Sea of Crete Project 2007
NRV *Alliance*
Cruise Report

Institute for Exploration &
Institute for Archaeological Oceanography

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1 Cruise overview

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Itinerary -

29 July-2 August - Mobilization in La Spezia, Italy
2-5 August - Transit to Sea of Crete
5-9 August - On site
9-10 August - Transit to Istanbul
10 August - Personnel transfer in Istanbul

Participating organizations -

Center for Coastal and Ocean Mapping, University of New Hampshire
French Research Institute for Exploitation of the Sea
Graduate School of Oceanography, University of Rhode Island
Immersion Presents
Institute for Exploration
Institute for Geology and Mineral Exploration

NATO Undersea Research Center
Naval Meteorology and Oceanography Command
NOAA Office of Ocean Exploration
Office of Naval Research
Woods Hole Oceanographic Institution

Vessel Identification -
NRV *Alliance*

Vehicles, sensors, and other equipment -
Atlas Hydrosweep multibeam, ROV *Hercules*, ROV *Argus*, gravity core, elevators

Geographic area of operations -
Western Sea of Crete, southern Aegean Sea

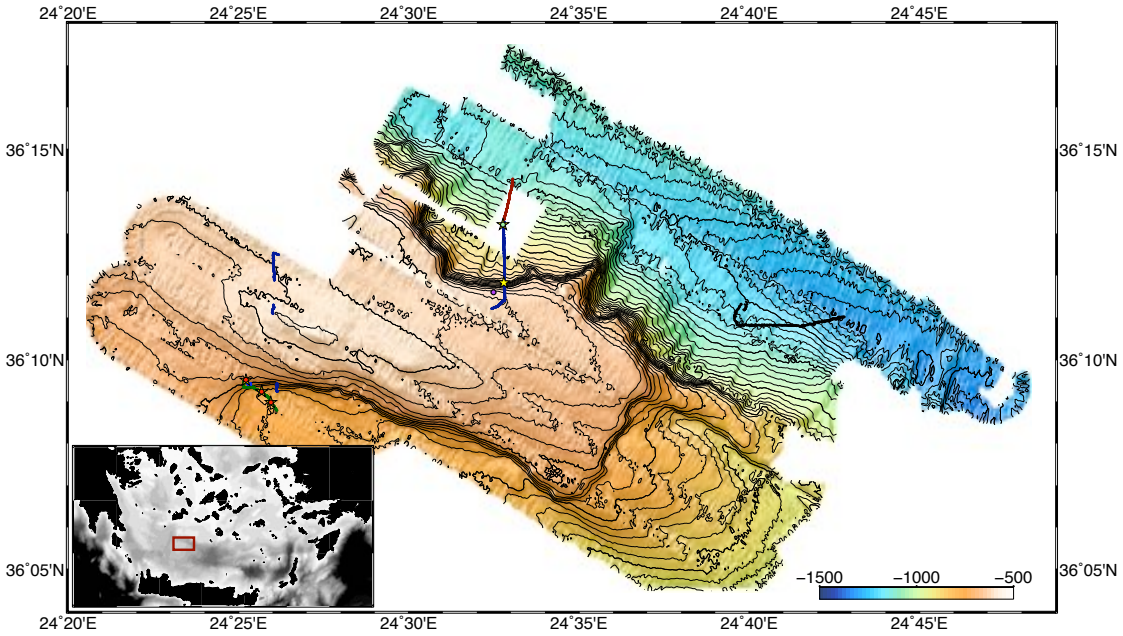


Figure 1: Sea of Crete operating area: multibeam data, dive tracklines and sample locations. Map created by K. Croff using Generic Mapping Tools.

2 Background and objectives

The Sea of Crete, located in the southern Aegean Sea, is the most tectonically and volcanically active region of the Mediterranean. The Aegean Sea has experienced many large scale explosive volcanic eruptions during the late Pleistocene [3] some of which have developed multiple calderas [5, 4]. One of the more recent (3.6 ka) events occurred on Santorini which is the second largest explosive eruption recorded in historical times. And later in 1650AD, the submarine volcano Kolumbo, which is located 7 km to the northeast of Santorini, erupted. The Thera and Sea of Crete Projects carried out in 2006 revealed evidence of sediment movement on the submarine slopes of the Santorini volcano and Sea of Crete basin. The significance of these volcanic events is that most of the erupted materials were deposited into the adjacent seas. The impact to the proximal marine areas from these explosions is poorly understand as most earlier marine volcanology focused on distal marine sediments [11, 9, 10]. We returned in 2007 to this area to further investigate the history of these processes that is locked in the seafloor sediments of the Sea of Crete.

