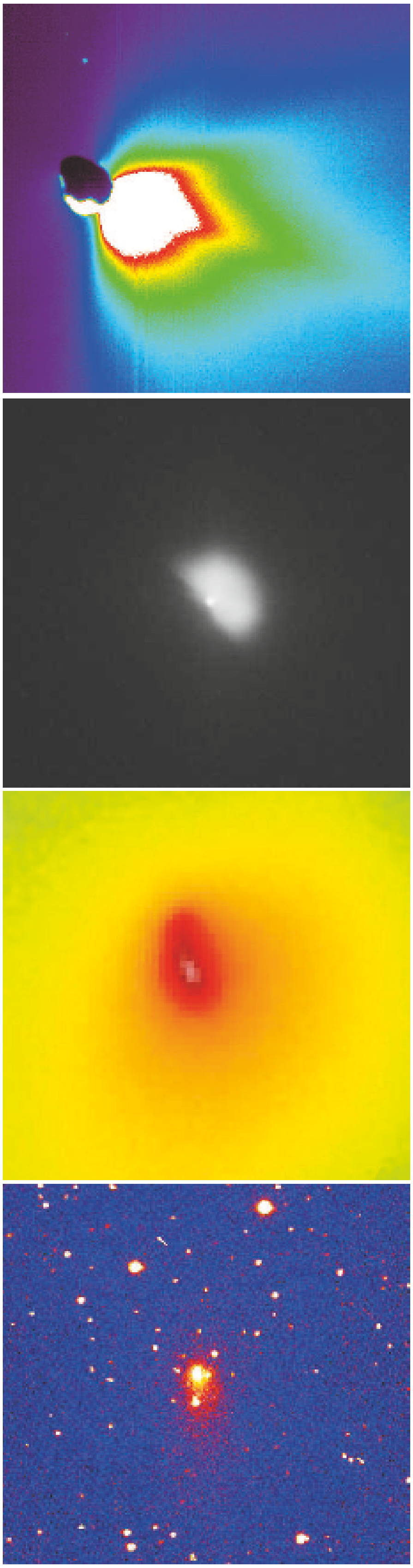
Deep Impact: sifting through the debris

When Deep Impact's washing-machine-sized probe slammed into comet Tempel 1 on 4 July, teams of astronomers watched using telescopes in space and around the world. *Nature* investigates what the images tell us so far about the comet's composition and history.



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Top, false-colour image from the Deep Impact mother ship after its probe smashed into comet Tempel 1. Second, image from orbiting Hubble telescope. Third, red-filtered image of dust from a ground-based observatory. Bottom, view from the Rosetta probe, due to meet its own comet in 2014.

The mission's goal was to probe a comet as never before. As the impactor neared the comet's surface at a 25° angle, it took pictures of the landscape beneath that reveal a complex geological history, sculpted by outgassing, melting and natural impacts. Cross-sections that are 20 to 30 metres high display several different layers, confirming that Tempel 1 must have spent time in different orbits. And pictures from the probe's last moments reveal surface features just four metres across, says principal investigator Michael A'Hearn of the University of Maryland, College Park. "That's nearly a factor of ten better than any previous comet mission."

But the aftermath of the collision is throwing up some surprises. The image top left is a false-colour picture taken by the Deep Impact mother ship as it looked back, 50 minutes after the crash. The dusty debris ejected from the impact crater formed a much bigger cloud than expected, and it is still reflecting bright sunlight to scores of telescopes back on Earth.

> "The dust from the comet's surface was extremely fine, more like talcum powder than beach sand."

"That suggests the dust excavated from the comet's surface was extremely fine, more like talcum powder than beach sand," explains A'Hearn. No large chunks of material have been seen, so the surface is unlikely to have an icy crust.

The dust plume was so thick that the mother ship couldn't even see the crater when it looked back. Mission scientists are busy massaging the images to pick out any details, but the diameter of the plume indicates that the crater is between 100 and 300 metres across. Second from top left is an image taken by the Hubble Space Telescope about 64 minutes after impact. The wider view shows debris extending about 720 kilometres from the nucleus. Rough calculations from the way it has scattered show the comet is much less dense than water ice, and is extremely porous.

As the impactor hit, the Deep Impact team also saw two bright flashes, separated by just milliseconds. This matches simulations conducted by Peter Schultz of Brown University in Providence, Rhode Island, who thinks the first flash came from surface material heated to thousands of degrees. The second, much brighter flash probably came as the molten probe burrowed deeper into the nucleus and hit a layer of more volatile material.

Before the crash, scientists wondered whether the water inside the crater would quickly refreeze to heal the scar created. Instead, the wound has been pumping out material ever since the 372-kilogram, copper-reinforced probe slammed into its target at 10 kilometres per second. Scientists working on NASA's Swift satellite report that the X-ray glow from the comet is still growing five days after impact. Based on these data, Paul O'Brien, part of the Swift team at the University of Leicester, UK, estimates that several tens of thousands of tonnes of material were released.

Astronomers are particularly interested in what compounds are present in Tempel 1. They are sure that comets played a key role billions of years ago in bringing water from the outskirts of the Solar System to the primitive Earth, which would have been too hot at first to hang on to its own water. But they could have also delivered the carbon and nitrogen that helped to get life established, says Schultz.

Molecular fragments with two and three carbon atoms and nitrogen-containing compounds have already been detected by the UK Schmidt Telescope at the Anglo-Australian Observatory in New South Wales. This supports the idea that the comet's interior may be rich in organics. "But one of the surprises is

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Sparks fly: the Deep Impact craft looks back at the comet's core, capturing the afterglow of the smash.

that we didn't see much gas," adds Andrew Coates of University College London, who is collating data from British telescopes around the world. "Most of it is dusty, grainy material." The third picture on the left is from the European Space Agency's Optical Ground Station in the Canary Islands; it uses a red filter to highlight the dust particles.

Infrared measurements have revealed only weak signatures of water, carbon dioxide and ammonia. "This event did not produce a gusher," says Gary Melnick, principal investigator for NASA's Submillimeter Wave Astronomy Satellite. First estimates suggest the comet produced just 250 kilograms of water per second after the impact, less than in natural outbursts observed in preceding weeks.

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A close-up taken by the impactor before it hit the comet shows the surface in unprecedented detail.

So Tempel 1 was probably not the 'pressure cooker' that some expected. Because the comet passes close to the Sun on each orbit, solar heating could have built up gas pressure inside, releasing a fierce blast when its crust was punctured. Instead, the Sun's heat seems to have baked out volatile materials from the outermost metres, leaving a fine dust of minerals and organics. "Theories about the volatile layers below the surface of short-period comets are going to have to be revised," says Charlie Qi, an astronomer at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

Working out how comets may have influenced our own origins will take much longer to assess, and will require a mission to bring back samples from a comet. Deep Impact is an important stepping stone, says Joe Veverka of Cornell University in Ithaca, New York. He points out that we now know that comet surfaces are strong enough to land on, yet loose enough to burrow through to retrieve subsurface material, behaving like a layer of fresh snow.

NASA's Stardust craft is expected to bring samples of comet Wild 2's dusty haze back to Earth in January 2006, and the European Space Agency's Rosetta mission is on course to land a probe on comet Churyumov-Gerasimenko in 2014. The bottom picture on the far left shows Rosetta's view of the Deep Impact crash, taken a few minutes after the strike. ■

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