Imaging Deep-Sea Life Beyond the Abyssal Zone

Observing Deep-Sea Fauna in the World's Deep Trenches With A Free Fall Baited Camera System Operational to 10,000 Meters

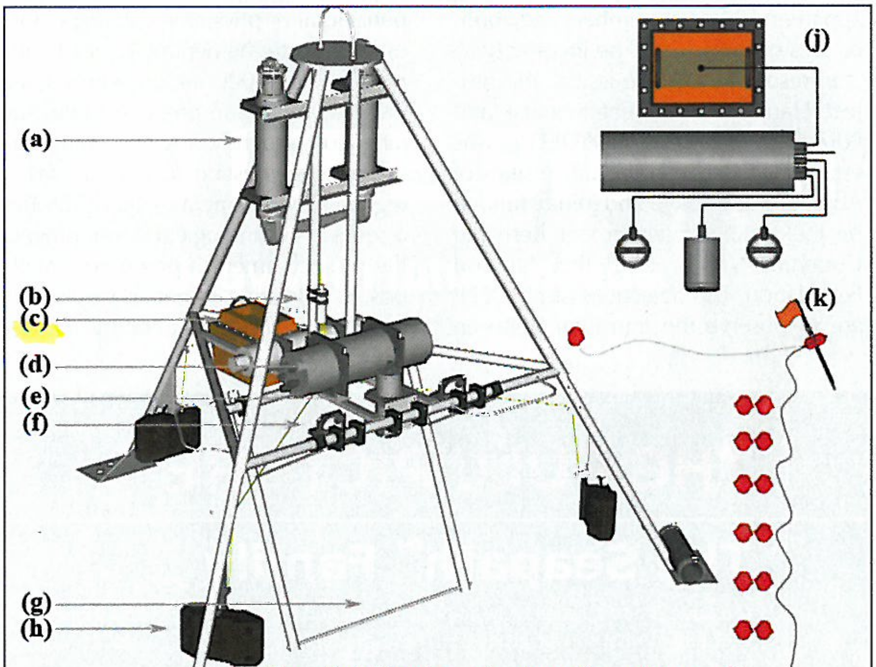
By Dr. Alan J. Jamieson
Research Fellow
Dr. Marin Solan
Senior Lecturer
and
Dr. Toyonobu Fujii
Research Fellow
Oceanlab
University of Aberdeen
Newburgh, Scotland

The depths to which ocean life is found remained unresolved until the 1940s. The depth distribution of deep-sea fauna has since been categorized into the littoral (zero to 200 meters), bathyal (200 to 2,000 meters), abyssal (2,000 to 6,000 meters) and hadal zones (6,000 to around 11,000 meters). The deepest of these zones remains the most inaccessible and poorly understood of the ocean, partly due to the technical challenges in sampling it.

The hadal zone consists of long and narrow deep trenches that plunge to depths of 11,000 meters, where pressures can exceed one ton per square centimeter.

While nearly 75 percent of the ocean floor is between 2,000 and 6,000 meters deep, only 4.5 by 104 square kilometers of the seafloor exceeds 6,000 meters, accounting for just one percent.

However, it does account for almost 45 percent of the total depth range.[1] The technological challenges associated with extreme pressure environments have resulted in the hadal zone only being studied a handful of times, representing a vast knowledge gap in human understanding of ocean life.[2]



The Hadal-Lander. a) Acoustic releases. b) Pressure/temperature sensor. c) Battery. d) Video system. e) Camera. f) Lamps. g) Bait arm. h) Ballast. i) Traps. j) Camera schematic. k) Mooring schematic (not to scale).