In 2006, Sigurdsson and Carey conducted detailed surveys in the coastal regions of Santorini to close this gap in knowledge about proximal marine volcaniclastic deposition and caldera development [7]. Their focus was on advancing the understanding of pyroclastic flow/seawater interaction so that ancient volcaniclastic sequences could be better studied and assessments of volcanic hazards improved [1].

During the Ballard and Croff 2006 expedition, high resolution seismic and sidescan surveys that extended beyond Sigurdsson and Carey's coastal focus, were collected. These surveys revealed a seafloor in the medial zone between the coastal and distal zones of Santorini (Figure 1) to be rife with undersea landslides. Our expedition, conducted this year in the Sea of Crete, examined this medial zone to determine (a) the character of the post-Santorini eruption and the underwater landslide features; and (b) the relationship of these features with the local volcanic and/or tectonic history in the Sea of Crete. Geographical regions of interest included a seafloor high in the western Sea of Crete and slumping on the slopes of that seamount and on the continental slope to the north.

3 Preliminary results

The study area was mapped using multibeam bathymetry and acoustic backscatter in regions selected from interpretations of the 2006 seismic and side scan data (Figure 1). These regions were interpreted to be covered by mass wasting deposits, such as slumps, slides, and submarine landslides. These data were groundtruthed with detailed visual observations along ROV transects selected along and across the underwater landslide sites selected from the multibeam. Samples were also collected using the ROV and the gravity

corer to further characterize the sediment and rocks in these disturbed seafloor areas.

3.1 The Minoan Eruption of Santorini and the Medial Seafloor

The Santorini eruption at 3.6 ka ranks as the second largest volcanic eruption in recorded history. Cioni et al., Sigurdsson et al., and Druitt et al. separately describe the four phases of this eruption [2, 8, 3]. The first phase was plinian (magma eruption coupled with a 36 km high eruption column). Next pyroclastic flows surged from the volcano and deposited up 10-12 meter-thick sequences confined to the island. The third phase was again characterized by pyroclastic flows, but during this phase, they were widespread over the island and covered parts of the sea surface. Finally, the most violent phase occurred with the eruption of very hot pyroclastic flows with huge volumes that covered the island and large volumes flowed to and extended onto the seafloor.

