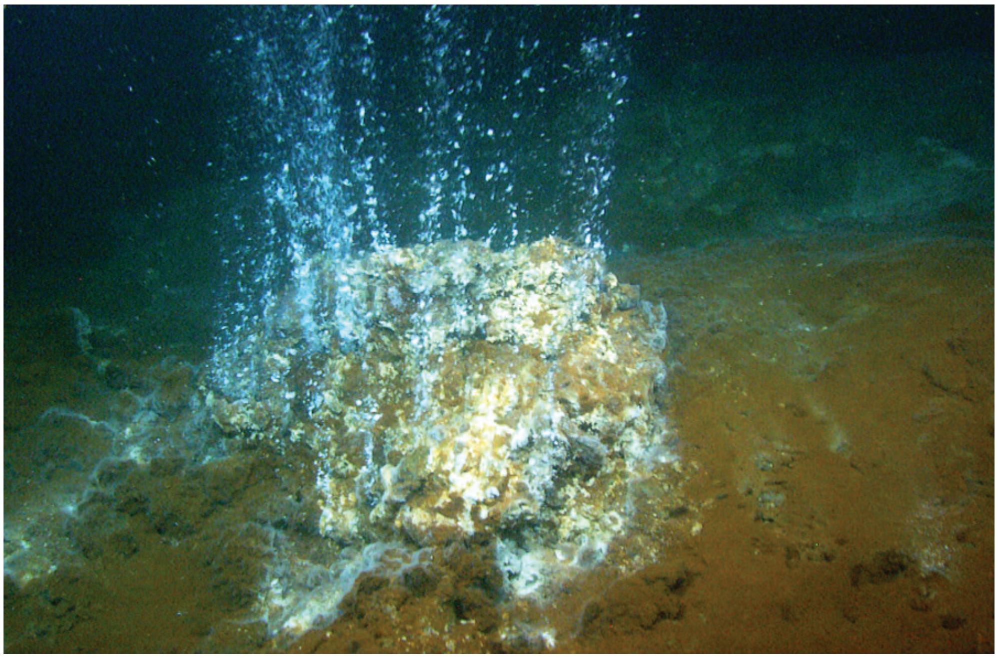
Final Cruise Report: EN-419



Project Title: Marine Geological Explorations of the Santorini Volcanic Field

Cruise Dates: May 30, 2006-June 7, 2006

Vessel/Cruise No: R/V Endeavor, cruise EN-419

Participating Organizations: University of Rhode Island, Hellenic Center for Marine Research, National Science Foundation, Ocean Exploration Program (NOAA)

Operating area: Santorini volcanic complex, Aegean Sea

Chief Scientist:
Dr. Haraldur Sigurdsson
Graduate School of Oceanography
University of Rhode Island
Narragansett, R.I. 02882
Email: haraldur@gso.uri.edu
Tel: 401-874-6596
Fax: 401-874-6811

I. Project Goals and Objectives

The Minoan eruption (~3600 yr.B.P.) of Santorini volcano in the Mediterranean Sea was one of the largest explosive events during the Quaternary. A minimum of 40 km^3 of pyroclastic material was ejected in the form of tephra fall, pyroclastic flows and pyroclastic surges (Sigurdsson et al. 1990; Pyle 1990). The majority of the products were deposited in the marine environment creating a complex assemblage of volcaniclastic facies. The discharge resulted in caldera collapse and major extension of the Santorini coastlines. Growth of the surrounding shelf also occurred to an unknown extent. This major sedimentation event has produced an important chronostratigraphic sequence in the Aegean and eastern Mediterranean area. Such events are unique modifications of continental or island shelves, in terms of the rate of the process, and pose an important hazard because of tsunami generation and the passage of pyroclastic flows or surges over the sea surface (Carey et al., 2000). The instability of rapidly accumulated volcaniclastic deposits on the shelf may also result in major submarine slumps and generation of far-traveled turbidites. An understanding of the processes of deposition and behavior of the pyroclastic material in the coastal zone, at the submarine caldera edge, and on the shelf and slope, requires sidescan and sub-bottom imaging of the deposits, and direct underwater observations.

An important aspect of the Minoan eruption was the discharge of high temperature pyroclastic flows and surges into the sea. This process remains a complex and controversial topic in the field of volcanology, stemming in part from the paucity of studies dealing with relatively young and well-documented eruptions (Cas and Wright 1991). An understanding of pyroclastic flow/seawater interaction is critical for interpreting ancient volcaniclastic sequences (e.g. Kano 1991; Cole and DeCelles 1991) and assessing the types of volcanic hazards associated with this process (Carey et al. 2000). A recent example is the 1883 eruption of Krakatau in the Sunda Straits, Indonesia, where approximately 10 km^3 of pyroclastic flows entered the ocean around the volcanic island (Sigurdsson et al. 1991a; 1991b; 1997; Carey et al.1996; 2001). The flows created major submarine deposits over 10 km from the volcanic source, and hot turbulent ash surges traveled over water up to 50 km from the volcano with deadly results on Sumatra. The accompanying tsunami rose to over 30 m height on adjacent coast lines on Java and Sumatra, with over 36,000 casualties. This event thus serves as an important historical analogue to the types of events that are likely to have taken place during the Minoan eruption of Santornini.

At Santorini, post-Minoan volcanic activity has modified both the caldera (by submarine and subaerial extrusion of lavas), and the surrounding shelf (by growth of the new submarine volcano Kolumbo, north-east of the caldera; Vougioukalakis et al. 1994). Kolumbo submarine volcano experienced a historic eruption in 1650 AD that produced volcanic ash fallout and a small tsunami. Consequently this center poses an ongoing potential volcanic hazard to the southern Aegean area.

