Rocks that go bump in the night

Derek C. Richardson

The planets were probably created by collisions between smaller rocky bodies over many millions of years. The identification of a recently formed asteroid family will tell us much about the dynamics of these collisions.

Between the orbits of Mars and Jupiter lie the remains of the early, violent history of the Solar System. These are asteroids, rocky bodies that range in diameter from a few hundred metres to just under 1,000 km. Over the past century, astronomers have realized that asteroids (and comets, their icy cousins originating further out in the Solar System) are the building blocks of planets. On page 720 of this issue, Nesvorný and colleagues[1] report their discovery of an asteroid family that offers unprecedented insight into the dynamics of asteroid collisions — and hence into how the planets of the Solar System formed.

For planets to grow in size from their humble beginnings, they must be continually bombarded by smaller bodies for tens to hundreds of millions of years. This process still happens today: not only do these small bodies continue to strike the Earth, with effects ranging from spectacular fireballs to mass extinctions, but they continue to bump into each other as well. In the past these bumps were relatively gentle, which allowed the first protoplanets to form. But as giant planets such as Jupiter came into existence, the gravitational fields they generated stirred up the smaller bodies. This energy increase made them more likely, if they collided, to break apart than grow, with the result that only the largest protoplanets survived to form planets while the rest were ground down to small fragments.

Nesvorný and colleagues[1] have uncovered the aftermath of one such energetic collision. What makes their discovery unique and exciting is that a large-scale break-up event has, for the first time, been precisely dated. Piecing together the fragments, Nesvorný *et al.* find that a 25-km asteroid in the Outer Main Belt between Mars and Jupiter broke up in collision 5.8 million years ago — a mere blink of an eye in the 4.5-billion-year lifetime of the Solar System.

Theorists studying planet formation would like nothing better than to smash two asteroids together and see what happens. Many questions could be answered. Under what conditions does an asteroid break apart? What happens to the debris? How do pre-existing fractures affect the outcome? Could a 'doomsday' asteroid threatening Earth be stopped by brute-force methods such as a nuclear blast? Of course, full-scale experiments are not possible, so planetary scientists rely on much smaller laboratory experiments as well as numerical simulations to predict collision outcomes[2,3]. But nature has provided a larger laboratory for us in the form of the ancient record of past collisions between asteroids. By studying this record, we can learn about the collision process.

Figure 1 **Aged asteroid. One of only a handful of asteroids that have been visited by spacecraft, Ida (pictured here) is a member of the Koronis family that formed over a billion years ago as a result of a catastrophic collision between two larger bodies. But the Karin asteroid cluster discovered by Nesvorný and colleagues[1] is only a few million years old and may greatly improve our understanding of collisional dynamics and planet formation.**

GALILEO/JPL/NASA

One way to understand the physics of large-scale impacts among asteroids is to investigate asteroid families, groups of asteroids that share similar orbital elements and spectral properties[4]. Orbital elements describe the shape and orientation of the path that an object follows around the Sun, whereas spectral properties provide information about the composition of an object according to how it reflects sunlight at different wavelengths.

Asteroid families are formed during catastrophic collisions, as the fragments are launched away from the impact site at high speeds[5]. The nature of each break-up event and the velocity distribution of the ejecta depend critically on the incoming projectile's mass and velocity relative to the collision target. The ejection speed of the fragments acts as an impulse that gives each member a slightly different orbit from the parent body. In the absence of any further disturbance, these orbits would remain unchanged.

In reality, however, these objects are subject to dynamical evolution through several mechanisms: subsequent collisions between family members and other nearby asteroids, after the family has formed; gravitational perturbations produced by planets and large asteroids; and non-gravitational forces such as the Yarkovsky effect that slowly cause the orbits of smaller, kilometre-sized asteroids to change over time[6]. (The Yarkovsky effect changes the spin and orbit of a body by the asymmetric re-radiation of thermal energy absorbed from the sun[7].) Together, these effects slowly muddle the memory of the family-forming impact, making it difficult both to identify the family and to piece together exactly what happened. In fact, the degree of dynamical diffusion can be used to estimate how long ago the original impact occurred, although it is not a precise measure.

Until now, most known asteroid families were thought to be the by-products of huge disruption events among bodies hundreds of kilometres in diameter[8]. Most of these families are estimated to be hundreds of millions, even billions, of years old (Fig. 1), so it is problematic to use their properties to constrain asteroid evolution models. Using a new database of orbital elements, however, Nesvorný and colleagues[1] have identified a cluster of 39 small asteroids inside the Koronis asteroid family that were probably produced by the recent disruption of a 25-km asteroid.

The youth of this cluster is suggested by two lines of evidence. First, the orbital elements of the cluster members are remarkably similar. Second, the researchers were able to determine the precise age of the break-up event by numerically integrating the orbital elements of 13 cluster members back through time. They found that particular elements (corresponding to the orbital orientation of each body) converged to a single value 5.8 ± 0.2 million years ago. Because this technique does not work on asteroid clusters that have suffered significant dynamical evolution, this is the first time that an asteroid break-up has been accurately dated.

