

were immunosuppressive, protecting parasitoid eggs from the lethal defensive response that would otherwise be mounted in parasitized caterpillars (7). Because tens of thousands of parasitoid wasp species were probably carrying this type of virus, it was widely assumed that we were looking at mutualism on a grand scale. But, were the polydnnaviruses really viruses?

The answer is a matter of semantics, and of how we define a virus. Perhaps the more important issue has to do with origins; that is, are the polydnnaviruses a cellular “invention” [a nuclear secretion sensu (8)] or did they originate from conventional viruses? Given that genes encoding viral structural and replicative functions are not packaged into polydnnavirions, then they must be sought in wasp genomic DNA. If such genes could be found and shown to have authentic viral relatives, then whatever we decide to call these entities, they must have descended from typical viruses.

As has now been convincingly demonstrated, homologs of genes derived from conventional viruses do indeed reside within wasp chromosomal DNA. Specifically, Bézier *et al.* have discovered 22 putative nudivirus gene homologs in the wasp genome, including 12 core genes that are also present in a close and well-known relative, the baculoviruses. Interestingly, a putative relationship between bracoviruses (one of the two major recognized polydnnavirus lineages) and *Oryctes rhinoceros* virus was suggested about 30 years ago, on the basis of a remarkable structural resemblance (9) (see the figure). At that time, the *Oryctes* virus was thought to represent a nonoccluded baculovirus, but recently, it has been assigned to the baculovirus-related genus, *Nudivirus* (10).

So, why is this important for virology? Again, there's the issue of how to define a virus. Should we exclude the polydnnaviruses? Consider a typical definition for “virus”: a transmissible agent that in extracellular form consists of a DNA or RNA genome minimally packaged within a protein coat, replicating by the coordinated assembly of subviral components, rather than by growth and division. “Extracellular” implies that all viruses are transmitted horizontally, from one host to another, even if some of them (e.g., temperate bacteriophages) can also on occasion be transmitted vertically within host genomes. In typical definitions of a virus, there is no mention of what the genome must encode, on the assumption that for every virus there is a host that is permissive for productive infection, from which progeny virions will result. This is impossible for polydnnaviruses. Much like the recombinant viral

vectors used in gene therapy experiments, polydnnaviruses are crippled, and so can rightly be viewed as naturally occurring gene-delivery vehicles, or even wasp organelles (11). If we do not wish to consider polydnnaviruses as bona fide viruses, then the standard definition of a virus must specify that the packaged genome encodes all functions required for viral replication. Finally, it is ironic that in all 1259 pages of the most recent compendium on virus taxonomy (12), “virus” is left undefined.

We would suggest that the more interesting lesson here for virologists and for evolutionary biologists may be that there is now reason to start thinking about virus-host relationships in much broader terms, so as to include not only mutualism, which may be a lot more common than previously contemplated (13, 14), but also obligatory mutualism, as exemplified by the wasp-nudivirus story. How did this kind of relationship arise? Parasitoid larvae feeding within their hosts are exposed to a

variety of viruses and will likely become infected by some. Moreover, the parasitoid ovary may represent a permissive environment for maintaining persistent virus infections (15). It may be that bilateral gene transfer has preserved some elements of these that were of mutual benefit.

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## PLANETARY SCIENCE

# Seeing the Missing Half

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Results from the Japanese SELENE mission shed light on differences between the far and nearsides of the Moon.

The Moon is our closest planetary neighbor and the only extraterrestrial body to which humans have traveled, yet many questions about its origin and early history remain unanswered. Four papers published in this issue by scientific teams of the Japanese SELENE (Kaguya) mission (1–4) offer a new global view of the Moon that helps to elucidate how the Moon evolved to its present state.

The Moon is lopsided: Its visible nearside (tidally locked to face the Earth) is covered with smooth, dark volcanic mare, whereas the far-side mainly consists of more heavily cratered, bright highland material. The differences in crustal thickness and density, apparent surface age, composition, and volcanic activity between the two sides are variously ascribed to external causes (such as a giant impact) or to internal causes (such as core formation, mantle convection, and crustal differentiation). The key to resolving these questions will be better data.

