Red Sea: Detailed Survey of Hot-Brine Areas

Abstract. *A bathymetric and geophysical survey of the Red Sea rift valley between 21°10′ and 21°30′N has defined three separate pools of hot brines. The brines and their associated heavy metals are believed to be periodically discharged from the eastern side of the largest deep,* Atlantis II. *Cores taken from the flanks of the deeps show repetitive cycles of sedimentation of hydrous amorphous iron oxides which fill most of* Atlantis II *Deep.*

In the fall of 1966 R.V. *Chain* (cruise 61) made a detailed survey of the known hot-brine areas in the rift valleys of the Red Sea (*1, 2*) to investigate the geochemical processes involved in the origin of the brines and the associated heavy metals. Analysis of the data and samples is incomplete, but we report some preliminary conclusions. More than 60 traverses were made of the rift valley between 21°10′ and 21°30′N; relative positions were determined by radar fixes on an anchored buoy. Temperatures were measured in all deeps with a temperature-telemetering pinger (*3*) and conventional hydrocasts using high-range reversing thermometers.

Atlantis II and *Discovery* deeps (Fig. 1) are connected by a narrow channel (*4*), but the sill is now apparently high enough to prevent mixing of the hot saline waters present in these deeps. *Chain* Deep is situated in a saddle in the channel, and its hot water appears to be isolated from that of the other two deeps (*5*). The largest brine pool is in *Atlantis II* Deep, which is approximately 12 km long and 5 km wide and contains three topographic highs that suggest an ancient caldera.

