

ESF Research Networking Programme MeMoVolc
Scientific meeting 4249 Final report

Unrest at Santorini Caldera (2011-2012)

27 & 28 March 2012, Santorini
Organized by ISMOSAV, ESF and EPOS
with the support of the Municipality of Thera and the EU

Organisers for the ESF: T.H. Druitt and L. Francalanci

Summary

The MeMoVolc network co-organized, and participated in, a meeting of Greek and overseas scientists and civil protection experts on the ongoing unrest at Santorini caldera. The meeting resulted in a series of initiatives to enhance monitoring capabilities and improve understanding of the Santorini caldera system.

Description of the scientific content of and discussion at the event

Santorini has had nine subaerial eruptions in the caldera centre in the last 2000 years; most of them have involved lava extrusion accompanied by explosive phases of mild to moderate intensity. The last eruption occurred in 1950. The magma has a dacitic composition and is recharged by a basaltic-andesite magma preserved as quenched enclaves within the dacite. The Kolumbo submarine volcanic cone, sited few kilometers northeast of Santorini, erupted explosively in 1650 AD, causing significant damage and fatalities on Santorini.

Since January 2011, the caldera has been in a state of unrest, with increased seismicity and uplift of the northern basin. The felt seismicity in 2011 was a source of considerable concern by the public and authorities on Santorini, and a committee, The ‘National Scientific Committee for the Monitoring of Santorini Volcano’ was created in order to address hazards and risk issues associated with the ongoing unrest and a possible eruption.

Given the considerable expertise on volcanic processes and hazards within the MeMoVolc network, it was decided to request funding for the organization of a meeting of experts on the unrest situation. The chief organizer was our Greek colleague Dr. Georges Vougioukalakis of IGME, and his co-organisers were T. Druitt and L. Francalanci of the MeMoVolc network. The meeting was organized at short notice so as to help the Greek scientific community respond to the rapidly evolving crisis.

The meeting took place over two days on Santorini, and was attended by 42 scientists and civil protection experts from 5 countries. Eleven of the participants were funded by the ESF. The meeting included 36 oral presentations on Santorini volcano in general and on the unrest monitoring results, and was followed by an extended discussion session on the second day. One session was devoted to the EPOS programme (<http://www.epos-eu.org/>), at which Greek, Italian and Icelandic colleagues

presented the EPOS initiatives in their respective countries, and how Santorini might benefit from the EPOS infrastructure.

The involvement of MeMoVolc in the meeting arose from the potential for the network to become involved in monitoring and research on a major European volcano in a state of evolving unrest. Funding for the meeting was jointly provided by the ESF, ISMOSAV (the Santorini monitoring observatory) and the Municipality of Thera.

The aims of the meeting were:

1. To bring together Greek scientists involved in monitoring of the unrest with overseas experts (in part represented by MeMoVolc members) to provide data, interpretations and advice to the National Scientific Committee for the Monitoring of Santorini Volcano.
2. To identify actions, initiatives and collaborations in order to improve monitoring capabilities at Santorini, and to increase understanding of the processes involved in generating unrest.

Assessment of the results and impact of the event on the future direction of the field

By the end of the meeting, the participants had agreed to:

1. Coordinate a series of projects on the research and monitoring of Santorini that would be submitted to the ‘National Scientific Committee for the Monitoring of Santorini Volcano’ for approval and suggestions. These projects would then be submitted for funding to the different national funding agencies of the participants. This was subsequently followed up by the preparation of project proposals from some countries, some of which were approved by the National Scientific Committee for the Monitoring of Santorini Volcano in official letters sent to overseas institutions.
2. Pursue longer-term discussions on the possible writing of a larger funding proposal involving several MeMoVolc countries and headed by Greece.
3. Submit for publication in the journal EOS a short text summarizing the main conclusions of the meeting. A draft version of this article is attached as an annex to this report.

