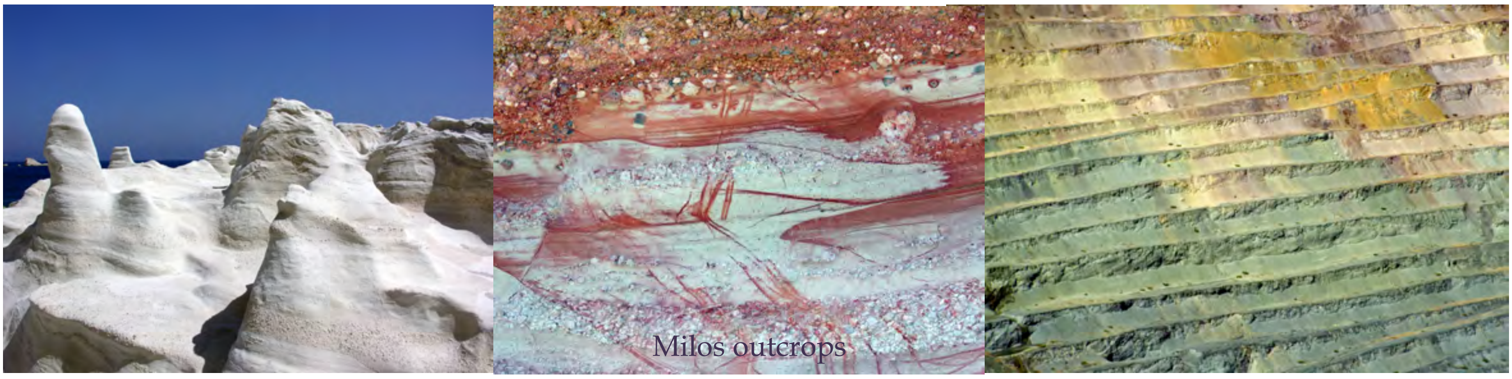
IAVCEI Commission on Volcano Geology
6th International Workshop

ABSTRACT BOOK

Santorini caldera



Milos outcrops

Santorini & Milos volcanoes
23-28 October 2023

6th International Workshop On Volcano Geology

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Geological evolution of Popocatepetl volcanic complex

Hugo Delgado Granados[1], Guillem Gisbert Pinto[2], William S. Cassata[3], Paul Renne[4]

1 Universidad Nacional Autónoma de México; Instituto de Geofísica; hdg@igeofisica.unam.mx
2 Universidad de Barcelona; Departamento de Mineralogía, Petrología y Geología Aplicada, Facultad de Ciencias de la Tierra
3 Livermore CA, USA; Nuclear and Chemical Sciences Division, Lawrence Livermore National Laboratory
4 Berkeley CA, USA; Berkeley Geochronology Center, UC Berkeley

Abstract

Popocatepetl is one of the most active volcanoes in Mexico and, due to the high population density in the surroundings, it is the most hazardous and risky volcano in the country. Its current activity is predominantly mild so far, with little effect on the population and infrastructure, which contrasts with a history of great effusive and explosive eruptions throughout >538 ka. Various successive edifices have grown, building up this volcanic complex (Popocatépetl Volcanic Complex, PVC) through time, separated by sector collapse events that have partially destroyed every one of them. Combining the information of the existing literature (radiometric, geophysical, and volcanological data) with new field observations, aerial images and interpretations of digital elevation models, together with new radiometric dates, there has been an updated and complete reconstruction of the growth and evolution of the PVC throughout its geological history. The PVC consists of four successive volcanic buildings separated by three sector collapse events that have produced avalanche deposits: Tlamacas volcano (>538 – >330 ka), first described by Gisbert et al. (2021); Nexpayantla volcano (~330 to >98 ka); Ventorrillo volcano (~98–23.5 ka); and Popocatepetl volcano (<23.5 ka). Popocatépetl was formed after the last collapse event, but was partially destroyed by an explosive eruption of large magnitude at ~14 ka producing the “Pómez con Andesita” deposit described by Mooser (1967). This deposit is also known as pumice Tutti Frutti (Siebe et al., 1995). Given the geomorphological and volcanological relevance of this Plinian explosive process, Popocatepetl volcano is subdivided into two stages: the El Fraile phase (Pereña and Martin del Pozzo, 2006), whose deposits are prior to the eruption of ~14 ka, and the modern cone (Popocatépetl volcano proper). The knowledge of the processes and evolution of the PVC is essential for the correct evaluation and mitigation of the hazards associated with the potential future activity of great magnitude of the PVC.

Postglacial Eruptive History Established by Mapping and Tephra Stratigraphy Provides Perspectives on Magmatic System beneath Laguna del Maule, Chile

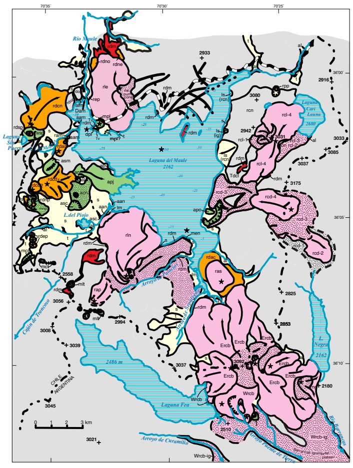
Judy Fierstein

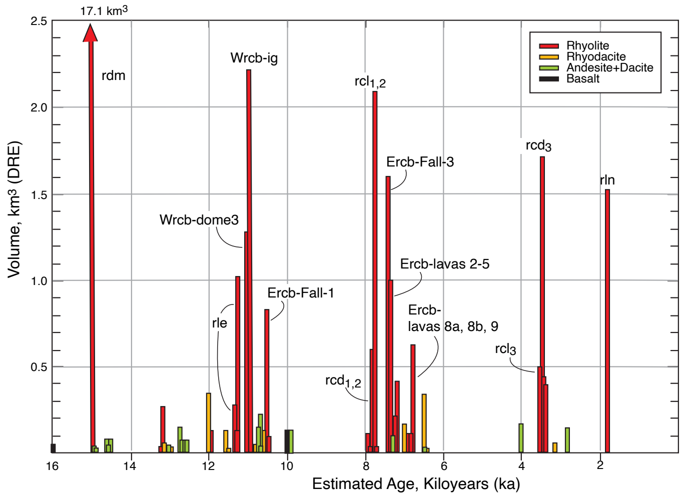
U.S. Geological Survey, Volcano Science Center, Menlo Park, CA , USA

