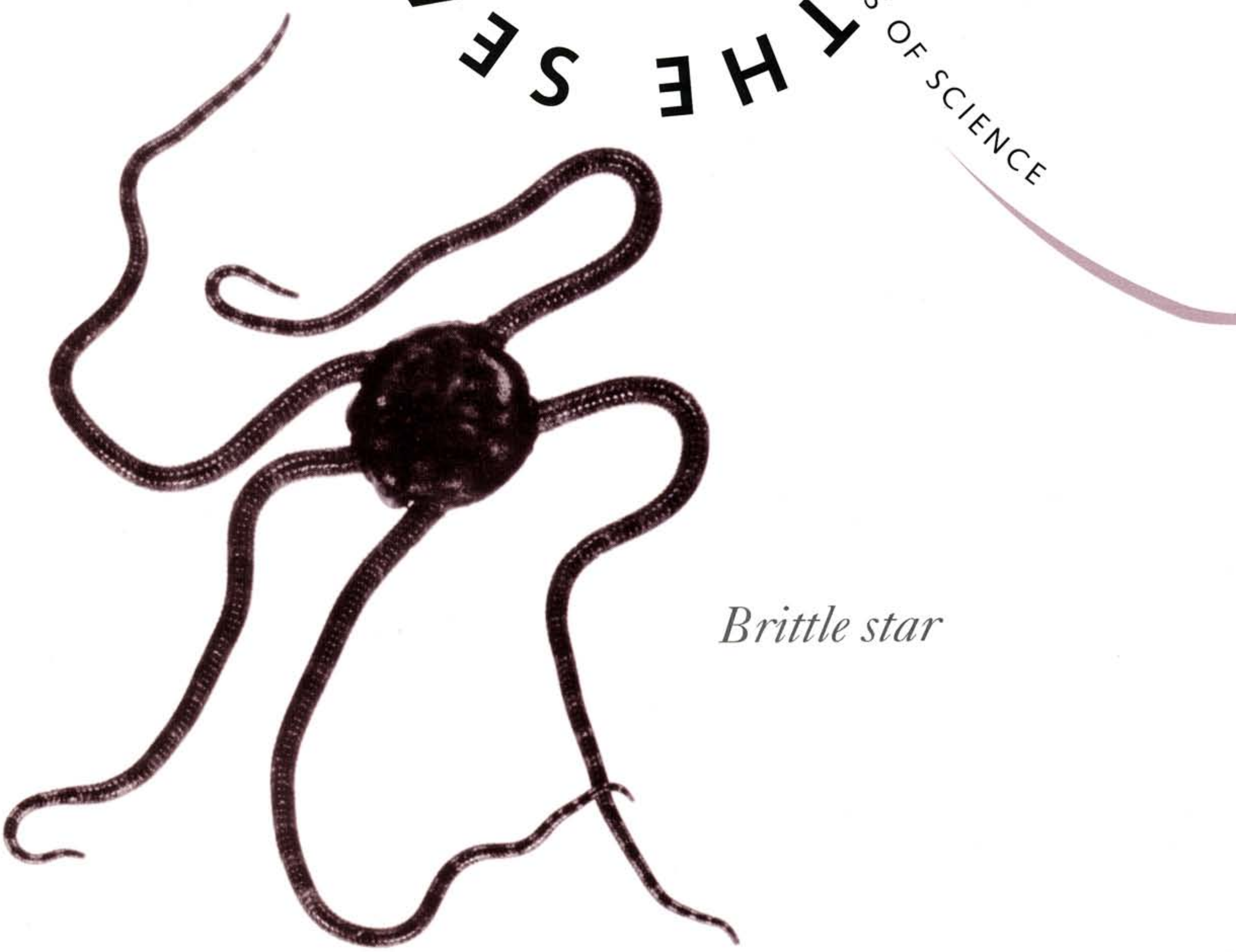
