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From the Editors

Opaque minerals in primitive stony meteorites

The opaque minerals in chondritic meteorites have been the subject of study since Ernst Chladni (1797) first recognized the tiny metallic flecks that are ubiquitous in many of these rocks. The term *opaque minerals* refers to the fact that these minerals do not transmit light when viewed in a standard petrographic thin section. It is a term that reflects (no pun intended) the early history of mineralogy and meteoritics, when the majority of meteorite characterization was done with a polarizing microscope. These minerals are quite bright when viewed with an electron microscope, a tool that is now in common use in the characterization of meteorite samples. One can only guess at the terminology that would be used to describe this class of minerals if such instrumentation had predated recognition of the importance of meteorites.

Since the first observations of Chladni, numerous investigators have analyzed the compositions of metal grains and associated opaque phases such as sulfides, oxides, and carbides. These studies have provided a wealth of information about chemical and physical processes in the early solar system. Characterization of opaque minerals has been used to gain insight into meteorite oxidation states (Rubin *et al.*, 1988), the extent of thermal metamorphism on small asteroidal bodies (McSween *et al.*, 1988), parent-body cooling rates (Herpfer *et al.*, 1994), post-shock thermal histories (Bennett and McSween 1996), chondrule formation environments (Lauretta *et al.*, 2001), and large-scale thermal events in the solar nebula (Meibom *et al.*, 2000), to give just a few examples.

It is not surprising that metallic iron and related minerals can provide such detailed information about processes in the early solar system. After all, Fe, Ni, and S are three of the most abundant rock-forming elements in the solar system. As a result, metal and sulfides are present in almost every type of chondrite. Furthermore, in the ordinary chondrites alone, metal grains are associated with minerals containing Si, P, Cr, Ca, Na, Co, and Cu, thus playing a central role in the chemistry of 10 of the 20 most abundant elements in the solar system.

The collection of opaque minerals in enstatite chondrites represents one of the most complicated chemical systems in extraterrestrial samples. These rocks formed under extremely low oxygen fugacities and high sulfur fugacities, relative to other chondrite classes. As a result of the reducing conditions of their formation (and subsequent thermal metamorphism), nearly all of the Fe is in the metallic state, which also contains significant metallic Si (over 3 wt% in some metal grains). In some cases, metals and sulfides comprise over 40% of these meteorites by weight. Furthermore, elements that behave as lithophiles in most geochemical systems act as chalcophiles in the enstatite chondrites and these meteorites contain sulfides of Ni, Ca, Mg, Mn, Zn, Na, K, Ti, Cu, P, and Cr. Thus, opaque minerals play an important role in the chemistry of 15 of the 20 most abundant rock-forming elements in the enstatite chondrites.

The multitude of opaque minerals that form under reducing conditions, such as those experienced by the enstatite chondrites, allows for some detailed and exciting petrologic investigations. The majority of enstatite chondrites, particularly the EL chondrites, are of petrologic type 6, indicating that they have experienced extensive thermal metamorphism on their parent asteroids. The complex phase relations between opaque minerals in enstatite chondrites have allowed for precise determinations of the equilibrium temperatures under which these rocks were metamorphosed, analyses that are not possible using the relatively simple opaque mineralogy of the equilibrated ordinary chondrites.

The dazzling variety of opaque minerals that occur in unequilibrated enstatite chondrites can be seen in the manuscript by Lin and El Goresy (2002) in this issue of *Meteoritics and Planetary Science*. This paper opens a new chapter in the study of enstatite chondrite opaque mineralogy. The authors present the results of a detailed and meticulous survey of opaque minerals in the Qingzhen (EH3) and MacAlpine Hills 88136 (EL3) chondrites. These meteorites represent the most primitive, unaltered samples of the two enstatite chondrite classes: the high-Fe, high-siderophile-content group (EH) and the low-Fe, low-siderophile-content group (EL). The discovery of primitive (non-type-6) EL chondrites is a relatively recent event and the work of Lin and El Goresy (2002) represents the first comprehensive study of opaque minerals in this meteorite class. Most of the minerals described in this paper have been identified in prior studies. However, as an example of the intricacy of opaque phases in these meteorites, the authors add at least one previously unknown compound to the list of minerals unique to meteorites.

