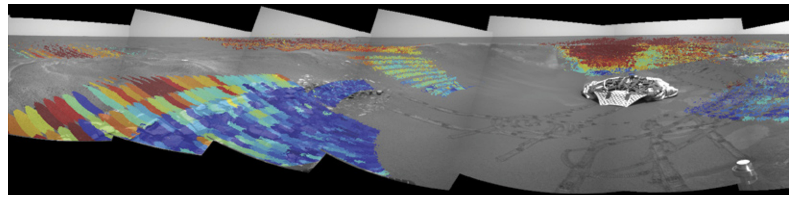


Opportunity by the Sea

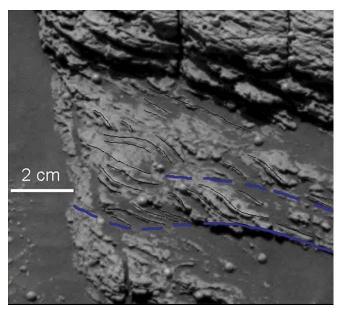
As *E&S* was going to press, it was announced that Opportunity, one of JPL's twin Mars rovers, had found conclusive evidence of gently flowing saltwater at its landing site on Meridiani Planum. The layers in a rock called Last Chance "were shaped into ripples by water at least five centimeters deep, possibly much deeper, and flowing at a speed of 10 to 50 centimeters per second," said MIT's John Grotzinger, a member of the science team. "Ripples that formed in wind look different than ripples formed in water."

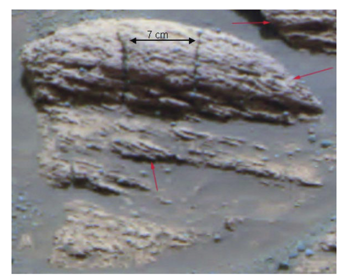
This cross-bedding, as it's called, is a characteristic of sedimentary rock and corroborates other physical and chemical evidence that hinted of minerals precipitating out of salty water as it evaporated.

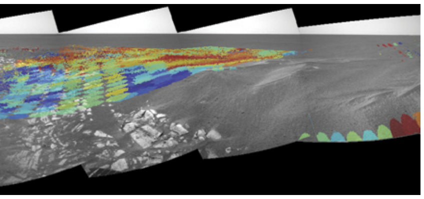
It's still unknown how long the water lasted, how extensive it was, or how long ago it was there, but it clearly shows that Mars was more hospitable to life in the past. And life's traces may remain—such rocks "offer excellent capability for preserving evidence of any biochemical or biological material" for future missions, said Cornell University's Steve Squyres, the principal investigator for the rovers' science payload.

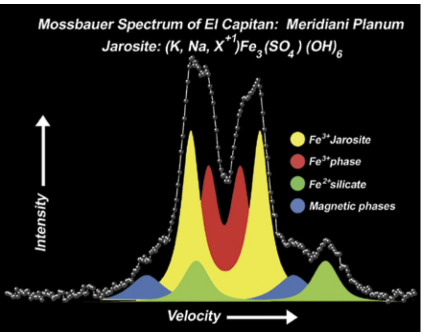
On the opposite side of the planet, the other rover, Spirit, has picked its way through the ejecta field to the rim of Bonneville crater (below), sampling rocks en route. Alas, the interior proved devoid of interesting outcrops, and Spirit is now setting out for the Columbia Hills to the far right, a couple of kilometers and perhaps several months away. □—*DS*