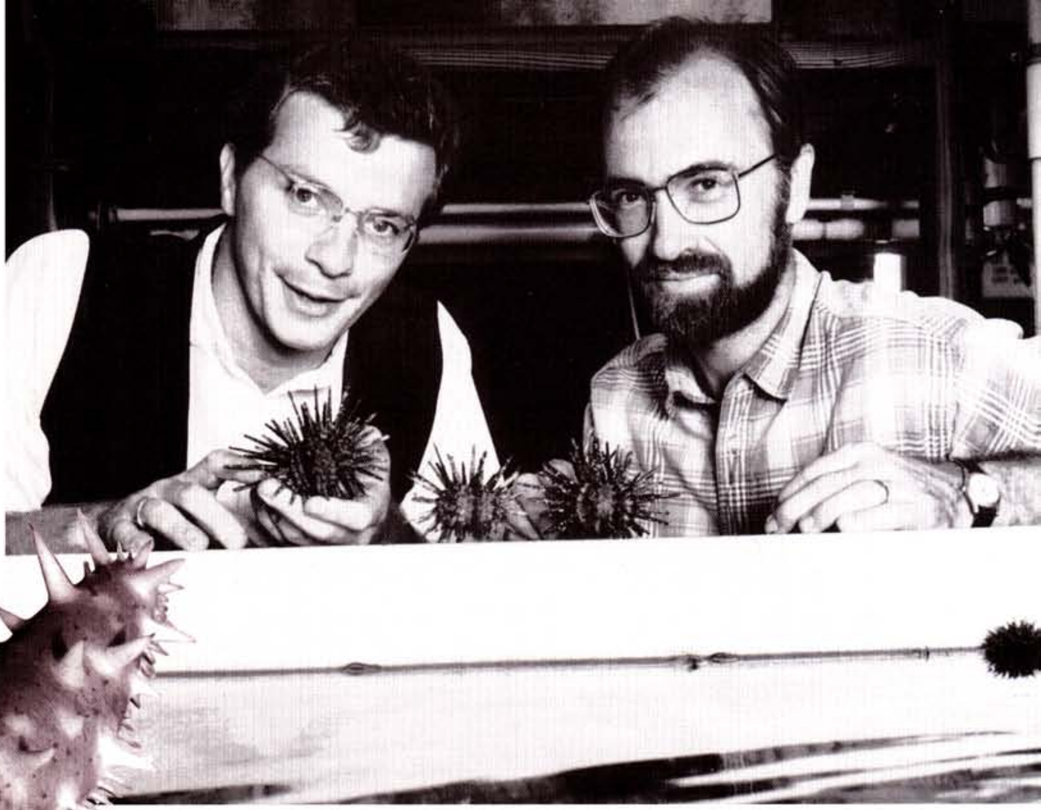
CONTORTIONISTS OF THE SEA

