USGS
Sound Waves
Coastal and Marine Research News from Across the USGS
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Fieldwork

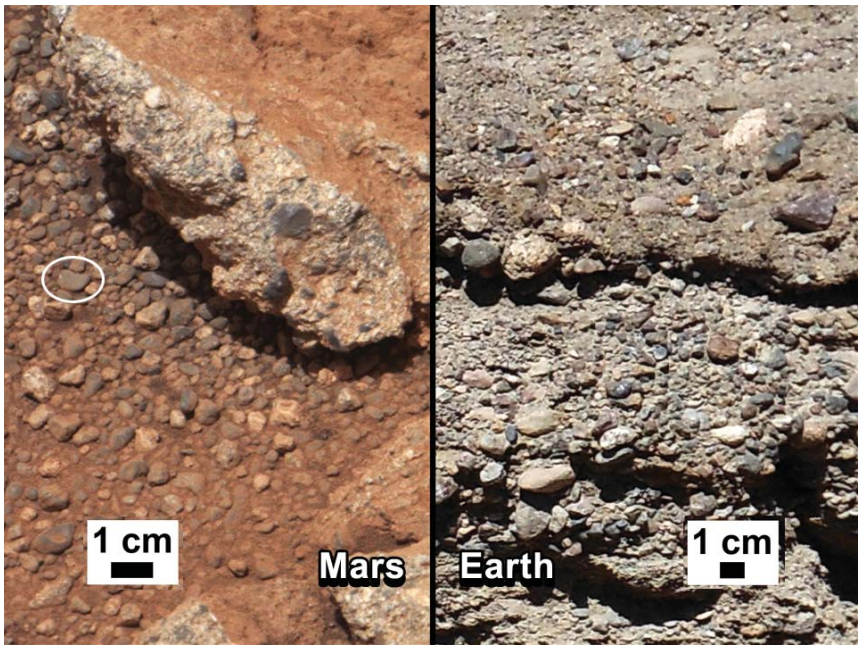
USGS Scientists Exploring Mars as Part of NASA's Mars Science Laboratory

By Helen Gibbons

Editor's Note: Why does a newsletter about coastal and ocean science contain articles about fieldwork on Mars? Well, when sedimentary geologist **Dave Rubin** of the U.S. Geological Survey's Pacific Coastal and Marine Science Center was selected to contribute his expert knowledge of marine, riverborne, and windblown sediment to the Mars Science Laboratory (MSL), the opportunity was too exciting to pass up. So we're leading off this issue with an article about the mission and, because maps are central to what we do, a companion article about the high-resolution mapping that makes the mission possible. Although Mars is cold and dry now, studies in recent decades indicate that before about 3.7 billion years ago, the planet underwent a warm and wet phase, with rivers, lakes, and possibly oceans. MSL scientists recently found evidence of an ancient streambed (see photograph below) and are eager to make more exciting discoveries as the mission progresses.

Three U.S. Geological Survey (USGS) researchers—astrogeologist **Ken Herkenhoff**, Shoemaker Postdoctoral Fellow **Ryan Anderson**, and sedimentary geologist **David Rubin**—were among the jubilant scientists at NASA's Jet Propulsion Laboratory in Pasadena, California, on August 5, 2012, as incoming data showed that the rover *Curiosity* had landed safely on Mars. Having survived an intricate series of landing maneuvers—referred to by some NASA engineers as "7 minutes of terror"—*Curiosity* was poised to begin its mission: exploring and assessing the region around the landing site as a potential habitat for life, past or present.

Curiosity landed in Gale crater near Mars' equator. The site was chosen partly because data from Mars orbiters show evidence of past water there, increasing the chances that the rover might find evidence of past life. Scientists working with *Curiosity* are particularly interested in Aeolis Mons, known informally as Mount Sharp. This mountain of layered material in the middle of the crater may be the eroded remnant of sedimentary layers that once filled the crater completely. Some of these layers may have originally been deposited on a lakebed. With an array of scientific instruments for observing its surroundings and for acquiring and analyzing samples of rock, soil, and atmosphere, the rover will gradually make its way to and up the mountain, studying the makeup and structure of the layers to investigate how they formed.



Rounded gravel fragments on Mars (left) and in a stream deposit on Earth (right). Fragments of rock are rounded by abrasion as they bounce against each other during transport by wind or water. Gravel fragments are too large to be transported by wind. Scientists consider the Martian fragments, like their counterparts on Earth, to have been rounded by water transport in a stream. Mars outcrop imaged by 100-mm Mast Camera on September 2, 2012. From NASA/JPL-Caltech/MSSS and PSI. Learn more at ***http://mars.jpl.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1360****.*

Living on Mars Time

Directing the rover's activities are **Herkenhoff**, **Anderson**, **Rubin**, and the many other scientists working on Mars Science Laboratory—the name of the mission using *Curiosity* to explore Mars (**http://mars.jpl.nasa.gov/msl/**). For approximately 3 months after the landing, the scientists will be living on "Mars time." Although they are directing the rover's daylight operations, their work shift is during Mars night. In Mars afternoon, the

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Sound Waves

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Submission Guidelines

Deadline: The deadline for news items and publication lists for the January/February issue of *Sound Waves* is Thursday, November 1.
Publications: When new publications or products are released, please notify the editor with a full reference and a bulleted summary or description.
Images: Please submit all images at publication size (column, 2-column, or page width). Resolution of 200 to 300 dpi (dots per inch) is best. Adobe Illustrator© files or EPS files work well with vector files (such as graphs or diagrams). TIFF and JPEG files work well with raster files (photographs or rasterized vector files).

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Need to find natural-science data or information? Visit the USGS Frequently Asked Questions (FAQ's) at URL **http://www.usgs.gov/faq/**

Can't find the answer to your question on the web? Call 1-888-ASK-USGS

Want to e-mail your question to the USGS? Send it to this address: ask@usgs.gov

Fieldwork, continued

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rover starts sending its data to Earth, where the scientists study the incoming images and analyses. (The time it takes information to travel between Earth and Mars at the speed of light varies with the distance between the two planets; when *Curiosity* landed on August 5, data transfer from Mars to Earth took about 14 minutes.) Each of three groups of scientists—focused on geology, environment, and mineralogy—comes up with a plan for what it would like the rover to do on the following day. The plans are discussed and integrated into a single plan, which the rover drivers convert into a list of commands to be sent to the rover by Mars dawn.

Days on Mars, called "sols," are 24 hours, 39 minutes, and 35.2 seconds long—not much different from days on Earth, but different enough that each Earth day the scientists start work about 40 minutes later than the day before, and so sometimes they are working in the middle of Earth's night. As the mission progresses—it is expected to last at least 1 Martian year, or 687 Earth days—the MSL scientists will transition to "Earth shifts" that allow them to consistently work during Earth's daylight hours.

Eyes on Mars—Specialized Cameras

Ken Herkenhoff is a research geologist from the USGS Astrogeology Science Center in Flagstaff, Arizona, with a particular interest in using specialized cameras to study landforms and surface processes

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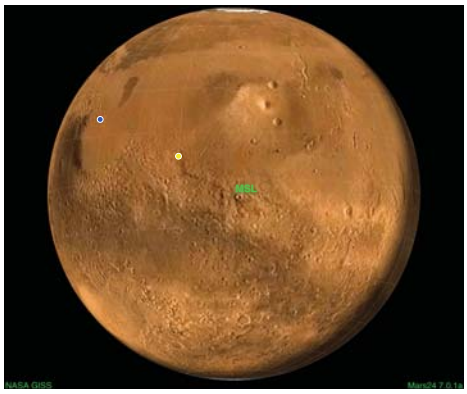
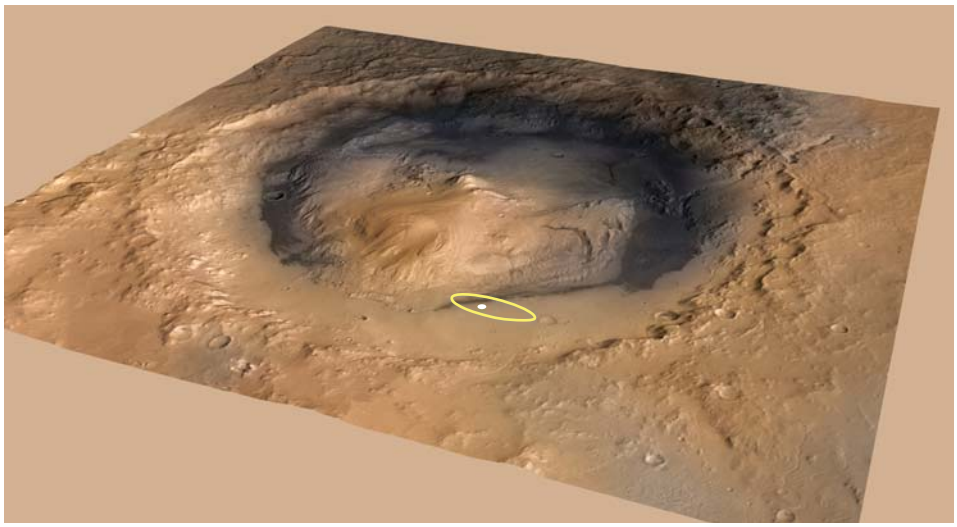


◄ *Orthographic map of Mars, centered on* Curiosity*'s landing site (green label "MSL" stands for Mars Science Laboratory). Yellow dot marks point at which the Sun was directly overhead when screenshot was taken (approx 10:55 a.m. PDT August 29, 2012); blue dot marks point at which the Earth was directly overhead. Slightly modified from Mars24 Sunclock application,* ***http://www.giss.nasa.gov/tools/mars24/****.*



Oblique, southward-looking view of Gale crater, showing landing point (white dot), which is well within targeted landing ellipse (outlined in yellow). Inside crater is mountain of layered rock that NASA's rover Curiosity *will explore. Gale crater is 154 kilometers (96 miles) in diameter; layered mountain rises about 5.5 kilometers (3.4 miles) above crater floor. View derived from a combination of elevation and imaging data from three Mars orbiters; no vertical exaggeration. From NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS (slightly modified from image at* ***http://www.nasa.gov/mission_pages/msl/multimedia/pia16058.html****) .*

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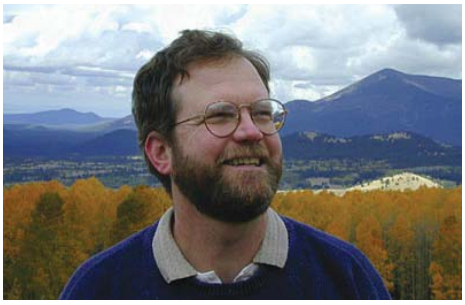
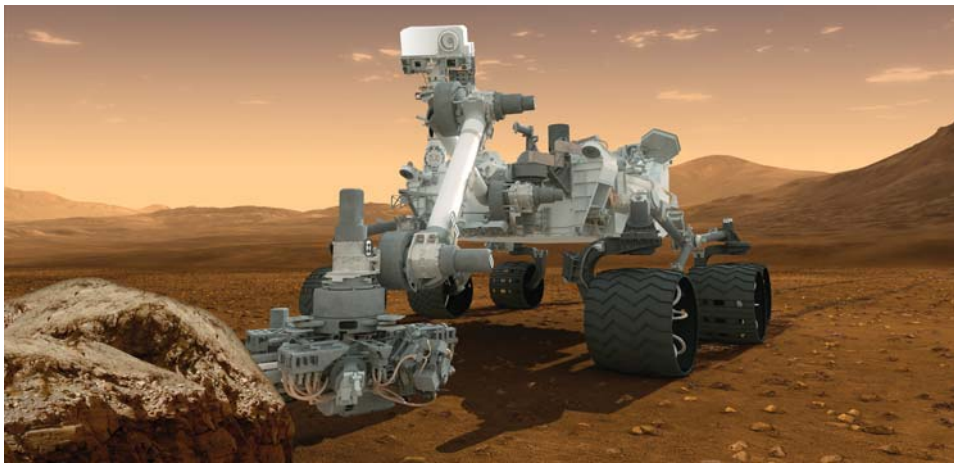
on Mars (see **http://astrogeology.usgs.gov/people/ken-herkenhoff**). During 7 years as a research scientist at the Jet Propulsion Laboratory, **Herkenhoff** took part in numerous Mars exploration and mapping projects, including the 1997 Mars Pathfinder mission, the first U.S. mission to put a rover (*Sojourner*) on Mars. After joining the USGS in 1998, **Herkenhoff** continued his Mars work, including leading the Microscopic Imager team for the Mars Exploration Rover (MER) mission, which landed two rovers, *Spirit* and *Opportunity*, on Mars in 2004. A Co-Investigator on the current mission since instruments were selected in December 2004, **Herkenhoff** works with several instruments on *Curiosity*: the Mastcam, MAHLI, and MARDI cameras and the ChemCam spectrometer and remote microscopic imager.