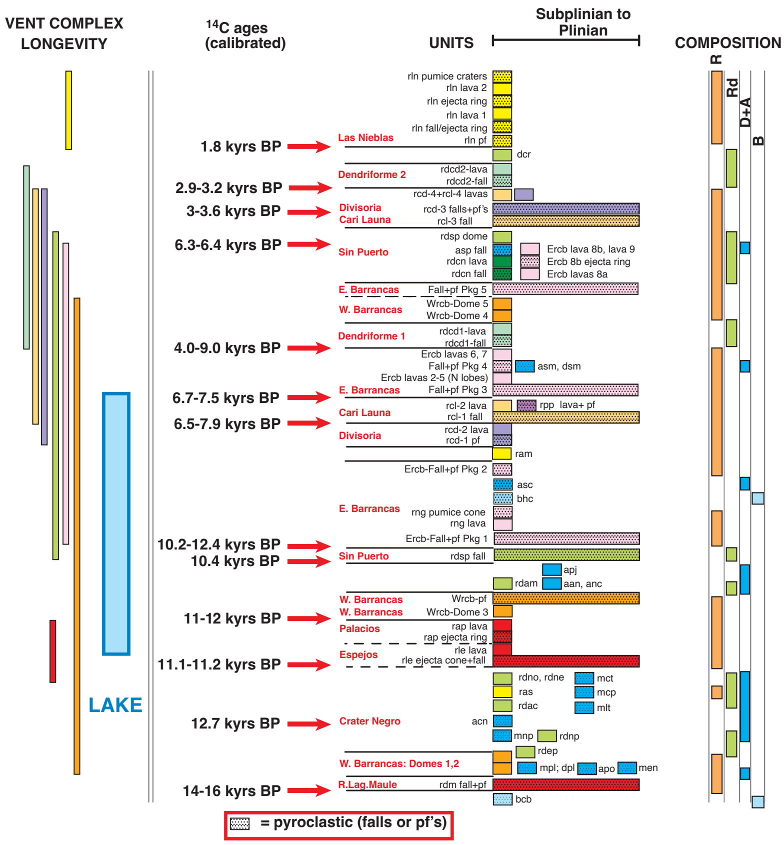
Abstract

Mapping and tephra studies have established the eruptive history of Laguna del Maule (LdM), including nearly 100 postglacial events (50-77.6% SiO2) that erupted from >70 separate vents around the ~100-km2 LdM basin on the Chile-Argentina border. Most (~70) of the young events were silicic, making the LdM volcanic field a unique focus of postglacial rhyolitic eruptions. Spatial and temporal distribution of the eruptive vents reflect the magmatic system that supports the volcanic field. Correlations of distal tephra deposits in Argentina to vents in Chile and radiocarbon dating show that many of the silicic vents cluster into a few multi-vent complexes that each erupted intermittently for decades or millennia between ~15 ka and 2 ka. The most voluminous postglacial eruption (~20 km3: the Plinian rhyolite of Laguna del Maule, unit rdm) is inferred to have erupted at a site covered by the subsequent lake ~15 ka, producing aphyric, high-silica rhyolite (76-77.6% SiO2) pyroclastic flows and fallout that impacted both sides of the border. Rhyolite and rhyodacite eruptions that followed issued from vents that surround the lake, nearly all within 10 km of the rdm vent site. The most long-lived center is the Barrancas complex—with 2 edifices that together include as many as 17 vents, which erupted episodically between ~14.5 and ~3.5 ka, ~16 km SE of rdm. All of the rhyolites are crystal-poor, some are truly aphyric, but most rhyodacites include 5-25% phenocrysts (pl, hb, bt). In and near the LdM basin, an additional 13 mafic vents (50-61% SiO2) and two dacites (63%; 66% SiO2) erupted during the same time interval, most in a sector west to southwest, 6–10 km from the lake center. Notably, one scoria ring along the SE lakeshore, and two scoria rings on the NW shore are only 4 and 5.5 km, respectively, from the rdm vent site. Mafic components are conspicuous in the rhyodacite eruptions as enclaves and mixed pumices, but are rarely seen in the rhyolites. One exception is rdm itself, which has mafic enclaves in the rhyolite pumice and cognate cauliflower-shaped mafic clasts (53-61% SiO2) that were comagmatic liquids. The eruption sequence shows that rhyolite, dacite, and mafic magma erupted throughout the entire postglacial interval, sometimes concurrently, with no systematic trends in either vent location or composition through time.

Laguna del Maule, Chile/Argentina Andes post glacial eruptive history: ~100 eruptive events from ~70 vents: 15 ka-2 ka







Sedimentology and stratigraphy of the Chiancone deposit (Mt Etna). Sedimentological and stratigraphical features

G. Groppelli[1], F. Barilaro[1], A. Di Capua[1], Y.K. Sohn[2], G. Kim[3], G. Norini[1], R. Sulpizio[4]

1. *CNR – IGAG, Via Mario Bianco 9, 29131 Milano, Italy*
2. *Department of Geology, Gyeongsang National University, Jinju 52828, Republic of Korea*
3. *Department of Geological Sciences, Pusan National University, Busan 46241, Republic of Korea*
4. *Dipartimento di Scienze della Terra e Geoambientali, University of Bari, Via Re David, 70125 Bari Italy*

Abstract

The Chiancone (CH) is a volcaniclastic deposit (Calvari and Groppelli, 1996) cropping out along the lower eastern flank of Mt. Etna at the exit of the Valle del Bove depression from 350 m a.s.l. to the sea covering an area of about 40 km^2. The maximum outcropping thickness is about 30 m, but some geophysical data and water holes suggest a maximum thickness of about 300 m, leading to an estimated maximum volume of about 12 km^3, which is comparable to the volume of the Valle del Bove (Calvari et al. 2004). We are carrying on a sedimentological and stratigraphic study to investigate in detail this clastic bodies, generally well stratified, made of mostly rounded clasts of lava, indicating mainly a fluvial reworking of a large amount of lava clasts. This large amount of class can be related to the flank collapse of the Valle del Bove (Calvari et al., 1998; Malaguti et al. 2023) and the formation of Milo lahar or Milo member (Branca et al. 2011). An in-depth comprehension of the Chiancone deposit can highlight the holocenic evolution of the Etna volcano and mainly what happened after the flank collapse.

This work was supported in part by the Italian Ministry of Foreign Affairs and International Cooperation, grant number KR23GR08

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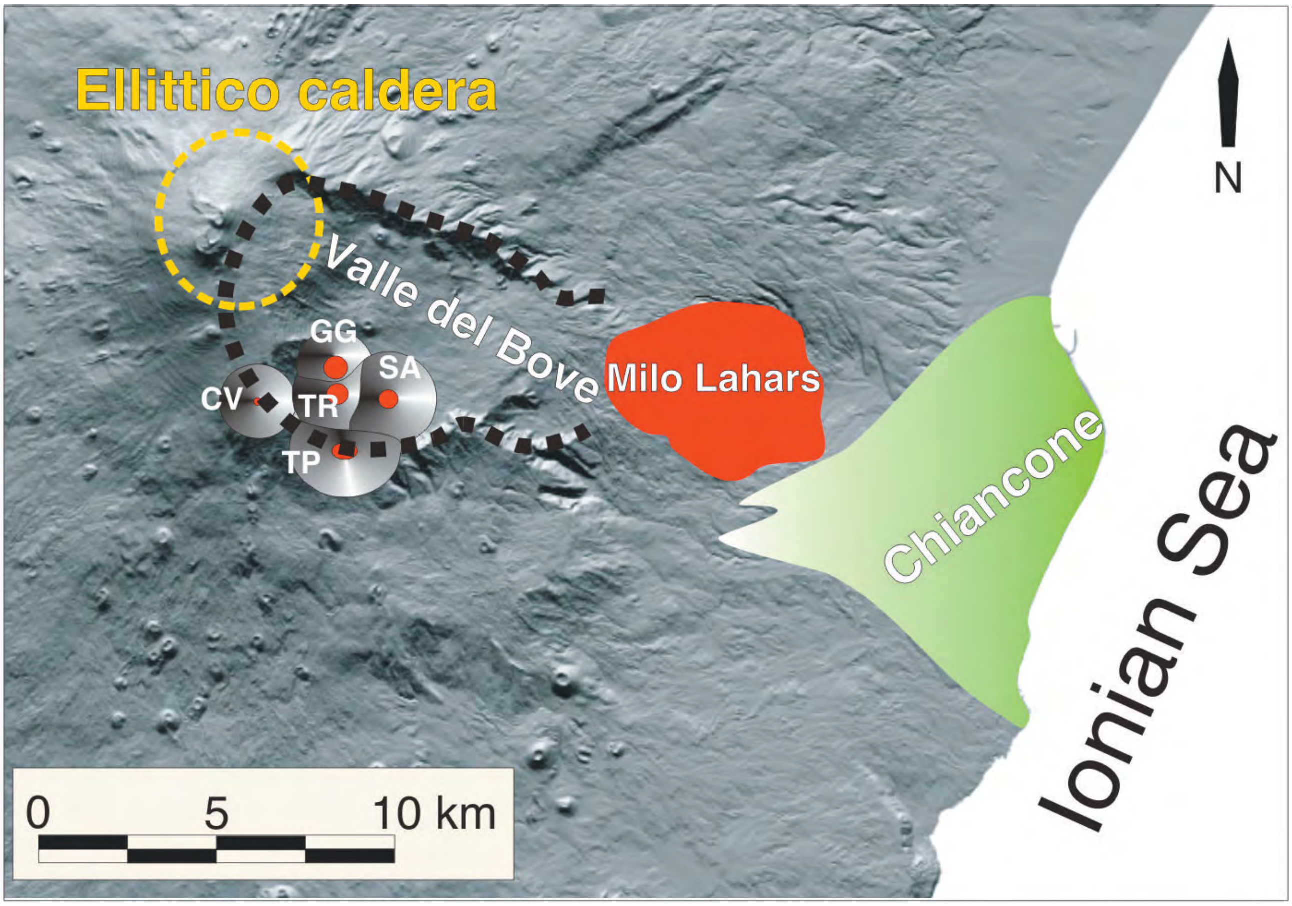

Figure 1. The Eastern flank of Mount Etna with the valle del Bove depression, and Milo and Chiancone deposits (modified from Calvari et al. 2004)

Figure 2. The Chiancone deposit cropping out along the coast close to Praiola village.