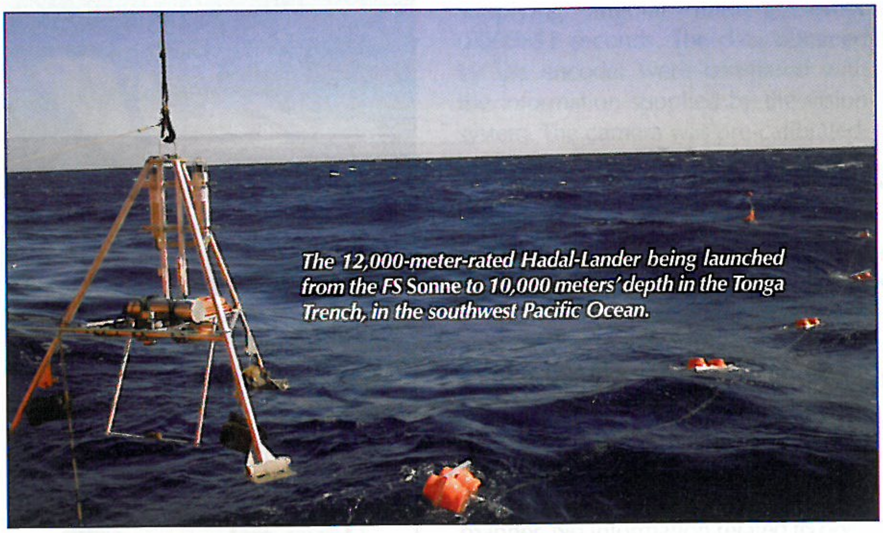
Life Beyond 6,000 Meters

From the sea surface to the hadal zone, there is a progressive increase in pressure and remoteness from surface-derived food.

Food from the surface descends in two main forms: particulate organic matter (POM) and carrion, like fish carcasses.

The quantity of POM reaching the seafloor decreases with depth, so that at greater than 6,000 meters, this food supply is extremely sparse. In principle, however, carrion falls should occur independent of depth.

This dependency on carrion can be exploited though the use of baited cameras as a method of imaging life at these depths. The trawling efforts of Soviet and Danish expeditions in the 1950s proved that fish do inhabit the hadal zone, albeit in low numbers.[3,4] However, historical data is lacking as no quantitative analysis has ever been seriously attempted, therefore prohibiting a strong determination of depth succession of hadal species. With a limited number of trawls exceeding 8,500 meters (about 35) and baited cameras deployed in the abyssal-hadal transition



The 12,000-meter-rated Hadal-Lander being launched from the FS Sonne to 10,000 meters' depth in the Tonga Trench, in the southwest Pacific Ocean.

zone (less than 10), it is possible that the apparent decline in numbers and abundances of species may be incorrect.

In response to these issues, the project Hadal Environment Science and Education Program (HADEEP) was established between the universities of Aberdeen and Tokyo and jointly funded by the Natural Environment Research Council (NERC) and the Nippon Foundation. The objectives of HADEEP are to observe the transition between abyssal and hadal scavengers and any behavioral or physiological adaptations of life at extreme depths. Typically animals below 1,000 meters will not survive the change in pressure to the surface; consequently, any observations of live animals must be done *in situ*, favoring the baited camera method. Through a series of technological developments, the project aimed to prove new methods of delivering scientific experimentation to depths exceeding 10,000 meters in hadal trenches. The extremely low accessibility of equipment rated beyond abyssal depths and the availability and technical problems involved when using wire-deployed gear over such great depths make free fall landers a sensible technique. Therefore, a 12,000-meter-rated free fall lander vehicle, known as the Hadal-Lander, was designed, constructed and deployed between 6,000 and 10,000 meters.

Basic Delivery System

The lander delivery system is comprised of four components: instrument frame, ballast weights, ballast release system and flotation modules. The frame is a 2.5-meter-high aluminim tripod with three telescopic legs that provide adjustable height. Within the frame are two newly developed 12,000-meter-rated acoustic releases (IXSEA's [Marly-le-Roi, France] OCEANO 2500 titanium ultimate depth acoustic releases, model AR861B2T). The twin release system provides one backup should one fail to activate. The releases secure a release yoke connected to a pulley system and toggles that temporarily hold three 50-kilogram steel ballast blocks under each leg. When at least one release is triggered, the yoke drops, the toggles open and the ballast is jettisoned. Above the lander is a 120-meter-long mooring line with six pairs of 17-inch, 12,000-meter-rated glass spheres from Nautilus Marine Services (Bremen, Germany), providing the necessary positive buoyancy (266 kilograms) to surface the vehicle after ballast release. The lander descends and ascends at a rate of 50 and 36 meters per minute, respectively.