A joint research project on the study of volcaniclastic sediments, marine geology, and submarine volcanology of the region around Santorini (Thera) volcano in the Aegean Sea has been undertaken. Primary objectives of this work are to determine the extent and nature of volcanic deposits from Santorini on the ocean floor, to study the subsidence of the volcanic island during caldera formation at the time of the late Bronze-Age Minoan eruption, to explore potential hydrothermal vents in the Santorini caldera and to investigate the caldera area of the Kolumbo submarine volcano. The marine geological work was carried out as a collaborative project between scientists at the The Hellenic Centre for Marine Research, Greece, (HCMR), the Institute of Geology and Mineral Explorations in Athens, and the University of Rhode Island, USA (URI). Cruise EN-419 was the second phase of the oceanographic work that began with an earlier cruise of the *R/V Aegaeo* in May of 2006. The focus of EN-419 was to use an ROV to observe and sample the marine geological deposits around Santorini volcano.

II. Operations

A. Participants

Table 1. List of Cruise Participants for cruise EN-419

Last	First	Role	Affiliation	Gender
Anagnostou	Chris	Engineer	HCMR	M
Alexandri	Matina	Oceanography/geology	HCMR	F
Carey	Steve	Oceanography/geology	URI	M
Croff	Katherine	Oceanography/geology	URI	F
DeRoche	Mark	Bosun	IFE	M
Durbin	Mike	Satellite	IFE	M
Gregory	Todd	Engineer	URI	M
Lovalvo	Dave	Engineer	IFE	M
Martin	Eric	Engineer	URI	M
Newman	Jim	Engineer	IFE	M
Nichols	Mary	Eng/tech?	IFE	F
Orvosh	Tom	Marine technician	URI	M
Phillips	Brennan	Engineer	IFE	M
Pinner	Webb	Data/eng	NOAA	M
Raynes	Brian	Eng/tech	IFE	M
Roman	Chris	Engineer	URI	M
Sigurdsson	Haraldur	Oceanography/geology	URI	M
Vougiolakis	George	Oceanography/geology	HCMR	M

Affiliations: Hellenic Center for Marine Research (HCMR), University of Rhode Island (URI), Institute for Exploration (IFE), National Oceanic and Atmospheric Administration (NOAA).

B. ROV exploration and sampling

The principal activity during cruise EN-419 was the exploration and sampling of the seafloor 1) within the caldera of Santorini volcano, 2) around and in the crater of Kolumbo submarine volcano, and 3) on the submarine slopes of Santorini using the remotely operated vehicle *Hercules* and *Argus* (fig. 1). Eight ROV dives using *Hercules* were carried out during the cruise and *Argus* was used as a camera sled for an additional four lowering due to problems with the bow thruster on *Endeavor (table 2).* High and standard definition video was collected using *Hercules* and *Argus* , in addition to high definition still images.

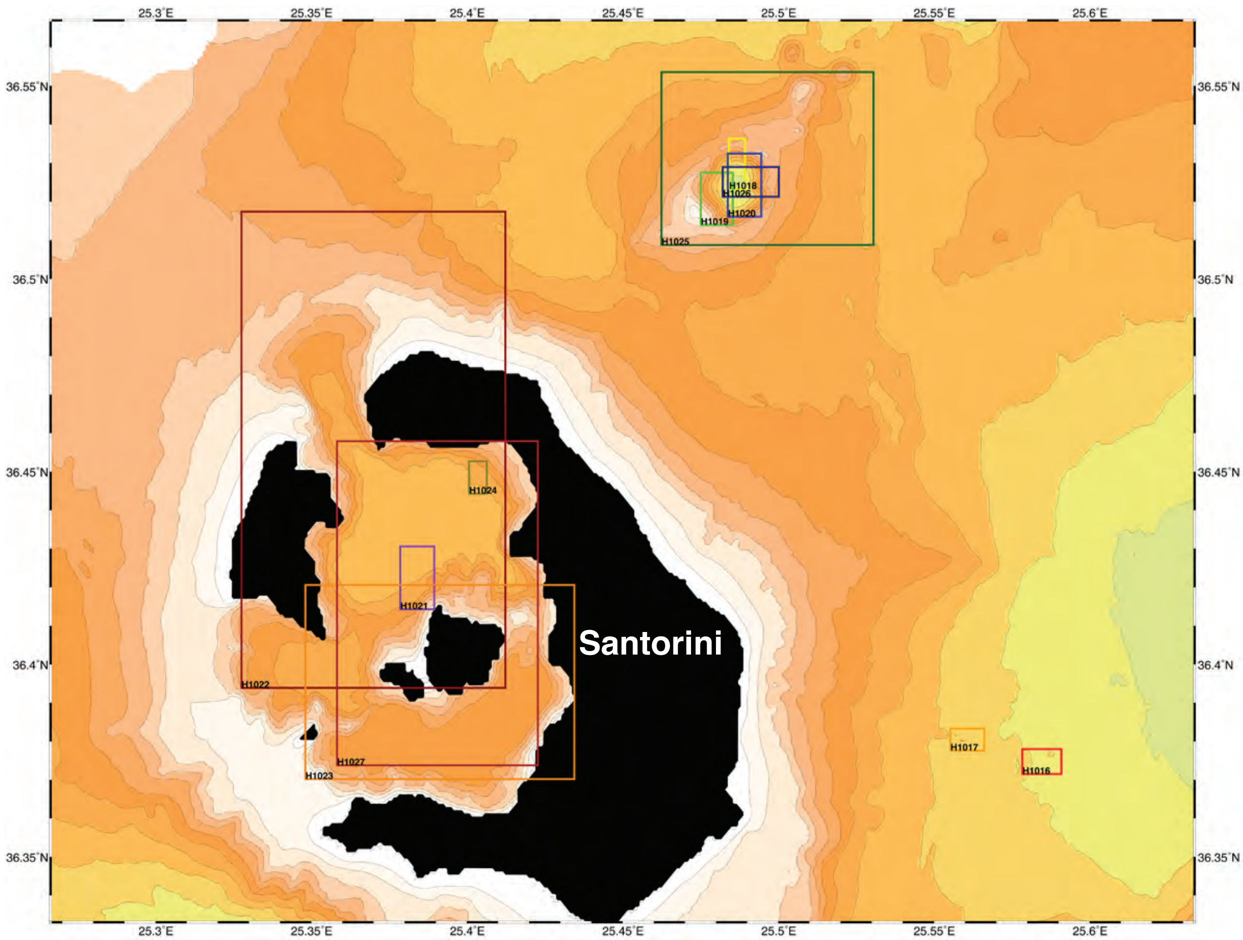


Fig. 1. Map showing the location of ROV (Hercules) and Argus (camera sled) operations during cruise EN-419.