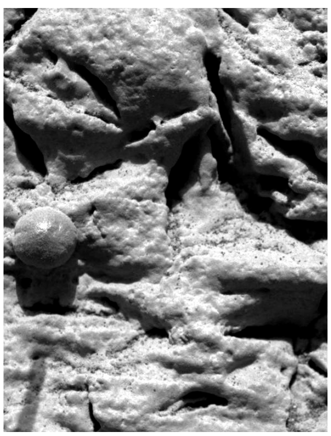
The case for a seashore, clockwise from above: 1) Opportunity scored a hole-in-one, landing in a shallow crater some 22 meters wide, and then hit the jackpot when the crater proved to have exposed bedrock—the flat, whitish stones. The rover verified high levels of gray hematite (seen in red in the overlay), which usually forms in water. 2) The outcrop contains jarosite, a mineral that incorporates water in the form of OH groups. 3) BB-sized "blueberries" of hematite are eroding out of the rock, littering the area. The embedded blueberries, like the one near the image's left edge, continue the rock's fine layering, most notably as the groove around the blueberry's middle. This shows that they formed in situ through precipitation. And the thin, flat voids, called "vugs," were created where salt crystals grew and later dissolved away; high levels of bromine and chlorine still remain. 4) The blueberries can also be seen on and around Last Chance, where the arrows point to cross-bedded areas. 5) A close-up of Last Chance's central region has black lines added to highlight the smile-shaped ripples, or "festoons." The blue dashes mark where the ripples changed direction with the shifting currents.











Meanwhile, at the Edge of the Solar System. . .

A Caltech-led team has discovered the most distant member of the solar system so far. The new planetoid, more than 13 billion kilometers from Earth, or over three times the distance to Pluto, is well beyond the recently discovered Kuiper belt and is likely the first detection of the long-hypothesized Oort cloud. This cloud, predicted 54 years ago by Dutch astronomer Jan Oort to explain the existence of certain comets, extends halfway to the nearest star and is the repository of small icy bodies that occasionally get pulled in toward the sun. The object was found on November 14, using the 48-inch Samuel Oschin Telescope at Caltech's Palomar Observatory.

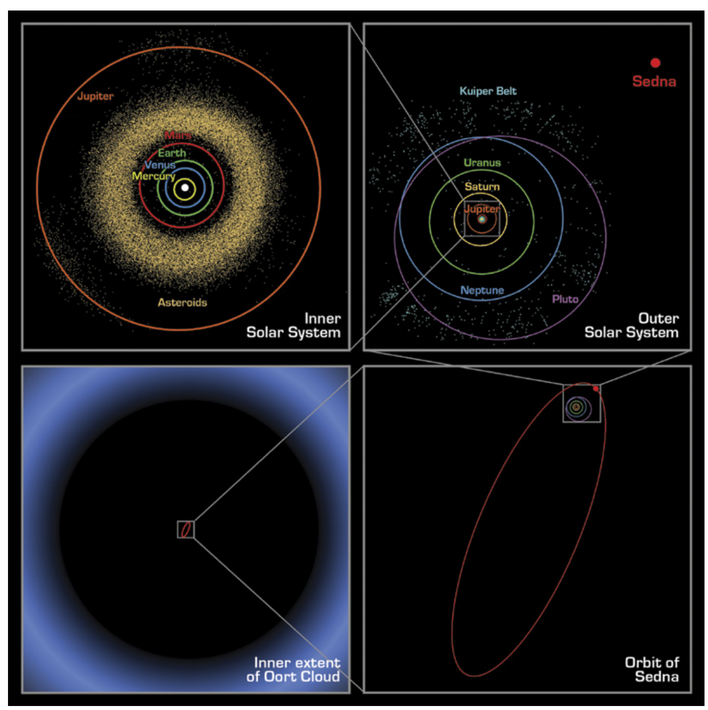
The sun is so far from this planetoid, says team leader Mike Brown, associate professor of planetary astronomy, "that you could completely block it out with the head of a pin." And the object gets this close only briefly during its 10,500-year orbit. At its most distant, it is 130 billion kilometers, or 900 times Earth's distance, from the sun, and its temperature plummets to just 20 degrees above absolute zero.

Thus Brown and his colleagues Chad Trujillo of the Gemini Observatory and David Rabinowitz of Yale University propose that the frigid planetoid be named "Sedna," after the Inuit goddess who created the sea creatures of the Arctic. She lives in an icy cave at the bottom of the ocean—an appropriate spot for the namesake of the coldest known body in the solar system.

