ENDOGENOUS SURFACE PROCESSES ON ASTEROIDS, COMETS AND METEORITE PARENT BODIES. Derek W. G. Sears, Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA.

It is known that (i) almost half of the known asteroids are CI- or CM-like, and these meteorites are 10-20% water; (ii) many asteroids have water on their surfaces despite impact heating and evaporative drying; (iii) many asteroids, including Apollo-Amor asteroids that have been linked to the ordinary chondrites, are possibly related to comets. It is therefore suggested that endogenous processes involving the mobilization and loss of water and other volatile compounds on meteorite parent bodies should be considered in explaining the properties of ordinary chondrite meteorites. It is suggested that water and other volatile compounds from the interior of the meteorite parent body passing through the unconsolidated surface layers produced many of the major meteorite properties, including the aerodynamic and gravitational sorting of their components, and occasional aqueous alteration.

Asteroids are almost certainly the immediate parent bodies of most meteorites (1), and some asteroids could be cometary in origin (2,3). There is considerable uncertainty as to which meteorite properties reflect processes occurring on the meteorite parent body (MPB) and which occurred in interstellar or interplanetary space (e.g. 4,5). The impact history and the formation of regoliths on asteroids (and thus MPB) are often discussed (6,7), but not the possibility of endogenous surface alteration processes. Many asteroids have CI- or CM-like surfaces (8), and these meteorites are 10-20 percent total water (9). Despite the expected impact and evaporative drying of asteroidal surfaces, spectroscopic evidence for water ice or bound water on their surfaces has been reported for a growing number of asteroids (Table 1). Endogenous activity on comets has been studied in great detail (Fig. 1). The sublimation of ices as the comet comes within 5-6 AU of the Sun causes the accumulation of a refractory silicate and carbonaceous regolith, while near the surface recondensation of volatile compounds moving into the comet and crystallization of amorphous ices causes significant temperature gradients and internal structure (11). Impact working of the surface of comets has been discussed, and is important for cm-sized objects impacting on km-sized comet nuclei.

Table 1. Asteroids with spectroscopic evidence for water on their surface (10).

Asteroid	Class (16)	Asteroid	Class (16)
10 Hygeia	C	13 Egeria	G
19 Fortuna	G	51 Nemausa	CU
70 Panopaea	C	130 Elektra	S
375 Ursula	C	386 Siegena	C
409 Aspasia	CX	410 Chloris	C
505 Cava	FC	511 Davida	C
773 Irmintraub	C	1467 Mashona	GC
1 Ceres	C		

Table 2. Asteroids that are probably or possibly derived from comets (2).

Probably	Class (16)	Possibly	Class (16)
944 Hidalgo	D	1566 Icarus	--
2060 Chiron	B	1580 Betulia	C
2102 Adonis	--	1620 Geographos	S
2201 Oljato	--	1685 Toro	S
2212 Hephaistos	SG	1862 Apollo	Q
3200 Phaeton	F	1866 Sisyphus	--
3552 Don Quixote	D	1917 Cuyo	--
		1981 Midas	--
		2062 Aten	S

There are three possibilities for endogenous processes altering the surfaces of small solar system bodies. (i) Some asteroids are probably or possibly evolved comets (Table 2) and they will have suffered the processes described in Fig. 1. (ii) Evaporation of ices and bound water due to ^{26}Al heating in the early solar system or by (iii) impact during accretion and the terminal cataclysm (13). As is evident from the lunar surface, impact is a potentially efficient means of localized and regional heating of airless bodies. About half the asteroids have suffered complete melting and presumably account for the large numbers of igneous meteorites (8). An even larger fraction of asteroids should have suffered heating enough to lose volatile compounds without melting.

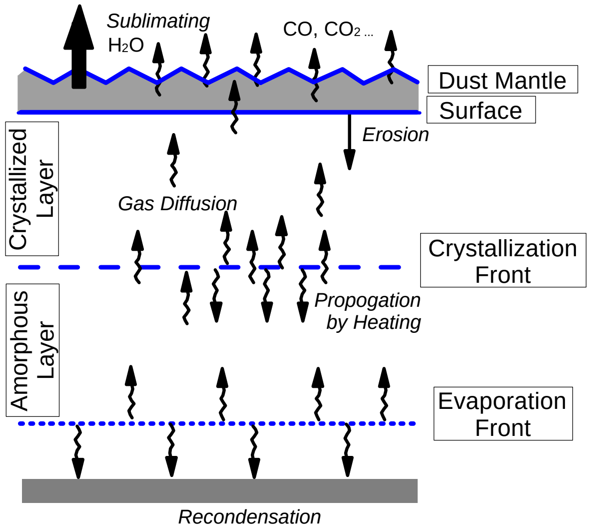

Fig. 1. Surface processes on comets according to a review by Rickman (20).

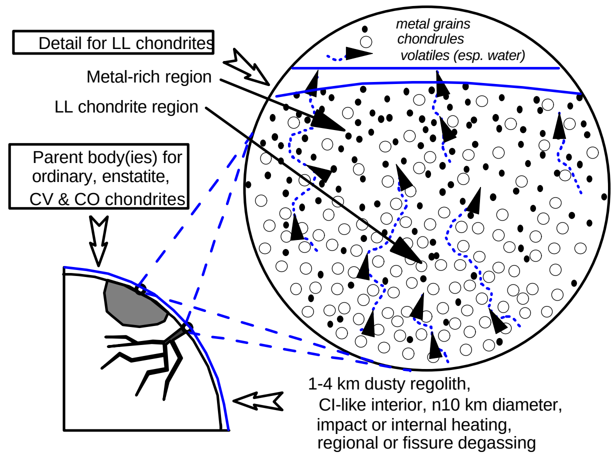

Fig. 2. Possible processes on the surface of a volatile-rich asteroid that would produce the chondritic meteorites (14)

Depending on the scale and timing, water and other volatile compounds which evolved from the interior through the surface regolith layers of the MPBs will cause chemical reactions and physical sorting of the surface components. Thus several processes that are important in understanding chondrite genesis and history, might accompany endogenous activity on the MPB. (i) Formation of zones characterized by differences in thermal processing and volatile loss (17). (ii) Hydration and oxidation reactions in the altered zones, including alteration of oxygen isotope proportions (18). (iii) Size sorting of components mobilized during the devolatilization process (14). (iv) Metal-silicate fractionation, assuming metals and silicates coexisted in the surface layers (14). (v). If impact was occurring during endogenous activity, and under favorable circumstances, chondrule-formation (15). Processes (ii)-(v) are sometimes ascribed to events that pre-date the parent body, while process (i) is usually (and probably safely) assumed to have been located in the parent body. We suggest that all could be ascribed to processes occurring near the surfaces of volatile-rich asteroid- and comet-sized MPB.

The nebula phase only lasted about 10^5 years. We have elsewhere argued that new chronological data indicating that chondrules may be several million years older than CAI and the MPB of igneous meteorite precludes many chondrite processes, including the formation of chondrules and the agglomeration of chondrites, being the result of nebula processes (15). Further, since chondrules formed after proto-Jupiter, relative velocities in the asteroid belt were sufficient for chondrules to be produced by impact melting especially since, contrary to the views of two decades ago, asteroids are capable of retaining deep regoliths. There is evidence that brecciation and aqueous alteration were sometime contemporary processes.

We suggest that in attempting to decide between "nebula" and "parent body" processes for the formation and history of chondrites, a whole category of processes has been neglected, namely endogenous processes that involved internal volatile compounds. That bodies are now dry need not have always been so, and that there is enough evidence that small asteroid-sized bodies can support a wide variety of complex surface processes.

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