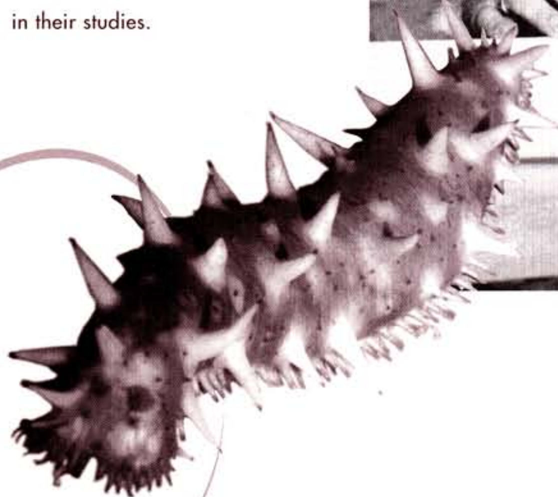
FEATS OF FLEXIBILITY STRETCH LIMITS OF SCIENCE



Brittle star



Graduate student Greg Szulgit (left) and advisor Robert Shadwick with sea urchins used in their studies.



Sea cucumber

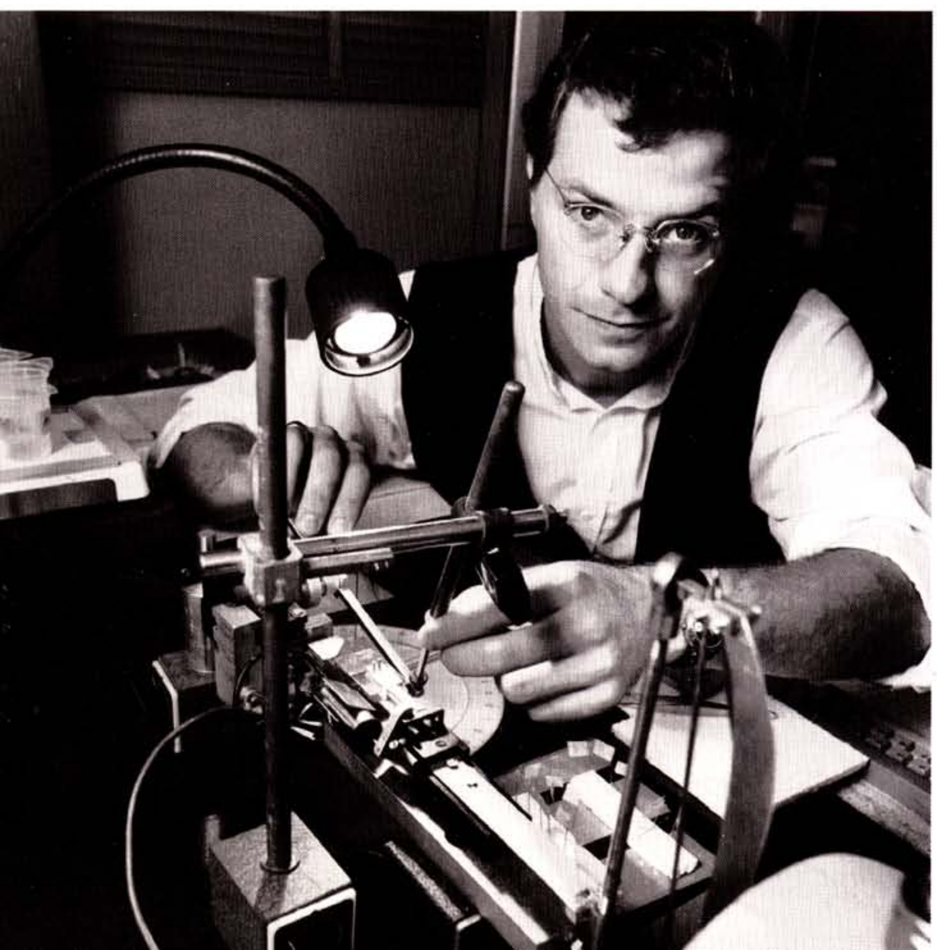
BY JOE HLEBICA

The remarkable fibrous protein collagen is found in the connective tissues of most animal groups. In a laboratory at Scripps's Center for Marine Biotechnology and Biomedicine, graduate student Greg Szulgit works with his advisor Robert Shadwick to understand how collagens in the connective tissues of sea cucumbers and their relatives enable these creatures to accomplish some amazing feats.

Szulgit thinks this research has the potential for making important contributions to the new science of tissue engineering. If a comparable understanding

"The diversity of marine organisms can provide biologists with unlimited opportunities for research, because no matter what questions you ask, chances are there's an animal in the ocean that is uniquely suited for providing answers."

Szulgit contructed this shear-testing apparatus, his scratch-built version of a machine used by polymer engineers.



can be reached regarding the connective tissues of higher-order animals–including humans–there may be valuable applications.

Currently in his fifth year of graduate studies at Scripps, Szulgit pursues an eclectic range of interests outside of his research, from paddling outrigger canoes to playing the Celtic *bodhran* drum. A gregarious spokesperson, he is often called upon to address entering biology students. He encouragingly informs them that "The diversity of marine organisms can provide biologists with unlimited opportunities for research, because no matter what questions you ask, chances are there's an animal in the ocean that is uniquely suited for providing answers."

Regarding the significance of his own research, he claims, "Some diseases of the connective tissues may involve faulty interactions between collagen fibrils [spindly protein aggregates]. Scientists can observe these interactions in sea cucumbers and other echinoderms more readily than they can in any other group of animals."

The Echinodermata is a group of marine animals that includes such common tide-pool inhabitants as sea urchins, sea stars, and brittle stars. In subtidal waters, sand dollars and sea cucumbers are often seen by divers. The bodies of most echinoderms consist mainly of bony plates and tough, fibrous connective tissues. They are exceedingly hardy creatures, and occupy habitats from the deep seafloor to the high-intertidal zone.

Bat star

What makes such commonplace creatures uniquely interesting to researchers Szulgit and Shadwick? The latter explains, "Echinoderms have the ability to dramatically change the tensile properties of their connective tissues. Controlled by the animal's nervous system, these changes can take place in mere seconds."