Challenges in reconstructing old volcanic systems: case studies from the Miocene-Quaternary Călimani-Gurghiu-Harghita volcanic range (Eastern Carpathians, Romania)

V. Mirea[1], P. Luffi[1,2], I. Seghedi[1]

[1] *Sabba S. Ştefănescu Institute of Geodynamics, Romanian Academy, Bucharest, Romania*
[2] *Geological Institute of Romania, Caransebeş str. 1, Bucharest, Romania*

Abstract

The Călimani-Gurghiu-Harghita volcanic range (CGH) of the Eastern Carpathians, Romania, consists of twelve juxtaposed medium-sized composite volcanoes as well as several close-by isolated monogenetic cones. Volcanological observations and K/Ar geochronology attest that CGH is the result of a nearly continuous eruptive activity that migrated from NNW to SSE between ca. 11 and 0.03 Ma (e.g., Pécskay et al., 2006 and references therein). Detailed geological mapping, petrographic observations, and K-Ar geochronology led to the identification of a series of major edifice failures (e.g., Szakács & Seghedi, 1995, 2000, Seghedi et al. 2019, 2023 in press). Volcanic debris avalanche deposits (VDADs) have resulted from the failure of several main volcanic edifices: Rusca-Tihu (~7.8Ma) in Călimani Mts, Fâncel-Lăpușna (~6.8Ma) in Gurghiu Mts, Ostoroș (~5.7Ma), Ivo-Cocoizaș (~4.8Ma) and Vârghiș (~5.15 Ma) in North Harghita Mts, Luci-Lazu (~4.0 Ma) and Pilișca (~1.5 Ma) in South Harghita Mts.

Using a digital surface model, here we discuss volume estimation techniques for VDADs associated with two volcanoes, Fâncel-Lăpușna and Ostoroș. The volumes of VDADs were constrained following two methods: (1) estimating their present-day volumes (Vd) and (2) estimating the volumes of collapse scars (Vs) left after the displacement of the debris avalanches.

The present-day volume of each VDAD was calculated in QGIS 2022 by integrating its thickness over its surface area resulted from field mapping (1). For collapse scar estimation (2), we used pre-collapse models obtained by two approaches: a) a simple model for edifices preserving remnants of the scar amphitheatre via reconstruction of the collapsed volcano top and b) a complex model using the median elevation profile calculated from radial profiles of the volcano. Failure of the relatively small Ostoroș edifice left behind a well-preserved, eastward oriented semi-circular scar. The sector collapse of the Fâncel-Lăpușna edifice, one of the most complex volcanic structures of CGH, was triggered by a massive caldera-forming Plinian eruption, and has affected ~40% of the volcano, leaving behind a giant south-facing semi-circular depression.

Challenges in estimating VDAD volumes are related to extensive burial by later volcanic deposits (e.g., partial coverages of the Fâncel-Lăpuşna VDAD by the Seaca-Tătarca volcano) or younger sediments (e.g., Ostoroș). Challenges in pre-collapse modelling of volcanic edifices are related to uncertainties associated with the paleo-relief as well as the base elevations and heights of the edifices, which significantly influence the reconstruction of the modelled volcanoes. Uncertainties also arise from reconstructing the uneroded shapes of edifices and estimating the volume of scars caused by avalanches. This is due to contributions from pre- and post-avalanche weathering and erosion, as well as volcanic debris avalanche deposits. Present-day VDAD volumes (Vd) appear systematically lower than the volumes of collapse scars (Vs) estimated for their source volcanoes, regardless if edifice denudation is accounted for or not. We attribute these discrepancies mainly to uncertainties associated with the thicknesses and areas of VDADs, which may be underestimated given the unknown effects of substrate topography and erosion affecting their distal deposits.

Estimated Fâncel-Lăpușna volumes are: volcano volume—255±17 km^3, Vs ~127 km^3 and Vd—107±34 km^3. Ostoroș estimated volumes are: volcano volume—31±1.3 km^3, Vs—~1.85 km^3 and Vd—1.3±0.4 km^3.

References: **Pécskay et al., 2006** Geol. Carpath. 57,511–530; **Seghedi et al 2019**, Phys. Earth Planet. Inter. 293; **Seghedi et al 2023 in press**, J. Volcanol. Geotherm. Res.; **Szakács & Seghedi, 1995** Acta Vulcanol., 7(2), 145-153; **Szakács & Seghedi, 2000** Gordon Breach Science Publishers, pp. 131-151; **QGIS.org,2022,** QGIS Association. http://www.qgis.org

Reassessment of the eruptive history of the Atitlán volcano: towards hazard evaluation

Pico R. Eduard1, Capra P. Lucia[1], Torres O. Rafael[2], Secaira Z. Daniel E.[3], Chigna M. Gustavo A.[4], Moncada V. María [3]

1. *Centro de Geociencias, Campus Juriquilla, Universidad Nacional Autónoma de México, Querétaro, México*
2. *Centro de Ciencias de la Tierra, Universidad Veracruzana, Xalapa, México*
3. *Asociación Vivamos Mejor Guatemala, Panajachel, Guatemala*
4. *Área de Vulcanología, Instituto de Sismología, Vulcanología, Meteorología e Hidrología de Guatemala (INSIVUMEH), Ciudad de Guatemala, Guatemala*

Abstract

The Atitlán volcano is Guatemala's third most hazardous volcano after Santiaguito and Fuego. The Atitlán volcano is a composite volcano that buries the southern rim of the ~20 km-diameter Atitlan caldera in Guatemala's central plateau, inside of which other two stratocones (San Pedro and Tolimán) also exist. The Atitlán volcano has a symmetrical cone shape characterized by alternating deposits of lava flows and pyroclastic fall and density currents. Eruptions at the Atitlán volcano began 10,000 years ago, and at least nine historical events have been documented since the arrival of the Spaniards between the years 1469 and 1853. Previous works in the area were focused only on developing a regional geologic map of the Quaternary and Tertiary deposits without any detailed distinction, and on studying the largest eruption and evolution of the Atitlan caldera. This work presents an updated geologic map and stratigraphy of the Atitlán stratovolcano with a detailed distribution of lava flows and pyroclastic density currents (PDC). Additionally, new C14 ages confirm that hazards associated with PDC flooding have been frequent, and could impact more than 70,000 people living within 10 kilometers of the volcano summit in case of reactivation. This work is the result of an inter-institutional and international collaboration between UNAM, INSIVUMEH, CONRED and Vivamos Mejor Association of Guatemala, founded by the Swiss Cooperation.

Geological map of the western sector of El Hierro Island (Canary Archipelago)

L. Poletti[1], M. Telmon[2], G. Groppelli[3], S. Meletlidis[4], J. Martì Molist[5], C. Principe[6], G. Norini[3], A. Di Capua[3]

1. *Università degli studi di Milano – Bicocca, Piazza della Scienza 4, 20126, Milano, Italy*
2. *UiT – The Arctic University of Norway, Tromsø, Norway*
3. *CNR – IGAG, Via Mario Bianco 9, 29131 Milano, Italy*
4. *Instituto Geografico Nacional, Grupo de Volcanologia, Spain*
5. *Department of Geosciences, IDAEA, CSIC, Barcellona, Spain*
6. *CNR – IGG, Via Giuseppe Moruzzi 1, 56124, Pisa, Italy*

Abstract

This work presents a new geological map of the western side of El Hierro Island at a 1:12’500 scale, as the result of a geological survey carried out during the 2022 spring. Fieldwork analyses revealed this sector is characterized by the presence of lava flows, pyroclastic deposits and volcanological morphologies that were resumed in a scheme of the stratigraphic relationships and organized into 3 syntematic units, named as El Julan-1 Synthem, the El Julan-2 Synthem, and the El Golfo Synthem. Such units were accumulated after a major flank collapse (El Julan collapse), whereas two of them were emplaced before the occurrence of the El Golfo collapse. The aforementioned subdivision allowed the identification of a change in the eruptive style before and after the El Golfo collapse: lava flows emplaced before such event are generally tens of meters thick, flowing from the collapsed volcanic part to the sea for some kilometres, whereas lava flows emplaced after it are definitely thinner and shorter. Fieldwork analyses also allowed the identification of a fault plain in the southwestern part of the island, as well as the recognition of a surficial control of eruptive fissures’ trends, probably related to the presence of the two escarpments of the collapses. The map represents a step towards the realization of a high-resolution geological map of the entire island, begun with the realization of the geological map of the southern part of the island through the work of Abis et al. (2023).

Reference

Abis, C., Dajma, F., Di Capua, A., Martì Molist, J., Meletlidis, S., Norini, G., Principe, C., Groppelli, G., 2023. Geology of El Hierro Southern Rift, Canary Islands, Spain. Journal of Maps, DOI: 10.1080/17445647.2023.2214173

Resumed field investigations of the Mogoșa composite volcano (Miocene Gutâi Volcanic Zone, north-western Romania) to understand its structure and eruptive history. Work in progress.