Scientific Payload

The video system is comprised of four components: camera, control/logging system, battery and lamps. The camera is a 3CCD high-resolution (800 TV lines) color camera (Hitachi [Tokyo, Japan] HV-D30) with a 2.8 to eight-millimeter wide-angle lens. Video capture was controlled by mission control software specially developed for the project by NETmc Marine (Turfhill, Scotland), allowing the user to program power up/down sequences, repetitions and start delay. A relay board, with built-in microprocessor, interfaces the camera, lights and recorder and enables the recorder to be switched off and on, thus saving battery life. The recorder itself, a modified NETmc Marine DVR Inspector, is a high-end broadcast-quality MPEG2 recorder utilizing an Optibase encoder card (type MPG9005), providing a screen resolution of 704 by 576 pixels. The encoder card supports various bit rates, but was set at eight megabits per second for this project. Illumination was provided by twin 50-watt lamps. The entire system was powered by a single 12-volt, 28-ampere-hour lead acid battery (SeaBattery; Deep Sea Power & Light [San Diego, California]), providing approximately 12 hours of autonomous operations. Temperature and pressure were recorded throughout by an SBE-39 sensor (Sea-Bird Electronics Inc. [Bellevue, Washington]).

The video system was positioned on the lander's lower deck, one meter off the seafloor. The camera and lamps were facing vertically downward and focused on a 10-millimeter-diameter by 1,000-millimeter bar to which bait was secured. The seafloor viewing area was 0.35 square meters.

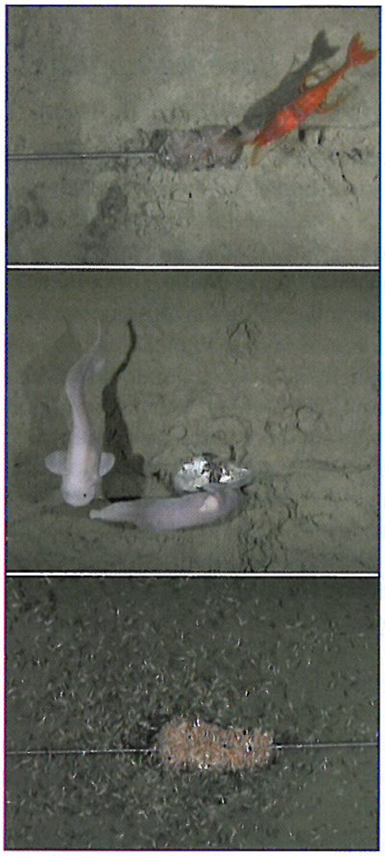
Modifications for Depth

All components were housed within pressure-resistant containers except for the pressure-compensated battery. The camera was housed remotely from the control electronics.

The main body of both the camera and electronics housings were custom designed and machined from duplex stainless steel UNS32550, both comprising a main cylindrical body with a double-nitrile 70 radial O-ring seal on either endcap.

A series of tests were performed to design the camera viewport. A set of acrylic beveled discs of varying dimensions were tested in a hydrostatic pressure vessel to 1,400 bar and revealed baroplastic behavior at pressures exceeding 800 bar.[5,6,7] Acrylic was subsequently abandoned in favor of a special plane disc sapphire viewport, 80 millimeters in diameter and 15 millimeters thick, with a viewing area of 30 millimeters.

This was pressurized to 1,400 bar successfully for more than 24 hours and subsequently incorporated into the design. The lamps were housed inside miniature vacuum-filled borosilicate



A decapod predating crustaceans at 6,133 meters (top), endemic snailfish* **Notoliparis kermadecensis** *at 7,049 meters (middle), swarms of thousands of scavenging crustaceans at 10,015 meters (bottom).