Table 2. Summary of ROV and camera sled operations during cruise EN-419

Dive	Area	Vehicle	Start_date	Start_time	End_date	End_time
H1016	Hummocky	Hercules	30-May-06	18:16:28	31-May-06	6:02:18
H1017	Hummocky	Hercules	31-May-06	9:52:46	31-May-06	15:08:29
H1018	Kolumbo	Hercules	31-May-06	19:02:54	1-Jun-06	0:48:55
H1019	Kolumbo	Hercules	1-Jun-06	6:45:43	1-Jun-06	15:29:42
H1020	Kolumbo	Hercules	1-Jun-06	19:56:07	2-Jun-06	10:03:02
H1021	Caldera	Hercules	2-Jun-06	15:27:15	2-Jun-06	21:56:12
H1022	Caldera	Argus	3-Jun-06	10:07:31	4-Jun-06	9:01:03
H1023	Caldera	Argus	4-Jun-06	11:35:29	5-Jun-06	10:33:32
H1024	Caldera	Argus	5-Jun-06	13:07:20	5-Jun-06	17:54:40
H1025	Kolumbo	Argus	6-Jun-06	0:04:35	6-Jun-06	17:29:39
H1026	Kolumbo	Hercules	6-Jun-06	21:29:28	7-Jun-06	17:33:49
H1027	Caldera	Hercules	7-Jun-06	22:27:01	8-Jun-06	18:39:24

Caldera= Santorini caldera

C. Summary of ROV Explorations

1. H1016 (*Hercules and Argus*): Located to the east of Santorini on the submarine slopes of the volcano in an area of suspected debris avalanche hummocks. Observed poorly-sorted brownish-gray sediment that is likely to be pyroclastic flow deposit. Numerous cliffs and exposed outcrops. Box core attempted but unsuccessful.

2. H1017 (*Hercules and Argus*): Located to the east of Santorini on the submarine slopes of the volcano in an area of suspected debris avalanche hummocks. Observed poorly sorted brownish-gray sediment that is likely to be pyroclastic flow deposit. Numerous cliffs and exposed outcrops. Collected samples of pyroclastic flow deposit using manipulator arm and suction sampler on the ROV. Noted the occurrence of black and yellow corals.

3. H1018 (*Hercules and Argus*): Located within the crater of Kolumbo submarine volcano. Begin at crater floor with covering of fine-grained reddish sediment. Progressing towards the north wall of the crater encountered white streams of bacteria and hot water vents up to 65^{o} C. Further towards the north wall found meter-sized hydrothermal chimneys covered with tunicates. Ascending up the crater wall observed abundant pumiceous scree that transitioned into well-bedded pumice-rich pyroclastic deposits up to the crater rim. Collected samples of bacterial mat and pumices.

4. H1019 (*Hercules and Argus*): Located within the crater of Kolumbo submarine volcano. Begin at crater floor with covering of fine-grained reddish sediment. Ascended the southwest wall of the crater examining the stratigraphy of lava flows and pyroclastics. The base of the section contained abundant pumiceous scree that grades into well-bedded pumice-rich pyroclastic deposits in the upper ~200 m of the section. Collected samples of pumice and reddish bacterial mat.

5. H1020 (*Hercules and Argus*): Located within the crater of Kolumbo submarine volcano. Begin at crater floor with covering of fine-grained reddish sediment and white bacterial seeps. Observed several extinct hydrothermal chimneys. Large field of extinct and active hydrothermal vents with abundant bacterial coatings. Some bubbling seeps observed and temperatures up to 63^{o}C.

6. H1021 (*Hercules and Argus*): Located within the Santorini caldera near the island of Nea Kameni. Explored outcrops of recent lava flows with abundant talus deposits. Sampled multiple lava flow outcrops. Fish commonly observed.

7. H1022 (*Argus only*): Begin in the northeast corner of the northern basin of the Santorini caldera. Observed low temperature mounds less than 1 m high scattered on the seafloor in soft sediment. Proceeded outside of the channel between Thera and Aspronisi and returned into the caldera. Generally fine grained sediment with occasional larger rock fragments. Central part of the northern caldera basin characterized by flat-lying fine-grained sediment. Approached the shallow divide between the northern and southwestern basins of the caldera and observed lava outcrops.

8. H1023 (*Argus only*): Explored the area to the south and east of the islands of Palea Kameni and Nea Kameni within the Santorini caldera. Lava outcrops and talus observed to the south of the islands and in the area between the eastern side of Nea Kameni and the caldera wall.

9. H1024 (*Argus only*): Begin in the northeast corner of the northern basin of the Santorini caldera. Observed low temperature hydrothermal mounds less than 1 m high scattered on the seafloor in soft sediment. Most are circular shaped with a small crater on the top. Colors range from yellowish orange to yellowish brown.

10. H1025 (*Argus only*): Explored the northern crater floor of Kolumbo submarine volcano and parts of the eastern crater wall. Observed numerous active and inactive hydrothermal chimneys and many areas with white streaming bacterial mats. Crater wall outcrops include pumiceous talus and dikes.

