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Bringing Part of an Asteroid Back Home

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PLANETARY SCIENCE

Bringing Part of an Asteroid Back Home

A space mission that took samples of an asteroid has provided insights into the evolution of the solar system.

Alexander N. Krot

Meteorites are the oldest rocks in our solar system, and therefore record the earliest stages of its evolution. On the basis of their mineralogy, petrography, bulk chemistry, and oxygen-isotope compositions, meteorites are classified into more than 70 groups. Each group is believed to represent samples of one or a few larger bodies that formed early in the solar system and may still be represented by asteroids (*1*) in the main asteroid belt, which lies between the orbits of Mars and Jupiter. Various types of asteroids have been identified based on their spectral properties. Linking the meteorite groups to these asteroid types is critical for assessing the meteorite data and using it as a basis for inferring, for example, the composition and growth of Earth and other planets. Because we have lacked direct samples of specific asteroids, we have had to rely on remote observations of asteroids and relate them to the meteorite groups. This has been problematic because the surfaces of asteroids have been heavily modified by space weathering, which changes their spectral properties. To establish such a connection and understand the role of space weathering, the JAXA (Japan Aerospace Exploration Agency) spacecraft Hayabusa was sent to near-Earth asteroid 25143 Itokawa, which is 0.5 by 0.3 by 0.2 km in size to collect and bring back to Earth samples of its surface (see the figure). Itokawa is an S-type asteroid, the most abundant spectral type of asteroid in the inner asteroid belt.

On 25 November 2005, Hayabusa gently landed on Itokawa. Because of several glitches, it wasn't clear whether the spacecraft had successfully sampled the asteroid, and the return to Earth became longer and more harrowing than planned. However, on 13 June 2010, Hayabusa successfully returned to Earth along with more than 1500 rocky particles, up to 180 μm in size, from Itokawa. These particles are the first samples returned from an asteroid and the second set of samples of extraterrestrial surface rock material returned to Earth. (The first were the lunar samples collected by the NASA Apollo and Soviet Luna missions.) The detailed laboratory studies of the mineralogy, petrography, chemistry, and noble gas and oxygen-isotope compositions of the Itokawa particles reported in this issue (*2–7*) provide unequivocal evidence that S-type asteroids like Itokawa were the parent bodies of ordinary chondrites, the most abundant type of meteorites found on Earth. Three groups of ordinary chondrites are currently recognized—H, L, and LL (*1*)—with slightly different chemistry and thermal histories. Itokawa is composed of thermally metamorphosed LL4, LL5, and LL6 materials.

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Sampling an asteroid. Illustration of the release of the target marker by Hayabusa before landing on the surface of the Itokawa asteroid.

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Despite the small sizes of the samples returned (typically 10 to 50 μm), they revealed that Itokawa had a complex formation history and that its surface is dynamic today. The asteroid was initially much larger, more than 20 km in diameter, and experienced intensive thermal metamorphism at ~800°C, possibly by decay of a short-lived radionuclide ^{26}Al, during the first 10 million years of solar system evolution. It was subsequently catastrophically disaggregated by impacts into small pieces, some of which reaccreted into the present rubble-pile asteroid (*2*).

High-resolution x-ray microtomography combined with scanning and TEM (*5*, *6*) and noble gas analyses (*7*) of Itokawa particles provide insights into the formation of the loose material on the surface of the asteroid (regolith), the history of irradiation by cosmic rays and solar wind, and the nature of space weathering on asteroid-sized bodies. The Itokawa particles resulted from mechanical disaggregation by meteoroids and grain abrasion due to seismic-induced grain migration, but escaped in situ melting and formation of agglutinates, commonly observed in lunar regolith. Space weathering was also different from the lunar-style space weathering and resulted in vapor deposition of sulfur-bearing Fe-rich nanoparticles and formation of an amorphous surface layer accompanied by minor in situ reduction of Fe^{2+} to nanophase Fe metal by deeply implanted solar wind ions (*6*). The grains experienced multiple implantations of solar wind particles and on average resided for less than 8 million years on the surface. Itokawa is thus continuously losing surface materials into space at a rate of tens of centimeters per million years. At this rate, it will disappear in less than 1 billion years (*7*).

The results from the JAXA Hayabusa (*2–7*) and NASA Stardust (returned samples of Jupiter Family Comet Wild2) (*8*, *9*) and Genesis (returned samples of solar wind) missions (*10*, *11*) have demonstrated that solar system samples returned for study in terrestrial laboratories are crucial in understanding the origin and evolution of the solar system. These missions, however, have not delivered any water-bearing mineral species, which are important for understanding one of the most outstanding questions in planetary science—the origin of Earth's water (*12*). Several potential sources of that water are being discussed, including cometary, asteroidal, and water adsorbed on the surface of fine-grained dust during the initial stages of planetary accretion (*12–14*). Hydrogen isotopic measurements of water-bearing minerals in terrestrially uncontaminated samples from the hydrated B-, C-, or D-type asteroids, possible sources of hydrated carbonaceous chondrites, can potentially provide a key for understanding a role of asteroidal water in the origin of Earth's oceans. Two sample-returning missions to asteroids rich in organ-

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ics and hydrated minerals have been recently approved. The JAXA Hayabusa-2 spacecraft will be launched in 2014 to a C-type asteroid, 1999 JU3. The NASA mission OSIRIS-Rex (standing for Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer) scheduled for 2016 will explore a B-type asteroid, 1999 RQ6.