The Mastcam (short for Mast Camera) takes high-definition videos of the Martian terrain, as well as color photographs, including stereopairs—photographs taken from slightly different angles whose combination produces three-dimensional views. These images will be used to study the Martian landscape, rocks, and soils; to view frost and weather phenomena; and to support the rover's driving and sampling operations.



Ken Herkenhoff

The MAHLI, or Mars Hand Lens Imager, functions like a geologist's hand lens, providing closeup views of the minerals, structures, and textures in Martian rocks and dust. MAHLI is similar to the Microscopic Imager used by *Spirit* and *Opportunity* but has more capabilities; for example, MAHLI takes color rather than monochrome images, and it has its own light sources, enabling it to take images



Artist's concept of NASA's Mars Science Laboratory rover Curiosity*, a mobile robot for investigating Mars' past or present ability to sustain microbial life. Whereas the rovers* Spirit *and* Opportunity*, which landed on Mars in 2004, were powered by solar-charged batteries,* Curiosity *runs on nuclear power, likely to give it a longer lifespan. The rover's arm extends about 2 meters (7 feet) and contains scientific tools that include a sample-acquisition system and the MAHLI (Mars Hand Lens Imager). The mast, or rover's "head," rises to about 2.1 meters (6.9 feet) above ground level, about as tall as a basketball player. It supports two scientific instruments: the Mast Camera, or "eyes," for stereo color viewing of surrounding terrain and material collected by the arm, and the Chemistry and Camera instrument, which uses a laser to vaporize a speck of material on rocks as far as about 7 meters (23 feet) away and determines what elements they contain. Learn more at* ***http://mars.jpl.nasa.gov/msl/mission/rover/****. Image from NASA/JPL-Caltech.*

in shadow and even at night. In addition to white-light sources, like the light from a flashlight, MAHLI has ultraviolet-light sources, like the light from a tanning lamp. The ultraviolet light is used to induce fluorescence in order to help detect carbonate and evaporite minerals, both of which would indicate that water helped shape the landscape. MAHLI's lens has a focusing mechanism that allows images to be acquired at a range of target distances, from less than an inch (resolution better than the MER Microscopic Imager) to infinity.

The MARDI, or Mars Descent Imager, took color video during the rover's descent, providing an "astronaut's view" of the landing site to help *Curiosity*'s drivers steer it around loose debris, boulders, cliffs, and other potential obstacles, as well as to provide geologic context for the rover's early investigations. Shot at 4 frames per second, the video supplements high-resolution digital topographic models of the study area prepared by USGS astrogeologist **Randy Kirk** (see related article, this issue). The video frames, which have very large file sizes, are gradually being transferred to Earth; some of them have been combined into a movie posted at **http://www.youtube.com/watch?v=e1ebHThBdlY&feature=channel&list=UL**. Although MARDI has completed its main task—imaging the ground during the rover's descent—it can still take useful pictures of Mars, looking straight down at the surface just behind Curiosity's left front wheel. Eventually the scientists hope to use MARDI to take images as the rover drives.

The ChemCam (short for Chemistry and Camera) fires a laser at rocks and soils and analyzes the elemental composition of vaporized materials from surface areas smaller than 1 millimeter. From as far away as 7 meters (23 feet), the ChemCam can rapidly identify rock types (for example, determine whether rocks are volcanic or salty), measure the abundance of most chemical elements, recognize ice and minerals with water molecules in their crystal structures, and much more. The ChemCam contains a remote microscopic imager to capture detailed images of the spot analyzed by the laser and the surrounding area. If *Curiosity* cannot reach a rock or outcrop of interest, the ChemCam

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will enable scientists to analyze it from a distance.

Herkenhoff is using data from all these instruments to study rocks and fine regolith (loose materials) in the study region. He is particularly interested in eolian (wind-formed) features and the geologic history recorded in the layers exposed on Aeolis Mons. Making use of his previous mission operations experience, **Herkenhoff** is serving in various MSL operational roles, including Chair of the Science Operations Working Group, which meets daily to discuss and decide what the rover will do the following sol. Other tactical roles include Payload Uplink Lead, which involves preparing instrument command sequences for transmission to the spacecraft ("uplink"). He is also refining the calibration of some of *Curiosity*'s cameras and planning coordinated observations by multiple instruments. Read **Herkenhoff's** sol-by-sol updates at **http://astrogeology.usgs.gov/news/**.

Communicating with Curiosity

Ryan Anderson is a Shoemaker Postdoctoral Fellow who works with **Herkenhoff** at the Astrogeology Science Center (**http://astrogeology.usgs.gov/people/ryan-anderson**). His use of data from Mars orbiters to study landforms and layered deposits in Gale crater contributed to its selection as *Curiosity*'s landing site (see technical paper posted at **http://dx.doi.org/10.1555/mars.2010.0004**). A Collaborator on the MSL project, **Anderson** is a ChemCam science-team member and a Payload Downlink Lead for ChemCam. "Downlink" is the transfer of data from *Curiosity* to Earth. As these data arrive, **Anderson** and his group check to see that the rover's instruments are functioning properly and performing the scientific tasks as commanded; then they translate the data into information that can be examined by the science teams. **Anderson** has uplink responsibilities as well. His observations about being part of MSL are posted on his blog "The Martian Chronicles," **http://blogs.agu.org/martianchronicles/**.

***Ryan Anderson** stands beside a full-scale model of* Curiosity *at the Jet Propulsion Laboratory. Photograph from **Anderson's** August 4, 2012, blog entry (**http://blogs.agu.org/martianchronicles/2012/08/04/sol-2-loose-ends-interviews-landing-site-bingo-and-pixar/**).*

*USGS research geologist **David Rubin** in Qaidam Basin, China, 1988. **Rubin** was invited to join scientists from the Australian Academy of Science and the Chinese Academy of Science in a collaborative study of longitudinal sand dunes (dunes that are elongate parallel to the net sand-transport direction).*

Sediments Past and Present

Dave Rubin is a research geologist from the USGS Pacific Coastal and Marine Science Center in Santa Cruz, California, with a particular interest in sediments, both modern and ancient, and how they are moved and deposited by water and wind (**https://profile.usgs.gov/drubin**). His computer animations depicting the formation of bedding structures, particularly cross-beds (layers within a bed that are at an angle to the main bedding plane), have proved extremely valuable in the interpretation of complex bedding patterns exposed in outcrops (**http://walrus.wr.usgs.gov/seds/bedforms/animation.html**). **Rubin's** work on the orientation of ripples and dunes in multidirectional flows has been applied to bedforms on Earth, Mars, and Saturn's moon Titan. In 2004, he was asked to review NASA scientists' interpretations of sedimentary structures in images of a Martian outcrop taken by the rover *Opportunity* (see "USGS Sedimentologist David Rubin Serves As External Expert During NASA Announcement of Evidence for Flowing Water on Mars," *Sound Waves*, April 2004, **http://soundwaves.usgs.gov/2004/04/**). **Rubin** joined the Mars Science Laboratory in November 2011, when he was selected as a Participating Scientist. He has three roles in the mission: Geology Theme Group Member, Geology Science Theme Leader, and Surface Properties Scientist.

Rubin is examining images of sedimentary structures taken by *Curiosity*'s cameras and comparing them with terrestrial analogs to reconstruct past geologic processes—particularly flowing water and wind—that may have produced them. For example, cross-beds in an outcrop can indicate the shape and motion of ripples along an ancient streambed or lakebed. In the case of complex structures, three-dimensional computer modeling and animation will be used to aid in this reconstruction. (View "Ripples to Rocks on Mars," a video using computer animation to illustrate the process that likely formed cross-beds in an outcrop imaged by *Opportunity* in 2004, **http://walrus.wr.usgs.gov/seds/bedforms/extras/movies/mars_morph7.mov**).

Curiosity may have to drive over sand dunes or other loose sediment on its journey to Aeolis Mons, and so mission

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leaders assembled a Surface Materials and Mobility Working Group to help keep the rover from getting stuck. As a Surface Properties Scientist in this group, **Rubin** works with the rover drivers to pick the safest routes for the rover to drive and the safest outcrops for the rover to drill.

Supporting Actors

Like any epic production, MSL has a "cast of thousands." Here are some USGS personnel who, though not official members of the mission, are supporting the project from the Astrogeology Science Center:

Mark Rosiek is leading the analysis of MAHLI calibration data to determine the modulation transfer function (image sharpness) of the camera at various target distances.

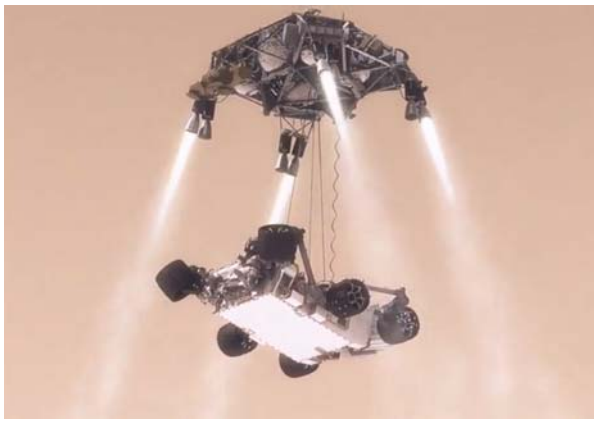
Ella Lee is assisting **Rosiek** in the processing of MAHLI calibration data.

Bob Sucharski set up and maintains the USGS subscription to the Mars Science Laboratory File Exchange Interface, allowing secure transfer of data between the Astrogeology Science Center in Flagstaff and the Mars Science Laboratory project at the Jet Propulsion Laboratory in Pasadena.

Scientist and cartographer **Ken Tanaka** of the Astrogeology Science Center served on the landing-site selection committee.

(See additional USGS contributors in "High-Resolution Digital Topographic Maps Help *Curiosity* Navigate Mars," this issue.)

To follow *Curiosity*'s exploration of Mars, visit the Mars Science Laboratory websites at **http://www.nasa.gov/mission_pages/msl/** and **http://mars.jpl.nasa.gov/msl/**.