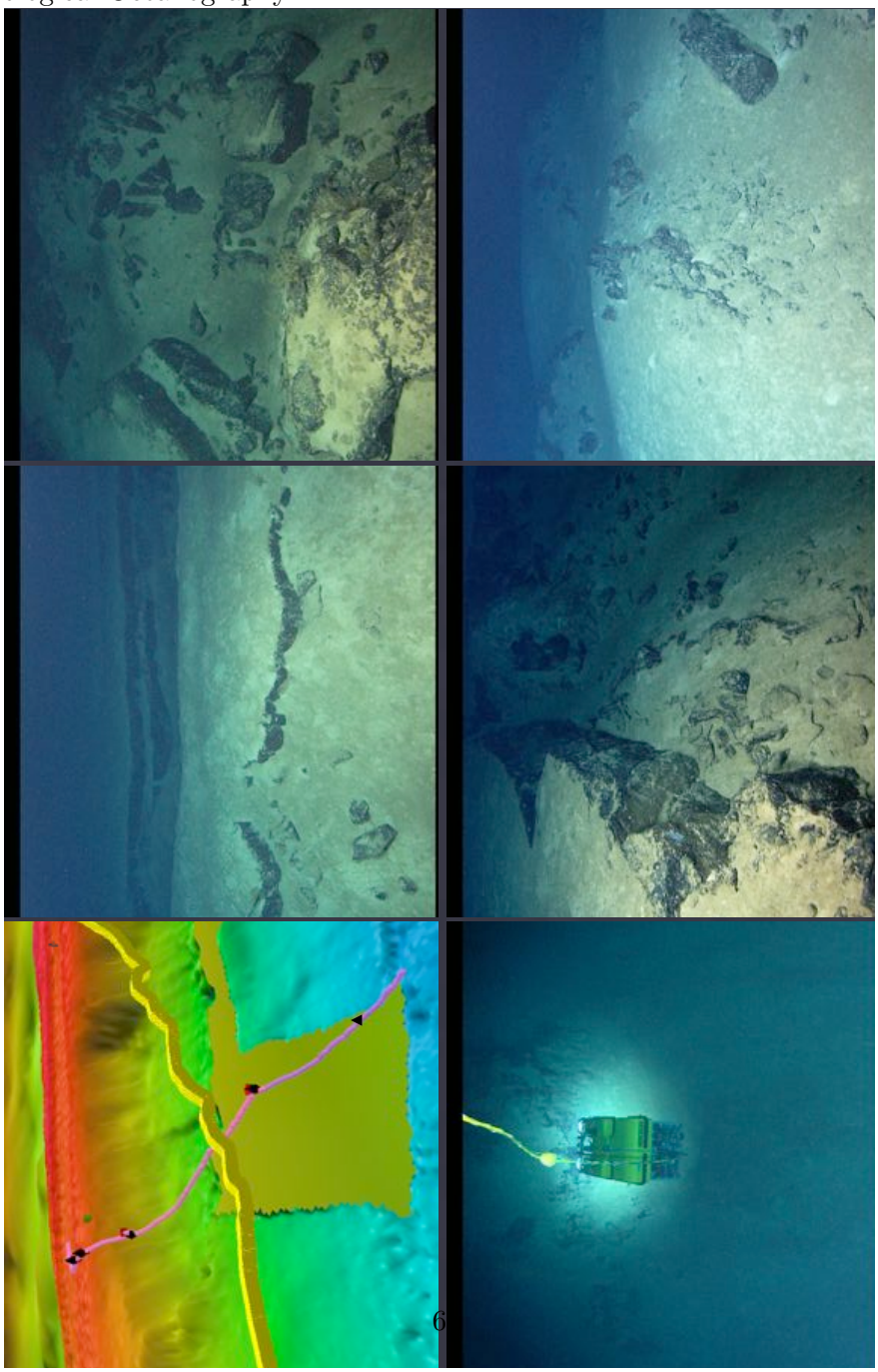
It is well-documented that the impact of these phases of events extended to the distal marine environment based on deep sea core studies that contained co-ignimbrite fallout. However, this extensive, prolonged, and voluminous eruption of material likely had a greater and potentially colossal impact on the proximal and medial marine environments. This study of the medial marine environments in the Sea of Crete focuses on understanding the changes to the environment from before to after the eruption.

During this expedition, all three operational aspects (ROV dives, multibeam with backscatter, and core samples) were collected to endeavor to reconstruct the effects of the eruption in the study area, northwest of Crete. This area physiographically includes two distinct features: a seamount and a large trough. The trough is coincident with a regional tectonic fault separating a regional uplifting continental shelf where Santorini is location from the subsiding seafloor south of the trough. The expedition found massive debris flow, rock slides, sloped debris-filled terraces, escarpments, slide scars and slides on the the seamount and within the trough. Sediments and rocks ranged from carbonate-rich (possible, this observation was based on visual observations) clays, pumice, manganese-coated soft rocks (potentially lithic tuff), and possibly ash. These, along with data collected in 2006, will be analyzed to determine the source of the sediment cover, the character of deposition (and seafloor mass wasting), and, hopefully, the timing of each with respect to the Santorini eruption.

3.2 Relationship of physiography & the Holocene history

The volcanic and tectonic history of the Sea of Crete is quite complex. As the data is further processed, we will focus on the most recent geologic time, during the Holocene, to reconstruct the regional framework within which the Santorini eruption occurred with a

Figure 2: North slope of seamount, view is looking from the trough toward the southwest up the north slope of the seamount. Four failure zones were discovered along dives H1053 (purple) and H1054(pink). Black diamonds indicate the locations of the images; red cubes are the locations of grab samples; the green cylinder is the location of the gravity cores. Map created by K. Croff; underwater images copyright Institute for Exploration and Institute for Archaeological Oceanography.



special focus on the medial physiography of the seamount and the trough. Seismic data, collected in 2006, will be merged with seafloor bathymetry collected on this expedition, and interpreted with regional tectonic models [6].