These voyages of exploration will undoubtedly expand our knowledge of near-Earth space as it currently exists and contribute significantly to humanity's understanding of Earth's most distant past.

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CELL BIOLOGY

Arranging a Cellular Checkerboard

Heterotypic cell adhesion mediated by nectins directs the complex cellular architecture of the inner ear.

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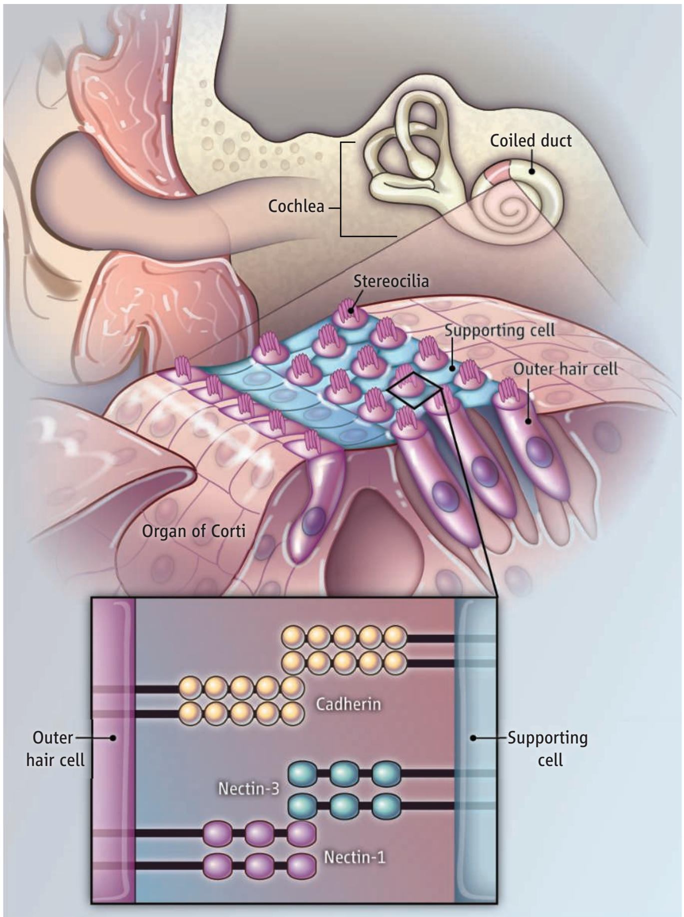
Biological patterns are all around us, ranging from the complex patterns on butterfly wings to the baroque architecture of kidney tubules. These patterns reflect the organization of millions of cell types in intricate yet reproducible ways to build tissues and organs. Even more remarkable, these patterns often arise through the self-assembly of undifferentiated cells. Understanding how this occurs is a key challenge for biologists. On page 1144 in this issue, Togashi *et al*. (*1*) implicate the interactions between nectin adhesion molecules in this process.

More than 50 years ago, experiments revealed that cells from different tissues sort from one another in reproducible ways (*2*). We now know that this also occurs during development, modulating events as diverse as segmentation of the vertebrate hindbrain and separation of the front and back halves of fruit fly wings (*3*). Large-scale cell sorting was hypothesized to occur by differential cell adhesion (*4*) and to underlie tissue segregation, in which the attachment of an adhesion molecule on one cell binds to an identical (homophilic) adhesion molecule on an adjacent cell. Cell surface membrane proteins called cadherins (*5*) are expressed in patterns consistent with roles in tissue sorting. However, there are only a few clear examples of cadherin-based tissue segregation—the positioning of oocytes by E-cadherin during ovary development in the fly *Drosophila melanogaster*; boundary formation between the cerebral cortex and striatum by classic cadherins in the developing mouse brain; and the segregation of groups of motor neurons by type II cadherins in the chick spinal cord (*3*).

Tissue sorting shapes the body plan but does not explain more intricate patterns seen at the single-cell level. The human inner ear provides a striking example (*6*). We hear because sound generates fluid waves within the inner ear, which are detected when they deflect stereocilia projecting from inner-ear hair cells. Outer and inner hair cells are arranged in a "checkerboard" pattern that is interspersed with different types of supporting cells, but the cellular mechanisms that produce this pattern have not been known.

Togashi *et al*. provide evidence for cell sorting at the single-cell level that relies on cell surface proteins called nectins. Like cadherins, nectins mediate cell-cell adhesion (*7*). They are part of the immunoglobulin superfamily, with extracellular domains distantly related to antibodies. Mammals have four distinct nectins that mediate both homophilic adhesion and binding to nonidentical (heterophilic) nectins. The latter interaction is preferred, with a range of binding strengths: Binding of nectin-1 to nectin-3 is strongest, followed by nectin-2–nectin-3, and then either nectin-1–



Adhesion and patterning. The organ of Corti in the cochlea of the mammalian inner ear contains sensory hair cells interspersed with supporting cells. In the mouse ear, heterophilic interaction between nectin-1 expressed on hair cells and nectin-3 on supporting cells generates a checkerboard pattern of hair cells and supporting cells during development (shown). Homophilic interactions between cadherins (one or more types) may also regulate cell-cell adhesion between these cell types.

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