Alexandru Szakács[1], Marinel Kovacs[2]

1 Institute of Geodynamics, Romanian Academy, Bucharest, Romania
2 Technical University of Cluj-Napoca, North University Centre of Baia Mare, Romania

Abstract

The Miocene Gutâi Volcanic Zone (GVZ) of the north-western East Carpathians in Romania is composed of a contiguous area of ca. 450 km2 hosting numerous volcanic edifices and shallow subvolcanic structures having complex mutual spatial relationships and time-space evolution in the 15.4-7.0 Ma interval. One of them, Mogoșa, located in the south-central part of the GVZ, is a typical example of complex structure and evolution at the level of a single volcanic edifice. Although mapped at great detail (1:5.000 scale) decades ago, its volcanological features and eruptive history remined elusive so far. Renewed fieldwork focused on the recognition of diagnostic features of its various volcanic formations, both massive/coherent and clastic, led to a new perspective on the internal structure and evolution of this Miocene volcano.

According to available K-Ar ages, its volcanic history is bracketed within the 11.4-9.5 Ma time range. During this interval volcanic activity started and developed in the southern part of the today edifice through an eruptive center building up a dome-shaped structure around it - the Arșița dome. A series of eruptive events including phreatomagmatic episodes disrupting an initial dome structure, followed by resumed extrusive dome building phases generating block-and-ash-flow deposits around it and a final coherent dome cupola at the end are recorded in the evolution of the Arsita dome. Petrographically, this evolution stage is characterized by pyroxenes-dominated basaltic andesites (SiO2 range of 51.46-54,26 %). Next, the eruptive activity shifted northward forming a new effusive vent through which lavas of the roughly same chemical composition built up a larger dome structure around the present summit of the edifice. Much less voluminous dome-related clastic volcanic material was generated in this stage. Volcanic evolution continued by the emplacement of a north-south-elongated dome – the Valea Morii dome – in the present summit area of the volcano built up of more viscous lavas characterized by the presence of large-sized plagioclase phenocrysts in a high-silica andesite/dacite (10.3 Ma). The youngest (9.5 Ma K-Ar age) and less voluminous effusive products of the volcano, composed of amphibole-phyric basaltic andesites occur in a very limited area at the summit, around the present-day Mogoșa peak.

It is to note that despite its various types of eruptive products (coherent and fragmentary), and petrographic types (basaltic andesites macroscopically dominated by pyroxene or plagioclase feldspars or amphibole, allowing discrimination of various phases of volcanic evolution, the Mogoșa rocks (with the only exception of the Valea Morii dome rocks), display a strikingly homogenous chemical composition (in terms of both major and trace elements), characteristic to this volcano and differentiating it for its neighboring volcanic edifices.

Despite the progress obtained in deciphering the structure and evolution of Mogoșa volcano, unresolved problems still wait to be addressed in the near future. For example, the local and clustered presence of breccia megablocks in a restricted area ("Giant's garden") at the western foot of the edifice showing relevant details indicating their origin by dome collapse still has to be explained and their origin localized.

A new lithostratigraphy scheme for the Late Miocene volcanic formations of Tokaj Mts., Carpathian-Pannonian Region

J. Szepesi[1,2], R. Lukács[2,3,4], Sz. Harangi[2,4], P. Gál[2], A. Di Capua[5], R. Sulpizio[5,6], G. Groppelli[5], G. Norini[5], L. Fodor[7,8]

1. *Geochronology Laboratory, HUN-REN Institute for Nuclear Research, Debrecen, Hungary*
2. *HUN-REN-ELTE Volcanology Research Group, Pázmány P. sétány 1/C, 1117 Budapest, Hungary*
3. *Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budaörsi út 45, 1112 Budapest, Hungary*
4. *Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Petrology and Geochemistry, Pázmány P. s. 1/C, 1117 Budapest, Hungary*
5. *CNR IGAG – Institute of Environmental Geology and Geoengineering, Via M. Bianco 9, 20131, Milan, Italy*
6. *University of Bari "Aldo Moro", Department of Earth and Geoenvironmental Sciences, Via Orabona 4, 70125, Bari, Italy*
7. *Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, Pázmány P. s. 1/C, 1117 Budapest, Hungary*
8. *HUN-REN Institute of Earth Physics and Space Science, 9400 Sopron, Csatkai E. u 6-8.*

Abstract

Defining stratigraphic units and hierarchy in volcanic areas is a complex task. The present study deals with such exercise in the Tokaj Mountains (Carpathian-Pannonian region, Hungary, Fig. 1), where lithostratigraphic revision work has been done as part of the national lithostratigraphic revision project of the Hungarian Stratigraphic Committee (HSC, Babinszky et al. 2023). The calc-alkaline volcanic activity occurred between the Badenian and early Pannonian (15-9.4 Ma (Pécskay et al. 1987; Pécskay and Molnár, 2002). The depositional environment gradually changed from submarine to subaerial (from Badenian to Sarmatian) with thickened volcanic graben infill (over 2000 m). The silicic formations are represented by extensive ignimbrite sheets (Szepesi et al. 2018) and fallout deposits. The effusive-intrusive volcanism is represented by intermediate to silicic lavas including andesitic composite volcanoes with erosional calderas, several subvolcanic bodies (andesite-dacite), and rhyolitic lava domes. Much of the exposed subvolcanic bodies are hydrothermally altered (silicification, adularia-sericite, propilitic alteration, Pécskay & Molnár 2002). The revised lithostratigraphic classification uses formal units, as recommended by the International Commission on Stratigraphy (ISG Murphy & Salvador 1999). In the case of pyroclastic rocks, the definition of lithostratigraphic units follows the concept used for sedimentary systems (formation, member, bed), where the designation of the units is mainly based on petrographic characteristics completed with geochemical and geochronological information. In contrast, there is no stratigraphic superposition in the case of unstratified intrusive rock bodies and also in case of more complex igneous assemblages including effusive and explosive deposits. Following the consensual decision of the HSC, we have introduced the use of "complex" for larger and more complex igneous assemblages, and so grouped such rocks in the Tokaj Volcanic Complex. The distinguishable lithological units within the complex can be defined by their petrographic, geochemical and geochronological properties and also named separately (e.g. Baskó Andesite, Telkibánya Rhyolite).

Revised stratigraphic units of the study area

a,Pyroclastic formations

Lithology: Poorly to unsorted non welded, massive lapilli tuffs (mLT). Lithic- and pumice-rich lapilli tuffs. Stratified lapilli tuff and ash. Geochemistry: predominantly rhyolites, minor rhyodacite.

Sátoraljaújhely Rhyolite Lapilli Tuff Formation

Petrography: rhyolites (q, san, plag, bi, ~10%, up to 20%) zeolitic, argillic alteration, silicification. *Thickness:* up to several hundred meters in boreholes. *Age:* Upper Badenian. Zircon U-Pb ages (Vilyvitány, Mikóháza, Sátoraljaújhely exposures) 13.2-13.1 Ma. Variable K-Ar ages (biotite 14.6 Ma, feldspar 13.8Ma). *Member:* Csattantyú (rhyodacite tuffs).

Szerencs Rhyolite Lapilli Tuff Formation

Petrography: generally phenocrystal poor rhyolites (<10%, Hegyköz: plg, q+bi, Szerencs: q, san, plg +bi *Thickness:* in rhyolitic calderas up to 350-500 m *Age:* Sarmatian. U-Pb from 12.6 Ma (Hegyköz-Telkibánya) to 12 Ma (Szerencs caldera). Prolonged hydrothermal activity (Mád, alunite K-Ar 10.9 Ma). *Member:* Erdőbénye (quartzite, limnosilicite, geyserite).

Vizsoly Rhyolite Lapilli Tuff Formation
Petrography: generally phenocrystal poor rhyolites (<10%, plg,opx + q,bi,cpx) except Hidegoldal unit (~20% q,plg,bi+san). *Thickness:* Average thickness 50 m, but may exceed 100 m. Age: Late Sarmatian - Early Pannonian. Zircon U-Pb 11.5 Ma, K-Ar (lithoclast whole rock) 11.2 Ma. No published ages are available for the Cserehát Member. Member: Cserehát Rhyolite Lapilli Tuff (rhyodacite tuffs, tuffite, bentonite).

b, Effusive, intrusive lavas:
Lithology: coherent lavas and clast-supported, non-stratified monolithic breccias (autoclastic, hyaloclastite, peperite). Geochemistry: basalt, andesite, dacite, rhyolite

Tokaj Volcanic Complex
Petrography: basalt (plg+ol+cpx ~20%), andesite (plag, opx, cpx, hbl + bi,q up to 40-60%), dacite (plag, opx, cpx, hbl + bi,q,san, 25-40%) rhyolites (same as volcaniclastics). Silicification, adularia-sericite, propilitic alteration. *Thickness:* Single lava flows, domes from several meters over 150 meters thick. Composite edifices with coherent lavas, lithic breccias and lapilli tuff interbedding over 1000 m. Age: Middle to upper Miocene (Upper Badenian- Lower Pannonian). K-Ar data: variable between 14.2-10.1 Ma, basalt 9.4 Ma. Units: Kovácsvágás, Baskó, Amadévár andesites, Kányahegy metasomatite, Vágáshuta, Szavahegy, Tarcal Dacite, Mád Dacite Tuff, Végardó, Telkibánya, Sulyomtető Rhyolite, Pusztafalu Rhyodacite, Apróhomok Basalt.