4 Operations

Three types of operations were conducted: remotely operated vehicle (ROV) surveys and sampling using *Hercules* and *Argus*; multibeam bathymetric and backscatter surveys using the ships hull-mounted Atlas Hydrosweep MD system; and coring using the *Hercules* push cores and a separately deployed gravity corer.

Table 1: Summary of digital data collected on the Sea of Crete Project

Data type	**Volume**
Vehicle/sensor	66 GB
Multibeam bathymetry	650 MB
High definition still images	9 GB
High definition video	20 hours
Standard deifinition video	50 hours

4.1 Multibeam bathymetry

Multibeam bathymetric data was collected in the 650 km^2 area surrounding the shipwreck site, using the hull-mounted Atlas Hydrosweep multibeam system. Dive and gravity core sites were selected based on initial interpretation of this data, as well as from side scan sonar data collected during the 2006 Sea of Crete project.

After the first day of multibeam data collection, the *Alliance* multibeam technician realized that there had been a change in the configuration of the system, and that it was incorrect. We therefore had to resurvey the area, with a loss of approximately 24 hours of shiptime.

4.2 ROV lowerings

In the Sea of Crete, five dives were made with mean depths ranging from 580 to 1050 meters. Average working time on the bottom was approximately 5 hours; total bottom time was approximately 24 hours.

H1050 - *Hercules* and *Argus*

Dive STARTED at 2007/08/05 19:34:52 at 36.146446°N, 24.435518°E
Dive ENDED at 2007/08/06 00:22:12 at 36.158849°N, 24.420594°E
Distance covered is 2917.902930 meters at a mean depth of 729.115646 meters

H1051 - *Argus*

Dive STARTED at 2007/08/07 7:35:44 at 36.184095°N, 24.719031°E
Dive ENDED at 2007/08/07 10:34:30 at 36.183275°N, 24.659702°E
Distance covered is 11537 meters

H1052 - *Hercules* and *Argus*

Dive STARTED at 2007/08/07 16:18:03.088 at 36.156942°N, 24.422364°E
Dive ENDED at 2007/08/07 16:59:20 at 36.156968°N, 24.421859°E
Distance covered is 323.629586 meters at a mean depth of 700.635859 meters

H1053 - *Hercules* and *Argus*

Dive STARTED at 2007/08/08 07:06:52 at 36.238338°N, 24.550956°E
Dive ENDED at 2007/08/08 09:08:07.696 at 36.220179°N, 24.546110°E
Distance covered is 2139.926403 meters at a mean depth of 1046.979468 meters

H1054 - *Hercules* and *Argus*

Dive STARTED at 2007/08/08 14:25:27 at 36.221144°N, 24.546914°E
Dive ENDED at 2007/08/08 21:18:48 at 36.186835°N, 24.540519°E
Distance covered is 5040.222924 meters at a mean depth of 787.292643 meters

Dive STARTED at 2007/08/09 00:01:48 at 36.208238°N, 24.436394°E
Dive ENDED at 2007/08/09 01:23:49 at 36.198280°N, 24.434281°E
Distance covered is 1582.580951 meters at a mean depth of 601.913658 meters

Dive STARTED at 2007/08/09 01:47:03.522 at 36.188383°N, 24.433739°E
Dive ENDED at 2007/08/09 02:08:17 at 36.184971°N, 24.433440°E
Distance covered is 500.494359 meters at a mean depth of 579.614102 meters

Dive STARTED at 2007/08/09 03:11:21 at 36.154086°N, 24.435675°E
Dive ENDED at 2007/08/09 03:39:31 at 36.156986°N, 24.435623°E
Distance covered is 435.119902 meters at a mean depth of 735.159499 meters

4.3 Samples

Twelve samples were collected during the Sea of Crete Project, including six geological ROV grab samples, three push cores, two gravity cores and one fluid sample. Details of each sample are listed in Appendix 7.

5 Clearance

Clearance to work in the Sea of Crete met with misinformation from the US State Department, causing a last-minute scramble to apply for clearance for Marine Scientific Research. Thanks to the understanding of the Greek Ministry of Foreign Affairs, the issue was resolved in time for the project, and lessons have been learned.