11. H1026 (*Hercules and Argus*):Explored the northern crater floor of Kolumbo submarine volcano. Sampled several hydrothermal vent chimneys with manipulator arm and recovered excellent samples of massive sulphide deposits. Suction sampler was used to collect bacterial mats from the base and tops of hydrothermal vent chimneys. Measured fluid discharge temperatures up to 224^{o} C and observed several gas discharging vents.

12. H1027 (*Hercules and Argus*): Begin in the northern basin of the Santorini caldera in the area of low-temperature hydrothermal vents. Several samples of the mound collected by push cores and suction sampler. Proceeded south across the northern basin to the western basin and observed lava flow talus around the western margin of Palea Kameni. Sampled lava outcrop on the ridge separating the western and southern basins of the caldera. Continued along the southern margin of Nea Kameni and sampled lava flow outcrop.

D. Sampling

During cruise EN-419 the Hercules ROV was used to take 63 grab samples, 15 push cores, 14 suction samples and 3 box cores. Sample collection data and descriptions are presented in table 3.

Figure 2. Sample of massive sulphide deposits from hydrothermal vents in the crater of Kolumbo volcano.

Table 3. Samples collected by ROV during cruise EN-419

SAMPLE	LATITUDE		LONGITUDE		DEPTH (m)	DATE	DIVE	DESCRIPTION
EN419-01 ROVG	36	22.0498	25	35.2566	452	5/30/2006	1017	black dacite lava fragment
EN419-02 ROVG	36	22.0551	25	35.2494	446	5/30/2006	1017	black dacite lava fragment
EN419-03 ROVG	36	22.5444	25	35.1972	446	5/30/2006	1017	black dacite lava fragment
EN419-04 ROVG	36	22.4466	25	34.9746	454	5/30/2006	1017	black dacite lava fragment
EN419-05 ROVG	36	22.4727	25	34.9372	430	5/30/2006	1017	Lava fragment with biological crust
EN419-06 ROVG	36	22.5069	25	34.9129	428	5/30/2006	1017	Angular dacite lava fragment
EN419-07 ROVG	36	22.5118	25	34.8509	428	5/30/2006	1017	Dacite lava fragment
EN419-08 ROVBC	36	22.6008	25	34.8576	428	5/31/2006	1017	poorly sorted pyroclastic flow like material
EN419-09 ROVS	36	22.5864	25	34.9488	444	5/31/2006	1017	Suction Sample of pyroclastic flow like material
EN419-10 ROVS	36	22.6026	25	34.9932	436	5/31/2006	1017	Suction Sample of pyroclastic flow like material
EN419-11 ROVG	36	22.7800	25	33.7625	405	5/31/2006	1017	Brown indurated crust
EN419-12 ROVG	36	22.7788	25	33.7663	405	5/31/2006	1017	Poorly sorted pumice bearing ash
EN419-13 ROVG	36	22.8434	25	33.6273	405	5/31/2006	1017	brown lithofied sediment crust
EN419-14 ROVS	36	22.8645	25	33.5161	393	5/31/2006	1017	loose pumice rich sediment
EN419-15 ROVG	36	22.8640	25	33.5106	390	5/31/2006	1017	white angular pumice with pumice rich sediment
EN419-16 ROVPC	36	31.4773	25	29.2443	500	5/31/2006	1018	Red-orange bacterial mat
EN419-17 ROVG	36	31.7703	25	29.1322	475	5/31/2006	1018	white pumice block with rusty coating
EN419-18 ROVG	36	31.7898	25	29.1223	461	5/31/2006	1018	Grey - dense pumice
EN419-19 ROVG	36	31.8019	25	29.1256	448	5/31/2006	1018	Dense grey pumice
EN419-20 ROVG	36	31.8373	25	29.1145	382	5/31/2006	1018	Dark grey pumice with inclusions
EN419-21 ROVG	36	31.8739	25	29.1050	374	5/31/2006	1018	Green dacite lava fragment
EN419-22 ROVPC	36	31.8920	25	29.0987	359	5/31/2006	1018	Sandy - lepili pumice
EN419-23 ROVG	36	31.9259	25	29.0935	327	5/31/2006	1018	white pumice block with rusty coating
EN419-24 ROVG	36	31.9460	25	29.0993	310	5/31/2006	1018	black glassy dacite
EN419-25 ROVG	36	31.9576	25	29.1012	291	5/31/2006	1018	white pumice block with rusty coating
EN419-26 ROVG	36	31.9756	25	29.0915	276	5/31/2006	1018	green hydrothermally altered dacite
EN419-27 ROVG	36	31.9986	25	29.1003	233	5/31/2006	1018	white pumice block with rusty coating
EN419-28 ROVG	36	32.0106	25	29.1008	227	5/31/2006	1018	black dacite lava fragment
EN419-29 ROVG	36	32.0333	25	29.1119	202	6/1/2006	1018	white pumice block with brown coating
EN419-30 ROVG	36	32.0628	25	29.1145	177	6/1/2006	1018	rounded brown black low density - probably pumice
EN419-31 ROVG	36	31.1912	25	29.0412	467	6/1/2006	1019	white pumice block with rusty coating
EN419-32 ROVG	36	31.1459	25	29.0151	435	6/1/2006	1019	white pumice block with rusty coating
EN419-33 ROVG	36	31.1228	25	28.9655	403	6/1/2006	1019	white pumice block with rusty coating
EN419-34 ROVG	36	31.1045	25	28.9287	371	6/1/2006	1019	white pumice block with rusty coating
EN419-35 ROVPC	36	31.1430	25	28.9082	361	6/1/2006	1019	White tuff outcrop
EN419-36 ROVG	36	31.0859	25	28.8972	346	6/1/2006	1019	white pumice block with brown coating
EN419-37 ROVG	36	31.0602	25	28.8880	330	6/1/2006	1019	white pumice block with rusty coating
EN419-38 ROVG	36	31.0376	25	28.8532	296	6/1/2006	1019	yellow - white pumice block
EN419-39 ROVG	36	31.0320	25	28.8522	290	6/1/2006	1019	failed
EN419-40 ROVG	36	31.0043	25	28.8447	279	6/1/2006	1019	Pumice block with moderately vesicular
EN419-41 ROVG	36	30.9608	25	28.8323	229	6/1/2006	1019	Pumice block with brown rusty coating
EN419-42 ROVG	36	30.9528	25	28.8042	199	6/1/2006	1019	Pumice block with rusty coating
EN419-43 ROVG	36	30.9473	25	28.7977	166	6/1/2006	1019	Pumice block with rusty coating
EN419-44 ROVG	36	30.9232	25	28.7586	138	6/1/2006	1019	Dense dacite lava fragment
EN419-45 ROVG	36	30.9084	25	28.7355	110	6/1/2006	1019	Greenish -Grey altered breccia
EN419-46 ROVG	36	31.2094	25	28.5696	187	6/1/2006	1019	Dense poorly vesicular crystal poor dacide
EN419-47 ROVG	36	31.2108	25	28.5656	174	6/1/2006	1019	Dense lava block with biological crust
EN419-48 ROVG	36	31.2146	25	28.5631	147	6/1/2006	1019	Dense grey crystal poor dacite
EN419-49 ROVPC	36	31.6340	25	29.2449	496	6/1/2006	1020	sample on the centre of Grey hydrothermal area - temp. 60 oC

