Treasure in the Making Under the Sea Floor

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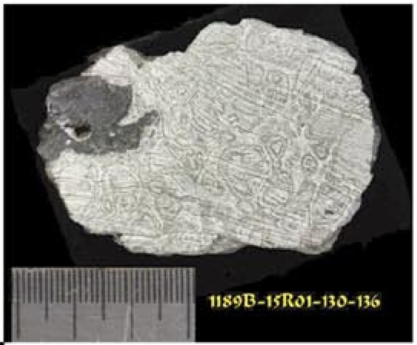
Much excitement surrounded the preparations for ODP Leg 193 when the *JOIDES Resolution* planned to drill a tremendously promising target: a modern analogue to the rich ancient massive sulfide deposits well known on land as major mineral resources for metals such as copper and gold. This feature, a hydrothermal field located in the Manus Basin north of Papua New Guinea, is known as PACMANUS and could one day become the first deep-sea mine for metallic resources. Drilling this site looked particularly tempting in view of its geological setting, which is very different from the mid-ocean ridges previously investigated, and because the hydrothermal field, on the surface, is composed of chimneys extremely rich in copper and gold (beside zinc and other metals). Also, study of the chimneys revealed the involvement of an unusually high proportion of magmatic fluid. Leg 193 was devoted not so much to investigate the orebody itself, but rather to understanding the geological framework of what on land are prime mining targets.

Drilling operations were not easy. The host rocks at PACMANUS were expected to be hard, glassy, silica and alkali-rich volcanic rocks, lithologies (rock types) never drilled before in the submarine environment. We took with us all the drilling paraphernalia that ODP could provide for hard and brittle rock. New tools were included, such as the advanced diamond core barrel and the newly- developed hammer drill. All proved invaluable in various situations. Lithologies encountered, however, were mostly very soft and fractured rocks, but more than once the ingenuity of the operations engineers and crew made success possible. Another key component was logging, both after and while drilling, which provided essential information complementary to that provided by the cores recovered.

The main result of Leg 193 was to show that the PACMANUS volcanic sequence, under a cover of about 30 meters of fresh lava, is intensely (often 100%) altered, both physically and chemically, though commonly with good preservation of original igneous textures that allowed reconstruction of its architecture. The main alteration minerals are clays and other sheet silicates, silica minerals, and anhydrite. The rocks are typically soft and light colored, white to light gray and greenish, in strong contrast with the hard, black rocks from which they are derived. We expected to evaluate the relative weight of magmatic versus seawater-derived hydrothermal fluids. Our initial conclusion was that, in contrast with the overlying chimneys, subseabed mineralization and alteration is largely dominated by a seawater-derived component. Magmatically-derived fluids may have passed through footwall rocks with minor alteration only, possibly through large, open fractures. Breccias (coarse rocks composed of broken rock fragments) abound, from true fragmental lava crusts formed during submarine eruptions to hydrothermal breccias generated *in situ* through extreme alteration and local fluidization and loss of coherence. The Leg 193 core documents these processes as never before. Processes related to this "hydrothermal corrosion" may create the necessary space for precipitation of sulfide minerals from hydrothermal fluids.

We drilled right under the rich chimney field Roman Ruins (Hole 1189B), but did not core the fragile chimneys themselves. Under the cover of fresh rhyodacite, we attained extremely fast coring speeds (87 m cored in 8 hours of overall operations) and we only recovered about 1% of the drilled interval. The latter consists of a few handfuls of small fragments of massive sulfides and deeply altered volcanic rock, abundantly cemented and partly replaced by anhydrite/gypsum and quartz. Collectively, these data suggest that the rock is very incoherent, probably with many trapped pockets of fluid. In detail, a number of possibilities are conceivable. Based on the observations mentioned above, and on extensive well logging, it appears likely that the original volcanic sequence is being replaced by sulfide-anhydrite-silica assemblages, largely incoherent, with altered rhyodacite remnants. A rather exciting possibility is that this may be the actively forming precursor to a "subhalative" massive sulfide body, demonstrating in action a process believed responsible for creation of "giant orebodies" of this style in ancient sequences. We may have drilled PACMANUS before it was itself ready to mine, but nevertheless our results will provide new guidelines for future land-based mineral exploration.

Set of photographs from Hole 1189B, drilled through the Roman Ruins vent field. Sample numbers below 10R01 correspond to the Upper Sequence, in which 87 meters were drilled in about 8 hours of total operations (see text). The “rock” referred to in individual captions was originally glassy rhyodacite/dacite (acid to intermediate) now completely altered into clays, silica and anhydrite in variable proportions. All scales are in millimeters.



Development of pseudo-breccia on flow-banded volcanic rock (with exotic fragment of siliceous material, dark, on the left hand side). Note the development of alteration stains cutting the flow-banding. Differential alteration can transform the rock into pseudoclasts surrounded by a matrix that originally had the same composition. About 170 meters below surface.

Fragments of breccia composed of fragments of deeply altered rock, cemented by a matrix (dark) composed of iron and copper sulfides (pyrite and chalcopyrite) and anhydrite. About 90 meters below surface.

Rock intensely veined and with vesicles filled by quartz and anhydrite /pyrite (white and gray). Note partial replacement of the volcanic rock. About 120 meters below surface.

A true sea-floor breccia, with a variety of rock fragments, believed to result from the accumulation of volcanic rubble on the sea floor. About 200 meters below surface.