

**CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES**

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**TRIP REPORT**

**SUBJECT:** Field Research at the Akrotiri Natural Analog Site - 20-5704-063

**DATE/PLACE:** August 22 through September 2, 1994; Akrotiri, Santorini, Greece

**AUTHOR(S):** William M. Murphy and Ronald T. Green

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**PERSONS PRESENT:** William M. Murphy and Ronald T. Green (CNWRA)  
Professor Christos Doumas, University of Athens, and his group of research archaeologists and students

### **BACKGROUND AND PURPOSE OF TRIP:**

This trip constituted the third field season by CNWRA scientists at the Akrotiri natural analog site to conduct research under task 3 of the Natural Analogs Research Project. Data are being collected to support and evaluate models for contaminant migration from well constrained buried archaeological sources in unsaturated silicic tuff in an arid environment over a period of millennia as an analog to contaminant migration in the proposed nuclear waste disposal site at Yucca Mountain.

### **SUMMARY OF PERTINENT POINTS:**

Numerous rock samples were collected to explore the extent of the contaminant plume under investigation. Gas samples were collected to constrain unsaturated zone groundwater chemistry. Samples of bronze corrosion products and clearly contaminated volcanic ash materials were collected. Samples from several phases of the Minoan tuff and the underlying Cape Riva Formation were collected for laboratory measurement of unsaturated hydraulic properties. In-situ permeameter tests were conducted on rocks from two phases of the Minoan eruption. Gypsum blocks were emplaced in the Cape Riva formation to provide information on suction pressures and flux rates. An invited seminar was given to the archaeological field group.

### **SUMMARY OF ACTIVITIES:**

#### **Investigations in $\Delta 3$ .**

Six samples were taken to depths of 50 to 60 cm in and adjacent to  $\Delta 3$ , with approximately forty rock samples taken at monitored depths. The percussion coring device with manual auger overcoring is labor intensive and produces samples of mostly pulverized rock from the Cape Riva formation in  $\Delta 3$ . Locations of the boreholes were mapped on the  $\Delta 3$  base map. Additional packed earth samples were taken. A sample of bedrock from the east wall of the  $\Delta 3$  cellar was taken. Samples should provide constraints on the magnitude and extent of the contaminant plume emanating from the bronze artifacts that were buried

in Δ3. Samples from one borehole located upstream and outside the east wall of Δ3, and the cellar wall should also provide multiple constraints on background elemental concentrations. Pre-Minoan rock samples were also collected from the larger stream valley to the east of the site. The rock is similar in texture and lithology to the rock at Δ3, however it is red in color as opposed to dull purple.

Flagstones in the southeast corner of Δ3 were removed revealing a stepped depression at this corner. Discarded material (mostly rock) was excavated from this depression to a level of unexcavated Minoan materials including rounded stones similar to those commonly observed in the dig. Excavation was halted. Following discussions with Professor Doumas it was advised that further excavation in this area would be curtailed, particularly due to the unstable nature of the Minoan wall between Δ3 and Δ8 to the south, and the unknown nature of its unexcavated foundation. Mapping of this area was improved on the base map.

The Δ3 site was photographed to document the excavations and covered with flagstones to minimize contamination, attention, and confusion.

### **Investigations under the "Square"**

Excavations by the archaeologists in 1994 explored the area underneath the "square" in the area north of Δ3 and the Δ building. The stratigraphy and buried artifacts give a record of Minoan habitation ranging perhaps 500 to 1000 years before the Minoan eruption of the volcano. Two bronze pins and a bronze chisel were found in these excavations located above a small hollow in the Cape Riva bedrock. A potential plume of contaminants in the bedrock derived from these pieces could extend the record of transport to longer times that provided in Δ3, in effect another point on the curve. However, the objects under the square pose a number of ambiguities. Until the Minoan eruption the site was occupied by people and effectively paved. Also, these artifacts are located almost directly in the line of the "torrent" that eroded into the site in modern times. Two samples of bedrock from depths to 5 and 10 cm were taken at this site to evaluate whether or not a contaminant plume exists.

### **Stratigraphic Investigations**

Additional reconnaissance and descriptive work was conducted to confirm the nature of the alluvial materials identified variously as Phase IV of the Minoan eruption, or post Phase IV flood deposits, or "torrent" deposits. Conclusions reached previously and reported in the February 1994 semiannual research report were generally confirmed. Our best present working hypothesis is that the alluvial materials are post Phase IV flood deposits possibly due to catastrophic floods caused by caldera wall collapse. Historical photographs were examined to develop a better reconstruction of the site prior to excavation. The "torrent" was narrow and incised. It is unlikely that it exposed Δ3, and it is likely that there were at least 2 or 3 meters of volcanic ash and alluvial material above the site of the bronzes in Δ3.

