On the Source of Liquid H$_2$O in the Carbonaceous Chondrite Parent Bodies. Laurel L. Wilkening, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721

It has been clearly demonstrated that the mineralogy of CI and CM chondrites is the result of the action of liquid H$_2$O upon the original minerals which constituted the carbonaceous chondrite parent bodies (Du Fresne and Anders, 1962; Kerridge and Bunch, 1979; McSween, 1979; Bunch and Chang, 1980). This paper is concerned with the immediate source of the water in the carbonaceous chondrite parent bodies. There seem to be two cosmochemically reasonable hypotheses: (1) Primordially condensed hydrated silicates released water upon being heated in the interior of the parent bodies. (2) Water ice which condensed and accreted with silicates to form the parent bodies released water when melted by internally generated heat.

There are several questions related to these hypotheses which merit further investigation. In this paper I focus on three: (1) Are hydrated silicates a probable primary accretionary material? (2) If carbonaceous chondrite parent bodies were asteroids, could ice have been a primary accretionary material in the asteroid belt? (3) Or if they were comets, could cometary nuclei have ever reached the melting point of H$_2$O?

(1) If condensation of solids in the early solar nebula was governed by thermodynamic equilibrium, then hydrated silicates would have formed by the reaction of higher temperature silicates with water vapor in the nebula at $\sim 350$ K (Lewis, 1972). Bunch and Chang have questioned whether this is kinetically feasible and have proposed that the phyllosilicates in CI's and CM's were formed by the reaction of primordial olivine and pyroxene with water in the parent body. This is also a kinetically difficult process at low temperatures.

Let us consider an entirely different line of evidence. It has been known for several years from infrared spectroscopic data that interstellar silicate dust cannot be well-ordered crystalline solids such as olivine or pyroxene (Donn et al., 1970, Day et al., 1974; Martin, 1975). In fact, the best optical analogs to interstellar matter are the matrix material of CI or CM chondrites (Day, 1974) or synthetic vapor-deposited, non-crystalline silicates (Day, 1979). In experiments which have been designed to simulate nebular condensation, disordered silicates or other non-crystalline solids are invariably the result (Day and Donn, 1978ab, Stephens and Kothari, 1978). If interstellar silicates are indeed phyllosilicates, our point is made. If they are anhydrous initially, they are not likely to remain so in the nebula. The metastable solids produced during condensation will be very reactive with respect to water vapor. This would largely negate the kinetic arguments against hydrated silicate
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formation in the nebula. Although the experimental condensation results speak strongly against equilibrium condensation of solids in general, near equilibrium should be maintained among the major gaseous species as the temperature falls in the nebula. Thus, highly reactive silicate species will react with $\mathrm{H}_2\mathrm{O}$ in the only energetically favorable reactions, producing hydrated silicates.

Although one must agree with Bunch and Chang that there is no evidence requiring formation of phyllosilicates or hydrated silicates in the solar nebula, the formation of hydrated silicates in space seems, in fact, a highly probable occurrence and is in agreement with only observations which bear on the question.

(2) Did ice condense sunward of Jupiter?
From the compositions of the Galilean satellites, Callisto and Ganymede, we know that ice condensed at 5 AU from the sun. Bound water has been detected on the surfaces of asteroids (Lebofsky, 1978, 1980), but no evidence of ice has been found. Conventional ideas about the temperature gradient in the solar nebula (e.g., Lewis, 1974) are derived from the present day bulk densities of the planets. These ideas, however, do not fully account for the recent data concerning the atmospheres and evolution of Mars, Earth and Venus. Maybe the picture is wrong and water ice condensed on the surfaces of Mars and even Earth. Nevertheless, the implications of ice condensation sunward of 5 AU are not trivial and have not been explored.

(3) The mean sublimation rate of water ice on rapidly rotating asteroids ranges from 427.3 cm/yr for dark asteroids at 2.0 AU to 0.9 cm/yr for bright asteroids at 4.0 AU (Lebofsky, 1980). At the lowest rate a layer of ice on a 200 km diameter asteroid which accreted an additional layer of ice of equal volume (225 km layer of ice) would persist about $10^7$ years and only 10 years for the high evaporation rates. Of course, if the ice and rock were well mixed initially or by subsequent cratering, this would prolong the lifetime of the ice. The lifetime of the ice layer on asteroids seems long enough to allow favorable aqueous alteration reactions to occur if the $\mathrm{H}_2\mathrm{O}$ solid could be melted.

The problem then becomes one of ascertaining whether or not conditions at the ice layer/silicate interface were such that liquid water was formed. Surface heating only results in enhanced sublimation of ice; an interior heat source is required. At this point we will draw comets into consideration because once we focus on internal heat sources, the problems of comets and asteroids become similar. Consolmagno and Lewis (1978) showed that bodies which are mixtures of ices and rocky material and are $< 500$ km in radius will never be warm enough to melt ice if long-lived radioactivities are the only source of heat. However, if $^{26}\mathrm{Al}$ was present in small bodies in amounts that have been inferred from the study of CV chondrites, then rocky bodies as small as 0.6 km in radius can be heated to the melting temperature of silicates (Lee et al., 1976) and the interiors of ice and rock...
mixtures could easily be raised to and beyond the melting point of ice (Irvine et al., 1980). In fact, Irvine et al. did not consider the effects of convecting $H_2O$ which should result in total melting of the nucleus. The problem then is the familiar one of the phasing of the $^{26}Al$ half-life with accretion. Both the $7 \times 10^5$ year half-life of $^{26}Al$ and the $10^4$ year timescale for accretion of planetesimals (Greenberg et al., 1978) are sufficiently short on a cosmic scale that there is plenty of room to be skeptical of the degree of overlap between the two time scales. Furthermore, most of the observational evidence for the small bodies (meteorites, asteroids and comets) does not point to widespread heating of planetesimals by any heat source. The hypothesis that water ice was the source for liquid $H_2O$ raises a number of nontrivial difficulties in a broader context of the origin and evolution of volatiles in the inner solar system and for the thermal evolution of small bodies. The evidence supporting this idea is not any more compelling than that supporting the idea that hydrated silicates are the source of water. It seems premature to discard either possibility at this time.

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