The Apollo missions that ended in 1972 led to the current paradigm for the Moon's formation following a collision between the early Earth and a Mars-sized body (5). Analysis of lunar samples led to the hypothesis that the Moon was initially engulfed in a deep magma ocean and then differentiated to form a crust different from that of Earth. This crust subsequently hardened but was battered by meteorites during the late heavy bombardment that ended around 3.8 billion years ago, resulting in a surface covered by basins.

Some basins are as large as 2500 km across and 13 km deep (6), unlike anything on Earth. Their preservation indicates that the Moon's lithosphere formed rapidly and has since remained intact, but gives few clues to the present structure and thermal state of the lunar interior. The Apollo seismometers resolved the shallow crustal structure in a few locations, and detected deeper moonquakes whose origin remains elusive. A core-mantle boundary has not been detected, but data from more than 30 years of laser ranging to retro-reflectors left on the lunar surface are consistent with a small liquid core (7).

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The Moon's gravity field can be used to infer heterogeneities in the density of its interior. Large positive gravity anomalies associated with nearside mare basins were recognized very early from spacecraft radio tracking (8). Are these "mascons" (for mass concentrations) a result of loading by the volcanic mare deposits that filled the basins after their formation (9), or were they produced by dynamic mantle uplift during impact (10)? Given the intense heat produced by large impacts, preservation of the dynamic uplift seemed unlikely. But tracking data from the Clementine and Lunar Prospector missions in the 1990s showed the same mascon features with better spatial resolution and revealed new mascons not covered with visible mare (11, 12).

Unlike most nearside mascons, the mascon beneath Mare Orientale on the Western limb (see the figure, lower right) is surrounded by a ring of negative gravity anomaly; this feature could not be readily explained by loading of volcanic material (13). Speculation arose as to whether similar mascons, created by dynamic uplift, might exist beneath the nonmare-filled basins on the farside. However, no valid comparison of gravity anomalies on the near and farsides was possible, because lunar orbiters cannot be tracked by direct link from Earth when the orbiter traverses the farside.

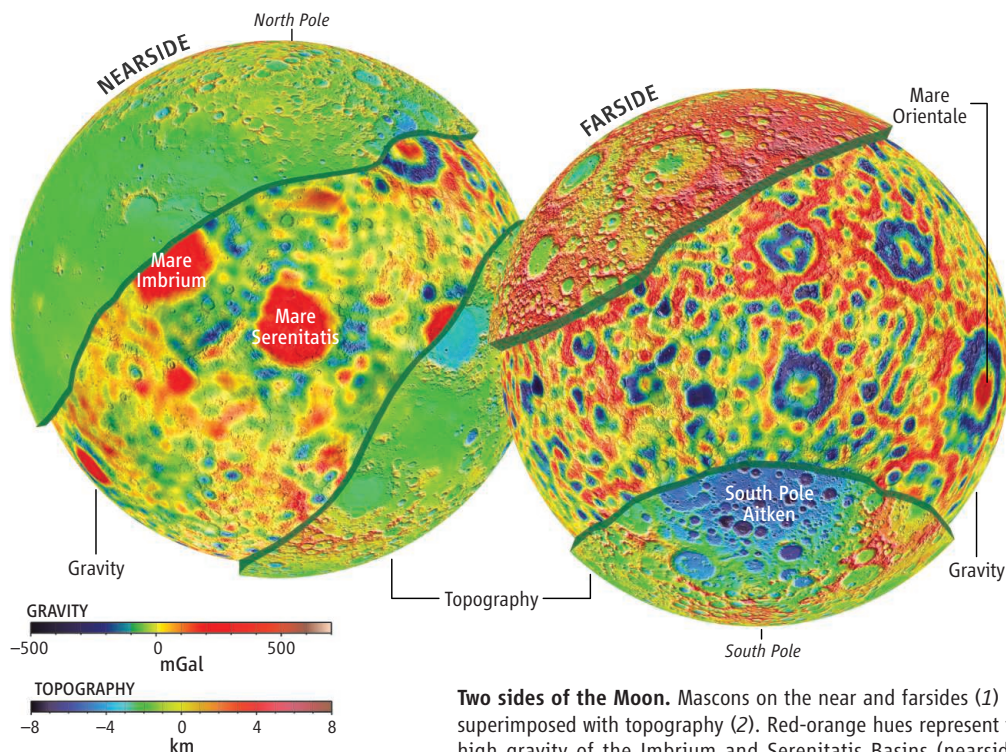
The SELENE orbiter overcomes this problem by using a small companion satellite in a higher elliptical orbit to relay the radio signals of the main orbiter to and from Earth. On page 900, Namiki *et al.* (1) present a dramatically improved gravity model that includes the first farside tracking data. The results reveal farside mascons with small central gravity highs and wider rings of negative gravity anomaly that do not resemble their nearside counterparts (see the figure). The authors interpret the new mascons as indicating cooler, more rigid early conditions on the farside than previously thought.