Mars rover Curiosity *(lower object) beginning to unfold its "legs" as the sky crane (upper object) starts lowering it toward the surface of Mars.* Curiosity *is about twice as long (approx 3 meters [10 feet]) and five times as heavy as NASA's 2004 Mars Exploration Rovers,* Spirit *and* Opportunity*, making it too large for an airbag-assisted landing. Screenshot from NASA video "7 Minutes of Terror" at* ***http://www.jpl.nasa.gov/video/index.cfm?id=1090****. Credit: NASA/JPL-Caltech.*

"Where Am I?"—High-Resolution Digital Topographic Maps Help *Curiosity* Navigate Mars

By Helen Gibbons

Mars rover *Curiosity*, which landed on Mars on August 5, 2012, is busy exploring Gale crater near Mars' equator for evidence that life did or could exist there. (See "USGS Scientists Exploring Mars…," this issue, **http://soundwaves.usgs.gov/2012/10/**.) A key tool for scientists directing the rover is a set of high-resolution digital topographic maps prepared by geophysicist **Randy Kirk** (**http://astrogeology.usgs.gov/people/randolph-kirk**) and his team at the U.S. Geological Survey (USGS) Astrogeology Science Center in Flagstaff, Arizona.

Their mapmaking began in 2007 in support of landing-site selection for the Mars Science Laboratory (MSL), the mission using *Curiosity* to explore Mars. The ideal site must not only contain features of scientific interest but must also have terrain in which the rover can safely land and drive. How rough is the surface? How steep are the slopes? Are there reasonable routes the rover can traverse to reach the scientific targets? Topographic maps, which show not just features' positions but also their elevations, are needed to answer such questions.

Kirk's team used the HiRISE (High Resolution Imaging Science Experiment) camera on the Mars Reconnaissance Orbiter to map the landing-site candidates. HiRISE can take stereopairs—two photographs of the same area from slightly different angles—whose combination produces a three-dimensional image from which elevation data for every pixel can

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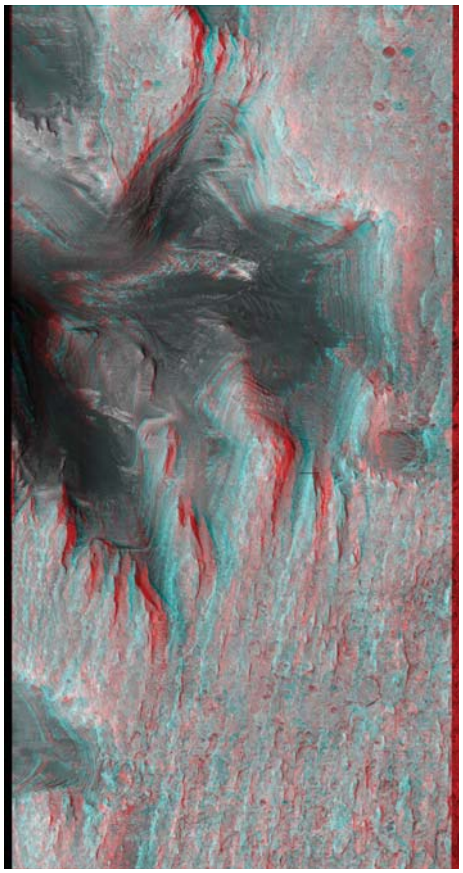

*Use red-blue glasses (red lens over left eye) to view this three-dimensional image of a canyon eroded into strata interpreted as sulfate beds on the flanks of Aeolis Mons in Gale crater. Image was created by combining low-resolution versions of a stereopair—two photographs from slightly different angles—taken by the High Resolution Science Imaging Experiment (HiRISE) camera on the Mars Reconnaissance Orbiter. Aside from the "wow!" factor, such images provide elevation data needed to make topographic models. (Vertical exaggeration varies with distance of your eyes from the image—try it!) From NASA/JPL/University of Arizona (****http://hirise.lpl.arizona.edu/ESP_012907_1745****).*

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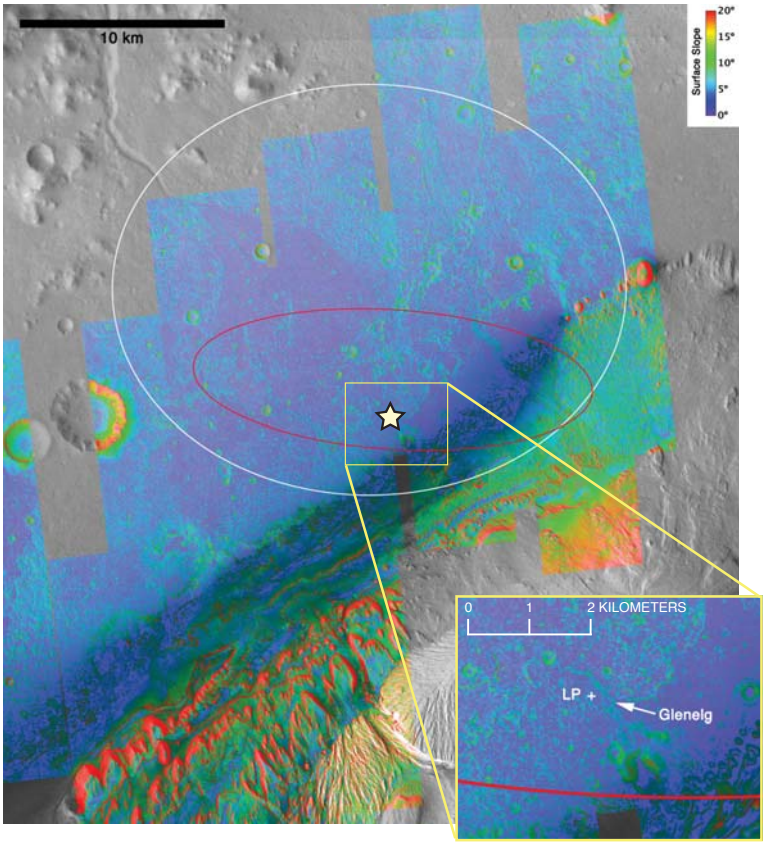
be derived. The digital topographic maps produced by **Kirk** and his team assign an elevation to each pixel, which represents 1 square meter on Mars' surface. These maps provide much more elevation data than the paper topographic maps familiar to hikers, on which elevations are shown by contour lines and must be interpolated for areas between the lines. To distinguish their digital maps from traditional topographic maps, **Kirk** and his team call their products digital topographic models, or DTMs.

The group has created a total of 13 DTMs of Gale crater with a grid spacing of 1 meter, which means that any object larger than about a meter is visible. Such detailed views result in huge datasets. By the time Gale crater was chosen as the final landing site on June 11, 2012, **Kirk's** team had delivered an average of half a dozen DTMs for each of the four finalist sites—about as much information for each site as is contained in the entire global topographic map of Mars (which comes from the Mars Orbital Laser Altimeter on the Mars Global Surveyor spacecraft; see **http://pubs.usgs.gov/imap/i2782/**). Thanks to rapidly advancing technology, this information was also about a million times the amount of data **Kirk's** team produced by nondigital stereo mapping of the 1997 Mars Pathfinder landing site, the team's first landing-site assessment. After Gale was selected, the team more than doubled the number of DTMs for it, filling in gaps in the landing zone and mapping the rugged science study area where the rover will drive.

Kirk and his group have provided key input in selecting landing sites for every successful U.S. Mars landing since 1997—including Mars Pathfinder, the first U.S. mission to put a rover (*Sojourner*) on Mars; the Mars Exploration Rover mission, which landed the rovers *Spirit* and *Opportunity* on opposite sides of Mars in 2004; and the 2008 Phoenix Mars mission. Current members of the group, in addition to **Kirk**, are:

- **Elpitha "Annie" Howington-Kraus** (cartographer)—Developed software under **Kirk's** direction and supervised DTM production during the early years of the MSL project.
- **Trent Hare** (information technology [IT] specialist, geographic-information-system [GIS] software)—Led Web delivery of data to the MSL project.
- **Lynn Weller** (cartographer)—Prepared slope maps from DTMs.
- **Donna Galuszka** (cartographer)—Set up project for individual DTMs (data preparation, control, and automatic DTM production), supervised and trained student editors, and conducted final quality control.
- **Bonnie Redding** (cartographic technician)—Set up project for individual DTMs, conducted final quality control, and mosaicked completed sets of DTMs.
- **Jac Shinaman** (IT specialist)—Prepared illustrations showing location, image map, and topographic map for each DTM.
- **Joseph Antonsen**, **Kelly Coker**, **Eric Foster**, **Megan Hopkins**, and **Adam Licht** (students)—Performed interactive editing of automatically produced DTMs.



Map of Curiosity's *landing site in Gale crater, Mars. Color-coding indicates slope steepness, from flat (purple) to slopes of 20° and more (red). Slopes were measured from digital topographic models produced at the USGS Astrogeology Science Center by analyzing high-resolution images from NASA's Mars Reconnaissance Orbiter (see text for details). Slope data are overlaid on image obtained by High Resolution Stereo Camera (HRSC) onboard the European Space Agency's Mars Express orbiter. White ellipse, about 25 by 20 kilometers (16 by 12 miles), was landing zone used for planning purposes. Red ellipse, about 20 by 7 kilometers (12 by 4 miles), is target area as revised in early June 2012. Yellow star shows approximate location of landing point. Inset shows location of landing point (LP) and the Glenelg site to which* Curiosity *is driving at this writing (Sept. 20, 2012). 3-D image on previous page is outside this map, about 50 kilometers (30 miles) south-southwest of landing point. Maps courtesy of* ***Randy Kirk****, USGS.*

Additional contributions to the Mars Science Laboratory mapping came from **Robin Fergason**, research geophysicist at the USGS Astrogeology Science Center, who provided the team with thermal (infrared) imagery of the four finalist landing sites. These images—taken by the Thermal Emission Imaging System (THEMIS) on the Mars Odyssey spacecraft—provide information beyond that revealed by visible light that can be used to discriminate solid rocks from loose sediment. (Read more about THEMIS at **http://themis.asu.edu/about**.)

Now that *Curiosity* has landed, the highly detailed topographic models created by **Kirk** and his team are helping the rover navigate the terrain in Gale crater. Follow *Curiosity*'s progress at **http://www.nasa.gov/mission_pages/msl/** and **http://marsprogram.jpl.nasa.gov/msl/**.