The meeting was immediately followed by a press conference at which our Greek colleagues presented the main conclusions of the meeting to local and national press representatives.

Short meeting report submitted to EOS (American Geophysical union)

MEETINGS

Intrusion of magma beneath Santorini Caldera?

International workshop on the Unrest at Santorini Caldera (2011-2012), Santorini (Greece), 27-28 March, 2012.

Santorini Volcano has been in a state of unrest for over a year, with increased seismicity and uplift of the caldera. A recent meeting on the unrest was attended by 40 Greek and overseas scientists.

The last plinian eruption of Santorini (the 'Minoan' eruption) took place around 1600-1630 BC. Since then effusive eruptions have built up a $\sim 3 \text{ km}^3$ intracaldera edifice, the summit of which forms the islands of Palea Kameni and Nea Kameni. Nine subaerial eruptions of viscous dacitic magma with mafic enclaves have taken place in historical times from a NE-SW-trending linear zone 6 km long and 500 m wide through the centre of the caldera. The first occurred in 197 BC, and the last in 1950. The historical eruptions have been largely effusive, accompanied by vulcanian explosions with plumes up to 2-3 km high and ballistic showers to 0.5 to 2 km. A more energetic vulcanian, or subplinian, eruption took place in AD 726.

Since January 2011 the number of small magnitude ($M < 3.3$) quakes beneath Santorini has greatly increased. The events are located beneath the Kameni Islands on a NE-SW-striking plane 6 km long, 5 km deep and inclined at 80° to the north. They are interpreted as volcanotectonic in nature, with fault plane solutions that are normal with strike-slip components. The increased seismicity has been accompanied by inflation of the caldera floor, as revealed by GPS and InSAR data. The northern part of Nea Kameni has risen several cm. Mogi modelling indicates a pressure source situated at 4-5 km depth, about 2 km north of Nea Kameni. This depth corresponds approximately to that of the magma reservoirs of previous Kameni eruptions (5-7.5 km; from petrological data), suggesting that the inflation source is intruding magma. The source volume increase over 14 months is estimated to be about 14 million m^3 . Seismic activity is highest at periods of increased uplift rate, showing a causal relationship between the deformation and seismicity.

Fluctuations of sea temperature around the Kameni islands since September 2010 are attributed to increased discharge of hot fluids into the sea. The CO_2 soil flux emitted from Nea Kameni has nearly doubled since measurements in 1995. Increase of H_2 concentration in fumarolic gas discharges since July 2010 are suggestive of increased temperature of deep fluids filtered by shallow aquifers. Increase of CO_2/CH_4 ratio in the same gases is consistent with increased contribution of magmatic gas to the shallow hydrothermal system. No SO_2 output from Nea Kameni has been detected.

Magma is probably intruding at 4-5 km beneath the caldera at a rate of about 10 million m^3 per yr, but at the time of writing there is no evidence (e.g., ascending earthquake foci, ascending deformation sources, long-period earthquakes) that it is rising to the surface. It is possible that this intrusive episode will not result in eruption. Larger amounts of inflation have occurred at other calderas, such as Campi Flegrei in Italy, without subsequent eruption. Analysis of past historical behaviour of the Kameni edifice suggests that, were eruption to occur in the next few years, the most likely event would be similar to the eruption of 1925-28, which lasted three years and was largely effusive. The main hazards from such an eruption would be (i) plumes of ash and gas, and (ii) ballistic ejecta. An AD 726-like subplinian eruption is thought to be much less probable, but more research is required to establish the frequency of such events at Santorini. Full evaluation of the ongoing unrest requires increased monitoring and research on Santorini. A detailed risk assessment is urgently required. Any on-site research must be carried out with the collaboration of the National Scientific Committee for the Monitoring of Santorini Volcano.

The workshop was cosponsored by the Institute for the Study and Monitoring of the Santorini Volcano, the European Science Foundation (MeMoVolc Research Networking Program), EPOS and the Municipality of Thera.

