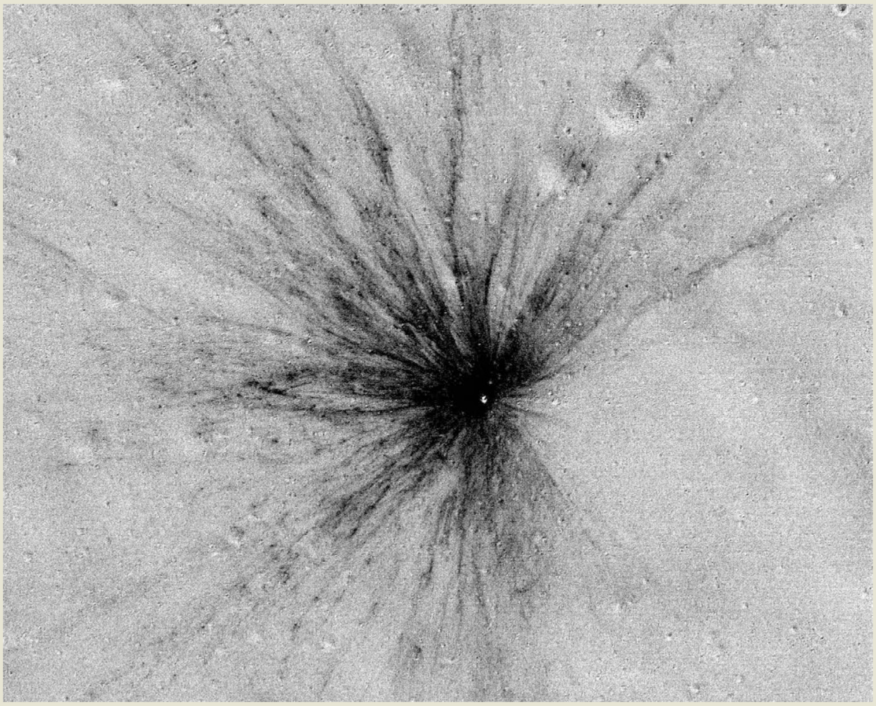
NASA/GSFC/ASU

PLANETARY SCIENCE

Moon churn



The Moon's surface is being mapped by NASA's Lunar Reconnaissance Orbiter spacecraft, to aid planning for future missions. On page 215, Speyerer *et al.* report how images taken by the orbiter's camera have been used to quantify the current rate at which lunar craters form as a result of surface impacts by comets, asteroids and associated fragments (E. J. Speyerer *et al. Nature* **538,** 215–218; 2016).

The authors compared pairs of images of the Moon's surface taken at different times, and discovered that 222 craters had formed in the periods between the images being taken. They therefore estimate that about 180 craters of at least 10 metres in diameter form annually across the entire Moon. This is 33% more than would have been expected from a commonly used model of impact frequency.

By calculating the ratios of surface reflectance between pairs of images, Speyerer *et al.* uncovered distinct zones of subtly modified reflectance around the newly formed craters. The zones extend many crater widths out from the centre and are not visible to the naked eye (pictured are the ratios for a 12-m crater; dark regions reveal a zone that splays out up to 1,800 m from the centre). The authors propose that these zones are caused by impact-induced jets of melted and vaporized material formed early in the crater-formation process.

The researchers also detected thousands of subtle surface disturbances — changes in local reflectance that lack a resolvable crater rim. They interpret many of these as the scars of secondary impacts that churned up the upper few centimetres of the surface without forming a resolvable crater. Speyerer and colleagues therefore propose that the upper 2 centimetres of loose surface material on the Moon will be reworked in about 81,000 years, 100 times faster than previously predicted.

Andrew Mitchinson

In retrospect

Fifty years of C_4 photosynthesis

Half a century after the discovery of a plant photosynthetic pathway termed C_4, researchers are working to engineer this efficient pathway into crops such as rice to maintain food security.

JULIAN M. HIBBERD & ROBERT T. FURBANK

Fifty years ago, Hatch and Slack[1] published an analysis of photosynthesis that gave birth to a new field. Their work not only stimulated intense biochemical research to define the mechanisms of a new photosynthetic pathway, but also fed into many other disciplines. Ecologists found that the pathway could explain species distributions. Geologists gained greater insight into changes in the isotope composition of sediments and fossils. And evolutionary biologists started to investigate the highly complex pathway, which is found in many plant lineages and is now considered one of the most remarkable examples of convergent evolution — a process in which the same feature evolves independently in different unrelated species.

Fifteen years before Hatch and Slack's work, Calvin and co-workers had identified the first photosynthetic pathway by which inorganic atmospheric CO_2 is incorporated (fixed) into organic carbon-containing molecules[2]. The initial step in the pathway produces a molecule that contains three carbon atoms, and it was widely thought that all land-dwelling plants used this 'C_3' photosynthesis. However, this assumption was disproved by Hatch and Slack's carefully executed experiments. They used the carbon-14 isotope to create $^{14}CO_2$ and then tracked how the ^{14}C was incorporated into molecules in sugarcane plants. Remarkably, they found that the first step of carbon fixation was actually into a four-carbon molecule[1]. This alternative pathway became known as C_4 photosynthesis. At the time, the significance of Hatch and Slack's finding was that two photosynthetic pathways were now known to operate in plants.

The study by Hatch and Slack explained some puzzling reports. Laboratories as far apart as Hawaii and Russia had observed unexpected carbon incorporation patterns when $^{14}CO_2$ was supplied to sugarcane and maize (corn) leaves[3,4]. However, Calvin and others questioned the validity of those reports, and the findings were not accepted by the field. The main objection was that $^{14}CO_2$ had often been introduced to leaves in the dark, when photosynthesis is not active, which risks creating artefacts of non-photosynthetic metabolism.

Hatch and Slack's key advance was providing a pulse of $^{14}CO_2$ to leaves in light, followed by introduction of CO_2 that did not contain ^{14}C. Such 'pulse chase' experiments can track a ^{14}C wave as it transits through molecules in a pathway. The approach showed that the carbon was first incorporated into malate (Fig. 1), a molecule containing four carbons,