According to Szulgit, "Collagen is one of the most abundant and important proteins in our bodies. However, scientists do not understand what binds collagen fibrils into strong and relatively unstretchable connective tissue fibers." Shadwick elaborates, "Collagen proteins can spontaneously assemble themselves into fibrils independent of the cells that manufacture them. Under laboratory conditions, fibrils can just as easily be produced in a test tube, much as crystals are grown by chemists."

Szulgit speculates, "Echinoderms may provide us with some insights because they can easily bind and unbind their collagen fibrils in response to external stimuli. This response is used for defense, while feeding, and during changes in their physical environment."

In an effort to better understand the uncanny properties of connective tissues in echinoderms, Szulgit and Shadwick have taken an innovative tack. Rather than adhering to strictly biological approaches, they are applying engineering methods to their studies. Through a variety of electronic, mechanical, and mathematical analyses, they are striving to reveal what happens between the collagen fibrils in the tissue matrix of two local sea cucumber species.

Szulgit explains, "There are several components in the sea cucumber's dermis [skin tissue], including collagen, that may be responsible for altering the rigidity of its tissue. In the laboratory, I'm attempting to resolve the mechanical contributions of these tissue components by measuring their mechanical response to oscillatory shear. This is a test often used by engineers to determine the elasticity of various polymers or structures. The induction of stiffness in echinoderm tissues is believed by many to be the result of an extracellular, calcium-dependent process. However, my experiments show that the process is very likely dependent upon some cellular agent other than calcium. I hope to identify this agent."

Research in this area is relatively new. Until the 1960s, there was little if any understanding of the unique structure and function of connective tissues in echinoderms. As recently as the turn of the century, it was assumed that the phenomenal strength and resilience of the common sea star, for example, could be attributed to an ordinary muscular system.

Ounce for ounce, a sea star must be one of nature's most capable predators. Collagens in a sea star's tough yet flexible body help it to infiltrate rocky cracks and crevices well into the high-intertidal zone, where the force of crashing waves can be tremendous. Says Szulgit, "Their tissues have some distinct advantages over muscles. They

Using its arms to envelop its prey, the sea star literally pulls the animal's shell open. It then everts its stomach and inserts it into the open shell, digesting its prey alive.

Marine technician Ron McConnaughey collects sea cucumbers for Szulgit's research during a dive in the La Jolla kelp beds.

Sea star

may allow the sea star to lock its limbs into a certain force-resisting position while only expending a fraction of the energy that muscles do."

The sea star preys voraciously on clams, mussels, oysters, and other bottom-dwelling invertebrates. It can sometimes be seen clinging to mussels on exposed rocks or piers. Using its arms to envelop its prey, the sea star literally pulls the animal's shell open. It then everts its stomach and inserts it into the open shell, digesting its prey alive.

"The need for the sea star to exert constant force when opening a shell may be offset by locking its connective tissues in a rigid state," suggests Szulgit. "This is possibly due to the unique nature of the collagen fibrils."

The reclusive brittle star is known not so much for its predatory habits as for a peculiar defense mechanism. Something Szulgit describes as a "super-softening response" in the brittle star's connective tissues allows it to instantaneously disconnect its snakelike arms at any of a number of joints when disturbed. This may divert attackers in the same way a lizard does by shedding its tail. Like its relative the sea star, the brittle star can regenerate lost limbs.

