Hot Vents and Hydrocarbon Seeps in the Sea of Cortez

by

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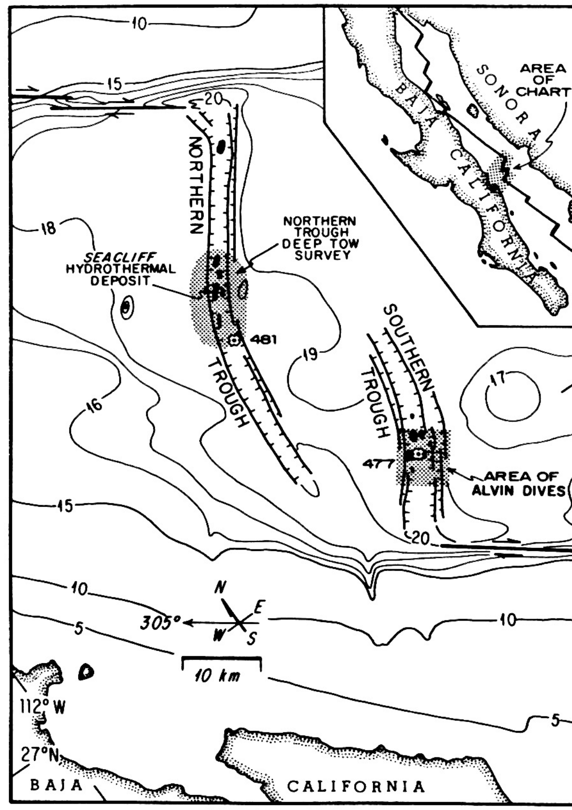

Figure 1. Location of the Guaymas Basin within the Sea of Cortez. Deep Sea Drilling Project core sites 477 and 481 are also shown.

In August 1980, we raised a remarkable dredge haul from the muddy 2-kilometer-deep floor of the Sea of Cortez to the deck of the research vessel *Melville*. Entangled in the chain bag were boulders of glistening sulfides, blocks of shiny white talc and barite minerals, mudstone soaked in oil that had the foul smell of diesel, and half a dozen living giant tube worms (*Riftia*) of the type previously known only from the rocky crests of mid-ocean ridges.

Earlier that same day our attempt to core the upper 20 meters of sediment had been equally spectacular, though less productive. The upper 10 meters of mud are cut by mineralized veins through which hot fluids have flowed, but sampling was poor in the lower 10 meters because the plastic core liner had been melted by seabed temperatures in excess of 100 degrees Celsius. Thermometers attached to the corer to measure the temperature gradient and upward flux of heat through the sediment were uselessly off-scale, but separate measurements nearby with a specialized heat-flow probe recorded vertical gradients near the seafloor of more than 4 degrees Celsius per meter.

Background to Discovery

The exciting results from this day's work were not wholly unexpected because, as usual, we were directed to this site by earlier efforts that suggested the presence of a deep-sea hydrothermal field. Extensive geophysical surveying had established that within the Sea of Cortez, also known as the Gulf of California, there is a whole system of spreading centers at which new oceanic crust is formed by cooling of molten rock.

Where this system comes ashore, beneath the Colorado River delta in the Salton Trough, there are high-temperature geothermal fields being exploited for electricity generation. In the Guaymas Basin in the central gulf, where we were working, there are two spreading centers that occupy shallow overlapping rift valleys, the Northern and Southern Troughs (Figure 1).

Previous temperature measurements had defined zones of greater-than-average heat flow in both troughs, and chemical analyses of bottom waters had detected trace components derived from thermal springs. A core drilled 270 meters into the crust of the Southern Trough, 2.5 kilometers from our sampling site, had sampled an igneous intrusion that was initially emplaced as molten rock (near 1,200 degrees Celsius) within the upper 50 meters of sediment. This intrusion had already cooled, however, and temperatures in the drill hole approached 100 degrees Celsius only at sub-seafloor depths near 200 meters.

Many dredge and core samples had been taken in Guaymas Basin on previous expeditions, some of them specifically designed to search for hydrothermal minerals. No such minerals had been recovered. We were successful because our sampling efforts in the Southern Trough were immediately preceded by a very detailed survey with the Scripps Institution of Oceanography's *Deep Tow* vehicle. This unmanned instrument package was towed 10 to 100 meters above a 30-square-kilometer area of the trough floor for three days. Its sonars mapped more than 100 piles of rocky mineral deposits, commonly 20 to 50 meters in diameter and up to 30 meters high. Measurements of bottom-water temperature and conductivity over these deposits indicated plumes of highly diluted hydrothermal discharges (at 45 meters above the seafloor the hottest was only 0.4 degrees Celsius above ambient seawater temperatures). Stereo and color photographs showed that some deposits were covered with thickets of tubeworms and surrounded by clusters of clams and crabs, and also by mats of fluffy white and yellow material that we interpreted as sheets of dispersed mineral crystals. All these observations were precisely located, to within a few meters, by use of a moored transponder net, so it was a relatively simple procedure to use the same transponders to place sampling devices and heat sensors directly onto the vent areas.

