Using a series of hand signals, resident technician Tammy Koonce directs deployment of the fish.

Fishing for Faults:

Students Explore Local Seafloor Geology

A towed mapping instrument, called a fish, is brought aboard R/V *Melville*; veteran Scripps oceanographer Robert Fisher observes in the background.

For the past several million years the seafloor within a few miles of San Diego's northern coastline has been periodically warped, faulted, and folded. Much of this activity has taken place in the Rose Canyon Fault Zone, an area of great scientific interest to Scripps geology professor Kevin Brown. He is conducting a series of graduate student cruises here, the first of which took place last October.

The Rose Canyon Fault cuts through the heart of San Diego's urban area, beginning near the U.S.-Mexico border and running north beneath San Diego Bay. It continues through downtown and along Interstate 5 before bending to the west and moving out into the Pacific just one mile south of Scripps Institution. From there it heads north until merging with the Newport-Inglewood Fault in the waters off northern San Diego County.

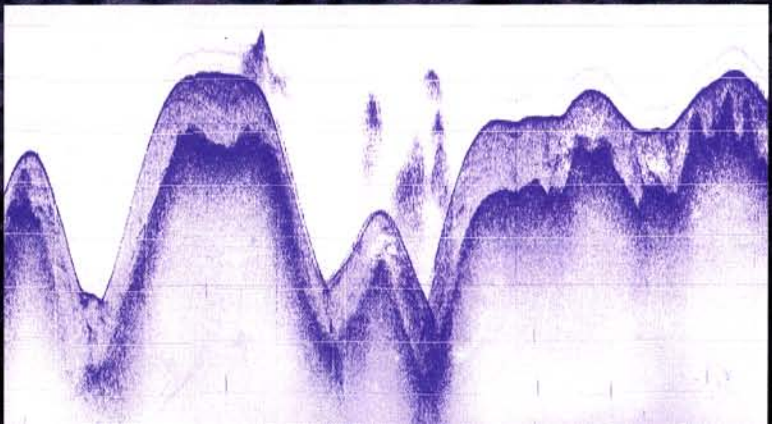
With a research team consisting of students and colleagues, Brown spent four October days aboard the Scripps research vessel *Melville* conducting preliminary examinations of the underwater geology on and around the northern end of the Rose Canyon Fault, within a few miles of the coast. As a scientist and a professor, his objectives

BY PAIGE JENNINGS

In the ship's well-equipped computer lab (above), Kevin Brown points to a specific seabed feature detected by a subbottom profiler. At the beginning of the cruise, Brown (upper right) reviews shift assignments during the first science meeting. Scripps associate specialist Allan Sauter (right) and volunteer Alan Trujillo prepare the fish for deployment.

Sauter affixes an acoustic device to the fish, which will help determine the instrument's orientation in the water column.

This cross section of the seafloor in the Rose Canyon Fault Zone shows a top layer of recent sediments draped over a previously eroded surface (shown in dark shading). Vertical clouds rising from the seeps are potential gas plumes. For reference, the horizontal lines are 10 meters (33 ft.) apart.



were threefold: to teach the students geophysical research techniques, to locate movement of recently active faults along the continental margin, and to study the hydrogeologic processes within the regions of active faulting.

Brown also used the cruise as an opportunity to "test drive" a towed mapping instrument equipped with subbottom-profiling and seafloor-imaging systems. The manufacturer of the instrument supplied a demonstration model for the cruise so that Brown could check out its capabilities before deciding whether to purchase one for Scripps. The instrument, commonly called a fish, often is used in industry for such things as determining where to place cables or pipelines on the seafloor. Brown was interested in its ability to map geologic structures, such as faults, in the upper layers of the seabed.

The fish, which was towed through the water column, was linked to an onboard computer by an electrical connection imbedded in the ship's wrist-thick metal tow cable. The cable was constantly reeled in and out to keep the fish at the desired altitude, which averaged about 160 feet (50 m) above the seafloor. Transducers in the fish provided two types of images: an acoustic cross section taken immediately beneath the instrument depicting sediment stratification, surface structures, and areas of seeping activity; and a side-scan profile of the seabed surface reflectivity along either side of the ship's track, out to approximately 980 feet (300 m).

Deeper seafloor structure, below 100 feet (30 m), has been mapped previously, but Brown is interested in what is taking place closer to the surface, in the top layers of sediment and rock. Here he is hoping to find areas, known as seeps, where natural gases and water are escaping into the water column through faults that have broken the sediment surface.

"There is gas coming up almost everywhere along our coastline, from southern California to Oregon," explained Brown. "Not all of the seeps are associated with faulting. They can come from either the fault zones themselves or from porous sediment beds, such as sandstone."