EN419-50	ROVS	36	31.6410	25	29.2350	494	6/1/2006	1020	Mixture of White/Grey bacterial mat and pucime
EN419-51	ROVPC	36	31.6410	25	29.2346	494	6/2/2006	1020	Push core in White and Grey hydrothermal sediment - temp. 63 oC
EN419-52	ROVPC	36	31.6730	25	29.2370	495	6/2/2006	1020	Push core in grey patch sediment in hydrothermal vent
EN419-53	ROVS	36	31.6370	25	29.2370		6/2/2006	1020	vent 25 - foating pumice on sample - temp. 65 oC
EN419-54	ROVS	36	31.6440	25	29.2420	492	6/2/2006	1020	Sampling from summit of chimney 9 (5?) - coarse fragments of brown/orange mineral deposits -temp < 15 oC
EN419-55	ROVG	36	31.6437	25	29.2423	492	6/2/2006	1020	Sample from the top of the chimney - stratified pieces of mineral deposits
EN419-56	ROVPC	36	31.5696	25	29.3731	484	6/2/2006	1020	Dark grey silty sandy ash
EN419-57	ROVG	36	31.3999	25	29.3810	498	6/2/2006	1020	Grey poorly vesicular dacite
EN419-58	ROVG	36	25.4268	25	23.2906	338	6/2/2006	1021	Block from the edge of nea kameni lava flow
EN419-59	ROVG	36	25.3301	25	23.3043	254	6/2/2006	1021	Sample of lava flow
EN419-60	ROVG	36	25.3058	25	23.3066	242	6/2/2006	1021	Block from lava surface
EN419-61	ROVG	36	25.2834	25	23.3006	244	6/2/2006	1021	Lava block on top of flow banded cliff
EN419-62	ROVG	36	25.1770	25	23.2658	314	6/2/2006	1021	Lava block from scree
EN419-63	ROVG	36	25.1721	25	23.1299	324	6/2/2006	1021	Lava scree sample near contact glassy block
EN419-64	ROVG	36	31.5980	25	29.2120	492	6/7/2006	1026	Black hydrothermal oxide - Temp 123 oC
EN419-65	ROVS	36	31.5980	25	29.2120	492	6/7/2006	1026	Temperature 123 oC
EN419-66	ROVS	36	31.5980	25	29.2120	492	6/7/2006	1026	Yellow bacterial mat - like scrambled eggs - Temp 123 oC
EN419-67	ROVS	36	31.5980	25	29.2120	492	6/7/2006	1026	Suction of a white chaulky crust - Temp 123 oC
EN419-68	ROVG	36	31.5910	25	29.2103	489	6/7/2006	1026	A layered hydrothermal vent sample - Temp 205 oC
EN419-69	ROVG	36	31.5780	25	29.1930	490	6/7/2006	1026	Large hydrothermal vent sample - Temp 206 oC
EN419-70	ROVG	36	31.5850	25	29.1960	490	6/7/2006	1026	A spire with bacterial
EN419-71	ROVG	36	31.5680	25	29.2290	492	6/7/2006	1026	top of a chinmey with bacterial mat
EN419-72	ROVG	36	31.6060	25	29.2050	492	6/7/2006	1026	sample of a chimney
EN419-73	ROVG	36	31.5810	25	29.1980	491	6/7/2006	1026	irregular black block with a rusty coating
EN419-74	ROVPC	36	31.5890	25	29.2030	492	6/7/2006	1026	Push core near a chinmey
EN419-75	ROVPC	36	31.5930	25	29.2039	492	6/7/2006	1026	Push core in sediment
EN419-76	ROVPC	36	31.5736	25	29.1780	491	6/7/2006	1026	Push core in sediment
EN419-77	ROVBC	36	31.5957	25	29.2058	493	6/7/2006	1026	Box core in sediment
EN419-78	ROVG	36	31.5662	25	29.2970	500	6/7/2006	1026	Section from the top of a white chimney - temp 147 oC
EN419-79	ROVG	36	31.5819	25	29.2030	500	6/7/2006	1026	Section of a part from a chimney
EN419-80	ROVS	36	31.5817	25	29.1916	500	6/7/2006	1026	Suction sample of the wall of a chimney
EN419-81	ROVPC	36	31.5763	25	29.2043	501	6/7/2006	1026	push core in sediment
EN419-82	ROVPC	36	26.9630	25	24.1090	342	6/8/2006	1027	push core on top of yellow mound
EN419-83	ROVPC	36	26.9720	25	24.1090	343	6/8/2006	1027	push core on top of large mound
EN419-84	ROVPC	36	26.9740	25	24.1030	343	6/8/2006	1027	push core on top of a mound
EN419-85	ROVPC	36	27.0000	25	24.1760	338	6/8/2006	1027	push core on the side of a mound
EN419-86	ROVBC	36	27.0190	25	24.1460	332	6/8/2006	1027	in sediments in between the mounds
EN419-87	ROVS	36	27.0000	25	24.1080	336	6/8/2006	1027	Suction sample of orange material at the top of mound
EN419-88	ROVS	36	26.9440	25	24.1750	334	6/8/2006	1027	Suction sample of orange material at the top of mound - temp 16.3 oC
EN419-89	ROVS	36	26.9750	25	24.1460	334	6/8/2006	1027	Suction sample of black grey sediment at the bottom of mound
EN419-90	ROVS	36	26.9920	25	24.1240	336	6/8/2006	1027	Suction sample temp 18 oC
EN419-91	ROVG	36	24.6307	25	22.1987	239	6/8/2006	1027	scoria block
EN419-92	ROVG	36	24.6023	25	22.1672	246	6/8/2006	1027	scoria block from tuff outcrop
EN419-93	ROVG	36	23.9012	25	21.9801	260	6/8/2006	1027	2 pieces of Scoria
EN419-94	ROVG	36	23.1920	25	22.0671	180	6/8/2006	1027	Lava outcrop from ridge separating W from S basin
EN419-95	ROVG	36	23.5076	25	24.1552	216	6/8/2006	1027	From Lava outcrop