Unusual Vents

The particular geographical setting and geological conditions of the Guaymas Basin spreading centers make their hydrothermal phenomena rather different from those at mid-ocean rises. Sea-floor spreading in the central gulf, caused by attachment of Baja California to the Pacific plate and its subsequent rifting away from mainland Mexico, has been underway for only about 3 million years, so despite a fairly fast spreading rate, the gulf is still quite narrow, in a few places not much more than 100 kilometers from shore to shore. Enormous volumes of sediment from erosion on land and from prolific nearshore plankton blooms are delivered by river slumps and turbidity currents* to the floor of this steep-sided depression, especially to its deepest parts, the spreading-center troughs. The influx of mud, accumulating on the spreading zones at rates of several meters per thousand years, smothers the usual spreading-center volcanism, and lava eruption is prevented. Instead, rising magma spreads out and cools beneath low-density water-saturated sediments.

Some short-lived thermal vents result from expulsion of water from the muds in contact with the shallow intrusions. As at mid-ocean rises, most of the high-temperature circulation within the seabed must be driven by the heat energy of larger magma chambers at deeper levels, but before the fluid emerges at the seafloor it must pass through several hundred meters of highly reactive sediments. John Edmond's article describes some of the chemical changes that occur during this passage (see page 15).

One of the most important consequences of hot fluids passing through recent organic-rich muds is that hydrothermal petroleum is formed and transported in solution by the rising fluids. Fractions of this material condense at the seafloor and give the mineral deposits their petroliferous odor.

Another practical consequence of the sediment-smothering of the Guaymas Basin spreading centers is that finding and sampling vent minerals and animals is easier than at mid-ocean rises. Whereas at rise crests most sonar targets are piles of pillow lava a few of which hide chimneys and mounds of hydrothermal sulfides, in the Southern Trough piles of hydrothermal minerals are the only targets on the muddy trough floor.

Even the best positioned dredges at rise crests almost inevitably collect blocks of lava. But these rocks are absent from the Guaymas Basin spreading centers, and thus cannot destroy the delicate mineral structures and sampled animals dredged up in this region. Add to this the calm seas prevailing (except when mid-winter storms sweep down the gulf), the nightly sunsets over the clear mountains and volcanoes of Baja California, and the excellence of shrimp restaurants in nearby ports, and it is no wonder that oceanographers have convinced themselves that the Sea of Cortez is not some obscure and bizarre backwater of the ocean, but is the perfect archetype of a young, growing ocean basin, full of insights into the early history of major basins like the Atlantic, and well worth further study.

Explorations North and South

In 1982, a diverse group of geologists, physicists, chemists and biologists revisited the Southern Trough of Guaymas Basin and used the submersible *Alvin* to get their first close-up view of these vents. We were scheduled into the brief bad-weather window, so our little ship spent several days tossing about in a full gale or sheltering behind headlands and islets.

However, when we eventually reached the seafloor, the stresses of the expedition were forgotten. The submersible's sonar displayed the mineral deposits just as well as *Deep Tow's* had, so we were able to drive directly to them and start collecting samples and photographs. At once we were able to see that the fluffy mats were not loose mineral deposits, but patches of the large bacterium *Beggiatoa* (see Somero's article, page 67).

The fluids discharging through elaborate columns and chimneys of sulfides and sulfates, the sources of the plumes sensed by *Deep Tow*, had temperatures from 270 to 314 degrees Celsius. Local heating of the sediment around the vents proved to be responsible for very high temperature gradients (more than 10 degrees Celsius per meter) in the surrounding mud, where "world record" heat flows (9 watts per square meter) were measured with *Alvin*'s heat flow probe. A few of the springs were open "black smoker" chimneys through which mineral-depositing hydrothermal fluids exited at high velocity (Figure 2), but many chimneys were capped with horizontal sheets of precipitated minerals, and discharged slowly downward.

Some mineral mounds seemed to be completely sealed, but when the surface was broken with *Alvin*'s manipulator, hot fluid burst out violently from a hollow interior. Not only were many of the

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* Density currents that carry sediments from underwater slopes and scarps into the deep ocean.

deposits saturated with petroleum, but some of the springs released emulsions of hydrocarbons and mineralized water.

The 1982 *Alvin* dives covered only a small area of the Southern Trough. The Northern Trough of Guaymas Basin also has an active hydrothermal circulation, marked by high, but variable, heat flow, clusters of vent animals (clams), and a different suite of hydrothermal minerals. Sulfides sampled there in 1977 by another submersible, the U.S. Navy's *Seacliff*, were among the first such deposits collected at an oceanic spreading center (Figure 3).