After the first few hours of operation, Brown was excited about the detailed images of the seafloor that were coming back from the fish.

"Sediments, bedrock, gas; we have it all," exclaimed Brown. "This is a great place to try out this technology. We haven't found very many recent faults yet, but lots of seeps."

Melville steamed back and forth for four days, making more than two dozen lines parallel to the coastline and either perpendicular to or at an angle to the beach. Each time the ship finished a line, it would turn around and run a line back in the other direction, much like mowing a lawn.

During this time students and scientists worked around the clock. Teams of two to four people, including at least one student, sat for six-hour shifts in the ship's main lab in front of a computer that displayed what the fish was "seeing." One person logged locations of significant structures and potential seeps into the computer database; another team member created a paper log of the same information—which included the time sighted and the latitude, longitude, and characteristics of each structure. This team member also made sure that the fish maintained a safe altitude in the water.

Although a representative from the manufacturer of the fish was onboard, Brown and his team were given the task of "driving" the fish, which turned out to be a tricky endeavor over some of the wildly varying seabed topography. On a few occasions, the combination of decrease in ship speed and appearance of unexpected structures, such as canyon walls, made it impossible to reel in the cable quickly enough to avoid collision. There were a few tense incidents when the fish was slowly brought on to the deck for damage assessments. Luckily, the sturdy fish was only mildly scratched and continued to work throughout the cruise.

To supplement the fish data, Brown used other acoustic tools, including the *Melville*-mounted SEA BEAM, to map the seafloor. He also helped Scripps

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Salton Sea Conceals Seismic Junction

The Salton Sea, located in the midst of the California desert, shrouds some of the planet's wildest terrain, which may reveal secrets behind plate tectonics. The southern end of the Salton Sea is where Scripps geology professor Kevin Brown and graduate student Mike Tryon have come to look for some of those secrets.

The Salton Sea is a saline lake that came into modern existence when diversion controls for the Colorado River broke in the early 1900s and filled a salt-covered depression left over from a prehistoric lake. Currently the lake is 30 miles (48 km) long, 10 miles (16 km) wide, about 65 feet (20 m) deep, and is sustained mostly by drainage water from regional irrigation.

This body of water has received much environmental and media attention because it has been the site of mass die-offs of fish and bird populations. The health of the lake concerns Tryon and Brown and can make working there unpleasant, but it is not the reason for their research.

They are there to investigate a field of hydrothermal seeps that lie on the bed of the Salton Sea—just one indicator of the intense and not well-understood tectonic activity taking place. This location is part of a complex transition zone where the southern end of the San Andreas Fault, marking the schism between the Pacific and North American Plates, steps over and joins the Imperial Valley Fault.

Graduate student Mike Tryon (left) carefully deploys the flux meter while undergraduate student Don Elliott keeps the small boat steady.

"It is a funny part of the world," explained Brown. "You are getting away from the true strike-slip of the San Andreas Fault Zone and moving down into the area of the Sea of Cortez, where you have true seafloor spreading. It looks like the northern end of this significant extension [spreading] might be beneath the southern end of the Salton Sea area. There is some type of extension and volcanic intrusion, whether you might call that true seafloor spreading is a mute point, but something is being created there."

With all of this geologic excitement happening just three hours away, in San Diego's backyard, the scientists saw it as a perfect laboratory for testing their equipment and theories regarding the relationship between fluids and tectonic systems. Currently, they are focusing on a 10 km^2 geothermal area near the southern shoreline where heat flow varies dramatically, from high magnitudes at the center to low magnitudes along the perimeter of the area.

The rates of fluid flow that they are studying in the Salton Sea, as well as in some coastal research areas, are relatively low—down to less than an inch per year. Existing flux meters were not capable of measuring such minute occurrences, so Brown and Tryon have designed one to meet their specialized needs. Brown came up with geophysicist LeRoy Dorman deploy four ocean-bottom seismometers (OBSs) equipped with flux meters. Dorman planned to leave the OBSs down for more than a month to gather information on recent movement around the Rose Canyon Fault. The OBSs were deployed on the last day of the cruise, allowing Brown and Dorman to select sites of potential seeping activity. The attached flux meters, provided by Brown, measure water flow from active seeps, which will help Brown select sites for future investigation.

In conjunction with the student cruise, Scripps geophysicist Steve Constable brought along a UC San Diego undergraduate student to help test a new method of electromagnetic sensing. Constable was trying out a novel arrangement of electrodes, towed on a line behind the fish, to see if this technique could be used to log some of the same seeping activity.