Tip from USGS and MBARI Scientists Leads to Discovery of Methane Seep off San Diego, California, by Scripps Graduate Students

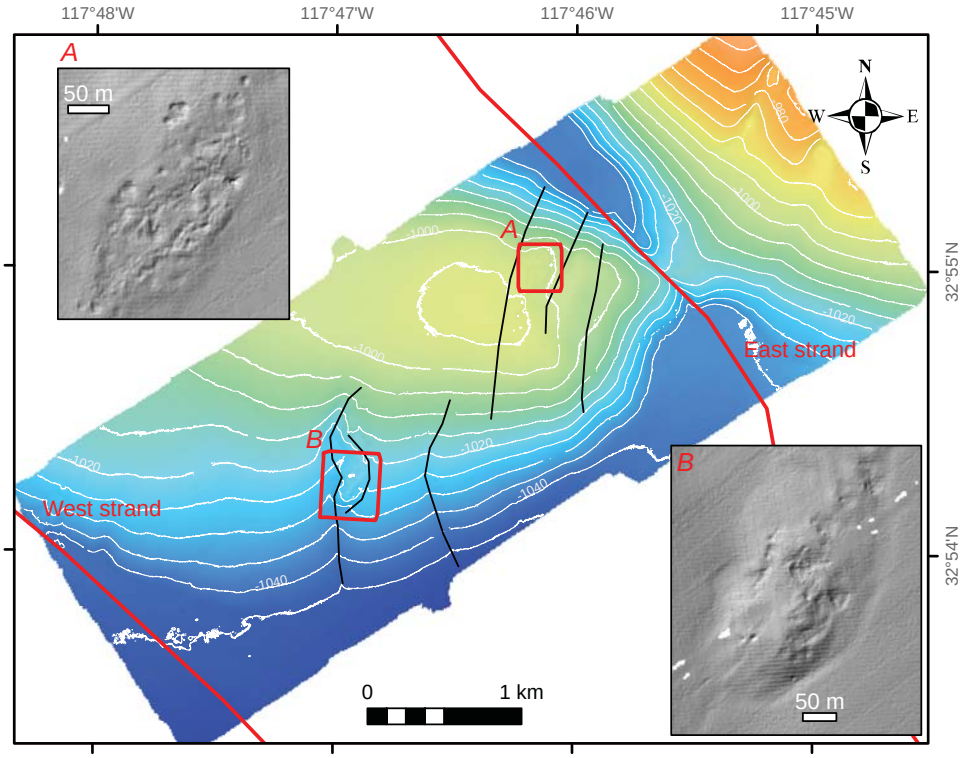
By Helen Gibbons

A tip from U.S. Geological Survey (USGS) scientists and their colleague at the Monterey Bay Aquarium Research Institute (MBARI) led to the discovery of a deep-sea methane seep by graduate students from Scripps Institution of Oceanography at the University of California, San Diego. Evidence for the seep was discovered during the San Diego Coastal Expedition (**http://bit.ly/sdcoastex**) in July 2012.

Methane seeps are known in several areas off the coast of California, but this is the first such finding off San Diego County. The seep was discovered about 20 miles west of Del Mar, in a fault zone known as the San Diego Trough fault zone. Methane, the most common form of natural gas, exists in sediment beneath the seafloor along many of the world's continental margins. Faults can provide a pathway for methane to "seep" upward toward the seafloor.

The newly discovered seep occurs at a mound on the seafloor that is 1,036 meters (3,400 feet) beneath the sea surface, has an area the size of a city block, and rises to the height of a two-story building. USGS scientists **Jamie Conrad** and **Holly Ryan** and MBARI scientist **Charlie Paull** surveyed the mound in 2010 as part of an effort to determine a slip rate for the San Diego Trough fault zone. Their findings, to be published December 2012 in the *Bulletin of the Seismological Society of America*, will affect estimates of earthquake hazards in the region.

Conrad, **Ryan**, and **Paull** were familiar with the mound from a seismic-reflection profile (a side view of sub-seafloor sediment layers) collected in 2000 by the late USGS geologist **Bill Normark** (**http://soundwaves.usgs.gov/2008/06/staff.html**). The profile reminded **Paull** of a "mud volcano" in Santa Monica Bay where a core collected during a 2003 USGS expedition recovered methane hydrate (an icelike crystalline solid in which methane gas molecules are trapped; see **http://soundwaves.usgs.gov/2006/03/research.html**). Because of **Paull's** hunch that the mound would be associated with methane, and because it is in a complex area of the San Diego Trough fault zone that they wanted to investigate, **Conrad**, **Ryan**, and **Paull** included the mound in their 2010 survey. Using an autonomous underwater vehicle (AUV) developed by MBARI (**http://www.mbari.org/auv/**), they mapped the bathymetry of the mound at ultra-high resolution, revealing distinctive patches of rough seafloor that are typically associated with fluid venting.



*Ultra-high-resolution multibeam bathymetric data acquired by USGS and Monterey Bay Aquarium Research Institute (MBARI) scientists in 2010 across a mound between two strands of the San Diego Trough fault zone (east and west strands shown in red). Scripps Institution of Oceanography graduate students discovered a methane seep in this area in July 2012. Contour interval, 5 meters. Insets A and B show distinctive patches of rough seafloor typically associated with fluid venting; these patches include fault scarps. Figure courtesy of **Holly Ryan**, USGS.*

In late 2011, **Conrad** got a call from Scripps graduate student **Jillian Maloney**, a geologist helping two fellow graduate students—biological oceanographers **Ben Grupe** and **Alexis Pasulka**—plan a search for offshore methane seeps. Such seeps host unusual biological communities about which much remains to be learned. When **Maloney** asked **Conrad** where they might find undersea gas vents, he suggested a couple of spots, including the mound that he and his colleagues had mapped off San Diego.

During the following summer's San Diego Coastal Expedition, the Seeps Team, now a group of five graduate students, included the mound in their search for methane seeps. "It was farther from shore than we had planned to go," said **Maloney**, "but we had some extra time, so we went out to take a look."

They mapped the mound with the research vessel's multibeam sonar and subbottom echosounder, both of which send out sound waves that reflect off objects in the water column, the seafloor, and the sedimentary layers beneath the seafloor. The reflected sound signals produce images of the seafloor surface (in

(Methane Seep continued on page 8)

(Methane Seep continued from page 7)

the case of the multibeam sonar) and subseafloor sedimentary layers (in the case of the sub-bottom echosounder). (Learn more about sonar-mapping methods at **http://earthguide.ucsd.edu/earthguide/diagrams/sonar/sonar.html**.)

"In the 'chirp' data [the sub-bottom data], we saw the most convincing evidence for a seep that we had seen all cruise—a distinctive disruption of the subsurface layers that's typical of fluid seepage," said **Maloney**.

Ordinarily, the next step would be to send the vessel's remotely operated vehicle (ROV) down to image the suspected seep. But at 1,036 meters (3,400 feet) below the surface, the mound was too deep for the ROV's tether. **Pasulka** and **Grupe** decided to drop a multicore sampler, a frame that supports a ring of eight 1-meter-long corers. When the sampler came back on deck, its contents added to the evidence that the team had discovered a seep.

*Multicore sampler being deployed. Photograph by **Noah Brookoff**.*

"As soon as we began slicing a core open, we started smelling hydrogen sulfide, and about 10 cm down into the core we started seeing carbonate nodules," said **Pasulka**. "As we continued to sift through the mud and examine the organisms under the microscope, it gradually became clear that we had hit a seep."

Carbonate nodules and hydrogen sulfide (which has a rotten-egg smell) are both products of anaerobic oxidation of methane by microbes that use methane as their main energy source. The organisms in the cores included siboglinids, thread-like worms that have no digestive system but gain nutrition from symbiotic bacteria living inside them, and vesicomyid clams, which gain nutrition from bacteria living on their gills. The bacteria metabolize the hydrogen sulfide produced by methane oxidation. "These symbiotic bacteria make a lot of energy," said **Pasulka**, "with enough left over to be used by their hosts."

*A sediment-core sample reveals black marks where hydrogen sulfide is present, an indication of a methane-seep environment. The hydrogen sulfide is a byproduct of methane oxidation by microbes living around the seep, as well as an energy source for bacteria in the seep community. Photograph by **Kirk Sato**, Scripps Institution of Oceanography.*

*Siboglinids (left), which lack a mouth and digestive system, live inside tubes (right) in methane- or sulfide-rich environments. The worms get their nutrition from symbiotic bacteria that metabolize hydrogen sulfide. Photographs by **Ben Grupe**, Scripps Institution of Oceanography.*

The various microbes that produce energy from chemicals in seep fluids form the base of food webs for these rich ecosystems, making methane seeps biological oases in seafloor areas that otherwise are sparsely populated.

Pasulka and **Grupe**, who are interested in the biology of seep ecosystems, are excited to have discovered a seep so close to San Diego. The site's relative proximity to Scripps—about 3 to 4 hours by boat—will allow repeated visits over months and years to study the ecosystem and observe how it changes. The Seeps Team is already planning to revisit the site during the San Diego Coastal Expedition's second leg in December 2012, when they hope to get video footage and additional samples.

To learn more about the seep discovery and the process that led to it, read the Scripps news release at **http://scrippsnews.ucsd.edu/Releases/?releaseID=1280** and **Jillian Maloney's** blog post at **https://sites.google.com/site/sandiegoseaflex/blog/methaneseepsfaultsandagiantcricket**. Read additional blogs from the expedition—and watch for posts during the December 2012 leg—at **https://sites.google.com/site/sandiegoseaflex/blog**. Visit the expedition's Facebook page at **http://www.facebook.com/sdcoastex**. ❁

*The Seeps Team: Scripps Institution of Oceanography graduate students (left to right) **Rachel Marcuson** (geophysicist), **Alexis Pasulka** (biological oceanographer), **Ben Grupe** (biological oceanographer), **Valerie Sahakian** (geophysicist), and **Jillian Maloney** (geologist). Photograph by **Shannon Casey**, Scripps Institution of Oceanography.*

Sea-Level Rise Accelerating on U.S. Atlantic Coast

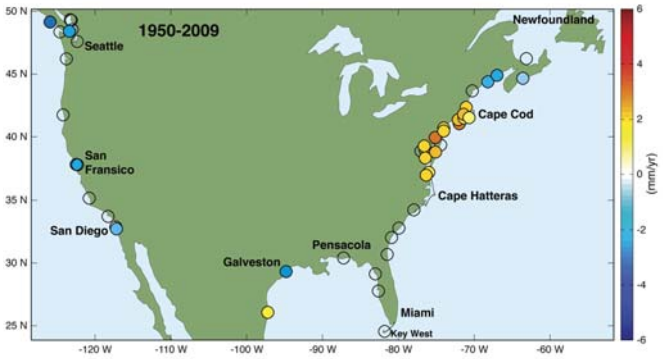
By Melanie Gade

Rates of sea-level rise are increasing 3 to 4 times faster along parts of the U.S. Atlantic coast than globally, according to a U.S. Geological Survey (USGS) report published in *Nature Climate Change* in June 2012 by **Asbury (Abby) Sallenger**, **Kara Doran**, and **Peter Howd**.

Since about 1990, sea-level rise in the 1,000-km (600 mile) stretch of coastal zone from Cape Hatteras, North Carolina, to north of Boston, Massachusetts—coined a "hotspot" by the authors—has increased 2 to 3.7 millimeters per year; the global increase over the same period was 0.6 to 1.0 millimeter per year. Data and analyses included in the report indicate that if global temperatures continue to rise, rates of sea-level rise in this area are expected to continue increasing.

The report shows that the sea-level-rise hotspot is consistent with the slowing of Atlantic Ocean circulation. Models show that this change in circulation may be tied to changes in water temperature, salinity, and density in the subpolar North Atlantic.

"Many people mistakenly think that the rate of sea-level rise is the same everywhere as glaciers and ice caps melt, increasing the volume of ocean water, but other effects can be as large or larger than the so-called 'eustatic' rise," said USGS Director **Marcia McNutt**. "As demonstrated in this study, regional oceanographic contributions must be taken into account in planning for what happens to coastal property."