Isotopic composition of minerals associated with these sulfides indicate that they precipitate at temperatures near 300 degrees Celsius, but most Northern Trough springs are probably cooler, or more temporary, than those in the Southern Trough; an extensive search with the same *Deep Tow* system that first discovered and sampled hydrothermal plumes (in 1976 at the Galápagos Rift) failed to locate any at this spreading center.

The two tectonically similar spreading centers in the Guaymas Basin may differ in intensity of venting because they are at different stages in the life of a hydrothermal field. The huge heat loss of multiple 300-degrees-Celsius springs in the Southern Trough cannot be supported permanently; it is probably at the peak stage of extracting heat from a freezing magma chamber. Most of the time there is a shallower, cooler circulation as in the present Northern Trough.

Another type of plume rises from both the Northern Trough and the cooler parts of the

Figure 2. A 314°C black smoker with a 25-centimeter-long chimney on the side of a sulfide deposit in the Southern Trough of Guaymas Basin. (Photo taken with Alvin *external camera.)*

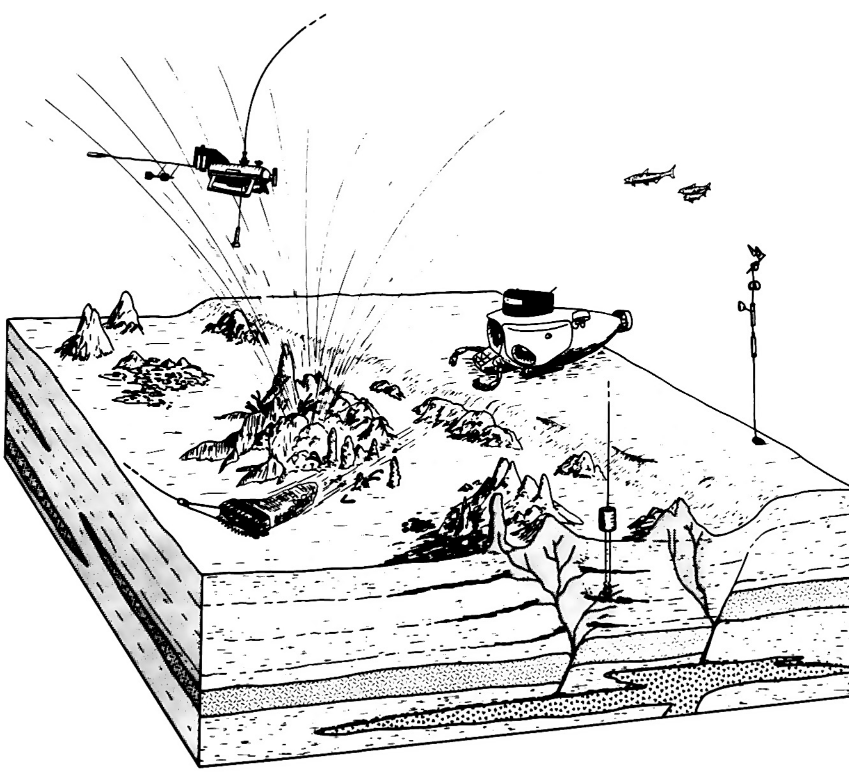

Figure 3. The seafloor at a Guaymas Basin spreading center, showing faulted igneous sills within the sediment and hydrothermal deposits built up around the vents. Among the instruments illustrated are the Deep Tow *vehicle, the submersible* Seacliff, *a transponder-plus-current-meter mooring, a melting corer, and a rock dredge.*

Southern Trough. These plumes were sensed not by *Deep Tow*'s conductivity-temperature probe, but by its sonars, especially the up-looking sonar, which recorded columns of small sonar targets extending up to 900 meters above the seafloor.

We have interpreted these sonar plumes, which have not yet been seen or sampled, as rising columns of buoyant hydrocarbon droplets that escape from the seabed at natural seeps like those found on some continental shelves. A line of acoustically similar plumes also was found along the transform fault zone at one of the basin's margins, where the shallow sediments are rich in methane produced by decay of organic matter in near-surface sediments. Clusters of benthic animals photographed in this region may be seep communities comparable to those at shallow-water oil seeps.

Natural Laboratory

Only one of the nine or ten spreading centers within the gulf has been adequately sampled by submersible, and only two have been surveyed in any detail. None of the sonar plumes or the low-temperature hydrocarbon seeps that probably underlie them have been examined. Much work remains to be done, even at the basic exploratory level.

Until both the vertical and lateral extent and composition of the mineral deposits and hydrothermal fields are better defined, no sensible answer can be given as to whether they represent a potential resource, be it of metal ores, hydrocarbons, or geothermal energy. Their greatest value at present is surely as a natural laboratory where ore and petroleum-forming processes can be studied. Perhaps, in an enlightened future, the region will form a 2,000-meter-deep underwater park, where *Alvin*'s successors will treat tourists to sights that rival Yellowstone's.

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