

Surficial evidence of fluid expulsion from the Costa Rica accretionary prism

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Abstract. The nature and distribution of authigenic carbonates, chemosynthetic bacterial mats, and unique macrobenthic chemosynthetic communities of bivalves and tube worms are important for evaluating and reconstructing present and past fluid venting of accretionary complexes. This paper describes the authigenic carbonates, chemosynthetic fauna, and fluid venting observed at the four tectonic regions of the Costa Rica accretionary wedge in February 1994 during an ALVIN diving program of 20 submersible dives. We found no surficial evidence of highly focused fluid venting at the toe of the prism (outermost 3 km), as implied by the absence of authigenic carbonates and chemosynthetic fauna. The absence of vent communities on the lower 3 km of the prism and the relatively elevated heat flow with respect to the adjacent, incoming Cocos plate (Langseth and Silver, this issue), suggests diffuse, rather than focused flow through the toe of the prism. Twelve active and relict vent sites marked by small clusters of live vesicomyid clams are localized at the bases and tops of out-of-sequence-thrusts, implicating fracture permeability as the fluid conduit in the lower slope region (but upslope from the toe). Vast authigenic carbonates and seven active and relict vent sites marked by large, dense clusters of chemosynthetic organisms predominate the largest mud diapir in the mid-slope region. Fluid expulsion appears to be more restricted on the upper slope, with only 2 small but dense vents marked by chemosynthetic fauna observed at one wall of one canyon.

Introduction

Fluid flow helps govern the structural, mechanical, thermal, and geochemical behavior of accretionary prisms (Moore and Vrolijk, 1992). As accreted sediments are compacted by tectonic processes, methane- and sulfate/sulfide-rich fluids are expelled through high permeable conduits such as sand-rich stratigraphic horizons and fault zones (Behrmann, 1991; Moore and Vrolijk, 1992). Significant fluid volumes are expelled from the wedge (Carson et al., 1990; Le Pichon et al., 1990, 1991) having substantial chemical and isotopic differences from that of present-day bottom sea water (Peacock, 1990; Gieskes et al., 1990; Kastner et al., 1991). Where vent fluxes have been measured or inferred at vent sites elsewhere, rates of vent flow are generally much higher than could be sustained by steady-state dewatering of incoming strata (Carson et al., 1990; Fisher and Hounslow, 1990; Le Pichon et al., 1990, 1991). Thus it is likely that venting is temporally and spatially episodic, although Gieskes et al. (1990) and Kastner et al. (1991) show that other sources of fluid can be significant.

The venting of fluids from an accretionary wedge can be subtle, unlike the highly visible fluid flow from hydrothermal vents (Corliss et al., 1979). Surficial venting is recognized by

the presence of unique macrobenthic communities of bivalves and tube worms harboring chemosynthetic bacterial endosymbionts, that rely upon sulfide- and/or methane-rich fluids as an energy source (Suess et al., 1985; Ohta and Laubier, 1987; Fisher, 1990; Jollivet et al., 1990; Gaillard et al., 1992). High densities of chemosynthetic bacteria, free-living as surface bacterial mats, may also manifest at a fluid vent site. Authigenic carbonates are precipitated in-situ from byproducts produced by the oxidation of methane from the same fluid source (Kulm et al., 1986; Han and Suess, 1987; Haggerty, 1987; Ritger et al., 1987; Goedert and Squires, 1990; Kulm and Suess, 1990).

This paper describes chemosynthetic communities and authigenic carbonates observed at the Costa Rica accretionary wedge in February 1994 during an ALVIN diving program of 20 submersible dives. Macrobenthics and carbonates were sampled from 17 vents. Molecular biology investigations were conducted on each species of clam, confirming their chemosynthetic origin (R. Vrijenhoek, personal communication, 1995). Geothermal and geochemical investigations were additionally conducted.

Evidence and Implications of Fluid Venting

Active and relict fluid venting sites are identified along the Costa Rica accretionary complex (Fig. 1) by authigenic carbonates, bacterial mats, lamellibrachiid vestimentiferan tube worms, mytilid mussels, and solemyid and vesicomyid clams. The wedge hosts five types of vesicomyid clam species, several of which are previously undescribed species (R. Vrijenhoek, personal communication, 1995).