This work is important for many reasons. First, through their detailed petrographic and mineralogical work, they have revealed distinct differences in the initial mineralogies of EH and EL chondrites. Moreover, by coupling their mineralogical data with thermodynamic models of the early solar system, they are able to constrain the conditions under which the two different enstatite chondrite groups formed. Finally, the authors are able to determine the peak temperatures that these meteorites experienced on their parent asteroids and constrain the rate at which these bodies cooled. Thus, this study provides insight into two distinct chemical environments in the solar nebula as well as constraining the thermal history of at least two different small bodies in the early solar system. The results of this study will also help decipher the history of the more heavily thermally metamorphosed EL chondrites, which comprise the bulk of this meteorite group. I expect that this paper will serve as an invaluable reference on enstatite chondrite mineralogy for many years to come.

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About noble gases in E chondrites

In cosmochemistry and planetary science noble gases often have the—of course undeserved—reputation of being "complicated" or—in less diplomatic words—a bit tiring. Two consecutive talks on noble gases in our institute's weekly seminar would lead to desperate muttering among our colleagues from the extraterrestrial physics community.

Of course, this is exaggerated: the publication of just two new comprehensive books on the subject (Ozima and Podosek, 2002; Porcelli *et al.*, 2002) demonstrates that noble gases are an interesting and powerful tool in planetary science allowing us to study such diverse topics as the composition of the protosolar cloud, solar evolution, accretion of the planets and development of their atmospheres, history of planetary surfaces and ejection of material, the chronology of early solar system processes and—later—catastrophic events. Isotopically "exotic" noble gas components even established a new field of research, the analysis and interpretation of presolar grains (Reynolds and Turner, 1964).

In this issue, Patzer and Schultz (2002) successfully resume another chapter in the "book of noble gases" that had been opened by Crabb and Anders (1981) who systematically analysed the noble gases in E chondrites. They discovered a new component intermediate between the Sun's noble gas composition (as represented by the solar wind) and the component found in most unequilibrated meteorites ("Q-gases"). Q-gases are largely depleted in the light elements relative to solar composition (Fig. 1). The new "subsolar" component found in E chondrites, best represented in the EH4/5 chondrite South Oman, is enriched in Ar and Kr relative to Q-gas and Xe but depleted in these elements relative to solar. Carrier(s), origin and trapping mechanisms of the subsolar gases remain unclear. Crabb and Anders suggested the carrier to be probably enstatite. Busemann *et al.* (2001) showed that a fraction of the subsolar

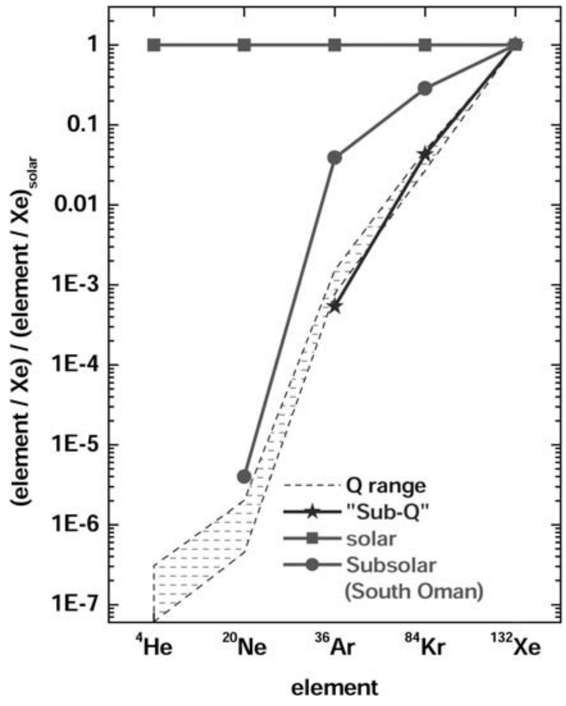

FIG. 1. Elemental composition of subsolar, "sub-Q", and Q-noble gases normalised to solar composition and Xe.