*Differences in rates of sea-level rise from tide-gauge records across North America over a 60-year period (1950–2009). Circles are color coded to reflect computed differences; no color fill indicates differences in rates of sea-level rise that are not statistically different from zero. Cool colors indicate decreasing rates of sea-level rise over the 60-year period; warm colors indicate increasing rates of sea-level rise over the 60-year period. Note "hotspot" between Cape Hatteras and Cape Cod. After figure 2 in "Hotspot of Accelerated Sea-Level Rise on the Atlantic Coast of North America" (**http://dx.doi.org/10.1038/nclimate1597**).*

Although global sea level has been projected to rise about 1 meter (3 feet) or more by the end of the 21st century, it will not climb at the same rate everywhere. Differences in land movements, strength of ocean currents, water temperatures, and salinity can cause regional and local highs and lows in sea level.

"Cities in the hotspot, such as Norfolk, New York, and Boston, already experience damaging floods during relatively low intensity storms," said **Abby Sallenger**, USGS oceanographer and project lead. "Ongoing accelerated sea-level rise in the hotspot will make coastal cities and surrounding areas increasingly vulnerable to flooding by adding to the height that storm surge and breaking waves reach on the coast."

To determine accelerations of sea-level rise, USGS scientists analyzed tide-gauge data throughout much of North America in a way that removed long-term (linear) trends associated with vertical land movements. This analysis allowed them to focus on recent changes in rates of sea-level rise, caused, for example, by changes in ocean circulation.

The full citation for the report is:

Sallenger, A.H., Jr., Doran, K.S., and Howd, P.A., 2012, Hotspot of accelerated sea-level rise on the Atlantic coast of North America: *Nature Climate Change*, published online June 24, 2012, doi:10.1038/nclimate1597 [**http://dx.doi.org/10.1038/nclimate1597**].

Hawaiian Seabirds on Low-Lying Atoll Vulnerable to Sea-Level Rise

By Michelle Reynolds and Barbara Wilcox

The Hawaiian Islands' largest atoll, French Frigate Shoals, is key to understanding how seabird-nesting habitat will change with predicted rising sea levels, according to a team of U.S. Geological Survey (USGS) biologists.

The team, led by research wildlife biologist **Michelle Reynolds** of the USGS Pacific Island Ecosystems Research Center, studied the population dynamics of eight seabird species on French Frigate Shoals, an isolated atoll of low-lying coral islands in the Northwestern Hawaiian Islands about halfway between the main Hawaiian Islands and Midway Atoll in the mid-Pacific. These islands, which are part of the Hawaiian Islands National Wildlife Refuge and Papahānaumokuākea Marine Na-

(Hawaiian Seabirds continued on page 10)

*The White Tern is one of eight seabird species whose population density and susceptibility to sea-level rise were studied on French Frigate Shoals' Tern Island by biologists with the USGS Pacific Island Ecosystems Research Center's Northwestern Hawaiian Islands Climate Change Project. Photograph by **C. Cornett**, U.S. Fish and Wildlife Service.*

(Hawaiian Seabirds continued from page 9)

tional Monument, are managed by the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, and the State of Hawai'i. Papahānaumokuākea is a seasonal home to more than 14 million seabirds, making it the largest tropical seabird rookery in the world. Virtually all of the world's populations of Laysan Albatross and Black-footed Albatross live there, as well as globally significant populations of Red-tailed Tropicbirds, Bonin Petrels, Tristram's Storm-Petrels, and White Terns. The USGS research provides new information useful for wildlife management in the face of sea-level rise.

"It is troubling to think that these resilient seabirds, which have managed to endure and even thrive on this remote outpost despite the onslaught of storms and world war, could fall victim to the rising seas of climate change," said USGS Director **Marcia McNutt**. "These projections on the rate of shrinking useful habitat will help define the range of management options to help ensure the survival of these important species."

The investigators studied bird populations on Tern Island, the largest island in French Frigate Shoals since it was expanded in World War II by the U.S. Navy, which created a 3,000-foot-long coral-sand airstrip there. Using data collected over 3 decades on the ground by U.S. Fish and Wildlife Service refuges, the investigators concluded that although Tern Island is now at carrying capacity for some shrub-nesting bird species, such as Spectacled Terns (also known as Gray-backed Terns), restoration of habitat

*The Black Noddy (with a chick) is another seabird species whose population density was studied on French Frigate Shoals' Tern Island by the Northwestern Hawaiian Islands Climate Change Project. Photograph by **Pete Leary**, U.S. Fish and Wildlife Service.*

and seawalls could help mitigate the effects of sea-level rise on other bird species. In the long run, they say, restoration of seabird colonies on higher-elevation islands may be a more enduring conservation solution.

French Frigate Shoals' low elevation makes the atoll an important place to study sea-level rise. The eight islands, which lie, on average, only 2.2 meters above sea level, have lost landmass to erosion in recent decades. If sea levels rise 2 meters by 2100, as some studies have predicted, almost all the islands in the atoll except Tern Island will be submerged.

Using lidar (light detection and ranging)-derived elevation data, aerial imagery, and historical observations, the USGS investigators studied how various degrees of sea-level rise, from 0.5 meter to 2 meters, would affect bird populations. All of the scenarios show a decrease in the abundance of birds, except for Masked Boobies, which nest on bare ground, such as Tern Island's runway. The team also looked at what might happen if the inactive runway were decommissioned and either planted or passively managed for vegetation. Study models that incorporated decommissioning the runway increased the area of potential habitat and slowed losses of shrub land cover due to sea-level rise for all but the 1.5-meter and 2-meter scenarios.

"We were pleased to learn that seabirds have been doing so well at French Frigate Shoals, but if sea level rises much more, these birds may need help in the future," said **Jeff Hatfield**, a research ecologist at the USGS Patuxent Wildlife Research Center in Maryland and lead author of an article on the team's findings in *Conservation Biology* (**http://dx.doi.org/10.1111/j.1523-1739.2012.01853.x**).

Robyn Thorson, director of the U.S. Fish and Wildlife Service's Pacific Region, agrees. "This area remains a critical, world-class habitat for seabirds, worthy of our efforts to protect it," **Thorson** said. "What we learn now will make a difference in the future of these species."

The authors say that their study demonstrates both the resilience and the vulnerability of Pacific seabird populations. Although bird species have recolonized Tern Island despite intense human disturbance that included 38 years of weekly air traffic, they face an uncertain future as a result of sea-level rise and associated habitat loss.

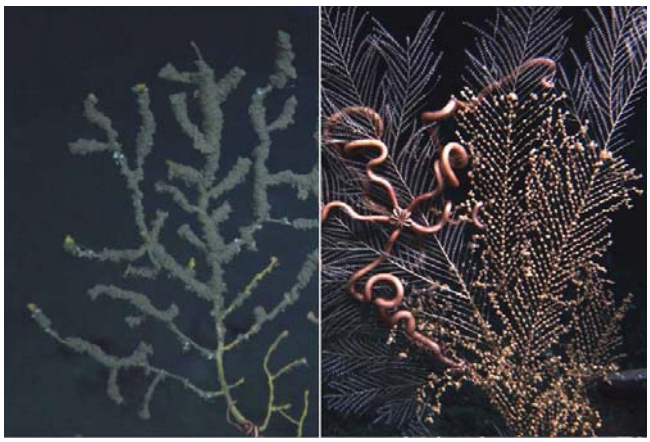
Corals Damaged in the Deep Gulf of Mexico by *Deepwater Horizon* Oil Spill

By Rachel Pawlitz

*[Modified from USGS Science Pick at **http://www.usgs.gov/blogs/features/usgs_science_pick/corals-damaged-by-deepwater-horizon/**.]*

Nearly 2 years after the *Deepwater Horizon* oil spill, the meticulous, long-term efforts of scientists finally yielded the official results: the brown, wilted, dying corals found at Mississippi Canyon lease block 294 were indeed damaged by a plume of oil from the spill. For many, it seemed a foregone conclusion. What else

(Corals Damaged continued on page 11)



Normal coral with some dead skeletal material covered by typical secondary colonization (right), in comparison with wilting, dying coral covered with oil-plume debris (left). Also affected were brittlestars, seen climbing in the healthy coral. Image courtesy of Lophelia II *2010 expedition (**http://oceanexplorer.noaa.gov/explorations/10lophelia/**), NOAA Office of Ocean Exploration and Research (OER) and BOEM.*

(Corals Damaged continued from page 10)

could brown gunk (flocculent matter, if you're a scientist) covering damaged corals 7 miles from the *Deepwater Horizon* drill site be, if not oil from the spill? Yet, to this team of scientists, it was worth taking a close look at the evidence with two-dimensional gas chromatography, sediment cores, coral samples, and mosaic imagery. Why? Because so much was at stake.

To understand the damage in the deep, the scientists had to start by understanding what was down there before the spill. To support that mission, enter U.S. Geological Survey (USGS) research benthic ecologist **Amanda Demopoulos** (**http://profile.usgs.gov/ademopoulos**), who studies life on the seafloor to describe what types of organisms typically live together in deep-sea communities. Her work involves digging sediment cores from the ocean bottom and sorting through the many tiny life forms found there. (For example, see "Scientists Cruise Deep Into Coral Ecosystems," *Sound Waves*, December 2009, **http://soundwaves.usgs.gov/2009/12/fieldwork2.html**.)

In addition to deep-sea coral ecosystems, **Demopoulos** studies communities in parts of the Gulf where oil naturally seeps up from the seafloor and is in fact a wellspring of life, not a source of damage. Chemosynthetic ecosystems—the ones where food webs are based on chemicals rather than sunlight—tend to host different life forms, such as tubeworms.

Demopoulos was on the November 2010 research expedition that first discovered the damaged corals. Led by biology professor **Charles Fisher** of the Pennsylvania State University (**http://bio.psu.edu/directory/crf2**) and funded by the Bureau of Ocean and Energy Management (BOEM) and the National Oceanographic and Atmospheric Administration (NOAA), the expedition's goal was to build a scientific understanding of the various undersea ecosystems. It was part of a decades-long collaborative effort among federal and university scientists to explore deep-sea ecosystems in order to provide sound baseline information for management decisions about how to best balance natural-resource use with protection. **Demopoulos** recalled watching the first images from the damaged site come in from a remotely operated vehicle (ROV).

"When we were watching the ROV video in the lab, I looked up at the video screen, and it looked starkly different from anything we'd ever seen before," **Demopoulos** said. "The corals were all dark grey and lumped over, and it was clear these animals were not healthy. We'd seen dead coral, but this was so different, we immediately knew it was worth investigating further. When we got closer, there didn't seem to be any secondary colonization, as we'd seen in the past on dead coral."

***Amanda Demopoulos** sorts and identifies animals in a sieved sample. Image courtesy of* Lophelia II *2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks (**http://oceanexplorer.noaa.gov/explorations/09lophelia/**).*

The fact that no new animals, such as barnacles or hydroids, had begun to attach and grow on the dead corals suggested that the coral deaths had been recent, noted **Demopoulos**. This process, known as secondary colonization, is commonly observed on dead corals but takes time to occur.

In December 2010, barely a month after the discovery of the damaged coral, **Fisher** led a followup expedition to further examine the damaged corals, supported by a special National Science Foundation RAPID grant. **Fisher**, along with assistant professor of chemistry **Helen White** of Haverford College (**http://www.haverford.edu/faculty/hwhite**), directed the coral-damage assessment in collaboration with scientists from Woods Hole Oceanographic Institution, Temple University, the USGS, and the BOEM. On the basis of her expertise with sediment samples, **Demopoulos** worked with **White** and **Fisher** to design the best approach for assessing the corals at the Mississippi Canyon lease block 294 for the presence of oil and the extent of damage.