III. Preliminary Results

The Santorini volcanic field extends 20 km to the north-east of the island of Thera, as a line of over 20 submarine cones of varying sizes. The line of craters lies within a rift that ends in the south-west as normal faults that dissect the caldera wall of north part of the island of Thera (fig. 3). By far the largest of these craters is Kolumbo, a 3 km diameter cone with an 1500 m wide crater, a crater rim as shallow as 10 m below sea level in the south-west and a crater floor 505 m in depth below sea level. Kolumbo was last active in 1650, when an explosive eruption

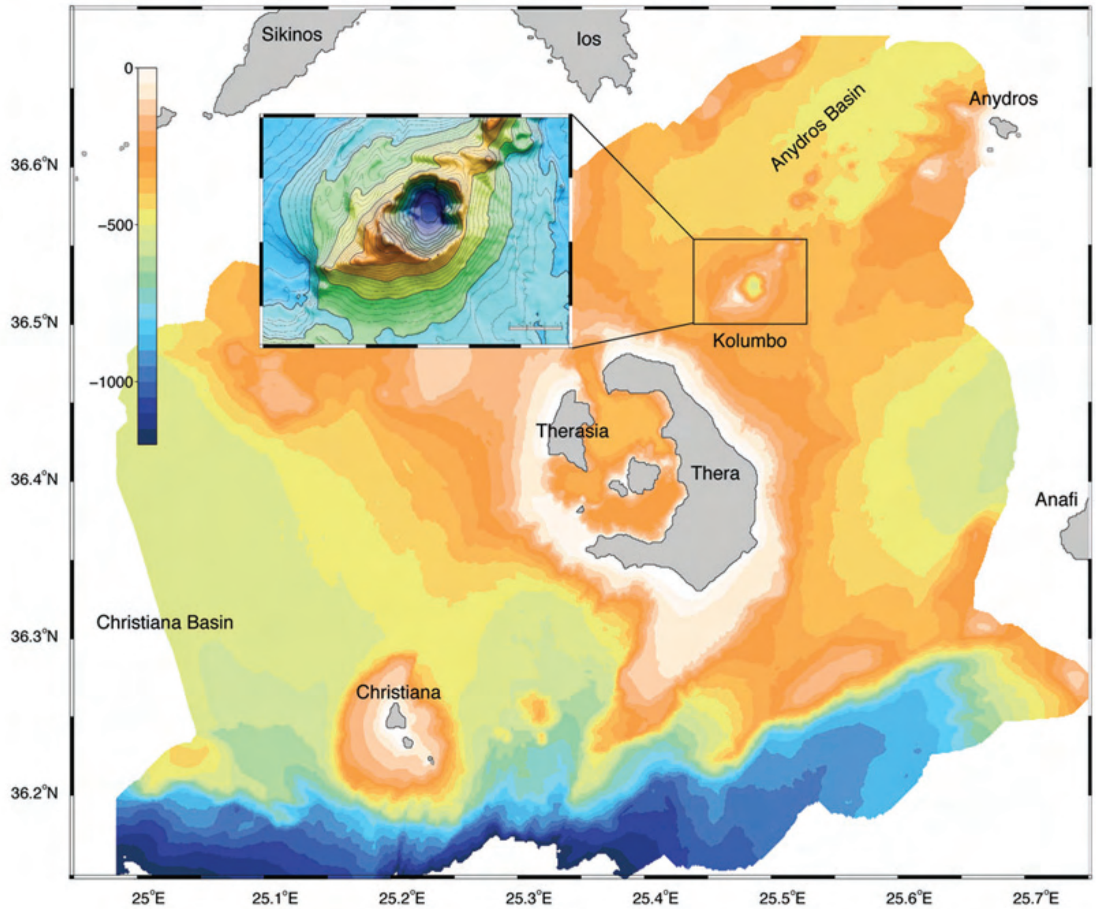


Figure 3. Map showing the bathymetry around Santorini volcano and the location of the Kolumbo submarine volcano.

produced hot surges that caused 70 deaths on Thera and other extensive damage (Fouque 1879; Vougioukalakis et al., 1996, Dominey-Howes, 2000). Seismic monitoring by the Institute for the Study and Monitoring of the Santorini Volcano (ISMOSAV) shows that seismicity in the Santorini region is almost exclusively limited to Kolumbo and the NE-trending Kolumbo volcanic line, but absent from the Santorini caldera (Dimitriadis et al. 2005).