Toe Region. Five submersible dives spanning approximately 25 km of the toe region (the outer 3-4 km of the prism), at depths ranging from approximately 4200 to 4500 m, found no chemosynthetic fauna or authigenic carbonates. No geothermal or geochemical indicators of highly focused venting were found in this region, although coring and heat flow penetration was difficult (Langseth and Silver, this issue; Zuleger et al., this issue). Relatively small clam shells were observed intermittently throughout Dives 2723 and 2732, but it remains unknown whether the clams are chemosynthetic or vent-related.

Lower Slope Region. Seven active vents marked by aggregations of 4 types of live clams were observed at the base of fault scarps on Dives 2720, 2727, 2728, 2730, and 2731 (Fig. 2) at depths ranging from approximately 3480 to 3800

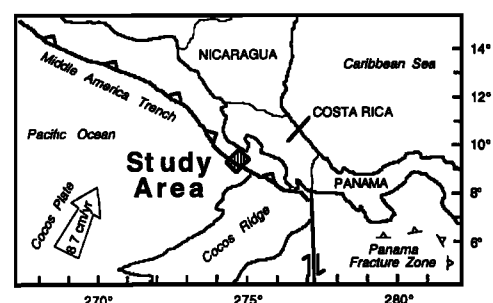


Figure 1. Location map of the study area of the Costa Rica accretionary prism.

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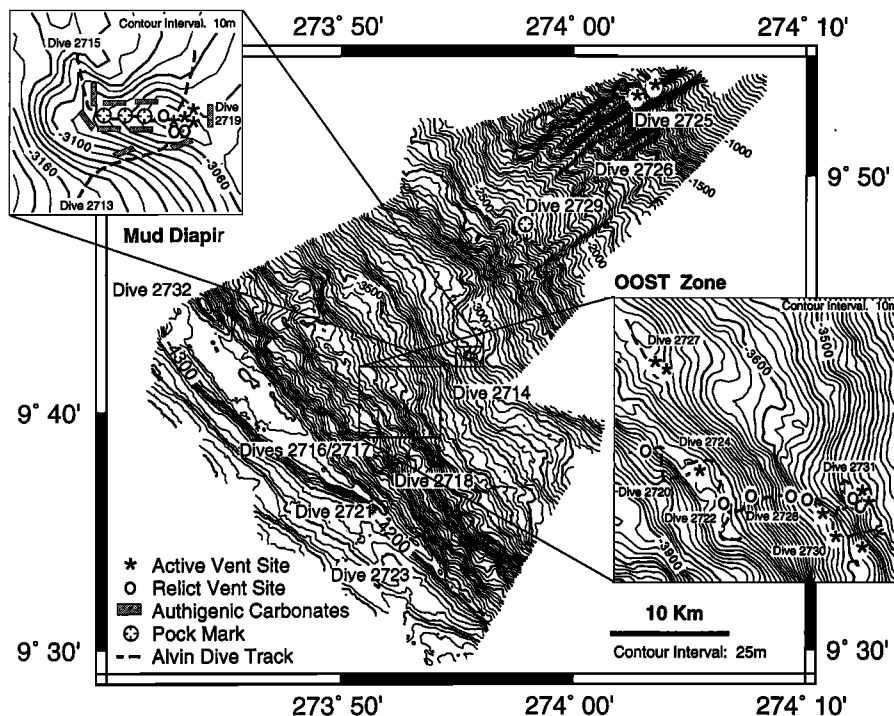


Figure 2. Bathymetric map of the Costa Rica accretionary prism, showing the location of the twenty ALVIN dives and all active and relict fluid vent sites, including authigenic carbonates and pockmarks. OOST Zone refers to the zone of Out-of-Sequence Thrusting.

m. One active site was observed at the top of an escarpment on Dive 2731. Clam distribution within the aggregations is not uniform, ranging from multiple clusters of a few individuals to loose groups of 10 to 30 clams embodied within a 0.5 to 2 m area. The active venting observed on Dive 2728 is further distinguished by a slight covering of gray bacterial mat. Black, sulfide-rich sediment is present at several sites underlying the live clams, which are often surrounded by scatterings of articulated and disarticulated vesicomid and solemyid clams. Non-chemosynthetic fauna, particularly galatheid crabs, are observed at greater concentrations at the seep sites compared to that of the surrounding region.

Distinct patches of 10 to 20 dead vesicomid and solemyid clams were observed at the bases of three fault scarps on Dive 2728, and at the top of an escarpment on Dive 2731. The articulation of the majority of the shells suggests that they are not far-traveled, indicating the close proximity of ceased venting. Additional intermittent scatterings of 1 to 5 dead clams were found at the base of several fault scarps along the transects of Dives 2720, 2722, and 2731. The localized active and relict sites at the escarpment bases indicate the seepage of fluids along high fracture permeability regions of the out-of-sequence-thrust faults. The vent sites observed at the escarpment tops suggest the seepage of fluids from the fault zone into the hanging wall section.