Brown hopes eventually to piece together a good picture of the hydrologic activity on both sides of the fault zone and through the fault itself. Water flowing through a fault can deform the geologic structure of the area, affecting the fault's strength. According to Brown, once deformation has weakened a section of the fault, the main activity probably localizes into the weakest area, which is usually quite small.

"Fluid flow also intrinsically affects the mechanical properties of plate boundaries through its impact on the frictional strength of faults," explained Brown. "We commonly see the fluids being expelled along fault-controlled conduits under highly geopressurized conditions, probably through dilated fracture systems. The high fluid pressure jacks the wall of the fault apart, greatly reducing the frictional coupling across the fault." This relationship between water and geology is what most interests Brown.

The fish data showed evidence of potential seeping activity, but there was no way to identify exactly what was escaping. Brown suspected it was mostly gas, but in some instances the bright reflectors could have been a school of fish. To be safe, the scientists referred to the possible seeps as "water-column events."

Following the October cruise, Brown was confident that many of the events mapped would turn out to be seeps. "I haven't actually gotten a picture in my mind yet of where all of the big seeps are, but I've roughly marked areas on a map. It looks like there is a broad linear zone with gas coming out of it that practically runs up onto the beach. It's a good candidate for a hydrogeologically active strand of the Rose Canyon Fault."

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Brown will return during 1998 with another group of students, a video-equipped remotely operated vehicle, and more flux meters to verify exactly what is escaping and how the seeps look on the seabed.

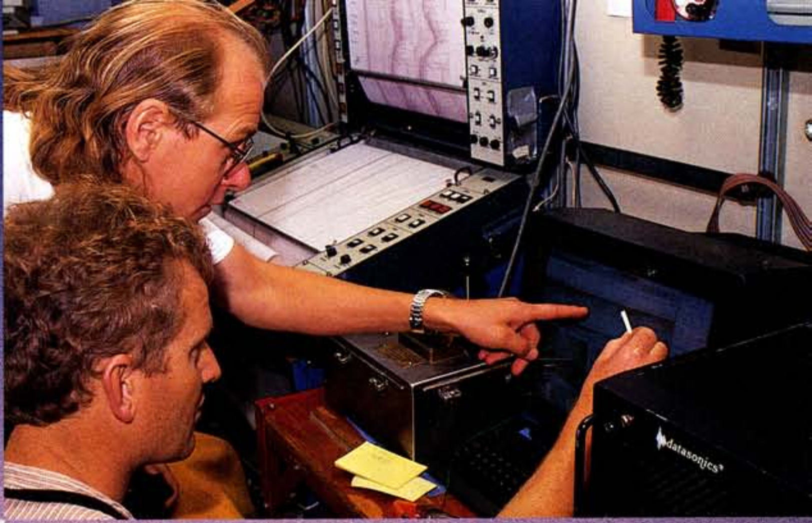
"Whether or not there is gas, water, or something else seeping out depends on what area of the world you are in. Within the Rose Canyon Fault Zone, an area that has undergone a lot of thrusting, faulting, and intense compression, the sediments have been compacted and probably heated up. This compaction is forcing water and gas to be squeezed out from the deeply buried regions through which the fault cuts. Oil is released this way in some areas, such as in the La Brea Tar Pits of Los Angeles."

Gas seeps support a variety of chemosynthetic life-forms that are of interest to some Scripps biologists. Brown is now working with Scripps biologist Lisa Levin, an expert on the ecology of benthic invertebrate communities, to look at organisms thriving around seeps in the coastal seabed.

"We are studying the interaction between chemical fluxes of such substances as hydrogen sulfide and communities of chemosynthetic animals and those that like organically rich areas," said Brown. He and Levin plan to track the variations in the biological makeup around the seeps at different depths and locations along the coastline.

The research of Brown and his colleagues illustrates that there is still an enormous amount of knowledge to be gained about the ocean, including the areas that have always been within our view from shore.

Steve Constable and Brown (right) attempt to identify a "water-column event" detected by the fish. Constable (below) works to recover his experimental equipment attached to the fish, which has just been brought on deck.



The ocean bottom seismometers (OBSs) (below and bottom right) deployed on this cruise by LeRoy Dorman housed Brown's flux meters down the center, between the bright yellow floats. On a few of the OBSs, the seismometer was held away from the frame by a metal arm so that it would sit directly on the seabed and not be affected by vibrations moving through the frame.

During the cruise, the students, including (left to right) Miriam Andres, Eric Hallenborg, Peter Selkin, Suzanne Lyons, and Kerry Key, worked as a team in the lab and on deck.