A widespread hydrothermal vent field was discovered on the floor of the Kolumbo submarine crater during ROV dives on cruise EN-419 (fig. 4). High-temperature venting occurs in the north central part of the crater with vigorous gas emission and fluid temperatures up to 220^{o} C from vent chimneys up to four meters in height, constructed of massive sulfides and sulfates. The exterior of most chimneys is densely covered with white, gray, and reddish filamentous bacteria. Some of the chimneys exhibit branching, trunk-like structures that have continuous gas and fluid streaming from multiple openings. Others consist of a series of tightly clustered tapered spires, up to a meter in height.

Lower temperature chimneys and vents along the northern and eastern margin of the crater floor discharge clear fluids up to 70° C with some gas streaming. The larger chimneys in this area are covered by more reddish bacteria and glassy tunicates. As the margins of the crater wall are approached in the north-east there are dramatic streams of white bacterial mats that appear to be the colonization of fluid seeps moving downwards towards the crater floor. In some of these areas there are patches of gray hydrothermally altered clays emitting shimmering water at temperature up to about 70° C. The entire crater floor of Kolumbo is covered by a reddish orange bacterial mat a few centimeters in thickness. In addition, the water column in the crater below 250 meters in depth is turbid with abundant bacterial filaments and other suspended particles.

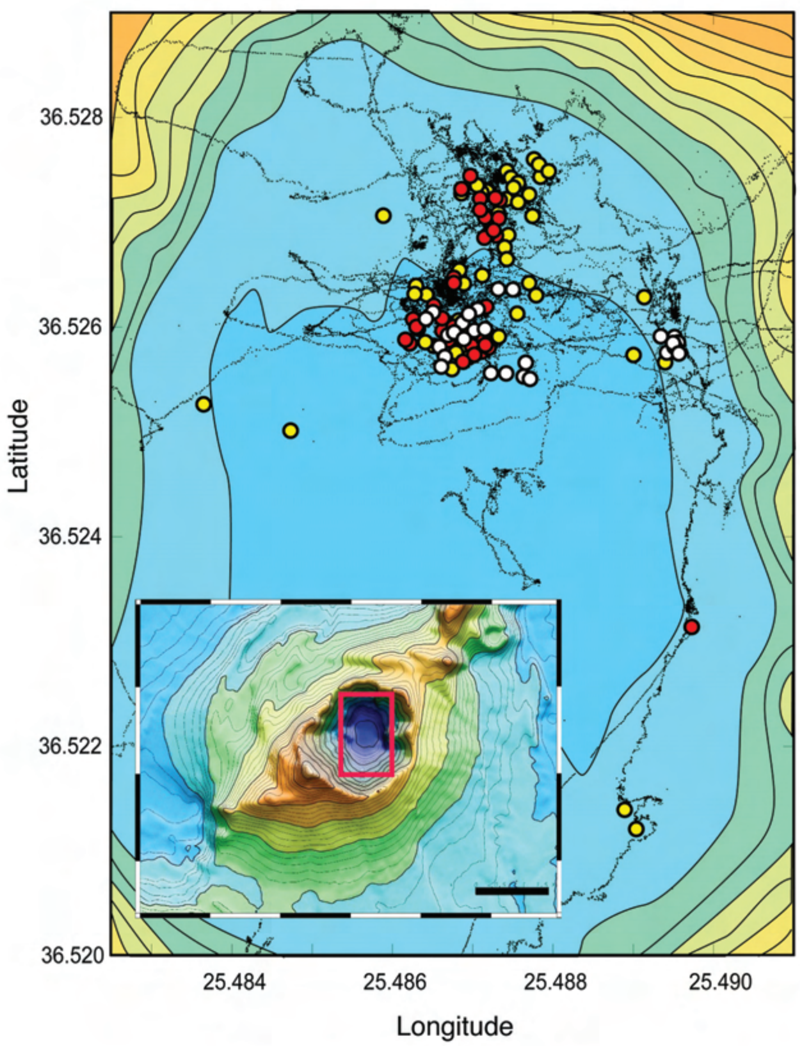


Fig. 4. Map showing the location of high (white circle) and low (red circle) temperature hydrothermal vents in the crater of Kolumbo volcano (inset). Yellow circles indicate the location of bacterial mats. ROV dives tracks are dotted lines.

In contrast to the high temperature venting found in Kolumbo submarine volcano, only relatively low temperature venting was observed within the Santorini caldera. The present configuration of the caldera consists of three distinct basins that form separate depositional environments, divided by the Kameni volcanic islands. The largest is the North Basin (389 m), to the west is the Aspronisi Basin (325 m), and the shallowest is the South Basin (297 m). The new seismic lines show that sediments in the Santorini caldera consist primarily of terrigenous material and volcaniclastic deposits from the activity of Kameni islands. Hydrothermal vents occur in both the North and South Basin of the caldera. They form a vent field in the NE part of the North Basin that is 200 by 300 m in extent (fig. 5). The vents form hundreds of 1 to 4 meter diameter mounds of yellowish bacterial mat that are up to 1 meter high. Temperatures in the mound are around 15 to 17^{o} C or about 5^{o} C above ambient temperature. The North Basin hydrothermal vent field is located in line with the normal fault system of the Kolumbo rift, and also near the margin of a shallow intrusion that occurs within the sediments of the North Basin. Similar vent mounds occur in the South Basin, where most of the low temperature vents are seeps along a ridge separating the West and South Basins and on the submarine flanks of the Kameni volcanic islands.