Mid-Slope Region. Two of the five mid-slope mud diapirs were explored with the ALVIN submersible (Fig. 2). Active and relict fluid expulsion is apparent at the largest, most seaward mud diapir, as inferred by the abundance of authigenic carbonates, bacterial mats, and chemosynthetic communities observed during dives 2713, 2714, 2715, and 2719 at depths ranging from approximately 2980 to 3140 m. The diapir is approximately 0.5 by 2 km in area with fairly gentle steeping slopes (see McAdoo et al., this issue). No signs of active venting are apparent on the second mud diapir, explored during Dive 2729.

Irregularly-shaped, yellowish-gray carbonate edifices cover approximately 50% of the western flanks and southeastern crest of the large diapir. The irregular edifices range from 10

cm to 1.5 m in height, varying in shape, and are characterized by sharp protrusions and/or angular- to sub-rounded knobs. Although small- to medium-sized irregular edifices scatter the western flanks, the edifices cover portions of the southeastern crest of the diapir so extensively that sparse underlying sediment can be seen in some regions. In hand specimen, the edifices appear to be relatively detritus-free with no shell hash or cemented pebbles. The external surfaces are extensively pitted and grooved with holes and cavities created either from dissolution by sea water or by the burrowing and secretion activities of benthic animals. Numerous small conduits penetrate the surfaces, tunneling throughout the edifices. Many of the specimens have iron-oxide stains, yellow stains possibly of sulfide origin, and/or black sulfide-stains on several of their edges. Detailed investigations of the carbonates are underway. They resemble carbonates interpreted as authigenic elsewhere (Kulm et al., 1986; Ritger et al., 1987; Han and Suess, 1989; Kulm and Suess, 1990; Goedert and Squires, 1990; Gaillard et al., 1992), and we refer to them here as such, leaving detailed analysis for separate publication.

Authigenic carbonates occur as massive, yellowish-gray blocks and small, scattered irregular edifices, covering approximately 10% of the western top flank and at the southeast portion of the diapir crest. The blocks range from approximately 0.5 to 3 m in height, length, and width, and are irregular or rectangular in shape. Encrusting corals and sponges are often attached to their surfaces.

Yellowish-gray authigenic carbonate slabs and crusts crop out at approximately 20% of the top flank and crest of the diapir. The slabs are approximately 6 to 25 cm thick, and are sub-angular to rounded and elongate or rectangular in shape. In hand specimen, they appear to be detritus-free with no shell-hash or coarse grains. The external surfaces are relatively smooth, with cursive, rounded-edged cavities and sparse pits, grooves, or tunnels. Some of the slabs and crusts are devoid of a sediment cover, whereas others were partially buried. Several of the specimens have apparent iron-oxide stains, yellow stains possibly of sulfide origin, and/or black sulfide-stains on their lower-sections that were adjacent to the sediment-water interface.



Photo 1. The most densely populated chemosynthetic bivalve community observed throughout the dive program, located in a slight depression at the south crest of the largest mid-slope mud diapir. The vent site is composed of a 1.5 m circular colony of live clams and bacterial matting, surrounded by 3 m of dead clams, irregular carbonate edifices and crusts, and serpulid worms.

Four active vents marked by chemosynthetic communities are located on the southern and eastern portions of the diapir crest. One site, situated in a depression at the south crest, is composed of a 1.5 m wide circular colony of 3 types of live vesicomid clams and bacterial matting surrounded by a 3 m wide circular patch of dead clams, irregular authigenic carbonate edifices and crusts, and serpulid worms (Photo 1). Clam distribution within the site is very densely-packed, consisting of over two hundred clams. Black, iron sulfide-rich sediment underlies the extent of the clam colony. Non-chemosynthetic fauna associated with the vent site is clearly distinguishable from both the surrounding regions and all other vent sites, as the clams are covered with egg mats, limpets, gastropods, and galatheid crabs.

A second region of venting is observed at the northeast section of the crest, marked by a 60 to 100 m² area of live serpulid worms with 2 types of live vesicomid clams dispersed 1 to 20 clams per meter², blankets of gray bacterial mats covering approximately 35% of the vent field, and loosely scattered dead vesicomid and solemyid clams. Whereas the tube worms are significantly dense in portions of the vent site, no underlying sediment can be seen in approximately 40% of the field. Although serpulids are not known to harbor bacterial endosymbionts, they may rely on the presence of chemosynthetic bacteria. The entire extent of the site is underlain by irregular authigenic carbonate edifices and sub-angular authigenic carbonate slabs. Galatheid crabs were also observed at greater concentrations at this seep site compared to that of the surrounding region.