As a further means to understand the structure of the basins, the expected contribution of topography to the gravity signal can be removed to reveal variations in crustal thickness and mantle topography under the basins. Altimetry data from the 1994 Clementine mission revealed a global dichotomy between the crustal thicknesses of the nearside basins and those of the farside highlands. However, the resolution was too low to elucidate geophysical

processes such as the formation of large basins (like Mare Orientale) and the subsequent volcanic activity leading to present-day mare.

On page 897, Araki *et al.* report global topographic mapping of the Moon with the laser altimeter onboard SELENE (2). The data offer 100-fold higher density and better vertical resolution than previously available. Spectral analysis of the topography shows more power at short wavelengths than the Earth. This could indicate that, similarly to Venus and Mars, the Moon's mantle is depleted in volatiles such as water. As shown by the use made of Martian laser altimeter data (14), new topography models of the Moon will be invaluable for geophysical lunar research.

Mascon basins commonly display associated tectonic features, such as extensional linear channels and compressional mare ridges (15). On page 909, Ono *et al.* use data from the SELENE Lunar Radar Sounder (3) to map echoes from subsurface stratigraphy beneath nearside mare regions. They did not identify the 1.6-km-deep reflective interface in Serenitatis observed in early Apollo experiments (16), but discovered shallower reflectors. The authors infer from the stratigraphic thicknesses that the ridges seen in the most recent volcanic flows were deformed not only by mascon stresses arising during their emplacement, as previously thought, but by a regional



**Two sides of the Moon.** Mascons on the near and farsides (1) are superimposed with topography (2). Red-orange hues represent the high gravity of the Imbrium and Serenitatis Basins (nearside). Green-blue hues represent gravity lows and topographic depressions such as the large South Pole–Aitken Basin (bottom right). Note the different character between the nearside mascons and the farside mascons with their large negative anomaly rings.

compressive stress that occurred sometime later, probably during an episode of global cooling and contraction.

The Terrain Camera investigation described by Haruyama *et al.* on page 905 (4) has imaged volcanic flows with optimal illumination at high resolution, allowing farside mare basins to be dated based on cratering statistics (17). The results suggest that episodic farside volcanic activity continued until at least 2.5 billion years ago. Such late activity in the thicker farside crust is an important constraint for a comprehensive model of the Moon's history.

The new results (1–4) do not offer a complete picture of the Moon's evolution, but it is now clear that the farside lithosphere was stronger than the nearside at the time of the late heavy bombardment when the mascons were formed. More data should soon become available not only from SELENE, but also from the Chinese Chang'e-1, the Indian Chandrayaan-1, and, this spring, the NASA Lunar Reconnaissance Orbiter. The 2011 GRAIL (Gravity Recovery and Interior Laboratory) mission will map the lunar gravity with an accuracy at least three orders of magnitude greater than the Kaguya gravity mission, and the International Lunar Network stations planned for 2013 and afterward will carry a suite of geophysics experiments. It will then



be the turn of lunar modelers to determine which theory for the asymmetrical evolution best fits the data.

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## CLIMATE CHANGE

# Sentinels of Change

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Given the vast and complex landscape of Earth's surface, where do we look for signals of how climate change influences ecosystems? Lakes and reservoirs are an important part of the answer. Although they make up a small percentage of Earth's surface, lakes and reservoirs act as sentinels by providing signals that reflect the influence of climate change in their much broader catchments (1). The sediments of inland waters integrate these signals over time, and the deposition of terrestrially derived carbon and outgassing of greenhouse gases make them hot spots of carbon cycling and, thus, climate change regulation. Furthermore, given that freshwater is one of Earth's resources most jeopardized by changing climate (2, 3), being able to detect changes that are detrimental to water quantity or quality is critically important.

