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Exploration of the Anaximander Mud Volcanoes

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New Frontiers in Ocean Exploration

The E/V *Nautilus* 2010 Field Season

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Exploration of the Anaximander Mud Volcanoes

By Timothy M. Shank, Santiago Herrera, Walter Cho, Christopher N. Roman, and Katherine L. Croff Bell

The Anaximander Mountains—Anaximander, Anaximenes, and Anaxagoras—located in the Mediterranean Sea between the Hellenic and Cyprus arcs (Figure 1) were formed in large part due to the ongoing convergence of the African and Anatolian plates (Zitter et al., 2006). As a result, it is a region of active mud volcanism and gas hydrate formation (Lykousis et al., 2009) that hosts (little known) chemosynthetic fauna, largely endemic to the Mediterranean. Previous expeditions observed methane seepage through these volcanoes and thriving chemosynthetic communities of megafaunal invertebrates. These communities stand in stark contrast to the low faunal biodiversity of the nonchemosynthetic surrounding deep Mediterranean seafloor (Danovaro et al., 2010).

In September 2010, we explored the summits and flanks of three mud volcanoes, Kazan, Amsterdam, and Thessaloniki, between 1300-m and 2000-m depth and two volcanic seamounts, Anaximenes and Anaxagoras (Figure 2). We discovered chemosynthetic cold-seep communities in previously unexplored areas of the mud volcanoes. These communities, consisting of siboglinid tubeworms and thyasirid clams, were similar, yet more widely distributed as small, localized patches compared to ones documented in the past (Olu-Le Roy et al., 2004).

Exploration of the three mud volcanoes documented diverse seep habitats in more than two dozen localized seep areas. We observed extinct and active seep sites with an abundance and richness of fauna rivaling those of previously known seep communities in the Mediterranean (Figure 3; Olu-Le Roy et al., 2004). The dominant and most abundant community members were siboglinid tubeworms (*Lamellabrachia* sp.), amphipods, brachyuran crabs, echinoid sea urchins, galatheid squat lobsters, mytilid mussels, and lucinid, vesicomyid, and thyasirid clams. Active seepage on the northern side of Kazan mud volcano's summit near ~1720-m depth fueled aggregations of tubeworms and bivalves in an area more than a 300 m^2. Amsterdam mud volcano (summit near 2050-m depth) hosted tubeworms and bivalves, and abundant crabs. In both of these areas, observations of numerous sediment scars were consistent with hypothesized bottom feeding of beaked whales (Woodside et al., 2006). Our observations of active and extinct seepage areas (as evidenced by the extent of bivalve shell aggregations) add significantly to our ability to determine the present and historical sizes and distributions of the seepage fields and their possible contribution to the ecology and chemistry of the Mediterranean Sea.

The seafloor of Anaximenes and Anaxagoras seamounts was generally sediment covered, even on steep razorback ridges and summits. In contrast to the mud volcanoes, the dominant megafauna on Anaximenes and Anaxagoras

