Effects of giant impacts on the atmosphere formation

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The recent works on the planetary formation show that several tens of Mars-sized proto-planets are formed in the terrestrial planet region at the final stage of the planetary accretion (e.g., Kokubo & Ida, 1998). Then, collisions of Mars-sized proto-planets occur due to gravitational perturbations among the proto-planets (e.g., Chambers & Wetherill, 1998).

Mars-sized proto-planets would have a mixed proto-atmosphere composed of solar and degassed components (Abe et al., 2002). The giant impacts modify the atmosphere. For example, a large amount of atmosphere may be blown-off by the giant impacts. It has an influence on the origin and evolution of planetary volatile budget, and especially on the quantity and isotopic fractionation of noble gases. Ahrens (1990, 1993) and Chan & Ahrens (1997) concluded that almost all atmosphere is lost by the strong antipodal ground motion (~6km/s) expected for a giant impact. On the other hand, isotopic composition of the present Earth's noble gas suggests the survival of the substantial atmosphere after the giant impact (e.g., Pepin, 1997).

We have re-examined the relations between the ground motion and the amount of the lost atmosphere by calculating the spherically one-dimensional atmospheric motion for six cases of the initial atmospheric conditions. We find that the loss fraction of the atmosphere is determined by only the surface velocity irrespective of the initial atmospheric conditions. For example, when the surface velocity is 0.55 times of the escape velocity, which corresponds to 6 km/s on the Earth's condition, 30% of the atmosphere escapes. The globally averaged surface velocity is less than 6 km/s, because the planetary core focuses the shock wave energy to the antipode (Watts et al., 1991). Therefore, most atmosphere survives the giant impact. We can also apply our results to the atmosphere of the impactor planet. About 50% of the impactor's atmosphere survive the giant impact, and is brought to the target planet.

References

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The time scales of magmatic differentiation at island arcs

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There is growing interest in how the time scales of magmatic differentiation might vary with magma composition and differentiation path. Available data imply differentiation times of 100's to 1000's of years for tholeiitic magmas and 1000's to perhaps 10,000's of years for calc-alkaline magmas. Numerical models can be used to predict both the rate of cooling and crystallisation in crustal magma chambers but if differentiation occurs by crystal settling, the time scale will also be controlled by the size of the crystals, their density contrast with the magma and the viscosity. Thus, the behaviour of natural systems will be complex; phenocrysts may find it hard to settle in a tholeiitic magma because the liquid line of descent yields dense, iron-rich differentiates, whilst the higher silica content and greater viscosity of calc-alkaline liquids at a similar degree of differentiation will also inhibit phenocryst-liquid separation.

The Aleutian-Alaska arc is well known for erupting both tholeiitic and calc-alkaline lavas. In order to investigate the relative roles of chemical and temporal controls on generating these contrasting liquid lines of descent we have studied tholeiitic lavas from Akutan in the Aleutian arc and Aniakchak on the Alaskan Peninsula. Akutan lavas exhibit little variation in SiO_2 or $^{87}Sr/^{86}Sr$ and are characterised by ^{238}U-excesses, consistent with fluid addition to their mantle source, whereas those at Aniakchak show a range in SiO_2 and $^{87}Sr/^{86}Sr$ and straddle the U-Th isotope equiline suggesting that partial melting affected the U-Th isotopes after fluid addition. The lavas preserve a range in $^{226}Ra/^{230}Th$ disequilibria which suggest that the time scale of crustal residence of magmas beneath both Akutan and Aniakchak appear to be around 0-5000 years. Our interpretation is that the tholeiitic Akutan magmas underwent minimal, closed-system, compositional evolution. In contrast, calc-alkaline magmas beneath Aniakchak volcano underwent significant compositional evolution suggesting that differentiation was more time-efficient in the calc-alkaline system. The simplest explanation is that the greater density of the tholeittic differentiates retarded crystal-liquid separation more effectively than any differences in viscosity between the two magma systems.