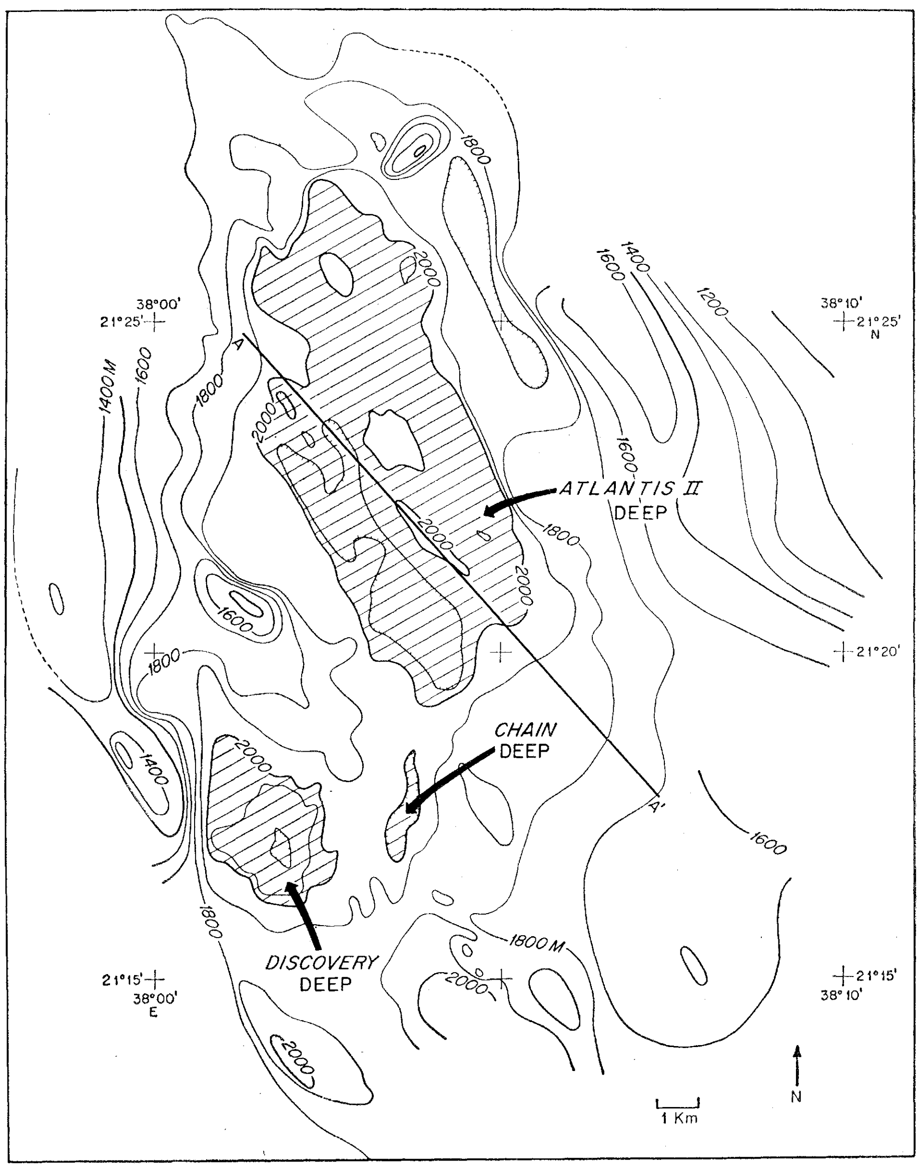

Fig. 1. Bathymetry of the hot-brine region in the Red Sea. Depth contours (m) corrected for sound velocity according to Matthews (*4*). No correction has been applied for the increase in sound velocity in the hot brine. Line *A–A′* refers to a continuous seismic profile (Fig. 2). Hot, saline water occurs in the hatched areas.

In *Atlantis II* Deep a temperature of about 56°C (*6*) and a salinity of about 255 per mille (*7*) occur below 2040 m; oxygen values of 0.1 ml/liter or less usually prevail below 2010 m. Water having a temperature of 44.2°C (*8*) and an approximate salinity of 131 per mille, occurring above the 56°C water, grades into typical 22°C Red Sea bottom water which prevails above 1980 m. Surface samples of sediment from *Atlantis II* Deep were mainly black, amorphous iron oxide high in water content (*1*).

Chain Deep is a narrow, elongated hole with considerable relief; it contains water of 34°C and a salinity of about 74 per mille (*5*). The deepest part of this hole (2066 m) was not sampled, so that maximum salinity and temperature are unknown.

Discovery Deep is 2.5 km wide and 4 km long; its water is 44.7°C and about 255 per mille in salinity (*9*) below 2038 m. The 44.7°C water appeared to be slightly cooler at the bottom, but this point needs confirmation. A layer of water at 36°C was indicated at about 2021 m on several lowerings of the temperature-telemetering pinger (*8*).

Microbiologic studies revealed the presence of anaerobic bacteria, including some sulfate reducers, in the 44°C water in *Discovery* and *Atlantis II* deeps. In contrast, the 56°C water of the *Atlantis II* hole was sterile, probably because of the combination of high salinity, high temperature, and low nutrient content. All areas deeper than 2000 m in the Red Sea north of 19°N were tested for hot water, either by the temperature-telemetering pinger or by coring with heat-flow equipment; none was found. Thus we believe that the hot brines are limited to the areas found (Fig. 1).

Continuous seismic reflections were obtained from the hot brine in both *Atlantis II* and *Discovery* deeps (Fig. 2); the reflections are due to the differences in density between the hot brine and the overlying Red Sea bot-