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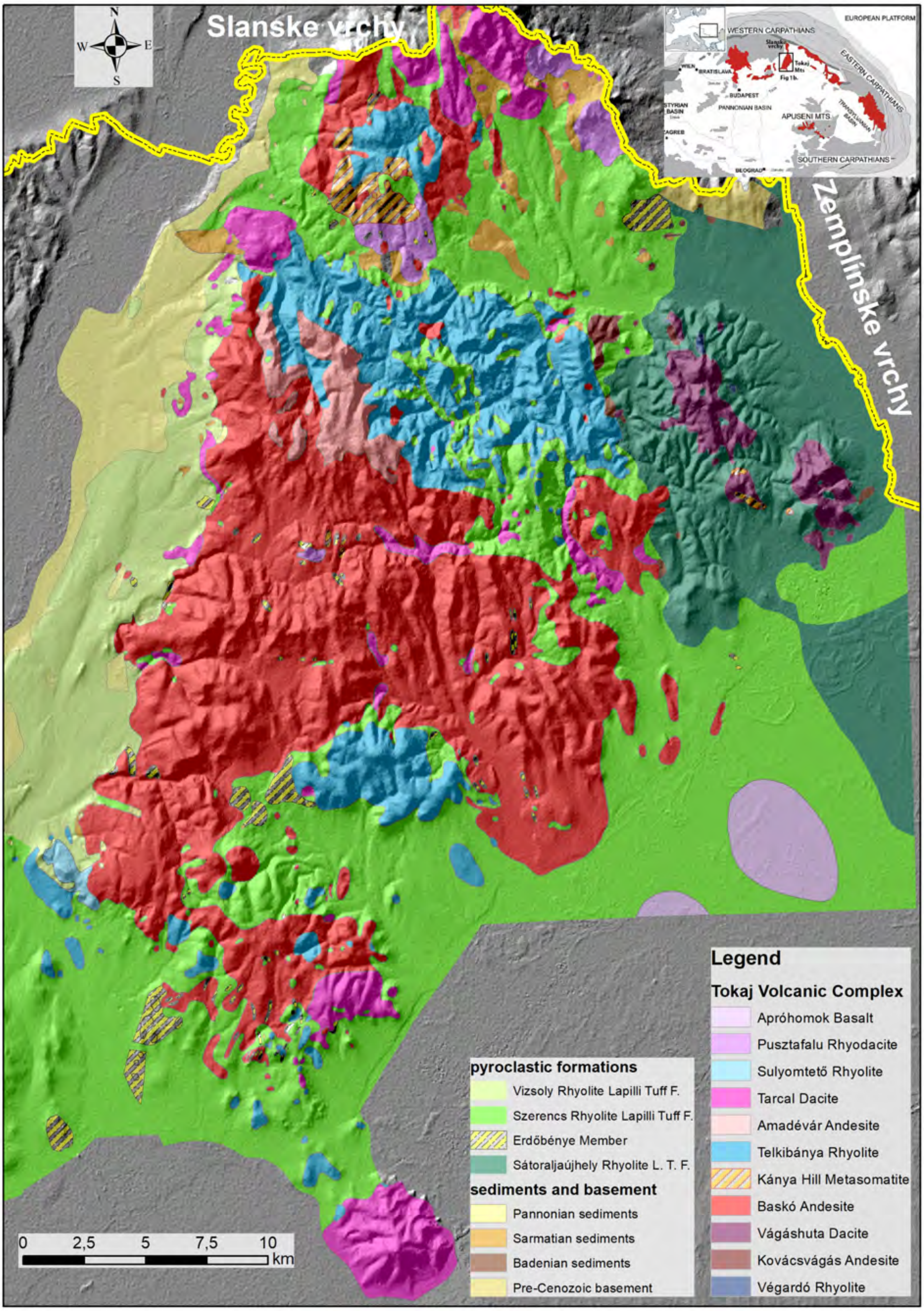

Fig. 1. Revised stratigraphy of the Tokaj Mountains including sedimentary formations and basement without Quaternary cover.

A scoria cone volcano complex in the Lusatian Volcanic Field, Czech Lusatian Mountains – The Zlatý and Stříbrný vrch Hills

O. Tietz[1], V. Kühnemann[2], J. Büchner[1]

1. *Senckenberg Museum of Natural History Görlitz, Am Museum 1, 02826 Görlitz, Germany*
2. *TU Bergakademie Freiberg, Institute of Geology, Bernhard-von-Cotta-Str. 2, 09599 Freiberg, Germany*

Abstract

The Palaeogene volcanic peaks of Zlatý and Stříbrný vrch Hill are part of the Lusatian Volcanic Field in the Germany-Poland-Czech Republic tri-border region. The two discrete hills in the Lusatian Mountains (Czech: Lužické hory) overtop prominently the subjacent sandstone of the Bohemian-Saxonian Cretaceous Basin. In the past there were only more detailed geological studies of the Zlatý vrch Hill. Their volcanological genesis was explained in multiple phases, most recently by Kühn (2011) with three eruption stages. The reason for this was the striking subdivision of the lava body into two or three units due to very different spatial positions and formation of the basalt columns (Fig. 1).

New geological mapping (Fig. 2), orientation measurement of basaltic columnar jointing as well as petrographic and geochemical analyses of both peaks can expand previous knowledge. Thus, it was possible to reconstruct the eruption history and size of both volcanic edifices (Kühnemann et al. 2022). Zlatý and Stříbrný vrch Hills represent two monogenetic scoria cones with scoria walls formerly surrounding the separated lava lakes, each probably situated above a buried maar. Field mapping and petrographic analyses point to a three-phase progression (Fig. 3): (1) the not directly detectable formation of an initial maar, caused by an initial phreatomagmatic phase, (2) a phase of Strombolian eruption with the formation of both scoria cones, and (3) post-volcanic uplift and erosion of the scoria wall. In contrast to previous studies (e.g. Kühn 2011), the new petrographic analyses do not show significant differences inside the tephrite lava bodies of both sites. The apparently multiphase structure of the lava body is interpreted as a single lava lake that developed an entablature structure as it cooled (Forbes et al. 2014; Fig. 1).

Important for this reconstruction of the two scoriae cone volcanoes was the evidence of large-scale spread of volcanic scoria around both basalt hills through numerous dipstick soundings. Furthermore, after the mapping results it must be assumed, that both scoria cone volcanoes where deepened into the sandstone frame work. This is the only way to achieve a realistic geometric reconstruction of the cinder cones, each with a lava lake, which has not yet been eroded today. This subsidence can be best explained as a result of the formation of a maar crater by phreatomagmatic eruptions. However, direct evidence of diatreme breccia could not be observed by the mapping. The mapped high sandstone ground between the two scoria cone volcanoes suggests that there must be two separate maar craters (Fig. 3).

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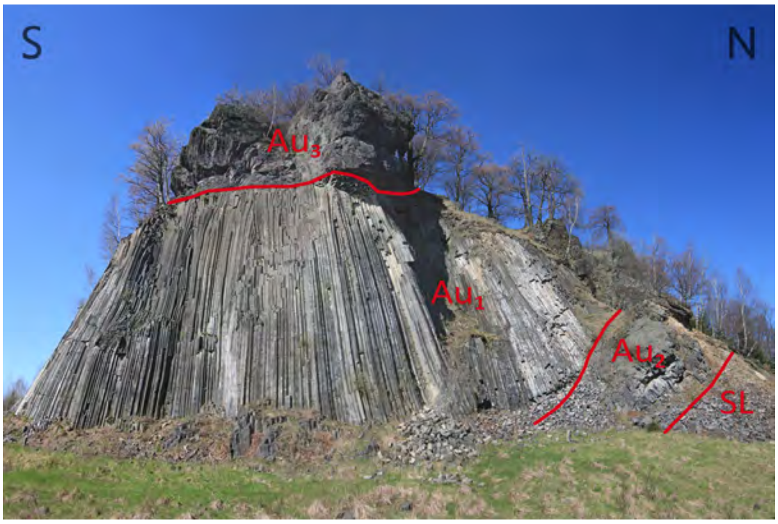

Fig. 1: View to west to the 40 m high rock wall of the abandoned main quarry of the Zlatý vrch Hill. SL: scoria lapilli stone, Au1-3: Lava lake units: Au2 = massive basalt represents so-called wallpaper as the contact to the inner crater wall, Au1 = lower Colonnades with long and thin columnar jointing and charcoal-pile-like inclination direction, Au3 = irregular columns as central part of the lava lake (the upper colonnade do not exist).

