High Tech on the High Seas: Mapping the Ocean Floor

Kim Kastens and Dale Chayes

Scientists and engineers at Columbia University's Lamont-Doherty Earth Observatory have designed sophisticated computer systems coupled with new inkjet technology to streamline sonar mapping of the ocean floor. Since 1949, scientists at the Lamont-Doherty Earth Observatory of Columbia University have been mapping the sea floor, making discoveries pivotal to the development of plate tectonics and sea floor spreading theories. Maurice Ewing, Lamont's founder, defined the structure of oceanic crust and Lamont-Doherty scientists Bruce Heezen and Marie Tharp discovered the Mid-Atlantic Ridge System and later created the first comprehensive map of global ocean floor.

In the early days, ships would collect data at sea and bring them back to the Observatory in Palisades, N.Y., where scientists would analyze results. Based on those results, scientists often returned to the same areas to gather additional data. Today, thanks to advances in onboard computer hardware and software capabilities coupled with enhanced wide-format color inkjet plotting technology, computer hardware and software, scientists can collect the data, analyze them, and fulfill many of their scientific objectives while still at sea. The advances are not only maximizing efficiency of scientific expeditions, but changing the way scientists are organizing them.

These advances have contributed to Lamont Doherty's standing as a global scientific resource. It has nearly 600 scientific, technical and support personnel, with 120 scientists and 100 graduate students pursuing research in the widest array

Lamont-Doherty's newest research ship, the *Maurice Ewing*.

of the earth sciences, including geophysics, geochemistry, seismology, petrology, paleontology, paleomagnetics, climatology, glaciology, and, of course, oceanography. The Observatory's first research vessel, a converted luxury yacht called the Vema, was the first ship to log more than 1 million miles of oceanographic research. The second to accomplish that feat was the Observatory's second ship, the Robert D. Conrad.

In August, Lamont-Doherty's newest research ship, the *Maurice Ewing*, embarked on a cruise that serves as an excellent example of how the high tech advances have dramatically changed the way scientists conduct research at sea. The ship took an international team of scientists led by Lamont-Doherty scientists Kim Kastens and Enrico Bonatti to the Vema Fracture Zone — a ridge hundreds of kilometers long and several kilometers high whose origin is enigmatic.

The plan for the Vema Fracture Zone expedition resembles a series of nested boxes. First, a fairly large area at a relatively large scale will be mapped with multibeam sonar system called Hydrosweep. Based in part on the results of the Hydrosweep survey, smaller areas will be selected for high-resolution imaging with near-bottom towed sonar and for sub-bottom imaging with a single-channel seismic system. Based in part on the results of the side-looking sonar survey, targets will be pinpointed for rock sampling by dredging. And based on the results of the single-channel seismic survey, targets will be selected for sediment coring and for near-bottom photography using a towed camera.

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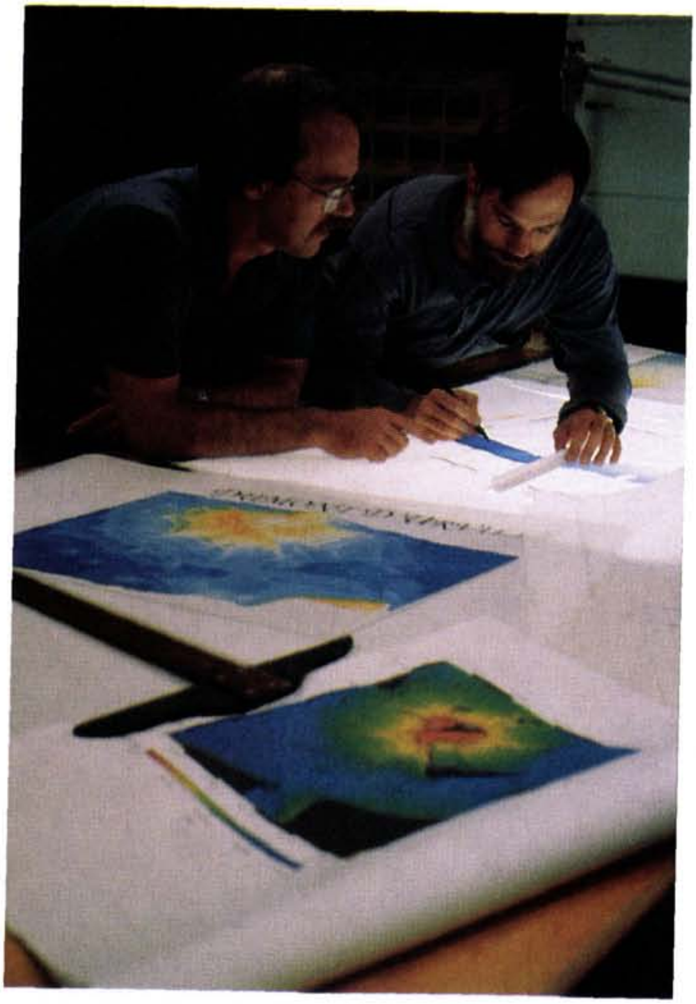

Scientists at work aboard ship.