"The challenge we faced in this study was piecing together what happened from multiple lines of evidence, because no one was sitting on the seafloor when the plume went by. The corals were the only witness," said **Demopoulos**. "We had to consider the proximity to the *Deepwater Horizon* site and the fact that a deep-water plume had recently passed over the site,

(Corals Damaged continued on page 12)

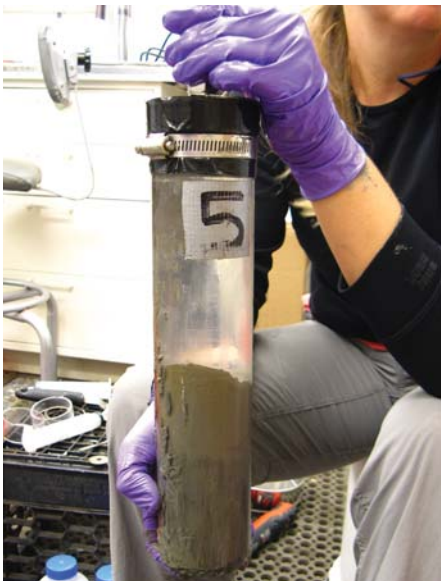
Damaged coral with brittlestar climbing through it. Image courtesy of Lophelia II *2010 expedition (**http://oceanexplorer.noaa.gov/explorations/10lophelia/welcome.html**), NOAA OER and BOEM.*

(Corals Damaged continued from page 11)

then closely examine the corals for tissue damage and signs of stress, such as the presence of mucus, and of course, the chemical signature of the oil. It was truly an interdisciplinary effort."

Demopoulos pointed out that the cumulative knowledge about deep-sea communities from previous expeditions provided the baseline for scientifically assessing what they saw at the site. "This is but one site in the Gulf of Mexico," she said, "but it has shown how important it was for us to have a frame of reference as to what a healthy deep-sea coral ecosystem looks like. We are still trying to understand the extent to which this is occurring elsewhere in the Gulf of Mexico."

The results of the scientists' efforts were published online in March 2012 in the *Proceedings of the National Academy of Sciences of the United States of America* (*PNAS*) at **http://dx.doi.org/10.1073/pnas.1118029109**. Additional information about the study is posted at **http://science.psu.edu/news-and-events/2012-news/Fisher3-2012**.



This push core shows discrete layers in a typical sediment sample. Light-brown organic layer sits above dark-gray clay sediment. Most animals occur in the top layer of sediment. Image courtesy of Lophelia II *2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks (**http://oceanexplorer.noaa.gov/explorations/09lophelia/**).*

Gulf Coast Vulnerable to Extreme Erosion During Category 1 Hurricanes—New Model to Help Community Planners, Emergency Managers

By Melanie Gade and Hilary Stockdon

About 70 percent of the Gulf of Mexico shoreline is vulnerable to extreme erosion and overwash during even the weakest hurricanes, according to a U.S. Geological Survey (USGS) report released just before the start of the 2012 hurricane season, which officially began on June 1 and ends on November 30. The report's findings were underscored in late August by Hurricane Isaac, a category 1 hurricane that caused widespread erosion and overwash along the Louisiana, Mississippi, and Alabama barrier islands.

The report, titled "National Assessment of Hurricane-Induced Coastal Erosion Hazards: Gulf of Mexico" (**http://pubs.usgs.gov/of/2012/1084/**), focuses on the sandy beaches on the mainland and barrier islands of the U.S. Gulf of Mexico shoreline. These beaches are among the most vulnerable in the nation because of low coastal elevations and frequent hurricanes. The new publication presents the probabilities of dune erosion, overwash, and inundation of these beaches during direct hurricane landfall, as determined by USGS scientists using state-of-the-art modeling.

The research is expected to help emergency managers at local, state, and federal levels as they prepare for hurricanes in this and future seasons. Planners will be able to determine how different categories of hurricanes would impact their beaches and surrounding communities, helping them better protect lives and property. The report also includes an interactive map (**http://coastal.er.usgs.gov/hurricanes/erosionhazards/gom/map.html**) that allows users to focus on different parts of the Gulf Coast shoreline to view how the probability of erosion caused by waves and storm surge varies with hurricane intensity.

*Erosion by Tropical Storm Debby on June 26, 2012, at Sunset Beach on Florida's west coast near St. Petersburg. Note cliff face eroded into dune at left. Stairway in background hangs suspended above the beach after erosion of sand beneath it. Photograph by **Hilary Stockdon**, USGS.*

"The Gulf Coast's beaches provide abundant recreational opportunities, contribute substantially to the local economy, and demand the highest real-estate values," said USGS Director **Marcia Mc-**

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Nutt. "This important research raises awareness on the specific nature of the vulnerability of these beautiful beaches to impacts from even Cat-1 hurricanes so that property damage can be minimized through proper planning."

In a storm, high waves and storm surge can act together to erode beaches and inundate low-lying lands; during hurricane landfall, these changes can sometimes be catastrophic.

"Beaches along the Gulf of Mexico are extremely vulnerable to erosion during hurricanes, in part because of low elevations along the coast," said **Hilary Stockdon**, a USGS research oceanographer and lead author of the study. "For example, the average elevation of sand dunes on the west coast of Florida is 8 feet; on Florida's Atlantic coast, the average is 15 feet."

During the landfall of a category 1 storm, in which sustained winds are between 75 and 94 miles per hour, overwash is very likely for 70 percent of Gulf Coast beaches. Overwash, which occurs when waves and storm surge overtop dunes and transport sand landward, is likely at these sites because of increased water levels at the shoreline. During category 1 hurricanes on the Gulf Coast, wave height and storm surge combine to increase water levels at the shoreline by 14½ feet above their normal levels.

"People continue to build communities in coastal areas that shift and move with each passing storm," said **Stockdon**. "This model helps us predict the potential impact of future storms and allows us to identify where the most vulnerable areas are located along the coast."

Additional findings from the report show that during a category 1 storm landfall, 27 percent of sandy beaches along the U.S. Gulf of Mexico are likely to be inundated, which occurs when increased water levels completely submerge beaches and dunes. If category 5 storms occur, in which wind speeds are 157 miles per hour or higher, 89 percent of these beaches are likely to be inundated during a direct landfall.

USGS scientists used methodology developed from a decade of USGS research on storm-driven coastal-change hazards as the basis for these calculations. Observational data were combined with sophisticated hydrodynamic modeling to predict the coastal changes provided in the report. As new data and storm predictions become available, the report's analysis will be updated to describe how coastal vulnerability may change in the future.

The full citation for the new report is: Stockdon, H.R., Doran, K.J., Thompson, D.M., Sopkin, K.L., Plant, N.G., and Sallenger, A.H., 2012, National assessment of hurricane-induced coastal erosion hazards—Gulf of Mexico: U.S. Geological Survey Open-File Report 2012–1084, 51 p. [**http://pubs.usgs.gov/of/2012/1084/**].

Key findings from the report are posted at **http://coastal.er.usgs.gov/hurricanes/erosionhazards/gom/**.

Sanctuary Exploration Center Opens on the Shores of the Monterey Bay National Marine Sanctuary in Santa Cruz, California

The Monterey Bay National Marine Sanctuary (MBNMS) opened its new Sanctuary Exploration Center in Santa Cruz, California, on Monday, July 23, 2012. The two-story, 12,387-square-foot building near the popular Santa Cruz Beach Boardwalk is full of interpretive and hands-on exhibits highlighting the sanctuary's extraordinary natural and cultural resources. Visitors can walk through a kelp forest, drive a miniature remotely operated vehicle (ROV), view high-definition videos of the sanctuary's underwater world, touch models of intertidal plants and animals, and much more—all for free.

"The Sanctuary Exploration Center encourages visitors of all ages to learn more about California's marine environment and issues affecting the sanctuary," said **Paul Michel**, MBNMS superintendent. "One of our missions is to educate the public about the vital role of protecting one of the nation's most ecologically significant and stunning underwater treasures."

The new Sanctuary Exploration Center in Santa Cruz, California. Photograph from National Oceanic and Atmospheric Administration (NOAA).

The U.S. Geological Survey (USGS) was represented at the opening ceremony by **Curt Storlazzi**, research geologist at the USGS Pacific Coastal and Marine Science Center in Santa Cruz and member of the MBNMS Research Activity Panel since 2005. The celebration included talks by U.S. Congressman **Sam Farr**, Santa Cruz mayor **Don Lane**, Santa Cruz Economic Development Department executive director **Bonnie Lipscomb**,

(Sanctuary Exploration continued on page 14)

(Sanctuary Exploration continued from page 13)

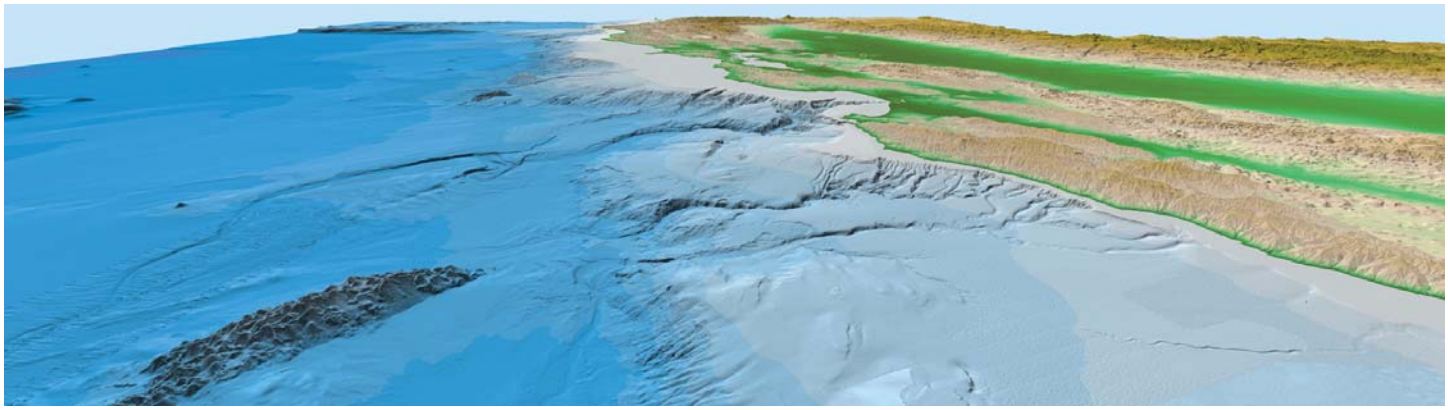
MBNMS superintendent **Paul Michel**, and California Secretary for Natural Resources **John Laird**. After speeches and a kelp-cutting ceremony, the doors of the new center were opened to the public, who swarmed in to explore the displays.

One of the exhibits, titled "Geology: The Sanctuary's Foundation," has as its centerpiece a contribution from the USGS Pacific Coastal and Marine Science Center: a sweeping (21 feet wide by 5 feet tall) perspective view of the sanctuary seafloor and the central California coast created by scientist **Pete Dartnell** from data collected by the USGS and its partners. The view is the background for six panels that highlight the varied terrain in the sanctuary, from nearshore habitats to submarine canyons and undersea mountains. The USGS perspective view was requested by **Lisa Uttal**, marine scientist and interim director of the Sanctuary Exploration Center.

Docents stationed throughout the center answer questions about the exhibits, help visitors drive the miniature ROV, and provide information about additional ways to enjoy the sanctuary, such as whale watching and kayaking tours. Nearly a thousand visitors came through the center on opening day, and daily visitor counts have remained high ever since. "It's a really well designed center," said one opening-day visitor. "It's full of inviting activities, but it's not overwhelming. Although I could happily spend a day in a place like this, I like that I could take in all the exhibits in about an hour."