Lake levels are highly visible signals of change in water quantity, with records that can span many decades (4). For instance, declining levels in closed-basin prairie lakes in North America indicate that at some time in this century, climate change may render these areas much drier than they have been since the late 19th century (5). Many of these changes are caused by long-term, cyclic climatic changes driven by ocean circulation patterns (4). For example, levels in smaller lakes in Wisconsin rise and fall with those of the nearby Laurentian Great Lakes, suggesting climate oscillations as a common driver (6). Lake sediments also store signals that are proxies for prehistoric climate change. The

height and position of beach ridges that can be dated are similarly useful in deducing the state of water supplies in past millennia.

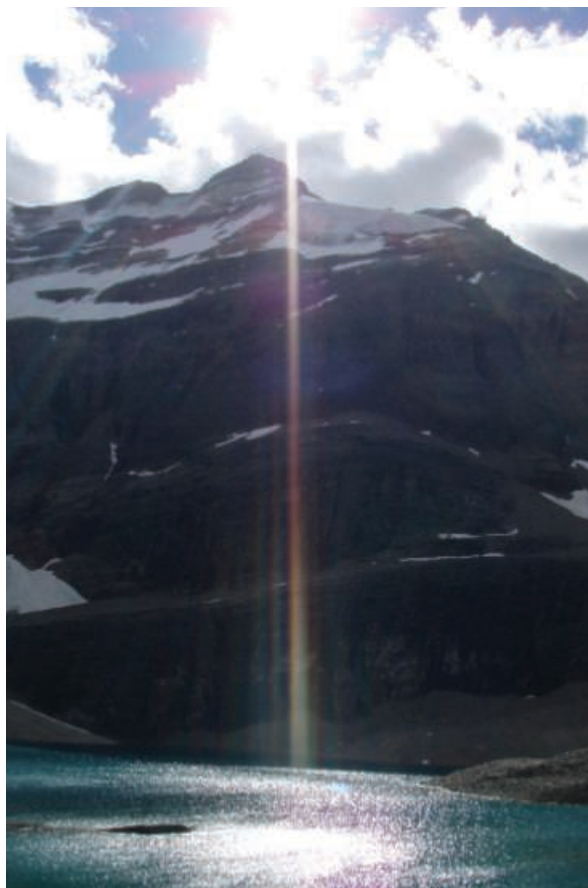
Some of these indicators are worrisome. For example, the Laurentian Great Lakes are often viewed as vast reservoirs for solving future water shortages in other parts of North

Lakes and reservoirs provide key insights into the effects and mechanisms of climate change.

America. But recent studies show that their water balance is precarious, with water renewal rates of less than 1% per year (7). In much of North America, the 20th century now appears to have been the wettest in the past millennium or more, with droughts up to several decades long commonplace in earlier centuries (8).

Water levels in the Great Lakes have been fairly stable in the past century, varying by less than 2.1 m, but proxy data suggest that climate-driven hydrologic imbalance led the connecting rivers and Niagara Falls to dry up between 8770 and 8290 years ago, leaving the Great Lakes as separate basins (7). Pollen and seeds in dated lake sediments have shown that between 3000 and 8000 years ago, grasslands around Lake Winnipeg extended well north of the present tree line; the climate in the catchment seems to have been very similar to 20th-century Medicine Hat, Alberta, one of the driest parts of the Canadian Prairies (9).

Other recent studies have elucidated the role of lakes as regulators in the global carbon cycle. Over 90% of the estimated 304 million lakes worldwide are small (less than 0.01 km<sup>2</sup>) (10) and shallow, with ample nutrients, light, and water to make them optimal environments for high levels of biological productivity. Much of the carbon reaching lakes originates in the vegetation and soils of their catchments. About twice



**Lakes as sentinels.** Alpine lakes, such as Lake Oesa in the Canadian Rockies pictured here, produce and store signals of climate change. Scientists are using these signals to determine how climate influences both terrestrial and aquatic ecosystems and to elucidate the role of inland waters in regulating climate change.

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