaching activities*:**

2007

Teaching assistant: 25 hours, "Geologia Generale 1, Mod. A", Laurea di primo livello in Scienze Geologiche (2006/2007).

2008

Teaching assistant: 25 hours, "Geologia Generale 1, Mod. A", Laurea di primo livello in Scienze Geologiche (2007/2008).

Foreign Activities:

2008

April 2008: fellowship at the IFM-GEOMAR INSTITUTE of the *Kiel University*, for collaboration with Prof. H. U. Schmincke

August 2008: fellowship at the *Institute of Earth Sciences*, *University of Iceland*

2009

February-August (7 months): *research collaborator* at the Department of Earth Sciences, University of Bristol, with R. S. J. Sparks

Others:

2007

4-6 October 2007: Archeological excavation campaign, Foresta, Tora & Piccilli, Caserta

2008

19-23 October 2008: Archeological excavation campaign, Carangi, Marzano Appio, Caserta

2009

12-18 October 2009: Archeological excavation campaign, Foresta, Tora & Piccilli, Caserta