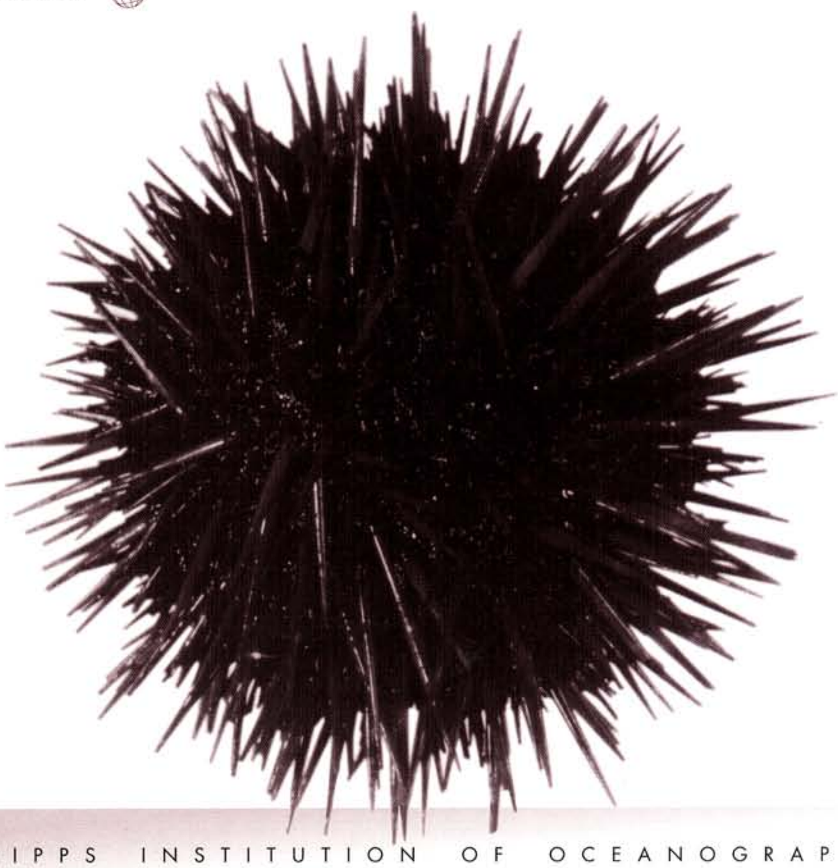
Another curious defense mechanism is used by some sea cucumbers. When seized, they can instantly disgorge their innards, surrendering them to predators and regenerating them later. Sea cucumbers also possess the curious ability to rapidly alter the structure of their connective tissues, so that the body may have the consistency of stretched taffy one moment and the stiffness of rope the next.

These soft-bodied echinoderms are seldom encountered by local tide-pool explorers because they inhabit deeper waters.

Equally effective at self-defense–and the source of a delicacy served in sushi shops–are sea urchins. These "pincushions of the sea" are distinguished by numerous spines extending from all surfaces of their spheroidal tests (shells). A sea urchin's spines–which can vary greatly in length, diameter, and sharpness, depending on the species–are attached to the test at tiny ball-and-socket joints surrounded by collagenous ligaments. A sea urchin's spines may wave in the water or instantly stand rigid when the animal is disturbed. Both conditions result from complicated mechanisms in the structure and function of the creature's connective tissues which, again, owe their versatility to unique collagens.

Are there properties of these marine collagens yet to be discovered that may one day help medical science repair damage to, and stimulate growth in, human connective tissues such as ligaments? Could "smart tissues" be developed to function adaptively under a variety of physiological demands? According to Szulgit and Shadwick, it is too soon for answers to these daring questions, though their research is demonstrating that collagen exhibits some truly astounding properties.

Sea cucumber skin consists largely of collagen. Changes in tissue rigidity can be quite dramatic.



Sea urchin

Jack of All Tradewinds

Ron McConnaughey's easygoing manner, trademark sun helmet, and beach bike create a laid-back impression, but his humble style belies a world of experience. Throughout his 30-year career at Scripps, this veteran marine technician has handled just about every situation imaginable, above, on, or under the water.

Ron's expertise includes diving, collecting, instrument handling, and boat operations. During the gusty weather typical of La Jolla Cove in winter and spring, the routine transfer of personnel from the end of Scripps Pier into the institution's boats can be a tricky operation, and Ron is the recognized master. For an opportunity to see him in action, we get permission to join a collecting excursion, and clamber into the pitching launch with him. Once our party is safely aboard, he admits, "Of all the people I've done this with, I was most worried about Walter Cronkite. I figured if I got Cronkite killed, there'd be nowhere to hide."

Long before this brush with fame, a 16-year-old Ron McConnaughey took a walk along the beach near Scripps. He found a fish washed up on shore and, curious to know what it was, took it into the Scripps vertebrate collection. Eminent vertebrate zoologist Carl L. Hubbs dropped everything to answer the inquisitive teenager's questions. The chance meeting made a deep and lasting impression upon McConnaughey, who was hired by Hubbs some years later as his field assistant. Prior to joining the institution, Ron had served in the U.S. Coast Guard, where he

acquired much of the skill in seamanship he was later to apply in the service of science.