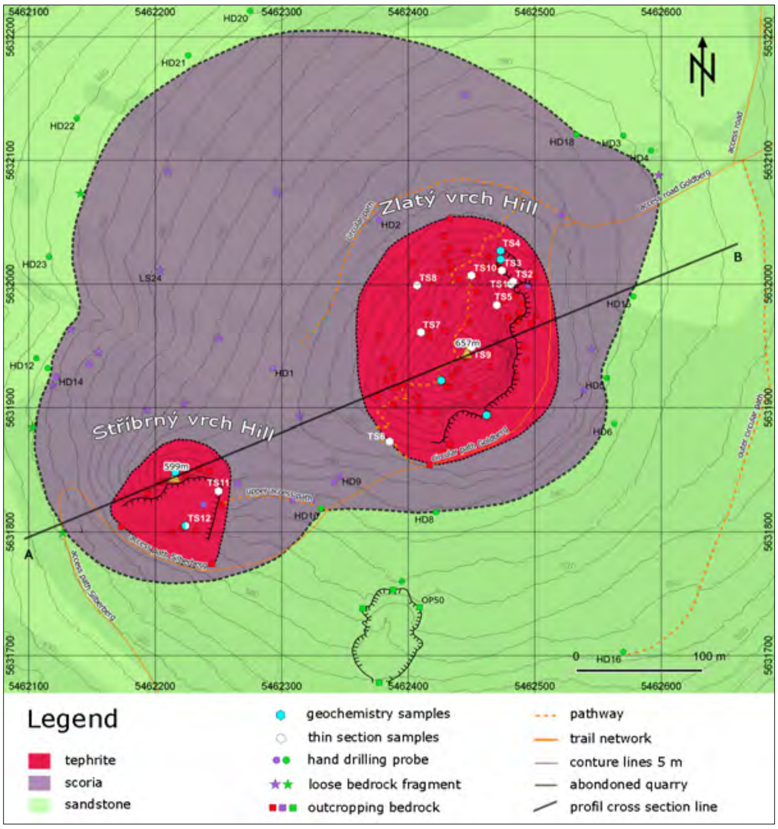

Fig. 2: Geological map of Zlatý/ Stříbrný vrch Hill complex with sampling points and line of the geological profile A–B (Fig. 3).

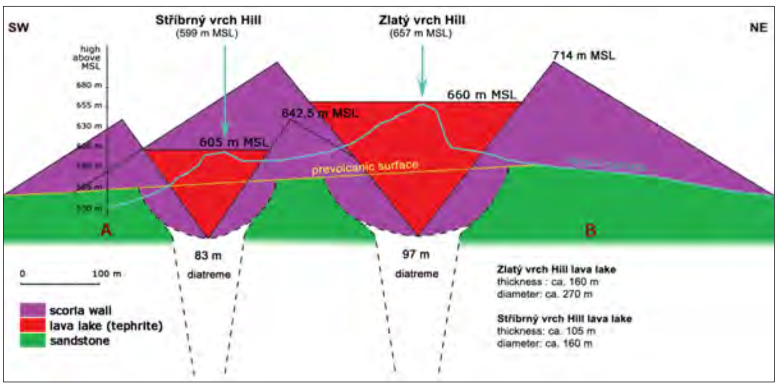

Fig. 3: Schematic geological profile A-B of Zlatý vrch and Stříbrný vrch Hill complex (see Fig. 2 for the course of the geological cross section).

The 70 ka Perote Pumice, a rhyodacite Ultra-Plinian eruption of Los Humeros volcanic caldera, Mexico

R. Torres-Orozco1, 2, R. Tlalpachito-Palomino1, J.L. Arce3, G. Carrasco-Núñez4

1. *Centro de Ciencias de la Tierra, Universidad Veracruzana, Cto. Aguirre Beltrán S/N, Edif. B, Zona Universitaria, Xalapa, 91090, México*
2. *Observatorio Sismológico y Vulcanológico de Veracruz, Universidad Veracruzana, Cto. Aguirre Beltrán S/N, Edif. B, Zona Universitaria, Xalapa, 91090, México*
3. *Instituto de Geología, UNAM, Av. Universidad 3000, Coyoacán, Ciudad de México, 04510, México*
4. *Centro de Geociencias, UNAM, Blvd. Juriquilla 3001, Juriquilla, Querétaro, 76230, México*

Abstract

The 164 ka and 18 km-diameter basaltic-andesite to rhyolitic Los Humeros volcanic caldera (LHVC) is the largest active caldera of the Trans-Mexican Volcanic Belt. The LHVC was formed by two caldera-collapse episodes that erupted at least two major voluminous ignimbrites at 164 ka and 69 ka, intercalated with repetitive intra-collapse and post-caldera explosive and effusive activity, the latest at 2.8 ka. Based on field mapping and lithostratigraphy, and major element chemical analyses, in this work we have reconstructed the eruption dynamics and hazards of the 70 ka rhyodacite (68-70 wt.% SiO2) Perote Pumice (PP), produced by the largest intra-caldera eruption of the LHVC. The PP consists of: (I) lower, up to 40 cm-thick, pyroclastic flow deposits, covered by 1-4 m-thick, bedded to diffusely-bedded fall deposits; (II) middle, 1-3 m-thick, massive fall deposits, interrupted by up to 10 cm-thick wet and dry surges; and (III) upper, 1-3 m-thick, bedded fall deposits, interrupted by at least one middle surge, and topped by the up to 30 cm-thick remnants of mostly reworked pyroclastic flow deposits. The lowermost levels are dominated by grey dacite pumice lapilli and ash ranging from microvesicular to extremely fibrous vitric textures, and by dense dacite ash and lapilli clasts. The middle and upper levels are dominated by white vesicular and fibrous rhyolite pumice lapilli, often interrupted by diffusely stratified beds of dense dacite ash and lapilli clasts. The eruption produced a total of 29 km3 of tephra, and the fall deposit facies and isopach and isopleth maps suggest a southeastern distribution from a ~34-40 km-high Ultra-Plinian plume towards the present-day city of Xalapa. The results of this work indicate that the PP comprises the relatively steady intra-caldera fallout end-member of the LHVC explosive volcanism, opposite to the highly unsteady and voluminous caldera-collapse ignimbrites. Still, the PP eruption column also experienced frequent partial collapse followed by the emplacement of both dilute and concentrated pyroclastic density currents during unsteady onset and waning phases. Despite the unlikely near future LHVC reactivation, in case of a Plinian eruption similar in size to the PP, > 1 million people in the easternmost Mexico would be threatened, and roughly 3000 km2 could become uninhabitable.

AN EARLY EOCENE INTERMEDIATE LARGE IGNEOUS PROVINCE, NORTHWEST CORDILLERA, NORTH AMERICA: ERUPTIVE PRODUCTS, TECTONICS AND CLIMATE

N. Van Wagoner[1], L. Ootes[2], M. Mihalynuk[2], and C. Wall[3]

1. *Thompson Rivers University, Department of Physical Sciences, Kamloops, British Columbia, Canada V2C OC8*
2. *British Columbia Geological Survey, Ministry of Energy, Mines and Low Carbon Innovation, Victoria, BC, Canada V8W 9N3*
3. *University of British Columbia, Department of Earth, Ocean and Atmospheric Sciences, Vancouver, BC, Canada V6T 1Z4*

Abstract

Within the Northwest Cordilleran orogen of Canada and the United States Late Paleocene to Early Eocene graben-fill volcanic and sedimentary rocks form a broad belt, extending from southern Yukon in Canada, to Idaho and Wyoming in the United States. Older arc terranes that were accreted to the ancestral North American margin form the basement to the Eocene volcanics. Numerous studies have focused on the petrogenetic/tectonic interpretation of these rocks within a local graben or region. To more fully understand the significance of Cordilleran Eocene volcanism we took a regional approach, conducting the a NW Cordilleran-wide compilation and synthesis of previous studies of these volcanic complexes, along with new geochemistry and high precision geochronology. Based on these data we show that the timing, extent, and characteristics of volcanism indicates that this belt of rocks represents a large igneous province, and proposed that it be referred to as the Eocene Northwest Cordillera Large Igneous Province (ENCLIP).

Previously referred to as the Challis-Kamloops belt, the ENCLIP is ~2,500 km long. The rocks are preserved as isolated remnants, separated by local graben-forming faults, and currently cover an outcrop area conservatively estimated at ~ 35,000 km^2. Within isolated grabens volcanic sequences are up to 4,000 m thick. However, these are minimal estimates of their original extent and thickness as the rocks have been subjected to post-deposition erosion, most recently by extensive Pleistocene glaciation. Eocene intrusive complexes cover an additional 70,000 km^2.