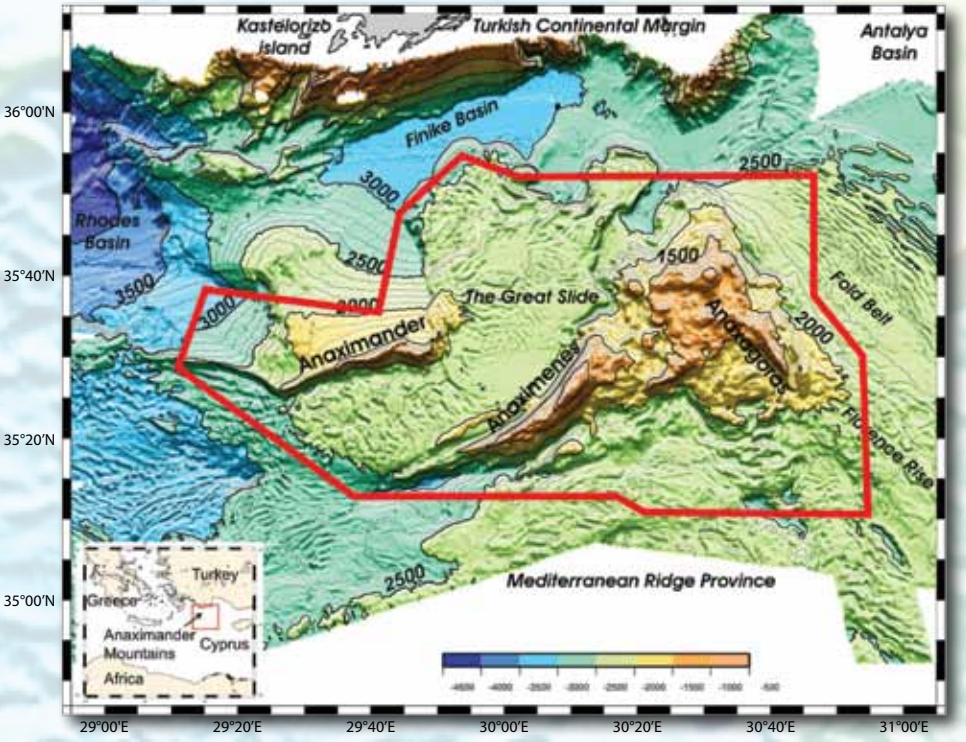


Figure 1. Bathymetric map of the Anaximander Mountain region and surrounding basins. Inset map shows location within the eastern Mediterranean Sea. Contour interval = 100 m (from Lykousis et al., 2009).

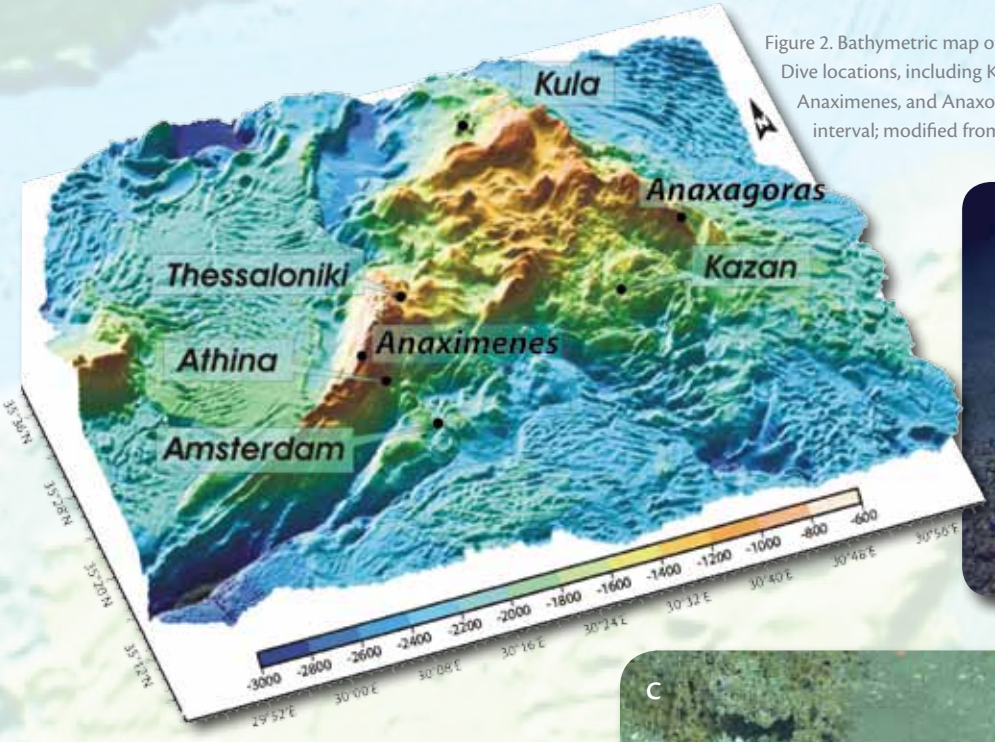
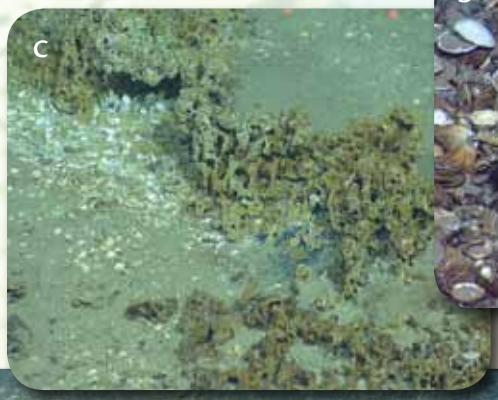
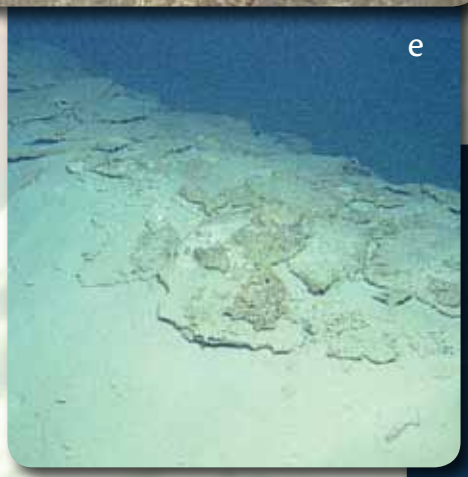