Distant as it is, Sedna is much closer than expected, as the Oort cloud had been predicted to begin 10 times farther away. Brown believes that the "inner Oort cloud" where Sedna resides was formed by the gravitational pull of a rogue star that came close to the sun early in the history of the solar system. Such a star, says Brown, "would have been brighter than the full moon and visible in the daytime sky for 20,000 years." Worse, it would have dislodged comets further out in the Oort cloud, leading to an intense comet shower that would have wiped out any life on Earth that existed at the time.

Images from the Spitzer Space Telescope, which Caltech and JPL run for NASA, indicate that Sedna is no more than 1,700 kilometers in diameter, making it smaller than Pluto.

Right: Sedna's highly elliptical orbit, inclined from the plane of the solar system by 11.9 degrees, travels from well outside Pluto's orbit to the boondocks between us and the Oort cloud.



Brown estimates that it is probably about three-quarters Pluto's size. Rabinowitz says that indirect evidence suggests that Sedna has a moon—a possibility best checked with the Hubble Space Telescope—and he notes that Sedna is redder than anything known in the solar system with the exception of Mars, but no one can say why. Trujillo admits, "We still don't understand what is on the surface of this body. It is nothing like what we would have predicted." But the astronomers aren't worried. They have plenty of time to figure things out—Sedna will get closer and brighter for the next 72 years before fading away again. □—*RT*

Below: Swords into plowshares—Art Center College of Design, the Caltech of the art world, has turned the onetime Southern California Cooperative Wind Tunnel on South Raymond Avenue into its new South Campus. The wind tunnel was built by Caltech during World War II for Consolidated Vultee, Douglas, Lockheed, and North American, and was upgraded in the mid-'50s to become one of the first large supersonic wind tunnels in the world. Under the directorship of Professor of Aeronautics Clark Millikan (PhD '28), it remained enormously productive through the Cold War until 1960, when operations ceased. (One of the last things tested in it was a 1/5-scale model of the Polaris missile.) This photo, taken during the upgrade, shows the tunnel's airlock, which contained the 12-foot-diameter test section. In its new life, the 17,000-square-foot tunnel hall in the background will become an exhibit and performace space. The rest of the 100,000-square-foot complex will house studios, offices, and a letterpress. The public is invited to an open house on Sunday, May 16.

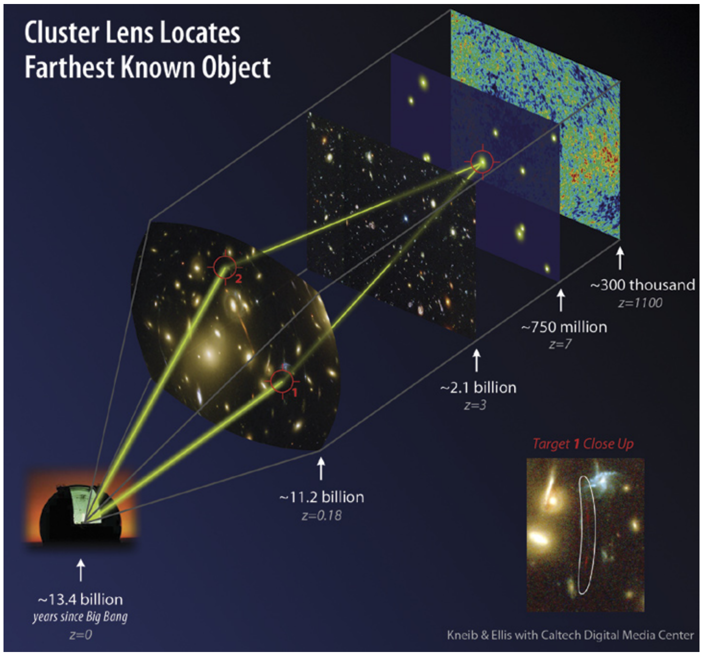
And at the Far End of the Universe. . .