Thus, the execution of the latter parts of the cruise plan will be shaped by the results from the early parts of the cruise — a strategy that can only work if results from the early part of the cruise are available to the shipboard scientific decision-makers in a clear and easily digested form, in near real time. The sophisticated data-handling facilities aboard the *Ewing* will contribute immeasurably to carrying out this multi-faceted cruise plan.

The *Ewing* is a 239-foot, 2,000-ton former oil exploration vessel purchased from Petro Canada by the Observatory. With National Science Foundation support, it was transformed into a sophisticated floating laboratory. It has a top speed of 14 knots and a cruising range of 15,000 miles at 12 knots. Part of the University-National Oceanographic Laboratory System (UNOLS) fleet, it is available for use by scientists from other institutions and universities.

Primary real-time navigation is provided on the Ewing by two Magnavox MX-4200 Global Positioning System (GPS) receivers. Two Magnavox T-Sets are still available for backup, but after many years of faithful service, are on their way to permanent retirement. A part of Magnavox MX-1107RS Transit satellite receivers are used to provide a reality check on the GPS solutions and are used as a fall-back to fill in the ever-decreasing gaps in GPS coverage. During near-shore work, hyperbolic Loran-C and RHO-RHO Loran receivers are available, but they are seldom used anymore because of the quality and duration of GPS. In addition to GPS, a dual axis Furuno CI-30 doppler speed log is used to measure the vessel's speed and course relative to the water mass. This high-resolution, high-update rate data is used to provide dead-reckoned fixes through short gaps in GPS coverage. All navigation data is time tagged and recorded by a Sun/SPARC-based data logging system written by Bill Robinson and Stephanus Budhypramono.

The *Ewing* is equipped with a comprehensive suite of acoustic imaging systems for probing into and measuring the shape of the sea floor. An Atlas Hydrosweep DS formed beam swath sonar operating at 15.5 kilohertz measures the crosstrack profile of the sea floor in a swath that is twice the water depth in width. This profile is measured to a resolution of 1 meter and an accuracy of about .5% of the water depth. Hydrosweep bathymetry is displayed in real time as a cross-profile or color-filled bottom map on the system console. In addition, custom software application called MapMaker, developed at Lamont by William B. F. Ryan and Suzanne O'Hara, is used to display color-shaded data overlaid by contours on any of the shipboard workstations in real time. Current efforts by O'Hara and Dave Caress at Lamont-Doherty have substantially enhanced the real-time capabilities of MapMaker.

High-resolution vertical profiles into the upper tens of meters of sediment on the sea floor are made with an EDO Western Model 248 3.5 kilohertz subbottom profiler. This wide-beam sounder operates with pulse widths from 0.1 to 3 milliseconds and output power of 2 to 10

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kilowatts. The resulting data is displayed in real time on an EPC model 9800 digital graphic recorder.

Vertical profiles into the sea floor of tens of meters to tens of kilometers are generated using an array of up to 20 pneumatic sound sources with an energy spectrum between 10 hertz and 200 hertz. This seismic data is received by and digitized in a 200- to 4,000-meter streamer towed behind the ship and recorded on a Digicon DSS-240 logging system. The data is stored on 3480 tape cartridges and can be post-processed on board using JDSeis, a custom software package developed at Lamont by John Diebold.

The *Ewing* routinely measures the gravity field using either a Bodenseewerk KSS-30 sea gravimeter or a BGM-3 gravimeter from Bell Aerospace. The KSS-30 emits raw gravity data via a standard RS-232 interface. A custom microcontroller driven interface converts the BGM-3 signals to raw gravity and generate ASCII messages on a RS-232 interface. The gravity data from either or both sub-systems is time stamped and logged by a data logger.

The earth's magnetic field is measured with a towed proton precession magnetometer. The BCD output is converted to serial data by a custom, microcontroller driven interface designed by Joe Stennett.