In December of 2006, the US State Department Office of Ocean Affairs was contacted for advice on application for Marine Scientific Research to conduct work in the Sea of Crete, outside the Greek Territorial Water limit of 6 nm. We were advised that we should not apply for research clearance because we were planning to work outside this limit. As it turned out however, because the work was planned on the Continental Shelf of Greece, we needed to apply for clearance. This requirement was brought to our attention shortly before the commencement of the cruise.

An application was quickly assembled and sent to the Greek Ministry of Foreign Affairs. A special meeting was called by Mr. Alexandros Rallis to consider it, because the mistake had been made in good faith. Thanks to his understanding of the situation, the application was accepted and an observer from the Institute for Geological and Mineral Exploration, Dr. Andreas Andrinopoulos, was able to join us for the duration of the Sea of Crete Project. Dr. Andrinopoulos disembarked *Alliance* with a copy of all data that was collected during the project.

6 Participants

Table 2: Sea of Crete cruise participants

Title	**Surname**	**Name**	**Institution**	**Function**
Dr	Andrinopoulos	Andreas	IGME	Scientist/Observer
Mr	Brennan	Michael	URI	Scientist
Mr	Buckley	Mark	URI	Scientist
Ms	Cantner	Kathleen	URI	Scientist
Mr	Catsambis	Alexis	NURC	Scientist
Ms	Croff	Katherine	URI	Chief Scientist
Mr	DeRoche	Mark	IFE	Deck Chief
Dr	Durbin	Michael	IFE	Satellite engineer
Ms	Fero	Julie	URI	Scientist
Dr	Galletti	Domenico	NURC	Scientist
Mr	Gregory	Todd	URI	ROV pilot

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Title	Surname	Name	Institution	Function
Dr	Kinsey	James	WHOI	Navigator
Mr	Knott	Robert	IFE	Video engineer
Mr	Martin	Eric	IFE	ROV pilot
Mr	Michel	Jean-Louis	IFREMER	Scientist
Dr	Moran	Kathryn	URI	Scientist
Mr	Newman	James	IFE	Operations Leader
Dr	Nichols	Mary	IFE	Video engineer
Mr	Phillips	Brennan	IFE	ROV pilot
LTCDR	Pica	Joseph	NOAA	Navigator
Mr	Pinner	J. Webb	NOAA	Data manager
Mr	Portell	Jeffrey	NMOC	Navigator
Mr	Raynes	Brian	IFE	Video engineer
LT(jg)	Samuelson	Nicola	NOAA	Navigator
Mr	Wright	David	IFE	ROV pilot

7 Sea of Crete sample log

Table 3: Types of samples

Abbreviation	Sample type
FL	Fluid
GC	Gravity core
PC	Push core
ROVG	ROV grab

C1001-01-ROVG

Date collected: 2007-08-05

Latitude: 36.14962100 °N

Longitude: 24.43249978 °E

Depth: 720.53 m

Dimensions: 20x12x11 cm

Figure 3: C1001-01-ROVG

Description: Black clast with partially lithified clay/ooze on the bottom; small round white particles; (approx. 0.5mm in diameter) mixed throughout grey clay - these are likely forams; when rock was broken - black outer crust broke easily

C1001-02-PC

Date collected: 2007-08-05

Latitude: 36.14961220 °N

Longitude: 24.43251056 °E

Depth: 720.599032 m

C1001-03-PC

Date collected: 2007-08-05

Latitude: 36.15390566 °N

Longitude: 24.42798471 °E

Depth: 720.580298 m

Figure 4: C1001-04-ROVG

C1001-04-ROVG

Date collected: 2007-08-05

Latitude: 36.15393461 °N

Longitude: 24.42799930 °E

Depth: 720.562560 m

Dimensions: 21x17x15 cm

Description: Dense pumice block. Orange brown in color with bands of dark brown. Inside is light tan, rock is very soft and breaks easily. Some dark black phenocrysts (possibly amphibole?)