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Programme

Unrest at Santorini Caldera (2011-2012)

27 & 28 March 2012, Santorini

Organized by ISMOSAV, ESF and EPOS

with the support of the Municipality of Thera and the EU

26 March 21.00 - Welcome dinner at the restaurant “Asirtico” in Fira (2286022463)

Day 1 (Tuesday 27 March)

09.30 to 10.10 Welcome and introductory speeches (open to the media)

- 09.30 - 09.40 Thira Municipality welcome.
- 09.40 - 09.50 Kosmas Stylianidis (National Scientific Committee for the Monitoring of Santorini Volcano).
- 09.50 - 10.10 Georges Vougioukalakis (Organizing committee)

10.20 to 12.30 Kameni and Kolumbo volcanism in the context of the evolution of Santorini Volcanic Field

- 10.20 - 10.40 Vougioukalakis, G., Overview of the system; Historic activity: Precursors, evolution, hazard assessment.
- 10.40 - 11.00 Druitt, T., Scaillet, B., Cadoux, A., Andujar, J., Costa, F., Deloule, E. Volcanological and petrological context of Kameni volcanism.

11.00 – 11.30 Coffee break

- 11.30 - 11.50 Pyle, D., Nomikou, P., Parks, M., Mather, T., Elliott, J. Volcanological development of the Kameni islands.
- 11.50 - 12.10 Francalanci, L., Petrone, C.M., Vaggelli, G., Vougioukalakis, G. Lava-enclave magma interaction at Kameni: Evidence from detailed petrochemical investigations.
- 12.10 - 12.30 Sakellariou, D., Rousakis, G., Nomikou, P., Croff Bell, K., Carey, S., Sigurdsson, H. The caldera of Santorini underwater: Swath bathymetry, seismic stratigraphy, structural interpretation and evolution.
- 12.30 - 12.50 Nomikou, P., Kiliyas, S., Godelitsas, A., Sakellariou, D., Argiraki, A., Bejelou, K., Carey S., Cantner, K., Croff Bell, K., Roman, C., Ballard B. Evidence of the Kolumbo magmatic system from the study of erupted products and hydrothermal activity.

12.50 to 14.20 Lunch

14.20 to 18.00 State of the volcano 2011-2012

- 14.20 - 14.30 Fytikas, M. Monitoring Santorini Volcano, a retrospective.
- 14.30 - 14.50 Papazachos, C., Panagiotopoulos, D., Vougioukalakis, G., Albanakis, K., Laopoulos, Th., Stiros, E., Fytikas, M., Karagianni, E., Vamvakaris, D. Current volcanic unrest in the Santorini caldera, as revealed by seismicity, temperature and sea-level data.
- 14.50 - 15.10 Chouliaras, G., Makropoulos, K. Real-Time seismic monitoring of the Santorini volcanic complex by the permanent and portable seismological networks of the Institute of Geodynamics, National Observatory of Athens.
- 15.10 - 15.20 Papadimitriou, P., Voulgaris, N., Kaviris, G., Karakonstantis, A., Kapetanidis, V., Kolaitis, A., Kouskouna, V., Kassaras, I., Makropoulos, K. Monitoring of the volcanoseismic activity in the broader Santorini area: Preliminary Results.

- 15.20 - 15.40 Newman, A., Stiros, S., Feng, L., Psimoulis, P., Moschas, F., Saltogianni, V., Jiang, Y., Briole, P., Geodetic studies of the Santorini caldera inflation.
- 15.40 - 16.00 Parcharidis, I., Papageorgiou, E., Foumelis, M. Long and short term deformation monitoring of Santorini Volcano: Unrest evidence by DInSAR analysis.