Volcanism is generally characterized by thick sequences of basaltic andesite to rhyodacite and rhyolite effusive flows, pyroclastic rocks, isolated domes, tuffaceous lacustrine deposits, and local large caldera complexes (Figure 1). One of the caldera complexes comprises interbedded lacustrine tuffaceous deposits, pillow flows, and hyaloclastites, with bedding disrupted by slump faults, dikes and domes. Outside of calderas, coherent lava flows interbedded with thick sequences of flow breccias dominate.

δD of hydrated glass or muscovite, and seismic tomography suggest that volcanism occurred on an elevated plateau ranging from ~3,000 m to 5000 m, whereas current elevations are ~ 300 m to 1200 m. The paleobotany and oxygen isotope signature indicates a warmer, wetter and more temperate climate.

Geochemically, the volcanic rocks are mostly intermediate to felsic compositions, with rare basaltic compositions, and primarily subalkaline with more alkalic rocks occurring in southern British Columbia and Montana in the east where ancestral North America forms to basement to Eocene volcanics. Trace element signatures are indicative of lithospheric melts with a long history of subduction modification. No asthenosphere input is detected. Crustal influence is indicated by trace elements and distinct Nd isotopes that clearly reflect the basement terranes.

Compiled radiometric ages range from 60 to 45 Ma. High-precision CA-IDTIMS ages show that the ENCLIP magmatism initiates at 57 Ma in the north and is progressively younger to the south, with most volcanism occurring within a 10.8 Ma window. Thus, significant volumes of volcanic rocks were erupted over a large area in a very short period of time, representing a LIP.

Tectonic models suggest that the basement terranes have transited north along the margin of ancestral North America since 60 Ma such that many of the volcanic complexes are not where they formed, and that volcanism is most likely related to extension associated with transcurrent fault systems. Because the onset of this volcanism immediately pre-dates the Paleocene-Eocene Thermal Maximum and tracks the Early Eocene Climate Optimum, its potential contribution to these climatic excursions is considered, along with a variety of factors that may have contributed to Late Paleocene and Eocene thermal excursions as the Eocene was a tumultuous time in Earth's history.

Figure 1. Hoodos formed in light, buff- and tan-coloured andesitic to dacitic tuffs, lahars, and lacustrine volcaniclastic deposits, truncated on the right by a NE-trending fault that juxtaposes sheet and pillow flows against the tuffaceous units. These rocks are cut by dikes forming a cliff just beyond the hoodos. The tan coloured rocks in the foreground are weathered hyaloclastite. Kamloops, British Columbia, western Canada.

Antimilos geology and volcanic hazard assessment. Preliminary findings.

G. Vougioukalakis[1], C. Kanelopoulos[1,2], L. Francalanci[3], I. Koufogiannis[4]

1. *Hellenic Survey of Geology and Mineral Exploration – HSGME, Greece, e-mail: gvoug@igme.gr , ckanellopoulos@gmail.com*
2. *Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, Panepistimiopolis, Zografou, 15784, Athens, Greece*
3. *Dipartimento di Scienze della Terra, Università di Firenze, Italy, e-mail: lorella.francalanci@unifi.it*
4. *Institute of Applied Mineralogy and Economic Geology, RWTH Aachen University, Aachen, Germany e-mail: ilias.koufogiannis@emr.rwth-aachen.de*

Abstract

Antimilos is a constituent of the Milos volcanic field, mostly consisting of volcanic materials, and is situated within the South Aegean Active Volcanic Arc. Limited geological data exists for Antimilos.

Based on new findings nine geological formations were identified on Antimilos. Additionally, volcano-tectonic structures and data were documented. The island consists of volcanic rock formations; no Alpine basements were identified. Thin eluvial mantles in shattered volcanic rocks are the sole post-Alpine sedimentary deposit on the island. Aeolian and thermal erosion produced fine-grained materials.

The main features are andesitic and rhyolitic lava flows and small volcanic domes. Thin, lengthy lava flows are andesites, whereas thicker, shorter ones are dacites or rhyolites. Dome and lava are porphyritic, with mafic enclaves, and big feldspars (0.5 cm).

Also present is debris and ash flow from lava front collapses or steep dome slopes. Small mud flow horizons were found in several situations. Their clasts match the collapsed lavas from which they originate. Only on the steep slopes of the NE coast does an andesitic pyroclastic tephra layer produced by thick flows appear.

Based on the up today, available information no pyroclastic deposits were identifyed, which might be linked to huge damaging explosions. Both the northern and southern major craters are non-explosive. They should be formed late in volcanic activity as magma retreats and shrinks owing to cooling. The island was produced by modest effusive-extrusive activity.

Tectonic characteristics are rare. Two large faults were identified on the island's NE steep slopes. However, the pattern of the volcanic centers clearly supports tectonic discontinuities that supplied magma and influenced crater locations NNE-SSW. Some NNE-SSW dykes exist. The primary tectonic formations of Milos island, active since the Pleistocene, face NNW-SSE.

No depositional or erosional horizons were found in the island's geological formations and structures, suggesting extensive volcanic activity pauses. Volcanic activity was likely constant.

The current evidence does not indicate hot springs, fumaroles, or hydrothermal modifications. Unlike Milos, no base or precious metal ore or industrial minerals were found.

Since until now, there is no new dating data, Antimilos' genesis date cannot be determined. The only known date (320 ± 50 ka) is for the earliest rhyolitic lavas on the northern shore of the island. The volcanic products' volume and sequence match those of southern Aegean volcanoes, suggesting that the island was built during Milos' last volcanic activity, when Trachila and Phyriplaka were formed around 360 and 110 ka, respectively. This idea must be confirmed by dating enough chosen volcanic materials, which have already been sampled.

Geological and archaeological evidence of small-scale phreatic eruptions on Milos Island, Greece.

G. Vougioukalakis[1], C. Kanelopoulos[1,2], S. Massaro[3,4], R. Sulpizio[3,4], F. Lucchi[5], C. Tranne[5], G. Chiodini[4], F. Tassi[6], O. Vaselli[6], G. Bini[4], P. Pantou[7]

1. *Hellenic Survey of Geology and Mineral Exploration – HSGME, Greece, e-mail: gvoug@igme.gr , ckanellopoulos@gmail.com*
2. *Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, Panepistimiopolis, Zografou, 15784, Athens, Greece*
3. *(3) Dipartimento di Scienze della Terra e Geoambientali, Università di Bari, Italy, e-mail: silvia.massaro@ingv.it , roberto.sulpizio@uniba.it*
4. *(4) Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy, e-mail: giovanni.chiodini@ingv.it , giulio.bini@ingv.it*
5. *(5) Dipartimento di Scienze Biologiche, Geologiche e Geoambientali, Università di Bologna, Italy, e-mail: federico.lucchi@unibo.it , claudio.tranne@unibo.it*
6. *(6) Dipartimento di Scienze della Terra, Università di Firenze, Italy, e-mail: franco.tassi@unifi.it , orlando.vaselli@unifi.it*
7. *(7) School of Archaeology, Hellenic Ministry of Culture, Greece, e-mail: ppantou@culture.gr*

Abstract

The Island of Milos is a South Aegean Active Volcanic Arc (SAAVA) constituent. The composition of the island mostly consists of volcanic materials that overlay remnants of the crystalline basement. The dynamic tectonic environment and the elevated seismic activity in the region also exert a significant influence.

The initiation of volcanic activity on the subaerial Milos island may be traced back to around 3.5 m Ma ago. However, tephrostratigraphic investigations conducted on marine sediments in the southern region of Milos have shown the likelihood of volcanic activity commencing earlier, namely within the 4.5 to 3.7 Ma time frame.

Three primary eruptive phases can be discerned, which are outlined as follows: (i) from 1.1 to 0.9 Ma ago, there was a presence of rhyolitic activity in a N-S oriented region located in the central part of the island. During this time, a lava field and domes were formed. (ii) Approximately 0.38 Ma ago, there was another episode of rhyolitic activity in the northernmost part of the previously mentioned north-south oriented region. This activity resulted in the formation of lava flows and the Trachylas tuff ring, which exhibited perlitic characteristics. (iii) Between 90 and 70 ka, there was a period of rhyolitic activity in the southern edge of the aforementioned N-S oriented region. This activity led to the formation of lava flows and the Fyriplaka tuff ring, which also displayed perlitic characteristics.

Recurrent hydrothermal (phreatic) explosions of varying magnitudes took place, facilitated by vigorous hydrothermal fluid circulation and likely triggered by seismic activity, both before and after the most recent volcanic eruption of Fyriplaka. In the central-eastern region of Milos, a rock formation known as the "Green Lahar" occurs. This formation is characterized by the deposition of extensive debris and mudflow, which contains many crystalline basement pieces.