C1001-05-ROVG

Date collected: 2007-08-05

Latitude: 36.15393383 °N

Longitude: 24.42799626 °E

Depth: 720.633760

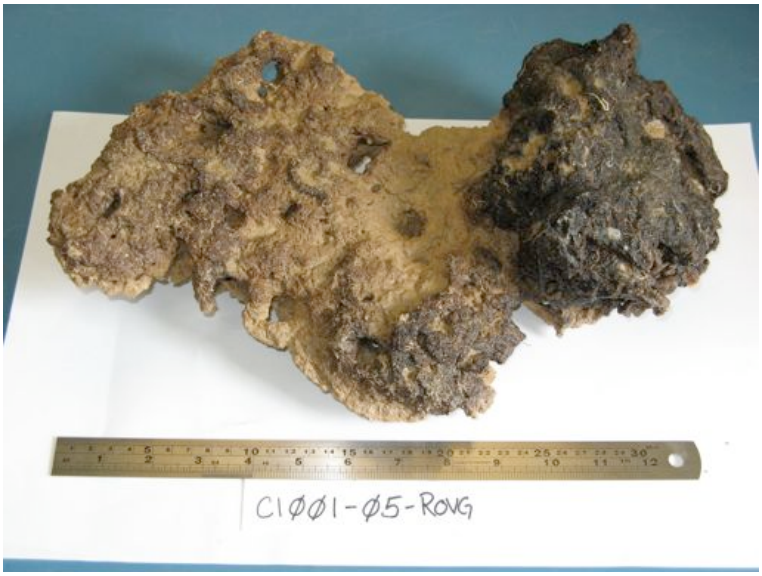

Figure 5: C1001-05-ROVG

Dimensions: 37x22x11 cm

Description: Dark black rock w/ dimensions 18x15x11 cm attached to a large flat light brown crust. Crust is covered in tan clay/ooze. Appears to have small round grains (approx. 0.5mm in diameter) interspersed (foraminfera?) many small worm casings covering the rock

C1001-06-PC

Date collected: 2007-08-05

Latitude: 36.15859627 °N

Longitude: 24.42031746 °E

Depth: 720.535758 m

C1001-07-ROVG

Date collected: 2007-08-06

Latitude: 36.15843880 °N

Longitude: 24.42029433 °E

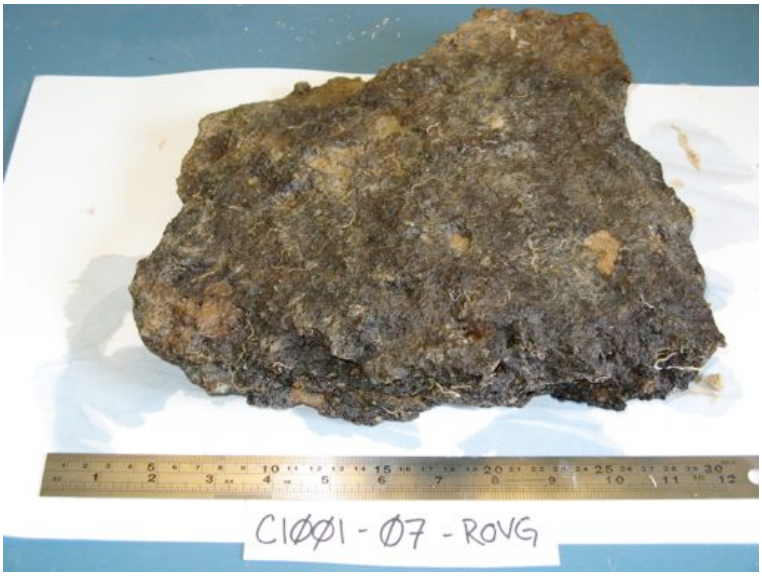

Figure 6: C1001-07-ROVG

Depth: 720.527208 m

Dimensions: 27x24x7 cm

Description: large flat slab, black outer crust with clayey/ooze material in the middle screw driver was easily hammered into the outer crust

C1001-08-ROVG

Date collected: 2007-08-08

Latitude: 36.22017934 °N

Longitude: 24.54610972 °E

Depth: 1067.133515

Dimensions: 10x8x5cm

Description: Dark brown with patches of lighter brown crust. Looks to be the same material as samples 01-ROVG, 05-ROVG and 07-ROVG Did not break it to see if it contained unconsolidated sediment inside Worm casings on surface Small piece of hard clay/ooze attached.

