New Constraints on the Size of Chondrite Parent Bodies

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Abstract - Carbonaceous chondrites make up a majority of asteroids in the asteroid belt, yet are relatively rare in meteorite collections at closer to 5%. The rare CR carbonaceous chondrites are providing a wealth of new discoveries including a) abundant organic compounds required for biochemical processes, b) pre-solar mineral grains that hold isotopic records of stellar processes, c) inclusions, chondrules, and chondrule rims that contain information about the early solar system, d) hydrous minerals that formed during aqueous alteration of the matrix and other components, and e) foreign clasts that formed at slightly higher pressures than normally expected in the early solar system. All of these discoveries suggest these carbonaceous meteorites will continue providing new information and help to revise our understanding of the broad range of conditions existing in the early solar system.

Carbonaceous chondrites are a special class of meteorites that are unique in providing constraints on the kinds of organic matter present in the early solar system and the nature of volatiles on asteroids. In fact, given that over half of the asteroid belt is comprised of carbonaceous asteroids (Gradie et al., 1989), the carbonaceous chondrites are under-represented in world meteorite collections at ~5%. This small percentage is dominated by familiar types like CM (Murchison), CV (Vigarano and Allende), and CO (Orgueil) chondrites. These groups (CM, CV, etc.) represent various ways in which the meteorites have been processed or altered. Yet another group, the CR chondrites represent a small percentage of the carbonaceous chondrites but in the last several years have provided an abundance of discoveries, such as the one reported by Kimura et al. (2013) in the NWA 801 CR chondrite. A holy grail amongst chondrite scientists is the identification of meteorites that have escaped the effects of aqueous alteration (such as experienced by CM1, CM2, CI1 chondrites), and thermal processing (such as experienced by CV and CK chondrites which are commonly metamorphosed). Even the CO3 and CV3 groups have commonly been subjected to temperatures of several hundred ^{o}C, which can destroy or transform primitive matrix mineralogy. A debate has raged among those studying CR chondrites about the extent of alteration in this class, but many workers now recognize that while such alteration effects are nonetheless present (Schrader et al., 2012), the grades of aqueous alteration are very low (e.g., Abreu and Brearley, 2010). Because several CR chondrites have experienced almost no aqueous or thermal alteration, they have been the focus of studies of pre-solar grains (Floss and Stadermann, 2009a,b; Nguyen et al., 2010), organic compounds (e.g., NH3, amino acids; Pizzarello et al., 2011; 2012; Glavin et al., 2010; Martins et al., 2007), and various isotopic and petrologic studies (e.g., Alexander et al., 2010; Makide et al., 2009; Busemann et al., 2006; Rubin, 2010). In general, CR chondrites have thus enabled discoveries on a wide variety of topics including chondrule formation, (chondrules are blebs of glass that are unique to the chondrites and give them their name), matrix CAI/AOA inclusions (calcium aluminum-rich inclusions and amoeboid olivine aggregate), metal compositions, pre-solar grains, isotopic studies and organics.

The recent discovery of Kimura et al. (2013) of eclogitic clasts in a CR chondrite is a good example of such discoveries. Since eclogites are formed at high pressures, they are unknown (and unexpected) in chondrite meteorites, since high pressures require that the meteorites that contain them experienced high pressures. Eclogites are most famously found in terrestrial metamorphic belts associated with high pressure metamorphic conditions formed in the relatively cold and deep compressional environment of a subduction zone, or in the deep crust. Eclogites are not expected in chondrites as this class of meteorites is thought to have escaped planetary-scale processing: eclogites would not be expected in the low-pressure conditions of the solar nebula or even in the higher pressure transient conditions of an impact among small bodies. Yet there they are - found with estimated equilibration pressures between 2.8 and 4.2 GPa and 940-1080 ^{o}C (Kimura et al., 2013). As the authors note, these pressures are too low to represent the conditions of impact, and so appear to require a chondrite parent body of at least 1500 km in radius—much larger than any known asteroid. It is anticipated that this discovery will lead to new insights into the conditions of eclogite formation such as the role of bulk composition of the chondrite system as well as pressure and temperature. A similarly unusual clast was documented in the CR chondrite QUE 99177 by Abreu and Brearley (2010). A hornblende-omphacite-graphite bearing clast was found embedded in the matrix of this meteorite. This unusual and somewhat oxidized assemblage indicated once again that the pressure conditions and volatile contents of this particular clast were higher than expected, pointing to the range of conditions expected in the solar nebula. Many of these new discoveries are being made in meteorites returned from Antarctica (McBride et al., 2013), yet many of the samples are small and thus remain in precious supply for current and future studies. The range of fascinating discoveries and demand for new materials (high request rates for the US Antarctic collection, for example) leads one to believe that the interest in this material will continue and that exciting new discoveries await us in the near future.

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