*Dignitaries at the Sanctuary Exploration Center's opening ceremony cut a "ribbon" of kelp. Left to right: Monterey Bay National Marine Sanctuary (MBNMS) education and outreach coordinator **Dawn Hayes**, National Marine Sanctuary Foundation president and CEO **Jason Patlis**, National Oceanic and Atmospheric Administration (NOAA) Office of National Marine Sanctuaries West Coast regional director **Bill Douros**, NOAA National Ocean Service assistant administrator **David Kennedy**, NOAA Office of National Marine Sanctuaries director **Dan Basta**, Santa Cruz mayor **Don Lane**, Santa Cruz Economic Development Department executive director **Bonnie Lipscomb**, Congressman **Sam Farr**, MBNMS superintendent **Paul Michel**, California Secretary for Natural Resources **John Laird**, NOAA's acting assistant secretary of commerce for conservation and management **Eric Schwaab**, Santa Cruz County treasurer **Fred Keeley**, and interim Sanctuary Exploration Center director **Lisa Uttal**. Photograph by **Wes Martin**.*

The Sanctuary Exploration Center is open to the public from 10 a.m. to 5 p.m. Wednesday through Sunday. All ages are welcome, and admission is free. Visit the center's website for directions and additional information: **http://montereybay.noaa.gov/vc/sec/about.html**. A video describing the history of the Sanctuary Exploration Center and highlighting some of the exhibits is posted at **http://www.youtube.com/watch?v=-uS0DOVmkhs&feature=youtu.be**.



*Northward-looking perspective view of the Monterey Bay National Marine Sanctuary and central California, created by **Pete Dartnell** (USGS Pacific Coastal and Marine Science Center). This view, printed at 21 feet by 5 feet, forms the backdrop for the Sanctuary Exploration Center's display on "Geology: The Sanctuary's Foundation."*

U.S. Extended Continental Shelf Project Holds Workshop in Woods Hole, Massachusetts

By Matt Arsenault and Debbie Hutchinson

The U.S. Extended Continental Shelf (ECS) Project held its 2012 Technical Workshop at the U.S. Geological Survey (USGS) Woods Hole Coastal and Marine Science Center in Woods Hole, Massachusetts, during the week of April 16, 2012. The workshop followed 18 months of gathering data and background from seven offshore regions of the United States where an extended continental shelf might exist.

Where a nation can demonstrate that it has extended continental shelf—seafloor beyond 200 nautical miles from shore that meets criteria set forth in Article 76 of the United Nations Convention on the Law of the Sea (**http://www.un.org/Depts/los/**)—it can exercise certain sovereign rights over seabed and sub-seabed resources there. Preliminary studies have indicated that the U.S. extended continental shelf likely totals at least 1 million square kilometers—an area about twice the size of California or nearly half the Louisiana Purchase. Data collection and analysis will help the ECS Project come to a more definitive conclusion as to the extent of U.S. extended continental shelf; progress in that direction was the aim of the April workshop.

The workshop's 22 attendees came from the three agencies that lead the U.S. ECS Project: the Department of State, the National Oceanic and Atmospheric Administration (NOAA), and the Department of the Interior. These participants—including members of the ECS Executive Committee, regional team leads, and a subset of team members—represented a broad range of expertise in geology, geophysics, hydrography, data management, and law. The workshop gave them a unique opportunity to discuss multiple facets of integrating the Earth sciences with law, coming to a greater understanding about associated ambiguities and differing perspectives. Overall, the workshop was intense, focused, and productive and was deemed a success by all who participated.

*At the 2012 Extended Continental Shelf Technical Workshop, **Deborah Hutchinson** (USGS, standing) leads a discussion about terminology used in describing submarine fans. Seated attendees include (clockwise from lower left) **Elliot Lim** (NOAA National Geophysical Data Center), **Andy Armstrong** (NOAA and University of New Hampshire), **Jennifer Henderson** (NOAA National Geophysical Data Center), **Craig McLean** (NOAA), **Larry Mayer** (University of New Hampshire, hidden), **Matt Arsenault** (USGS), **Barry Eakins** (NOAA National Geophysical Data Center, hidden), **Jim Gardner** (University of New Hampshire), **Chris Fox** (NOAA National Geophysical Data Center), **John McDonough** (NOAA), **Dave Balton** (Department of State), **Ginger Barth** (USGS), and **Jon Childs** (USGS).*

The workshop opened with a full day of presentations on seven regions of possible U.S. extended continental shelf: Gulf of Mexico, Non-Arctic Alaska (the Bering Sea, the Gulf of Alaska, and the Aleutian Islands), Atlantic, Arctic, Pacific West Coast (California and Oregon), Western Pacific, and Central Pacific. The leads for each Integrated Regional Team (IRT) discussed preliminary findings for their regions based on analysis of currently available data. Participants aimed to understand how the criteria were applied in the different regions, eliminate scenarios that had been ruled out by analyzing existing and new data, and strive to develop an approach consistent with Article 76.

Ginger Barth (USGS), IRT lead for Non-Arctic Alaska, presented her group's findings and some preliminary results from her 2011 seismic cruise across the Surveyor and Baranof submarine-fan systems (see "Three-Week Expedition Images Sediments Beneath the Gulf of Alaska," *Sound Waves*, August 2011, **http://soundwaves.usgs.gov/2011/08/fieldwork2.html**).

Western Pacific IRT lead **Dan Scheirer** (USGS) led discussions about the areas both east and west of the Mariana Island Arc (Guam, Saipan, and Farallon de Pajaros). The NOAA/University of New Hampshire Joint Hydrographic Center (**http://ccom.unh.edu/**) has conducted three multibeam seafloor-mapping cruises in this region. The complex tectonic history and seafloor topography in these areas led to some challenging discussions about identifying the "base of slope"—a critical parameter for applying the formulas in Article 76.

Matt Arsenault (USGS) presented results from two extended-continental-shelf regions in the Gulf of Mexico that lie beyond the 200-nautical-mile limits of the United States, Mexico, and Cuba: the so-called Western and Eastern Polygons. Abundant data from academic studies and hydrocarbon exploration are available for these regions, and the Western Polygon has been chosen for a pilot submission exercise to be conducted in 2013. Article

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76 of the Convention on the Law of the Sea calls for coastal nations to submit data and other material concerning the limits of their extended continental shelves to the Commission on the Outer Limits of the Continental Shelf for the commission's consideration and advice. Although the U.S. has not ratified the Convention on the Law of the Sea, the ECS Project is using the Article 76 guidelines to understand and map where the U.S. could potentially have an extended continental shelf. **Arsenault** will work with colleagues from the NOAA National Geophysical Data Center (NGDC) and the Department of State to draft the pilot submission for the Western Polygon.

The other team leads who presented regional results were **Larry Mayer** (University of New Hampshire, Atlantic IRT), **Andy Armstrong** (NOAA, Arctic IRT), **Barry Eakins** (NOAA, Central Pacific IRT), and **Jennifer Henderson** (NOAA, Pacific West Coast IRT).

Topical presentations throughout the week included discussions on "natural prolongation" (a scientific term interpreted within the legal framework of the Convention), sediment fans, seamounts, trenches, the nature of downslope processes, and the use of seismic data for determining sediment thickness. **Jason Chaytor** (USGS), a member of the Atlantic IRT, presented results from his studies of downslope processes on the Atlantic margin. Mapped features such as landslides and debris flows represent possible areas where a base-of-slope zone may be located.

Deborah Hutchinson (USGS) presented a comprehensive overview of the needs and pitfalls in collecting, processing, and interpreting seismic data and how these data are used to determine sediment thickness, which she illustrated with examples from the Arctic and the Atlantic. Significant seismic data have been collected in the Arctic as part of the ECS Project (for example, see *Sound Waves* articles at **http://soundwaves.usgs.gov/2012/02**/, **http://soundwaves.usgs.gov/2010/08/**, and **http://soundwaves.usgs.gov/2009/04/**).

Among other contributions, the group benefited from remote participation by **Rick Saltus** (USGS), **Pat Hart** (USGS), and representatives of the NGDC and the Bureau of Ocean Energy Management (BOEM). Part of the workshop was dedicated to planning for data needs and future ship time.

The group met again in Washington, D.C., in late June 2012 to review decisions and recommendations from the April technical workshop, engage senior government managers, and construct the roadmap for doing all the remaining work identified in the April workshop.

Additional information about the project and the participating agencies is posted on the ECS Project website (**http://www.continentalshelf.gov**) and the USGS project website (**http://walrus.wr.usgs.gov/research/projects/lawofsea.html**).

Second Biannual Meeting of the Monterey Bay Marine GIS User Group

By Nadine Golden

The second biannual meeting of the Monterey Bay Marine GIS User Group was held Thursday, July 19, 2012, at the National Oceanic and Atmospheric Administration (NOAA) Southwest Fisheries Science Center in Santa Cruz, California. A GIS (geographic information system) is a computer-based system for storing, manipulating, analyzing, and managing all types of geographically referenced information. The goals of this user group are to foster collaboration among academic institutions, the private sector, government agencies, and nongovernmental organizations (NGOs) in the Monterey Bay marine GIS science community; to facilitate hands-on GIS training; and to increase awareness of marine spatial datasets within the broader GIS science community in the Monterey Bay area.

Approximately 65 members of the coastal and marine community, including GIS users, marine scientists, and policy makers, gathered to hear four presenta-

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*Monterey Bay Marine GIS User Group meeting organizers **Nadine Golden** (USGS; far left) and **Lisa Wedding** (NOAA National Marine Fisheries Service; far right), along with (left to right) **Will McClintock** (University of California, Santa Barbara), **Melissa Foley** (Center for Ocean Solutions), **Pat Halpin** (Duke University), and **Jason Roberts** (Duke University). Photograph by **Lisa Krigsman**, NOAA National Marine Fisheries Service.*

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tions that focused on current GIS and scientific research and GIS tools. The keynote speaker, **Patrick Halpin**, director of the Marine Geospatial Ecology Lab at Duke University (**http://mgel.env.duke.edu/**), began the day with a talk titled "Illuminating the Oceans: Using Geospatial Analysis to Better Understand the Marine World." **Halpin** discussed the difficulties faced by marine geospatial scientists when dealing with time and space in the open ocean, and he concluded from his own experience that using the right technical tool set can help overcome these challenges.

Next, **Will McClintock** (University of California, Santa Barbara) introduced the group to recent advancements in SeaSketch (**http://mcclintock.msi.ucsb.edu/projects/seasketch**), a widely used GIS tool set specifically designed for solving marine geospatial issues. SeaSketch, based on a combination of open-source and Environmental Systems Research Institute (ESRI) technologies, provides a new platform for applying collaborative geodesign software to marine spatial planning. ("Geodesign" is an emerging field that integrates geographic science with spatial design; learn more at **http://www.esri.com/technology-topics/geodesign/**.) With the help of friends and colleagues in the audience, **McClintock** demonstrated the decision-support tool under development at the Marine Science Institute of the University of California, Santa Barbara. This platform for collaborative ocean planning allows public participants to contribute their ideas to the marine spatial planning discussions via a web browser and the Internet.