16.00 – 16.30 Coffee break

- 16.30 - 16.50 Lagios, E., Novali, F., Sakkas V., Vlachou K. Ground deformation in Santorini (1992-2012) based on SqueeSAR and DGPS observations.
- 16.50 - 17.10 Pyle, D., Parks, M., England, P., Biggs, J., Mather, T., Nomikou, P., Palamartchouk, K., Papanikolaou, X., Paradissis, D., Parsons, B., Raptakis, C., Zacharis, V. Santorini deformation from satellite geodesy and triangulation.
- 17.10 - 17.30 Vaselli, O., Tassi, F., Vougioukalakis, G., Giannini, L. Fluid geochemistry of the fumarolic gas discharges at Nea Kameni.
- 17.30 - 17.50 Carapezza M.L., Barberi, F., Gattuso, A., Ranaldi, M., Tarchini, L., Sortino, F., Granieri, D., Vougioukalakis, G. A geochemical contribution to the evaluation of the present Santorini unrest and plans for the improvement for the geochemical monitoring.
- 17.50 - 18.00 Vougioukalakis, G. Thermal and chemical monitoring future planning.

18.00 to 19.00 General discussion on Kameni – Kolumbo volcanism

21.00 Dinner at the tavern “Mario” in Monolithos (2286032000)

Day 2 (Wednesday 28 March)

09.00 to 10.00 Discussion on EPOS

- 09.00 - 09.20 Cocco, M. EPOS general presentation (through Skype).
- 09.20 - 09.40 Puglisi, G. Creation of an integrated initiative infrastructure for the European Volcano Observatories.
- 09.40 - 10.00 Sigmundsson, F. Stakeholders for the European volcanology.

10.00 to 11.00 Unrest and precursor phenomena at other volcanoes

- 10.00 - 10.20 Tait, S., Taisne, B. Pressure changes and deformation in a shallow magmatic system.
- 10.20 - 10.40 Sigmundsson, F. and 19 colleagues. Volcanic unrest and eruptions in Iceland: Measurements, models and mitigation.

10.40 - 11.10 Coffee break

11.10 to 12.30 Monitoring and modelling of volcanic processes and hazards

- 11.10 - 11.30 Ripepe, M. Volcano-acoustic monitoring.
- 11.30 - 11.50 Neuberg, J. Seismic monitoring strategies.
- 11.50 - 12.10 Puglisi, G. Geodetic monitoring of volcanic processes: state of the art and perspectives.
- 12.10 - 12.30 Barsotti, S., de' Michieli Vitturi, M., Esposti Ongaro, T., Neri, A. Modelling of volcanic processes and hazards.

12.30 – 14.00 Lunch

14.00 to 16.20 Volcanic hazards and risk management

- 14.00 - 14.20 Barberi, F. Risk assessment for volcano emergency planning.
- 14.20 - 14.40 Loughlin, S., Baptie, B. Volcanic crisis management: lessons from Soufriere Hills and other eruptions.
- 14.40 - 15.00 Hincks, T., Philips J., Sheldrake, T., Sparks, R.S.J., Vougioukalakis, G. Assessment of ash and gas hazards during a future eruption of Santorini.
- 15.00 - 15.20 Papazachos, C., Skarlatoudis, A., Vougioukalakis, G. A preliminary deterministic seismic hazard assessment for the Santorini island for the current volcanic unrest.
- 15.20 - 15.40 Aspinall, W. Combining different precursory signals with an evidential Bayesian Belief Network: preliminary application to Santorini
- 15.40 - 16.00 Poyiadji, E. IGME future research within NSRF on GeoHazards – Santorini case study site.
- 16.00 - 16.20 Vougioukalakis G., Sparks, R.S.J., Pyle, D., Druitt, T., Barberi, F., Papazachos, K., Fytikas, M. Possible evolution of the Santorini unrest, expected scenarios and response proposals.

16.20 – 16.50 Coffee break

16.50 to 19.00 Round-table discussion, general questions, proposals, final remarks

21.00 Dinner at the restaurant “Selene” in Pyrgos (2286022249)

(Courtesy of the Municipality of Thera)

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