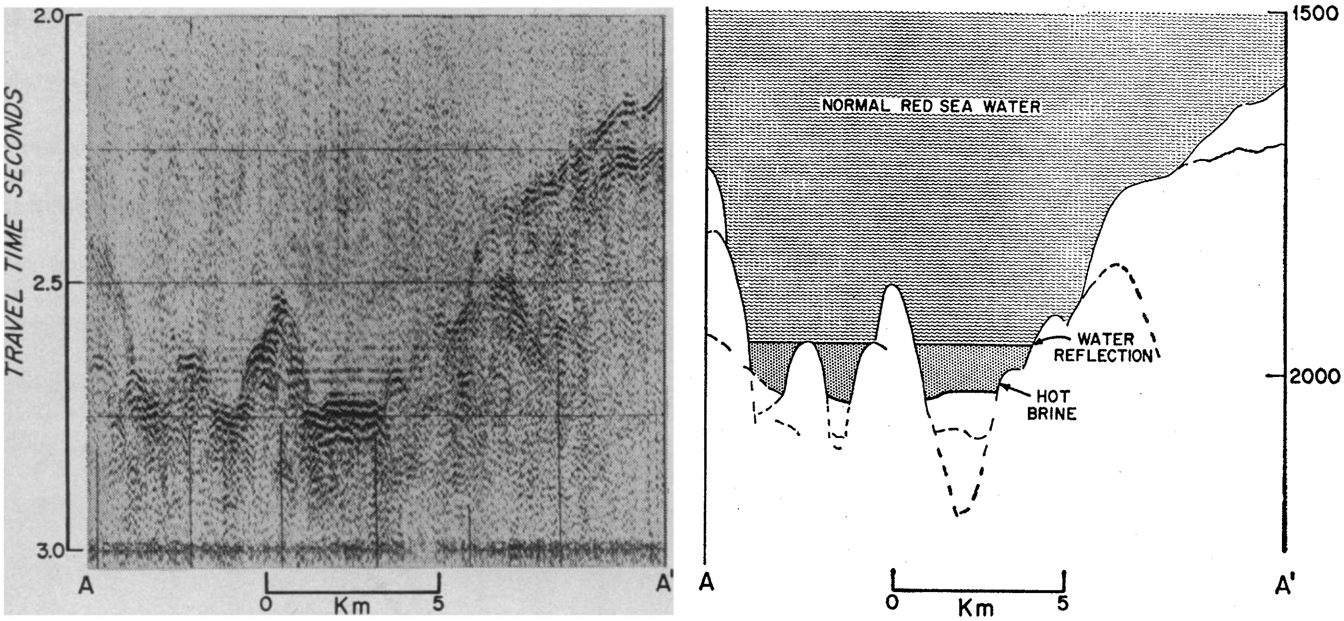

Fig. 2. Continuous seismic-reflection profile record from *Atlantis II* Deep (Fig. 1); recording bandwidth, 37.5 to 150 Hz. Record proper is on the left; a line-drawing interpretation, on the right. Dashed lines on the line drawing indicate uncertainties. Travel time is two-way time.

tom water. The fact that deeper holes north and south of the hot-brine area yielded no water reflections supports the conclusion from temperature measurements that this is the only hot-brine area in the Red Sea.

The hot-brine area is in the center of a 170-km section of the Red Sea rift valley that follows a north–south direction, in contrast to the normal northwest–southwest trend of the rift valley. Continuous seismic-reflection profiles were obtained from the flanks of the deeps to define their relation to the rift valley; faulting was indicated in some areas. A continuous seismic-reflection profile (Fig. 2) across *Atlantis II* Deep shows a reflector on its flank that may represent a pre-Pleistocene erosional surface. Knott *et al.* (*10*) have noted a strong reflector in other areas of the rift zone that they postulate to be late Miocene or early Pliocene in age.

A measured gravity anomaly of about + 120 mgal is within the range normally observed in the rift area. The total magnetic field was measured with a Varian proton precession magnetometer. The anomaly over *Atlantis II* Deep is about $-650\ \gamma$; in contrast, the anomaly over *Discovery* Deep is about $+350\ \gamma$. The strong gradient between these two deeps (a difference of about 1000 γ in about 8 km) may reflect higher subsurface temperatures beneath *Atlantis II* Deep.

Heat-flow measurements in the sediments of *Atlantis II* Deep indicate high temperature gradients that varied widely over short distances; the gradients were 10 to 20 times the world average of 1°C per 16 m. Extreme variation in gradients along the eastern flank of *Atlantis II* Deep suggest that this area is the most likely source of the hot brines. Less pronounced are the temperature gradients in *Discovery* Deep, and there is some indication that temperatures decrease within the top few meters of the sediments.