This spring, the *Ewing* switched over to its newest generation data logging system. The current system runs on Sun/SPARC hardware under SunOS version 4.1. Based on a process-per-data stream design philosophy, it has a central process for distributing real-time data over Ethernet for use by other workstations. The current logging system is an evolved version of one that ran on Masscomp hardware that was initially deployed on a previous Lamont-Doherty vessel, the R/V Conrad, in the fall of 1986 and was transferred to the Ewing in 1990.

In addition to the Sun and Silicon Graphics workstations that are committed to the real-time tasks of data acquisition and logging, there are three general purpose workstations available for onboard data processing and analysis by the scientific party. Using commercial, public domain, and custom-developed software in the relative peace and quite of the high seas, the ship provides a sophisticated and fully supported computer environment with limited distractions for scientists to make the most of their opportunity.

Along with developing the computer system to handle the data collection and imaging, Lamont-Doherty's technical staff was intent on improving the hard-copy output. The recent acquisition of two ENCAD NOVAJET II wide-format color inkjet plotters has substantially enhanced the Ewing's capabilities. Until then, the ship had been equipped only with two Calcomp 965 pen plotters.

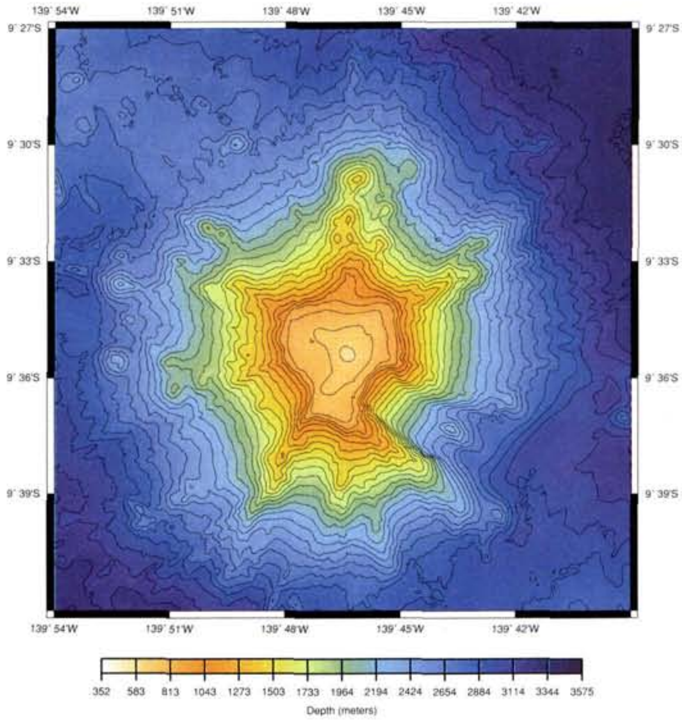
Although they were reliable, they had a number of disadvantages. The most obvious were their slow speed and inability to reproduce raster images. These had not really posed major problems until computer system enhancements made the pen plotters' weaknesses so conspicuous. Scientists had to wait until they returned home to use more sophisticated hard-copy devices to view the majority of their data.

Solving the hard-copy problem was not easy. One obvious answer – installing a $50,000 electrostatic printer – turned out to be impractical. The cost was high, but the main problem was the ship's continuous pitch and roll, which would have played havoc with the electrostatics' liquid toners. A printer that could operate in an unstable environment was required.

In the fall of 1992, Dale Chayes and Dave Caress discovered the NOVAJET, the wide-format color inkjet plotter from ENCAD, Inc., in San Diego. They evaluated one at a local distributor and were impressed enough to include two in a proposal to the National Science Foundation.

By the time the money became available, they were able to purchase the newer NOVAJET II, which is the enhanced version of the NOVAJET. Among NOVAJET II's significant improvements was the virtual elimination of "banding," the visible lines caused by the multiple passes of the inkjet head. Lamont-Doherty bought two NOVAJET IIs and installed them aboard the Ewing. The printers came through with flying colors during sea trials off the East Coast and a recently completed working leg from Massachusetts to Iceland. NOVAJET II's output is almost as good as an electrostatic and less expensive and produces in 10 to 30 minutes a full-detail plot that would take a pen plotter many hours. The NOVAJET II's ability to make large-format raster plots is a substantial aid to interpreting complex data sets at sea.