Researchers who have relied upon Ron over the years include renowned ichthyologist Richard Rosenblatt, chairman of the Scripps graduate department. "Everybody at Scripps knows that if you don't know how to do something, you ask Ron because he knows how to do everything. One reason he's one of the best collectors around is because he knows so many methods."

A visit to McConnaughey's office in Hubbs Hall bears this out. Benches and desks overflow with fishing tackle, traps, nets, jars, buckets, and diving equipment. Slings in the ceiling hold fishing poles, spearguns, gaffs, and dip nets. Long shelves support taxonomic references, field guides, and papers.

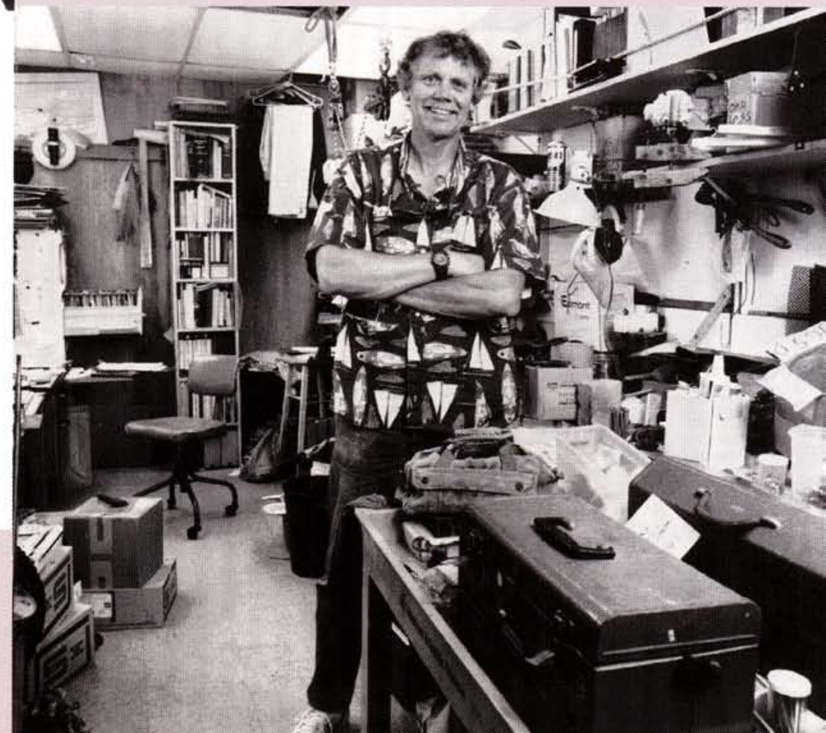
Rosenblatt enjoys telling the story of a trip to Chile joined by Ron. "The handle came off my suitcase right there in the airport in San Diego. Ron reached in his backpack and pulled out a length of nylon line–which he quickly wove into a very nice handle. I never replaced it; that seaman's handle worked until the suitcase fell apart."

After 30 years at Scripps, McConnaughey's consummate skill and constant readiness to assist scientists in need is legendary. This dedication continues. On today's excursion, he is collecting sea cucumbers for graduate student Greg Szulgit's research. During the dive, the ocean conditions steadily deteriorate, and those of us waiting in the boat are beginning to feel queasy. After returning to the surface with ample specimens, Ron's thoughts turn to getting his passengers back to the comfort of land.

McConnaughey's contribution is an invaluable one, for without the help of expert collectors, much research in marine biology would grind to a halt. From beginning graduate students to leading scientists, it's difficult to name researchers in marine biology at Scripps who have not come to rely on Ron.

"There's a lot more to collecting than catching fish," asserts Stephen Birch Aquarium-Museum collector Robert Snodgrass. "Expert collectors like Ron possess an intimate familiarity with the habitat. He knows exactly when, where, and how to find just about any species needed by a researcher."

While colleagues are laudatory about his dedication, Ron remains modestly practical; "When conditions get so bad that we can't dive, the pressure to produce specimens can really mount. Though many Scripps researchers are divers with collecting experience, most just don't have the time. That's where we come in."



From left to right: Ron McConnaughey uses a dip net during a local collecting dive. McConnaughey prepares to launch a boat from the pier. Ron's office in Hubbs Hall, where much of his technical wizardry is accomplished.