A square box-coring device was used

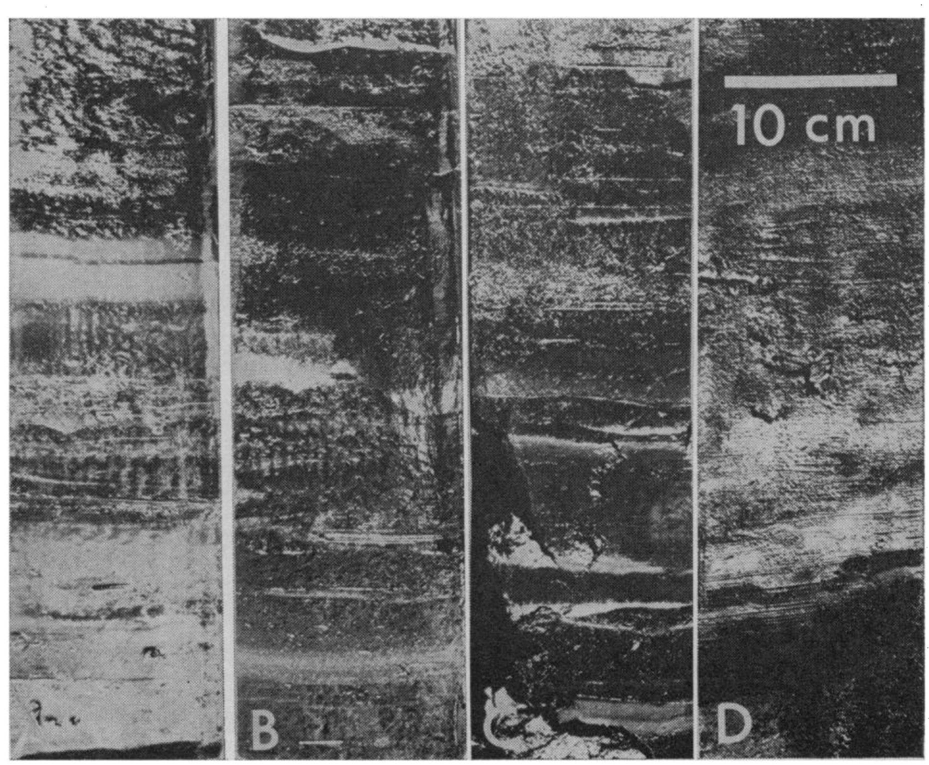

Fig. 3. Sections of core 161 from about 0.2 km north of *Chain* Deep. Note the many different layers which are due to amorphous iron oxide material in various states of oxidation and goethite. The photographs were taken at sea immediately after the core was collected. The sequence *A*, *B*, *C*, and *D* indicates progressively deeper sections.

to obtain large sediment cores (4 m by 15 cm by 15 cm). Cores from the flanks of the brine pools, above the hot-water zones, contained brightly colored sediments comprising alternating black, brown, red, orange, and yellow layers (Fig. 3). The layers are dominantly of amorphous iron oxides in various states of oxidation and goethite, with minor amounts of montmorillonite and foraminiferal debris; the amorphous material does not give an x-ray-diffraction pattern. Microscopically the amorphous iron material appears as yellow-red 1- to 10-μ spherulites that are opaque under crossed polarizers. The spherulites become slightly birefringent with depth in the cores, and x-ray-diffraction patterns indicate goethite. These indications suggest that the amorphous material is crystallizing with time to goethite. Goethite comprises 70 percent of the dried salt-free sediment at the bottom of the 4-m core.

Our preliminary interpretation of these data is that the hot salty waters and their associated heavy metals are being forcibly discharged periodically from *Atlantis II* Deep. Isotope data suggest that the water essentially derives from the Red Sea (*11*). The source of the heat and some of the heavy metals is probably associated with some local geothermal event. As hot waters meet the Red Sea waters above the present brine-pool levels and contact oxygenated waters, the metals dissolved in the brine are oxidized to varying degrees depending on the available supply of oxygen, as has been suggested (*1*). Bottom currents then may sweep away part of the water, the remainder being stratified in the three known deeps. This situation would result in the most recent discharge filling the deeps with amorphous iron oxides, while adjacent, more-elevated areas would add another thin layer to their accumulations of colored iron oxides. Box cores collected near the hot-brine areas indicate that several of these discharges have occurred within the last several thousand years.

JOHN M. HUNT
Department of Chemistry and Geology, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543
EARL E. HAYS
Department of Geophysics
EGON T. DEGENS
DAVID A. ROSS
Department of Chemistry and Geology