(Vitrovex™) spheres (114 millimeters in diameter, with a seven-millimeter wall thickness).

The flotation spheres were specifically redesigned for this application via a new production mold to increase the standard 17-inch model wall thickness. The acoustic releases comprised the standard electronic sub-assembly of the OCEANO 2500 range, rehoused in a titanium grade-5 body tested to 1,420 bar. The acoustic performance allows ranges well in excess of 12,000 meters in good environmental conditions—due to the frequency range, the secure command coding and the use of associated TT801 deck set for remote control.

Deployments and Results

The Tonga and Kermadec trenches are subduction zones that run north to south between Samoa and New Zealand. Respectively, the trenches have maximum depths of 10,800 and 10,047 meters—the second and fifth deepest places on Earth.[1] The bottom temperature has previously been recorded between 1.2 and 1.8° C, making Tonga and Kermadec two of the coldest oceanic trenches, due to their openness to Antarctic water.[3,4] The trenches lie under the South Pacific Subtropical Gyre, resulting in a low export of surface-derived food to the trench floor, highlighting the significance of carrion falls to the trenches as important sources of food.

In July 2007, the lander was deployed five times in the Tonga and Kermadec trenches at 6,133, 7,049, 8,170, 9,036 and 10,014 meters from the German research vessel FS *Sonne*. The lander was baited with approximately one kilogram of tuna and was set to record one minute of video every five minutes for eight hours after touchdown.

All five deployments were successful and observed a very active scavenging community. Footage showed an increase in small crustaceans (amphipods) with increasing depth and distinct species zonation. The deeper deployments observed thousands of amphipods, thought to be the hadal-endemic *Hirondellea* species.[8] Funnel traps tied to the lander feet collected more than 5,000 specimens for further analysis in the laboratory. The most notable findings were of crustacean decapods and endemic snailfish. Until now, decapods were not known to exist beyond 5,500 meters.[2] Using this lander, decapods were seen at 6,000 and 7,000 meters. Furthermore, they were observed frequently and actively feeding on the smaller invertebrates. Similarly, at 7,000 meters, two individual *Notoliparis kermadecensis* fish were present for more than three hours.[1] This fish has never been seen alive until now and has only ever been trawled once, more than 50 years ago. It is endemic to the trenches, and their behavior and predation of amphipods gave the first insights into the ecology of these trenches.

The bottom temperatures showed a steady rise of 0.15° C every 1,000 meters to a maximum of 1.78° C at 10,014 meters. This difference is caused by deep adiabatic heating in the trench with a minimum near the abyssal boundary.[4,9]

More extensive sampling efforts are necessary to accomplish a more comprehensive understanding of the distribution and occurrence of hadal animals. The results from the Hadal-Lander have highlighted the huge gap in knowledge of this environment, which is primarily limited by technological capabilities. For an entire and relatively conspicuous order of crustacea to remain undiscovered from such a large deep-sea habitat emphasizes the need for further exploration of hadal environments with more appropriate techniques.

"The results from the Hadal-Lander have highlighted the huge gap in knowledge of this environment, which is primarily limited by technological capabilities."

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References

For a full list of references, please contact author Dr. Alan Jamieson at a.jamieson@abdn.ac.uk. ■

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Dr. Alan Jamieson is a marine engineer with the University of Aberdeen Oceanlab. He specializes in high-pressure engineering, free fall landers and remotely operated vehicle-deployed technology for biological research.

Dr. Martin Solan is a marine benthic ecologist and senior lecturer at the University of Aberdeen.

Currently employed on the Natural Environment Research Council Hadal Environment Science and Education Program project, Toyonobu Fujii studies factors affecting the distribution of marine fauna and ecological responses to environmental changes.

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COVER—*D'Artagnan* working at the port of Avilés in Spain, where the dredge is enlarging the river channel by 12 meters with the support of the vessels *Buckingham* and *Pantagruele*. (Photo courtesy of Javier Menéndez.)