Caltech astronomers may have discovered the farthest known object in the universe—a galaxy so distant that its light would have left for Earth when the universe was perhaps just 750 million years old. Visiting Associate Jean-Paul Kneib, the lead author of a paper in an upcoming issue of the *Astrophysical Journal*, says the galaxy has a redshift of 7.05, so great that its ultraviolet light is now seen at infrared wavelengths. Redshift is a measure of the factor by which light's wavelength is stretched as it passes through the expanding universe. The greater the shift, the more distant the object and the earlier it is being seen in cosmic history.

The galaxy, which was found with the Hubble Space Telescope and later studied at the Keck Observatory, is relatively small—perhaps only 2,000 light-years across, compared to our own Milky Way's 100,000 light-year diameter—but forming stars at an extremely high rate. Oddly, it seems to lack the typically bright hydrogen emission seen in many distant objects. And its intense ultraviolet signal is much stronger than that seen in later star-forming galaxies, suggesting that it may be composed primarily of massive stars. "These unusual properties, if verified, could represent those to be expected for the young stellar systems that ended the dark ages," said coauthor Richard Ellis, the Steele Family Professor of Astronomy.

The term "Dark Ages" was coined by the British astronomer Sir Martin Rees to signify the period in cosmic history when hydrogen atoms had formed, but stars had not yet had the opportunity to condense and ignite. Nobody is quite clear how long this phase lasted, and the detailed study of its end is a major goal of modern cosmology.

The team consists of Kneib; Ellis; Mike Santos, now a postdoctoral researcher at the Institute of Astronomy in Cambridge, England; and Johan Richard. Kneib and Richard are also affiliated with the Observatoire Midi-Pyrénées of Toulouse, France. □—*RT*



Above: The galaxy lies behind a relatively nearby cluster of galaxies called Abell 2218, which is at a redshift of 0.18 and whose light left for us when the universe was about 11.2 billion years old. As Einstein predicted, Abell 2218's mass bends the path of light in its vicinity, acting as an enormous lens that happens to focus the newfound galaxy's light on Earth. In this case, the galaxy is not only magnified by a factor of 25, making it visible to us, but three weirdly distorted images of it are produced, two of which are circled and one of which is shown in the inset. Also shown are some intermediate-aged galaxies at a redshift of 3, and the cosmic microwave background, which dates back to about 300,000 years after the Big Bang.

Like most neophyte drivers, Bob tended to ride his brakes. As he crept around the vast, deserted parking lot at the Santa Anita racetrack in Arcadia, the '96 Chevy Tahoe bucked and lurched every 10 feet or so, brake lights flashing. His instructors, a cluster of undergrads pounding on laptops under a marquee tent a hundred yards away, conferred with their advisor, Richard Murray (BS '85), professor of mechanical engineering and chair of the Division of Engineering and Applied Science. "It's some bug in the software." "No, the gain is set wrong." No problem—the big race was still two weeks off.

Since spring 2003, when more than 50 undergrads did the preliminary studies for course credit, Caltech has been an entrant in the Defense Advanced Research Projects Agency's Grand Challenge Race. Looking for fresh approaches to tough problems, DARPA has offered a million bucks cash to the first vehicle to drive itself off-road from L.A. to Las Vegas in under 10 hours without human intervention. To prevent folks from tailoring their software to the course, the exact route was kept secret until two hours before the 6:30 a.m. race time on March 13. In fact, the course actually ran from Barstow to Primm, on the California-Nevada border, a distance of 142 miles as the dune buggy jounces. (By contrast, JPL's autonomous Mars rovers might go 80 meters on a good day.)