Figure 7: C1001-08-ROVG

C1001-09-FL

Date collected: 2007-08-08

Latitude: 36.22017908 °N

Longitude: 24.54611029 °E

Depth: 1067.317055

Description: Seawater sample

C1001-10-GC

Date collected: 2007-08-08

Latitude: 36.19345 °N

Longitude: 24.54157 °E

Dimensions: 11.5 cm length

Description: light brown homogeneous clay/ooze? with small black sand to gravel sized particles dispersed throughout, layer of these particles on the surface small pieces of crust material throughout coarser crust at bottom?shear strength test: 0.2x0.8 kg/cm^2 core recovery: large section fell

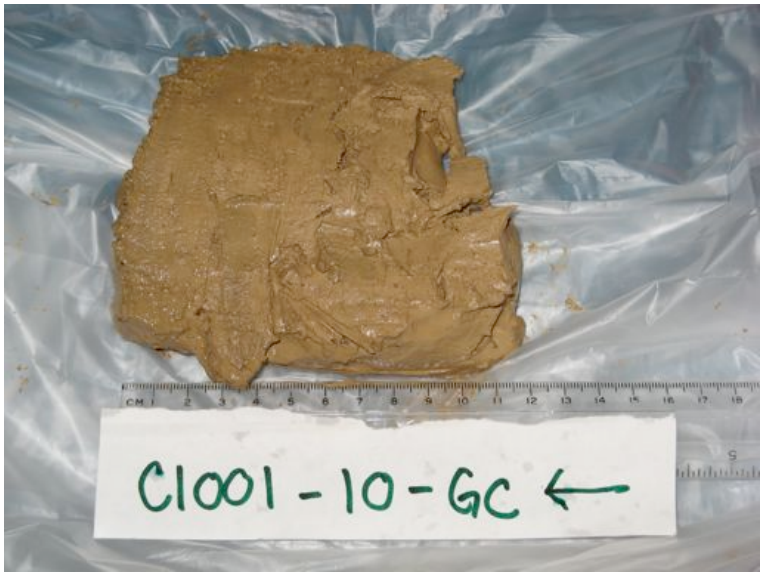

Figure 8: C1001-10-GC

as corer was lifted from the water. The 11.5 cm that was recovered was removed from the core barrel by hand subsample taken for sed strength testing - sample is stored in small jar

C1001-11-GC

Date collected: 2007-08-08

Latitude: 36.19345 °N

Longitude: 24.54157 °E

Description: Some core material fell during recovery. Remaining section sealed and stored. Bivalve shell recovered from core catcher, stored in plastic sample case.

C1001-12-ROVG

Date collected: 2007-08-08

Latitude: 36.19713254 °N

Longitude: 24.54655607 °E

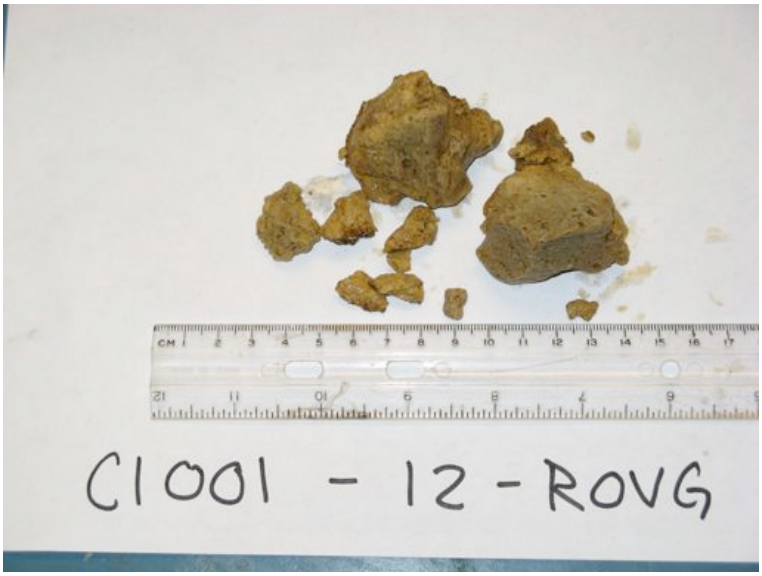

Figure 9: C1001-12-ROVG

Depth: 918.760507 m

Dimensions: 5x4x3 cm

Description: Pumice fragments - two larger pieces with numerous smaller clasts. Outside is dark colored - inside lighter. Some clay/ooze stuck to outside - 2 fragments

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