The *Ewing* is presently equipped with three winches and two A-frames. All three of theses winches carrying 10,000 meters of cable. The largest carries 9/16" wire rope, which is typically used for lowering core samplers and dredge buckets to the sea floor. A second winch is equipped with 0.322 inch four-conductor cable for lowering an instrument called a "CTD" that profiles conductivity and temperature of the water column. The third winch carries .250 inch non-conducting wire and can be



Color fill contour bathymetry map of Dumont D'Urville, a seamount in the Marquesas Island chain in French Polynesia.

used for taking small sediment cores or water samples.

In July, a fourth winch was added to allow use of a 10,000 meter coaxial conducing cable. Typical uses of this kind of two conductor cable are deep-towed acoustic imaging sonars, sea-floor video and still cameras, and sophisticated mid-water sampling systems. These kinds of systems telemeter data up to the surface in real time as well as send power and control signals down the cable.

The *Ewing's* imaging, mapping, and sampling facilities will be used extensively on the expedition to try to reconstruct the geological history of the Vema Fracture Zone — halfway between South America and Africa, just north of the equator in the Atlantic Ocean. It seems particularly appropriate that a team led by Lamont-Doherty scientists will return aboard a Lamont-Doherty ship to this particular geological feature, which was named after Lamont's first ship, the Vema.

The Vema Fracture Zone is a portion of the Mid-Atlantic Ridge System, which is the boundary between the African and South American tectonics plates. At fracture zones like Vema, the two tectonic plates slide side-by-side past each other. The African plate slides eastward, and the South American plate slides westward. In theory, oceanic crust is neither created nor destroyed at fracture zone plate boundaries.

The *Ewing's* Hydrosweep swathmapping system will be used to map a long (hundreds of kilometers), high (several kilometers) ridge that parallels the fault separating the two plates. The origin of this ridge is enigmatic. In theory, the only major crustal movements at a fracture zone plate boundary should be horizontal movements. Vertical movements, capable of building a ridge several kilometers high, indicate that additional processes not predicted by the simple tenets of plate tectonics must be active.

After mapping the entire fracture zone ridge with Hydrosweep, the *Ewing* will use a side-looking sonar system to image a region on one flank of the fracture zone ridge where they think that faulting has exposed deep portions of the oceanic crust and upper mantle. The side-looking sonar instrument package, developed at Lamont, is towed behind the ship on the 0.68-inch coaxial conducting cable. Constant adjustments of the winch are used to "fly" the instrument package a few hundred meters above the sea floor. Side-looking sonar data provides marine geologist with the same sort of information that a land geologist would extract from an aerial photograph. In this case, they hope to map the location and strike of the faults that accommodated the vertical uplift of the fracture zone ridge, and the boundaries between the rock units that were exposed by the vertical uplift.

On the shallowest part of the fracture zone ridge, previous cruises have dredged up samples of reef limestone. These rocks contain fossils of organisms that lived on a shallow water reef

Color 3D perspective image of Dumont D'Urville.

within reach of sunlight. At present, however, the water depth where these limestones occur exceed 600 meters. The interpretation is that the fracture zone ridge was even shallower when these organisms lived, 9-3 million years ago. Following the tectonic uplift that built the ridge, tectonic subsidence apparently dropped the ridge back down to its present depth. They will use the Ewing's single channel seismic system to map the extent of this shallow water limestone, and thus constrain the breadth of the area that was uplifted sufficiently high to reach sunlight.

The remote sensing data from the Hydrosweep, side-looking sonar and seismic systems will be grounded-truthed by rock and sediment samples. To sample hard rock outcrops, a steel mesh bucket, or "dredge" will be dragged along the sea floor on the 9/16-inch wire rope. To sample the semi-lithified portions of the limestone cap, they will use a gravity corer. A steel tube, lined with a plastic tube and tipped with a sharp cutting edge, will be driven into the sea floor by the force of a 2,500-pound weight.

In the fall of 1994, the scientific drill ship JOIDES Resolution will conduct a test of an experimental diamond coring system on top of the Vema Fracture Zone transverse ridge. The final goal for this summer's Ewing cruise is to locate a suitable site for this test. The diamond coring system requires a large platform or "guidebase," which is placed on a hardrock outcrop on the sea floor. Even one meter of sediment over the outcrop can destabilize the guidebase and jeopardize the drilling effort. To locate suitable hardrock outcrops, the Ewing will tow a camera vehicle a few meters above the sea floor. The battery-powered towed camera takes approximately 1,200 35mm Ektachrome transparencies on each camera tow.

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