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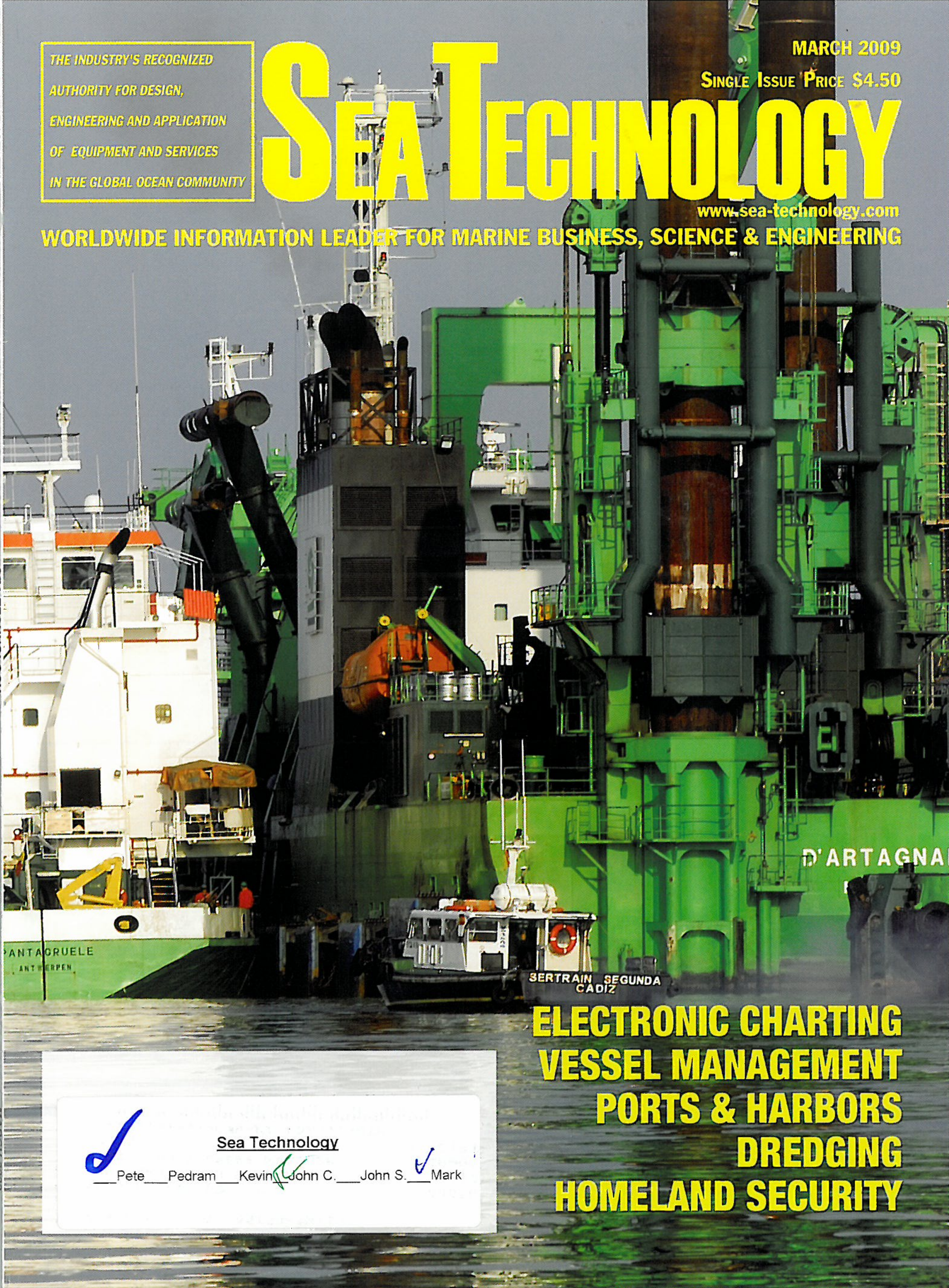

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