Planetary science

Evolution by bombardment?

from Michael Prather

THE atmospheres of the planets contain a cryptic record of the origin and evolution of our Solar System. The current composition of planetary atmospheres reflects the initial composition of protoplanetary material, the mode of planetary accretion, the release and reabsorption of volatiles by the solid planet, the chemical processes coupling atmosphere and lithosphere, and the escape of atmospheric constituents to the interplanetary medium over the last 4.5×10^9 years. Cameron has now invoked erosion by planetesimal bombardment as an important and hitherto neglected process in the evolution of planetary atmospheres; moreover, he suggests that the formation of the Moon followed a collision between Earth and a planetesimal the size of Mars[1].

While the outer planets (Jupiter and beyond) appear to have retained large quantities of volatiles from the original solar nebula, the inner planets (Mars, Earth and Venus) appear to have no vestige of a primordial atmosphere. Instead, their atmospheres must reflect the substantial processing and differentiation of materials in the early Solar System. But the story is far from simple. The quantities of noble gases in the atmospheres of Mars and Venus are particularly puzzling and have spawned various theoretical models for origins of the terrestrial planets[2-7]. A consistent model for the inner planets must account for relative concentrations of 70:1:0.006 for ^{36}Ar on Venus, Earth and Mars respectively and for the smaller range in the relative concentrations (3:1:0.2) of N_2 (the abundance on Mars is corrected for the escape of nitrogen predicted by isotope fractionation). One explanation attributes the abundance of noble gases on Venus to solar wind implantation of the protoplanetary material and associates Mars and Earth with the noble gas component found in many meteorites[5,6]. This argument is supported by the difference in neon isotope ratios between Venus and Earth, but cannot readily explain the similar ratios of Ne/^{36}Ar for all three planets.

Cameron's provocative assertion is that the early atmospheres, which evolved from degassing of the partially molten planet, were significantly eroded by collisions with the remaining interplanetary debris. Accordingly, a planetesimal with dimensions comparable to the scale height of the atmosphere is supposed to have generated a shock wave, ejecting part of the atmosphere above the region of impact. This aspect of the theory is not quantitative and, like most theories of primordial atmospheres, is calibrated after the fact by the present atmosphere. Moreover, Cameron's analogy to calculations of stellar collisions does not seem appropriate.

A second major premise of Cameron's paper is that the Moon formed from the collision of Earth with a planetesimal the size of Mars. During the suggested impact, siderophile elements such as iron would gravitate to the Earth's core and lithophile elements on the surface would be vaporized. The expanding cloud would condense into large circumterrestrial silicate ring which in turn would gravitationally coalesce into the Moon. In its favour, the mechanism could explain the Moon's lack of both volatiles and a significant iron core. But there are difficulties with the energetics of this ring–Moon system[8] that Cameron considers but fails to resolve entirely.

Models for early bombardment are regrettably unquantitative and create problems while solving others. One implication of Cameron's theory of lunar creation is the removal of a major portion of the Earth's atmosphere through interaction with the silicate ring. He argues that more than 99 per cent of the original atmospheric content of xenon was lost and that even greater proportions of the lighter noble gases Ar and Kr would have been removed. His theory has to face the fact that the Earth is anomalously low in xenon in comparison with the ^{132}Xe/^{36}Ar ratio in meteorites. One contested explanation for this anomaly has the 'missing' xenon buried in sedimentary rocks[9,10]. Cameron's theory requires the opposite, a primordial atmosphere with relatively little xenon. The only known source for such a mix of noble gases would be the original nebula or, later, the solar wind. That source is generally believed to account for Venus' noble gases, but it would predict unacceptable ratios of N/^{36}Ar and ^{20}Ne/^{22}Ne for the Earth.

Mars' low abundance of ^{40}Ar (derived from decay of ^{40}K with half life of 1.3×10^9 years) is used by Cameron as evidence of an extended period of bombardment and atmospheric erosion. This premise contradicts evidence supporting early loss of Mars' volatiles. The high ratio of ^{40}Ar/^{36}Ar for Mars (10 times that for Earth) argues for substantial loss of ^{36}Ar before the radiogenic production of ^{40}Ar. A similar interpretation is required by the xenon isotopic composition[5].

The potential importance of early bombardment in the evolution of the terrestrial atmospheres should not be ignored. Cameron has highlighted some interesting consequences of major collisions in the early Solar System. He has chosen examples which may resolve some of the intriguing puzzles about formation of the terrestrial planets but which fail to explain numerous other constraints imposed by observations. □

1. Cameron, A.G.W. *Icarus* **56**, 195 (1983).
2. Anders, E. & Owen, T. *Science* **198**, 453 (1977).
3. Pollack, J.B. & Black, D.C. *Science* **205**, 56 (1979).
4. Morgan, J.W. & Anders, E. *Geochim. cosmochim. Acta* **30**, 43, 1601 (1979).
5. McElroy, M.B. & Prather, M.J. *Nature* **293**, 535 (1981).
6. Wetherill, G.W. *Icarus* **46**, 70 (1981).
7. Pollack, J.B. & Black, D.C. *Icarus* **51**, 169 (1982).
8. Thompson, A.C. & Stevenson, D.J. *Lunar planet. Sci.* **14**, 787 (1983).
9. Fanale, F.A. & Cannon, W.A. *Earth planet. Sci. Lett.* **11**, 362 (1971).
10. Podosek, F.A., Honda, M.S. & Ozima, M. *Geochim. cosmochim. Acta* **44**, 1875 (1980).

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Cell biology

Rheumatoid sera unravel microtubule organizers

from Jeremy S. Hyams

THE complex arrays of microtubules in cultured cells, revealed so spectacularly in recent years by techniques of immunofluorescence, are organized by two types of cellular structure, the centrosome and the kinetochore. Both will nucleate the assembly of microtubules *in vitro*, although it is still debated whether the kinetochore performs that role in the living cell[1]. Either way, the composition of both structures and the nature of any changes they might undergo during the cell cycle is of considerable interest; indeed, it is probably not stretching a point to call it the most important current focus of microtubule research. A timely shove to progress in this area has recently come from the unlikely source of the sera of humans suffering from various rheumatoid conditions. Several publications in the last few months have made use of the autoantibodies in such sera to help characterize centrosomes and kinetochores.

The centrosome is the major microtubule-organizing centre of almost all animal cells and is visible throughout the cell cycle. During interphase, a single centrosome, containing a pair of centrioles, initiates the array of cytoplasmic microtubules; at G_2, the centrosome divides in two, one for each pole of the mitotic spindle. The kinetochore is only clearly visible at mitotic prophase when one develops on each side of the chromosomal centromere; microtubules from the kinetochore anchor each chromosome to