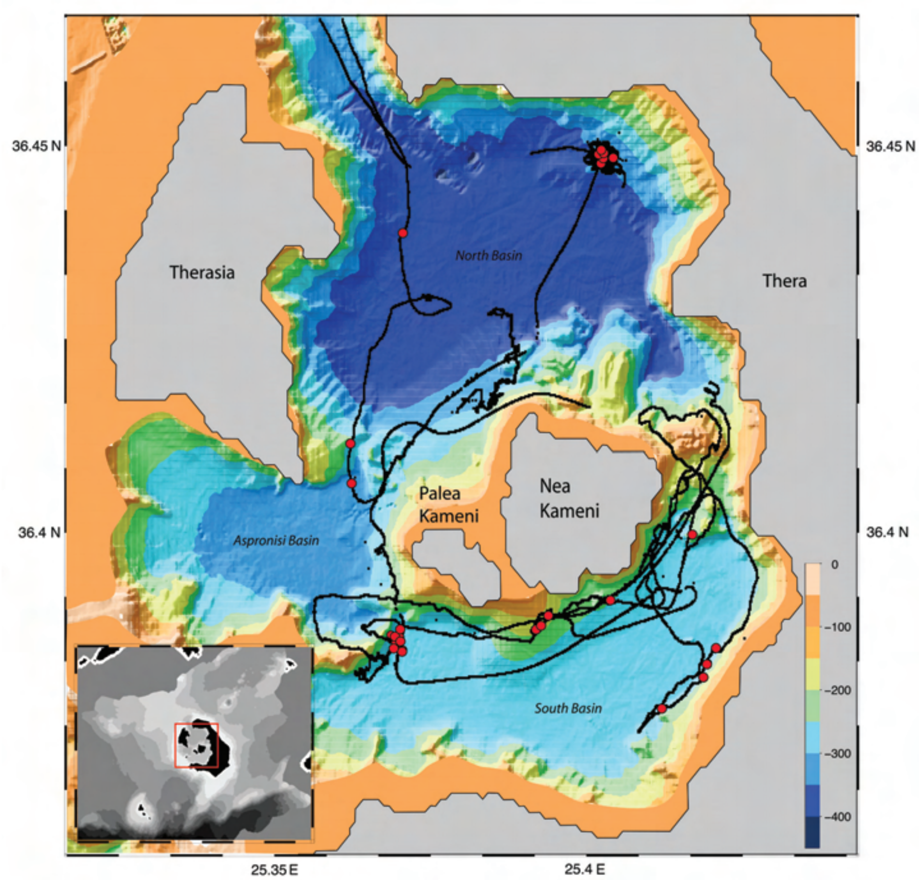


Figure 5. Map of the Santorini caldera showing the distribution of low-temperature hydrothermal mounds (red circles). ROV tracks show as black lines. Inset map shows the Santorini volcanic complex.

IV. References

Carey, S., H. Sigurdsson, C. Mandeville and S. Bronto 1996: Pyrolcastic flows and surges over water: an example from the 1883 Krakatau eruption. Bull. Volcanol. 57, 493-511.

Carey, S., Sigurdsson, H., Mandeville, C. and Bronto, S. (2000). Volcanic hazards from pyroclastic flow discharge into the sea: examples from the 1883 eruption of Krakatau, Indonesia. *Geol. Soc. Amer. Spec. Paper* 345, 1-14.

Cas, R.A.F. and Wright, J.V. (1991). Subaqueous pyroclastic flow and ignimbrites: an assessment. *Bull. Volcanol.*, 53: 357-380.

Cole, R. and DeCelles, P. (1991). Subaerial to submarine transitions in early Miocene pyroclastic flow deposits, southern San Joanquin basin, California. *Geol. Soc. Amer. Bull.,* 103: 221-235.

Dominey-Howes, D., Papadopolulis, D., Dawson, A. (2000). Geological and historical investigation of the 1650 Mt. Columbo (Thera Island) eruption and tsunami, Aegean Sea, Greece. *Natural Hazards*, 21: 83-96

Fouqué, F. (1879) *Santorin et ses Éruptions.* Masson et Cie, Paris.

Kano, K. (1991). An ash flow tuff emplaced in shallow water, Early Miocene Koura formation, southwest, Japan. *Jour. Volcanol. Geotherm. Res.*, 40: 1-9**.**

Pyle, D.M., 1990: New estimates for the volume of the Minoan eruption. In: Thera and the Aegean World III, (Ed. D.A. Hardy), London, 113-121.

Sigurdsson, H., S. Carey and J. Devine, 1990: Assessment of mass, dynamics and environmental effects of the Minoan eruption of Santorini volcano. In: Thera and the Aegean World III, Proceedings of the Third Thera Conference, vol. 2, 100-112.

Sigurdsson, H., S. Carey and C. Mandeville, 1991a: Krakatau: Submarine pyroclastic flows of the 1883 eruption of Krakatau volcano. *National Geographic Research*, 7, 310-327.

Sigurdsson, H., S. Carey, C. Mandeville and S. Bronto, 1991b: Pyroclastic flows of the 1883 Krakatau eruption. *EOS,* 377-381.

Sigurdsson, H., S.N. Carey and S. Bronto 1997: Sub-bottom Stratigraphy of Krakatau 1883 Submarine Pyroclastic Flows. EOS, 78, F806.

Vougioukalakis, G., L. Francalanci, A. Sbrana and D. Mitropoulos, 1994: The 1649-1650 Kolumbo submarine volcano activity, Santorini, Greece. Int. Workshop on European Laboratory Volcanoes, Aci Castello (Catania) Italy. Proceedings 189-192.

Vougioukalakis, G., Francalanci, L., Mitropoulos, D. and Perissoratis, K., 1996. The 1649-1650 eruption of the Kolumbo submarine volcanic center, Santorini. Second Workshop on "European Laboratory Volcanoes", Thira, Santorini, Greece, May 1996.