The Karin cluster — as Nesvorný *et al.* have named it, after its largest member — is a compelling target for a space mission. The cluster is young enough that many erosional and weathering processes thought to occur on asteroid surfaces[9] may not have had time to erase the tell-tale signatures of the break-up. So it might be possible to determine whether the family members are intact fragments or gravitational re-accumulations of smaller pieces. This new cluster will no doubt be the focus of attention for the asteroid community for some time. Meanwhile, the search for ever younger families will continue, in the hope of taking us closer to understanding the origins of our Solar System. ■

Derek C. Richardson is in the Department of Astronomy, University of Maryland at College Park, College Park, Maryland 20742, USA.
e-mail: dcr@astro.umd.edu

1. Nesvorný, D., Bottke, W. F. Jr, Dones, L. & Levison, H. F. *Nature* **417,** 720–722 (2002).
2. Housen, K. R., Holsapple, K. A. & Voss, M. E. *Nature* **402,** 155–157 (1999).
3. Asphaug, E., Ostro, S. J., Hudson, R. S., Scheeres, D. J. & Benz, W. *Nature* **393,** 437–440 (1998).
4. Zappalà, V., Bendjoya, Ph., Cellino, A., Farinella, P. & Froeschle, C. *Icarus* **116,** 291–314 (1995).
5. Michel, P., Benz, W., Tanga, P. & Richardson, D. C. *Science* **294,** 1696–1700 (2001).
6. Bottke, W. F. Jr, Vokrouhlický, D., Brož, M., Nesvorný, D. & Morbidelli, A. *Science* **294,** 1693–1696 (2001).
7. Farinella, P., Vokrouhlický, D. & Hartmann, W. K. *Icarus* **132,** 378–387 (1998).
8. Durda, D. D., Greenberg, R. & Jedicke, R. *Icarus* **135,** 431–440 (1998).
9. Clark, B. E. *et al. Meteor. Planet. Sci.* **36,** 1617–1637 (2001).

Ecology

Density and diversity

Hans ter Steege and Roderick Zagt

One explanation for the especially rich diversity of trees in the tropics is that a process called 'density-dependent mortality' operates there. It turns out, however, that this process occurs in temperate forests too.

The latitudinal gradient in species diversity is arguably the most universal pattern in global biodiversity: the lower the latitude, the higher the number of species in a given area. This pattern, with biodiversity peaking in the tropics (Fig. 1), is found in most taxonomic groups and may be as old as life itself[1–3]. For plants, one explanation centres on a phenomenon called 'density-dependent mortality', in which the survival rates of species decrease as they become more common, leaving space for rarer species. It has been suggested[4,5] that density-dependent mortality is more intense at lower latitudes, so, at least in part, accounting for the gradient in diversity. As they describe on page 732 of this issue, however, Hille Ris Lambers and colleagues[6] have tested this hypothesis and found it wanting.

It is not surprising that many researchers have sought to find an explanation for the latitudinal pattern in species diversity. Biologists study diversity at different scales and it is becoming clear that scale is an important bridging element between the various theories that have been developed for regional and local levels. As far as trees are concerned, local processes such as the rate and extent at which gaps for seedling colonization occur, as well as density-dependent mortality, may limit the extent to which one species excludes another, and thus promote local diversity. Density-dependent mortality, however, will maintain high diversity only if it is species specific — that is, if it decreases the density of a species as a function of the density of that species alone, rather than of the density of all species.

If species-specific, density-dependent mortality contributes to the latitudinal gradient in species diversity, the effect should be stronger in the tropics than in temperate areas. The rationale for this is that much seed and seedling destruction stems from attack by insects and fungi, which reach higher densities in tropical regions because the tropics do not experience seasonal variations and tend to remain hot and humid[4,5].

Hille Ris Lambers *et al.*[6], however, show that density-dependent mortality acts in temperate as well as in tropical forests. Their results come from a forest in North Carolina, where they found that six out of seven tree species experience density-dependent mortality at one or more transitions in their early stages: from seed to seedbank; from seed or seedbank to seedling; and in seedling survival (the seedbank phase is a latent period in which seeds lie dormant in the soil before germination). The results clearly show not just the effect of general density-dependent mortality, but also species-specific, density-dependent mortality. This suggests that rather than the driving factors being resource competition for light or nutrients alone, predators or pathogens are responsible. Hille Ris Lambers *et al.* also compared previous studies carried out in temperate and tropical areas, in which several species were tested for density-dependent mortality, and conclude that the proportion of species affected is not greater in the tropics.

All in all, this study[6] adds support to those who claim that general ecological mechanisms, such as the creation of gaps in vegetation that allow colonization by seedlings, and density-dependent regulation, operate similarly in the tropics and temperate zones. So theories invoking these processes fail to explain the higher diversity in the tropics compared with temperate zones.

Still, further investigations are required. As Hille Ris Lambers *et al.* point out, many different protocols have been used in this kind of research, producing varying and sometimes confusing results. By re-analysing their own data with the approaches used in other studies, the authors show that these approaches have invariably underestimated the effects of density dependence. They propose a framework for simultaneously assessing the impact of seedling and adult density on seed and seedling fate. This framework should now be applied in future work at various latitudes.

The authors' main message, then, is that the proportion of species subject to density-dependent regulation is not lower in temperate areas than in the tropics. But the ecologically more significant question may be to what extent species are actually regulated by the process. Are the effects strong or weak? And is there a latitudinal component? Addressing these questions will require identifying and quantifying latitudinal trends in the relevant factors. Earlier work demonstrated that density-dependent patterns of seed loss tend to be associated with predation by

ROINE MAGNUSSON/THE IMAGE BANK

Figure 1 **Trees in the tropics — the height of diversity.**