Hydrothermal explosions persisted throughout the historical period between 80 and 200 AD in the Agia Kyriaki region, which now presents a geothermal anomaly. This is shown by the existence of fumarolic discharges with temperatures reaching up to 100 °C. During the period of Roman times, the region had a significant presence of hydrothermal pools with high levels of silica. These pools were extensively used for the extraction of hydrothermal water and the mining of silica-rich muds. The hydrothermal pool region saw significant destruction due to the simultaneous occurrence of several shallow phreatic explosions, with over

250 craters being identified. This is shown by the widespread presence of Roman pottery fragments in the phreatic deposits. Based on a preliminary investigation, the ceramic fragments have been tentatively dated to the approximate period of the 2nd-3rd century AD. According to historical records, it is documented that the people of Milos Island chose to evacuate the area in reaction to the phreatic explosions that occurred.

The analysis of explosion craters' morphometry, geographical distribution, deposit stratigraphy, and geochemistry of fragmented material and substratum provides insights into the underlying processes that drive shallow phreatic eruptions.

The craters have small sizes, often measuring less than 20 meters, and are seldom seen in isolation, instead tending to form clusters. The explosive energy of the hydrothermal system was calculated to be around 1010-1012 J, with depths ranging from 2 to 10 meters. The temperature of the system reached up to 370 °C. These data allowed us to facilitate the development of a conceptual framework pertaining to the initiation of phreatic eruptions within the specified region of Milos Island. This framework has yielded valuable insights that contribute to the ongoing assessment of potential hazards on the island and in other comparable locations.

DISTAL RECORDS OF KATLA'S EXPLOSIVE PAST: OCEAN-RAFTED PUMICE FOUND IN ARCHAEOLOGICAL CONTEXTS AND RAISED SHORELINES IN NORWAY

A.V. Zernack[1], E. Kirkeng Jørgensen[2], A. Newton[3], A. Romundset[4]

1. *Volcanic Risk Solutions, Massey University, Palmerston North, New Zealand*
2. *Norwegian Institute of Cultural Heritage Research, Tromsø, Norway*
3. *University of Edinburgh, School of Geosciences, Edinburgh, United Kingdom*
4. *Norwegian Geological Survey, Trondheim, Norway*

Abstract

Ocean-rafted pumice is found on modern and paleo-beaches in volcanic and non-volcanic areas from the North Atlantic (Fig. 1) and Mediterranean to the South Pacific. While not as accurate as tephrochronology, ocean-rafting events can be correlated to their source and used to date sedimentary sequences and landforms, including raised shorelines. They also provide records of large explosive eruptions that might not be preserved near the volcano due to extensive erosion or a submarine volcanic source and as such can be used for petrological and geochemical investigations. Furthermore, geochemical fingerprinting of artefacts made from ocean-rafted pumice can provide age constraints for pumice-bearing archaeological sites.

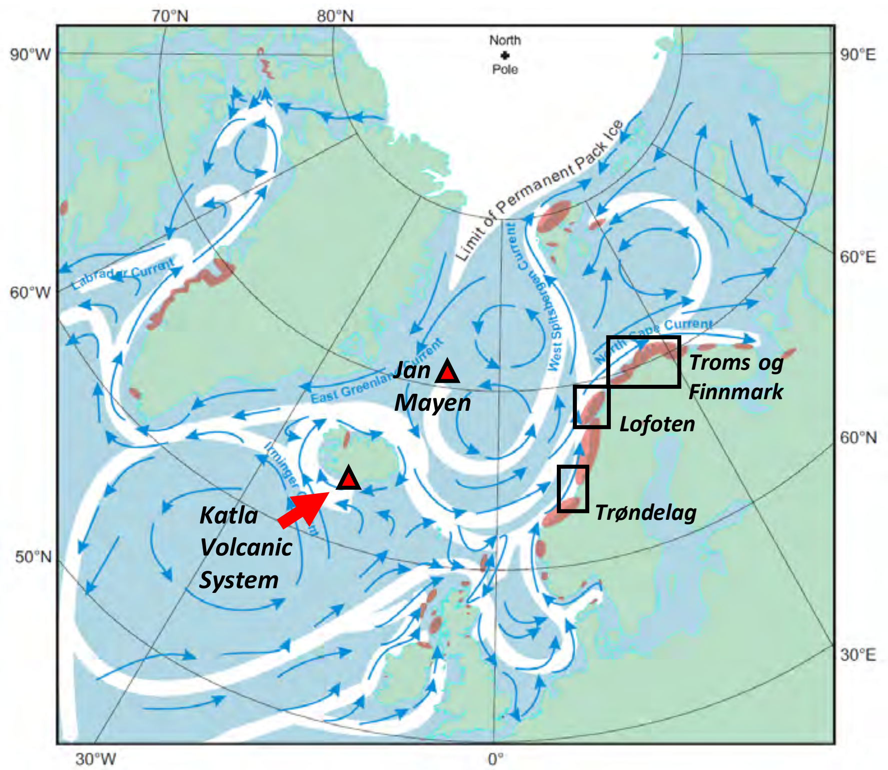

Fig. 1. Map from Newton's PhD thesis (1999) showing pumice finds across the North Atlantic (red areas) along with present-day ocean currents (arrows) and potential pumice transport routes (white lines).

The three focus areas of this study are marked by black boxes (archaeological and beach pumice from Troms og Finnmark; archaeological pumice from Lofoten and beach pumice from the Trøndelag coast). Confirmed and potential volcanic sources are shown as red triangles.

Our study explores links between spatiotemporal patterns of pumice redeposition along the Norwegian coastline, from Trøndelag to Northern Norway, and prehistoric human use of this versatile resource. For this we first focused on a set of samples from archaeological contexts of variable isostatic uplift in Northern Norway. Use-wear analysis of pumice from these spatially diverse Mesolithic to Norse-medieval sites showed that most pieces were being used as abrasive tools (Fig. 2). Based on their geochemical composition, the samples were correlated to individual Holocene eruptions or groups of tephras from the Katla Volcanic System in Iceland. The age data revealed that the estimated eruption dates typically predate the contexts by several hundred and up to 2-3,000 years, probably reflecting abundance and availability of certain pumice types at the time.

Fig. 2 A) Worked pumice from Slettnes with grooves and furrows, correlated to the 8-10 ka Vikurholl eruption.

B) Facetted pumice from Høyvikhaugen used for polishing, correlated to the 6.6-6.2 ka SILK-A7,8,9.

To investigate how distal resource availability is influenced by geological processes such as eruption frequency, ocean-currents, and deposition/preservation of rafted pumice, we conducted a detailed field study on Varanger Peninsula in Northern Norway. Here, strong Holocene uplift rates and sea-level changes have built a unique record of raised shorelines that provide windows into fossil beach ridges up to the marine limit, covered in little vegetation. We found that pumice was abundant on specific paleo-shorelines and in defined geomorphic settings but absent from older beach ridges, with the distinct mid-Holocene transgression high-stand accumulating the largest variety of pumice types and clast sizes. No products of the early Holocene Katla eruptions were found and apart from a few exceptions, most beach pumices correlate with the <7 ka record. One group of samples from younger raised shorelines form a distinct cluster that overlaps with SILK tephra compositions but does not correspond to any of the known Katla units. In addition, a single pumice plots outside the field defined by Katla eruptives and resembles compositions known for Jan Mayen. Both outliers require further investigation.

Fig. 3. Well-preserved raised shorelines near Båtsfjord/Varanger Peninsula (Northern Norway). Here, six fossil beach ridges between 6-18 m a.s.l. comprised ocean-rafted pumice.

Subsequent field surveys along the Trondelag and Nordland coast, where fossil beach ridges are heavily overgrown, support our hypothesis of pumice being readily available for limited periods of time following eruption, rafting and onshore deposition. Here, pumice was only found at isolated sites that displayed the right conditions, important factors being a) the paleo-setting of the beach (e.g., currents, orientation, morphology) favouring *accumulation* in the first place, b) rapid uplift and limited erosion to enable *preservation* of the pumice and c) *exposure* of pumice-bearing beach ridges (sections cut by rivers/erosion, roads/construction) as subsequent burial by sediments, soil and vegetation further reduces access to previously available pumice resources.

In a next step, we will integrate our pumice datasets with compositional information of archaeological pumice pieces from a recent archaeological excavation in Lofoten to further test our hypothesis. Further geochemical work will provide a better understanding of the nature and frequency of Holocene silicic eruptions from Katla while also improving age control for existing relative sea-level curves and archaeological contexts in Norway.