The challenge drew robotics enthusiasts, programming wizards, and homegrown mechanical geniuses of all sorts. They modified SUVs, ATVs, sand rails, and even a motorcycle—an idea with some seductive advantages, and some really obvious drawbacks. And there were scratch-built creations like the six-wheeler with three articulated body segments that looked like a toddler's pull toy. But Carnegie Mellon University's Sandstorm, a modified Humvee—military surplus, not the H2 marketed to yuppies—was widely seen as the 'bot to beat. CMU had spent over

QID finalists came in all shapes and sizes. TerraMax (left) is a 16-ton Army truck whose paint job screams, "Get the @#%*! out of my way!" The U. of Louisiana at Lafayette's ATV (below) weighs a few hundred pounds.

$3.5 million, and had been profiled in *Scientific American*.

At Caltech, 23 undergrads spent their summer modifying Bob and writing his software. Sixteen have continued this academic year as the "working team," with assorted faculty members and folks at JPL, Northrop Grumman, the University of Delaware, and Ford providing advice. Bob's rear seats were torn out to make room for the electronics. "The computers are mounted on foam and strapped down with bungee cords," says Project Manager David van Gogh, a Caltech staff member. "They survive the bouncing pretty well." It takes a lot of juice to run all of Bob's systems, the steering gear, and the air conditioning that keeps the computers happy, so a six-kilowatt gasoline-powered generator rides shotgun.

In case you don't remember the adrenaline rush from your first time behind the wheel in oncoming traffic, driving is hard. It takes Bob eight PCs. One operates the inertial measurement unit (IMU), which does "dead reckoning" based on data from three accelerometers and three gyroscopes. Another handles the roof- and bumper-mounted LADARs, scanning laser "radars" that look for obstacles. Computer number three takes data from the long-range stereo cameras, and number four from the short-range cameras, all of which are mounted on the roof. The fifth PC runs road-following software—"it looks for parallel line segments in each video frame, and computes where they go," says van Gogh. "We have 30 gigs of color data that are going to make a really cool movie of Bob following the road." The sixth brain does "state estimation," taking data from the onboard GPS unit, a magnetometer (a fancy compass), and the IMU, and calculating Bob's location, heading, and slope. Number seven does vehicle management, using Bob's own diagnostic package—the same one your mechanic taps into when you take your car into the shop.

The eighth computer runs a software package called the "arbiter." The arbiter presents Bob's possible next moves to the other computers, which rate them on a scale of zero to 100. "So if they all say go right," explains Murray, "Bob will turn right." If opinions diverge, the arbiter makes the call. A single "nay" can veto a plan, if cast strenuously enough. "In one early test, we were supposed to make a U-turn to the left," says Murray. "But it was late in the day, and the sun was low enough to be in our field of view, and one computer kept saying, 'Omigod, there's this huge obstacle—DON'T TURN! DON'T TURN!!' So we kept going straight until a pole blocked the sun for a moment, and then it let us turn. But by then we were way off course, because we'd gone too far forward."

Out of hundreds of submissions, DARPA picked 25 for the Qualification, Inspection, and Demonstration (QID) at the California Speedway in Fontana. In this five-day event leading up to Saturday's race, the 'bots were to complete a 1.35-mile dogbone course with such obstacles as a cattle crossing, a sand pit, and an overpass with pillars to squeeze between. Freeway-sized concrete K-rails protected the spectators from errant entrants.

Each 'bot got a detailed safety inspection, and then had a half-hour turn to show its stuff. (Bob sports an amber light and beeper, like those found on construction equipment, to warn bystanders that it's driving itself.) Bob was the third 'bot up. It was not an auspicious beginning—the first two had sat in the starting chute for their full half hour, not advancing so much as a single wheel turn. Bob didn't begin much better—for the first 15 mintues or so, he, too, was lost in thought. Then the generator revved, and, beeping and flashing, Bob rolled onto the course to cheers from the crowd—followed immediately by a collective groan when he ground to a halt after about 20 feet, well before the first obstacle. (It turned out later that this was a prescribed live test of his remote-control kill switch.)