After a lunch of networking and socializing, **Jason Roberts** (Duke University), developer of Marine Geospatial Ecology Tools (MGET; **http://mgel.env.duke.edu/mget/**), gave an overview of this free, open-source geoprocessing toolbox designed for coastal and marine GIS analysis. MGET can be invoked from most programming languages and includes more than 300 tools designed for and requested by marine researchers.

The closing speaker, **Melissa Foley** (Center for Ocean Solutions), highlighted a study that assessed the cumulative impact of multiple human activities in Monterey Bay, California. (Learn more about quantifying cumulative impacts at **http://www.centerforoceansolutions.org/initiatives/cumulative-impacts**.)

***Jason Roberts** (Duke University), Marine Geospatial Ecology Tools (MGET) developer, leads the group through some of the most popular offerings in the MGET suite of more than 300 GIS tools. Photograph by **Lisa Jensen**, Seafloor Mapping Lab, California State University, Monterey Bay.*

The following day, July 20, the Monterey Bay GIS User Group sponsored a predictive modeling MGET workshop at the California State University, Monterey Bay (CSUMB) Chapman Science Academic Center, in Seaside, California. This hands-on workshop, led by **Jason Roberts**, was attended by 40 GIS professionals and students from the Monterey Bay area and beyond. **Roberts** led the workshop attendees through an example of predictive modeling using MGET and downloadable datasets. Working through more than 25 steps and tools, participants were able to utilize some of MGET's most popular features. MGET overview presentation slides from the workshop are posted on the MGET website at **http://mgel.env.duke.edu/mget/files/2012/07/MBGIS_July_2012_Online.pptx** (about 13 MB). The modeling example reviewed in the daylong workshop will be converted to an online tutorial for posting on the MGET website.

The Monterey Bay Marine GIS User Group will meet again in spring 2013; details will be posted soon on the NOAA Southwest Fisheries Science Center website (**http://swfsc.noaa.gov/MontereyBayGIS/**). For questions about the Monterey Bay Marine GIS User Group or its meetings, please contact **Lisa Wedding** at **lwedding@ucsc.edu** or **Nadine Golden** at **ngolden@usgs.gov**.

*MGET workshop participants take a lunch break at California State University, Monterey Bay (CSUMB). Photograph by **Lisa Jensen**, Seafloor Mapping Lab, CSUMB.*

Coastal and Marine Geology Program Goes for the Gold, Participates in Federal Food Drive

By Carolyn Degnan

During the summer months, food banks traditionally encounter a lull in the level of giving due to vacations and other demands on donors' time. This year, a surge in demand coupled with a drop in donations literally emptied the shelves of many food pantries. In the spirit of the 2012 Olympic Games, the three science centers of the U.S. Geological Survey (USGS) Coastal and Marine Geology Program (CMGP) competed in a "CMGP Challenge" to see which center could donate the most nonperishable food to the 2012 Feds Feed Families campaign (**http://www.fedsfeedfamilies.gov/**). The Pacific Coastal and Marine Science Center (Santa Cruz, California) took an early lead at the first weigh-in, but the Woods Hole Coastal and Marine Science Center (Woods Hole, Massachusetts) made great strides at the second weigh-in. The St. Petersburg Coastal and Marine Science Center (St. Petersburg, Florida), spurred on by seeing the early numbers from the other centers, worked hard to boost their tally. By the end of the drive, on August 31, the CMGP Challenge's cumulative total was 1,270 pounds, collected by staff, contractors, and volunteers at the three centers working on their own time. The Pacific center took the gold, St. Petersburg the silver, and Woods Hole the bronze.

The CMGP Challenge was initiated by USGS scientist **Fran Lightsom** at the Woods Hole Coastal and Marine Science Center. Collection coordinators at each center were **Andrea Toran** (Woods Hole), **Molly McLaughlin** (St. Petersburg), and **Carolyn Degnan** (Santa Cruz).

Feds Feed Families—a government-wide effort led by the Chief Human Capital Officers Council in partnership with the Office of Personnel Management, the U.S. Department of Defense, and the U.S. Department of Agriculture—collects nonperishable food donations during June, July, and August. This national food drive by multiple federal agencies contributes to local food banks across the country.❁

USGS personnel at the Pacific Coastal and Marine Science Center in Santa Cruz, California, kick off the center's Feds Feed Families food drive. Clockwise from lower left: ***Julia Klofas, Carolyn Degnan, Michael Torresan, Anthony Guerriero, Amy Foxgrover, Guy Gelfenbaum, Jane Reid*** *(partly hidden),* ***Hannah Waiters, Carol Reiss,*** *and* ***Angela Lam*** *(partly hidden). Photograph by* ***Laura Torresan****.*

Quantifying How Often Sediments Move on the U.S. Continental Shelf—the U.S. Geological Survey Sea Floor Stress and Sediment Mobility Database

By P. Soupy Dalyander and Bradford Butman

Tidal currents, wind-driven currents, and ocean waves all create a force at the seabed called bottom shear stress. This stress, if sufficiently strong, can cause sediment to be resuspended from the seafloor (see "How Often Do Sediments on the Seafloor Move?" in *Sound Waves*, March/April 2012, **http://soundwaves.usgs.gov/2012/04/research3.html**). Information on the strength and variability of bottom shear stress, and the consequent frequency and intensity of sediment mobility events, is of interest to geologists and others because of implications for seafloor geology, benthic habitats, and human use, such as installation of offshore wind turbines where near-bottom forces

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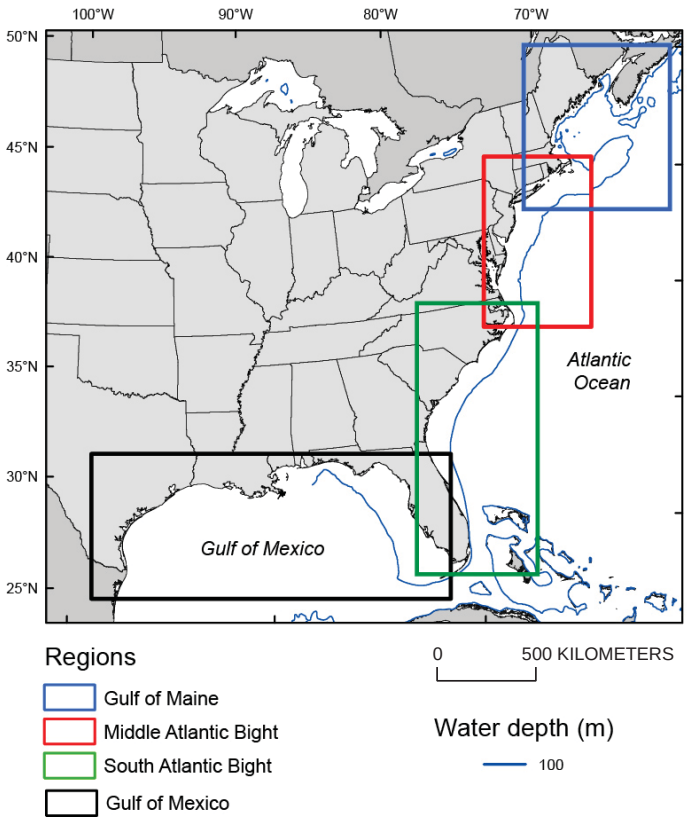
may induce scour around structures and cables.

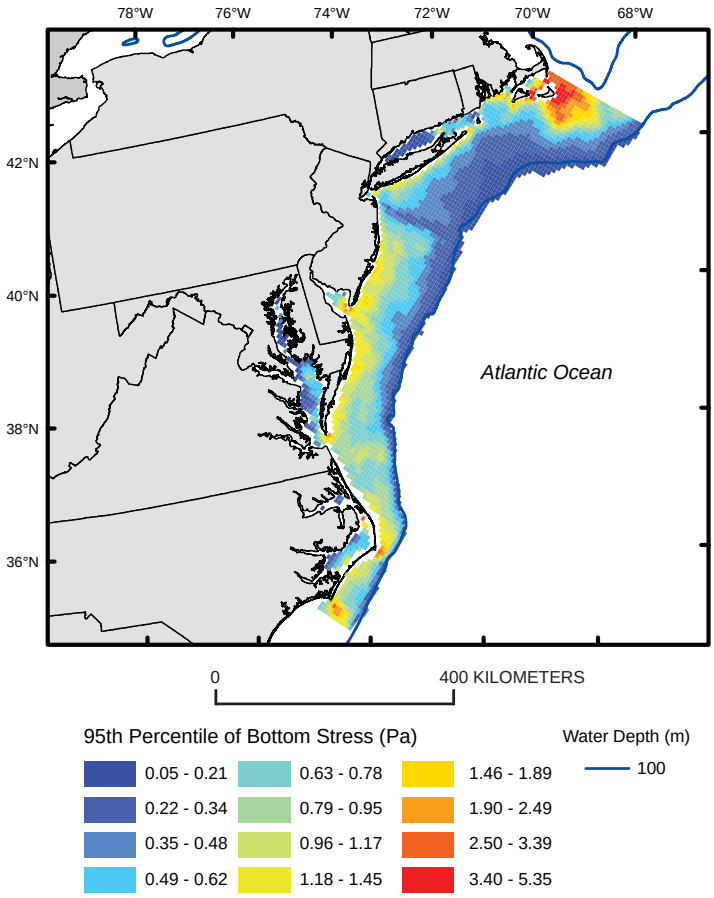
The U.S. Geological Survey Sea Floor Stress and Sediment Mobility Database has been established (**http://pubs.usgs.gov/of/2012/1137/**), and data for the Middle Atlantic Bight—the continental-shelf area between Cape Hatteras and Cape Cod—are now online (**http://woodshole.er.usgs.gov/project-pages/mobility/**).

The database provides spatially and seasonally resolved statistics on bottom shear stress estimated at an approximately 5-kilometer scale using numerical models. Statistics on sediment mobility, reported as the percentage of time that bottom shear stress is sufficient to move sediments, are also provided where data on the grain size of the seafloor sediment are available.

The statistical representations of bottom shear stress and sediment mobility are available for download as ArcGIS polygon and point shapefiles. Statistics for the South Atlantic Bight, the Gulf of Mexico, and the Gulf of Maine will be added to the database as analysis is completed.



*Map showing location of the four study areas included in the U.S. Geological Survey Sea Floor Stress and Sediment Mobility Database (**http://woodshole.er.usgs.gov/project-pages/mobility/**). Statistics for the Middle Atlantic Bight are currently available; data for the other regions will be added in late 2012 and early 2013 as analysis is completed. Users can download zip files containing ArcGIS shapefiles and associated metadata in polygon format (for characterizations of bottom shear stress) and point format (for characterizations of sediment mobility). Statistics for bottom shear stress include spatially variant, yearly and seasonal estimates of the median, representing the midpoint in the range of values; the interpercentile range, characterizing variability; and the 95th percentile, representing the shear-stress value that is exceeded 5 percent of the time. Statistics for sediment mobility include the percentage of time bottom sediment is subject to being mobilized and the recurrence interval of mobility events by season and year.*



Sample of the data available for download in ArcGIS format from the U.S. Geological Survey Sea Floor Stress and Sediment Mobility Database. Shown is the 95th percentile (an estimate of the most extreme values, exceeded only 5 percent of the time) of combined wave- and current-induced bottom shear stress in pascals (Pa) for the Middle Atlantic Bight. The analysis delineates regions of high stress, shown in reds and yellows and commonly found in coastal areas owing to the stronger influence of waves at shallower depths; and more quiescent regions, shown in blue and found at greater depths extending to the edge of the continental shelf.

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