Two active venting sites are located at the eastern portion of the crest. One site is composed of a 2.5 m circular patch of live serpulid worms, 2 types of live vesicomid clams, and irregular authigenic carbonate edifices in a slight depression. The second site is composed of a 1 m cluster of 2 types of live vesicomid clams, arranged in a circular pattern of approximately 100 clams. In addition to the four active vent sites, three relict vent sites are observed on the southwest and southeast portions of the crest. One southwest site is characterized by a 1 m patch of loosely scattered dead vesicomid clams and dead serpulid worm tubes, surrounded by sub-angular authigenic carbonate slabs and crusts. A second southwest site is characterized by a 0.5 m patch of loosely scattered dead vesicomid clams surrounded by sub-angular

carbonate slabs. The southeast site is marked by an area of loosely scattered vesicomid clams surrounded by irregular carbonate edifices.

Three circular pockmarks are aligned in a linear trend along the top flank of the diapir, increasing in size toward the crest. The pockmarks ranged from 1.5 to 4 m in diameter and 1 to 1.5 m in depth. Carbonate-cement crust apparently supports the rim of the western-most pockmark with sparse, relatively very small irregular fragments of carbonate at the crater bottom. No carbonate crusts or fragments mark the interior of the eastern-most pockmark, but the crater is surrounded by sparse, blocky carbonates. One pockmark, 3 m in diameter and 1.5 m in depth, was observed on the top flank of the second explored mud diapir. No carbonates or crusts distinguish this pockmark or the surrounding area. The craters appear to be too large to have been created by a benthic animal. In addition, no cold seep fauna or elevated concentrations of non-vent fauna characterize the pockmark areas. Pockmarks have been concluded as evidence of biogenic or thermogenic gas escape from seafloor sediments, though generally in more shallow-water environments (Kelley et al., 1994; Vogt et al., 1994). For water depths of 3-4 kms, it may be more likely that the pockmarks represent rapid escape of water, possibly in conjunction with sediment fluidization during seismic events (e.g. Hovland and Judd, 1988).

Upper Slope Region. Two linear, parallel upper-slope canyons were explored during dives 2725 and 2726 (Fig. 2). Two active vent sites were observed at the northwest wall of the larger canyon at depths of approximately 1590 to 1610 m. Neither venting site appears to be associated with fractures or faulting. The venting thus appears to indicate high permeability horizons in the larger canyon's northwest wall, and are inferred to be stratigraphically controlled. One site is marked by a 1 m area consisting of three live lamellibrachiid tube worm clusters, approximately 50 worms per cluster. Scattered among the tube worms were 10 to 20 live clams and mussels. Although positive identification is not currently possible because none were collected, the clams and mussels are similar in external morphology to vesicomids and mytilids respectively. The second site is characterized by a 0.5 by 4 m gray bacterial mat with approximately 10 live and dead vesicomid clams, adjacent to a 2 m area consisting of approximately five live lamellibrachiid tube worm clusters, consisting of approximately 50 tube worms per cluster. Scattered among the tube worms were 10 to 20 live vesicomid clams.

Discussion

Three different ecosystems are observed at the lower slope out-of-sequence-thrust zone, one mid-slope mud diapir, and at one upper slope canyon wall as described in the previous sections. Active and relict vents are localized at the bases and tops of out-of-sequence-thrusts, indicating fracture permeability as the fluid conduit. Active venting on the largest mud diapir in the mid-slope region is shown by five pockmarks and four large colonies of chemosynthetic organisms. Relict venting on this diapir is inferred by the prevalence of carbonate blocks and edifices which could have formed above the seafloor by upward growth or below the sea water-sediment interface and later exposed by either uplift or erosion of the surrounding, non-cemented sediments. Hand specimens appear to be relatively detritus-free, which generally indicates upward growth (Ritger et al., 1987). Only two vents were observed on the upper slope. Vent sites at the lower slope out-of-sequence-thrusts include both living and non-living colonies of chemosynthetic clams. The absence of surficial fluid vent manifestations at the toe region and the evidence for elevated heat flow relative to the incoming plate, may be explained by diffuse flow through at least the outer 3 km of the prism (Silver et al., 1994).

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