Five minutes of dead silence ensued, and it looked like Bob's day was going to

Some of Bob's support team. Front row, from left: Sue Ann Hong (with white visor), Raquel "Rocky" Velez, Meghan Crowley, Jacki Wilbur (with sunglasses), Tully Foote, and Mike Thielman. Back row: Ike Gremmer, Lars Cremean, Scott Fleming, Thyago Consort (holding water bottle), Jeremy Gillula's arms, and Meaghan Paceley.

Left: Bob takes a hill on the QID. The LADARs are the gray things that look like coffee makers. Note the good-luck toy flamingo next to the IMU, below the stereo cameras. Below: Alan Somers and Jason Raycroft cheer Bob on.

Above: In the starting chutes at the Slash X Café near Barstow are, from left, Sandstorm, SciAutonics II, and Bob.

be over almost before it began. Then—doot, doot, doot—he came to life. He took off at a brisk five miles per hour, with a cheering crowd of Techers, media, and other onlookers in hot pursuit. Bob aced the first half of the course, pausing at times for bouts of intense cogitation, and headed for the overpass. He shot the gap, but lost his GPS signal under the bridge. The IMU wasn't working, so Bob drifted to the right. As soon as he cleared the K-rails protecting the bridge, he made a hard right and took off toward a second set of K-rails some 30 yards from the course. He stopped about 10 feet short, and considered his options. "The sensors are telling him there's an obstacle ahead," explained undergrad Scott Fleming. "And he knows that he's too close to the wall to just cut his wheels and go forward. So what he should do is back up, straighten out, and get back on the course. But we've been having trouble with the transmission controller, and I don't know if we *have* reverse. He's been stuck in first gear all day."

After what seemed like an eternity, but was probably only two or three minutes, Bob very slowly and deliberately drove into the wall. Caltech's track time was over for that round, but the buzz of being the first live contender was tremendous, and Team Caltech's triumph was all over CNN by the time Bob got back to the garage.

What the QID mainly demonstrated was the programmer's version of Murphy's Law: There are three things one should never expect to do tricks on command—your children, your pets, and your software. Everyone suffered from glitches at one point or another. Virgina Tech managed to get crosswise in the starting chute. Sandstorm shifted into gear of its own accord and rammed a closed gate. And Digital Auto Drive nearly crashed into a minivan parked on the course as an obstacle, and was shut down by remote control. (After some discussion, DAD's handlers were allowed to come out and reposition it to clear the van, like a kid picking up an errant slot car and putting it back on the track.)

By Thursday afternoon, Bob had successfully run the course twice, as had Sandstorm, which, 24 hours after Bob's big start, became the first entrant to actually finish a lap. Five other teams, including DAD, completed one lap. In toto, 15 vehicles were given the nod to try their luck in Barstow.

The desert's secret weapon proved not to be rocks, brush, or ditches, but barbed wire. Hard for even humans to see, at least four vehicles wound up wearing it. Bob ran afoul of it at mile 1.3. Says Lecturer in Engineering Antony Fender, who returned at the same hour the next morning and followed Bob's tracks, "The contrast between the dirt road and the shadows across it was extremely high. It appears that Bob tried to drive around a large shadow. He turned left through the wire fence at a shallow angle, maneuvering neatly to avoid the posts, and drove parallel to the road for a couple of hundred yards, weaving among the bushes. Then he made a right-angle turn to go back on the road, absolutely dead center between two posts, and got stuck."

Sandstorm did the best, and even it only got to mile 7.4. It ran off a mountain switchback, and was saved from a career-ending plunge by getting its undercarriage stuck on the berm. With its left wheels dangling in space, the right rear tire dug in, snapping the half-shaft, and the front one spun until it caught fire. DARPA's chase crew hit the kill switch and extinguished the blaze before it spread.

Caltech is already planning for the rematch, for which DARPA has upped the prize to $2 million. The date has not been announced, but, says van Gogh, "It would be nice if it were in 18 months instead of 12." □—*DS*

Bob's front bumper and its LADAR unit left a perfect impression in the barbed wire.