### **Other Artifacts**

Prior to our arrival a bronze saw blade was taken from room Δ8A by the archaeologists. Its configuration had been fairly well predicted by electromagnetic measurements made by Green during our 1993 field season, and the archaeologists were duly impressed. Unfortunately, material surrounding the saw was discarded. However, we were given a vial of green to gray-brown corrosion products and adjacent ash cleaned from the saw. Also, while we were there, and in our ignorance, a 45 cm long bronze tong was

removed from room Δ18A. A small amount of materials consisting of corrosion products and surrounding ash from this find was given to us. These clearly contaminated materials will be used to refine selective leaching techniques used for rock samples collected under the Δ3 room.

### **Gas Sampling**

Soil gas samples were collected from two sites at depths of 50 to 75 cm below the ground surface and from the air. Gas samples were collected through a long hollow cylinder that was pounded in the ground. Numerous duplicate samples were collected to investigate precision. These will be analyzed for CO<sub>2</sub> and CH<sub>4</sub> to help constrain unsaturated groundwater chemistry.

### **Hydrologic tests**

Disk permeameter tests were conducted on the Phase II and Phase IV Minoan tuff deposits to determine values for unsaturated hydraulic conductivity. These tests were conducted at several levels of suction pressure, from 20 mm to about 230 mm. Additional samples of these media were collected and transported to the CNWRA hydraulic characterization laboratory for analysis of their unsaturated hydraulic properties.

Five additional gypsum blocks were emplaced in the Cape Riva Formation. This brings the number of gypsum blocks emplaced at the Akrotiri site to eight. At two locations in the Cape Riva, two gypsum blocks were emplaced in the same borehole, one at a depth of 25-30 cm and the other at 50-60 cm. One of these boreholes is located within the covered portion of the archeological site and the other is located outside to the east of the site. All eight gypsum blocks will be monitored monthly by on-site personnel, who will relay the recorded results to CNWRA. This information will be used to interpret the suction pressure and the flux at the site.

In-situ, undisturbed samples of the Phase II and IV Minoan tuff were preserved using epoxy. After hardening, these samples were collected and transported to CNWRA to measure their unaltered pore structure and porosity. These values will be compared with porosity values measured in the hydraulic characterization laboratory using un-epoxied core samples

### **Seminar**

One evening Murphy and Green were invited by Professor Doumas to present a seminar to the combined students and archaeologists (about 30 people). The seminar titled "Relations between Greek Archaeology and Nuclear Waste" was well received, prompted many questions, and should have left a clear impression of our interests and objectives.

### **CONCLUSIONS:**

Field work was successful, and most intended objectives were achieved. Unanticipated sampling of bronze corrosion products was enabled by serendipitous discovery of artifacts by the archaeologists.

### **PROBLEMS ENCOUNTERED:**

The PVC tube with 20 kg of coring and auguring gear was broken in transit to the field, but fortunately none of the gear was damaged. The percussion coring device employed is, in effect, a percussion

pulverizing device for the principal samples of interest. It was not possible to use it to obtain cores for hydraulic testing as anticipated. Uncertainties in funding the Greek research team made it impossible for them to give us good information about their plans prior to the trip. Consequently, we were not told about the excavation of an artifact where we had hoped to collect adjacent materials until after it had been completely removed and the adjacent materials discarded.

**PENDING ACTIONS:**

- Refine leaching tests with clearly contaminated materials.
- Perform leaching tests on rocks from Δ3 and from under the square.
- Reduce hydrologic data.
- Collect additional hydrologic lab data on new samples.
- Analyze gas samples for CO<sub>2</sub>.
- Refine models for contaminant transport using new data, and compare blind model results to field data.

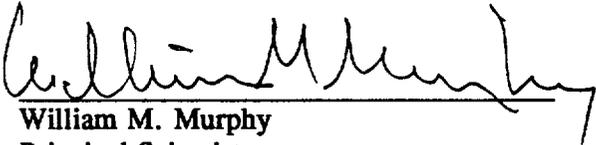
**RECOMMENDATIONS:**

Investigate the possibility of acquiring an electrically powered coring device.  
Continue to communicate our interest to collect materials from adjacent to newly found artifacts.

**REFERENCES:**

None

**SIGNATURES:**

  
\_\_\_\_\_  
William M. Murphy  
Principal Scientist

10/11/94  
Date

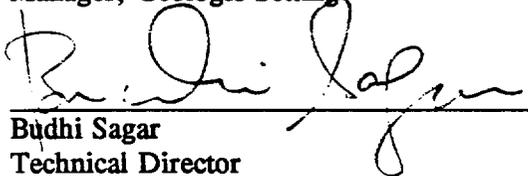
  
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Date

**CONCURRENCE SIGNATURES AND DATE:**

  
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Date