Figure 2. Bathymetric map of the region of exploration. Dive locations, including Kazan, Amsterdam, Thessaloniki, Anaximenes, and Anaxogoras are shown (20–50-m grid interval; modified from Lykousis et al., 2009).

were local patches of cold-water octocorals and scleractinian corals. Brittle stars, chirostylid crabs, shrimp, and polychaetes, typically observed living on deepwater corals on seamounts worldwide, were not observed on corals in the Anaximenes and Anaxagoras region. Other organisms observed thriving on these hard substrates included actinarians and solitary scleractinian (cup) corals. Remarkably, these cup corals were also observed on the exposed surfaces of (ancient) shipwrecked amphorae, suggesting that these anthropogenic artifacts could constitute important habitats for these organisms as well as providing information (through radiocarbon dating) about the currently unknown rates of colonization and growth of these developing coral ecosystems.

Future exploration and investigation of mud volcanoes and gas hydrate-related seeps in the Anaximander region will be key to understanding their important role in accessing global carbon budgets, nonconventional energy sources, marine geohazards, and the evolution and diversity of deep-sea life.





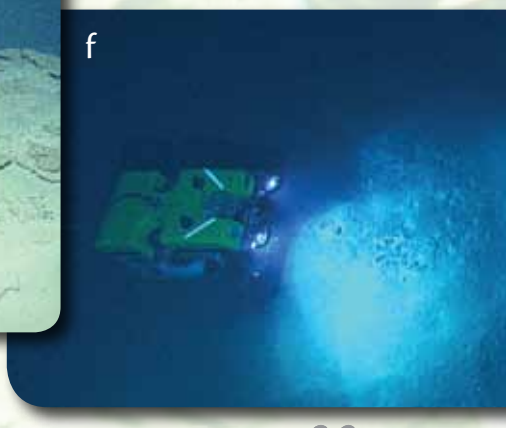


Figure 3. Diverse benthic habitats in the Anaximander Mountain region: (a) sedimented mounds on Kazan mud volcano, with articulated bivalves, gastropod snails, galatheid crabs, and siboglinid tubeworms (b, close up); (c) biomineralized organic debris hosting live thyasirid clams, galatheid crabs, caridean shrimp, and coiled gastropods; (d) near the summit of Amsterdam mud volcano, broken carbonate carapace through which seep fluids emanate and support a partially live yet dense assemblage of tubeworms; and (e) plates of hard substrate on which small tubeworms, gastropods, urchins, and brachyuran crabs were observed. (f) The ROV *Hercules* investigating a seep populated with bivalves and tubeworms on the flanks of Kazan mud volcano.