References and Notes

1. A. R. Miller, *Nature* **203**, 590 (1964); A. R. Miller *et al.*, *Geochim. Cosmochim. Acta* **30**, 341 (1966).
2. J. C. Swallow and J. Crease, *Nature* **205**, 165 (1965); P. G. Brewer, J. P. Riley, F. Culkin, *ibid.* **206**, 1345 (1965).
3. D. A. Ross and C. Tyndale, *Geo-Marine Technol.*, in press.
4. D. J. Matthews, *Brit. Admiralty Hydrog. Dept. Rept. 282* (1939).
5. D. A. Ross and J. M. Hunt, *Nature* **213**, 687 (1967).
6. Similar temperatures have been reported by Miller *et al.* (*1*) and by G. Krause and J. Ziegenbein, *Institut für Meereskunde der Universität Kiel* **53** (1966).
7. Total solids by evaporation to dryness at 200°C (F. T. Manheim, personal communication).
8. D. A. Ross, in preparation. Some water masses with temperatures between that of the brine and of normal sea water have been noted by Krause and Ziegenbein (*6*).
9. By calculation from the analysis of Brewer *et al.* (*2*). Chlorinity values for *Discovery* Deep have been determined by Brewer *et al.* (*2*) at about 155 per mille for the 44°C water; for *Atlantis II* Deep, by Miller *et al.* (*1*) at about 155 per mille for the 56°C water. Temperatures in the same range have been reported by Swallow and Crease (*2*), Miller *et al.* (*1*), and Krause and Ziegenbein (*6*).
10. S. T. Knott, E. T. Bunce, R. L. Chase, *Geol. Surv. Can. 66–14* (1966).
11. H. Craig, *Science* **154**, 1544 (1966).
12. Work supported by NSF grant GA-584. We thank F. C. Allstrom for preparation of the bathymetric map and C. D. Densmore, R. G. Munns, and R. L. Stanley for hydrographic data. J. Woodside, A. Erickson, and J. L. Bischoff provided some preliminary data from R.V. *Chain's* cruise 61. K. O. Emery and F. T. Manheim reviewed the manuscript. We appreciate the cooperation of the officers and crew of R.V. *Chain*. Woods Hole Oceanographic Institution contribution No. 1902.

15 February 1967

Glycerol Excretion by Symbiotic Algae from Corals and Tridacna and Its Control by the Host

Abstract. *Zooxanthellae isolated from reef corals and* Tridacna crocea *incorporate labeled carbon dioxide photosynthetically. In the presence of some component of the host tissue, up to 40 percent of the labeled algal photosynthate is liberated primarily as glycerol. Excretion of glycerol by the algae* in situ *and its control and utilization by the host may represent a mechanism by which zooxanthellae contribute to productivity of coral reefs.*

All reef-building corals possess unicellular algae (zooxanthellae) in their gastrodermal cells. These symbionts accelerate the calcification process in corals (*1*), but knowledge of their contribution to the organic productivity of reef corals has remained inconclusive (*2*). This report describes the production of soluble extracellular organic material by zooxanthellae from reef corals and the reef-dwelling bivalve mollusk *Tridacna crocea*. Data show that the algae liberate soluble organic material in vitro, principally as glycerol. It is interesting that excretion occurs in significant amounts only in the presence of some component of host tissue.

Algae were isolated from the reef coral *Pocillopora damicornis* by crushing 100-g (fresh weight) portions of freshly collected coral in an aluminum foil envelope and then vigorously shaking the coarsely fragmented slurry in a flask of sea water (100 ml) for several minutes. The abrasive action yielded a brownish supernatant that was decanted through several layers of surgical gauze, leaving behind the skeletal material and a small fraction of nonrecoverable algae and animal tissue. The brownish supernatant containing the algae and the homogenized animal tissue was treated in either of two ways: (i) centrifuged (2 minutes at 3000 rev/min) to yield about 1 ml of wet packed algae which were then washed virtually free of animal tissue by additional centrifugations, or (ii) divided into 4-ml portions, containing about 0.1 ml of wet packed algae, and centrifuged; the homogenate was removed, the algae were washed with sea water, and then the original homogenate (4 ml) was added back to the tube. The first treatment was used in experiments in which algae were incubated in sea water only; the second in experiments in which algae were incubated in the original homogenate containing animal tissue.

Specimens of *T. crocea* were dissected free of the valves; the distal portion of the mantle where algae reside was excised, cut into pieces, and about 50 g (fresh weight) was placed in 50 ml of sea water in a Waring Blendor (with a serological head) and homogenized for 1 minute at high speed. The homogenate was filtered through gauze, leaving behind small pieces of muscle and connective tissue and a small fraction of the algae, and the filtrate was treated in the two ways mentioned above. All suspensions were incubated in stoppered test tubes with 20 to 100 μc of $Na_2C^{14}O_3$ for periods ranging from 1 minute to 4 hours in daylight in